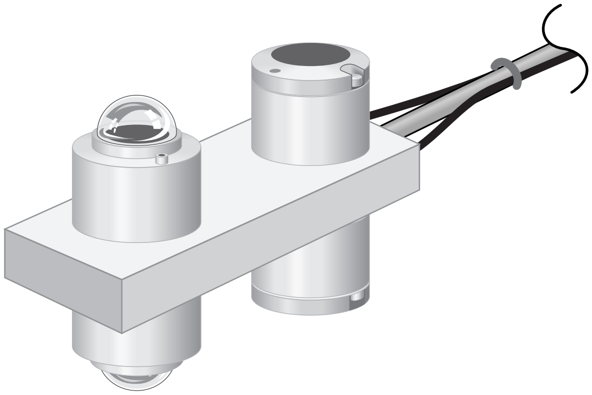
INSTRUCTION MANUAL

CNR1 Net Radiometer

Revision: 5/11



Warranty and Assistance

PRODUCTS MANUFACTURED BY CAMPBELL SCIENTIFIC, INC. are warranted by Campbell Scientific, Inc. ("Campbell") to be free from defects in materials and workmanship under normal use and service for twelve (12) months from date of shipment unless otherwise specified on the corresponding Campbell invoice. Batteries, fine-wire thermocouples, desiccant, and other consumables have no warranty. Campbell's obligation under this warranty is limited to repairing or replacing (at Campbell's option) defective products, which shall be the sole and exclusive remedy under this warranty. The customer shall assume all costs of removing, reinstalling, and shipping defective products to Campbell. Campbell will return such products by surface carrier prepaid within the continental United States of America. To all other locations, Campbell will return such products best way CIP (Port of Entry) INCOTERM® 2010, prepaid. This warranty shall not apply to any Campbell products which have been subjected to modification, misuse, neglect, improper service, accidents of nature, or shipping damage. This warranty is in lieu of all other warranties, expressed or implied. The warranty for installation services performed by Campbell such as programming to customer specifications, electrical connections to products manufactured by Campbell, and product specific training, is part of Campbell's product warranty. CAMPBELL EXPRESSLY DISCLAIMS AND EXCLUDES ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. Campbell is not liable for any special, indirect, incidental, and/or consequential damages.

Products may not be returned without prior authorization. The following contact information is for US and International customers residing in countries served by Campbell Scientific, Inc. directly. Affiliate companies handle repairs for customers within their territories. Please visit www.campbellsci.com to determine which Campbell Scientific company serves your country.

To obtain a Returned Materials Authorization (RMA), contact Campbell Scientific, Inc., phone (435) 753-2342. After an applications engineer determines the nature of the problem, an RMA number will be issued. Please write this number clearly on the outside of the shipping container. Campbell Scientific's shipping address is:

CAMPBELL SCIENTIFIC, INC.
RMA#_____
815 West 1800 North
Logan, Utah 84321-1784

For all returns, the customer must fill out a "Declaration of Hazardous Material and Decontamination" form and comply with the requirements specified in it. The form is available from our website at www.campbellsci.com/repair. A completed form must be either emailed to repair@campbellsci.com or faxed to 435-750-9579. Campbell Scientific will not process any returns until we receive this form. If the form is not received within three days of product receipt or is incomplete, the product will be returned to the customer at the customer's expense. Campbell Scientific reserves the right to refuse service on products that were exposed to contaminants that may cause health or safety concerns for our employees.

CNR1 Table of Contents

PDF viewers note: These page numbers refer to the printed version of this document. Use the Adobe Acrobat® bookmarks tab for links to specific sections.

Figures

Tables

CNR1 Net Radiometer

1. General Description

The CNR1 Net Radiometer is intended for the analysis of the radiation balance of Solar and Far Infrared radiation. The most common application is the measurement of Net (total) Radiation at the earth's surface.

The CNR1 design is such that both the upward-facing and the downward-facing instruments measure the energy that is received from the whole hemisphere (180 degrees field of view). The output is expressed in Watts per square meter. The total spectral range that is measured is roughly from 0.3 to 50 micrometers. This spectral range covers both the Solar Radiation, 0.3 to 3 micrometers, and the Far Infrared radiation, 5 to 50 micrometers.

The design of CNR1 is such that Solar radiation and Far Infrared radiation are measured separately. Solar radiation is measured by two CM3 pyranometers, one for measuring incoming solar radiation from the sky, and the other, which faces downward, for measuring the reflected Solar radiation. From these two pyranometers, albedo, the ratio of reflected and incoming radiation, can also be determined. Far Infrared radiation is measured by two CG3 pyrgeometers, one for measuring the Far Infrared radiation from the sky, the other from the soil surface.

An incorporated heater allows the CNR1 to be heated to prevent dew or frost accumulation on the sensors.

Additional information on the CNR1 sensor can be found in the Kipp & Zonen CNR1 Manual. The primary intent of this manual is to provide information on interfacing the CNR1 to Campbell Scientific dataloggers.

2. Sensor Specifications

2.1 CNR1 Specifications

See the Kipp & Zonen manual for additional specifications.

Sensor sensitivities:	All four sensors have equal sensitivity
Pt-100 sensor temperature measurement:	DIN class A
Expected accuracy of the temperature measurement:	± 2 K, under non-stable conditions with solar heating or heating by using the heating resistor.
Operating temperature:	-40 to +70 degrees Celsius
Requirements for data acquisition:	
Radiation components:	4 differential or 4 single-ended analog channels
Pt-100 temperature:	1 excitation and 2 differential analog channels
Expected accuracy for daily totals:	± 10 %

Cable length:	15 m (each cable)
Weight:	4 kg
Mounting arm attached to CNR1:	14.5” (37 cm) long 5/8” (1.6 cm) diameter

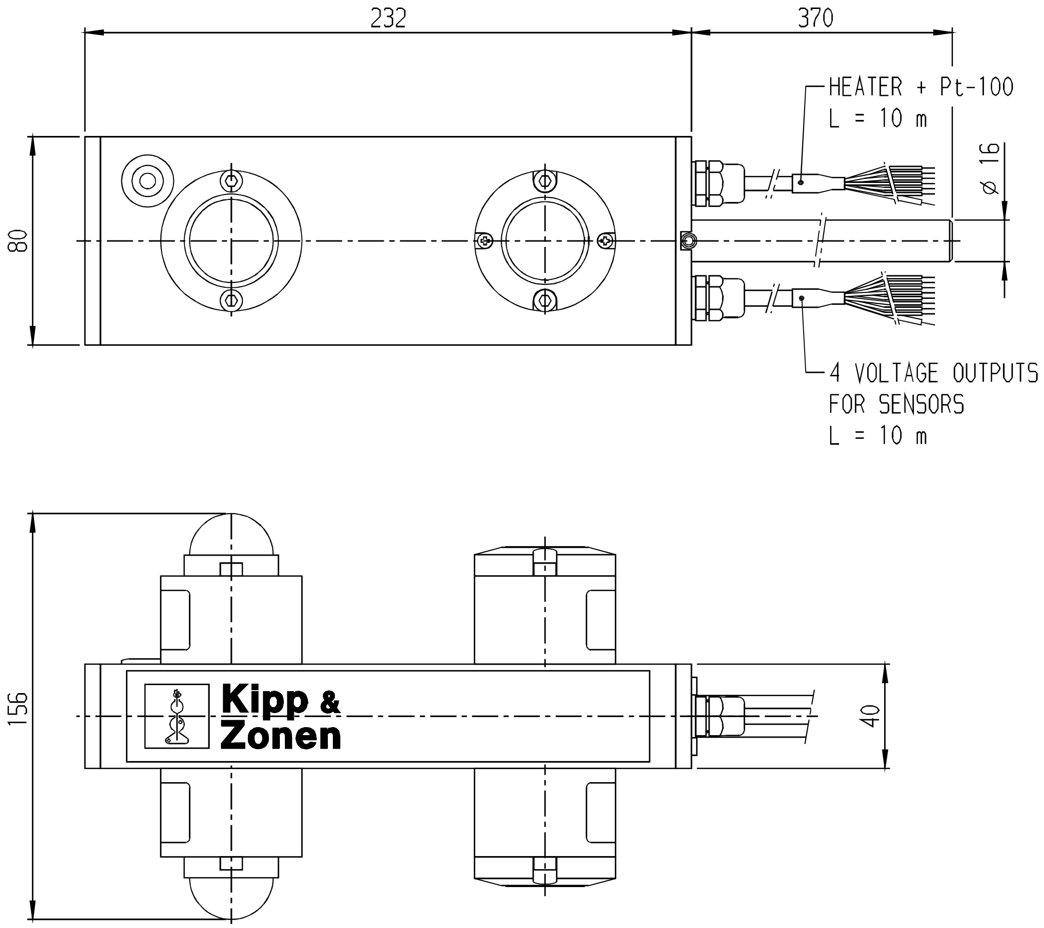


FIGURE 2-1. The Dimensions of the CNR1

2.2 CM3 Specifications

Specifications that are part of the ISO classification:

Response time 95%:	18 s
Non-stability:	< 1% change per year
Non-linearity:	Max. dev. 2.5% (0-1000 W m^{-2})
Directional error:	Max. 25 W m^{-2} at 1000 W m^{-2}
Spectral selectivity:	Max. dev. 5% (350-1500 nm)
Temperature dependence of sensitivity:	6% (-10 to +40^{o}C)

Tilt response:	Max. dev. 2%
Overall ISO classification:	second class
Sensitivity:	10 - 35 µV/(W m^{-2})
Impedance:	125 Ohm nominal
Operating temperature:	-40°C to +80°C
Spectral range:	305-2800 nm (50% points)
Expected signal range for atmospheric application:	0 - 15 mV typical
Expected accuracy for daily sums:	± 10%
Window heating offset:	Max. 25 W m^{-2} at 1000 W m^{-2} normal incidence solar radiation

2.3 CG3 Specifications

Response time 95%:	18 s
Non-stability:	< 1% change per year
Non-linearity:	Max. dev. 2.5% (0-1000 W m^{-2})
Temperature dependence of sensitivity:	6% (-10°C to +40°C)
Tilt response:	Max. 3% when facing downwards
Field of view:	150 degrees
Sensitivity:	5 - 35 µV/(W m^{-2})
Impedance:	125 Ohm nominal
Operating temperature:	-40°C to +80°C
Temperature range for specified behavior:	-10°C to +40°C
Measurement range:	-250 to +250 W m^{-2}
Spectral range:	5 to 50 µm
Expected signal range for atmospheric application:	-4 to 4 mV
Expected accuracy for daily sums:	± 10%

3. Installation

For measurement of the Net Radiation, it is most important that the instrument is located in a place that is representative of the entire region that one wishes to study.

When installed on a mast, the preferred orientation should be such that no shadow is cast on the Net Radiometer at any time during the day. In the

Northern Hemisphere this implies that the Net Radiometer should be mounted south of the mast.

It is suggested that the CNR1 is mounted at a height of at least 1.5 meters above the surface to avoid shading effects of the instruments on the soil and to promote spatial averaging of the measurement. If the instrument is H meters above the surface, 99% of the input of the lower sensors comes from a circular area with a radius of 10 H. Shadows or surface disturbances with radius < 0.1 H will affect the measurement by less than 1%.

It is recommended that the CNR1 be mounted to a separate vertical pipe at least 25’ from any other mounting structures. PN 14264 mounting bracket is used to mount the CNR1 directly to a vertical pipe. Mount the sensor as follows:

1. Attach PN 14264 mounting bracket to the vertical mounting pipe.

2. Insert the CNR1 mounting arm of the sensor into the 14264 mounting block. Tighten the four set screws just enough to secure the mounting arm position, but loose enough to allow the arm to be rotated.

NOTE Do not attempt to rotate the instrument using the sensor heads or you may damage the sensors; use the mounting arm only.

3. Loosen the vertical adjustment screws on the back of the 14264 mounting bracket. Adjust the sensor mounting arm horizontally and vertically until the bubble level on the sensor head shows level. Tighten the adjustment screws to secure the position.

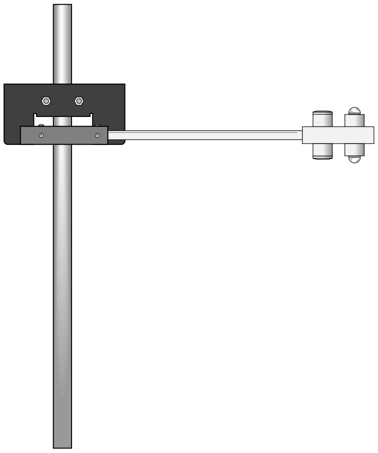


FIGURE 3-1. CNR1 Mounting Options

For installation in buildings or in solar energy applications, one will often have to mount the CNR1 parallel to the surface that is being studied. This may be in a tilted or a vertical position. The sensitivity of the radiometers will be affected, but only in a minor way. This is specified as the so-called tilt effect. From the specifications one can see that the tilt effect (this is a change in sensitivity) remains within 3 %.

3.1 Connecting and Using the Heater

Only use the sensor's heater when there is risk of dew forming on the sensors, especially for low power installations. Furthermore, the heater should be turned on and off infrequently because it may take some time for the sensor to come to thermal equilibrium. No damage will result if the heater is powered continuously, but as with all thermopile sensors, it is best if the sensor operates at ambient temperatures and is not subject to rapid temperature changes.

The sensor power can be controlled using one of the 12V power switches built into Campbell dataloggers or using an external solid state switch such as a PSW12/SW12. The heater's current drain is approximately 500 mA when using a 12V battery. Connect the ground return from the heater either directly to the battery or to a G terminal close the power input to the logger (i.e., not to an analog ground near the measurement inputs).

The heater power can be controlled by adding instructions to the datalogger program that turns on the heater only when the light level falls below 20 W m^{-2} or, if a measurement of air humidity is available, when the dew point of the air falls to within 1ºC of the sensor body temperature. More details about using the heater are provided in Appendix B. Appendix C provides an example CR3000/CR5000 program that controls the CNR1 heater.

4. Using the CNR1 in the Four Separate Components Mode (4SCM)

In the 4SCM configuration (measuring two Solar Radiation signals, two Far Infrared signals and, for calculation purposes, one Pt-100 signal), all signals are measured separately. Calculation of Net-Radiation and albedo can be done by the datalogger, or later by the computer from the radiation and temperature data.

The two CM3s will measure the solar radiation, both incoming and reflected. The two CG3s will measure the Far Infrared radiation. For proper analysis of the CG3 measurement results, they must be temperature corrected using the temperature measurement performed by the Pt-100.

The following paragraphs describe how one should treat the instrument, and how different parameters like net Solar radiation, net Far Infrared radiation, soil temperature, sky temperature, and Net (total) radiation can be calculated.

4.1 Measuring Solar Radiation with the CM3

Measuring with the upward-facing CM3 the so-called global (solar) radiation is measured. The downward-facing CM3 measures the reflected solar radiation. When calculating the Net radiation, the Reflected radiation must be subtracted from the global radiation. See Section 4.5.

The CM3 pyranometer generates a mV signal that is simply proportional to the incoming Solar radiation. The conversion factor between voltage, V, and Watts per square meter of solar irradiance E, is the so-called calibration constant C (or sensitivity).

For the CM3 $$E = V/C \tag{4.1}$$

4.2 Measuring Far Infrared Radiation with the CG3

The downward-facing CG3 measures the Far Infrared radiation that is emitted by the ground. The upward-facing CG3 measures the Far Infrared radiation from the sky. As the sky is typically colder than the instrument, one can expect negative voltage signals from the upward-facing CG3. For this measurement, the Pt-100 output is required. The Equation 4.2 is used to calculate the Far Infrared irradiance of the sky and of the ground.

When using the CG3 pyrgeometer, one should realize that the signal that is generated by the CG3 represents the exchange of Far Infrared (thermal) radiation between the CG3 and the object that it is facing. This implies that the CG3 will generate a positive voltage output, V, when it faces an object that is hotter than its own sensor housing, and that it will give a negative voltage signal when it faces an object that is colder. This means that for estimating the Far Infrared radiation that is generated by the object that is faced by the pyrgeometer, usually the sky or the soil, one will have to take the pyrgeometer temperature, T, into account. This is why a Pt-100 is incorporated in the CNR1's body. (This body is in very good thermal contact with the CG3 and has the same temperature as the CG3 sensor surface.) The calculation of the Far Infrared irradiance, E, is done according to the following equation:

For the CG3 only $$E = V/C + 5.67 \cdot 10^{-8} * T^4 \tag{4.2}$$

In this equation C is the sensitivity of the sensor. Please bear in mind that T is in Kelvin, and not in Celsius or Fahrenheit.

4.3 Measuring the CNR1’s Temperature with the Pt-100

The Pt-100 temperature sensor is located in the CNR1 body. It will not measure the exact temperature of the CG3 unless the whole instrument is in thermal equilibrium. Errors, however, are minimized in the design by making solid metal connections between the sensors and the temperature sensor. When the sun is shining, the largest expected deviation between real sensor temperature and Pt-100 reading is 2 degrees. This results in a worst-case error for the CG3 of 10 Watts per square meter.

The Pt-100 will not give a good indication of ambient air temperature; at 1000 Watts per square meter Solar radiation, and no wind, the instrument temperature will rise approximately 12 degrees above ambient temperature.

The offsets of both pyranometers and pyrgeometers might be larger than 10 Watts per square meter if large temperature gradients are forced on the instrument (larger than 5 K/hr). This happens, for example, when rain hits the instrument. The occurrence of this can be detected using the Pt-100 readout. It can be used as a tool for quality assurance of your data.

The 4WPB100 module is used to interface the Pt-100 to the datalogger, and is included with the CNR1 sensor purchased from CSI. The 4WPB100 configures the Pt-100 as a 4-wire half bridge circuit that requires one excitation and two differential channels on the datalogger (Section 5).

