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

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Model HFP01SC
Self-Calibrating Soil Heat Flux Plate

1. Introduction

The HFP01SC Self-Calibrating Heat Flux Sensor™ measures soil heat flux, typically for energy-balance or Bowen-ratio flux systems. It is intended for applications requiring the highest possible degree of measurement accuracy. At least two sensors are required for each site to provide spatial averaging. Sites with heterogeneous media may require additional sensors.

Before installing the HFP01SC, please study

- Section 2, Cautionary Statements
- Section 3, Initial Inspection

The installation procedure is provided in Section 6, Installation.

2. Cautionary Statements

- Care should be taken when opening the shipping package to not damage or cut the cable jacket. If damage to the cable is suspected, consult with a Campbell Scientific applications engineer.

- Although the HFP01SC is rugged, it should be handled as a precision scientific instrument.

3. Initial Inspection

- Upon receipt of the HFP01SC, inspect the packaging and contents for damage. File damage claims with the shipping company.

- The model number and cable length are printed on a label at the connection end of the cable. Check this information against the shipping documents to ensure the correct product and cable length are received.

- The HFP01SC is shipped with a calibration sheet and an instruction manual or a ResourceDVD.

4. Overview

The HFP01SC Soil Heat Flux plate consists of a thermopile and a film heater. The thermopile measures temperature gradients across the plate. During the in-situ field calibration, the film heater is used to generate a heat flux through the plate. The amount of power used to generate the calibration heat flux is measured by the datalogger. Each plate is individually calibrated, at the factory, to output flux.
In order to measure soil heat flux at the surface, several HFP01SCs are used to measure the soil heat flux at a depth of eight centimeters. A TCAV, *Averaging Soil Thermocouple*, is used to measure the temporal change in temperature of the soil layer above the HFP01SC. Finally, a CS650, CS655, or CS616 water content reflectometer is used to measure the soil water content. The temporal change in soil temperature and soil water content are used to compute the soil storage term.

The -L option on the model HFP01SC Soil Heat Flux Plate (HFP01SC-L) indicates that the cable length is user specified. The HFP01SC-L has two cables; the first cable is the signal output cable and the second is the heater input cable. Two analog inputs are required to measure the HFP01SC-L. This manual refers to the sensor as the HFP01SC.

The sensor’s cable can terminate in:

- Pigtailed that connect directly to a Campbell Scientific datalogger (option –PT).
- Connector that attaches to a prewired enclosure (option –PW). Refer to [www.campbellsci.com/prewired-enclosures](http://www.campbellsci.com/prewired-enclosures) for more information.

### 5. Specifications

**Features:**

- Corrects for errors due to differences in thermal conductivity between the sensor and the surrounding medium, temperature variations, and slight sensor instabilities

- Compatible with most of our dataloggers

- Uses Van den Bos-Hoeksema self-calibration method to provide high-degree of measurement accuracy

**Compatibility**

<table>
<thead>
<tr>
<th>Dataloggers</th>
<th>CR800 series</th>
<th>CR1000</th>
<th>CR3000</th>
<th>CR5000</th>
<th>CR9000(X)</th>
<th>CR7X</th>
<th>CR10(X)</th>
<th>CR23X</th>
<th>21X</th>
</tr>
</thead>
</table>

**Operating Temperature:**

-30° to +70°C

**Storage Temperature:**

-30° to +70°C

**Plate Thickness:**

5 mm (0.2 in)

**Plate Diameter:**

80 mm (3.15 in)

**Average Power Consumption:**

0.02 to 0.04 W
6. Installation

6.1 Placement in Soil

The HFP01SC soil heat flux plates, the TCAV averaging soil temperature probes, and the CS616, Water Content Reflectometer, are installed as shown in FIGURE 6-1.

Partial emplacement of the HFP01SC and the TCAV sensors is shown for illustration purposes. All sensors must be completely inserted into the soil face before the hole is backfilled.

FIGURE 6-1. Placement of heat flux plates
The location of the heat flux plates and thermocouples should represent the area of study. If the ground cover is extremely varied, it may be necessary to have additional sensors to provide a valid spatial average of soil heat flux.

Use a small shovel to make a vertical slice in the soil. Excavate the soil to one side of the slice. Keep this soil intact to ensure replacement with minimal disruption.

The sensors are installed in the undisturbed face of the hole. Measure the sensor depths from the top of the hole. With a small knife, make a horizontal cut eight centimeters below the surface into the undisturbed face of the hole. Insert the heat flux plate into the horizontal cut.

**NOTE**
Install the HFP01SC in the soil such that the side with the text “this side up” is facing the sky.

**CAUTION**
In order for the HFP01SC to make quality soil heat flux measurements, the plate must be in full contact with the soil.

Never run the sensors leads directly to the surface. Rather, bury the sensor leads a short distance back from the hole to minimized thermal conduction on the lead wire. Replace the excavated soil into its original position after all the sensors are installed.

