INSTRUCTION MANUAL

SI-111 Precision Infrared Radiometer

Revision: 7/10

Warranty and Assistance

The **SI-111 PRECISION INFRARED RADIOMETER** is warranted by Campbell Scientific, Inc. to be free from defects in materials and workmanship under normal use and service for twelve (12) months from date of shipment unless specified otherwise. Batteries have no warranty. Campbell Scientific, Inc.'s obligation under this warranty is limited to repairing or replacing (at Campbell Scientific, Inc.'s option) defective products. The customer shall assume all costs of removing, reinstalling, and shipping defective products to Campbell Scientific, Inc. Campbell Scientific, Inc. will return such products by surface carrier prepaid. This warranty shall not apply to any Campbell Scientific, Inc. products which have been subjected to modification, misuse, neglect, accidents of nature, or shipping damage. This warranty is in lieu of all other warranties, expressed or implied, including warranties of merchantability or fitness for a particular purpose. Campbell Scientific, Inc. is not liable for special, indirect, incidental, or consequential damages.

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RMA#_____
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Logan, Utah 84321-1784

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SI-111 Precision Infrared Radiometer

NOTE Prior to November 2008, the SI-111 was named the IRR-P. Only the name changed.

1. General Description

The SI-111 is an infrared temperature sensor that provides a non-contact means of measuring the surface temperature of an object. It senses the infrared radiation being emitted by the target. The SI-111 can be widely used for measurements of leaf, canopy, and average surface temperature. With contact sensors it is difficult to avoid influencing the temperature, maintain thermal contact, and provide a spatial average.

By mounting the infrared sensor at an appropriate distance from the target, it can be used to measure an individual leaf, a canopy, or any surface of interest.

The SI-111 is an infrared temperature sensor that includes a thermopile for measuring a millivolt output dependent on the target to sensor body temperature difference. A thermistor measures the temperature of the sensor body. The sensor body temperature is used to reference the target temperature.

2. Specifications

Input Power	2.5 V excitation for thermistor
Absolute Accuracy	±0.2°C @ -10° to 65°C ±0.5°C @ -40° to 70°C
Uniformity	±0.1°C @ -10° to 65°C ±0.3°C @ -40° to 70°C
Repeatability	±0.05°C @ -10° to 65°C ±0.1°C @ -40° to 70°C
Mass	190 grams
Dimensions	6.3 cm long by 2.3 cm diameter
Response Time	Less than 1 second to changes in target temperature
Target Output Signal	60 µV per °C difference from sensor body
Body Temperature Output Signal	0 to 2500 mV
Optics	Germanium lens
Wavelength Range	8 to 14 micrometers
Field of View	22° half angle
Operating Environment	Highly water resistant, designed for continuous outdoor use; operating range is -55° to 80°C, 0 to 100% RH

3. Installation

The field of view for infrared sensors is calculated based on the geometry of the sensor and lens. However, optical and atmospheric scatter and unwanted reflections from outside the field of view may influence the measurement. Under typical conditions, 95 to 98 percent of the IR signal is from the field of view and 2 to 5 percent is from the area surrounding the field of view. If the target surface is small, for example a single leaf, try to mount the sensor close enough that the surface extends beyond the field of view.

NOTE Remove green cap from the SI-111 before mounting to a crossarm, mast, or user-supplied support.

The SI-111 is often mounted to a CM202, CM204, or CM206 crossarm, a tripod or tower mast, or a user-supplied pole via a CM220 right angle mount (see Figure 3-1) or CM230 adjustable inclination mount. The CM230 allows the sensor to be pointed at the surface of interest. When using the CM230, fix the declination of the sensor by tightening the u-bolt that mounts on the mast or crossarm. The inclination is then adjusted with the other u-bolt and nuts (see Figure 3-2). A hole threaded for a standard tripod camera mount screw (1/4 inch diameter; 20 threads per inch) can be used to mount the sensor to a user-supplied support.