4.4 Calculation of the Albedo for Solar Radiation

The albedo is the ratio of incoming and reflected Solar radiation. It is a figure somewhere between 0 and 1. Typical values are 0.9 for snow, and 0.3 for grassland. To determine albedo, the measured values of the two CM3s can be used. The CG3s are not involved, as they do not measure Solar radiation. Do not use measured values when solar elevation is lower than 10 degrees above the horizon. Errors in measurement at these elevations are likely and thus yielding unreliable results. This is due to deviations in the directional response of the CM3s.

$$\text{Albedo} = (\text{E lower CM3}) / (\text{E upper CM3}) \qquad (4.3)$$

In the above formula, E is calculated according to Equation 4.1.

Albedo will always be smaller than 1. Checking this can be used as a tool for quality assurance of your data. If you know the approximate albedo at your site, the calculation of albedo can also serve as a tool for quality control of your measured data at this specific site.

4.5 Calculation of the Net Solar Radiation (Net Short-Wave)

Net Solar radiation is equal to the incoming solar radiation minus the reflected solar radiation.

$$\text{Net Solar radiation} = (\text{E upper CM3}) - (\text{E lower CM3}) \qquad (4.4)$$

In this formula E is calculated according to Equation 4.1.

Net Solar radiation will always be positive. Checking this can be used as a tool for quality assurance of your measured data.

4.6 Calculation of the Net Infrared Radiation (Net Long-Wave)

Net Far Infrared radiation is, like Net Solar radiation, the part that contributes to heating or cooling of the earth's surface. In practice, most of the time Net Far Infrared radiation will be negative.

$$\text{Net Far Infrared radiation} = (\text{E upper CG3}) - (\text{E lower CG3}) \qquad (4.5)$$

In this formula E is calculated according to Equation 4.2. From this equation the term with T cancels.

The E measured with the CG3 actually represents the irradiance of the sky (for the upward- facing CG3) or the ground (for the downward-facing CG3). Assuming that these two, ground and sky, behave like perfect blackbodies (actually this is only in theory), one can calculate an effective "Sky temperature" and an effective "Ground temperature".

$$\text{Sky temperature} = \left[\frac{\text{E upper CG3}}{5.67 \cdot 10^{-8}}\right]^{1/4} \qquad (4.6)$$

$$\text{Ground Temperature} = \left[\frac{\text{E lower CG3}}{5.67 \cdot 10^{-8}}\right]^{1/4} \qquad (4.7)$$

As a rule of thumb, for ambient temperatures of about 20 degrees Celsius, one can say that one degree of temperature difference between two objects results in a 5 Watts per square meter exchange of radiative energy (infinite objects):

1 degree of temperature difference = 5 Watts per square meter (rule of thumb)

4.7 Calculation of the Net (total) Radiation

In the 4 Separate Components Mode, Net radiation, NR, can be calculated using the individual sensor measurement results:

$$NR = (E\ \text{upper CM3}) + (E\ \text{upper CG3}) - (E\ \text{lower CM3}) - (E\ \text{lower CG3}) \qquad (4.8)$$

Where E is the irradiance that is calculated for the CM3 according to Equation 4.1, for the CG3 according to Equation 4.2, the terms with T cancel from this equation.

5. Wiring

Figure 5-1 shows the CNR1 schematic with the four radiation outputs, Pt-100 temperature sensor, and the heater. The use of the heater is described in detail in the Appendix B. All wiring schemes shown in this manual will show wiring for both CNR1 and 4WPB100 modules. Wiring diagrams and Tables 5-1 and 5-2 are applicable only if you bought the CNR1 Net Radiometer from Campbell Scientific, Inc.

Use of the CNR1 Net Radiometer, which you bought outside of Campbell Scientific, is possible only on the CR3000 and CR5000 dataloggers. The PT-100 can connect directly to the CR3000 and CR5000 because they have current excitation inputs. Table 5-3 and Program Example 6.2.4 show wiring and programming on the CR5000 datalogger without the 4WPB module.

All other CSI dataloggers require the 4WPB100 module to interface the PT-100 to the datalogger.

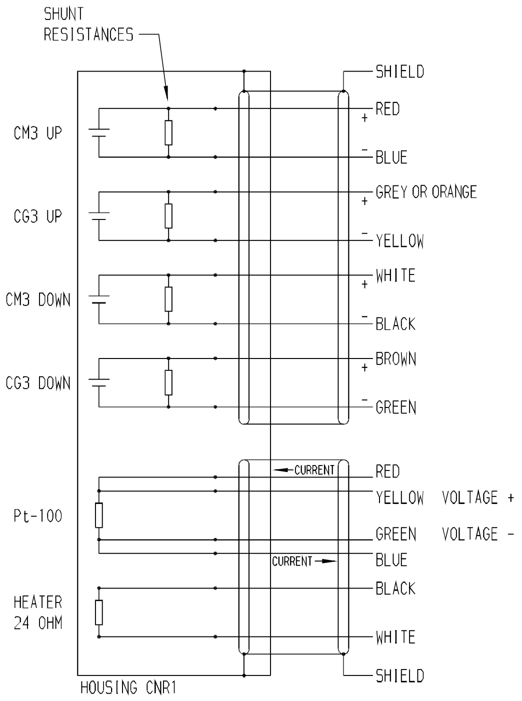


FIGURE 5-1. CNR1 Schematic

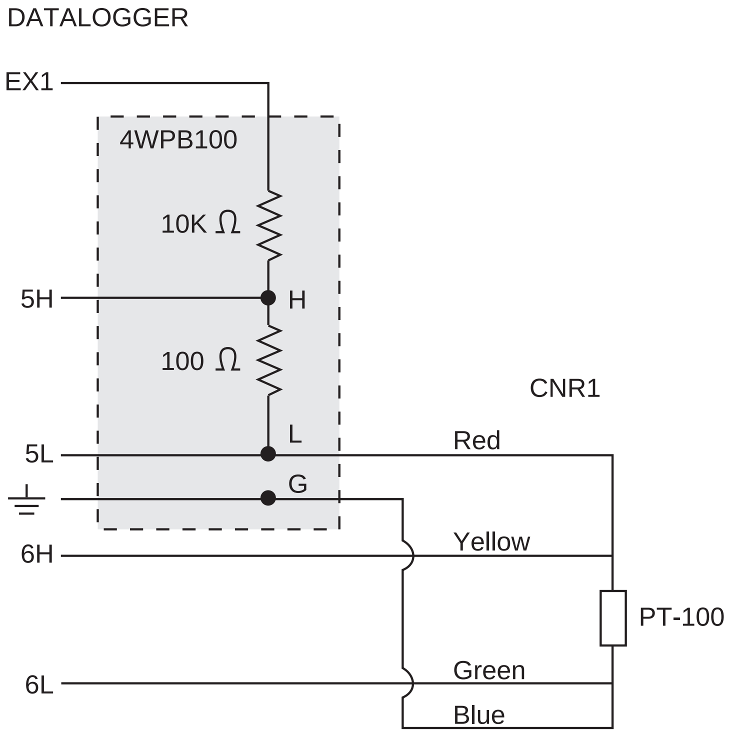


FIGURE 5-2. Interfacing the Pt-100 Using the 4WPB100 Module

The four radiation outputs can be measured using Differential or Single-Ended inputs on the datalogger. A differential voltage measurement (Instruction 2) is recommended because it has better noise rejection than a single-ended measurement. When differential inputs are used, jumper the low side of the input to AG or ⏚ to keep the signal in common mode range.

TABLE 5-1. Datalogger Connections for Differential Measurement, When Using a 4WPB100

Function	Color	CR10X	CR800, CR850, CR1000	21X/CR7, CR23X
CM3 Up Signal	Red	Differential Input (H)	Differential Input (H)	Differential Input (H)
CM3 Up Reference	*Blue	Differential Input (L)	Differential Input (L)	Differential Input (L)
CM3 Down Signal	White	Differential Input (H)	Differential Input (H)	Differential Input (H)
CM3 Down Reference	*Black	Differential Input (L)	Differential Input (L)	Differential Input (L)
CG3 Up Signal	Grey or †Orange	Differential Input (H)	Differential Input (H)	Differential Input (H)
CG3 Up Reference	*Yellow	Differential Input (L)	Differential Input (L)	Differential Input (L)
CG3 Down Signal	Brown	Differential Input (H)	Differential Input (H)	Differential Input (H)
CG3 Down Reference	*Green	Differential Input (L)	Differential Input (L)	Differential Input (L)
Shield	Shield	G	⏚	⏚

*Jumper to AG or ⏚ with user supplied wire.
†Cables extended > 48' have an orange wire.