*FIGURE 6-2. HFP01SC plate*
### TABLE 6-1. Datalogger Connections for a Single-Ended Measurement

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>CR10X</th>
<th>CR3000, CR5000, CR23X, CR9000(X), CR7, 21X</th>
<th>CR800, CR850, CR1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Signal Reference</td>
<td>Green</td>
<td>AG</td>
<td>✦</td>
<td>✦</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td>G</td>
<td>✦</td>
<td>✦</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference</td>
<td>Purple</td>
<td>AG</td>
<td>✦</td>
<td>✦</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td>G</td>
<td>✦</td>
<td>✦</td>
</tr>
<tr>
<td>Power</td>
<td>Red</td>
<td>SW12</td>
<td>SW12</td>
<td>SW12</td>
</tr>
<tr>
<td>Power Reference</td>
<td>Black</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>External Power Control</td>
<td>Jumper Wire</td>
<td>SW12-CTRL to Control Port</td>
<td>External Power Control Not Needed</td>
<td>External Power Control Not Needed</td>
</tr>
</tbody>
</table>

### TABLE 6-2. Datalogger Connections for a Differential Measurement

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>CR10(X)</th>
<th>CR3000, CR5000, CR23X, CR9000(X), CR7, 21X</th>
<th>CR800, CR850, CR1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Signal</td>
<td>White</td>
<td>Differential Input (H)</td>
<td>Differential Input (H)</td>
<td>Differential Input (H)</td>
</tr>
<tr>
<td>Sensor Signal Reference</td>
<td>Green</td>
<td>Differential Input (L)</td>
<td>Differential Input (L)</td>
<td>Differential Input (L)</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td>G</td>
<td>✦</td>
<td>✦</td>
</tr>
<tr>
<td>Heater Resistor Signal</td>
<td>Yellow</td>
<td>Differential Input (H)</td>
<td>Differential Input (H)</td>
<td>Differential Input (H)</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference</td>
<td>Purple</td>
<td>Differential Input (L)</td>
<td>Differential Input (L)</td>
<td>Differential Input (L)</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td>G</td>
<td>✦</td>
<td>✦</td>
</tr>
<tr>
<td>Power</td>
<td>Red</td>
<td>SW12</td>
<td>SW12</td>
<td>SW12</td>
</tr>
<tr>
<td>Power Reference</td>
<td>Black</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>External Power Control</td>
<td>Jumper Wire</td>
<td>SW12-CTRL to Control Port</td>
<td>External Power Control Not Needed</td>
<td>External Power Control Not Needed</td>
</tr>
</tbody>
</table>
6.2 Wiring

Connections to Campbell Scientific dataloggers are given in FIGURE 6-1, TABLE 6-1, and TABLE 6-2. The output of the HFP01SC can be measured using a single-ended analog measurement (\texttt{VoltSE()}) or Instruction 1), however, a differential analog measurement (\texttt{VoltDiff()}) or Instruction 2) is recommended.

The wiring convention is that the white wire is positive with respect to the green wire, when energy is flowing through the transducer from the side with the text “this side up” to the other side.

**NOTE**
The switched 12 Vdc port can source enough current to calibrate four HFP01SC plates. If additional HFP01SC plates are needed, an external relay is required to power the additional plates (see example 4).

For dataloggers without a SW12V output (CR7X, 21X and CR10), a relay (A21REL-12) is required for the in-situ calibration (see Example 4).

6.3 Programming

The HFP01SC has a nominal calibration of 15 W m\(^{-2}\) mV\(^{-1}\). Each sensor is accompanied by a calibration certificate. Each sensor also has a unique calibration label on it. The label is located on the pigtail end of the sensor leads.

6.3.1 Example 1. Sample CR3000 Program Using a Differential Measurement Instruction

TABLE 6-3 provides the wiring for Example 1.

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>CR3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Signal #1</td>
<td>White</td>
<td>9H</td>
</tr>
<tr>
<td>Sensor Signal Reference #1</td>
<td>Green</td>
<td>9L</td>
</tr>
<tr>
<td>Shield #1</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Sensor Signal #2</td>
<td>White</td>
<td>10H</td>
</tr>
<tr>
<td>Sensor Signal Reference #2</td>
<td>Green</td>
<td>10L</td>
</tr>
<tr>
<td>Shield #2</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Sensor Signal #3</td>
<td>White</td>
<td>11H</td>
</tr>
<tr>
<td>Sensor Signal Reference #3</td>
<td>Green</td>
<td>11L</td>
</tr>
<tr>
<td>Shield #3</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Sensor Signal #4</td>
<td>White</td>
<td>12H</td>
</tr>
<tr>
<td>Sensor Signal Reference #4</td>
<td>Green</td>
<td>12L</td>
</tr>
<tr>
<td>Shield #4</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Heater Resistor Signal #1</td>
<td>Yellow</td>
<td>13H</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------</td>
<td>-----</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference #1</td>
<td>Purple</td>
<td></td>
</tr>
<tr>
<td>Shield #1</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Power #1</td>
<td>Red</td>
<td>SW12-1</td>
</tr>
<tr>
<td>Power Reference #1</td>
<td>Black</td>
<td>G</td>
</tr>
<tr>
<td>Heater Resistor Signal #2</td>
<td>Yellow</td>
<td>13L</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference #2</td>
<td>Purple</td>
<td></td>
</tr>
<tr>
<td>Shield #2</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Power #2</td>
<td>Red</td>
<td>SW12-1</td>
</tr>
<tr>
<td>Power Reference #2</td>
<td>Black</td>
<td>G</td>
</tr>
<tr>
<td>Heater Resistor Signal #3</td>
<td>Yellow</td>
<td>14H</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference #3</td>
<td>Purple</td>
<td></td>
</tr>
<tr>
<td>Shield #3</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Power #3</td>
<td>Red</td>
<td>SW12-1</td>
</tr>
<tr>
<td>Power Reference #3</td>
<td>Black</td>
<td>G</td>
</tr>
<tr>
<td>Heater Resistor Signal #4</td>
<td>Yellow</td>
<td>14L</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference #4</td>
<td>Purple</td>
<td></td>
</tr>
<tr>
<td>Shield #4</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Power #4</td>
<td>Red</td>
<td>SW12-1</td>
</tr>
</tbody>
</table>

