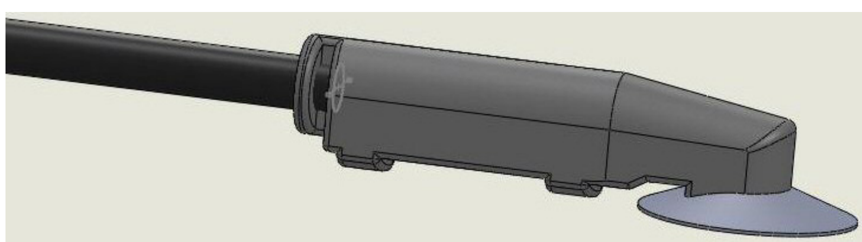
INSTRUCTION MANUAL

110PV Surface Temperature Probe

Revision: 10/11



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110PV Surface Temperature Probe

1. General

The 110PV-L temperature probe uses a thermistor to measure temperature. The probe is designed for measuring the back of photovoltaic (PV) module temperature but also can be used to measure other surface temperatures. The 110PV-L is compatible with all Campbell Scientific dataloggers.

The 110PV-L consists of a thermistor encased in an aluminum disk (see Figure 1-1). The aluminum disk protects the thermistor and promotes heat transfer from surfaces.

The probe measures temperature from –40° to +135°C. For temperatures up to 70°C, an adhesive tab on the probe's aluminum disk fastens the 110PV to the measurement surface. If the temperature may exceed 70°C, Kapton tape or high temperature epoxy is recommend to secure the probe to the measurement surface. Kapton tape (P/N 27015) is available from Campbell Scientific.

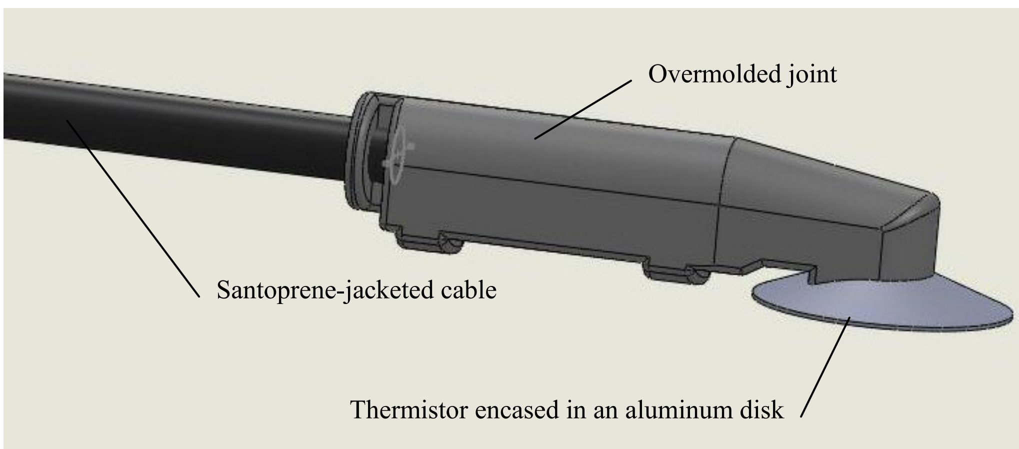

FIGURE 1-1. 110PV Temperature Probe

The –L portion of the probes model number indicates the probe has a user defined cable length which will be specified when the probe is ordered.

The probe'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.
- Connector that attaches to a CWS900 Wireless Sensor Interface (option –CWS). The CWS900 allows the 110PV to be used in a wireless sensor network. Refer to www.campbellsci.com/cws900 for more information.

For readability purposes, the probe will be referred to as the 110PV throughout this document.

The 110PV ships with:

1) Adhesive Backed 3 cm Cable Tie Mount
2) Cable Ties 8” UV Stabilized
3) Resource CD

1.1 Specifications

Temperature Range: -40° to +135°C

Survival Range: -50° to +140°C

110PV Temperature Uncertainty

-40° to 70°C: ±0.2°C
71° to 105°C: ±0.5°C
106° to 135°C: ±1°C

Time Constant (average):

Test	τ
Still Air	252 seconds
Surface	25 seconds

Water Submersion Depth: 50 ft (21 psi)

Linearization Error: Steinhart & Hart equation; maximum error is 0.0024°C at -40°C.

Maximum Cable Length: 1000 ft

Disk Diameter: 1.0 in. (2.54 cm)

Overall Probe Length: 2.5 in. (6.35 cm)

Overmolded Joint Dimensions:

Width: 0.44 in. (1.12 cm)
Height: 0.58 in. (1.47 cm)
Length: 2.25 in. (5.72 cm

Cable Diameter: 0.245 in. (0.622 cm)

Material

Disk:	Anodized Aluminum
Cable Jacket:	Santoprene
Cable/Probe Connection:	Santoprene

Weight: 0.2 lbs (90.7 g) with 10.5 ft (3.2 m) cable

NOTE The black outer jacket of the cable is Santoprene® rubber. This compound was chosen for its resistance to temperature extremes, moisture, and UV degradation. However, this jacket will support combustion in air. It is rated as slow burning when tested according to U.L. 94 H.B. and will pass FMVSS302. Local fire codes may preclude its use inside buildings.

2. Accuracy

The overall probe accuracy is a combination of the thermistor's interchangeability specification and the accuracy of the bridge resistor. The Steinhart-Hart equation used to calculate temperature has a negligible error (Figure 2-1). In a "worst case" the errors add to an accuracy of ±0.2°C over the range of -40° to 70°C; ±0.5°C over the range of 71°C to 105°C; and ±1°C from 106°C to 135°C. The major error component is the interchangeability specification (tolerance) of the thermistor. The bridge resistor has a 0.1% tolerance with a 10 ppm temperature coefficient. Figures 2-2 to 2-7 show the possible worst case probe and measurement errors.

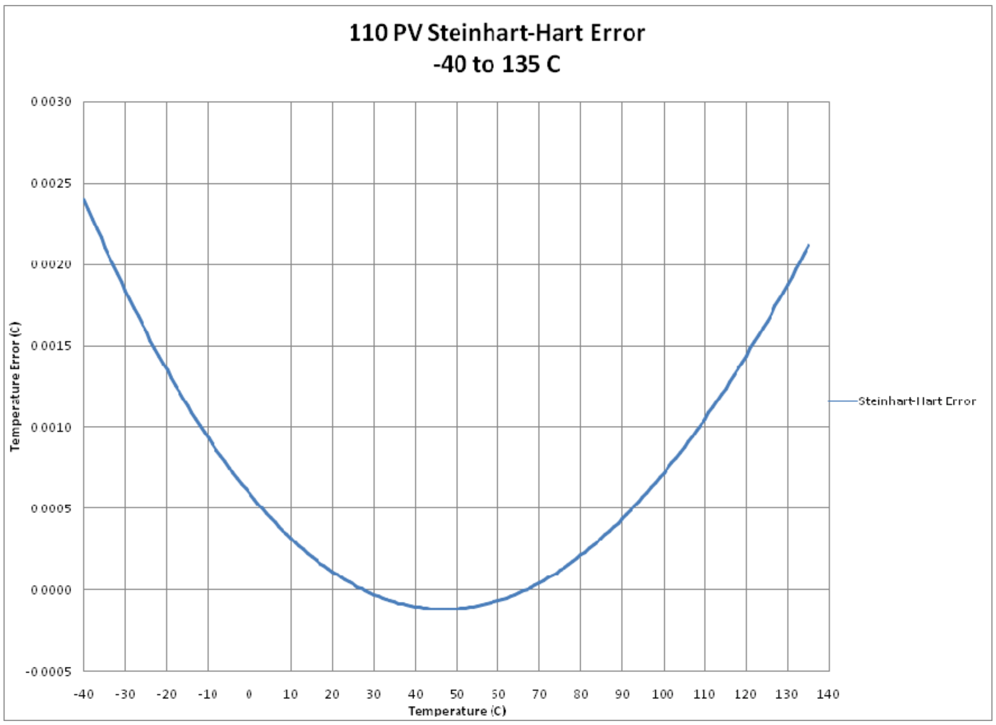

FIGURE 2-1. Steinhart-Hart Error

Uncertainty on the graphs below is symmetric about 0.