Pt-100 Temperature Sensor Connections to 4WPB100 and Datalogger

Function	Color	4WPB100	Datalogger
	Black	Wire	Excitation
		H	Differential Input (H)
Pt-100 Excitation +	Red	L	Differential Input (L)
Pt-100 Excitation -	Blue	G	⏚ (AG CR10X/CR510)
Pt-100 Signal +	Yellow		Differential Input (H)
Pt-100 Signal –	Green		Differential Input (L)

TABLE 5-2. Datalogger Connections for Single-Ended Measurement, When Using a 4WPB100

Function	Color	CR10X	CR23X, 21X, CR7	CR800, CR850, CR1000
CM3 Up Signal	Red	Single-Ended Input	Single-Ended Input	Single-Ended Input
CM3 Up Reference	Blue	AG	⏚	⏚
CM3 Down Signal	White	Single-Ended Input	Single-Ended Input	Single-Ended Input
CM3 Down Reference	Black	AG	⏚	⏚
CG3 Up Signal	Grey or Orange	Single-Ended Input	Single-Ended Input	Single-Ended Input
CG3 Up Reference	Yellow	AG	⏚	⏚
CG3 Down Signal	Brown	Single-Ended Input	Single-Ended Input	Single-Ended Input
CG3 Down Reference	Green	AG	⏚	⏚
Shield	Shield	G	⏚	⏚

TABLE 5-3. CR3000 and CR5000 Connections for Differential Measurement

Function	Color	CR3000/CR5000
CM3 Up Signal	Red	Differential Input (H)
CM3 Up Reference	Blue	Differential Input (L)
CM3 Down Signal	White	Differential Input (H)
CM3 Down Reference	Black	Differential Input (L)
CG3 Up Signal	Grey or Orange	Differential Input (H)
CG3 Up Reference	Yellow	Differential Input (L)
CG3 Down Signal	Brown	Differential Input (H)
CG3 Down Reference	Green	Differential Input (L)
PT-100 Signal +	Yellow	Differential Input (H)
PT-100 Signal -	Green	Differential Input (L)
PT-100 Current Excitation +	Red	Current Excitation IX
PT-100 Current Excitation -	Blue	Current Excitation IXR
Shield	Clear	⏚

6. Datalogger Programming

The CNR1 outputs four voltages that typically range from 0 to 15 mV for the CM3 sensors, and ± 5 mV for the CG3 sensors. A differential voltage measurement (VoltDiff or Instruction 2) is recommended because it has better noise rejection than a single-ended measurement. If differential channels are not available, single-ended measurements (VoltSe or Instruction 1) can be used. The acceptability of a single-ended measurement can be determined by simply comparing the results of single-ended and differential measurements made under the same conditions.

For the CR3000 and CR5000, one differential channel and a current excitation channel are required to measure the PT-100.

For the other dataloggers, two differential channels and the 4WPB100 module are required to measure the Pt-100 temperature sensor.

NOTE The 4WPB100 is included with the CNR1 sensor purchased from CSI.

FIGURE 6-1. 4WPB100 Module

6.1 Calibration Factor

Each CNR1 is provided with a 'Certificate of Calibration' by the manufacturer that shows the sensor serial number and 'sensitivity', or calibration factor. The serial number and sensitivity are also shown on a label attached to the sensor.

The calibration factor is in units of μV/(W m^{-2}), which needs to be converted to units of (W m^{-2})/mV for the multiplier parameter in the datalogger program. To convert the units, divide the calibration factor into 1000. For example, if the calibration factor is 7.30 μV/(W m^{-2}), the multiplier is 1000/7.3 = 136.99 (W m^{-2})/mV.

6.2 Example Programs

6.2.1 Example 1, CR1000 Using Differential Channels

Program Example 1 requires six differential channels and the 4WPB100 module to measure the four radiation outputs and the Pt-100 temperature sensor. The program measures the sensors every 2 seconds and calculates and stores the following data to final storage every 60 minutes:

Year
Julian Day
Hour/Minute
Avg CM3 Up (shortwave radiation)
Avg CM3 Down (shortwave radiation)
Avg CG3 Up (longwave radiation)
Avg CG3 Down (longwave radiation)
Avg CNR1 temperature (degrees C)
Avg CNR1 temperature (degrees K)
Avg Net shortwave radiation
Avg Net longwave radiation
Avg Albedo
Avg Total Net radiation
Avg temperature corrected CG3 Up
Avg temperature corrected CG3 Down

```
'CR1000

'Declare Variables and Units
Public Batt_Volt
Public CM3Up
Public CM3Dn
Public CG3Up
Public CG3Dn
Public CNR1TC
Public CNR1TK
Public NetRs
Public NetRl
Public Albedo
Public UpTot
Public DnTot
Public NetTot
Public CG3UpCo
Public CG3DnCo

Units Batt_Volt=Volts
Units CM3Up=W/meter²
Units CM3Dn=W/meter²
Units CG3Up=W/meter²
Units CG3Dn=W/meter²
Units CNR1TC=Deg C
Units CNR1TK=K
Units NetRs=W/meter²
Units NetRl=W/meter²
Units Albedo=W/meter²
Units UpTot=W/meter²
Units DnTot=W/meter²
Units NetTot=W/meter²
Units CG3UpCo=W/meter²
Units CG3DnCo=W/meter²

'Define Data Tables
DataTable(Table1,True,-1)
    DataInterval(0,60,Min,10)
    Average(1,CM3Up,FP2,False)
    Average(1,CM3Dn,FP2,False)
    Average(1,CG3Up,FP2,False)
    Average(1,CG3Dn,FP2,False)
    Average(1,CNR1TC,FP2,False)
    Average(1,CNR1TK,FP2,False)
    Average(1,NetRs,FP2,False)
    Average(1,NetRl,FP2,False)
    Average(1,Albedo,FP2,False)
    Average(1,UpTot,FP2,False)
    Average(1,DnTot,FP2,False)
    Average(1,NetTot,FP2,False)
    Average(1,CG3UpCo,FP2,False)
    Average(1,CG3DnCo,FP2,False)
EndTable
```

```
'Main Program
BeginProg
    Scan(2,Sec,1,0)
        'Default Datalogger Battery Voltage measurement Batt_Volt:
        Battery(Batt_Volt)
        'CNR1 Net Radiometer measurements CM3Up, CM3Dn, CG3Up, CG3Dn, CNR1TC, CNR1TK,
        'NetRs, NetRl, Albedo, UpTot, DnTot, NetTot, CG3UpCo, and CG3DnCo:
        *    VoltDiff(CM3Up,1,mV25,1,True,0,_60Hz,100.0,0)
        *    VoltDiff(CM3Dn,1,mV25,2,True,0,_60Hz,100.0,0)
        *    VoltDiff(CG3Up,1,mV7_5,3,True,0,_60Hz,100.0,0)
        *    VoltDiff(CG3Dn,1,mV7_5,4,True,0,_60Hz,100.0,0)
        **   BrHalf4W (CNR1TC,1,mV25,mV25,5,Vx1,1,2100,True ,True ,0,250,1.0,0)
        PRT(CNR1TC,1,CNR1TC,1,0)
        CNR1TK=CNR1TC+273.15
        NetRs=CM3Up-CM3Dn
        NetRl=CG3Up-CG3Dn
        Albedo=CM3Dn/CM3Up
        UpTot=CM3Up+CG3Up
        DnTot=CM3Dn+CG3Dn
        NetTot=UpTot-DnTot
        CG3UpCo=CG3Up+5.67*10^-8*CNR1TK^4
        CG3DnCo=CG3Dn+5.67*10^-8*CNR1TK^4
        'Call Data Tables and Store Data
        CallTable(Table1)
    NextScan
EndProg
```

*   mV20 range for the CR5000
**   mV50 range (both) with 4200 mV excitation for CR5000

6.2.2 Example 2, CR5000 Using Differential Channels (no 4WPB100)

Program Example 2 requires five differential channels and one current excitation channel to measure the four radiation outputs and the Pt-100 temperature sensor. The program measures the sensors every second and calculates and stores the following data to final storage every 60 minutes:

Year
Julian Day
Hour/Minute
Avg CM3 Up (shortwave radiation)
Avg CM3 Down (shortwave radiation)
Avg CG3 Up (longwave radiation)
Avg CG3 Down (longwave radiation)
Avg CNR1 temperature (degrees C)
Avg CNR1 temperature (degrees K)
Avg Net shortwave radiation
Avg Net longwave radiation
Avg Albedo
Avg Total Net radiation
Avg temperature corrected CG3 Up
Avg temperature corrected CG3 Down

```
'CR5000 Series Datalogger

'ANALOG INPUT
'1H      CM3 UP - downwelling shortwave radiation signal (red)
'1L      CM3 UP - downwelling shortwave radiation signal reference (blue)
'gnd     CNR1 shield (clear)

'2H      CM3 DOWN -  upwelling shortwave radiation signal (white)
'2L      CM3 DOWN -  upwelling shortwave radiation signal reference (black)

'3H      CG3 UP -  downwelling longwave radiation signal (gray)
'3L      CG3 UP -  downwelling longwave radiation signal reference (yellow)

'4H      CG3 DOWN -  upwelling longwave radiation signal (brown)
'4L      CG3 DOWN -  upwelling longwave radiation signal reference (green)

'6H      CNR1 Pt100 (yellow)
'6L      CNR1 Pt100 (green)

'Current Excitation
'IX1     CNR1 Pt100 (red)
'IXR     CNR1 Pt100 (blue)

'Declare Variables and Units
Public Batt_Volt
Public CM3Up
Public CM3Dn
Public CG3Up
Public CG3Dn
Public CNR1TC
Public CNR1TK
Public NetRs
Public NetRl
Public Albedo
Public UpTot
Public DnTot
Public NetTot
Public CG3UpCo
Public CG3DnCo

Units Batt_Volt=Volts
Units CM3Up=W/meter²
Units CM3Dn=W/meter²
Units CG3Up=W/meter²
Units CG3Dn=W/meter²
Units CNR1TC=Deg C
Units CNR1TK=K
Units NetRs=W/meter²
Units NetRl=W/meter²
Units Albedo=W/meter²
Units UpTot=W/meter²
Units DnTot=W/meter²
Units NetTot=W/meter²
Units CG3UpCo=W/meter²
Units CG3DnCo=W/meter²
```

```
'Define Data Tables
DataTable(Table1,True,-1)
    DataInterval(0,60,Min,10)
    Average(1,CM3Up,FP2,False)
    Average(1,CM3Dn,FP2,False)
    Average(1,CG3Up,FP2,False)
    Average(1,CG3Dn,FP2,False)
    Average(1,CNR1TC,FP2,False)
    Average(1,CNR1TK,FP2,False)
    Average(1,NetRs,FP2,False)
    Average(1,NetRl,FP2,False)
    Average(1,Albedo,FP2,False)
    Average(1,UpTot,FP2,False)
    Average(1,DnTot,FP2,False)
    Average(1,NetTot,FP2,False)
    Average(1,CG3UpCo,FP2,False)
    Average(1,CG3DnCo,FP2,False)
EndTable

'Main Program
BeginProg
    Scan(1,Sec,1,0)
    'Default Datalogger Battery Voltage measurement Batt_Volt:
        Battery(Batt_Volt)

    'CNR1 Net Radiometer measurements CM3Up, CM3Dn, CG3Up, CG3Dn, CNR1TC, CNR1TK,
    'NetRs, NetRl, Albedo, UpTot, DnTot, NetTot, CG3UpCo, and CG3DnCo:
    'CNR1 Sensitivity 7.30 uV/m^2
        VoltDiff(CM3Up,1,mV20C,1,True,200,250,136.99,0)
        VoltDiff(CM3Dn,1,mV20C,2,True,200,250,136.9,0)
        VoltDiff(CG3Up,1,mV20C,3,True,200,250,136.9,0)
        VoltDiff(CG3Dn,1,mV20,4,True,200,250,136.9,0)
        Resistance (CNR1TC,1,mV200,6,Ix1,1,1675,True ,True,200,250,1.0,0)

        'Formulate the ratio Rs/R0
        CNR1TC=CNR1TC/100
        PRT(CNR1TC,1,CNR1TC,1,0)

        'Compute Net short-wave radiation, Net long-wave radiation, Albedo and Net Radiation
        CNR1TK=CNR1TC+273.15
        NetRs=CM3Up-CM3Dn
        NetRl=CG3Up-CG3Dn
        Albedo=CM3Dn/CM3Up
        UpTot=CM3Up+CG3Up
        DnTot=CM3Dn+CG3Dn
        NetTot=UpTot-DnTot
        CG3UpCo=CG3Up+5.67*10^-8*CNR1TK^4
        CG3DnCo=CG3Dn+5.67*10^-8*CNR1TK^4
        'Call Data Tables and Store Data
        CallTable(Table1)
        NextScan
EndProg
```

6.2.3 Example 3, CR23X Program Using Differential Channels

Program Example 3 requires six differential channels and the 4WPB100 module to measure the four radiation outputs and the Pt-100 temperature sensor. The program measures the sensors every 2 seconds and calculates and stores the following data to final storage every 60 minutes:

Array ID
Year
Julian Day
Hour/Minute
Avg CM3 Up (shortwave radiation)
Avg CM3 Down (shortwave radiation)
Avg CG3 Up (longwave radiation)
Avg CG3 Down (longwave radiation)
Avg CNR1 temperature (degrees C)
Avg CNR1 temperature (degrees K)
Avg Net shortwave radiation
Avg Net longwave radiation
Avg Albedo
Avg Total Net radiation
Avg temperature corrected CG3 Up
Avg temperature corrected CG3 Down

Wiring for Program Example 3

Color	Function	Example CR23X Program Channels Used
Red	CM3 Up Signal	1H
Blue	CM3 Up Reference	1L
White	CM3 Down Signal	2H
Black	CM3 Down Reference	2L
Grey or Orange	CG3 Up Signal	3H
Yellow	CG3 Up Reference	3L
Brown	CG3 Down Signal	4H
Green	CG3 Down Reference	4L
Shield	Shield	⏚

Pt-100 Temperature Sensor Connections to 4WPB100 and Datalogger

Color	Function	4WPB100	CR23X
Black		Wire	EX1
		H	5H
Red	Pt-100 Excitation +	L	5L
Blue	Pt-100 Excitation -	G	⏚
Yellow	Pt-100 Signal +		6H
Green	Pt-100 Signal -		6L

```
;{CR23X}
;Program Example 1 for CR23X datalogger
;
;CNR1 sensitivity for program example = 7.30 uV/W/m^2
;Multiplier for measurement instructions = 1000/7.30 = 136.99
;
;*Table 1 Program
   01:  2              Execution Interval (seconds)

;Measure CM3 Up and CM3 Down (shortwave radiation)
;Note: Multiplier (Parameter 5) will be different for each CNR1

1:  Volt (Diff) (P2)
   1:    2             Reps
   2:    22+           50 mV, 60 Hz Reject, Slow Range
   3:    1*            DIFF Channel
   4:    1*            Loc [ CM3_up    ]
   5:    136.99        Mult                          ; mult = 1000/CNR1 sensitivity
   6:    0             Offset

;Measure CG3 Up and CG3 Down (longwave radiation)
;Note: Multiplier (Parameter 5) will be different for each CNR1

2:  Volt (Diff) (P2)
   1:    2             Reps
   2:    21++          10 mV, 60 Hz Reject, Slow Range
   3:    3*            DIFF Channel
   4:    3*            Loc [ CG3_up    ]
   5:    136.99        Mult                          ; mult = 1000/CNR1 sensitivity
   6:    0             Offset

;Measure CNR1 temperature

3:  Full Bridge w/mv Excit (P9)
   1:    1             Reps
   2:    22**          50 mV, 60 Hz Reject, Slow, Ex Range
   3:    22**          50 mV, 60 Hz Reject, Slow, Br Range
   4:    5*            DIFF Channel
   5:    1             Excite all reps w/Exchan 1
   6:    4200***       mV Excitation
   7:    5*            Loc [ Temp_C    ]
   8:    1             Mult
   9:    0             Offset

4:  Temperature RTD (P16)
   1:    1             Reps
   2:    5             R/R0 Loc [ Temp_C    ]
   3:    5             Loc [ Temp_C    ]
   4:    1.0           Mult
   5:    0             Offset

5:  Z=X+F (P34)
   1:    5             X Loc [ Temp_C    ]
   2:    273.15        F
   3:    6             Z Loc [ Temp_K    ]
```

```
;Net CM3 shortwave radiation = CM3 Up - CM3 Down

6:  Z=X-Y (P35)
   1:    1                 X Loc [ CM3_up    ]
   2:    2                 Y Loc [ CM3_dn    ]
   3:    7                 Z Loc [ Net_Rs    ]

;Net CG3 longwave radiation = CG3 Up - CG3 Down

7:  Z=X-Y (P35)
   1:    3                 X Loc [ CG3_up    ]
   2:    4                 Y Loc [ CG3_dn    ]
   3:    8                 Z Loc [ Net_Rl    ]

;Albedo = CM3 Down / CM3 Up

8:  Z=X/Y (P38)
   1:    2                 X Loc [ CM3_dn    ]
   2:    1                 Y Loc [ CM3_up    ]
   3:    9                 Z Loc [ Albedo    ]

;Net total radiation = (CM3 Up + CG3 Up) - (CM3 Down + CG3 Down)

9:  Z=X+Y (P33)
   1:    1                 X Loc [ CM3_up    ]
   2:    3                 Y Loc [ CG3_up    ]
   3:    23                Z Loc [ Up_total  ]

10:  Z=X+Y (P33)
   1:    2                 X Loc [ CM3_dn    ]
   2:    4                 Y Loc [ CG3_dn    ]
   3:    24                Z Loc [ Dn_total  ]

11:  Z=X-Y (P35)
   1:    23                X Loc [ Up_total  ]
   2:    24                Y Loc [ Dn_total  ]
   3:    10                Z Loc [ Net_total ]

;Correct CG3 Up and CG3 Down for temperature
```

; $CG3\_upCor = CG3\_up+5.67 \cdot 10^{-8} * Temp\_K^{4}$
; $CG3\_dnCor = CG3\_dn+5.67 \cdot 10^{-8} * Temp\_K^{4}$

```
12:  Z=F (P30)
   1:    5.67              F
   2:    -8                Exponent of 10
   3:    25                Z Loc [ scratch_1 ]

13:  Z=F (P30)
   1:    4                 F
   2:    0                 Exponent of 10
   3:    26                Z Loc [ scratch_2 ]

14:  Z=X^Y (P47)
   1:    6                 X Loc [ Temp_K    ]
   2:    26                Y Loc [ scratch_2 ]
   3:    27                Z Loc [ scratch_3 ]
```

```
15:  Z=X*Y (P36)
   1:   25              X Loc [ scratch_1 ]
   2:   27              Y Loc [ scratch_3 ]
   3:   28              Z Loc [ scratch_4 ]

16:  Z=X+Y (P33)
   1:   3               X Loc [ CG3_up    ]
   2:   28              Y Loc [ scratch_4 ]
   3:   11              Z Loc [ CG3_upCor ]

17:  Z=X+Y (P33)
   1:   4               X Loc [ CG3_dn    ]
   2:   28              Y Loc [ scratch_4 ]
   3:   12              Z Loc [ CG3_dnCor ]
;
;Output data to final storage every 60 minutes

18:  If time is (P92)
   1:   0               Minutes (Seconds --) into a
   2:   60              Interval (same units as above)
   3:   10              Set Output Flag High (Flag 0)

19:  Real Time (P77)
    1:  0220            Day,Hour/Minute (midnight = 2400)

20:  Average (P71)
   1:   12              Reps
   2:   1               Loc [ CM3_dn    ]
```

