

INSTRUCTION MANUAL



CDM-A100 Series

CDM-A108 and CDM-A116

Revision: 11/16



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- 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, 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.

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- 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.

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CDM-A100 Series

1. Introduction

The CDM-A108 and CDM-A116 are 24-bit analog input modules that significantly increase the number of analog channels in a datalogger system. The CDM-A108 has eight differential channels and the CDM-A116 has 16 differential channels.

The CDM-A108 and CDM-A116 feature a 24-bit analog-to-digital converter and a low-noise, analog front-end to provide superior analog measurements. They also support period average measurements and include both current and voltage excitation channels.

Connect up to 50 CDMs to a single datalogger.

Throughout this manual, any reference to the CDM-A100 applies to both the CDM-A108 and CDM-A116, 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 CDM-A100 every three years.

3. Initial Inspection

- The CDM-A108 and CDM-A116 ship with the following:
 - Pn 29389, *CDM Parts Kit* (1)
 - *ResourceDVD* (1), which includes the following:
 - This manual
 - *Device Configuration Utility* software ([DevConfig](#) (p. 32))
- 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](#) (p. 32) version in the CDM-A100, the datalogger, and the [SC-CPI](#) (p. 33) (if used), and update as needed. See Section 7.2, *Operating Systems* (p. 18).

4. QuickStart

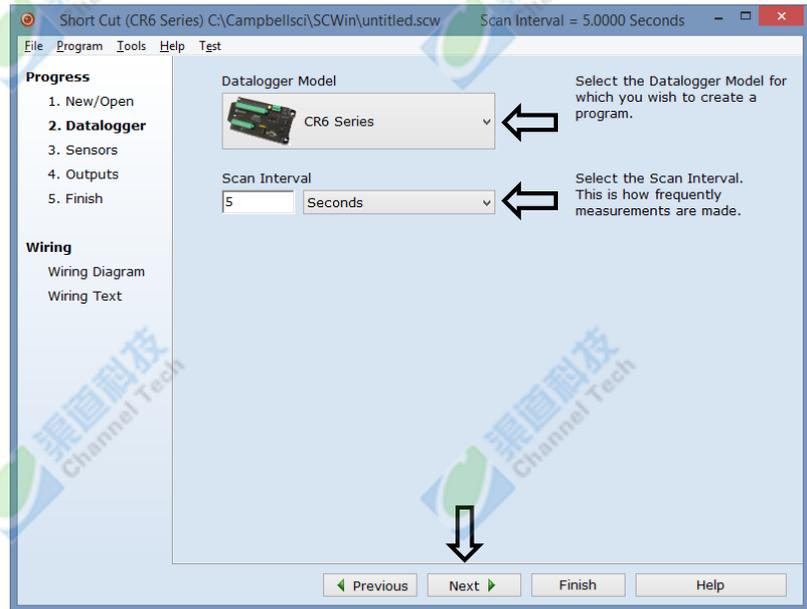
Short Cut is an easy way to program your datalogger to measure sensors through a CDM-A108 or CDM-A116 and assign wiring terminals. *Short Cut* is available as a download on www.campbellsci.com and the *ResourceDVD*. It is included in installations of *LoggerNet*, *PC200W*, *PC400*, or *RTDAQ*.

This section will guide you through programming a CR6 datalogger to read a single-ended voltage measured by a CDM-A108. With minor changes, these steps can apply to other compatible dataloggers and measurements.

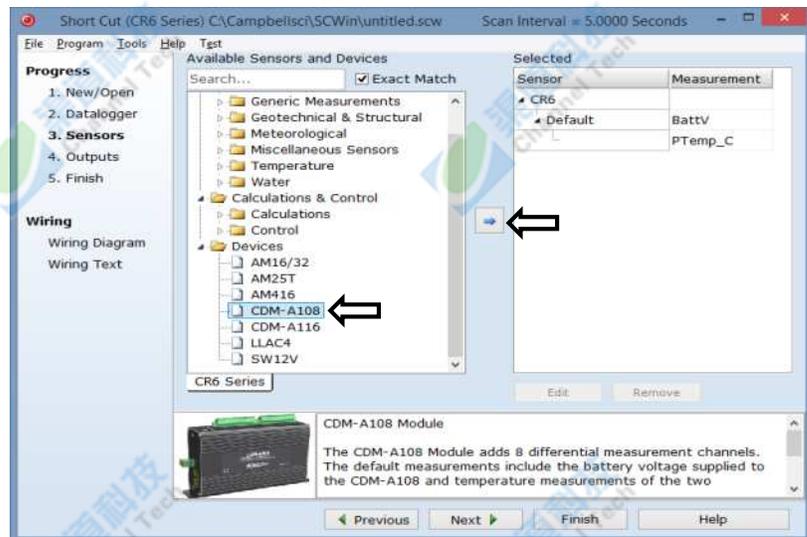
1. Open *Short Cut*. Click **New Program**.



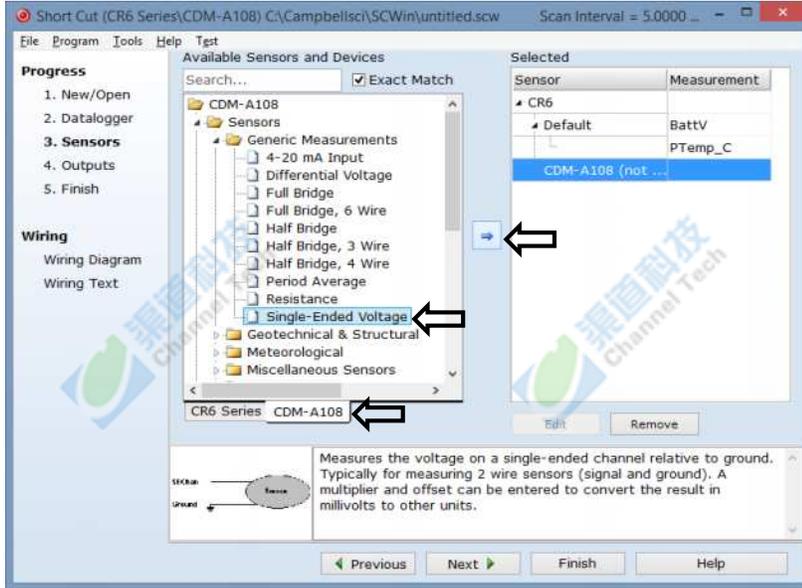
2. Select **Datalogger Model** and **Scan Interval** (default of 5 seconds is OK for most applications). Click **Next**.



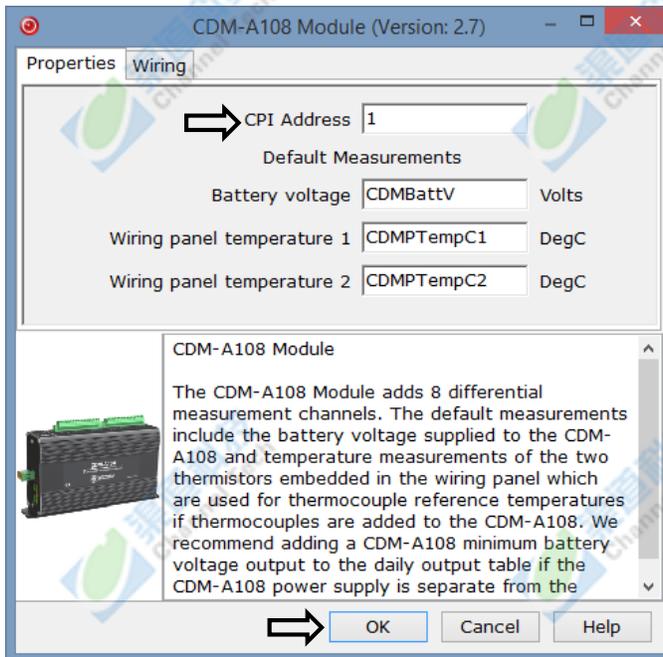
3. Under the **Available Sensors and Devices** list, select the **Devices** folder, then select the **CDM-A108**. Click  to move the selection to the **Selected** device window.



- When the CDM-A108 is added as a device, a new **CDM-A108** tab will appear at the bottom of the **Available Sensors and Devices** pane. With the **CDM-A108** tab selected, select the **Sensors | Generic Measurements** subfolder. Select **Single-Ended Voltage**. Click  to move the selection to the **Selected** device window.



- In the resulting window, enter the CPI Address of the CDM-A108. The default address is 1.



- Next, provide the attributes of the single-ended measurement. Leave all settings at the default for this example. To learn more about any setting, click **Help**.