FIGURE 3-1. SI-111 Mounted onto a CM204 Crossarm via the CM220

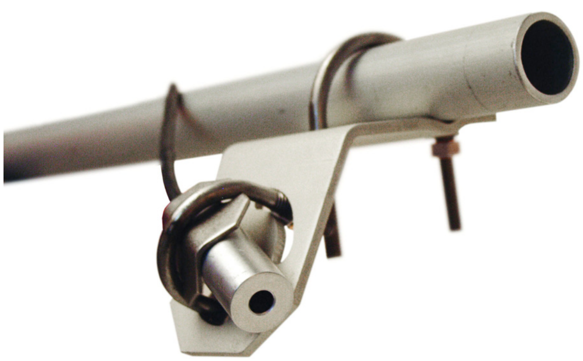
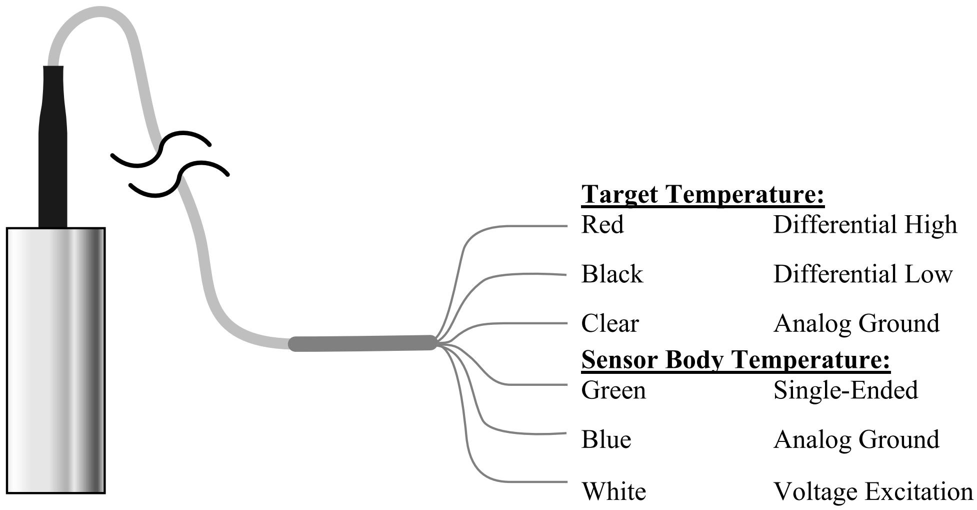


FIGURE 3-2. SI-111 Mounted onto a CM204 Crossarm via the CM230

4. Wiring



5. Example Programs

The example datalogger programs measure the SI-111's thermistor to obtain the SI-111 sensor body temperature and measure the SI-111's thermopile to obtain the target-to-sensor-body temperature difference.

After measuring the thermopile and thermistor outputs, the sensor-body temperature is used to reference the target temperature.

Wiring for the example programs is shown in Table 5-1. The actual channels used need to be adjusted for the actual installation and application.

NOTE Coefficients used to calculate the slope (m) and intercept (b) are specific to individual SI-111 sensors. The unique coefficients for each individual sensor is provided on the calibration sheet shipped with the sensor.

TABLE 5-1. Wiring for Example Programs

Sensor/Lead	**Description**	**CR10X**	**CR1000**
SI-111 Thermopile	Target Temp		
Red	Diff. High	2H	2H
Black	Diff. Low	2L	2L
Clear	Analog Ground	AG	⏚
SI-111 Thermistor	Sensor Temp		
Green	SE	1	1
Blue	Analog Ground	AG	⏚
White	Excitation	E1	VX1 or EX1

5.1 CR1000 Example Program

This example CR1000 program measures the sensor every 5 seconds and outputs a sample once every 60 seconds. The actual measurement rate and output intervals need to be adjusted for the actual installation and application.

Explanation of Variables and Constants Used in the Program

PanelT = datalogger panel temperature
BattV = datalogger battery voltage
SBTempC = sensor body temperature in degrees Celsius
SBTempK = sensor body temperature in Kelvin
TargmV = mV output of thermopile infrared detector (dependent on temperature difference between target and sensor body)
m = slope of equation relating target and sensor body temperatures to mV output of thermopile
b = intercept of the equation relating target and sensor body temperatures to mV output of thermopile
TargTempK = target temperature in Kelvin
TargTempC = target temperature in degrees Celsius
mC2 = polynomial coefficient (C2) used to calculate slope (m)
mC1 = polynomial coefficient (C1) used to calculate slope (m)
mC0 = polynomial coefficient (C0) used to calculate slope (m)
bC2 = polynomial coefficient (C2) used to calculate intercept (b)
bC1 = polynomial coefficient (C1) used to calculate intercept (b)
bC0 = polynomial coefficient (C0) used to calculate intercept (b)