*   Proper entries will vary with program and input channel usage.
**   25 mV range for CR10X, 50 mV for 21X and CR7
*** 4200 mV for 21X and CR7, 2100 mV for CR10X
\+   25 mV range for CR10X, 50 mV for 21X and CR7
++   7.5 mV range for CR10X, 5 mV for 21X and CR7

6.2.4 Example 4, CR23X Program Using Single-Ended Channels

Program Example 4 requires four single-ended channels to measure the four radiation outputs, and two differential channels and the 4WPB100 module to measure the Pt-100 temperature sensor. The program measures the sensors every 2 seconds and stores the following data to final storage every 60 minutes:

Array ID
Year
Day
Hour/Minute
Avg CM3 down (shortwave radiation)
Avg CM3 up (shortwave radiation)
Avg CG3 down (longwave radiation)
Avg CG3 up (longwave radiation)
Avg CNR1 temperature (degrees C)
Avg CNR1 temperature (degrees K)

Wiring for Program Example 4

Color	Function	Example CR23X Program Channels Used
Red	CM3 Up Signal	SE1
Blue	CM3 Up Reference	⏚
White	CM3 Down Signal	SE2
Black	CM3 Down Reference	⏚
Grey or Orange	CG3 Up Signal	SE3
Yellow	CG3 Up Reference	⏚
Brown	CG3 Down Signal	SE4
Green	CG3 Down Reference	⏚
Shield	Shield	⏚

Pt-100 Temperature Sensor Connections to 4WPB100 and Datalogger

Color	Function	4WPB100	CR23X
		H	5H
Red	Pt-100 Excitation +	L	5L
Blue	Pt-100 Excitation -	G	⏚
Yellow	Pt-100 Signal +		6H
Green	Pt-100 Signal -		6L

```
;{CR23X}
;
;CNR1 sensitivity for program example = 7.30 uV/W/m^2
;Multiplier for measurement instructions = 1000/7.3 = 136.99

*Table 1 Program
   01:  2              Execution Interval (seconds)

;Measure CM3 Up and CM3 Down (shortwave radiation)
;Note: Multiplier (Parameter 6) will be different for each CNR1

1:  Volt (SE) (P1)
   1:    2             Reps
   2:    22            50 mV, 60 Hz Reject, Slow Range
   3:    1             SE Channel
   4:    1             Loc [ CM3_up    ]
   5:    136.99        Mult ; mult = 1000/CNR1 sensitivity
   6:    0             Offset

;Measure CG3 Up and CG3 Down (longwave radiation)
;Note: Multiplier (Parameter 6) will be different for each CNR1

2:  Volt (SE) (P1)
   1:    2             Reps
   2:    21            10 mV, 60 Hz Reject, Slow Range
   3:    3             SE Channel
   4:    3             Loc [ CG3_up    ]
   5:    136.99        Mult ; mult = 1000/CNR1 sensitivity
   6:    0             Offset
```

```
;Measure CNR1 temperature

3:  Full Bridge w/mv Excit (P9)
   1:    1              Reps
   2:    22             50 mV, 60 Hz Reject, Slow, Ex Range
   3:    22             50 mV, 60 Hz Reject, Slow, Br Range
   4:    5              DIFF Channel
   5:    1              Excite all reps w/Exchan 1
   6:    4200           mV Excitation
   7:    5              Loc [ Temp_C    ]
   8:    1              Mult
   9:    0              Offset

4:  Temperature RTD (P16)
   1:    1              Reps
   2:    5              R/R0 Loc [ Temp_C    ]
   3:    5              Loc [ Temp_C    ]
   4:    1.0            Mult
   5:    0              Offset

5:  Z=X+F (P34)
   1:    5              X Loc [ Temp_C    ]
   2:    273.15         F
   3:    6              Z Loc [ Temp_K    ]

;Output data to final storage every 60 minutes

6:  If time is (P92)
   1:    0              Minutes (Seconds --) into a
   2:    60             Interval (same units as above)
   3:    10             Set Output Flag High (Flag 0)

7:  Real Time (P77)
   1:    0220           Day,Hour/Minute (midnight = 2400)

8:  Average (P71)
   1:    6              Reps
   2:    1              Loc [ CM3_up    ]

Copy range code options from example 1 here:

* Proper entries….
```

*   Proper entries will vary with program and input channel usage.
**   25 mV range for CR10X, 50 mV for 21X and CR7
*** 4200 mV for 21X and CR7, 2100 mV for CR10X
\+   25 mV range for CR10X, 50 mV for 21X and CR7
++   7.5 mV range for CR10X, 5 mV for 21X and CR7

7. Calibration

The CNR1 should be recalibrated every two years, or as an alternative, by letting a higher standard run parallel to it over a two-day period and then comparing the results. For comparison of pyranometers, one should use a clear day. For comparison of pyrgeometers, one should compare nighttime results. Deviations of more than 6% can be used to correct the calibration factors.

8. Troubleshooting

If there is no clue as to what may be the problem, start performing the following "upside-down test", which is a rough test for a first diagnosis. It can be performed both outdoors and indoors. Indoors, a lamp can be used as a source for both Solar and Far Infrared radiation. Outdoors one should preferably work with a solar elevation of more than 45 degrees (45 degrees above horizon) and of course under stable conditions (no large changes in solar irradiance, preferably cloudless).

1. Measure the radiation outputs in the normal position. Record the measured values when the signals have stabilized, i.e. after about three minutes.

2. Rotate the instrument 180 degrees, so that the upper and the lower sensors are now in the reverse orientation as to the previous position.

3. Measure the radiation outputs once more. Record the measured values when the radiometers have stabilized.

4. Since of the all sensors are trimmed, the values in the rotated position should be equal in magnitude, only differing in sign. In a rough test like this, deviations of +/- 10 % can be tolerated. If deviations greater than this are encountered, the following tests might help.

8.1 Testing the CM3

As a first test we recommend that one check the sensor impedance. It should have a nominal value as indicated in the specifications. Zero, or infinite resistance, indicates a failure in hardware connection.

Before starting the second test measurement, let the CM3 rest for at least five minutes to let it regain its thermal equilibrium. For testing, set a voltmeter to its most sensitive range setting. Darken the sensor. The signal should read zero. Bear in mind that the response takes about one minute. Small deviations from zero are possible; this is caused by thermal effects like touching the pyranometer with your hand. The latter effect can be demonstrated by deliberately heating the CM3 with your hand. Another cause might be the zero offset of the amplifier. When this is the case, the same offset will also be present when the amplifier is short-circuited with a 200 Ohm resistor. This is an amplifier error. This amplifier error should not be larger than 5 Watts per square meter. If the amplifier error is within specifications, proceed with the third test.

In the third test the sensor should be exposed to light. The signal should be a positive reading. Set the voltmeter range in such a way that the expected full-scale output of the pyranometer is within the full-scale input range of the voltmeter. The range can be estimated on theoretical considerations. (When the maximum expected radiation is 1500 Watts per square meter, which is roughly equal to normal outdoor daylight conditions, and the sensitivity of the pyranometer is 15 mV per Watt per square meter, the expected output range of the pyranometer is 1500 times 15 which is equal to 22500 mV, or 0.0225 Volts). One can calculate the radiation intensity by dividing the pyranometer output (0.0225 volts) by the calibration factor (0.000015 volt per watt per square meter). Still no faults found? Your pyranometer is probably doing fine.

8.2 Testing of the CG3

It is assumed that the amplifier circuit is the same as the one used for the CM3, and that its zero offset is no more than a few watts per square meter, let us say 5 Watts per square meter just as an example (see second test in 7.1).

The pyrgeometer, the mounting plate, and ambient air should be at the same temperature as much as possible. Let the CG3 rest for at least five minutes to regain its thermal equilibrium. Set the voltmeter to its most sensitive range. To test if the CG3 is working properly, we suggest putting your hand in front of the CG3. The thermal radiation will cause CG3 to generate a positive voltage when the hand's surface temperature is higher than the pyrgeometer temperature. The CG3 will generate a negative voltage if the hand is colder. The signal is proportional to the temperature difference (see the rule of thumb of Section 4.5). The radiation that is emitted by the hand can be calculated by dividing the pyrgeometer output by the calibration factor, and subsequently correcting for the temperature, according to Equation 4.2. Still no faults found? Your pyrgeometer is probably doing fine.