Single-Ended Voltage (Version: 2.8)

Properties Wiring

How many VoltsSE sensors? (Max=16) 1

Measurement Result SEVolt mV

Range of sensor voltage 5000 mV

First notch frequency Reject 60 Hz Noise (60 Hz)

User entered first notch frequency (Hz) 15000

Measure offset each measurement

Settling time (us) 500

Multiplier 1

Offset 0

Optional Field Calibration

Two Point, Multiplier and Offset

Zeroing Calibration

Select Zeroing Calibration Group Do Not Group

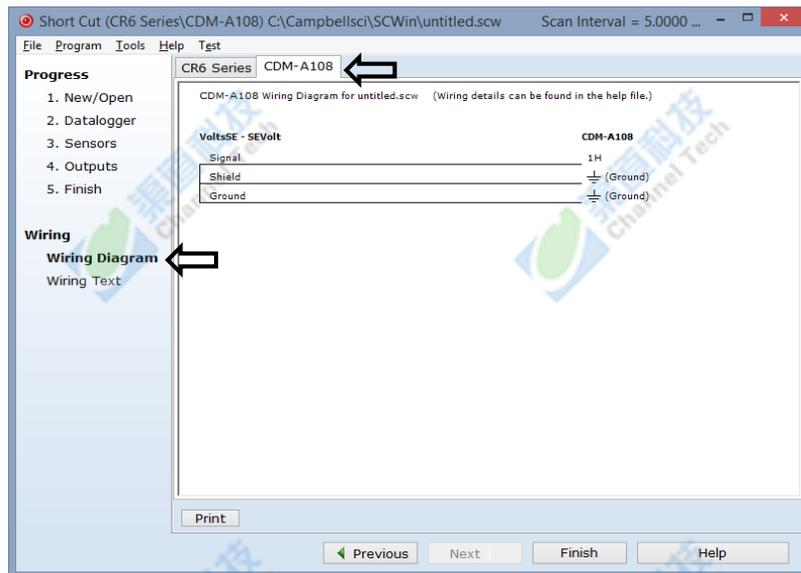
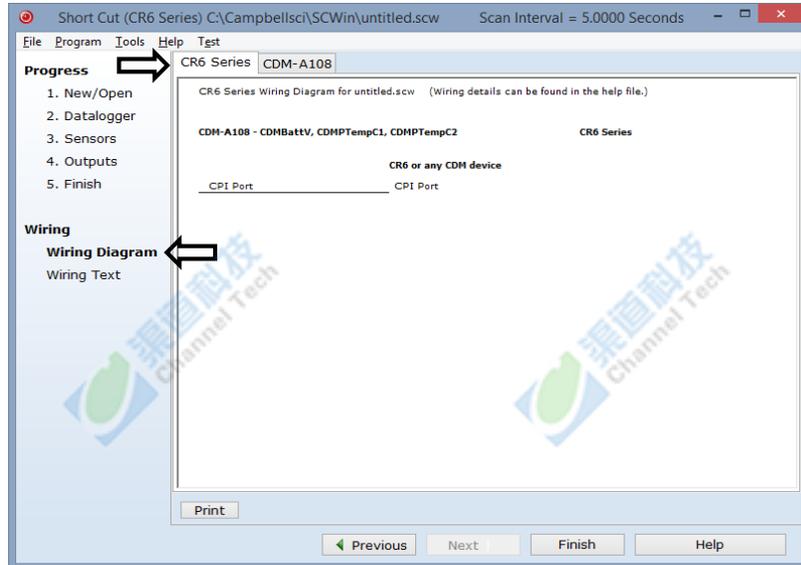
Signal — Sense

Ground

Measures the voltage on a single-ended channel relative to ground. Typically for measuring 2 wire sensors (signal and ground). A multiplier and offset can be entered to convert the result in millivolts to other units.

OK Cancel Help

- After selecting the measurement, click **Wiring Diagram** to see how the sensor is to be wired to the datalogger. The wiring diagram can be printed now or after more sensors are added. The **CR6 Series** tab shows the connection between the CDM-A108 and the datalogger, and the **CDM-A108** tab shows the sensor connection to the CDM-A108.



- Select any other sensors you have in the **Sensors** section, and then finish the remaining *Short Cut* steps to complete the program. The remaining steps are outlined in *Short Cut Help*, which is accessed by clicking on **Help | Contents | Programming Steps**.
- If *LoggerNet*, *PC400*, *RTDAQ*, or *PC200W* is running on your PC, and the PC to datalogger connection is active, you can click **Finish** in *Short Cut*, and you will be prompted to send the program just created to the datalogger.

10. Wire the sensors and devices as shown in the wiring diagrams in step 7. Check the output of the sensor in the [datalogger support software](#) (p. 32) data display to make sure it is making reasonable measurements.

5. Overview

The CDM-A100 expands the number of analog measurement channels and increases the measurement-speed potential in a datalogger system. CDMs operate through a datalogger program and communicate using the CAN peripheral interface ([CPI](#) (p. 32)). A single datalogger can operate up to 50 CDMs.

5.1 Wiring Panel – Overview

CAUTION

To avoid damage to sensors and devices, ensure that each removable wiring-terminal strip is connected to the CDM-A108 and CDM-A116 in the proper location before applying power. Each strip is keyed identically.

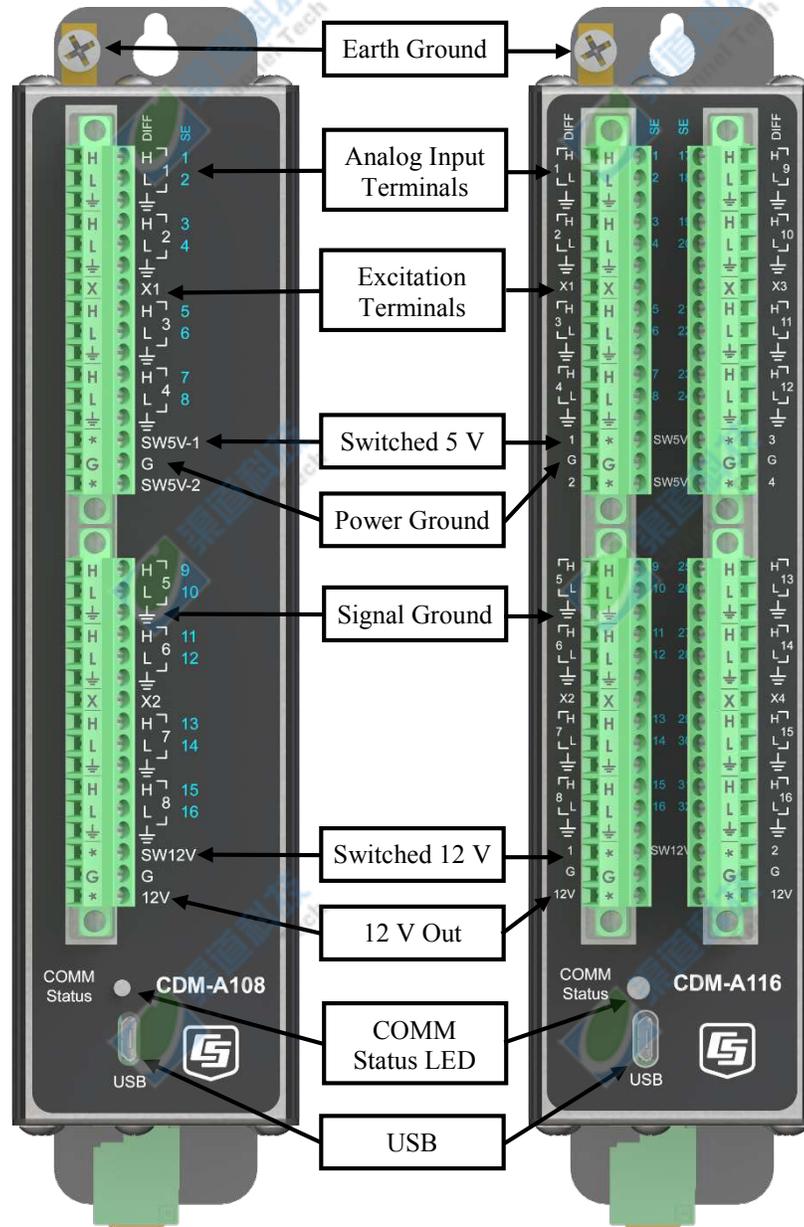


FIGURE 5-1. Wiring panel of CDM-A108 (left) and CDM-A116 (right)

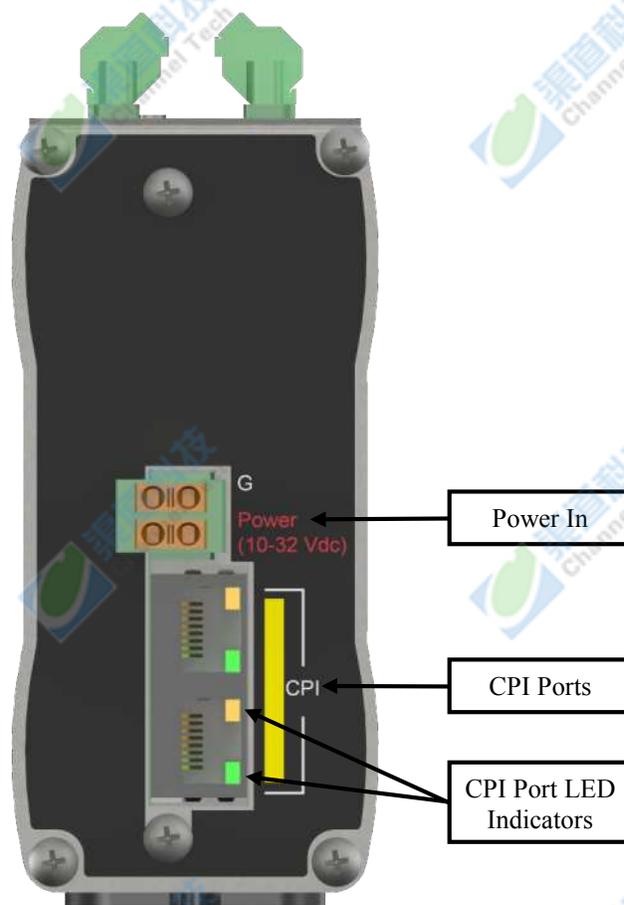


FIGURE 5-2. Power and CPI ports view

5.1.1 Analog Input

Analog sensors output a continuous voltage or current signal that varies with the phenomena measured. Sensors compatible with the CDM-A100 output a voltage. Current output can be made compatible with a resistive shunt.

