INSTRUCTION MANUAL

Model HFP01SC Self-Calibrating Soil Heat Flux Plate

Revision: 10/16

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Campbell Scientific (Canada) Corp.
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DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC**. FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.ca or by telephoning (780) 454-2505 (Canada). You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified personnel (e.g. engineer). If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General

- Prior to performing site or installation work, obtain required approvals and permits.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 6 meters (20 feet), or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CLIENT ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.

PLEASE READ FIRST

About this manual

Please note that this manual was originally produced by Campbell Scientific Inc. (CSI) primarily for the US market. Some spellings, weights and measures may reflect this origin.

Some useful conversion factors:

Area:	1 in^2 (square inch) = 645 mm^2
Length:	1 in. (inch) = 25.4 mm
	1 ft (foot) = 304.8 mm
	1 yard = 0.914 m
	1 mile = 1.609 km
Mass:	1 oz. (ounce) = 28.35 g
	1 lb (pound weight) = 0.454 kg
Pressure:	1 psi (lb/in2) = 68.95 mb
Volume:	1 US gallon = 3.785 litres

In addition, part ordering numbers may vary. For example, the CABLE5CBL is a CSI part number and known as a FIN5COND at Campbell Scientific Canada (CSC). CSC Technical Support will be pleased to assist with any questions.

About sensor wiring

Please note that certain sensor configurations may require a user supplied jumper wire. It is recommended to review the sensor configuration requirements for your application and supply the jumper wire is necessary.

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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.

NOTE This manual provides information only for CRBasic dataloggers. It is also compatible with most of our retired Edlog dataloggers. For Edlog datalogger support, see an older manual at *www.campbellsci.com/old-manuals*.

2. Cautionary Statements

- READ AND UNDERSTAND the *Safety* section at the front of this manual.
- Care should be taken when opening the shipping package to not damage or cut the cable jacket. If damage to the cable is suspected, contact Campbell Scientific.
- 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:

- Pigtails 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* 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
- Ideal for energy-balance or Bowen-ratio systems
- Uses Van den Bos-Hoeksema self-calibration method to provide high-degree of measurement accuracy
- Compatible with Campbell Scientific CRBasic dataloggers: CR6 series, CR800 series, CR1000, CR3000, CR5000, and CR9000(X)

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
Sensor:	Thermopile and film heater
Heater Voltage Input:	9 to 15 Vdc
Heater Voltage Output:	0 to 2 Vdc
Expected Accuracy:	±3% of reading
Sensitivity (nominal):	50 $\mu V\ W^{-1}\ m^{-2}$

Sensor Resistance (nominal): 2 Ω

Heater Resistance (nominal): 100 Ω

Duration of Calibration: ±3 min. @ 1.5 W; typically done every 3 to 6 hours

Weight without Cable: 200 g (7.05 oz)

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.