NOTE All calibration coefficients are sensor-specific; those listed below are examples and must be changed based on the sensor being used.

```
'CR1000 Series Datalogger Program for Measuring Apogee Model SI-111 Infrared Radiometer

'Declare public variables
Public PanelT, BattV, SBTempC, SBTempK, TargmV, m, b, TargTempK, TargTempC

'Declare constants (replace the listed values with coefficients received with sensor)
Const mC2 = 82213
Const mC1 = 7841000
Const mC0 = 1419700000
Const bC2 = 13114
Const bC1 = 185020
Const bC0 = -17215000

'Define data table (table is outputting data every 60 seconds)
DataTable (IRR,1,-1)
    DataInterval (0,60,Sec,10)
    Minimum (1,BattV,FP2,0,False)
    Sample (1,PanelT,FP2)
    Average (1,TargmV,FP2,False)
    Average (1,SBTempC,FP2,False)
    Average (1,TargTempC,FP2,False)
EndTable
```

```
'Main program (program is making a measurement every 5 seconds)
BeginProg
    Scan (5,Sec,0,0)
        PanelTemp (PanelT,_60Hz)
        Battery (BattV)

'Instruction to measure sensor body temperature (green wire to SE1, white wire to EX1, blue wire 'to ground)
        Therm109 (SBTempC,1,1,Vx1,0,_60Hz,1.0,0)

'Instruction to measure mV output of thermopile detector (red wire to 2H, black wire to 2L, clear
'wire to ground)
        VoltDiff (TargmV,1,mV2_5,2,True ,0,_60Hz,1.0,0)

'Calculation of m (slope) and b (intercept) coefficients for target temperature calculation
        m = mC2 * SBTempC^2 + mC1 * SBTempC + mC0
        b = bC2 * SBTempC^2 + bC1 * SBTempC + bC0

'Calculation of target temperature
        SBTempK = SBTempC + 273.15
        TargTempK = ((SBTempK^4) + m * TargmV + b)^0.25
        TargTempC = TargTempK - 273.15

'Call output tables
        CallTable IRR
    NextScan
EndProg
```

5.2 CR10X Example Program

This example CR10X program measures the sensor once a second and outputs the average values once an hour. The actual measurement rate and output intervals need to be adjusted for the actual installation and application.

Explanation of Labels Used in the Program

mV_thrm = mV output of the thermistor.
1_mV_thrm = first step in converting the mV output of the thermistor to resistance.
2_mV_thrm = second step in converting the mV output of the thermistor to resistance.
R_thrm = resistance of the thermistor.
InR_thrm = natural log of the resistance of the thermistor.
Scaled_R = intermediate step in converting the natural log of the resistance to temperature.
SH_Coeff = application of the Steinhart and Hart coefficients to convert the scaled resistance to the reciprocal of temperature.
SB_Temp_K = sensor body temperature in Kelvin.
SB_Temp_C = sensor body temperature in degrees Celsius.
mV_tpile = mV output of the thermopile (dependent on the temperature difference between the target and the sensor body).
m_slope = slope of the equation relating target and sensor body temperature to mV output of the thermopile.
b_inter = y-intercept of the equation relating target and sensor body temperature to mV output of the thermopile.
Exponent1 = exponent used to raise the sensor body temperature to the 4th power.
Exponent2 = exponent used to calculate the 4th root of the sum of the terms used to calculate the target temperature.
1_SB_4Pow = first calculation step; sensor body temperature (Kelvin) raised to the fourth power.
2_mVxm = second calculation step; mV output of the thermopile multiplied by m (slope).