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.

- Maximum input voltage range: ± 5000 mV
- Measurement resolution range: 0.020 to $14.756 \mu\text{V}_{\text{RMS}}$

5.1.1.1 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 labeled in blue. The CDM-A108 has 16 **SE** terminals, and the CDM-A116 has 32. For example, single-ended channel **1** is comprised of terminals **1** and \perp .

5.1.1.2 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 CDM-A108 has 8 H/L differential terminals, and the CDM-A116 has 16.

5.1.1.3 Period-Averaging

Single-ended terminals on the CDM-A108 and CDM-A116 are also configurable for measuring the period of an analog signal.

- Voltage gain: 1, 3.8, 19, 67
- Maximum frequency: 200 kHz
- Resolution: 130 ns ÷ number of cycles to be measured

5.1.2 Voltage and Current Excitation

X terminals supply switched voltage or current to sensors. The CDM-A108 has two X terminals, and the CDM-A116 has four.

- Voltage Excitation (switched-analog 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. Each terminal will source up to ± 50 mA.
- Current Excitation (switched-analog 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.

5.1.3 Switched Voltage Output

SW5V and SW12V terminals supply voltage and control for sensors. The CDM-A108 includes two SW5V and one SW12V terminals. The CDM-A116 includes four SW5V and two SW12V terminals.

- 5 V control – SW5V terminals supply 5000 mV. See Section 6.5.3, *Switched 5 Vdc (p. 16)*, for information on voltage and current sourcing limits.
- Switched 12 V – SW12V terminals supply 12 V and will source up to 200 mA each.

5.1.4 Grounding Terminals

Proper grounding lends stability and protection to a data acquisition system. It is the easiest and least expensive insurance against data loss — and often the most neglected. The following terminals are provided for connection of sensor and CDM-A100 grounds:

- Signal Ground (\perp) – reference for single-ended analog 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 analog-voltage-measurement section of the wiring panel, which can cause single-ended voltage measurement errors.

- Earth Ground Lug (\oplus) – connection point for a heavy-gage earth-ground wire. A good earth connection is necessary to secure the ground potential of the CDM-A100 and shunt transients away from electronics. 14 AWG wire, minimum, is recommended.

5.1.5 Power Terminals

5.1.5.1 Power In

The removable **Power** connector is the connection point for external power supply components. The power supply must be in the range of 10 to 32 Vdc.

5.1.5.2 Power Out

The CDM-A100 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 Section 6.5.3, *Switched 5 Vdc* (p. 16), for information on voltage and current sourcing limits.

5.1.6 Communication Ports

5.1.6.1 USB Port

One micro-B USB port, labeled **USB**, for communicating with a PC through [Device Configuration Utility](#) (p. 32) software.

5.1.6.2 CPI Port

[CPI](#) (p. 32) is a proprietary protocol that supports CDMs. Two RJ45 ports labeled **CPI** enable communications with a Campbell Scientific datalogger and other CDMs.

5.1.7 LED Indicators

5.1.7.1 COMM Status

When the CDM-A100 has successfully been configured by a datalogger, the **COMM Status LED** (p. 32) 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 10-2, *COMM Status LED Activity* (p. 31).

5.1.7.2 CPI Port

When the CDM-A100 has successfully been configured by a datalogger, the green **LED** (p. 32) 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. See TABLE 10-3, *CPI Port LED Activity* (p. 31).

6. Specifications

All CDM-A100 units are tested to meet electrical specifications in a standard –40 to 70 °C, or extended –55 to 85 °C, non-condensing environment. Recommended calibration interval is every three years.

6.1 Voltage Measurements – Specifications

Voltage measurements use a 24-bit Analog-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

CDM-A108:	DIFF 1H/1L – 8H/8L
CDM-A116:	DIFF 1H/1L – 16H/16L

Single-Ended Configuration

CDM-A108:	SE 1 – 16
CDM-A116:	SE 1 – 32

Range:	See TABLE D-1, <i>Analog Voltage Measurement Range and Resolution (p. D-1)</i>
Accuracy¹	
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 D-1, <i>Analog Voltage Measurement Range and Resolution (p. D-1)</i>
Speed:	See TABLE 6-2, <i>Analog Voltage Measurement Speed (p. 13)</i> See also Section 8.2, <i>Fast Measurements (p. 25)</i>
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

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

²See TABLE 6-1, *Analog Voltage Measurement Accuracy Offsets (p. 13)*

TABLE 6-1. Analog 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 6-2. Analog Voltage Measurement Speed¹

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
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

¹Default settling time of 500 μs .

²Refers to multiplexing circuitry internal to the CDM-A100 series.

6.2 Resistance Measurements – Specifications

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

CDM-A108:	SE terminals 1-16 DIFF terminals 1H/1L – 8H/8L Excitation terminals X1 – X2
CDM-A116:	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)

¹Assumes 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.

²See CR6 Datalogger 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 V_s/I_x , where I_x is the measured excitation current and V_s is the returned sensor signal.

6.3 Voltage and Current Excitation – Specifications

Two terminals on the CDM-A108 and four terminals on the CDM-A116 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

CDM-A108:	X1 – X2
CDM-A116:	X1 – X4

Voltage Excitation

Range: ±5000 mV

Accuracy¹

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
Accuracy¹	
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 Voltage²:	±5000 mV

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

²Voltage limits within which current excitation setting will meet specified accuracy limits.

6.4 Period Averaging – Specifications**Terminals**

CDM-A108:	SE 1 – 16
CDM-A116:	SE 1 – 32

Range: See TABLE 6-3, *Period Average Ranges*

Accuracy: ±(0.01% of reading + resolution)

Resolution: 130 ns ÷ number of cycles

TABLE 6-3. 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

¹With signal centered around CDM-A100 ground.
²Maximum period average signal amplitude = 20 V peak-to-peak.

6.5 Voltage Output – Specifications**6.5.1 Continuous 12 Vdc****Terminals**

CDM-A108:	12V
CDM-A116:	12V

Voltage Output¹: 12.5 ± 0.5 Vdc

Current Sourcing Limit (each): 200 mA typical, 180 mA minimum

¹Unregulated below 14.5 V.

6.5.2 Switched 12 Vdc

Terminals

CDM-A108: SW12V-1
 CDM-A116: SW12V-1-2

Voltage Output¹: 12.5 ± 0.5 Vdc

Current Sourcing Limit (each): 200 mA typical, 180 mA minimum

¹Unregulated below 14.5 V.

6.5.3 Switched 5 Vdc

Terminals

CDM-A108: SW5V-1-2
 CDM-A116: SW5V-1-4

Voltage Output

On, no load: 4.75 ± 0.25 Vdc
Off: <0.1 V

Output Resistance: 30 Ω

Current Sourcing Limit: See FIGURE 6-1, *Current sourcing on SW5V terminals*

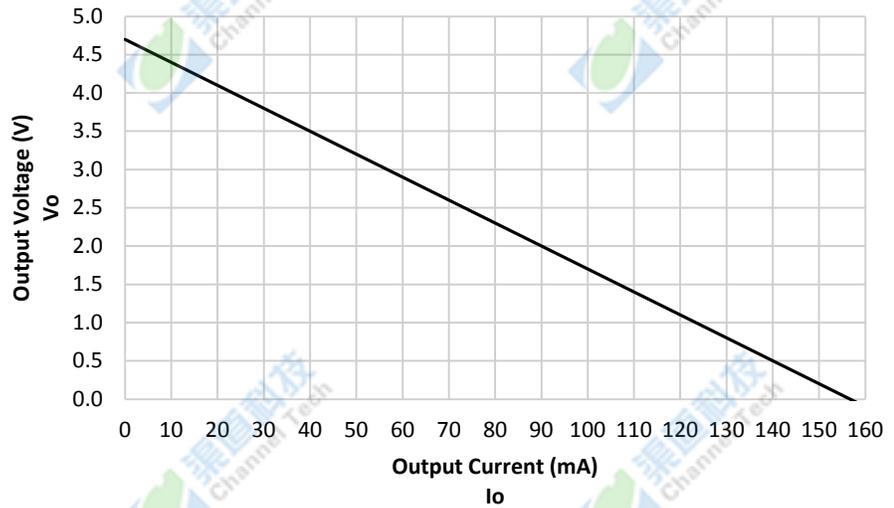


FIGURE 6-1. *Current sourcing on SW5V terminals*

6.6 Module – Specifications

6.6.1 Communications

CPI: RJ45 interface to Campbell Scientific dataloggers and CDM measurement peripherals and sensors

USB: USB micro-B device only, 2.0 full-speed 12 Mbps, for computer connection.