'CR3000 Series Datalogger
Const OUTPUT_INTERVAL = 30 'Online mean output interval in minutes.
Const CAL_INTERVAL = 1440 'HFP01SC insitu calibration interval (minutes).
Const END_CAL = OUTPUT_INTERVAL-1 'End HFP01SC insitu calibration one minute before the next Output.
Const HFP01SC_CAL_1 = 15 'Unique multiplier for HFP01SC #1 (1000/sensitivity).
Const HFP01SC_CAL_2 = 15 'Unique multiplier for HFP01SC #2 (1000/sensitivity).
Const HFP01SC_CAL_3 = 15 'Unique multiplier for HFP01SC #3 (1000/sensitivity).
Const HFP01SC_CAL_4 = 15 'Unique multiplier for HFP01SC #4 (1000/sensitivity).

'*** Variables ***
Public shf(4)
Public shf_cal(4)
Units shf = W/m^2
Units shf_cal = W/(m^2 mV)
'HFP01SC calibration variables.
Dim shf_mv(4)
Dim shf_mv_0(4)
Dim shf_mv_180(4)
Dim shf_mv_end(4)
Dim V_Rf(4)
Dim V_rf_180(4)
Dim shf_cal_on_f As Boolean
Dim sw12_1_state As Boolean 'State of the switched 12Vdc port 1.
Dim ii As Long
DataTable (mean,TRUE,100)
DataInterval (0,OUTPUT_INTERVAL,Min,10)
Average (4,shf(1),IEEE4,shf_cal_on_f)
Sample (4,shf_cal(1),IEEE4)
EndTable
BeginProg

'HFP01SC factory calibration in W/(m^2 mV) = 1000/sensitivity.
shf_cal(1) = HFP01SC_CAL_1
shf_cal(2) = HFP01SC_CAL_2
shf_cal(3) = HFP01SC_CAL_3
shf_cal(4) = HFP01SC_CAL_4

Scan (1,Sec,3,0)
'Measure the HFP01SC soil heat flux plates.
VoltDiff (shf_mV(1),4,mV50C,9,TRUE,0,60Hz,1,0)

'Apply calibration to HFP01SC soil heat flux plates.
For ii = 1 To 4
  shf(ii) = shf_mV(ii)*shf_cal(ii)
Next ii

'Power the HFP01SC heaters.
PortSet (9,sw12_1_state)

'Measure voltage across the heater (Rf_V).
VoltSe (V_Rf(1),4,mV5000,25,TRUE,0,60Hz,0.001,0)
CallTable (mean)

'Begiin HFP01SC calibration on a fixed interval.
If ( IfTime (1,CAL_INTERVAL,Min) ) Then
  shf_cal_on_f = TRUE
  Move (shf_mV_0(1),4,shf_mV(1),4)
  sw12_1_state = TRUE
EndIf

If ( IfTime (4,CAL_INTERVAL,Min) ) Then
  Move (shf_mV_180(1),4,shf_mV(1),4)
  Move (V_Rf_180(1),4,V_Rf(1),4)
  sw12_1_state = FALSE
EndIf

If ( IfTime (END_CAL,CAL_INTERVAL,Min) ) Then
  Move (shf_mV_end(1),4,shf_mV(1),4)
  'Compute new HFP01SC calibration factors.
  For ii = 1 To 4
    shf_cal(ii) = V_Rf_180(ii)*V_Rf_180(ii)*128.7/ABS (((shf_mV_0(ii)+shf_mV_end(ii))/2)-shf_mV_180(ii))
  Next ii
  shf_cal_on_f = FALSE
EndIf
NextScan
EndProg
6.3.2 Example 2. Sample CR10(X) Program Using a Single-Ended Measurement Instruction

TABLE 6-4 provides the wiring for Example 2.

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>CR10(X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Signal</td>
<td>White</td>
<td>1H</td>
</tr>
<tr>
<td>Sensor Signal Reference</td>
<td>Green</td>
<td>AG</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td>G</td>
</tr>
<tr>
<td>Heater Resistor Signal</td>
<td>Yellow</td>
<td>1L</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference</td>
<td>Purple</td>
<td>AG</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td>G</td>
</tr>
<tr>
<td>Power</td>
<td>Red</td>
<td>SW12</td>
</tr>
<tr>
<td>Power Reference</td>
<td>Black</td>
<td>G</td>
</tr>
<tr>
<td>External Power Control</td>
<td></td>
<td>jumper wire SW12-CTRL to C8</td>
</tr>
</tbody>
</table>

```plaintext
;;{CR10X}
;;*Table 1 Program
01: 1 Execution Interval (seconds)
;;Measure HFP01SC on smaller range.
;
1: Volt (SE) (P1)
  1: 1 Reps
  2: 22 7.5 mV 60 Hz Rejection Range
  3: 1 SE Channel
  4: 2 Loc [ shf_mV ]
  5: 1 Mult
  6: 0 Offset

;;Measure HFP01SC on larger range.
;
2: Volt (SE) (P1)
  1: 1 Reps
  2: 23 25 mV 60 Hz Rejection Range
  3: 1 SE Channel
  4: 8 Loc [ shf_mV_a ]
  5: 1 Mult
  6: 0 Offset

;;Load in the factory calibration.
;;
3: If (X<=F) (P89)
  1: 3 X Loc [ cal ]
  2: 1 =
  3: 0 F
  4: 30 Then Do
```
Model HFP01SC Self-Calibrating Soil Heat Flux Plate

; Factory calibration in W/(m^2 mV) = 1000/sensitivity.

