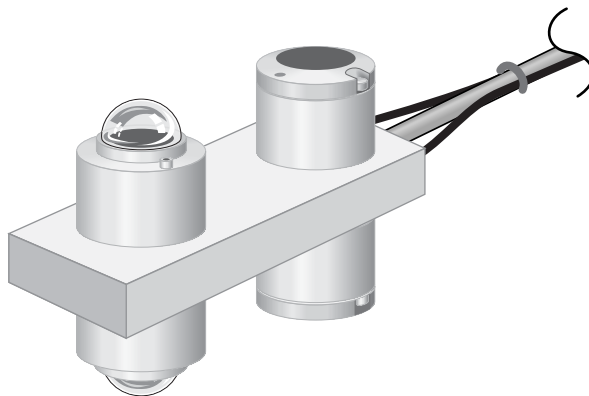


INSTRUCTION MANUAL



CNR1 Net Radiometer

June 2008



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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

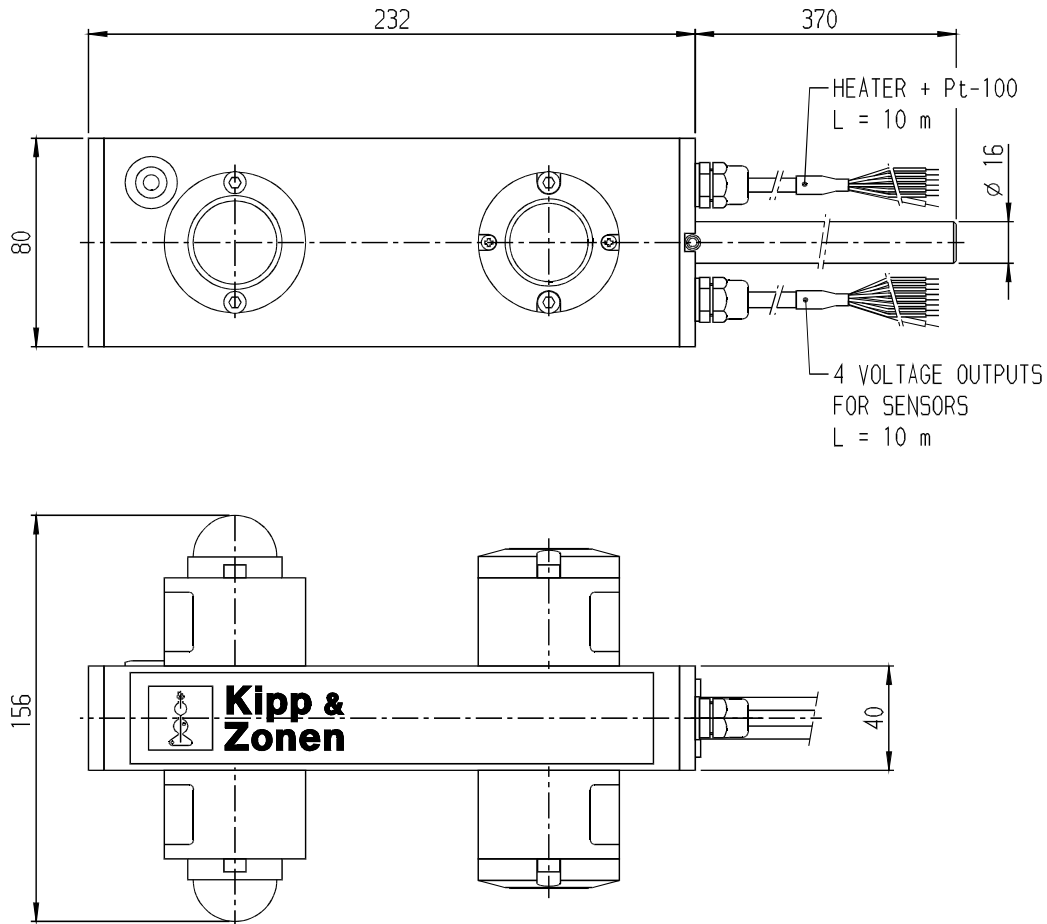


FIGURE 2-1. The Dimensions of the CNR1

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°C)

Tilt response:	Max. dev. 2%
Overall ISO classification:	second class
Sensitivity:	10 - 35 $\mu\text{V}/(\text{W m}^{-2})$
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:	$\pm 10\%$
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 $\mu\text{V}/(\text{W m}^{-2})$
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:	$\pm 10\%$

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, or to a UT018 Tower Mounting Bracket and Crossarm. Mount the sensor as follows:

1. Attach PN 14264 mounting bracket to the vertical mounting pipe or UT018 crossarm using the hardware provided.
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.

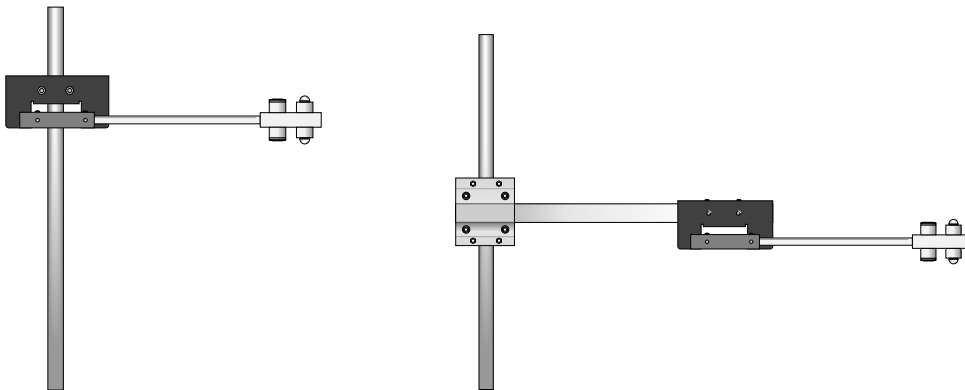


FIGURE 3-1. CNR1 Mounting Options

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 %.