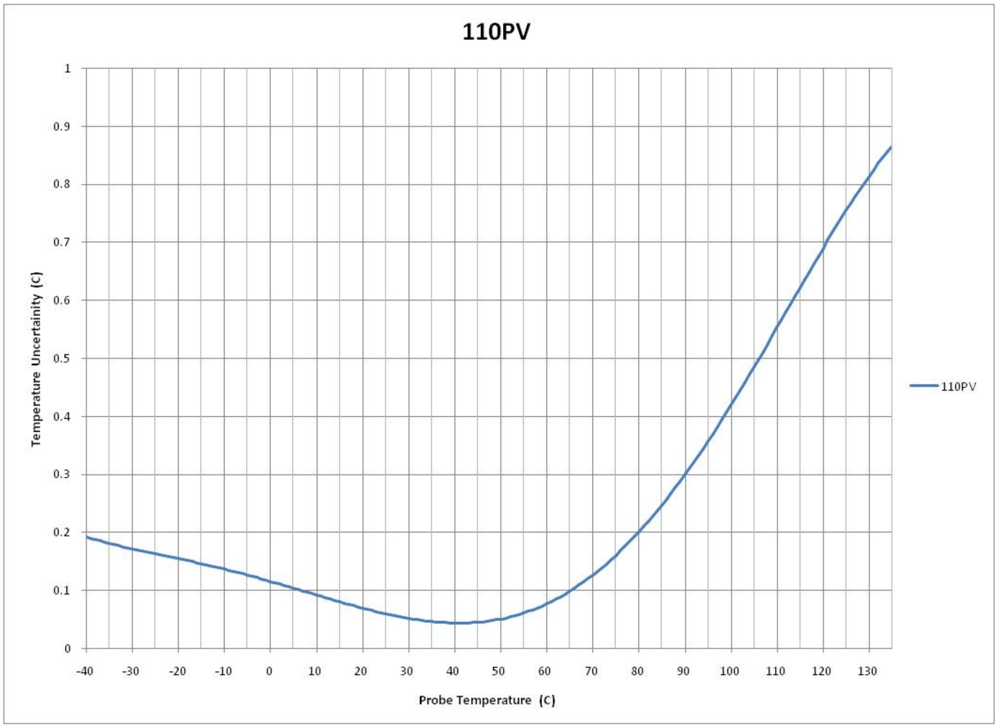

FIGURE 2-2. 110PV measured with a 3-wire half bridge

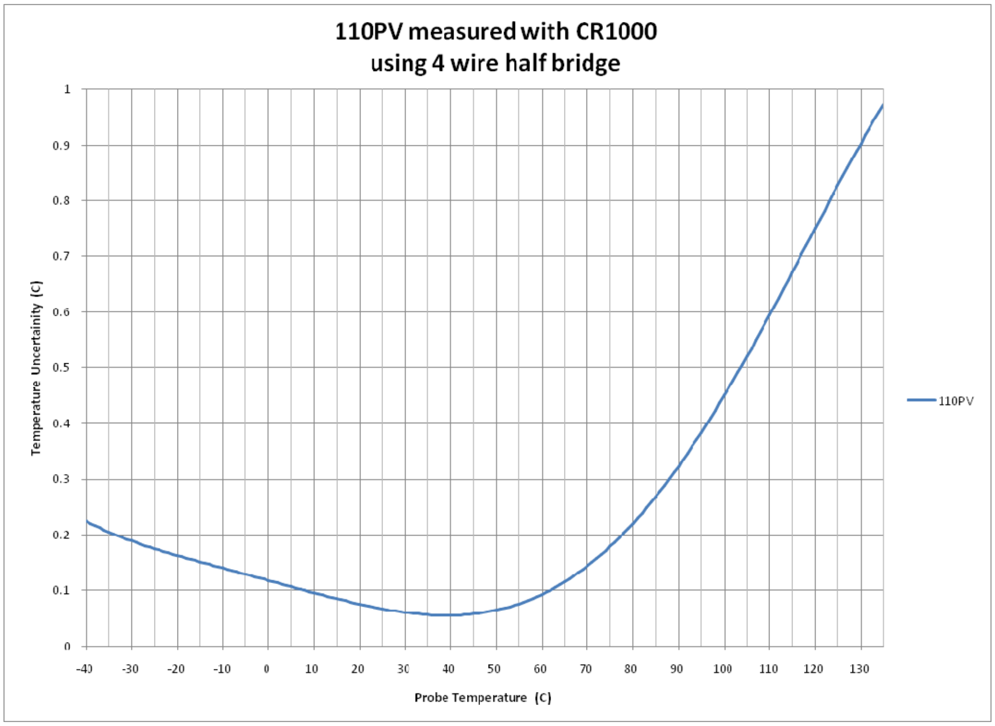

FIGURE 2-3. 110PV measured with a CR1000 using a 4-wire half bridge

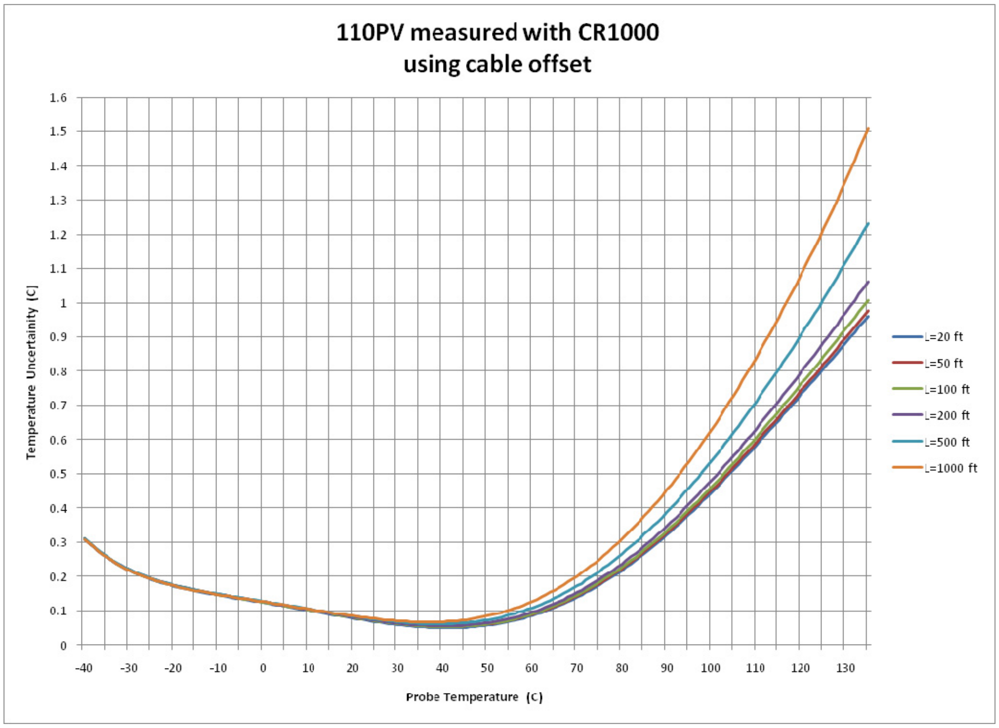

FIGURE 2-4. 110PV measured with a CR1000 showing effects of cable length when using a cable offset

