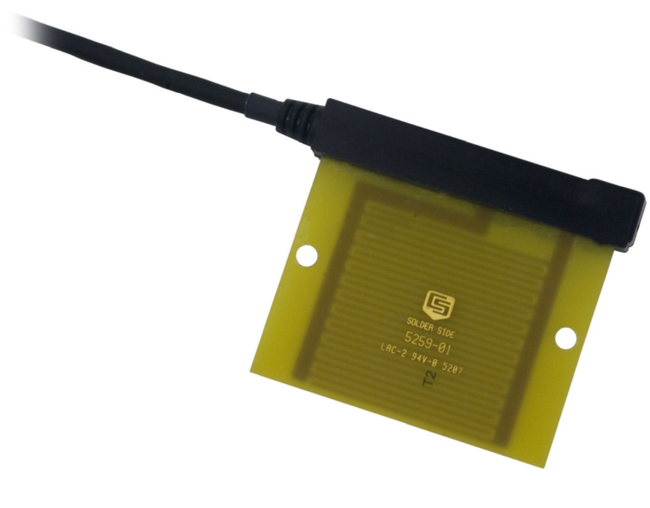
INSTRUCTION MANUAL

Model 237 Leaf Wetness Sensor

Revision: 1/10



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Model 237 Leaf Wetness Sensor

1. Introduction

The 237 Leaf Wetness Sensor is a simple resistive grid configured in a 3-wire half-bridge. The circuit is completed when water bridges two inter-digitate electrodes. Response is non-linear with a rapid decrease in resistance relative to an increase in wetness. The simplicity of the sensor lends it to various applications, means of preparation, and data interpretations.

1.1 Specifications

Temperature Range:	Operational 0° to 100°C; Survival -40° to 150°C Sensor may crack if temperature drops below -40°C
Dimensions:	2.75" W x 3.0" L x 0.25" D (7.1 x 7.6 x 0.64 cm)
Weight:	3 oz per 10' cable (91 g per 3.1 m cable)

2. Wiring

Figure 1 is a circuit schematic of the 237. Table 1 describes wiring to Campbell Scientific dataloggers.

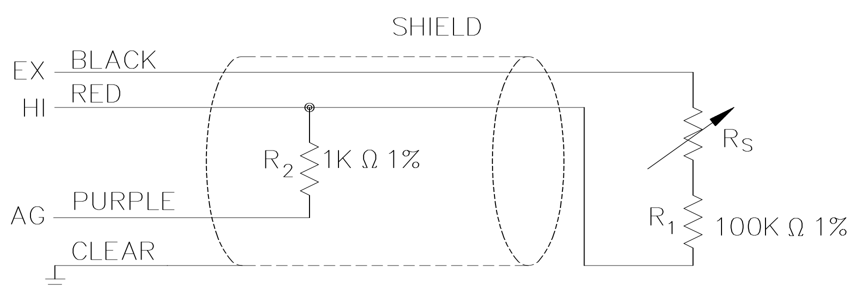

FIGURE 1. 237 Sensor Schematic

TABLE 1. Connections to Campbell Scientific Dataloggers				
Color	**Description**	**CR200(X) CR800 CR5000 CR3000 CR1000**	**CR510 CR500 CR10X**	**21X CR7 CR23X**
Black	Excitation	Switched Excitation	Switched Excitation	Switched Excitation
Red	Resistance Signal	Single-Ended Input	Single-Ended Input	Single-Ended Input
Purple	Signal Ground	⏚	AG	⏚
Clear	Shield	⏚	G	⏚

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.

3. Programming

Refer to programming examples in Section 4 for suggested implementation of measurement and processing concepts.

3.1 Measurement of Vs / Vx

The base measurement of the 237 sensor is Vs/Vx where Vs is the voltage measured and Vx is the excitation voltage supplied by the datalogger. Vs/Vx is measured by the datalogger with the instructions and parameters listed in Table 2.

