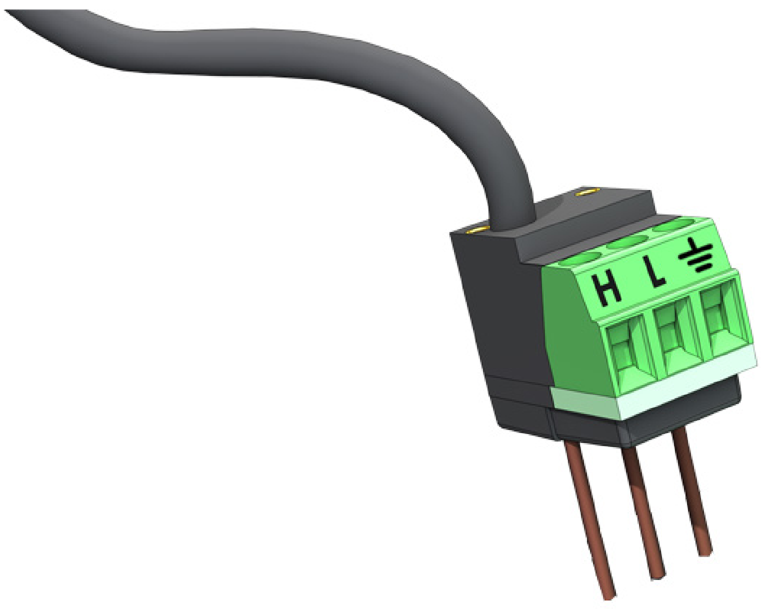
Product Manual

Measurement & Control Peripheral

4WFBS120, 4WFBS350, 4WFBS1K

4-Wire Full-Bridge Terminal Input Modules



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4WFBS120, 4WFBS350, 4WFBS1K 4-Wire Full-Bridge Terminal Input Modules (TIMs)

1. Introduction

The 4WFBS120, 4WFBS350, and 4WFBS1K Terminal Input Modules (TIMs) complete a full Wheatstone bridge for a single strain gage or other sensor that acts as a single variable resistor. The difference between the three models is in the resistor that matches the nominal resistance of 120, 350, or 1000 ohm quarter-bridge strain gage. It can also be used to complete the back half of a Wheatstone bridge for use in a quarter-bridge strain circuit (1 active element) using a dummy gage, or in a half-bridge strain circuit (2 active elements).

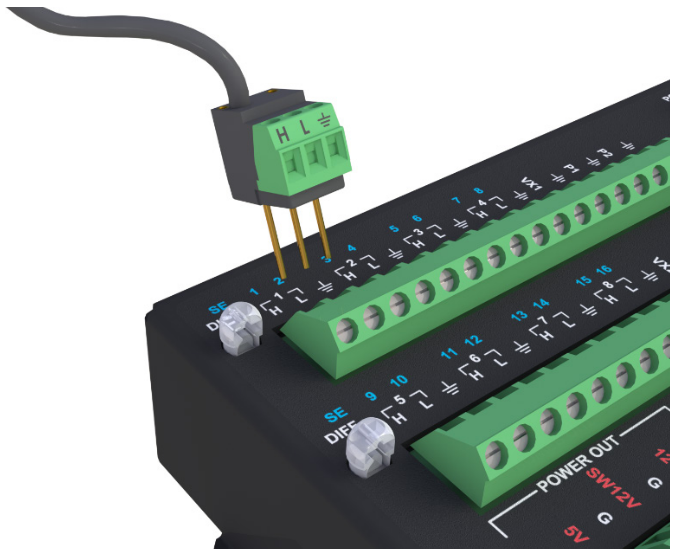

FIGURE 1-1. Terminal input module with CR1000

2. Precautions

- READ AND UNDERSTAND the *Safety* section at the front of this manual.
- The 4WFBS is a precision instrument. Handle with care.

3. Initial Inspection

- Upon receipt of the 4WFBS, inspect the packaging and contents for damage. File damage claims with the shipping company. Immediately check package contents against the shipping documentation. Contact Campbell Scientific about any discrepancies.