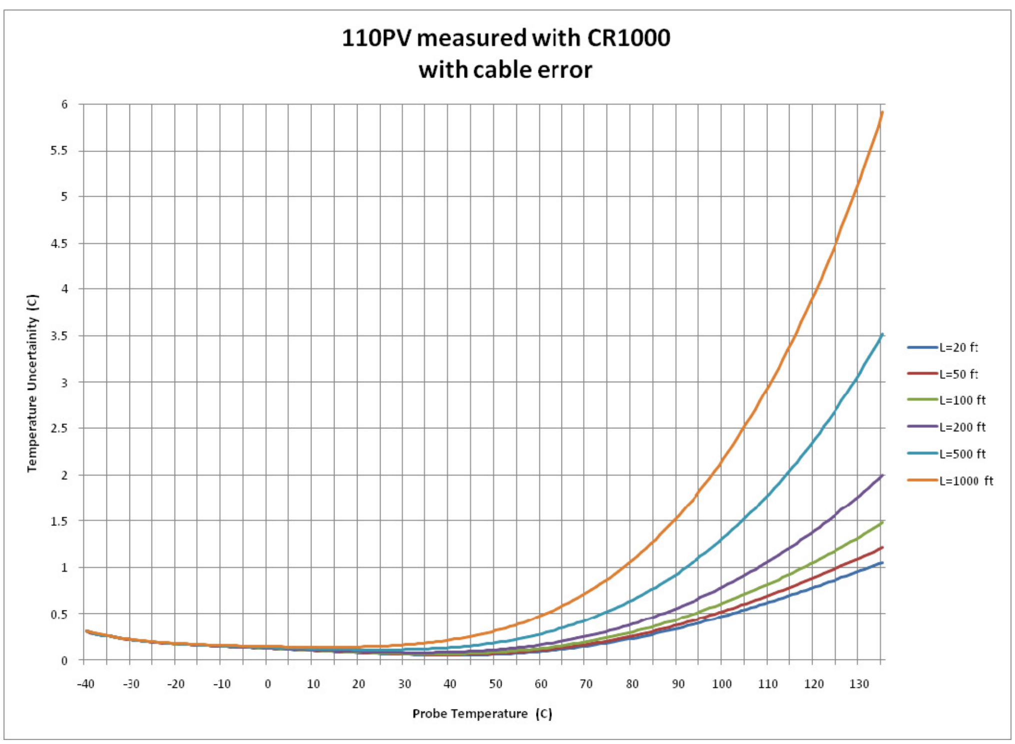

FIGURE 2-5. 110PV measured with a CR1000 showing effects of cable length

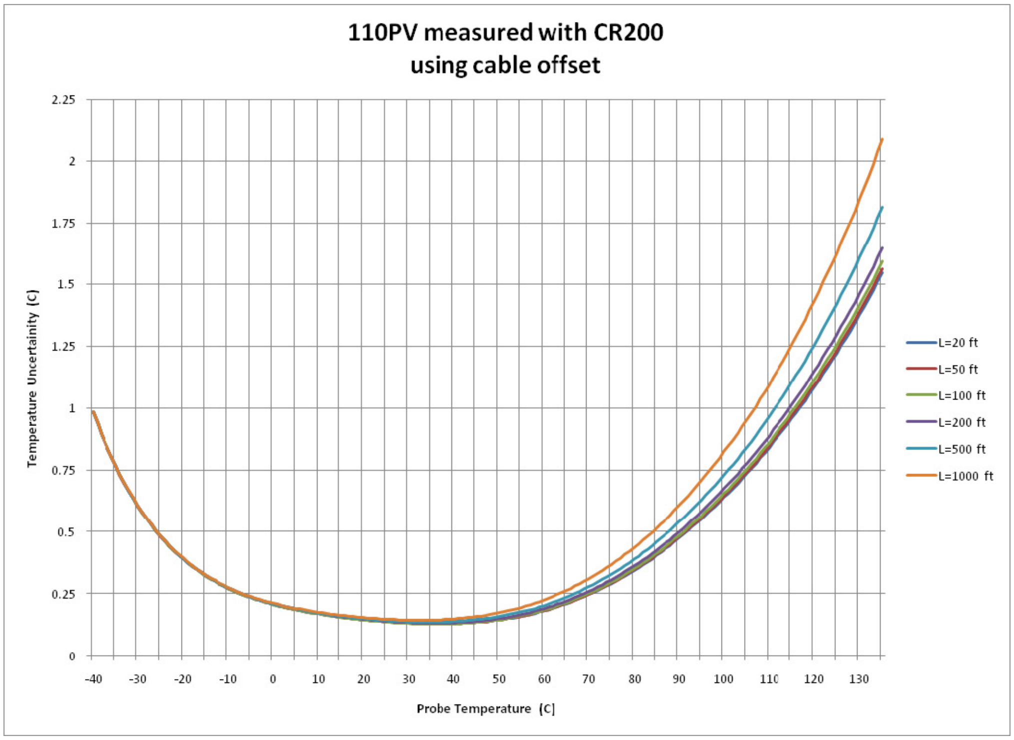

FIGURE 2-6. 110PV measured with a CR200(X) showing effects of cable length when a cable offset is used

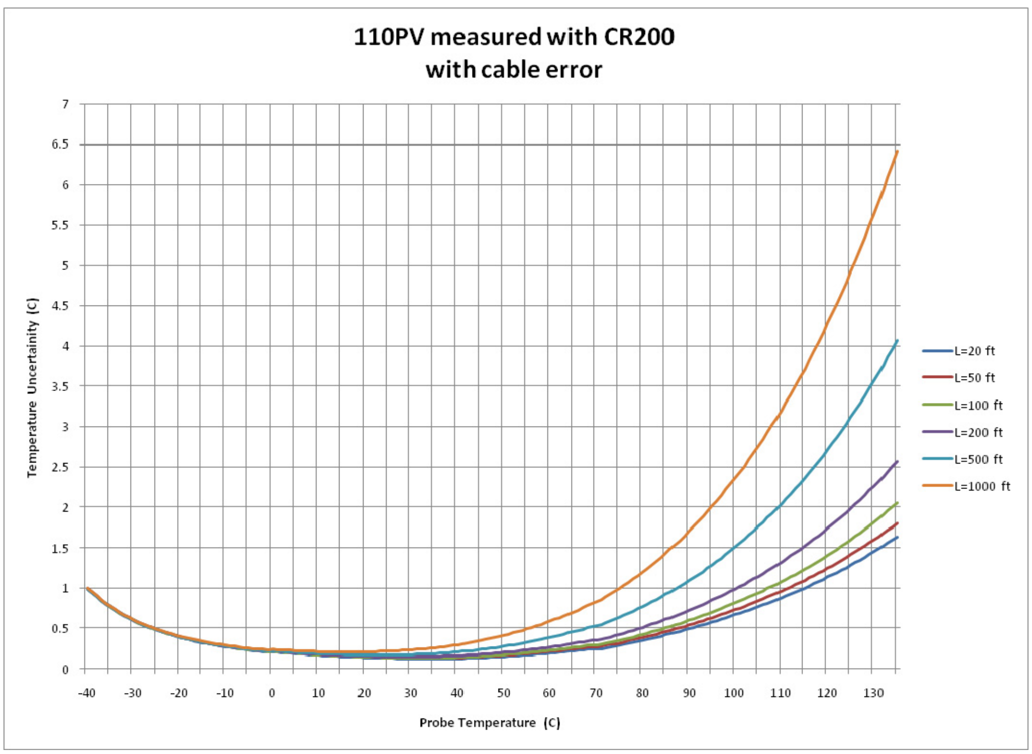

FIGURE 2-7. 110PV measured with a CR200(X) showing effects of cable length

3. Installation and Wiring

3.1 Placement on a Photovoltaic (PV) Module

The 110PV should be centered on the back of the PV module (see Figure 3-1). If the module has several distinctive photocells (see Figure 3-2), the 110PV should also be centered on the back of a photocell.