TABLE 2. Measurement Instructions, Parameters, Results

Datalogger	Measurement Instruction	Excitation (mV)	Input Range	Integration/ Delay	Multiplier	Offset	Result
CR510, CR10(X)	P5 AC Half Bridge	2500	±25 mV	fast	1	0	Vs/Vx
CR7	P5 AC Half Bridge	5000	±50 mV	fast	1	0	Vs/Vx
CR200(X)	ExDelSE ()	2500	n/a	500 µs	0.0004	0	Vs/Vx
CR800, CR1000	BrHalf ()	2500	±25 mV	250 µs	1	0	Vs/Vx
CR3000, CR9000X	BrHalf ()	5000	±50 mV	250 µs	1	0	Vs/Vx

3.2 Calculating Sensor Resistance

With reference to Figure 1, sensor resistance (Rs), expressed in kΩ, is calculated as follows:

$$Rs = R_2 / (Vs/Vx) - R_2 - R_1.$$

Therefore,

$$Rs\ (k\Omega) = 1/(Vs/Vx) - 101.$$

3.3 Interpreting Resistance Values

Table 3 lists 237 sensor resistance ranges and their interpretation.

TABLE 3. 237 Resistance Interpretations (Wet / Dry Threshold Set at 150 kΩ)

	CR1000		CR200(X)	CR10X	
Interpretation	**IEEE4[a]**	**FP2[b]**	**IEEE4[a,b]**	**Input Loc[a]**	**Low Res FS[b]**
Wet	0 to 150				
Slightly Wet	150 to ≥ 99999	150 to 7999	150 to ≥ 9999	150 to ≥ 99999	150 to 6999
Dry[c]	INF, ≥ 99999, ≤ -99999	INF, ±7999	-INF, ≥ 9999, ≤ -9999	INF, ≥ 99999, ≤ -99999	±6999
Voltage Input Over-range[d]	NAN	NAN	-100, -INF	-101	-101
Bridge Over-range[e]	< 0				
Missing Sensor[f]	Any Value				

[a] Input Memory

[b] Final Storage Memory

[c] The 1 kΩ bridge resistor holds the input channel at 0 mV when the sensor is completely dry. However, the measurement may intermittently deviate from zero slightly, but still be within the resolution specifications of the datalogger. When this occurs, Rs = either a very large or a very small number.

[d] Voltage input over-range is a state wherein voltage from the sensor exceeds the recommended 25 mV input voltage range. This highly conductive state may occur if the sensor is very very wet with very ionic water.

[e] If the measured voltage exceeds 24.75 mV, but does not exceed the input voltage range, the result of the bridge equation becomes negative.

[f] When no sensor is connected, or a cable has been cleanly cut, a "floating" voltage can occur and falsely indicate the presence of a missing sensor. In the CR1000, this can be avoided by using the mv25c range code.

3.4 Calculating Wet Time Fraction

Fraction of time wet are common data derived from 237 measurements. Calculating time fraction requires a wetness threshold. Refer to Section 5.4 Calibration for more information on determining the threshold.

Fraction of time wet is calculated in all current Campbell Scientific dataloggers, except the CR200(X), by using the Histogram instruction (P75 in Edlog / Histogram () in CRBasic) with a single bin and closed form. The bin select value for the histogram is the Input Location / Variable containing sensor resistance (Rs). The lower limit of the histogram is zero, and the upper limit is the wet / dry threshold. This will give the fraction of the output interval that the sensor is wet. A fraction of time wet of .33 when the output interval is one hour means that the sensor was wet for 20 minutes during that hour.

Refer to programming example 4.3 for information on calculating fraction of time wet with the CR200(X).

4. Programming Examples

Each example program measures leaf wetness and outputs a sample resistance and a time fraction the sensor is wet. In these examples, the output interval is set to 60 minutes, so a time fraction wet of .33 is equivalent to 20 minutes during that hour. Wetness threshold is set at 150 kΩ.