6.6.2 System

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

Memory: 2 MB SRAM

6.6.3 Power Requirements

Voltage: 9.6 to 32 Vdc

Typical Current Drain

Sleep: <1 mA

Active 1 Hz Scan¹: 2 mA, estimated

Active 20 Hz Scan¹: 20 mA

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

6.6.4 Compliance

View EU Declarations of Conformity at www.campbellsci.com/cdm-a108 and www.campbellsci.com/cdm-a116.

6.6.5 Physical Attributes

Dimensions: 20.3 x 12.7 x 5.1 cm (8 x 5 x 2 in); additional clearance required for cables and leads

Weight

CDM-A108: 0.8 kg (1.75 lb)

CDM-A116: 0.9 kg (1.95 lb)

7. Installation

7.1 Install Driver for PC Connection

Installing the CDM-A100 may require a connection to a PC. Install the device driver before plugging the CDM-A100 into your PC for the first time. You will need the device driver properly installed before you can connect to the CDM-A100 via USB. To install the device driver using the [Device Configuration Utility](#) (p. 32), select **Peripheral | CDM-A100 Series** under **Device Type**. Click the **Install the USB** driver link and follow the prompts.

7.2 Operating Systems

Campbell Scientific posts [OS \(p. 32\)](#) updates at www.campbellsci.com/downloads when they become available. Before deploying instruments, check operating system versions and update as needed to the most recent version. Follow the procedure on the [Device Configuration Utility \(p. 32\)](#) **Send OS** tab to load a new OS to the CDM-A100.

NOTE For best performance, use the most recent operating system for each device.

7.3 Configuring the CDM-A100 Series

The CDM-A100 arrives ready to be connected to a system. Device configuration is only required when multiple CDMs are connected to a single datalogger. Each module must have a unique address. Set a unique device name for further distinction between CDMs.

Configure the CDM-A100 using one of three methods: the **CPIAddModule()** program instruction, [Device Configuration Utility \(p. 32\)](#) software, or the **CPIStatus** table.

7.3.1 Configuring with the CPIAddModule() Instruction

To configure a CDM-A100 within a program, use the **CPIAddModule()** instruction. A separate instruction is used for each device. The **CPIAddModule()** instruction overrides any settings entered by any other means, such as *Device Configuration Utility* or the **CPIStatus** table.

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

The datalogger creates an internal list of [CPI \(p. 32\)](#) modules from each **CPIAddModule()** instruction. Modules added at any time to the CPI bus will be checked against this list and reconfigured accordingly. See CRBasic Example [B-1, Adding CDMs with CPIAddModule\(\) \(p. B-1\)](#).

NOTE The **CPIAddModule()** instruction overrides any changes made through either *Device Configuration Utility* or the **CPIStatus** table.

7.3.2 Configuring with Device Configuration Utility

Install the device driver before connecting the CDM-A100 to a PC. Refer to Section [7.1, Install Driver for PC Connection \(p. 17\)](#).

1. Open [Device Configuration Utility \(p. 32\)](#).
2. Under **Device Type**, select **Peripheral | CDM-A100 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 CDM-A100.

5. Apply 9.6 to 32 V to the power terminals on the device.
6. Click the browse button next to **Communication Port**.
7. Select the port labeled **CDM-A100**.
8. Click **OK**.
9. Click **Connect**.
10. Set the **Device Name** (optional) and the **CPI Address**.
 - a. **Device Name** is a user-editable field used to give a distinguishing name to the CDM-A100. The default name is **CDM-A100**.
 - b. **CPI Address** specifies the address of the CDM-A100. Each CDM connected to the same datalogger must have a unique address. By default, the CDM-A100 uses a CPI address of 1. It accepts addresses 1 through 120.
11. Click **Apply** to save your changes.

7.3.3 Configuring with the CPIStatus Table

When a CDM is used in a program, the datalogger adds a **CPIStatus** table to display current [CPI](#) (p. 32) information. View the **CPIStatus** table in the *LoggerNet Connect* screen, *PC200W* or *PC400 Monitor Data* tab, or *Device Configuration Utility Data Monitor* tab. Information about each module that is included in the datalogger program or connected to the CPI bus appears in the **CPIStatus** table within the **ModuleInfo()** array. Information is shown in the following order:

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

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 CDM-A100 through Campbell Scientific software.

7.4 Datalogger Programming

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

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

If your data acquisition requirements are simple, you can likely create and maintain a datalogger 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](#) (p. 32).

See Section 4, *QuickStart* (p. 2), for a *Short Cut* tutorial. If you wish to import *Short Cut* code into *CRBasic Editor* (p. 32) to create or add to a customized program, follow the procedure in Appendix A, *Importing Short Cut Code Into CRBasic Editor* (p. A-1). Complete program examples can be found in Appendix B, *Example Programs* (p. B-1).

7.4.1 Scan Buffers

When CDM-A100 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** ($2\text{ s} \div .05\text{ s} = 40$). At a minimum, the **BufferOption** should be set to **3**.

The datalogger processes the data from the CDM-A100 in batches according to frame syncs received from the CDM-A100. Upon receiving a batch of data, the datalogger puts it into a processing queue. Processing the data may take more time than is available in a single scan. The **BufferOption** allows the datalogger to balance its task load by processing the data from the CDM-A100 during subsequent scans while maintaining correct data time stamps. If a **BufferOption** is not set, the datalogger 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 datalogger is running in pipeline mode.

7.4.2 CDM Instructions

NOTE

For the most current information on datalogger instructions, refer to the *Help* files of *CRBasic Editor*.

The first two parameters for each CDM instruction are the **ModuleType** and **CPI_Addr**. **ModuleType** refers to the model of CDM used. Valid entries are **CDM_A108** and **CDM_A116**. **CPI_Addr** is the address of the CDM-A100. Wire sensors according to the channels specified within the corresponding measurement instructions. The program example below shows the use of the **CDM_VoltSE()** instruction.

CRBasic Example 7-1. Measuring a Single-Ended Voltage

```
'Program Example: Measuring a single-ended voltage
Public SEVolt

BeginProg
  Scan(5,Sec,3,0)
  'Measure Single-Ended Voltage on CDM-A108, CPI address 1
  CDM_VoltSe(CDM_A108,1,SEVolt,1,mV5000,1,True,500,60,1,0)
NextScan
EndProg
```

A full treatment of each instruction is located in the *Help* files of *CRBasic Editor*.

7.5 Datalogger Connection

CDM-A100 devices communicate with a datalogger through a **CPI** port. Each CDM-A100 ships with a 6-inch RJ45 cable for this connection, though any standard RJ45 cable can be used. To allow daisy-chaining, two **CPI** ports are available on the CDM-A100. Either can be used for connection to a datalogger.

The **CPI** port on CDM-A100 connects directly to the **CPI** port on the CR6. An [SC-CPI](#) (p. 33) device is required to connect to CR800-series, CR1000, and CR3000 dataloggers. 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 datalogger. Connect a **CPI** port on the CDM-A100 to the **CPI** port on the SC-CPI.

7.6 Connecting Multiple CDMs

The [CPI](#) (p. 32) bus, which handles the communication between the datalogger and CDMs, can accept addresses **1 – 120**. Multiple CDMs may be connected to a single datalogger 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 Section [8.2.2, CPI Network Bit Rate](#) (p. 28) and listed in [TABLE 8-2, Network Topology, Bit Rate, and Cable Length](#) (p. 28).

7.6.1 Daisy-Chain Topology

In a daisy-chain topology, CDM-A100s are connected one after another. An illustration of this is shown in [FIGURE 7-1](#).



FIGURE 7-1. Multiple CDM-A108s connected in a daisy-chain topology

For maximum system performance, insert a termination resistor plug (pn 28558) in the last open **CPI** port of the CPI bus.

7.6.2 Star Topology

A star topology uses a passive RJ45 hub, such as the [HUB-CPI 8-Channel RJ45 Hub for CPI Peripherals](#) (pn 30692), to connect multiple CDM-A100s. An illustration of this is shown in [FIGURE 7-2](#). This configuration does not allow termination resistor plugs.

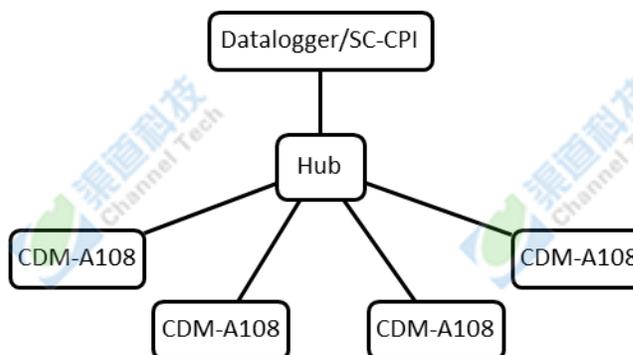


FIGURE 7-2. Multiple CDM-A108s connected in a star topology

7.7 Power Connection

Connect the power supply to the removable **Power** connector on the side of the CDM-A100. Power supplies providing voltages from 9.6 to 32 Vdc may be used.