FIGURE 3-1. 110PV mounted to a PV module

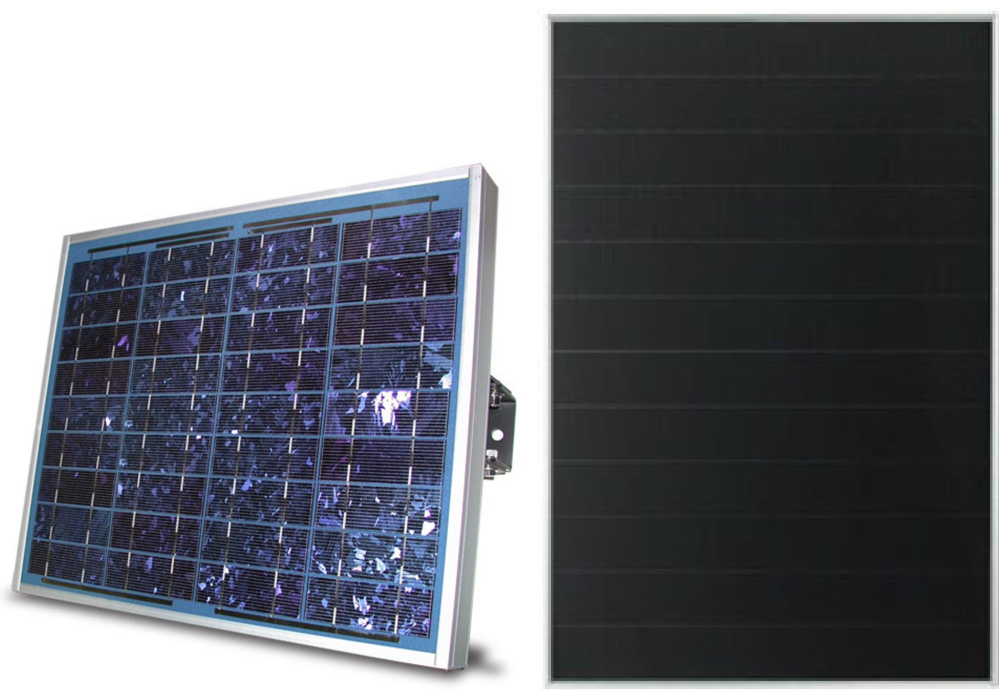

FIGURE 3-2. At left is a PV module with distinctive solar cells.
At right is a PV module that does not have distinctive solar cells.

3.2 Mounting to a PV Module or Other Device

For mounting the probe to the back of a PV module or another device, the 110PV comes with an adhesive mounting disc adhered to its flat surface. To mount the 110PV, remove the paper from the mounting disc and adhere it to the back of the PV module or other device; refer to Section 3.1 for proper placement on a PV module. The mounting disc must be adhered to a clean surface for its adhesive to function properly.

If the temperature is expected to exceed 70°C, use Kapton tape, epoxy, or other means to secure the probe to the measurement surface (see Figure 3-3); a roll of Kapton tape (P/N 27015) is offered by Campbell Scientific as a Common Accessory.

FIGURE 3-3. 110PV mounted to a PV module using Kapton tape

3.3 Cable Strain Relief

The 110PV's cable must be properly strain relieved after mounting the probe to the measurement surface. To accomplish this, the probe comes with cable ties and a cable tie mount. A yellow label on the 110PV's cable indicates where you should tie down the cable (see Figures 3-3 and 3-4).

NOTE Placement of the cable inside a rugged conduit is advisable for long cable runs, especially in locations subject to digging, mowing, traffic, use of power tools, animals, or lightning strikes.

FIGURE 3-4. 110PV's strain relief label

3.4 Submersion

The 110PV can be submerged to 50 ft. It must be adhered to a dry clean surface before submerging. The probe's adhesive mounting disc is not intended for submersion. Therefore the 110PV must be mounted to the measurement surface via a user-supplied method that is compatible with submersion.

4. Wiring

Connections to Campbell Scientific dataloggers are given in Table 4-1. Most CRBasic dataloggers can measure the 110PV using either a 4-wire half bridge or 3-wire half bridge. The CR200(X) and Edlog dataloggers can only use a 3-wire half bridge. The 4-wire half bridge method is preferred because it reduces cable errors (see Figures 2-2 and 2-3). The 4-wire half bridge method requires two differential input channels and one voltage excitation channel. The 3-wire half bridge method uses one single-ended input channel and one voltage excitation channel.

Multiple probes can be connected to the same excitation channel. The number of probes per excitation channel is physically limited by the number of lead wires that can be inserted into a single voltage excitation terminal, approximately six.

TABLE 4-1. Connections to Campbell Scientific Dataloggers					
Color	**Description**	**4-Wire Half Bridge CR800 CR850 CR3000 CR1000 CR5000**	**3-Wire Half Bridge CR200(X) CR800 CR850 CR3000 CR1000 CR5000**	**3-Wire Half Bridge CR510 CR500 CR10(X)**	**3-Wire Half Bridge 21X CR7 CR23X**
Black	Voltage Excitation	Switched Voltage Excitation	Switched Voltage Excitation	Switched Voltage Excitation	Switched Voltage Excitation
Red	Signal	Differential Input (H)	Single-Ended Input	Single-Ended Input	Single-Ended Input
Purple	Signal Reference	Differential Input (L)	⏚	AG	⏚
Blue	Signal Reference	⏚	Not Used	Not Used	Not Used
Clear	Shield	⏚	⏚	G	⏚
Green	Sense +	Differential Input (H)	Not Used	Not Used	Not Used
White	Sense -	Differential Input (L)	Not Used	Not Used	Not Used

5. Programming

NOTE This section is for users who write their own datalogger programs. A datalogger program to measure this sensor can be generated using Campbell Scientific's Short Cut Program Builder software. You do not need to read this section to use Short Cut.

The datalogger is programmed using either CRBasic or Edlog. Dataloggers that use CRBasic include our CR200(X) series, CR800, CR850, CR1000, CR3000, CR5000, and CR9000(X); see Section 5.1. Dataloggers that use Edlog include our CR10, CR10X, CR23X, and CR7; refer to Section 5.2. CRBasic and Edlog are included in our LoggerNet, PC400, and RTDAQ software.

The Steinhart-Hart equation is used to calculate the temperature. The coefficients used for the Steinhart-Hart equation are as follows:

A=1.129241*10^-3
B=2.341077*10^-4
C=8.775468*10^-8

If applicable, please read "Section 5.3—Electrical Noisy Environments" and "Section 5.4—Long Lead Lengths" prior to programming your datalogger. Measurement details are provided in Section 6.