3_Sum1 = third calculation step; sum of calculation steps one and two.
4_Sum2 = fourth calculation step; the sum of calculation step 3 and b (intercept).
T_Temp_K = target temperature in Kelvin; calculated by adding the temperature difference between the target and sensor body to the sensor body temperature.
T_Temp_C = target temperature in degrees C.

```
;{CR10X}

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

;Instruction string to measure the resistance of the thermistor and calculate the sensor body
;temperature.  See the Instruction Manual for Campbell Scientific Model 109 Temperature Probe for
;details.

1:  AC Half Bridge (P5)
  1:   1            Reps
  2:   25           2500 mV 60 Hz Rejection Range ;the range should at least match the excitation
  3:   1            SE Channel
  4:   1            Excite all reps w/Exchan 1
  5:   2500         mV Excitation
  6:   1            Loc [ mV_thrm ]
  7:   1.0          Mult
  8:   0.0          Offset

2:  Z=1/X (P42)
  1:   1            X Loc [ mV_thrm ]
  2:   2            Z Loc [ 1_mV_thrm ]

3:  Z=X+F (P34)
  1:   2            X Loc [ 1_mV_thrm ]
  2:   -1.0         F
  3:   3            Z Loc [ 2_mV_thrm ]

4:  Z=X*F (P37)
  1:   3            X Loc [ 2_mV_thrm ]
  2:   24900        F
  3:   4            Z Loc [ R_thrm ]

5:  Z=LN(X) (P40)
  1:   4            X Loc [ R_thrm ]
  2:   5            Z Loc [ InR_thrm ]

6:  Z=X*F (P37)
  1:   5            X Loc [ InR_thrm ]
  2:   0.001        F
  3:   6            Z Loc [ Scaled_R ]
```

```
7:  Polynomial (P55)
   1:   1            Reps
   2:   6            X Loc [ Scaled_R ]
   3:   7            F(X) Loc [ SH_Coeffs ]
   4:   .001129      C0
   5:   .234108      C1
   6:   0.0          C2
   7:   87.7547      C3
   8:   0.0          C4
   9:   0.0          C5

8:  Z=1/X (P42)
   1:   7            X Loc [ SH_Coeffs ]
   2:   8            Z Loc [ SB_Temp_K ]

9:  Z=X+F (P34)
   1:   8            X Loc [ SB_Temp_K ]
   2:   -273.15      F
   3:   9            Z Loc [ SB_Temp_C ]

;Instruction to measure the mV output of the thermopile.

10:  Volt (Diff) (P2)
   1:   1            Reps
   2:   21           2.5 mV 60 Hz Rejection Range
   3:   2            DIFF Channel
   4:   11           Loc [ mV_tpile ]
   5:   1.0          Mult
   6:   0.0          Offset

;Calculation of m (slope) coefficient for target temperature calculation.  Each sensor has unique
;C0, C1, and C2 values.  Refer to the calibration sheet shipped with the sensor to obtain the correct
;values for your sensor.

11:  Polynomial (P55)
   1:   1            Reps
   2:   9            X Loc [ SB_Temp_C ]
   3:   12           F(X) Loc [ m_slope ]
   4:   15182.65     C0
   5:   86.85177     C1
   6:   0.69817      C2
   7:   0.0          C3
   8:   0.0          C4
   9:   0.0          C5

12:  Z=X*F (P37)
   1:   12           X Loc [ m_slope ]
   2:   99999        F
   3:   12           Z Loc [ m_slope ]

;Calculation of b (intercept) coefficient for target calculation.  Each sensor has unique C0, C1, and
;C2 values.  Refer to the calibration sheet shipped with the sensor to obtain the correct values for
;your sensor.
```

```
13:  Polynomial (P55)
   1:    1              Reps
   2:    9              X Loc [ SB_Temp_C ]
   3:    13             F(X) Loc [ b_inter ]
   4:    -31.09271      C0
   5:    -2.95714       C1
   6:    0.25154        C2
   7:    0.0            C3
   8:    0.0            C4
   9:    0.0            C5

14:  Z=X*F (P37)
   1:    13             X Loc [ b_inter ]
   2:    99999          F
   3:    13             Z Loc [ b_inter ]

;Target temperature calculation based on m and b coefficients.

15:  Z=F x 10^n (P30)
   1:    0.4            F
   2:    1              n, Exponent of 10
   3:    14             Z Loc [ Exponent1 ]

16:  Z=F x 10^n (P30)
   1:    0.025          F
   2:    1              n, Exponent of 10
   3:    15             Z Loc [ Exponent2 ]

17:  Z=X^Y (P47)
   1:    8              X Loc [ SB_Temp_K ]
   2:    14             Y Loc [ Exponent1 ]
   3:    16             Z Loc [ 1_SB_4Pow ]

18:  Z=X*Y (P36)
   1:    11             X Loc [ mV_tpile ]
   2:    12             Y Loc [ m_slope ]
   3:    17             Z Loc [ 2_mVxm ]

19:  Z=X+Y (P33)
   1:    16             X Loc [ 1_SB_4Pow ]
   2:    17             Y Loc [ 2_mVxm ]
   3:    18             Z Loc [ 3_Sum1 ]

20:  Z=X+Y (P33)
   1:    13             X Loc [ b_inter ]
   2:    18             Y Loc [ 3_Sum1 ]
   3:    19             Z Loc [ 4_Sum2 ]

21:  Z=X^Y (P47)
   1:    19             X Loc [ 4_Sum2 ]
   2:    15             Y Loc [ Exponent2 ]
   3:    20             Z Loc [ T_Temp_K ]

22:  Z=X+F (P34)
   1:    20             X Loc [ T_Temp_K ]
   2:    -273.15        F
   3:    21             Z Loc [T_Temp_C ]
```

```
;Output average values once an hour

23:  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)

24:  Real Time (P77)
   1:    1220              Year, Day, Hour/Minute (midnight = 2400)

25:  Average (P71)
   1:    1                 Reps
   2:    21                Loc [ T_Temp_C ]

*Table 2 Program
   02:  0.0                Execution Interval (seconds)

*Table 3 Subroutines

End Program
```

6. Maintenance

As with any optical sensor, it is important to keep the lens and view clean. Otherwise the sensor will be measuring the temperature of the obstruction instead of the surface of interest.

Clean the lens gently with a moistened cotton swab. Distilled water or alcohol works well for most dust/dirt. Salt deposits dissolve better in a weak acid solution (~0.1 molar).

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