8.3 Testing the Pt-100

Using a meter which measures resistance, check the operation of the Pt-100. If connected properly, the resistance of two opposite wires of the Pt-100 should measure about 100 ohms (this includes the cable resistance for the standard 10-meter cable). The cable resistance should measure about 0.1 ohms per meter cable.

Appendix A. CNR1 Performance and Measurements under Different Conditions

Below, Table A-1, shows an indication of what one might typically expect to measure under different meteorological conditions.

The first parameter is day and night. At night, the Solar radiation is zero. The second column indicates if it is cloudy or clear. A cloud acts like a blanket, absorbing part of the Solar radiation, and keeping Net Far Infrared radiation close to zero. The third parameter is ambient temperature. This is included to show that the "sky temperature" (column nine) tracks the ambient temperature. Under cloudy conditions this is logical; cloud bases will be colder than the ambient temperature at instrument level, the temperature difference depends roughly on cloud altitude.

Under clear sky conditions it is less obvious that sky temperature "adjusts" to the ambient temperature. This can roughly be attributed to the water vapor in the air, which is a major contributor to the Far Infrared radiation.

It is assumed that when ambient temperature varies, the Net Far Infrared radiation remains roughly the same, independent of ambient temperature. The resulting measured values of the CG3's and CM3's are stated in columns 4 to 7. These are indicative figures only, they depend strongly on other circumstances; the CG3 results, of course, change with the sensor temperature. This is indicated in column 8. During the day, the Pt-100 reading may rise due to solar heating, up to 10 degrees above ambient temperature. During the night, the sensor temperature may be lower than the ambient temperature due to Far Infrared radiative cooling. The latter two effects do not influence the end result of the calculations of Sky T and ground T. Therefore they are not taken into account in the table. Actually in column 4 one might expect to see "0 to -50" for all positions that are showing "0", in column 5 the "0" values may in reality be "-20 to +20". The resulting sky temperature is indicated in column 9. Under cloudy conditions this sky temperature is equal to ambient temperature. Under clear conditions the sky temperature is lower than the ambient temperature.

The ground temperature in column 10 is assumed to be equal to the ambient temperature. In practice it may be higher during the day, due to solar heating. Ground temperature may be lower than ambient during the night, due to Far Infrared radiative cooling. The sky and the ground temperature can be calculated from the measured values of the sensors using Equations 4.6 and 4.7.

TABLE A-1. Typical output signals of CNR1 under different meteorological conditions. Explanation can be found in the text.

Day night	Cloudy clear	+20 ºC - 20 ºC	CG3 Up	CG3 low	CM3 up	CM3 low	Pt 100	sky T	ground T
d	cloud	20	0	0	0-500	0-150	20	20	20
d	cloud	-20	0	0	0-500	0-150	-20	-20	-20
d	clear	20	-100*	0	0-1300	0-400	20	1*	20
d	clear	-20	-100*	0	0-1300	0-400	-20	-53*	-20
n	cloud	20	0	0	0	0	20	20	20
n	cloud	-20	0	0	0	0	-20	-20	-20
n	clear	20	-100***	0	0**	0	20	1***	20
n	clear	-20	-100***	0	0**	0	-20	-53***	-20

* Values may suffer from the so-called window heating offset; the sun heats the pyrgeometer window causing a measurement error of + 25 Watts per square meter (maximum).

** Values may suffer from negative Infrared offsets, caused by cooling off of the CM3 dome by Far Infrared radiation. The maximum expected offset value is 15 Watts per square meter.

*** Values may suffer from dew deposition. This causes the CG3-up values to rise from -100 to 0 Watts per square meter.

Appendix B. Details about Using the Heater

NOTE Whenever the heater is used, the heating may cause errors in the measurement of the sensor temperature, see chapter 1.1.2.3. in the Kipp and Zonen CNR1 manual (http://www.kippzonen.com/?download/85182/CNR+1+Net+Radiometer+-+Manual+(English).aspx), two degrees typical, and zero offsets in the CM3 (10 Watts per square meter typical). Under most conditions the accuracy that is gained by heating will be larger than the errors that are introduced by heating.

In both the CM3 and CG3, thermal sensors are used. These sensors in principle measure a heat flow. For optimal performance, these sensors should be at equilibrium with the ambient air. Heating the sensor disturbs this equilibrium. This will give rise to zero offsets particularly in the CM3. A typical value under conditions with no wind is 10 Watts per square meter. Therefore heating should only be done if absolutely necessary. CG3 is less sensitive to this. Offset values for CG3 cannot be determined, and therefore are not specified.

B.1 General Information

There is one major reason for heating: avoiding water deposition on the CG3 window and on the CM3 dome. In case of dew deposition on the CG3 window, the dew will ultimately obstruct the Far Infrared radiation completely, causing a signal close to zero. In the case of rain, this will probably not lead to significant errors, because with an overcast sky the signal is close to zero anyway. The case of dew deposition is far more significant. Dew deposition will probably take place under conditions with large Far Infrared irradiation from the pyrgeometer detector to the clear sky, typically minus (-) 100 Watts per meter square. Under conditions where clouds or wind are present, dew is less likely to occur. A situation where dew depositing on the window of the CG3, causing a signal of -100 Watts per square meter to drop to zero, is certainly significant. If heating can avoid this, it certainly should be done because all errors that are described above are much smaller than the gain in accuracy of 100 Watts per meter square.

For decisions about heating one can make the following diagram:

12 VDC, 6 VA available?	Not available →	**DO NOT HEAT**
	Available →	Consider options below ↓
Clock and relay available?	Not Available →	**DO NOT HEAT** **(CSI recommendation)**
	Available →	Heat from 1 hour before the sunset until 1 hour after the sunset

The maximum allowable power for the heater is 50 VA. In case of snow or frost one might also consider heating at a higher level than the usual 6 VA. Heating at 20 VA will melt snow in most cases. 20 VA can be reached at 22 Volts. During high power heating, measurement accuracy cannot be specified. You are advised to reject measured data readings during this high power heating.

If lower voltage is available, one might consider heating at a lower power. The 6 VA is designed for extreme conditions. 2 VA is sufficient for moderate conditions.

Time needed for reaching a stable instrument temperature when heating is used is about 60 minutes.

Appendix C. CR3000/CR5000 Program that Controls the Heater

This program applies power to the CNR1 heater using the SW12V relay controller and the pulse width modulation instruction (PWM ()).

The program below uses the dew point value. The datalogger calculates dew point using the relative humidity (RH) measurements provided by the HMP45C Temperature/Relative Humidity probe. Enter 0 degrees C as the set point for the heater when a temperature/RH probe is not used.