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 in the slots shown in FIGURE 7-3. When the screwdriver is pushed in far enough, the orange terminals will depress, as shown in the image. 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 7-3. Opening the power connector terminals

7.8 Earth Ground Connection

Earth grounding provides protection from static discharge, transients, and power surges. A ground lug is provided on the CDM-A100 for connection to earth ground. Minimum 14 AWG ground wire is recommended. The earth side of the connection should be to a grounding rod or other grounded device.

7.9 Mounting in an Enclosure

The CDM-A100 baseplate has mounting holes through which small screws are inserted into nylon anchors in an enclosure backplate.

If mounting to a DIN rail, use the CDM DIN-Rail Mounting Kit (pn 29388), shown in FIGURE 7-4.



FIGURE 7-4. CDM DIN-Rail Mounting Kit

Follow the steps below to mount the CDM-A100 to a DIN rail.

1. Using a Phillips screwdriver, unfasten both screws on the baseplate of the CDM-A100 and remove the baseplate.
2. Screw the rubber bumper into the bottom outer hole.
3. Use the screw from the kit to attach the metal clip to the middle hole, with the comb pointing up as shown in FIGURE 7-5 (a).
4. Clip the CDM-A100 to a DIN rail. See FIGURE 7-5 (b) and (c).

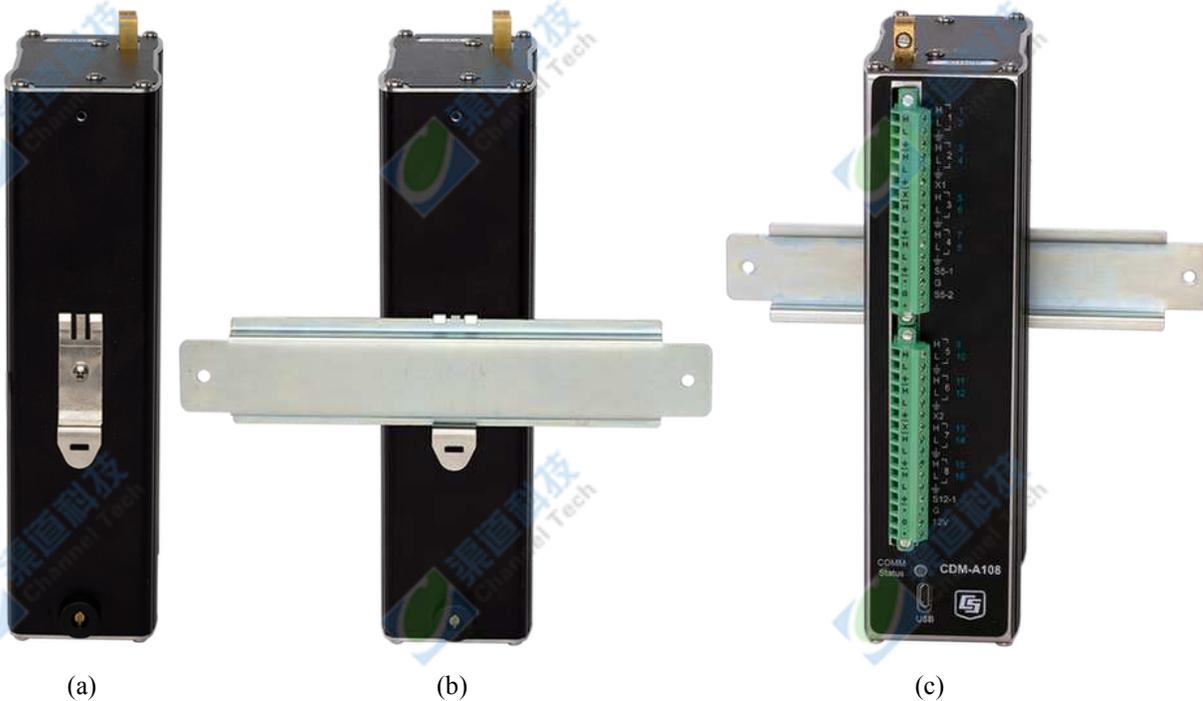


FIGURE 7-5. Mounting the CDM-A108 to a DIN rail

8. Operation

The CDM-A100 makes analog measurements under the direction of the datalogger. Upon compiling the program, the datalogger sends information to each CDM-A100 about every relevant sequence, scan, and measurement. The datalogger uses a data sync to initiate measurements on the CDM-A100. Because measurements can be made in multiple scans, slow sequences, sub-scans, and subroutines, the datalogger firsts sends a message to the modules indicating which scan's measurements are to be made upon the next data sync.

When the CDM-A100 receives a sync signal, it begins making measurements. The measurement order on the CDM-A100 follows the sequence of the instructions addressed to it within the current active scan of the datalogger program. After the measurements are completed, it sends the data to the datalogger for processing.

8.1 Measurements

Because the CDM-A100 series make measurements similar to the CR6 series datalogger, refer to the *CR6 Measurement and Control System manual* for in-depth measurement details. Information specific to the CDM-A100 series is provided in the subsequent sections.

8.1.1 First Notch Frequency

The first notch frequency (f_{NI}) 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_{NI} by averaging for a time equal to $1/f_{NI}$. 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 6-2, *Analog Voltage Measurement Speed* (p. 13).

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)

8.1.2 Panel Temperature

Each terminal strip has a panel temperature thermistor (Measurement Specialties 10K3A1A) located just under its center-point. The CDM-A108 includes two panel-temperature thermistors, and the CDM-A116 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 is measured with the `CDM_PanelTemp()` instruction, where each thermistor is numbered as shown in FIGURE 5-1, *Wiring panel of CDM-A108 and CDM-A116* (p. 8). In thermocouple measurements, using the panel temperature for the thermocouple-wiring strip will result in more accurate measurements. CRBasic Example B-2, *Measuring Thermocouples* (p. B-2), shows how to use the appropriate panel temperature reference for each thermocouple measurement. *Short Cut* automatically uses the proper reference. See the *CR6 Measurement and Control System manual* for more details on making good thermocouple measurements.

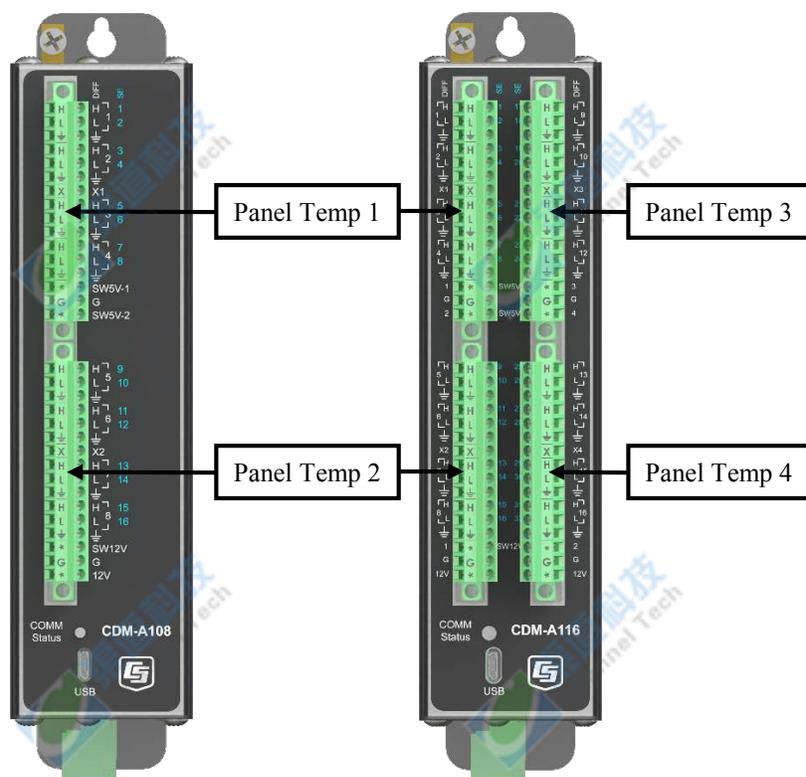


FIGURE 8-1. Wiring panel thermistor locations on CDM-A108 (left) and CDM-A116 (right)

8.2 Fast Measurements

Follow the steps below when designing fast-measurement CDM networks:

1. Work out the time the CDM-A100 will take to make all of the measurements (Section 8.2.1, *Measurement Speed* (p. 26)).
2. Calculate the CPI bit rate necessary to keep up with the sum of data generated by all devices (Section 8.2.2, *CPI Network Bit Rate* (p. 28)).
3. Determine if the physical layout of your network will allow for the calculated CPI bit rate (TABLE 8-2, *Network Topology, Bit Rate, and Cable Length* (p. 28)).