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

5:  End (P95)

; Use data from the larger measurement range.

6:  If (X<=F) (P89)
   1:  2  X Loc [ shf_mV ]
   2:  4  <
   3:  -99990  F
   4:  30  Then Do

7:  Z=X (P31)
   1:  8  X Loc [ shf_mV_a ]
   2:  2  Z Loc [ shf_mV ]

8:  End (P95)

; Apply custom calibration to the raw soil heat flux measurement.

9:  Z=X*Y (P36)
   1:  2  X Loc [ shf_mV ]
   2:  3  Y Loc [ cal ]
   3:  1  Z Loc [ shf ]

; Output data.

10: If time is (P92)
    1:  0  Minutes (Seconds --) into a
    2:  20  Interval (same units as above)
    3:  10  Set Output Flag High (Flag 0)

11: Real Time (P77)
    1:  0110  Day,Hour/Minute (midnight = 0000)

12: Resolution (P78)
    1:  1  High Resolution

; Do not include the calibration data in the soil heat flux.

13: If Flag/Port (P91)
    1:  18  Do if Flag 8 is High
    2:  19  Set Intermed. Proc. Disable Flag High (Flag 9)

14: Average (P71)
    1:  1  Reps
    2:  1  Loc [ shf ]

15: Do (P86)
    1:  29  Set Intermed. Proc. Disable Flag Low (Flag 9)

16: Sample (P70)
    1:  1  Reps
    2:  3  Loc [ cal ]

; Add other processing here.

; Call calibration routine.

17: Do (P86)
    1:  8  Call Subroutine 8
*Table 2 Program
- 02: 0 Execution Interval (seconds)

*Table 3 Subroutines

;Calibration routine.
;
1: Beginning of Subroutine (P85)
   1: 8 Subroutine 8

;Perform in-situ calibration.
;
2: If time is (P92)
   1: 1 Minutes (Seconds --) into a
   2: 180 Interval (same units as above)
   3: 30 Then Do

3: Z=X (P31)
   1: 2 X Loc [shf_mV ]
   2: 4 Z Loc [mV_0 ]

;Begin heating for calibration.
;
4: Do (P86)
   1: 48 Set Port 8 High

;Used to filter data during and after calibration.
;
5: Do (P86)
   1: 18 Set Flag 8 High

6: End (P95)

;End site calibration three minutes after calibration started.
;
7: If time is (P92)
   1: 4 Minutes (Seconds --) into a
   2: 180 Interval (same units as above)
   3: 30 Then Do

;Measure voltage across current shunt resistor (10 ohm 1% 0.25 W 50 ppm/deg C) during calibration. This measurement is used to compute power.
;
8: Volt (SE) (P1)
   1: 1 Reps
   2: 25 2500 mV 60 Hz Rejection Range
   3: 2 SE Channel
   4: 7 Loc [V_RF ]
   5: .001 Mult
   6: 0 Offset

9: Z=X (P31)
   1: 2 X Loc [shf_mV ]
   2: 5 Z Loc [mV_180 ]

;Turn off the soil heat flux plate heater.
;
10: Do (P86)
    1: 58 Set Port 8 Low

11: End (P95)
Model HFP01SC Self-Calibrating Soil Heat Flux Plate

; Stop filtering data.
;
12: If time is (P92)
   1: 39 Minutes (Seconds --) into a
   2: 180 Interval (same units as above)
   3: 30 Then Do

13: Do (P86)
   1: 28 Set Flag 8 Low

; Compute in-situ calibration.
;
14: Z=X (P31)
   1: 2 X Loc [ shf_mV ]
   2: 6 Z Loc [ mV_end ]

15: Z=X*Y (P36)
   1: 7 X Loc [ V_Rf ]
   2: 7 Y Loc [ V_Rf ]
   3: 3 Z Loc [ cal ]

16: Z=X*F (P37)
   1: 3 X Loc [ cal ]
   2: 128.7 F
   3: 3 Z Loc [ cal ]

17: Z=X+Y (P33)
   1: 4 X Loc [ mV_0 ]
   2: 6 Y Loc [ mV_end ]
   3: 9 Z Loc [ work ]

18: Z=X*F (P37)
   1: 9 X Loc [ work ]
   2: .5 F
   3: 9 Z Loc [ work ]

19: Z=X-Y (P35)
   1: 9 X Loc [ work ]
   2: 5 Y Loc [ mV_180 ]
   3: 9 Z Loc [ work ]

20: Z=ABS(X) (P43)
   1: 9 X Loc [ work ]
   2: 9 Z Loc [ work ]

21: Z=X/Y (P38)
   1: 3 X Loc [ cal ]
   2: 9 Y Loc [ work ]
   3: 3 Z Loc [ cal ]

22: End (P95)
23: End (P95)

End Program

- Input Locations -
1 shf
2 shf_mV
3 cal
4 mV_0
5 mV_180
6 mV_end
7 V_Rf
8 shf_mV_a
9 work
6.3.3 Example 3. Sample CR23X Program Using a Differential Measurement Instruction

TABLE 6-5 provides the wiring for Example 3.