5.1 CRBasic

The CR200(X)-series dataloggers use the ExDelSe instruction to measure the 110PV (see example in Section 5.1.1.1). The ExDelSe instruction has the following syntax:

ExDelSE(Dest, Reps, SEChan, ExChan, ExmV, Delay, Mult, Offset)

The CR800, CR850, CR1000, CR3000, CR5000, and CR9000(X) can use either the BrHalf4W instruction or BrHalf instruction to measure the 110PV (see examples in Sections 5.1.1.2 and 5.1.1.3).

For these dataloggers, the BrHalf4W instruction is typically preferred because it reduces cable errors (see Figures 2-2 and 2-3). The BrHalf instruction requires fewer input channels.

A typical BrHalf4W instruction follows:

BrHalf4W (Dest,1,mV2500,mV2500,1,Vx1,1,2500,True ,True ,0,250,1.0,0)

A typical BrHalf instruction follows:

BrHalf (Dest,1,mV2500,1,Vx1,1,2500,True ,0,250,1.0,0)

A multiplier of 1.0 and offset of 0.0 should be used in the ExDelSe, BrHalf4W, and BrHalf instructions to yield a temperature in degrees Celsius. For Fahrenheit multiply the calculated Celsius temperature by 1.8 then add 32.

5.1.1 CRBasic Examples

TABLE 5-1. Wiring for Example Programs

Color	Description	Datalogger Connection	
		BrHalf	**BrHalf4W**
Black	Voltage Excitation	VX1 or EX1	VX1 or EX1
Red	Signal	SE1	Diff 1H
Purple	Signal Reference	⏚	Diff 1L
Blue	Signal Reference	Not Used	⏚
Clear	Shield	⏚	⏚
Green	Sense +	Not Used	Diff 2H
White	Sense -	Not Used	Diff 2L

5.1.1.1 Sample Program for CR200(X) Series Datalogger

```
'CR200 Series Datalogger
'This example program measures a single 110PV-L probe
'once a second using the ExDelSE instruction and stores
'the average temperature in degrees C every 10 minutes.

'110PV-L Wiring configuration for program example
'Lead Color   CR200(X) Channel   Description
'Black------ VX1 ------------ Voltage Excitation
'Red-------- SE1------------- Signal
'Purple----- AG-------------- Signal Reference
'Blue ------- Not Used ------ N/A
'Green ----- Not Used ------ N/A
'White------ Not Used ------ N/A
'Clear------ AG-------------- Shield

'Declare variables for temperature measurement
Public T110PV_mV
Public T110PV_Res
Public T110PV_Temp_C
Public T110PV_Temp_F

'Declare constants to be used in Steinhart-Hart equation
Const A=1.129241*10^-3
Const B=2.341077*10^-4
Const C=8.775468*10^-8
Const R_cable=0                                    'see sensor cable for cable resistance

'Declare variable units
Units T110PV_mV= millivolts
Units T110PV_Res=Ohms
Units T110PV_Temp_C=Deg C

'Define a data table for 10 minute averages
DataTable (AvgTemp,1,1000)
  DataInterval (0,10,min)
  Average (1,T110PV_Temp_C,False)
EndTable

'Main Program
BeginProg
  Scan (1,Sec)
    ' Measure 110PV-L probe with SE1
    ExDelSE (T110PV_mV,1,1,Ex1,mV2500,500,1.0,0)

    ' Convert mV to ohms
    T110PV_Res = 4990*(2500/T110PV_mV)-4990

    ' Subtract off cable resistance (see 110PV-L cable for R_cable)
    T110PV_Res = T110PV_Res-R_cable

    ' Using the Steinhart-Hart equation to convert resistance to temperature
    T110PV_Temp_C = (1/(A+B*LOG(T110PV_Res)+C*(LOG(T110PV_Res))^3))-273.15
```

```
    'Convert Celsius to Fahrenheit
    T110PV_Temp_F = T110PV_Temp_C * 1.8 + 32

    'Call AvgTemp data table
    CallTable AvgTemp
  NextScan
EndProg
```

5.1.1.2 Sample Half Bridge Program for CR1000 Datalogger

```
'CR1000 Series Datalogger
'This example program measures a single 110PV-L probe utilizing
'the BrHalf instruction once a second and stores the average
'temperature in degrees C every 10 minutes.

'110PV-L Wiring Configuration
'Lead Color   CR1000 Channel   Description
'Black ------ VX1------------- Voltage Excitation
'Red -------- SE1 ------------- Signal
'Purple----- AG-------------- Signal Reference
'Blue ------- Not Used------- N/A
'Green------ Not Used------- N/A
'White ------ Not Used------- N/A
'Clear ------ AG-------------- Shield

'Declare variables for temperature measurement using Half Bridge configuration
Public T110PV_mV
Public T110PV_Res
Public T110PV_Temp_C
Public T110PV_Temp_F

'Declare Constants to be used in Steinhart-Hart equation
Const A=1.129241*10^-3
Const B=2.341077*10^-4
Const C=8.775468*10^-8
Const R_cable=0                                    'see sensor cable for cable resistance

'Declare variable units
Units T110PV_mV= millivolts
Units T110PV_Res=Ohms
Units T110PV_Temp_C=Deg C
Units T110PV_Temp_F=Deg F

'Define a data table for 10 minute averages
DataTable (AvgTemp,1,1000)
  DataInterval (0,10,Min,10)
  Average (1,T110PV_Temp_C,FP2,False)
EndTable
```

```
BeginProg
  Scan (1,Sec,3,0)
    ' Measure 110PV-L probe
    BrHalf (T110PV_mV,1,mV2500,1,Vx1,1,2500,True ,0,_60Hz,1.0,0)
    ' Convert mV to ohms
    T110PV_Res=4990*(1-T110PV_mV)/T110PV_mV
    ' Subtract off cable resistance (see 110PV-L cable for R_cable)
    T110PV_Res= T110PV_Res-R_cable
    ' Using the Steinhart-Hart equation to convert resistance to temperature
    T110PV_Temp_C = (1/(A+B*LOG(T110PV_Res)+C*(LOG(T110PV_Res))^3))-273.15
    'Convert Celsius to Fahrenheit
    T110PV_Temp_F = T110PV_Temp_C * 1.8 + 32
    'Call AvgTemp data table
    CallTable AvgTemp
  NextScan
EndProg
```

5.1.1.3 Sample 4-Wire Half BridgeProgram for CR1000

```
'CR1000 Series Datalogger
'This example program measures a single 110PV-L probe utilizing the
'BRHalf4Winstruction once a second and stores the
'average temperature in degrees C every 10 minutes.

'110PV-L Wiring Configuration
'Lead Color   CR1000 Channel   Description
'Black------ VX1/EX1 ------ Voltage Excitation
'Red-------- DIFF1H ------- Signal
'Purple----- DIFF1L-------- Signal Reference
'Blue ------- AG-------------- Signal Reference
'Green ----- DIFF2H ------- Sense +
'White------ DIFF2L-------- Sense -
'Clear------ AG-------------- Shield

'Declare variables for temperature measurement using Half Bridge configuration
Public T110PV_mV
Public T110PV_Res
Public T110PV_Temp_C
Public T110PV_Temp_F

'Declare constants to be used in Steinhart-Hart equation
Const A=1.129241*10^-3
Const B=2.341077*10^-4
Const C=8.775468*10^-8

'Declare variable units
Units T110PV_mV= millivolts
Units T110PV_Res=Ohms
Units T110PV_Temp_C=Deg C
Units T110PV_Temp_F=Deg F
```

```
'Define a data table for 10 minute averages
DataTable (AvgTemp,1,1000)
  DataInterval (0,10,Min,10)
  Average (1,T110PV_Temp_C,FP2,False)
EndTable

BeginProg
  Scan (1,Sec,3,0)
    ' Measure 110PV-L probe
    BrHalf4W (T110PV_mV,1,mV2500,mV2500,1,Vx1,1,2500,True,True,0,_60Hz,1.0,0)
    ' Convert mV to ohms
    T110PV_Res=4990 *T110PV_mV
    ' Use the Steinhart-Hart equation to convert resistance to temperature
    T110PV_Temp_C = (1/(A+B*LOG(T110PV_Res)+C*(LOG(T110PV_Res))^3))-273.15
    'Convert Celsius to Fahrenheit
    T110PV_Temp_F = T110PV_Temp_C * 1.8 + 32
    CallTable AvgTemp
  NextScan
EndProg
```

5.2 Edlog

In Edlog, Instruction 5 is typically used to measure the 110PV-L. The ratio metric output is then converted to resistance and finally to temperature (see Section 5.2.1).