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).

$$\text{For the CM3} \quad E = V/C \quad (4.1)$$

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:

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

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 sold separately. 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.

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

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.

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

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.

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

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".

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

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

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:

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

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 Kipp & Zonen manual. 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. Note that both Shield wires listed in Figure 5.1 consist of a large black wire. This wire is not shown in Figure 5.2. Please refer to Tables 5.1 to 5.3 for more information regarding wiring.

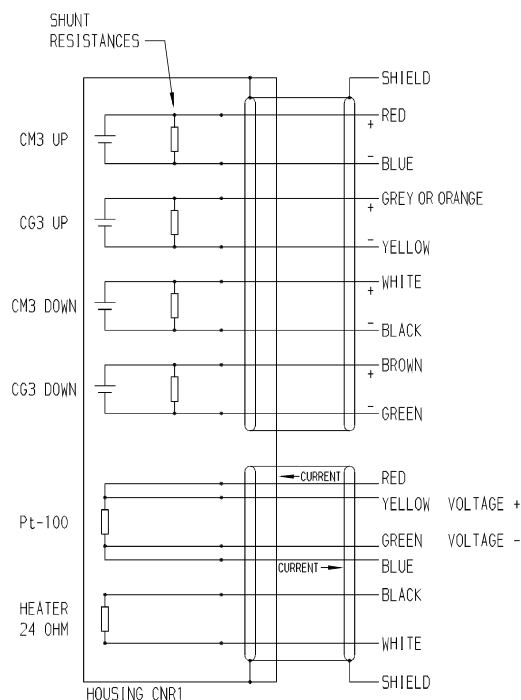


FIGURE 5-1. CNR1 Schematic

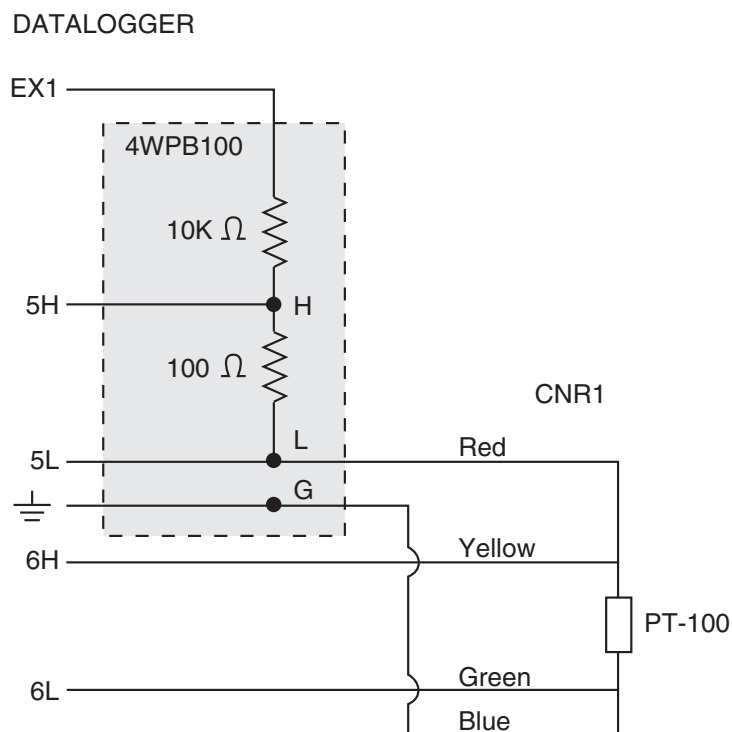


FIGURE 5-2. Interfacing the Pt-100 Using the 4WPB100 Module

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 AG to keep the signal in common mode range.

Function	Color	CR10X,CR510	CR23X	21X/CR7
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	Large Black	G	AG	AG

*Jumper to AG or AG 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)
Shield	Large Black		Ground (G)

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

Function	Color	CR10X,CR510	CR23X	21X/CR7
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	Large Black	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	Large Black	≡

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 (Instruction 2) is recommended because it has better noise rejection than a single-ended measurement. If differential channels are not available, single-ended measurements (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 sold separately from the CNR1.



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 $\mu\text{V}/(\text{W m}^{-2})$, which needs to be converted to units of $(\text{W m}^{-2})/\text{mV}$ 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 $7.30 \mu\text{V}/(\text{W m}^{-2})$, the multiplier is $1000/7.3 = 136.99 (\text{W m}^{-2})/\text{mV}$.

6.2 Example Programs

6.2.1 Example 1, CR23X Program 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:

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 1

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	5I
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: 273.18     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 · 10-8 * Temp_K4
; CG3_dnCor = CG3_dn+5.67 · 10-8 * Temp_K4

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

6.2.2 Example 2, CR23X Program Using Single-Ended Channels

Program Example 2 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 2

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: 273.18 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

```

6.2.3 Example 3, CR1000 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:

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+273.18
    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

6.2.4 Example 4, CR5000 Using Differential Channels (no 4WPB100)

Program Example 4 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,1,273.15)

  'Compute Net short-wave radiation, Net long-wave radiation, Albedo and Net Radiation
  CNR1TC=CNR1TK-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

```

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 °C - 20 °C	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 pyrgometer 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.