See Appendix C, *Calculating Network Restrictions (p. C-1)*, for complete examples.

8.2.1 Measurement Speed

Use the equations in TABLE 8-1 to ensure that the CDM-A100 is able to make measurements at the speed required. Compare that speed with the scan rate options for the datalogger to determine if the CDM-A100 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 CDM-A100 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 8-1. Multiplexed Analog Voltage Measurement Speed^{1,2,3}

Without Input or Excitation Reversal	Measurement Time (μs)	repetitions • $\left(T_{settle} + \frac{10^6 \mu\text{s/s}}{f_{N1}} + 184 \mu\text{s}\right) + 31 \mu\text{s}$
	Sample Rate (Hz)	$10^6 \cdot \left(T_{settle} + \frac{10^6 \mu\text{s/s}}{f_{N1}} + 184 \mu\text{s}\right)^{-1}$
With Input or Excitation Reversal	Measurement Time (μs)	repetitions • $\left[2 \cdot \left(T_{settle} + \frac{10^6 \mu\text{s/s}}{f_{N1}} + 180 \mu\text{s}\right) + 5 \mu\text{s}\right] + 31 \mu\text{s}$
	Sample Rate (Hz)	$10^6 \cdot \left[2 \cdot \left(T_{settle} + \frac{10^6 \mu\text{s/s}}{f_{N1}} + 180 \mu\text{s}\right) + 5 \mu\text{s}\right]^{-1}$
With Input and Excitation Reversal	Measurement Time (μs)	repetitions • $\left[4 \cdot \left(T_{settle} + \frac{10^6 \mu\text{s/s}}{f_{N1}} + 180 \mu\text{s}\right) + 8 \mu\text{s}\right] + 31 \mu\text{s}$
	Sample Rate (Hz)	$10^6 \cdot \left[4 \cdot \left(T_{settle} + \frac{10^6 \mu\text{s/s}}{f_{N1}} + 180 \mu\text{s}\right) + 8 \mu\text{s}\right]^{-1}$
Burst Measurement	Measurement Time (μs)	repetitions • $\frac{10^6 \mu\text{s/s}}{f_{N1}} + T_{settle} + 215 \mu\text{s}$
	Sample Rate (Hz)	f_{N1}

¹If the instruction uses excitation, calculate the measurement time separately and add 46 μs for each excitation terminal used. Refer to Example 3 in Appendix C, *Calculating Network Restrictions (p. C-1)*.
²Refers to multiplexing circuitry internal to the CDM-A100 series.
³Default settling time, T_{settle}, is 500 μs, minimum 100 μs.

NOTE

The CDM-A100 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.

8.2.1.1 Sub-Scans

To measure at rates faster than the maximum scan rate of the datalogger, the **SubScan()/NextSubScan** instruction pair is added within the datalogger 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_{NI} must be 500 or greater to allow for a single-ended measurement in a 5 ms SubScan. Refer to TABLE 6-2, *Analog Voltage Measurement Speed* (p. 13), for analog voltage measurement speeds associated with f_{NI} options.

CRBasic Example 8-1. 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(CDM_A108,1,FastSE(i),1,mV5000,1,False,150,500,1,0)
    i = i + 1 'increment index counter after each measurement
  NextSubScan
  CallTable FastSETable
NextScan
EndProg
```

8.2.1.2 Burst Measurements

To measure at rates greater than the maximum sub-scan rate of the datalogger, 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 CRBasic example below. Burst measurements do not allow offset measurement, input reversal, or excitation reversal.

The measurement rate is determined by the notch frequency (f_{NI}). With f_{NI} 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 6-2, *Analog Voltage Measurement Speed* (p. 13) or the *CRBasic 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 *CR6 Measurement and Control System manual* and *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 8-2. Measuring VoltSE() in Burst Mode

'Program Example
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(CDM_A108,1,BurstSE(),1735,mV5000,-1,False,150,15000,1,0)
  CallTable BurstSETable
  NextScan
EndProg
    
```

8.2.2 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 Section 7.6, *Connecting Multiple CDMs (p. 21)*). This is the rate that data are transferred from the CDM to the datalogger. When multiple CDMs 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 CDMs within the network.

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

Equation 8-1: 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 8-2 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 datalogger program.

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

¹Default Bit Rate is 250 kbps. Change with **CPISpeed()** instruction.

8.3 Multiple Devices

Multiple CDMs may be connected to a single datalogger using a daisy-chain or star topology (see Section 7.6, *Connecting Multiple CDMs (p. 21)*). 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*, which is available at www.campbellsci.com/app-notes.

When including two or more CDM-A100 devices in the program, the processing mode of the datalogger affects the measurement timing of each CDM-A100. In [sequential mode](#), the CDM-A100 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 CDM-A100 that provides the excitation voltage or current.

8.4 Switched Voltage Output

8.4.1 Switched 5 Vdc

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:

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

Where V_0 is the drive limit, and I_0 is the current required by the external device. FIGURE 6-1, *Current sourcing on SW5V terminals (p. 16)*, shows the relationship between supply voltage and current load.

8.4.2 Switched 12 Vdc

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.

9. Maintenance

- Protect the CDM-A100 from humidity and moisture.
- Send to Campbell Scientific for factory calibration every three years.

9.1 Factory Calibration or Repair Procedure

If sending the CDM-A100 to Campbell Scientific for calibration or repair, consult first with a Campbell Scientific representative. If the CDM-A100 is malfunctioning, be prepared to perform some troubleshooting procedures while on the phone with Campbell Scientific. Many problems can be resolved with a

telephone conversation. If calibration or repair is needed, the procedure shown in *Assistance* should be followed when sending the product.

10. Troubleshooting

10.1 Troubleshooting – Basic Procedure

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. If the program was written solely with *Short Cut*, the program is probably not the source of the problem. If the program was written or edited with *CRBasic Editor* (p. 32), logic and syntax errors could easily have crept into the code. To troubleshoot, create a stripped down 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 CDM-A100 in the network has a unique CPI address.
5. Check the datalogger and CDM-A100 operating system and update them as needed.
6. Check that the scan rate is long enough for the measurement time. (See Section 8.2.1, *Measurement Speed* (p. 26).)
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 Section 8.2.2, *CPI Network Bit Rate* (p. 28).)

10.2 Troubleshooting – CPIStatus Table

Information in the **CPIStatus** table, which is located in the datalogger, 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 TABLE 10-1.

TABLE 10-1. CPIStatus Activity	
Response	Meaning
Active	The module is connected to the CPI (p. 32) bus and is making measurements according to the datalogger 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 datalogger program.
Wait Config	The module has not yet responded to a datalogger's attempts to configure it.
Config Fail	The module could not be configured. A configuration error message is appended to this response.

10.3 COMM status LED

The COMM status [LED](#) (p. 32) indicates the current operation of the CDM-A100, as shown in TABLE 10-2 below.

TABLE 10-2. COMM Status LED Activity		
Green	Flashing	Module has been configured by datalogger and is receiving sync signals
Orange	Flashing	Device has not been configured by datalogger
Red	Single-Flash	Device has been configured but is not receiving sync signals
	Double-Flash	Device has encountered a scan timeout
	Solid	Error

10.4 CPI Port LEDs

Green and Orange LEDs on the [CPI](#) (p. 32) bus indicate the current operation of the CPI bus as shown in TABLE 10-3 below.

TABLE 10-3. CPI Port LED Activity		
Green	Flashing	Frame Sync
	Solid	CPI bus fault
Orange	Flashing	CPI activity
	Solid	CPI bus fault

10.5 Replacing a CDM-A108 or CDM-A116

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

11. Glossary

CPI

CAN Peripheral Interface — A proprietary protocol that supports Campbell Distributed Modules (CDMs). The CPI bus handles communication between the datalogger and CDMs.

CRBasic Editor

A utility included with datalogger support software. Use it to create and edit CRBasic datalogger programs. Update the CRBasic compiler by downloading the appropriate datalogger operating systems at www.campbellsci.com/downloads and running the downloaded executable file.

DevConfig (Device Configuration Utility)

A utility included with datalogger support software. It is also available on the *ResourceDVD* and at www.campbellsci.com/downloads. The CDM-A100 series is compatible with *DevConfig* 2.11 and newer.

Datalogger Support Software

For the purposes of the CDM-A100 series, these include *LoggerNet*, *PC400*, *PC200W*, and *RTDAQ*.

LED (Light Emitting Diode)

Lights on all CDM-A100s and related instruments are LEDs. For more information, see TABLE 10-2, *COMM Status LED Activity* (p. 31), and TABLE 10-3, *CPI Port LED Activity* (p. 31).

OS (Operating System)

The CDM-A100, datalogger, and SC-CPI each have an operating system. The operating system is a set of instructions that controls the basic functions of the device. The operating system is preloaded into the CDM-A100, the datalogger, and the SC-CPI at the factory but can be re-loaded or upgraded by using *Device Configuration Utility* software. Follow the procedure on the *Device Configuration Utility* **Send OS** tab to load a new OS to a device.