5.2.1 Example Edlog Program

TABLE 5-2. Wiring for Example Program

Color	Description	CR10X
Black	Voltage Excitation	E1
Red	Signal	SE1
Purple	Signal Reference	AG
Clear	Shield	G
Blue	Not Used	Not Used
Green	Not Used	Not Used
White	Not Used	Not Used

Example Program for CR10X

```
;{CR10X}
;This program measures a single 110PV-L probe utilizing the
;P5 instruction once a second and stores the average
;temperature in degrees C every ten minutes.

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

;Measure 110PV-L Probe
1:  AC Half Bridge (P5)
  1:  1            Reps
  2:  25           2500 mV 60 Hz Rejection Range
  3:  1            SE Channel
  4:  1            Excite all reps w/Exchan 1
  5:  2500         mV Excitation
  6:  1            Loc [ V_Vx     ]
  7:  1.0          Multiplier
  8:  0.0          Offset

;Convert ratio-metric output to resistance (next three instructions)
2:  Z=1/X (P42)
  1:  1            X Loc [ V_Vx     ]
  2:  2            Z Loc [ Vx_V     ]

3:  Z=X+F (P34)
  1:  2            X Loc [ Vx_V     ]
  2:  -1.0         F
  3:  3            Z Loc [ Vx_V1    ]

4:  Z=X*F (P37)
  1:  3            X Loc [ Vx_V1    ]
  2:  4990         F
  3:  4            Z Loc [ Rx       ]

;Correct for cable resistance (see 110PV-L cable label for resistance value F in Ohms)
5:  Z=X+F (P34)
  1:  4            X Loc [ Rx       ]
  2:  0.0          F
  3:  5            Z Loc [ Rtherm   ]

;Convert resistance to Temperature
6:  Steinhart-Hart Equation (P200)
  1:  1            Reps
  2:  5            Source Loc (R)(Ohms) [ Rtherm   ]
  3:  6            Destination Loc (Deg C) [ Temp_C   ]
  4:  1.12924      A
  5:  -3           x 10^n
  6:  2.34108      B
  7:  -4           x 10^n
  8:  8.77547      C
  9:  -8           x 10^n
```

```
;Every ten minutes set output flag high to write data final storage
7:  If time is (P92)
   1:   0000         Minutes (Seconds --) into a
   2:   10           Interval (same units as above)
   3:   10           Set Output Flag High (Flag 0)

;Time stamp data record
8:  Real Time (P77)^20972
   1:   110          Day,Hour/Minute (midnight = 0000)

;Write 110PV-L 10 minute average to final storage
9:  Average (P71)^4293
   1:   1            Reps
   2:   6            Loc [ Temp_C    ]

*Table 2 Program
   02:  0.0000       Execution Interval (seconds)

*Table 3 Subroutines

End Program
```

5.3 Electrical Noisy Environments

AC power lines, pumps, and motors, can be the source of electrical noise. If the 110PV probe or datalogger is located in an electrically noisy environment, the 110PV probe should be measured with the 60 or 50 Hz rejection option as shown in the examples in Section 5.1.1.2 and Section 5.2.1.

5.4 Long Lead Lengths

It is recommended that the cable resistance of the 110PV-L be corrected for noting it can contribute significant error (see Figure 2-6). The cable resistance of each 110PV-L probe in ohms is printed on a heat shrink label found on the sensor cable. When measuring the 110PV-L in three wire configurations the cable resistance can be subtracted from the measured resistance value as shown in the CR10X, CR200(X) and CR1000 Half Bridge program examples above.

Alternatively the 110PV-L is equipped with cable sense leads which can be used to correct for cable resistance as seen in the CR1000 4-Wire Half Bridge program example.

Additional settling time may be required for lead lengths longer than 300 feet, where settling time is the delay before the measurement is made.

For the CR200(X)-series, CR800, CR850, CR1000, and CR3000, the 60 and 50 Hz integration options include a 3 ms settling time; longer settling times can be entered into the Settling Time parameter.

6. Measurement

Understanding the details in this section is not necessary for general operation of the 110PV Probe with CSI's dataloggers.

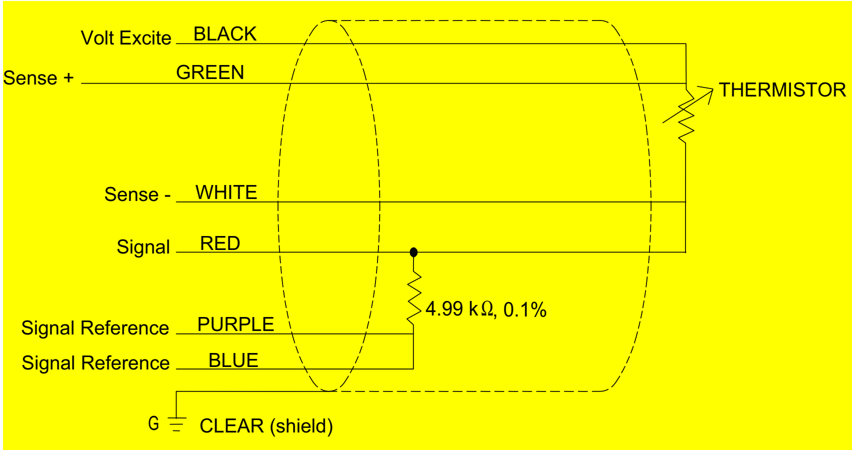

FIGURE 6-1. 110PV Thermistor Probe schematic

Simple half bridge measurement, ignoring cable resistance

The measured voltage, V, is:

$$V = V_{EX} \frac{4{,}990}{4{,}990 + R_t}$$

Where V_{EX} is the excitation voltage, 4,990 ohms is the resistance of the fixed resistor and R_t is the resistance of the thermistor

The resistance of the thermistor is:

$$R_t = 4{,}990\left(\frac{V_{EX}}{V} - 1\right)$$

The Steinhart-Hart equation is used to calculate temperature from Resistance:

$$T_K = \frac{1}{A + B\ln(R_T) + C(\ln(R_T))^3}$$

Where T_K is the temperature in Kelvin. The Steinhart- Hart coefficients used are:

$A = 1.129241x10^{-3}$
$B = 2.341077x10^{-4}$
$C = 8.775468x10^{-8}$

7. Maintenance, Removal, and Calibration

7.1 Maintenance

The 110PV probe requires minimal maintenance. Periodically check cabling for proper connections, signs of damage, and possible moisture intrusion.