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>CR23X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Signal</td>
<td>White</td>
<td>9H</td>
</tr>
<tr>
<td>Sensor Signal Reference</td>
<td>Green</td>
<td>9L</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Heater Resistor Signal</td>
<td>Yellow</td>
<td>10H</td>
</tr>
<tr>
<td>Heater Resistor Signal Reference</td>
<td>Purple</td>
<td>10L</td>
</tr>
<tr>
<td>Shield</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>Red</td>
<td>SW12</td>
</tr>
<tr>
<td>Power Reference</td>
<td>Black</td>
<td>G</td>
</tr>
</tbody>
</table>

```plaintext
;{CR23X}
;
*Table 1 Program
  01: 1  Execution Interval (seconds)

;Measure HFP01SC on smaller range.
   1: Volt (Diff) (P2)
      1: 1  Reps
      2: 21 10 mV, 60 Hz Reject, Slow Range
      3: 9  DIFF Channel
      4: 2  Loc [ shf_mV ]
      5: 1  Mult
      6: 0  Offset

;Measure HFP01SC on larger range.
   2: Volt (Diff) (P2)
      1: 1  Reps
      2: 25 5000 mV, 60 Hz Reject, Fast Range
      3: 9  DIFF Channel
      4: 8  Loc [ shf_mV_a ]
      5: 1  Mult
      6: 0  Offset

;Load in the factory calibration.
   3: If (X<>F) (P89)
      1: 3  X Loc [ cal ]
      2: 1  =
      3: 0  F
      4: 30  Then Do
```
; Factory calibration in \( \text{W}/(\text{m}^2 \text{mV}) = 1000/\text{sensitivity} \).

4: \( Z = F \) (P30)
   1: 1 \( F \) ; <- Enter the unique calibration here
   2: 0 Exponent of 10
   3: 3 \( Z \) Loc [ cal ]

5: End (P95)

; Use data from the larger measurement range.

6: If \( (X \leq F) \) (P89)
   1: 2 \( X \) Loc [ shf_mV ]
   2: 4 <
   3: -99990 \( F \)
   4: 30 Then Do

7: \( Z = X \) (P31)
   1: 8 \( X \) Loc [ shf_mV_a ]
   2: 2 \( Z \) Loc [ shf_mV ]

8: End (P95)

; Apply custom calibration to the raw soil heat flux measurement.

9: \( Z = X \times Y \) (P36)
   1: 2 \( X \) Loc [ shf_mV ]
   2: 3 \( Y \) Loc [ cal ]
   3: 1 \( Z \) Loc [ shf ]

; Output data.

10: If time is (P92)
    1: 0 Minutes (Seconds --) into a
    2: 20 Interval (same units as above)
    3: 10 Set Output Flag High (Flag 0)

11: Real Time (P77)
    1: 0110 Day,Hour/Minute (midnight = 0000)

12: Resolution (P78)
    1: 1 High Resolution

; Do not include that calibration data in the soil heat flux.

13: If Flag/Port (P91)
    1: 118 Do if Flag 18 is High
    2: 19 Set Intermed. Proc. Disable Flag High (Flag 9)

14: Average (P71)
    1: 1 Reps
    2: 1 Loc [ shf ]

15: Do (P86)
    1: 29 Set Intermed. Proc. Disable Flag Low (Flag 9)

16: Sample (P70)
    1: 1 Reps
    2: 3 Loc [ cal ]

; Add other processing here.

; Call calibration routine.

17: Do (P86)
    1: 8 Call Subroutine 8
*Table 2 Program
  02:  0 Execution Interval (seconds)

*Table 3 Subroutines

;Calibration routine.
;
1:  Beginning of Subroutine (P85)
   8: Subroutine 8

;Perform in-situ calibration.
;
2:  If time is (P92)
   1:  1 Minutes (Seconds --) into a
   2:  180 Interval (same units as above)
   3:  30 Then Do

3:  Z=X (P31)
   1:  2 X Loc [ shf_mV ]
   2:  4 Z Loc [ mV_0 ]

;Begin heating for calibration.
;
4:  Do (P86)
   1:  49 Turn On Switched 12V

;Used to filter data during and after calibration.
;
5:  Do (P86)
   1:  118 Set Flag 18 High

6:  End (P95)

;End site calibration three minutes after calibration started.
;
7:  If time is (P92)
   1:  4 Minutes (Seconds --) into a
   2:  180 Interval (same units as above)
   3:  30 Then Do

;Measure voltage across current shunt resistor during calibration.
;This measurement is used to compute power.
;
8:  Volt (Diff) (P2)
   1:  1 Reps
   2:  25 5000 mV, 60 Hz Reject, Fast Range
   3:  10 DIFF Channel
   4:  7 Loc [ V_Rf ]
   5:  .001 Mult
   6:  0 Offset

9:  Z=X (P31)
   1:  2 X Loc [ shf_mV ]
   2:  5 Z Loc [ mV_180 ]

;Turn off the soil heat flux plate heater.
;
10: Do (P86)
    1:  59 Turn Off Switched 12V

11: End (P95)

;Stop filtering data.
;
12: If time is (P92)
    1:  39 Minutes (Seconds --) into a
    2:  180 Interval (same units as above)
    3:  30 Then Do
13: Do (P86)
   1: 218 Set Flag 18 Low

   ;Compute in-situ calibration.