Pipeline Mode

A mode of processing a program which handles measurement, most digital, and processing tasks separately, and possibly simultaneously. Measurements are scheduled to execute at exact times and with the highest priority, resulting in more precise timing of measurement, and usually more efficient processing and power consumption. The datalogger automatically sets the processing mode according to the instructions in the program; however, it can be forced to pipeline mode by using the **PipelineMode** instruction at the beginning of the program.

SC-CPI

A CPI Communication interface that is required when using a CR800-Series, CR1000, or CR3000 datalogger in CPI network.

Sequential Mode

A mode of processing a program which executes instructions in the sequence in which they are written in the program. After a measurement is made, the result is converted to a value determined by processing arguments that are included in the measurement command, and then program execution proceeds to the next instruction. The datalogger automatically sets the processing mode according to the instructions in the program; however, it can be forced to sequential mode by using the **SequentialMode** instruction at the beginning of the program.

12. References

Campbell Scientific. 2015. *CR6 measurement and control system: Operator's manual*. Campbell Scientific.

<https://s.campbellsci.com/documents/us/manuals/cr6.pdf>

Campbell Scientific. 2012. *4WFBS120, 4WFBS350, 4WFBS1K 4 wire full bridge terminal input modules: Instruction manual*. Campbell Scientific.

<https://s.campbellsci.com/documents/us/manuals/4wfbs.pdf>

Madsen, C. and Cornelsen, S. 2014. *Designing physical network layouts for the CPI bus* [White paper]. Campbell Scientific.

<https://s.campbellsci.com/documents/us/technical-papers/cpi-bus.pdf>



Appendix A. Importing Short Cut Code Into CRBasic Editor

This tutorial shows:

- How to import a *Short Cut* program into a program editor for additional refinement
- How to import a wiring diagram from *Short Cut* into the comments of a custom program

Short Cut creates files, which can be imported into *CRBasic Editor*. Assuming defaults were used when *Short Cut* was installed, these files reside in the C:\campbellsci\SCWin folder:

- .DEF (wiring and memory usage information)
- .CR6 (CR6 datalogger code)
- .CR1 (CR1000 datalogger code)
- .CR8 (CR800 datalogger code)
- .CR3 (CR3000 datalogger code)

Use the following procedure to import *Short Cut* code and wiring diagram into *CRBasic Editor*.

1. Create the *Short Cut* program following the procedure in Section 4, *QuickStart* (p. 2). Finish the program and exit *Short Cut*. Make note of the file name used when saving the *Short Cut* program.
2. Open *CRBasic Editor*.
3. Click **File** | **Open**. Assuming the default paths were used when *Short Cut* was installed, navigate to C:\CampbellSci\SCWin folder. The file of interest has the .CR6, .CR1, .CR8, or .CR3 extension. Select the file and click **Open**.
4. Immediately save the file in a folder different from C:\Campbellsci\SCWin, or save the file with a different file name.

NOTE

Once the file is edited with *CRBasic Editor*, *Short Cut* can no longer be used to edit the datalogger program. Change the name of the program file or move it, or *Short Cut* may overwrite it next time it is used.

5. The program can now be edited, saved, and sent to the datalogger.
6. Import wiring information to the program by opening the associated .DEF file. Copy and paste the section beginning with heading “-Wiring for CRXXX-” into the CRBasic program, usually at the head of the file. After pasting, edit the information such that an apostrophe (') begins each line. This character instructs the datalogger compiler to ignore the line when compiling.

Appendix B. Example Programs

B.1 Adding CDMs with CPIAddModule()

The following program sets *CPI Addresses* and *Device Names* on CDM-A100s with serial numbers 1234, 1235, and 1236 and makes a single-ended measurement on each unit's SE 1 channel. With slight modifications, this program can be used with the CR800-series, CR1000, and CR3000 dataloggers.

CRBasic Example B-1. Adding CDMs with CPIAddModule()

```
'This program sets CPI Addresses and Device Names on CDM-A100s with serial numbers
'1234, 1235, and 1236 and 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
  CPIAddModule (CDM_A108,1234,"A",4)
  CPIAddModule (CDM_A108,1235,"12345",5)
  CPIAddModule (CDM_A116,1236,"CDM_A108 in Pump House",6)
'Main Scan
Scan(5,Sec,3,0)
  'Generic Single Ended Voltage measurement 'SEVolt' on CDM-A108 with CPI address 1
  CDM_VoltSe(CDM_A108,4,SEVolt1,1,mV5000,1,True,500,60,1,0)
  CDM_VoltSe(CDM_A108,5,SEVolt2,1,mV5000,1,True,500,60,1,0)
  CDM_VoltSe(CDM_A116,6,SEVolt3,1,mV5000,1,True,500,60,1,0)
  'Call Data Tables and Store Data
  CallTable Table1
NextScan
EndProg
```

B.2 Measuring Thermocouples

The following program measures 16 thermocouples on a CDM-A116. Because the CDM-A116 can measure 4 thermocouples per terminal strip, this program includes code to use the appropriate reference temperature measurement.

CRBasic Example B-2. Measuring Thermocouples

```

'This program example demonstrates measuring 16 thermocouples on a CDM-A116

'Declare Variables and Units
Dim CDMTCRef(16)
Public BattV
Public PTemp_C
Public CDMBattV
Public CDMPTempC(4)
Public Temp_C(16)

Units BattV=Volts
Units PTemp_C=Deg C
Units CDMBattV=Volts
Units Temp_C=Deg C
Units CDMPTempC=Deg C

'Define Data Tables
DataTable(Hourly,True,-1)
  DataInterval(0,60,Min,10)
  Average(16,Temp_C),FP2,False)
  Average(4,CDMPTempC),FP2,False)
EndTable

DataTable(Daily,True,-1)
  DataInterval(0,1440,Min,10)
  Minimum(1,BattV,FP2,False,False)
  Minimum(1,CDMBattV,FP2,False,False)
EndTable

'Main Program
BeginProg
  'Main Scan
  Scan(5,Sec,3,0)
    'Measure CR6 Datalogger Battery Voltage
    Battery(BattV)
    'Measure CR6 Datalogger Wiring Panel Temperature
    PanelTemp(PTemp_C,60)
    'Measure CDM-A116 Battery Voltage
    CDM_Battery(CDM_A116,1,CDMBattV)
    'Measure CDM-A116 Wiring Panel Temperatures
    CDM_PanelTemp(CDM_A116,1,CDMPTempC),4,1,60)
    'Populate CDMTCRef() array with copies of CDMPTempC() reference temperature
    'measurements from CDM-A116 for use in thermocouple measurements
    Move(CDMTCRef(1),4,CDMPTempC(1),1)
    Move(CDMTCRef(5),4,CDMPTempC(2),1)
    Move(CDMTCRef(9),4,CDMPTempC(3),1)
    Move(CDMTCRef(13),4,CDMPTempC(4),1)
    'Measure Type T (Copper-constantan) Thermocouple on CDM-A116
    'Syntax CDMTCRef(1)() increments reference temperature array with each repetition
    CDM_TCdiff(CDM_A116,1,Temp_C),16,mv200C,1,TypeT,CDMTCRef(1)(),True,0,60,1,0)
    'Call Data Tables and Store Data
    CallTable Hourly
    CallTable Daily
  NextScan
EndProg

```

B.3 Controlling an AM16/32B Multiplexer

The following program makes 32 differential measurements through an AM16/32B multiplexer controlled by a CDM-A108 connected to a CR6 datalogger. With slight modifications, this program can be used with the CDM-A116 or CR800 series, CR1000, and CR3000 dataloggers.

CRBasic Example B-3. Controlling an AM16/32B Multiplexer

```
'Program to make 32 differential measurements through an AM16/32B multiplexer
'controlled by a CDM-A108

'Wiring
'=====
'***Set AM16/32B to 2x32 mode**

'Sensor
'Function   Terminal
'-----
'High      H
'Low       L
'Ground    Ground Symbol

'AM16/32B   CDM-A108
'Terminal   Terminal
'-----
'RES        SW5-2
'CLK        SW5-1
'G          G
'12V        12V
'COM ODD H  1H
'COM ODD L  1L
'COM Ground Ground Symbol

'Declare Variables and Units
Dim LCount
Public MilliVolts(32)
DataTable(Table1,True,-1)
  DataInterval(0,10,Min,10)
  Average(32,MilliVolts(),FP2,False)
EndTable

'Main Program
BeginProg
'Main Scan
Scan(1,Min,3,0)
  'Turn AM16/32B Multiplexer on, and advance to first channel
  CDM_MuxSelect(CDM_A108,1,1,2,20,1,1)
  LCount=0 'reset loop counter
  SubScan(0,uSec,32)
  LCount+=1 'increment loop counter
  'Differential measurement on the AM16/32B Multiplexer
  CDM_VoltDiff(CDM_A108,1,MilliVolts(LCount),1,mV5000,1,True,5000,60,1.0,0)
  'Switch to next AM16/32B Multiplexer channel
  CDM_PulsePort(CDM_A108,1,1,20000)
NextSubScan
'Turn AM16/32B Multiplexer Off
CDM_SW5(CDM_A108,1,2,0,0)
Delay(0,150,mSec)
'Call Data Tables and Store Data
CallTable Table1
NextScan
EndProg
```

B.4 Measuring Bonded Foil Strain Gages

The following program example measures four quarter-bridge bonded foil strain gages using Campbell Scientific 4WFBS350 bridge completion modules (pn 20592) on **DIFF 1-4**. Equivalent resistance for each strain gage circuit is 518.52Ω (2000Ω in parallel with 700Ω) and can be found in the [4WFBS350 manual](#). Due to current sourcing limits, only three strain gages are excited per excitation channel.