7.2 Removal from Measurement Surface

Remove the 110PV from the measurement surface by heating the probe to 70° to 80°C, and then pulling it off.

CAUTION Prying the 110PV off without heating it will likely damage both the probe and PV module.

7.3 Recalibrations/Repairs

For all factory repairs and recalibrations, customers must get returned materials authorization number (RMA). Customers must also properly fill out a "Declaration of Hazardous Material and Decontamination" form, and comply with the requirements specified within. Refer to the "Assistance" page at the front of this manual for more information.

8. Troubleshooting

Symptom: Temperature is NAN, -INF, -9999, -273

Verify the red wire is connected to the correct single-ended analog input channel as specified by the measurement instruction, the black wire is connected to the switched excitation channel as specified by the measurement instruction, and the purple wire is connected to datalogger ground.

Symptom: Incorrect Temperature

Verify the multiplier and offset parameters are correct for the desired units (Section 5). Check the cable for signs of damage and possible moisture intrusion.

CAUTION If the 110PV needs to be sent to Campbell Scientific for repairs, remember that the probe must be heated to 70° to 80°C before removing it from the measurement surface. Prying the probe off without heating it will likely damage both the probe and the PV module.

NOTE For all factory repairs, customers must get an RMA. Customers must also properly fill out a "Declaration of Hazardous Material and Decontamination" form and comply with the requirements specified in it. Refer to the "Assistance" page at the front of this manual for more information.

Symptom: Unstable Temperature

Try using the 60 or 50 Hz integration options, and/or increasing the settling time as described in Sections 8 and 9. Make sure the clear shield wire is connected to datalogger ground, and the datalogger is properly grounded.

Appendix A. Probe Material Properties

The probe consists of 6061 aluminum (clear anodized), thermistor, 3M9485PC adhesive, and Santoprene jacketed cable.

A.1 3M 9485PC Adhesive

Humidity Resistance: High humidity has a minimal effect on adhesive performance. Bond strengths are generally higher after exposure for 7 days at 90°F (32°C) and 90% relative humidity.

U.V. Resistance: When properly applied, nameplates and decorative trim parts are not adversely affected by outdoor exposure.

Water Resistance: Immersion in water has no appreciable effect on the bond strength. After 100 hours in room temperature water the bond actually shows an increase in strength.

Temperature Cycling Resistance: Bond strength generally increases after cycling four times through:

- 4 hours at 158°F (70°C)
- 4 hours at -20°F (-29°C)
- 16 hours at room temperature

Chemical Resistance: When properly applied, adhesive will hold securely after exposure to numerous chemicals including gasoline, oil, Freon™ TF, sodium chloride solution, mild acids and alkalis.

Heat Resistance: Adhesive 350 is usable for short periods (minutes, hours) at temperatures up to 350°F (177°C) and for intermittent longer periods (days, weeks) up to 250°F (121°C).

Low Temperature Service: -40°F (-40°C). Parts should be tested for low temperature shock service.

A.2 Santoprene

The following information is from Advanced Elastomer Systems; Santoprene Rubber Fluid Resistance Guide; pp 2, 3, 9; copyright 2000.

Fluid Resistance of Santoprene Rubber General Purpose Grades

INTRODUCTION

This bulletin summarizes the physical properties of general purpose Santoprene® thermoplastic rubber after exposure to a variety of fluids and solvents. Immersion times were approximately one week (166 hours, per ASTM method D-471) at temperatures ranging from 5°C to 150°C (41°F to 302°F), depending upon the fluid. The data for a given hardness level are applicable to the 100 series (black) as well as the 200 series (colorable) general purpose grades of Santoprene rubber and are representative of performances expected for many of the grades.

Results of these tests demonstrate that Santoprene rubber is inherently resistant to a wide variety of oils, solvents and chemicals. Santoprene rubber is not readily soluble in any common solvent, but will swell in aromatic solvents, halogenated organic solvents and hot petroleum oils.

Highly polar fluids, such as alcohols, ketones, glycols, esters and aqueous solutions of acids, salts and bases have little effect upon Santoprene rubber. Weight changes in these fluids are typically less than 10%, and physical property changes are minimal.

Test Methods

Injection molded test plaques (82.4 mm x 117 mm x 2.97 mm) were prepared. Test specimens were die cut from these plaques to measure the effect of fluid immersion upon tensile properties, hardness and weight change, using ASTM procedures.

Property	ASTM Test Procedure
Ultimate Elongation	D 412, die C*
Tensile Strength	D 412, die C*
Stress at 100% Elongation	D 412, die C*
Hardness	D 2240, 5 sec. delay
Weight Change	D 471

*Note: 50D is D638

Discussion

Santoprene thermoplastic rubber is designed to offer fluid and oil resistance equivalent to that of conventional thermoset rubbers such as neoprene.

The resistance of the Santoprene rubber grades to oil and heat can be classified by using the SAE J200/ASTM D2000 Standard Classification System for rubber.

Santoprene Rubber Grade	Type and Class
111-35	AA, BA, BC, CA
111-45, 211-45	AA, BA, BC, CA
101-55, 201-55	AA, BA, BC, CA
101-64, 201-64	AA, BA, BC, BE, CA
101-73, 201-73	AA, BA, BC, BE, CA, CE
101-80, 201-80	AA, BA, BC, BE, BF, CA, CE
101-87, 201-87	AA, BA, BC, CA
103-40, 203-40	AA, BA, BC, BG

In this classification system, the first of the two letters designates the heat resistance of the rubber. The second letter designates the oil resistance (volume swell in IRM 903 oil). As the letters progress through the alphabet, the heat and oil resistance become progressively higher.

Rubber compounds with a hardness of 50 Shore D are not included in the ASTM D2000 classification. Therefore, Santoprene rubber grades 103-50 and 203-50 are not included.

Table I provides a qualitative rating of the effect of immersion in each fluid on Santoprene rubber grades with hardnesses 55A, 64A, 73A, 80A, 87A, 40D and 50D. In this rating, percent weight change is the variable shown according to the scale:

Rating	Percent Weight Change
A	< 20
B	20-39
C	40-59
D	60-79
E	80-100
F	> 100

Tables II-VIII provide detailed information on the effect of immersion upon tensile properties, hardness and weight change of general purpose Santoprene rubber grades with hardness of 35 Shore A to 50 Shore D, following ASTM test procedure D-471.

Fluid Resistance of Santoprene Rubber General Purpose Grades

TABLE I:

Fluid Resistance of Santoprene Thermoplastic Rubber, Qualitative Ratings[1,2]