4. Overview

The 4WFBS series of terminal input modules (TIMs) are used to complete a full Wheatstone bridge for a single strain gage or other sensor acting as a single variable resistor. Other common uses are to complete the back half of a Wheatstone bridge in a quarter-bridge strain circuit (using a dummy gage), or in a half-bridge strain circuit. The Wheatstone bridge circuit converts small changes in resistance to an output voltage that our data loggers can measure. The terminal input modules are available in 120, 350, or 1000 ohm values.

The 4WFBS120 includes two external pins, allowing a user to perform shunt calibrations to correct for sensitivity errors. The lead wire that emanates from the head of the 4WFBS120 connects to a data logger excitation channel.

5. Specifications

2:1 Resistive Divider

Resistors:	1 kΩ/1 kΩ
Ratio tolerance @ 25 °C:	±0.01%
Ratio temperature coefficient:	0.5 ppm/°C (–55 to 85 °C)
Power rating per element:	0.1 W @ 70 °C

Completion Resistor: 120, 350, or 1000 Ω

Tolerance @ 25 °C:	±0.01%
Temperature coefficient:	±0.8 ppm °C^{-1} (–55 to 85 °C)
Power rating:	0.25 W @ 70 °C

Compliance: View compliance documents at:
www.campbellsci.com/4wfbs120
www.campbellsci.com/4wfbs350
www.campbellsci.com/tim-4wfbs1k

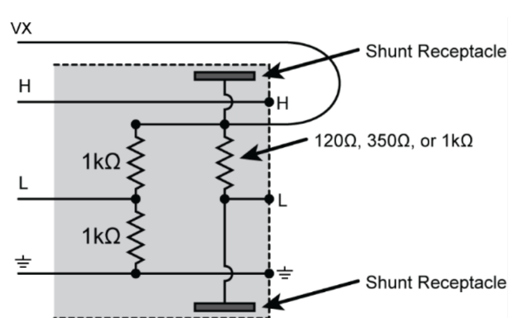

FIGURE 5-1. Schematic

6. Installation

The 4WFBS has three pins labeled **H**, **L**, and **Ground** (⏚). These terminals correspond with identical differential terminals on a Campbell Scientific data logger. The 4WFBS is secured to the data logger, and the wires from the strain gage or other sensor are then attached to the 4WFBS.

A single wire comes out of the 4WFBS. This wire it attached to an excitation (**VX**) terminal on the data logger.

The software program running on the data logger determines the terminals used by the 4WFBS and excitation wire.

7. Operation

7.1 Measurement Concepts

Measuring strain is measuring a change in length. Specifically, the unit *strain* (ε) is the change in length divided by the unstrained length ($\varepsilon = \Delta L / L$), and thus is dimensionless.

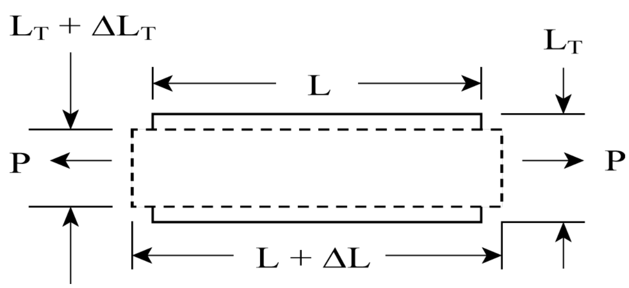

FIGURE 7-1. Strain definition

As the subject is elongated in the longitudinal direction, the material will be narrowed or thinned down in the transverse direction. The ratio of the transverse strain to the longitudinal strain is known as the Poisson's ratio (ν).

$$\nu = \frac{\Delta L_T / L_T}{\Delta L / L} \qquad \text{7-1}$$

This Poisson's ratio is a known property for most materials and is used in some half-bridge strain and full-bridge strain circuits.

Strain is typically reported in microstrain (με). Microstrain is strain expressed in parts per million, i.e.: a change in length divided by one millionth of the length.