14: Z=X (P31)
   1: 2 X Loc [shf_mV]
   2: 6 Z Loc [mV_end]

15: Z=X*Y (P36)
   1: 7 X Loc [V_Rf]
   2: 7 Y Loc [V_Rf]
   3: 3 Z Loc [cal]

16: Z=X*F (P37)
   1: 3 X Loc [cal]
   2: 128.7 F
   3: 3 Z Loc [cal]

17: Z=X+Y (P33)
   1: 4 X Loc [mV_0]
   2: 6 Y Loc [mV_end]
   3: 9 Z Loc [work]

18: Z=X*F (P37)
   1: 9 X Loc [work]
   2: .5 F
   3: 9 Z Loc [work]

19: Z=X-Y (P35)
   1: 9 X Loc [work]
   2: 5 Y Loc [mV_180]
   3: 9 Z Loc [work]

20: Z=ABS(X) (P43)
   1: 9 X Loc [work]
   2: 9 Z Loc [work]

21: Z=X/Y (P38)
   1: 3 X Loc [cal]
   2: 9 Y Loc [work]
   3: 3 Z Loc [cal]

22: End (P95)
23: End (P95)

End Program

-Input Locations-
1 shf
2 shf_mV
3 cal
4 mV_0
5 mV_180
6 mV_end
7 V_Rf
8 shf_mV_a
9 work
6.3.4 Example 4. Sample CR10X Program Using External Power and Relay

TABLE 6-6 provides the sensor wiring for Example 4, and TABLE 6-7 provides the datalogger wiring for Example 4.

### TABLE 6-6. Sensor Wiring for Example 4

<table>
<thead>
<tr>
<th>Description</th>
<th>Color</th>
<th>CR10X</th>
<th>A21REL-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Signal #1</td>
<td>White</td>
<td></td>
<td>1H</td>
</tr>
<tr>
<td>Sensor Signal #2</td>
<td>White</td>
<td></td>
<td>1L</td>
</tr>
<tr>
<td>Sensor Signal #3</td>
<td>White</td>
<td></td>
<td>2H</td>
</tr>
<tr>
<td>Sensor Signal #4</td>
<td>White</td>
<td></td>
<td>2L</td>
</tr>
<tr>
<td>Sensor Signal #5</td>
<td>White</td>
<td></td>
<td>3H</td>
</tr>
<tr>
<td>Sensor Signal #6</td>
<td>White</td>
<td></td>
<td>3L</td>
</tr>
<tr>
<td>All Signal References</td>
<td>Green</td>
<td></td>
<td>AG</td>
</tr>
<tr>
<td>All Shields</td>
<td>Clear</td>
<td></td>
<td>G</td>
</tr>
<tr>
<td>Heater Resistor Signal #1</td>
<td>Yellow</td>
<td></td>
<td>4H</td>
</tr>
<tr>
<td>Heater Resistor Signal #2</td>
<td>Yellow</td>
<td></td>
<td>4L</td>
</tr>
<tr>
<td>Heater Resistor Signal #3</td>
<td>Yellow</td>
<td></td>
<td>5H</td>
</tr>
<tr>
<td>Heater Resistor Signal #4</td>
<td>Yellow</td>
<td></td>
<td>5L</td>
</tr>
<tr>
<td>Heater Resistor Signal #5</td>
<td>Yellow</td>
<td></td>
<td>6H</td>
</tr>
<tr>
<td>Heater Resistor Signal #6</td>
<td>Yellow</td>
<td></td>
<td>6L</td>
</tr>
<tr>
<td>All Heater Resistor Signal References</td>
<td>Purple</td>
<td></td>
<td>AG</td>
</tr>
<tr>
<td>All Shields</td>
<td>Clear</td>
<td></td>
<td>G</td>
</tr>
<tr>
<td>Sensor Power #1</td>
<td>Red</td>
<td>REL 1 NO</td>
<td></td>
</tr>
<tr>
<td>Sensor Power #2</td>
<td>Red</td>
<td>REL 1 NO</td>
<td></td>
</tr>
<tr>
<td>Sensor Power #3</td>
<td>Red</td>
<td>REL 2 NO</td>
<td></td>
</tr>
<tr>
<td>Sensor Power #4</td>
<td>Red</td>
<td>REL 2 NO</td>
<td></td>
</tr>
<tr>
<td>Sensor Power #5</td>
<td>Red</td>
<td>REL 3 NO</td>
<td></td>
</tr>
<tr>
<td>Sensor Power #6</td>
<td>Red</td>
<td>REL 3 NO</td>
<td></td>
</tr>
<tr>
<td>All Power Reference</td>
<td>Black</td>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 6-7. Datalogger-to-A21REL-12 Wiring for Example 4

<table>
<thead>
<tr>
<th>Description</th>
<th>CR10X</th>
<th>A21REL-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>12V</td>
<td>+ 12V</td>
</tr>
<tr>
<td>Power Reference</td>
<td>G</td>
<td>GROUND</td>
</tr>
<tr>
<td>Control</td>
<td>C8</td>
<td>CTRL 1</td>
</tr>
<tr>
<td>Control</td>
<td>jumper from CTRL 2 to CTRL 1</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>jumper from CTRL 3 to CTRL 2</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>jumper from REL 1 COM to +12V</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>jumper from REL 2 COM to REL 1 COM</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>jumper for REL 3 COM to REL 2 COM</td>
<td></td>
</tr>
</tbody>
</table>
;{CR10X}

*Table 1 Program

 01: 1  Execution Interval (seconds)

;Measure HFP01SC on smallest range.