The algorithm turns the heater on/off at 4 Hz. The duty cycle of the pulse is changed depending on how close the radiometer body temperature is to the dew point temperature. At or below the dew point, the duty cycle is 100%. It drops off linearly to 20% until the body temperature is 5 degrees C above the dew point. For body temperatures greater than 5 degrees C above the dew point, the duty cycle continue to drop linearly, but with a different slope, until 0% at 33 degrees C above the dew point. If necessary, the user can change the two duty-cycle slope transitions.

```
'CR3000 or CR5000 Series Datalogger

'CR3000 Series Datalogger

'Copyright (c) 2009 Campbell Scientific, Inc. All rights reserved.

'11 March 09
'version 0.0

'*** Wiring ***

'ANALOG INPUT
'5H      HMP45C temperature signal (yellow)
'5L      HMP45C signal reference (white)
'gnd     HMP45C shield (clear)

'6H      HMP45C relative humidity signal (blue)
'6L      short jumper wire to 5L

'10H     CNR1 Pt100 signal (red)
'10L     CNR1 Pt100 signal reference (blue)
'gnd     CNR1 Pt100 shield (silver)

'11H     CNR1 downwelling shortwave radiation signal (red)
'11L     CNR1 downwelling shortwave radiation signal reference (blue)
'gnd     CNR1 shield (silver)

'12H     CNR1 upwelling shortwave radiation signal (white)
'12L     CNR1 upwelling shortwave radiation signal reference (green)

'13H     CNR1 downwelling longwave radiation signal (brown)
'13L     CNR1 downwelling longwave radiation signal reference (yellow)
```

```
'14H     CNR1 upwelling longwave radiation signal (purple or pink)
'14L     CNR1 upwelling longwave radiation signal reference (gray)

'CURRENT EXCITATION
'IX1     CNR1 Pt100 current excitation (white)
'IXR     CNR1 Pt100 current excitation reference (green)

'CONTROL PORTS
'C1      SW12V control (green)
'G       SW12V control/power reference (black)

'POWER OUT
'12V     HMP45C power (red)
'        SW12V power (red)
'G       HMP45C power reference (black)

'POWER IN
'12V     datalogger (red)
'G       datalogger (black)

'EXTERNAL POWER SUPPLY
'POS     datalogger (red)
'NEG     datalogger (black)

'SW12V Power Control Module
'SW12V  NR 01 heater excitation (brown)
'G       NR 01 heater excitation reference (yellow)

PipeLineMode

'*** Constants ***

Const NR01_SHORT_DW_CAL = 1000/13.41    'Unique NR 01 shortwave downwelling multiplier (1000/15.5).
Const NR01_SHORT_UW_CAL = 1000/13.93    'Unique NR 01 shortwave upwelling multiplier (1000/13.5).
Const NR01_LONG_DW_CAL = 1000/8.8       'Unique NR 01 longwave downwelling multiplier (1000/10.5).
Const NR01_LONG_UW_CAL = 1000/9.4       'Unique NR 01 longwave upwelling multiplier (1000/10.3).

Const MAX_DUTY_CYCLE_1 = 1
Const MAX_DUTY_CYCLE_2 = 0.2
Const DELTA_SET_POINT_1 = 5
Const DELTA_SET_POINT_2 = 28
Const SLOPE_1 = (MAX_DUTY_CYCLE_2-MAX_DUTY_CYCLE_1)/DELTA_SET_POINT_1
Const SLOPE_2 = (-MAX_DUTY_CYCLE_2)/DELTA_SET_POINT_2

'*** Variables ***

Public no_heat_flag As Boolean          'Turn off heater control when TRUE.
Public panel_temp                       'Datalogger panel temperature.
Public batt_volt                        'Datalogger battery voltage.
Public hmp(2)                           'HMP45C temperature and relative humidity.
Alias hmp(1) = t_hmp                    'HMP45C temperature.
Alias hmp(2) = rh_hmp                   'HMP45C relative humidity.
Public e_hmp                            'HMP45C vapor pressure.
Public nr01(9)                          'NR 01 net radiometer.
Alias nr01(1) = Rn
Alias nr01(2) = albedo
```

```
Alias nr01(3) = Rs_downwell
Alias nr01(4) = Rs_upwell
Alias nr01(5) = Rl_downwell
Alias nr01(6) = Rl_upwell
Alias nr01(7) = t_nr01
Alias nr01(8) = Rl_down_meas
Alias nr01(9) = Rl_up_meas
Units panel_temp = C
Units batt_volt = V
Units t_hmp = C
Units rh_hmp = percent
Units e_hmp = kPa
Units nr01 = W/m^2
Units albedo = unitless
Units t_nr01 = K

'Net radiometer heater control variables.
Public set_point_temperature
Public duty_cycle

'Working Variables
Dim scratch_out(3)
Alias scratch_out(1) = t_hmp_mean
Alias scratch_out(2) = e_hmp_mean
Alias scratch_out(3) = e_sat_hmp_mean
Dim rh_hmp_mean                              'Mean HMP45C relative humidity.
Dim t_dew_hmp_mean                           'Mean dew point temperature.
Dim e_sat_hmp                                'HMP45C saturation vapor pressure.
Units t_hmp_mean = C
Units e_hmp_mean = kPa
Units e_sat_hmp_mean = kPa
Units rh_hmp_mean = percent
Units t_dew_hmp_mean = C

DataTable (stats,TRUE,-1)
    DataInterval (0,5,Min,10)

    Sample (1,t_hmp_mean,IEEE4)
    Sample (1,e_hmp_mean,IEEE4)
    Sample (1,rh_hmp_mean,IEEE4)
    Sample (1,t_dew_hmp_mean,IEEE4)
    Sample (1,duty_cycle,IEEE4)
    Average (9,Rn,IEEE4,FALSE)
EndTable

DataTable (scratch,TRUE,1)
    TableHide
    DataInterval (0,5,Min,10)

    Average (1,t_hmp,IEEE4,FALSE)
    Average (1,e_hmp,IEEE4,FALSE)
    Average (1,e_sat_hmp,IEEE4,FALSE)
EndTable
```

```
BeginProg
    Scan (1,Sec,0,0)
        'Control the net radiometer heater.
        PWM (duty_cycle,4,250,mSec)

        'Datalogger panel temperature.
        PanelTemp (panel_temp,250)

        'Measure battery voltage.
        Battery (batt_volt)

        'Measure the HMP45C temperature and relative humidity.
        VoltDiff (t_hmp,1,mV1000C,5,TRUE,200,250,0.1,-40)
        VoltDiff (rh_hmp,1,mV1000C,6,TRUE,200,250,0.1,0)

        'Measure NR 01 Net Radiometer.
        Resistance (t_nr01,1,mV200,10,Ix1,1,1675,TRUE,TRUE,200,250,1,0)
        VoltDiff (Rs_downwell,1,mV20C,11,TRUE,200,250,NR01_SHORT_DW_CAL,0)
        VoltDiff (Rs_upwell,1,mV20C,12,TRUE,200,250,NR01_SHORT_UW_CAL,0)
        VoltDiff (Rl_down_meas,1,mV20C,13,TRUE,200,250,NR01_LONG_DW_CAL,0)
        VoltDiff (Rl_up_meas,1,mV20C,14,TRUE,200,250,NR01_LONG_UW_CAL,0)

        'Find the HMP45C vapor pressure and saturation vapor pressure (kPa).
        VaporPressure (e_hmp,t_hmp,rh_hmp)
        SatVP (e_sat_hmp,t_hmp)

        'Compute net radiation, albedo, downwelling and upwelling longwave radiation.
        t_nr01 = t_nr01/100
        PRT (t_nr01,1,t_nr01,1,273.15)

        Rn = Rs_downwell-Rs_upwell+Rl_down_meas-Rl_up_meas
        albedo = Rs_upwell/Rs_downwell
        Rl_downwell = Rl_down_meas+(5.67e-8*t_nr01*t_nr01*t_nr01*t_nr01)
        Rl_upwell = Rl_up_meas+(5.67e-8*t_nr01*t_nr01*t_nr01*t_nr01)

        CallTable (scratch)
        If ( scratch.Output(1,1) ) Then
            GetRecord (scratch_out(1),scratch,1)
            rh_hmp_mean = 100*e_hmp_mean/e_sat_hmp_mean
            DewPoint (t_dew_hmp_mean,t_hmp_mean,rh_hmp_mean)

            'Control the NR 01 heater using 4 Hz pulse width modulation. Below the dew
            ' point temperature applies 100% power. Above the dew point, power is reduced
            ' linearly to 20% until the dew point plus DELTA_SET_POINT_1. After the dew
            ' point plus DELTA_SET_POINT_1 and until the dew point plus
            ' DELTA_SET_POINT_2 plus DELTA_SET_POINT_2, the power is reduced linearly to 0%.
            If ( (t_nr01 <> NaN) AND (t_dew_hmp_mean <> NaN) AND (no_heat_flag <> TRUE) ) Then
                set_point_temperature = t_dew_hmp_mean+273.15
                Select Case t_nr01
                Case Is < ( set_point_temperature )
                    duty_cycle = 1
                Case Is < ( set_point_temperature+DELTA_SET_POINT_1 )
                    duty_cycle = MAX_DUTY_CYCLE_1+(t_nr01-(t_dew_hmp_mean+273.15))*SLOPE_1
                Case Is < ( set_point_temperature+DELTA_SET_POINT_1+DELTA_SET_POINT_2 )
                    duty_cycle = MAX_DUTY_CYCLE_2+(t_nr01-
                    (t_dew_hmp_mean+273.15+DELTA_SET_POINT_1))*SLOPE_2
```

```
                Case Else
                    duty_cycle = 0.01
                EndSelect
            Else
                duty_cycle = 0.01
            EndIf
        EndIf

        CallTable (stats)
    NextScan
EndProg
```

Campbell Scientific Companies

Campbell Scientific, Inc. (CSI)
815 West 1800 North
Logan, Utah 84321
UNITED STATES
www.campbellsci.com • info@campbellsci.com

Campbell Scientific Africa Pty. Ltd. (CSAf)
PO Box 2450
Somerset West 7129
SOUTH AFRICA
www.csafrica.co.za • cleroux@csafrica.co.za

Campbell Scientific Australia Pty. Ltd. (CSA)
PO Box 444
Thuringowa Central
QLD 4812 AUSTRALIA
www.campbellsci.com.au • info@campbellsci.com.au

Campbell Scientific do Brazil Ltda. (CSB)
Rua Luisa Crapsi Orsi, 15 Butantã
CEP: 005543-000 São Paulo SP BRAZIL
www.campbellsci.com.br • suporte@campbellsci.com.br

Campbell Scientific Canada Corp. (CSC)
11564 - 149th Street NW
Edmonton, Alberta T5M 1W7
CANADA
www.campbellsci.ca • dataloggers@campbellsci.ca

Campbell Scientific Centro Caribe S.A. (CSCC)
300 N Cementerio, Edificio Breller
Santo Domingo, Heredia 40305
COSTA RICA
www.campbellsci.cc • info@campbellsci.cc

Campbell Scientific Ltd. (CSL)
Campbell Park
80 Hathern Road
Shepshed, Loughborough LE12 9GX
UNITED KINGDOM
www.campbellsci.co.uk • sales@campbellsci.co.uk

Campbell Scientific Ltd. (France)
3 Avenue de la Division Leclerc
92160 ANTONY
FRANCE
www.campbellsci.fr • info@campbellsci.fr

Campbell Scientific Spain, S. L.
Avda. Pompeu Fabra 7-9, local 1
08024 Barcelona
SPAIN
www.campbellsci.es • info@campbellsci.es

Please visit www.campbellsci.com to obtain contact information for your local US or International representative.