	Fluids	Immersion Temperature °C	Santoprene Rubber Shore Hardness 55A	64A	73A	80A	87A	40D	50D
Acids and Alkalis	98% Sulfuric Acid	23	A	A	A	A	A	A	A
	10% Hydrochloric Acid	23	A	A	A	A	A	A	A
	50% Sodium Hydroxide	23	A	A	A	A	A	A	A
	10% Potassium Hydroxide	23	A	A	A	A	A	A	A
Aqueous Solutions	Water	100	A	A	A	A	A	A	A
	10% Zinc Chloride	23	A	A	A	A	A	A	A
	Sea Water	23	A	A	A	A	A	A	A
	15% Sodium Chloride	23	A	A	A	A	A	A	A
	18% Calcium Chloride/ 14% Calcium Bromide	150	A	A	A	A	A	A	A
	2.5% Detergent (Tide)	23	A	A	A	A	A	A	A
Organic Solvents	Acetic Acid	23	A	A	A	A	A	A	A
	Acrylonitrile	23	A	A	A	A	A	A	A
	Aniline	23	A	A	A	A	A	A	A
	Bromobenzene	23	F	E	D	C	B	B	B
	n-Butyl Acetate	23	A	A	A	A	A	A	A
	Cyclohexane	23	E	C	D	B	B	A	A
	Diethyl Ether	23	A	A	A	A	A	A	A
	Dimethylformamide	23	A	A	A	A	A	A	A
	Dioctyl Phthalate	23	A	A	A	A	A	A	A
	1,4-Dioxane	23	B	A	A	A	A	A	A
	95% Ethanol	23	A	A	A	A	A	A	A
	Glycerol	23	A	A	A	A	A	A	A
	n-Hexane	23	B	A	A	A	A	A	A
	Methylethylketone	23	B	B	A	A	A	A	A
	Nitrobenzene	23	A	A	A	A	A	A	A
	Piperidine	23	C	B	A	A	A	A	A
	1-Propanol	23	A	A	A	A	A	A	A
	Pyridine	23	A	A	A	A	A	A	A
	Trichloroethylene	23	F	F	F	F	E	D	C
	Turpentine	23	E	D	C	C	B	B	A
	Xylene	23	D	C	C	B	B	B	A
Petroleum Oils and Fuels	ASTM #1 Oil	100	B	B	B	A	A	A	A
		125	B	B	B	B	B	A	A
	IRM 902 Oil	100	D	C	C	B	B	A	A
		125	D	D	C	C	B	B	B
	IRM 903 Oil	100	E	E	D	C	B	B	B
		125	F	E	D	D	C	C	C
	Reference Fuel A (Isooctane)	23	B	B	B	B	A	A	A
	Reference Fuel B (Isooctane/Toluene, 70/30)	23	D	C	C	C	B	B	A
	Reference Fuel C (Isooctane/Toluene, 50/50)	23	D	C	C	C	B	B	A
Automotive Fluids	Automatic Transmission Fluid	125	D	C	C	C	C	B	B
	Hydraulic Brake Fluid	23	A	A	A	A	A	A	A
		100	B	A	A	A	A	A	A
	Lithium Grease	23	A	A	A	A	A	A	A
		100	C	C	B	B	A	A	A
	Power Steering Fluid	125	E	D	D	C	C	B	B
	Antifreeze, 50/50 Ethylene Glycol (Prestone®)/water	125	A	A	A	A	A	A	A
Industrial Fluids	Pydraul® 312 (Monsanto, phosphate ester)	125	A	A	B	A	A	A	A
	Skydrol® 500 B4 (Solutia, phosphate ester)	125	B	A	A	A	A	A	A
	Sunvis® 706 Fluid (Sun Oil, petroleum base)	125	C	C	C	C	B	B	B
	Ucon® CC732 (Union Carbide, polyalkylene glycol)	125	A	A	A	A	A	A	A
	Ucon® 50HB5100 (Union Carbide, polyalkylene glycol)	125	A	B	B	B	A	A	A
	Freon® 11 (DuPont, halocarbon)	5	F	C	C	C	B	B	B

[1] See note A, Disclaimer of Warranty and Liability, on inside front cover.
[2] All solution concentrations by weight. These alphabetical ratings are based on a specific range in the percentage of weight change as described on page 2.

Advanced Elastomer Systems 3

Fluid Resistance of Santoprene Rubber General Purpose Grades

TABLE VII: 80 Shore A

Effect of 166 Hour Immersion (ASTM D-471) on Properties of 80 Shore A General Purpose Santoprene Thermoplastic Rubber[1,2]

	Fluids	Temp., °C	Ultimate Elongation, % Change	Tensile Strength, % Change	Stress at 100% Elongation, % Change	Hardness Change, Shore A Units	Weight, % Change
Acids and Alkalis	98% Sulfuric Acid	23	-25	-19	8	0	3.0
	10% Hydrochloric Acid	23	7	11	1	1	0.6
	50% Sodium Hydroxide	23	-4	1	6	0	-0.1
	10% Potassium Hydroxide	23	0	-2	7	0	0.9
Aqueous Solutions	Water	100	-26	-13	2	-2	3.1
	10% Zinc Chloride	23	0	2	2	1	0.4
	Sea Water	23	-7	-8	2	0	0.5
	15% Sodium Chloride	23	-10	-14	2	0	0.4
	18% Calcium Chloride/ 14% Calcium Bromide	150	-27	-19	8	-4	0.7
	2.5% Detergent (Tide)	23	-1	-3	7	1	-0.1
Organic Solvents	Acetic Acid	23	-2	-3	3	-2	4.6
	Acrylonitrile	23	1	2	9	0	0.7
	Aniline	23	-2	-5	0	-1	1.3
	Bromobenzene	23	-19	-19	-10	-10	50.0
	n-Butyl Acetate	23	2	6	-3	0	-6.6
	Cyclohexane	23	-19	-21	-18	-14	54.8
	Diethyl Ether	23	-5	-6	-11	-5	0.3
	Dimethylformamide	23	2	4	-1	1	1.0
	Dioctyl Phthalate	23	0	-3	3	0	-1.0
	1,4-Dioxane	23	0	-4	-2	-1	1.6
	95% Ethanol	23	6	0	-2	0	-1.9
	Glycerol	23	-4	-6	4	0	0.4
	n-Hexane	23	-10	-11	-14	-12	11.3
	Methylethylketone	23	7	10	-3	2	-11.1
	Nitrobenzene	23	2	1	2	1	-4.6
	Piperidine	23	-6	-7	-7	-14	16.8
	1-Propanol	23	10	12	-6	1	-7.2
	Pyridine	23	2	8	3	2	-7.1
	Trichloroethylene	23	-29	-24	-13	-16	120.0
	Turpentine	23	-26	-27	-17	-15	48.9
	Xylene	23	-24	-24	-15	-14	37.8
Petroleum Oils and Fuels	ASTM #1 Oil	100	-17	-4	-2	-7	17.1
		125	-38	-23	-7	-10	25.2
	IRM 902 Oil	100	-27	-18	-3	-12	36.7
		125	-44	-26	-4	-16	45.9
	IRM 903 Oil	100	-40	-28	-10	-17	55.4
		125	-54	-38	-16	-24	71.3
	Reference Fuel A (Isooctane)	23	-10	-7	-4	-7	20.2
	Reference Fuel B (Isooctane/Toluene, 70/30)	23	-14	-16	-10	-9	40.7
	Reference Fuel C (Isooctane/Toluene, 50/50)	23	-17	-16	-10	-11	42.5
Automotive Fluids	Automatic Transmission Fluid	125	-43	-27	-18	-10	46.7
	Hydraulic Brake Fluid	23	7	16	-3	1	-1.7
		100	10	22	-1	3	-14.5
	Lithium Grease	23	-10	-5	-3	-1	5.5
		100	-24	-7	-4	-9	23.2
	Power Steering Fluid	125	-40	-30	-19	-21	56.0
	Antifreeze, 50/50 Ethylene Glycol (Prestone®)/water	125	-17	-21	-3	-2	4.2
Industrial Fluids	Pydraul® 312	125	-21	-11	-7	-8	18.3
	Skydrol® 500 B4	125	-12	-4	-6	0	-7.1
	Sunvis® 706 Fluid	125	-43	-24	-16	-17	44.2
	Ucon® CC732	125	-31	-4	-1	-3	4.6
	Ucon® 50HB5100	125	0	21	12	6	-21.8
	Freon® 11	5	-13	-12	-12	-12	41.8

[1] See note A, Disclaimer of Warranty and Liability, on inside front cover.
[2] All solution concentrations by weight.

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