1:  Volt (SE) (P1)
   1: 6  Reps
   2: 22  7.5 mV 60 Hz Rejection Range
   3: 1  SE Channel
   4: 7  Loc [ shf_mV_1 ]
   5: 1  Mult
   6: 0  Offset

;Measure HFP01SC on larger range.

2:  Volt (SE) (P1)
   1: 6  Reps
   2: 23  25 mV 60 Hz Rejection Range
   3: 1  SE Channel
   4: 44  Loc [ shf_mV_1a ]
   5: 1  Mult
   6: 0  Offset

;Load in the factory calibration.

3:  If (X<>F) (P89)
   1: 13  X Loc [ cal_1 ]
   2: 1  =
   3: 0  F
   4: 30  Then Do

;Factory calibration in W/(m^2 mV) = 1000/sensitivity.

4:  Z=F (P30)
   1: 1  F
   2: 0  Exponent of 10
   3: 13  Z Loc [ cal_1 ]

5:  Z=F (P30)
   1: 1  F
   2: 0  Exponent of 10
   3: 14  Z Loc [ cal_2 ]

6:  Z=F (P30)
   1: 1  F
   2: 0  Exponent of 10
   3: 15  Z Loc [ cal_3 ]

7:  Z=F (P30)
   1: 1  F
   2: 0  Exponent of 10
   3: 16  Z Loc [ cal_4 ]

8:  Z=F (P30)
   1: 1  F
   2: 0  Exponent of 10
   3: 17  Z Loc [ cal_5 ]

9:  Z=F (P30)
   1: 1  F
   2: 0  Exponent of 10
   3: 18  Z Loc [ cal_6 ]

10: End (P95)
11: Beginning of Loop (P87)
   1: 0       Delay
   2: 6       Loop Count

;Use data from the larger measurement range.
;
12: If (X<=F) (P89)
   1: 7      X Loc [ shf_mV_1 ]
   2: 4      <
   3: -99990 F
   4: 30     Then Do

13: Z=X (P31)
   1: 44     X Loc [ shf_mV_1a ]
   2: 7      Z Loc [ shf_mV_1 ]

14: End (P95)

;Apply custom calibration to raw soil heat flux measurement.
;
15: Z=X*Y (P36)
   1: 7      X Loc [ shf_mV_1 ]
   2: 13     Y Loc [ cal_1     ]
   3: 1      Z Loc [ shf_1     ]

16: End (P95)

;Output data.
;
17: If time is (P92)
   1: 0      Minutes (Seconds --) into a
   2: 20     Interval (same units as above)
   3: 10     Set Output Flag High (Flag 0)

18: Real Time (P77)^25251
   1: 0110     Day,Hour/Minute (midnight = 0000)

19: Resolution (P78)
   1: 1       High Resolution

;Do not include that calibration data in the soil heat flux.
;
20: If Flag/Port (P91)
   1: 18     Do if Flag 8 is High
   2: 19     Set Intermed. Proc. Disable Flag High (Flag 9)

21: Average (P71)^21989
   1: 6       Reps
   2: 1       Loc [ shf_1     ]

22: Do (P86)
   1: 29      Set Intermed. Proc. Disable Flag Low (Flag 9)

23: Sample (P70)^21779
   1: 6       Reps
   2: 13      Loc [ cal_1     ]

;Add other processing here.

;Call calibration routine.
;
24: Do (P86)
   1: 8       Call Subroutine 8

*Table 2 Program
  02: 0       Execution Interval (seconds)
*Table 3 Subroutines

; Calibration routine.

1: Beginning of Subroutine (P85)
2: 8 Subroutine 8

; Perform in-situ calibration.

2: If time is (P92)
1: 1 Minutes (Seconds --) into a
2: 180 Interval (same units as above)
3: 30 Then Do

3: Beginning of Loop (P87)
1: 0 Delay
2: 6 Loop Count

4: Z=X (P31)
1: 7 -- X Loc [ shf_mV_1 ]
2: 19 -- Z Loc [ mV_0_1 ]

5: End (P95)

; Begin heating for calibration.

6: Do (P86)
1: 48 Set Port 8 High

; Used to filter data during and after calibration.

7: Do (P86)
1: 18 Set Flag 8 High

8: End (P95)

; End site calibration three minutes after calibration started.

9: If time is (P92)
1: 4 Minutes (Seconds --) into a
2: 180 Interval (same units as above)
3: 30 Then Do

; Measure voltage across current shunt resistor during calibration.
; This measurement is used to compute power.

10: Volt (SE) (P1)
1: 6 Reps
2: 25 2500 mV 60 Hz Rejection Range
3: SE Channel
4: 37 Loc [ V_RF_1 ]
5: .001 Mult
6: 0 Offset

11: Beginning of Loop (P87)
1: 0 Delay
2: 6 Loop Count

12: Z=X (P31)
1: 7 -- X Loc [ shf_mV_1 ]
2: 25 -- Z Loc [ mV_180_1 ]

13: End (P95)

; Turn off the soil heat flux plate heaters.