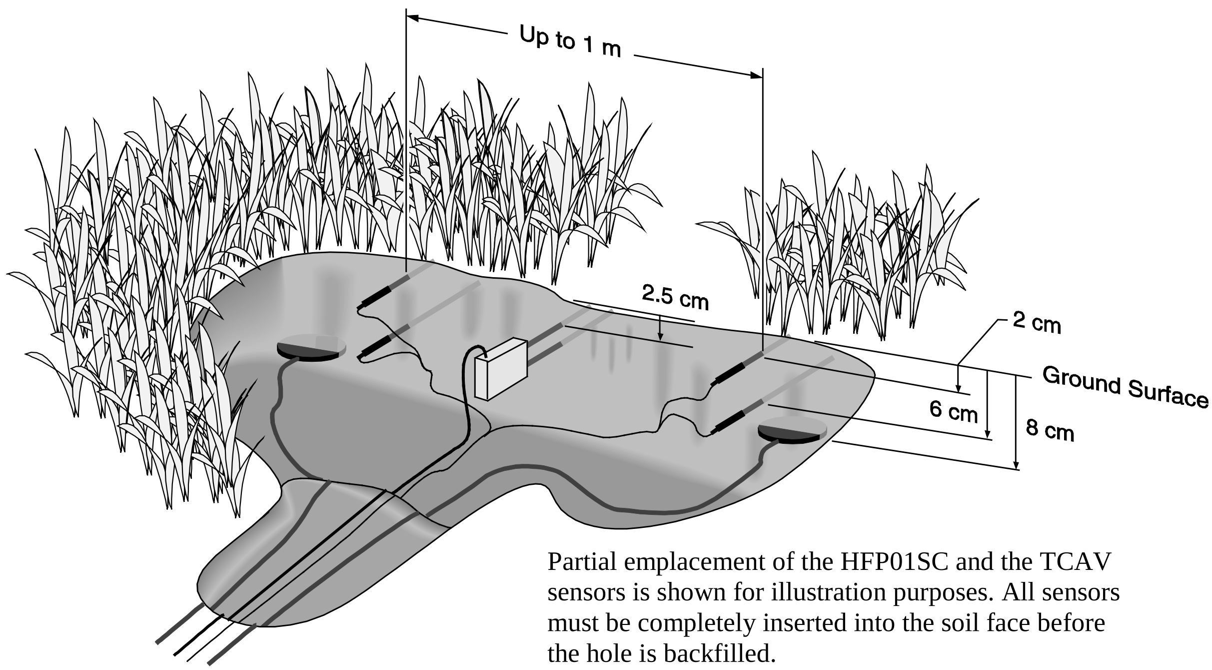

FIGURE 6-1. Placement of heat flux plates

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	To make quality soil heat flux measurements, the HFP01SC 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 minimize thermal conduction on the lead wire. Replace the excavated soil into its original position after all the sensors are installed.

6.2 Wiring

The HFP01SC includes a signal and heater cable (FIGURE 6-2). TABLE 6-1 provides the datalogger connections for both single-ended and differential measurements. Typically, differential measurements are used.

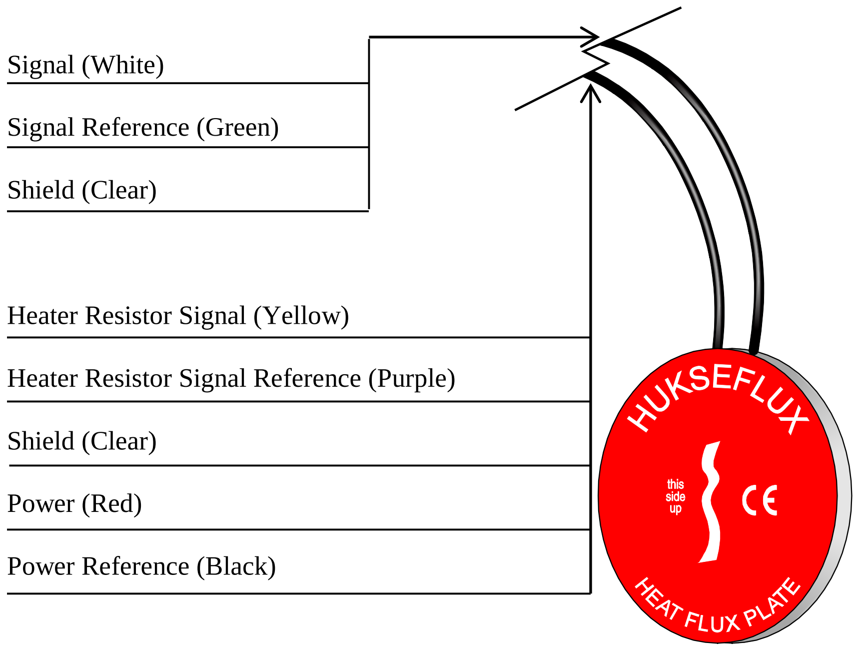

FIGURE 6-2. HFP01SC plate

TABLE 6-1. Wire Color, Function, and Datalogger Connections

Wire Color	Wire Function	Datalogger Single-Ended Measurement	Datalogger Differential Measurement
White	Sensor Signal	**U** configured for single-ended analog input[1], **SE** (single-ended, analog input)	**U** configured for differential analog input high[1], **DIFF H** (differential high, analog input)
Green	Sensor Signal Reference	**AG** or ⏚ (analog ground)	**U** configured for differential analog input low[1], **DIFF L** (differential low, analog input)
Clear	Shield	**AG** or ⏚ (analog ground)	**AG** or ⏚ (analog ground)
Yellow	Heater Resistance Signal	**U** configured for single-ended analog input[1], **SE** (single-ended, analog input)	**U** configured for differential analog input high[1], **DIFF H** (differential high, analog input)
Purple	Heater Resistance Signal Reference	**AG** or ⏚ (analog ground)	**U** configured for differential analog input low[1], **DIFF L** (differential low, analog input)
Clear	Shield	**AG** or ⏚ (analog ground)	**AG** or ⏚ (analog ground)
Red	Power	**SW12** (switched 12 V)	**SW12** (switched 12 V)
Black	Power Reference	**G** (ground)	**G** (ground)

[1]**U** channels are automatically configured by the measurement instruction.

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.

6.3 Programming

Programming basics for CRBasic dataloggers are in this section. A complete program example for a CRBasic datalogger can be found in Appendix A, *Example Program* *(p. A-1)*. Programming basics and programming examples for Edlog dataloggers are provided at *www.campbellsci.com/old-manuals*.