4.1 CR1000 Program Example

```
Public Vs_Vx
Public Rs_kOhms

DataTable(Wetness,true,-1)
    OpenInterval
    DataInterval(0,60,Min,10)
    Sample(1, Rs_kOhms, FP2)
    Histogram(Rs_kOhms, FP2, 0, 1, 011, 1 , 0, 150)      'Enter threshold in 8th parameter
EndTable

BeginProg
    Scan(60,Sec, 3, 0)
        BRHalf(Vs_Vx, 1, mV25, 1, VX1, 1, 2500, True, 0, 250, 1, 0)
        Rs_kOhms = (1 / Vs_Vx) - 101
        CallTable Wetness
    NextScan
EndProg
```

4.2 CR200(X) Programming

```
'CR200(X) Series Datalogger
Public Vs_Vx
Public Rs_kOhm
Public ScanIntervalWet
Public ScanIntervalSum
Public TimeFractionWet

DataTable (Wetness,1,-1)
    DataInterval (0,60,min)                    'Interval must match IfTime interval (below)
    Sample (1,Rs_kohm)
    Sample (1,TimeFractionWet)
EndTable

BeginProg
    Scan (1,Min)

        'Measure Wetness
        ExDelSE(Vs_Vx,1,1,1,mV2500,500,.0004,0)

        'Zero measurement when measurement < 0
        If Vs_Vx < 0 Then Vs_Vx = 0
        Rs_kOhm = (1 / Vs_Vx) - 101

        'Sum Scan Intervals
        ScanIntervalSum = ScanIntervalSum + 1
```

```
        'Check if Leaf wetness is below 150 kOhms transition and count as time dry
        If Rs_kohm < 150 AND Rs_kohm > 0 Then
            ScanIntervalWet = ScanIntervalWet + 1
        EndIf

        'Calculate Time Fraction Wet at top of each hour
        If IfTime (0,60,Min) Then                'Interval must match data table interval
            TimeFractionWet = ScanIntervalWet / ScanIntervalSum
            ScanIntervalWet = 0
            ScanIntervalSum = 0
        EndIf

        CallTable (Wetness)
    NextScan
EndProg
```

4.3 CR10(X) Programming Example

```
*Table 1 Program
  01:  60          Execution Interval (seconds)

1:  AC Half Bridge (P5)
  1:   1           Reps
  2:   13          25 mV Fast Range
  3:   1           SE Channel
  4:   1           Excite all reps w/Exchan 1
  5:   2500        mV Excitation
  6:   1           Loc [ Vs_Vx     ]
  7:   1           Multiplier
  8:   0           Offset

2:  Z=1/X (P42)
  1:   1           X Loc [ Vs_Vx     ]
  2:   2           Z Loc [ Rs_kOhms  ]

3:  Z=X+F (P34)
  1:   2           X Loc [ Rs_kOhms  ]
  2:   -101        F
  3:   2           Z Loc [ Rs_kOhms  ]

4:  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)

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

6:  Sample (P70)
  1:   1           Reps
  2:   2           Loc [ Rs_kOhms  ]
```

```
7:  Histogram (P75)
  1:   1              Reps
  2:   1              No. of Bins
  3:   1              Closed Form
  4:   2              Bin Select Value Loc [ Rs_kOhms  ]
  5:   0000           WV Loc Option [ _________ ]
  6:   0              Low Limit
  7:   150            High Limit              ;<<<<<<<<<<<<<<<<<<<Enter threshold here
```

NOTE When compiling this program, the message "Warning: zero is an invalid input address, Line: xx" will be returned from the compiler. Ignore the message, so long as "Line: xx" corresponds to the line number in the program where "WV Loc Option [__________]" appears.

5. Plant Pathology Application

Plant diseases are often associated with wet leaves. Duration of wetness and air temperature during wetness are inputs to many disease models. When estimating leaf wetness, the sensor emulates a leaf, thereby approximating the wetness state of surrounding foliage. The sensor does not (and should not!) come in contact with leaves. Water droplets that form at the onset of condensation are often too small to bridge the electrodes and so remain undetected. Droplets can be detected earlier in formation by application of a non-conductive spreader to the surface of the sensing grid. The spreader most commonly employed is flat latex paint.

5.1 Sensor Preparation

Campbell Scientific supplies only uncoated sensors since coating preferences vary between applications.

