INSTRUCTION MANUAL

SI-111 Precision Infrared Radiometer

Revision: 7/13

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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

* Where target temperature is within 20°C of sensor body temperature.
** Where target temperature is greater than 20°C of sensor body temperature.

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.

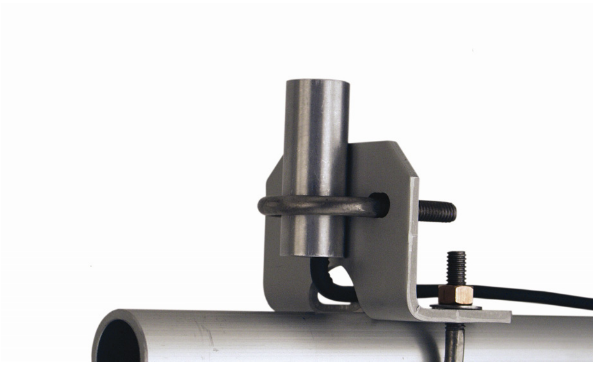
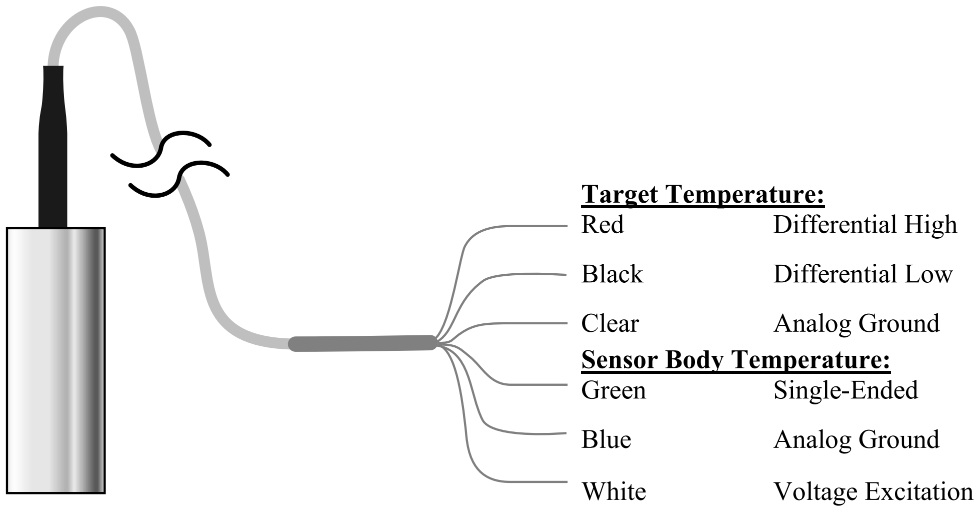


FIGURE 3-1. SI-111 mounted onto a CM204 crossarm via the CM220

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 are 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

A primary source of inaccurate measurements for any radiation sensor is blocking of the optical path to the detector. The window in the Apogee's infrared sensor is inset and protected, but it can become partially blocked in three ways:

1. Spiders can make a nest in the entrance. We recommend using a cotton swab to apply a spider repellent around the entrance to the aperture (not on the sensor window itself).

2. Calcium deposits can accumulate on the window if irrigation water sprays up on the head. These typically leave a thin white film on the surface and can be removed with a dilute acid like vinegar. Calcium deposits cannot be removed with solvents such as alcohol or acetone.

3. Dust and dirt can be deposited in the aperture in windy environments and are best cleaned with deionized water, rubbing alcohol, or in extreme cases, acetone.

Clean the inner threads and sensor window using a cotton swab dipped in the appropriate solvent. It is important to use only gentle pressure on the window to avoid scratching the thin optical coating on the window. Let the solvent do the cleaning, not mechanical force. The cleaning should be repeated with a second, fresh cotton swab to ensure a completely clean window. Sensors can go for many months and stay clean in some environments, but frequent cleaning is needed in other environments.

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 8108
Garbutt Post Shop QLD 4814
AUSTRALIA
www.campbellsci.com.au • info@campbellsci.com.au

Campbell Scientific do Brasil Ltda. (CSB)
Rua Apinagés, nbr. 2018 ─ Perdizes
CEP: 01258-00 ─ São Paulo ─ SP
BRASIL
www.campbellsci.com.br • vendas@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.