A metal foil strain gage is a resistive element that changes resistance as it is stretched or compressed. The strain gage is bonded to the object in which strain is measured. The gage factor, GF, is the ratio of the relative change in resistance to the change in strain: *GF = (ΔR / R) / (Δl / l)*. For example, a gage factor of 2 means that if the length changes by one micrometer per meter of length (1με), the resistance will change by two microohms per ohm of resistance. A more common method of portraying this equation is:

$$\varepsilon = \frac{\Delta R_G}{GF \bullet R_G} \qquad 7\text{-}2$$

Or in terms of microstrain:

$$\mu\varepsilon = \frac{10^6 \cdot \Delta R_G}{GF \bullet R_G} \qquad 7\text{-}3$$

Because the actual change in resistance is small, a full Wheatstone bridge configuration is used to give the maximum resolution. The Wheatstone bridge can be set up with 1 active gage (quarter-bridge strain circuit), two active gages (half-bridge strain circuit), or 4 active gages (full-bridge strain circuit). For each of these Wheatstone bridge circuits, there are multiple configurations.

The 4WFBS module provides three resistors that can be used for three of the arms of the Wheatstone bridge (FIGURE 7-2). There are two 1000-ohm precision resistors for the backplane of the Wheatstone bridge, and a resistor matching the strain gage's resistance for the bridge arm opposite the gage. The inputs of the 4WFBS are configured so that this matching resistor can be bypassed if it is desired to utilize a dummy gage, or to use two active gages (half-bridge strain circuit).

For full-bridge strain circuits, as all four arms of the Wheatstone bridge are active gages, there is no need for completion resistors, and thus a 4WFBS module is not required.

The resistance of an installed gage will differ from the nominal value. In addition, lead resistance imbalances can result in further unbalancing of the bridge. A zero measurement can be made with the gage installed. This zero measurement can be incorporated into the data logger program such that subsequent measurements can report strain relative to this zero basis point. This removes the apparent strain resulting from the initial bridge imbalance.

Strain is calculated in terms of the result of the full-bridge measurement. This result is the measured bridge output voltage, V_{out}, divided by the bridge excitation voltage, V_{in}.

All of the various equations that are used to calculate strain use V_r, the change in the bridge measurement from the unstrained (zero) state:

$$V_r = \left(\frac{V_{out}}{V_x}\right)_{Strained} - \left(\frac{V_{out}}{V_x}\right)_{Unstrained} \qquad 7\text{-}4$$

The result of the zero measurement, $(V_{out}/V_{in})_{Unstrained}$, can be stored and used in the calculation of future strain measurements. Alternatively, the zero reading value can be left at 0 (zero measurement is neither recorded nor used).

It should be noted the actual result of the full-bridge instruction (**BrFull()**) is the millivolts output per volt of excitation ($1000 \cdot V_{out}/V_{in}$). The **StrainCalc()** function used in CRBasic uses this raw output as its input to calculate microstrain. See Section 7.2.5, *Calculation of Strain for Quarter-Bridge Circuits (p. 26)*, for a detailed derivation of the equations used.

7.2 Quarter-Bridge Strain

A quarter-bridge strain circuit is so named because an active strain gage is used as one of the four resistive elements that make up a full Wheatstone bridge. The other three arms of the bridge are composed of inactive elements. There are various circuits that use a single active element, including two-wire gages, three-wire gages, as well as a few circuits that utilize a dummy gage for the arm opposite the arm holding the active gage instead of a resistor, R_D in FIGURE 7-2 (See FIGURE 7-7, FIGURE 7-8, and FIGURE 7-9). The 4WFBS TIM modules can support all types of these quarter-bridge strain circuits.

7.2.1 Quarter-Bridge Strain with Three-Wire Strain Element

A three-wire quarter-bridge strain circuit is shown in FIGURE 7-2. Strain gages are available in nominal resistances of 120, 350, and 1000 ohms. The 4WFBSXXX model must match the nominal resistance of the gage when using the three-wire circuit (e.g., the 4WFBS120 is used with a 120-ohm strain gage).

In FIGURE 7-2, R_1 and R_2 are 1000 ohm resistors making up the backplane of the Wheatstone bridge, as is done in the TIM design. R_D, the third resistive element, is the complementary resistor that has a nominal resistance of the un-strained gage. The 4th resistive element is the active strain gage.