NOTE Campbell Scientific has not researched, nor does it recommend, paint formulations. The following information regarding paint formulation is intended only to introduce the concept.

Preparing the sensor surface with a thin coat of flat latex paint is a generally accepted practice in plant disease applications. In addition to providing some protection for the gold plated electrodes, flat latex allows tiny water droplets to spread and bridge the electrodes. Gillespie and Kidd[1] found that paint color had significant effects on performance and found off-white worked well. Their paint was formulated with 1 part black pigment to 1000 parts white paint. East[2] found that greater precision is obtained using a high quality flat latex paint. Some researchers and agricultural weather networks do not paint the sensor.

However the surface is prepared, the response of the sensor is, in reality, only an index against which actual leaf wetness can be estimated. While the absence of a spreader will decrease sensitivity and increase the chance of scratching the gold plated electrodes, bare sensors may grant greater consistency and less maintenance across a network.

5.2 Plant Pathology Application Programming

An exact range of measurements is impossible to give since the 237 is field calibrated. The manufacture of the sensor is not precise and the quality of water bridging the electrodes varies. As demonstrated in program examples in Section 4, a common practice is to measures grid resistance in terms of kOhms using a 1 bin histogram to calculate at what fraction of the output interval the sensor is wet. If resistance is ≤ 150 kΩ, the grid is considered wet. Since the output interval is 60 minutes, if the histogram fraction equals 0.33, the leaf was wet for 20 minutes during that hour.

5.3 Sensor Deployment

The sensor is not supplied with a mounting bracket. Gillespie and Kidd[1] found that sensor orientation affects performance. As with surface preparation, orientation varies across applications and users. A common practice is to mount the sensor such that is receives minimal direct sunlight at mid-day during the growing season. Gillespie and Kidd favor a 60 degree tilt on a north facing sensor such that water runs away from the cable connection to minimize puddling on the electrodes. Figure 2 shows a simple-to-construct mounting bracket.

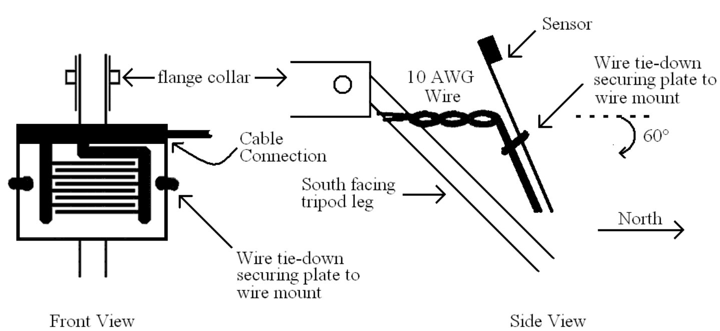

FIGURE 2. Mounting the 237 Sensor

5.4 Calibration

A wet / dry threshold of 150 kΩ is used in the programming examples in Section 4. While this threshold may work well, refining the threshold for a specific sensor and installation is recommended. A sharp change in resistance occurs at the threshold on uncoated sensors. A less defined threshold occurs with coated sensors. The threshold of uncoated sensors is normally between 50 and 200 kΩ. The threshold of the coated sensor is normally between 20 and 1,000 kΩ.

For best results, the sensor should be field calibrated. The transition point will vary for different areas, vegetation, and water quality. Place the sensor in vegetation, the wetness of which is to be monitored. Observe the vegetation until it reaches the desired wetness. When the vegetation is at the desired "wetness", the measured resistance can be used as a threshold. Sensitivity of the sensor is changed by contaminants such as fingerprints and smudges. Before painting and calibrating the sensor, clean it gently with alcohol.

6. References

[1] Gillespie, T.J. and Kidd, G.E. 1978. Sensing duration of leaf moisture retention using electrical impedance grids. Can. J. Plant Sci. 58:179-187.

[2] East, David (Ohio State University) 1994 Field Testing of Phone Accessible Multi-Channel Datalogger for Tomato IPM Programs. Unpublished.

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