14: Do (P86)
1: 58 Set Port 8 Low
Model HFP01SC Self-Calibrating Soil Heat Flux Plate

15: End (P95)

;Compute in-situ calibration.
;
16: If time is (P92)
  1: 39 Minutes (Seconds -->) into a
  2: 180 Interval (same units as above)
  3: 30 Then Do

17: Do (P86)
  1: 28 Set Flag 8 Low

18: Beginning of Loop (P87)
  1: 0 Delay
  2: 6 Loop Count

19: Z=X (P31)
  1: 7 -- X Loc [ shf_mV_1 ]
  2: 31 -- Z Loc [ mV_end_1 ]

20: Z=X*Y (P36)
  1: 37 -- X Loc [ V_RF_1 ]
  2: 37 -- Y Loc [ V_RF_1 ]
  3: 13 -- Z Loc [ cal_1 ]

21: Z=X*F (P37)
  1: 13 -- X Loc [ cal_1 ]
  2: 128.7 F
  3: 13 -- Z Loc [ cal_1 ]

22: Z=X+Y (P33)
  1: 43 -- X Loc [ mV_0_1 ]
  2: 31 -- Y Loc [ mV_end_1 ]
  3: 43 Z Loc [ work ]

23: Z=X*F (P37)
  1: 43 -- X Loc [ work ]
  2: .5 F
  3: 43 Z Loc [ work ]

24: Z=X-Y (P35)
  1: 43 -- X Loc [ work ]
  2: 25 -- Y Loc [ mV_180_1 ]
  3: 43 Z Loc [ work ]

25: Z=ABS(X) (P43)
  1: 43 Z Loc [ work ]

26: Z=X/Y (P38)
  1: 13 -- X Loc [ cal_1 ]
  2: 43 Y Loc [ work ]
  3: 13 -- Z Loc [ cal_1 ]

27: End (P95)
28: End (P95)
29: End (P95)

End Program

-Input Locations-
  1 shf_1 1 1 1
  2 shf_2 0 0 0
  3 shf_3 0 0 0
  4 shf_4 0 0 0
6.4 Soil Heat Flux and Storage

The soil heat flux at the surface is calculated by adding the measured flux at a fixed depth, d, to the energy stored in the layer above the heat flux plates. The specific heat of the soil and the change in soil temperature, $\Delta T_s$, over the output interval, t, are required to calculate the stored energy.

The heat capacity of the soil is calculated by adding the specific heat of the dry soil to that of the soil water. The values used for specific heat of dry soil and water are on a mass basis. The heat capacity of the moist is given by Equation 1 and Equation 2:

$$C_s = \rho_b (C_d + \theta_m C_w) = \rho_b C_d + \theta_v \rho_w C_w$$ (1)
\[ \theta_m = \frac{\rho_w \theta_v}{\rho_b} \]  
\[(2)\]

where \( C_S \) is the heat capacity of moist soil, \( \rho_b \) is the bulk density, \( \rho_w \) is the density of water, \( C_d \) is the heat capacity of a dry mineral soil, \( \theta_m \) is the soil water content on a mass basis, \( \theta_v \) is the soil water content on a volume basis, and \( C_w \) is the heat capacity of water.

This calculation requires site specific inputs for bulk density, mass basis soil water content or volume basis soil water content, and the specific heat of the dry soil. Bulk density and mass basis soil water content can be found by sampling (Klute, 1986). The volumetric soil water content is measured by the CS616 water content reflectometer. A value of 840 J kg\(^{-1}\) K\(^{-1}\) for the heat capacity of dry soil is a reasonable value for most mineral soils (Hanks and Ashcroft, 1980).

The storage term is then given by Equation 3 and the soil heat flux at the surface is given by Equation 4.

\[ S = \frac{\Delta T_s C_s d}{t} \]  
\[(3)\]

\[ G_{sfc} = G_{8cm} + S \]  
\[(4)\]

where \( S \) is the storage term, \( G_{8cm} \) is the soil heat flux at 8 cm, and \( G_{sfc} \) is the soil heat flux at the surface.

### 6.5 In-Situ Calibration Theory

For detailed information on the theory of the in-situ calibration, see the Theory section of the Hukseflux manual or visit the application section of the Hukseflux web site at www.hukseflux.com/downloads/thermalScience/applicAndSpec.pdf.

Equation 6 in the Hukseflux manual is used to compute a new calibration every three hours. The heater is on for a total of 180 seconds. TABLE 6-8 lists the variables used in the Hukseflux manual and those in the example datalogger programs.
### TABLE 6.8. Hukseflux and Campbell Scientific Variable Names

<table>
<thead>
<tr>
<th>Description</th>
<th>Hukseflux</th>
<th>Campbell Scientific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Heat Flux</td>
<td>$\varphi$</td>
<td>shf</td>
</tr>
<tr>
<td>Output of Sensor in mV</td>
<td>$V_{sen}$</td>
<td>shf$_{mV}$</td>
</tr>
<tr>
<td>1/Sensitivity</td>
<td>$1/E_{sen2}$</td>
<td>cal</td>
</tr>
<tr>
<td>Output of Sensor during calibration at t=0 seconds</td>
<td>$V$ (0)</td>
<td>mV$_{0}$</td>
</tr>
<tr>
<td>Output of Sensor during calibration at t=180 seconds</td>
<td>$V$ (180)</td>
<td>mV$_{180}$</td>
</tr>
<tr>
<td>Output of Sensor after calibration and just before output</td>
<td>$V$ (360)</td>
<td>mV$_{end}$</td>
</tr>
<tr>
<td>Voltage Across fixed 10 $\Omega$ resistor</td>
<td>$V_{cur}$</td>
<td>$V_{Rf}$</td>
</tr>
</tbody>
</table>

### 7. Maintenance

The HFP01SC requires minimal maintenance. Check the sensor leads monthly for rodent damage.

### 8. References


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