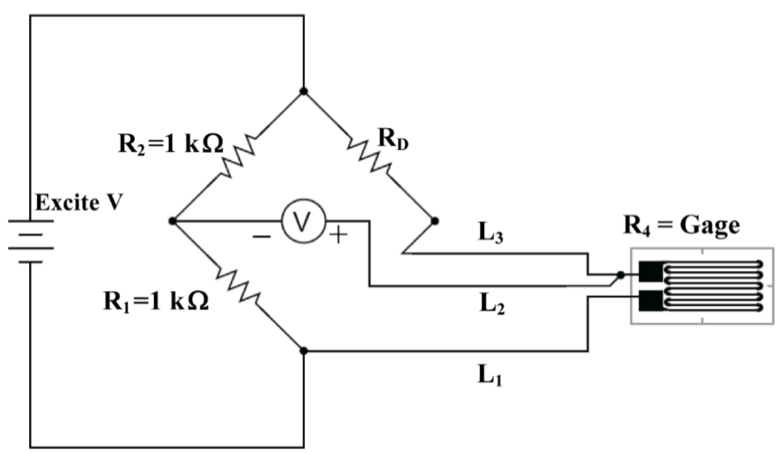

FIGURE 7-2. Three-wire quarter-bridge strain circuit

The three-wire gage alleviates many of the issues of the two-wire gage. As can be seen in FIGURE 7-2, lead wire L_3 is in the arm of the Wheatstone bridge that has the completion resistor while lead wire L_1 is in the arm that has the active gage. L_2 is tied back to the input channel of the data logger that has an input resistance greater than 1 GΩ, thus the current flow is negligible, negating effects of L_2's resistance. This circuit nulls temperature-induced resistance changes in the leads, as well as reduces the sensitivity effect that the wires have on the gage. See Section 7.2.4, *Quarter-Bridge Strain Lead Resistance Compensation (p. 17)*, for more on lead resistance effects and methods to compensate for them.

7.2.1.1 Quarter-Bridge Strain with Three-Wire Element Wiring

FIGURE 7-3 illustrates the wiring of the strain gage to the 4WFBS module and the wiring of the module to the data logger. It is important that the gage be wired as shown, and that the leads to the **L** and **G** terminals be the same length, diameter, and wire type. It is preferable to use a twisted pair for these two wires so that they will undergo the same temperature and electromagnetic field variations. With this configuration, changes in wire resistance due to temperature occur equally in both arms of the bridge with negligible effect on the output from the bridge.

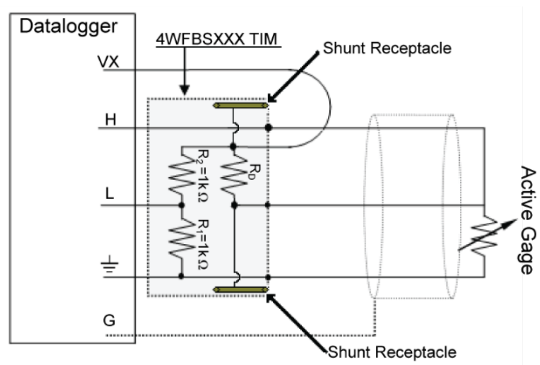

FIGURE 7-3. Three-wire quarter-bridge strain wiring

7.2.1.1.1 Quarter-Bridge Strain with Three-Wire Element Wiring Using a Multiplexer

When using a mechanical relay multiplexer such as the AM16/32B, the 4WFBS module should normally be placed on the face of the multiplexer similar as shown in FIGURE 7-4.