To perform real-time offset corrections, this program uses **FieldCal()**. Run the Calibration Wizard in *LoggerNet* or *RTDAQ*, and set the *zmode* variable to “true”.

Bonded foil strain gages are susceptible to ambient electrical noise. Adjust the notch frequency parameter (f_{NI}) to help reduce this noise. Use the **StdDev()** output processing instruction in a data table to see how changing the f_{NI} parameter affects the signal output. Graphing the real-time output using datalogger support software shows if the input noise can be reduced via the f_{NI} parameter.

CRBasic Example B-4. Measuring Bonded Foil Strain Gages

```
'This program measures four 350-Ohm bonded foil strain gages on DIFF channels 1-4.
'4WFBS350 bridge completion modules are used on each channel.
```

```
'Declare Variables and Units
```

```
Public BattV
Public FCLoaded
Public PTemp_C
Public CReps
Public ZMode
Public QBSSMode
Public CIndex
Public CAvg
Public LCount
Public Strain(4)
Public Vr1000(4)
Public GFAdj(4)
Public BrZero(4)
Public CKnown(4)
Public GFsRaw(4)={2.0,2.0,2.0,2.0}
```

```
Units BattV=Volts
Units PTemp_C=Deg C
Units Strain=microstrain
Units Vr1000=mV/V
Units GFAdj=unitless
Units BrZero=mV/V
```

```
'Define Data Tables
```

```
DataTable(Table1,True,-1)
DataInterval(0,1,Sec,10)
Average(1,Strain(1),IIEEE4,False)
Average(1,Vr1000(1),IIEEE4,False)
Average(1,Strain(2),IIEEE4,False)
Average(1,Vr1000(2),IIEEE4,False)
Average(1,Strain(3),IIEEE4,False)
Average(1,Vr1000(3),IIEEE4,False)
Average(1,Strain(4),IIEEE4,False)
Average(1,Vr1000(4),IIEEE4,False)
StdDev(1,Strain(1),IIEEE4,False)
StdDev(1,Vr1000(1),IIEEE4,False)
StdDev(1,Strain(2),IIEEE4,False)
```

```

StdDev(1,Vr1000(2),IEEE4,False)
StdDev(1,Strain(3),IEEE4,False)
StdDev(1,Vr1000(3),IEEE4,False)
StdDev(1,Strain(4),IEEE4,False)
StdDev(1,Vr1000(4),IEEE4,False)
EndTable

DataTable(Table2,True,-1)
DataInterval(0,1440,Min,10)
Minimum(1,BattV,FP2,False,False)
EndTable

'Calibration history table
DataTable(CalHist,NewFieldCal,10)
SampleFieldCal
EndTable

'Main Program
BeginProg
'Initialize calibration variables for
'Quarter Bridge Strain, 3-wire 350 ohm with 4WFBS350 TIM measurement 'Vr1000()'
CIndex=1 : CAvg=1 : CReps=4
For LCount = 1 To 4
  GFAdj(LCount)=GFsRaw(LCount)
Next
'Load the most recent calibration values from the CalHist table
FCLoaded=LoadFieldCal(True)
'Main Scan
Scan(500,mSec,4,0)
'Default Datalogger Battery Voltage measurement 'BattV'
Battery(BattV)
'Default Wiring Panel Temperature measurement 'PTemp_C'
PanelTemp(PTemp_C,15000)
'Quarter Bridge Strain, 3-wire 350 ohm with 4WFBS350 TIM measurement 'Vr1000()'
CDM_BrFull(CDM_A116,10,Vr1000(),4,mV200,1,X1,3,2500,False,True,500,2000,1,0)
'Calculated strain result 'Strain()' for
'Quarter Bridge Strain, 3-wire 350 ohm with 4WFBS350 TIM measurement 'Vr1000()'
StrainCalc(Strain(),4,Vr1000(),BrZero(),-1,GFAdj(),0)
'Quarter bridge strain shunt calibration for
'Quarter Bridge Strain, 3-wire 350 ohm with 4WFBS350 TIM measurement 'Vr1000()'
FieldCalStrain(13,Strain(),1,GFAdj(),0,QBSSMode,CKnown(),CIndex,CAvg,GFsRaw(),0)
'Zeroing calibration for
'Quarter Bridge Strain, 3-wire 350 ohm with 4WFBS350 TIM measurement 'Vr1000()'
FieldCalStrain(10,Vr1000(),CReps,0,BrZero(),ZMode,0,CIndex,CAvg,0,Strain())
'Call Data Tables and Store Data
CallTable Table1
CallTable Table2
CallTable CalHist
NextScan
EndProg

```



Appendix C. Calculating Network Restrictions

This section shows some common questions asked while designing networks with CDM-A100s and how to calculate their answers. For all examples, the CDM-A108 or CDM-A116 is connected to a CR6 datalogger.

C.1 Example 1

a) How fast can a CDM-A116 make 32 single-ended measurements?

The time to make 32 single-ended measurements (which are measurements without input or excitation reversal) is copied below from TABLE 8-1, *Multiplexed Analog Voltage Measurement Speed* (p. 26):

$$\text{Measurement Time} = \text{repetitions} \cdot \left(T_{\text{settle}} + \frac{10^6 \mu\text{s/s}}{f_{N1}} + 184 \mu\text{s} \right) + 31 \mu\text{s}$$

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 .

$$\begin{aligned} \text{Measurement Time} &= 32 \cdot \left(100 \mu\text{s} + \frac{10^6 \mu\text{s/s}}{30000 \text{ Hz}} + 184 \mu\text{s} \right) + 31 \mu\text{s} \\ &= 10186 \mu\text{s} \end{aligned}$$

The CR6 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 CDM-A116 and the CR6 to make these 32 measurements?

A scan rate of 20 ms (0.02 s) equals a measurement frequency of 50 Hz ($1 \div 0.02$ s). Using Equation 8-1, the kilobits of data generated each second is

$$\text{Kilobits per second} = (\text{number of measurements}) \times (\text{measurement frequency}) \times (0.064 \text{ kilobits per measurement})$$

$$\begin{aligned} &= (32 \text{ measurements}) \times (50 \text{ Hz}) \times (0.064 \text{ kilobits per measurement}) \\ &= 102.4 \text{ kbps} \end{aligned}$$

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 TABLE 8-2, *Network Topology, Bit Rate, and Cable Length* (p. 28), 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 $2\text{ s} \div 0.02\text{ s} = 100$. The CRBasic **Scan()** instruction would be written this way:

Scan (20,msec,100,0)

d) **If there were four other CDM-A116s on the network with this same configuration, what restraints would there be on the system?**

Because the system can run in pipeline mode, each CDM-A116 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 CDM-A116s, 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 TABLE 8-2, *Network Topology, Bit Rate, and Cable Length* (p. 28)).

C.2 Example 2

a) **How many differential measurements can a CDM-A116 or CDM-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 8-1, *Multiplexed Analog Voltage Measurement Speed* (p. 26):

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

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:

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

With $f_{N1} = 30000\text{ Hz}$, $T_{\text{settle}} = 100 \mu\text{s}$, 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:

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

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.

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

Thus, to improve measurement resolution, f_{N1} should be set to 15000. According to TABLE D-1, *Analog Voltage Measurement Range and Resolution (p. D-1)*, this would improve the resolution to 9.012 μV_{RMS} for the largest voltage range, $\pm 5000 \text{ mV}$.

C.3 Example 3

How fast can a CDM-A116 measure ten 3 k Ω 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 TABLE D-1, *Analog Voltage Measurement Range and Resolution (p. D-1)*. To achieve a resolution of less than 1 μV_{RMS} within the $\pm 5000 \text{ mV}$ 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:

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

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

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

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.



Appendix D. Analog Voltage Measurement Range and Resolution

TABLE D-1. Analog Voltage Measurement Range and Resolution

f_{N1}^1 (Hz)	Range ² (mV)	Typical Effective Resolution ³			
		Differential Measurements with Input Reversal		Single-Ended Measurements or Differential Measurements without Input Reversal	
		RMS (μ V)	bits	RMS (μ V)	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
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

f_{N1}^1 (Hz)	Range ² (mV)	Typical Effective Resolution ³			
		Differential Measurements with Input Reversal		Single-Ended Measurements or Differential Measurements without Input Reversal	
		RMS (μ V)	bits	RMS (μ V)	bits
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
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

¹First notch frequency
²Range overhead of $\approx 6\%$ on all ranges guarantees that full-scale values will not cause overrange.
³Effective resolution (ER) in bits is computed from ratio of full-scale range to RMS noise.

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