The HFP01SC output is measured using either a single-ended (**VoltSE**) or differential (**VoltDiff**) instruction. The differential measurement is recommended.

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.

6.4 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, ΔT_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:

$$C_s = \rho_b (C_d + \theta_m C_w) = \rho_b C_d + \theta_v \rho_w C_w \qquad (1)$$

$$\theta_m = \frac{\rho_w}{\rho_b} \theta_v \qquad (2)$$

where C_S is the heat capacity of moist soil, ρ_b is the bulk density, ρ_w is the density of water, C_d is the heat capacity of a dry mineral soil, θ_m is the soil water content on a mass basis, θ_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.

$$S = \frac{\Delta T_s C_s d}{t} \qquad (3)$$

$$G_{sfc} = G_{8cm} + S \qquad (4)$$

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 manual published by Hukseflux.

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 6-2 lists the variables used in the Hukseflux manual and those in the example datalogger programs.

TABLE 6-2. Hukseflux and Campbell Scientific Variable Names

Description	Hukseflux	Campbell Scientific
Soil Heat Flux	φ	shf
Output of Sensor in mV	V_{sen}	shf_mV
1/Sensitivity	$1/E_{sen2}$	cal
Output of Sensor during calibration at t=0 seconds	V (0)	mV_0
Output of Sensor during calibration at t=180 seconds	V (180)	mV_180
Output of Sensor after calibration and just before output	V (360)	mV_end
Voltage Across fixed 10 Ω resistor	V_{cur}	V_Rf

7. Maintenance

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

8. References

Hanks, R. J., and G. L. Ashcroft, 1980: *Applied Soil Physics: Soil Water and Temperature Application.* Springer-Verlag, 159 pp.

Klute, A., 1986: *Method of Soil Analysis.* No. 9, Part 1, Sections 13 and 21, American Society of Agronomy, Inc., Soil Science Society of America, Inc.

Appendix A. Example Program

A.1 Sample CR3000 Program Using a Differential Measurement Instruction

TABLE A-1 provides the wiring for CRBasic Example A-1.

TABLE A-1. Wiring for CRBasic Example A-1

Description	**Color**	**CR3000**
Sensor Signal #1	White	9H
Sensor Signal Reference #1	Green	9L
Shield #1	Clear	⏚
Sensor Signal #2	White	10H
Sensor Signal Reference #2	Green	10L
Shield #2	Clear	⏚
Sensor Signal #3	White	11H
Sensor Signal Reference #3	Green	11L
Shield #3	Clear	⏚
Sensor Signal #4	White	12H
Sensor Signal Reference #4	Green	12L
Shield #4	Clear	⏚
Heater Resistor Signal #1	Yellow	13H
Heater Resistor Signal Reference #1	Purple	⏚
Shield #1	Clear	⏚
Power #1	Red	SW12-1
Power Reference #1	Black	G
Heater Resistor Signal #2	Yellow	13L
Heater Resistor Signal Reference #2	Purple	⏚
Shield #2	Clear	⏚
Power #2	Red	SW12-1
Power Reference #2	Black	G
Heater Resistor Signal #3	Yellow	14H
Heater Resistor Signal Reference #3	Purple	⏚
Shield #3	Clear	⏚
Power #3	Red	SW12-1
Power Reference #3	Black	G
Heater Resistor Signal #4	Yellow	14L
Heater Resistor Signal Reference #4	Purple	⏚
Shield #4	Clear	⏚
Power #4	Red	SW12-1

CRBasic Example A-1. CR3000 Program Using a Differential Measurement Instruction

```
'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)

    'Begin 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
```

Campbell Scientific Companies

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

Campbell Scientific Canada Corp.
14532 – 131 Avenue NW
Edmonton AB T5L 4X4
CANADA
www.campbellsci.ca • dataloggers@campbellsci.ca

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

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

Campbell Scientific Southeast Asia Co., Ltd.
877/22 Nirvana@Work, Rama 9 Road
Suan Luang Subdistrict, Suan Luang District
Bangkok 10250
THAILAND
www.campbellsci.asia • info@campbellsci.asia

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

Campbell Scientific Australia Pty. Ltd.
PO Box 8108
Garbutt Post Shop QLD 4814
AUSTRALIA
www.campbellsci.com.au • info@campbellsci.com.au

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

Campbell Scientific (Beijing) Co., Ltd.
8B16, Floor 8 Tower B, Hanwei Plaza
7 Guanghua Road
Chaoyang, Beijing 100004
P.R. CHINA
www.campbellsci.com • info@campbellsci.com.cn

Campbell Scientific Ltd.
Fahrenheitstraße 13
28359 Bremen
GERMANY
www.campbellsci.de • info@campbellsci.de

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

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

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