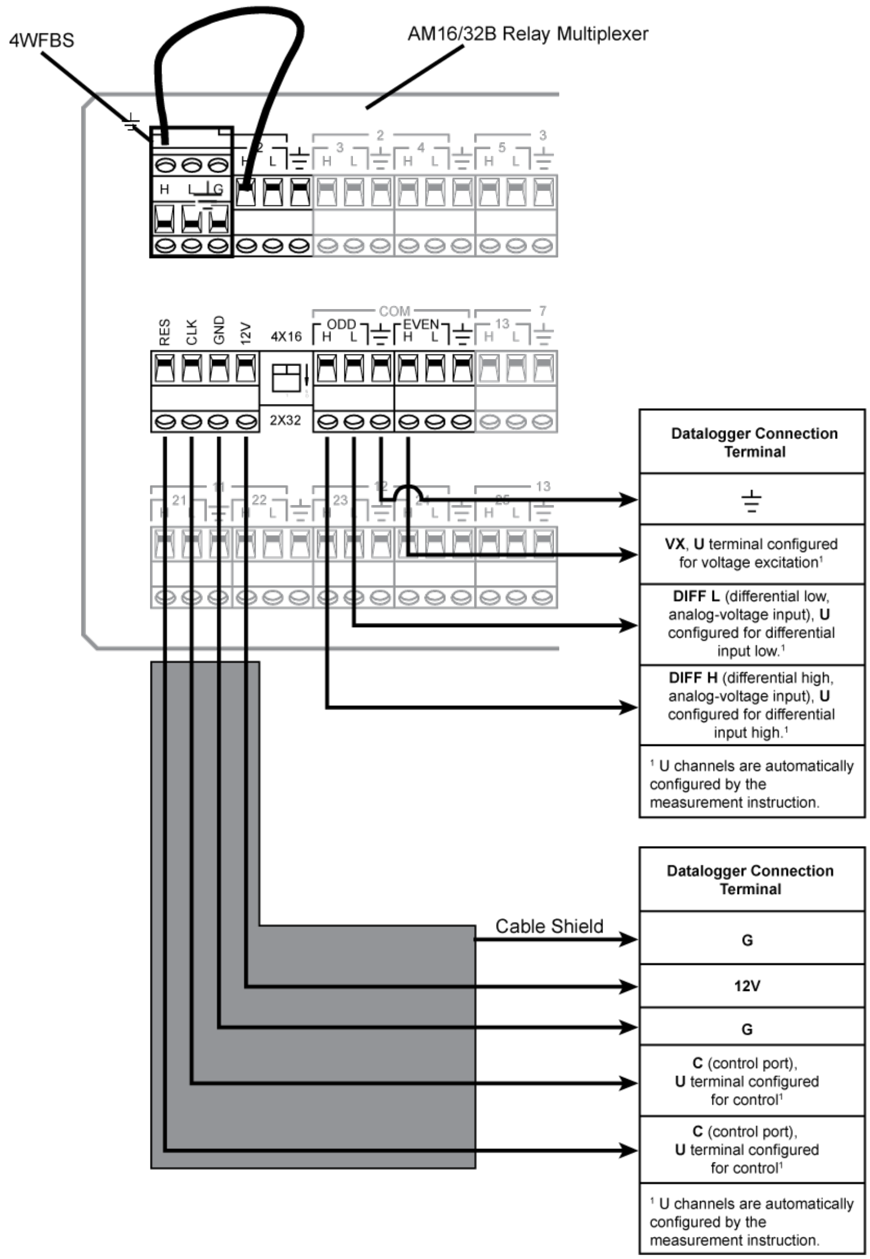

FIGURE 7-4. Three-wire quarter-bridge strain with multiplexer wiring

Although using an AM16/32B requires a 4WFBS module for each strain gage, it is important because placing relays internal a Wheatstone bridge strain system is discouraged. Any change in resistance of the multiplexer's relay contacts would result in a corresponding change in the bridge's output voltage.

Changes in contact resistance can be induced by temperature fluctuations, oxidation, environmental conditions, and normal wear of contact surfaces. The specification for the relays that are used in our multiplexers state that initial contact resistance will be less than 100 milliohms (AM16/32B). There is not a specification for change in contact resistance for the relays because there are so many variables that affect contact resistance. Test reports exist for various test conditions that show contact resistance changing over time by 10 to 20 mΩ.

These tests were performed using static test temperatures, so it is safe to assume that real world conditions would result in larger resistance shifts.

When strain gages are used in the Wheatstone bridge, small changes in contact resistance result in large apparent strains. To understand the error that can be introduced from allowing the relay contacts to be internal of the Wheatstone bridge, let us assume that the two relays carrying the current from the strain gage vary by 20 milliohms (40 milliohm total variance or $\Delta R_G = 40\ m\Omega$). Inserting this into Equation 7-3, using a 120-ohm strain gage with a gage factor of 2 results in an apparent strain of about 167 με.

$$167\mu\varepsilon = \frac{10^6 \bullet 0.04\Omega}{2 \bullet 120\Omega}$$

7.2.1.2 Quarter-Bridge Strain with Three-Wire Element Calculations

As noted in Section 7.1, *Measurement Concepts* *(p. 3)*, in real life applications the Wheatstone bridge starts out unbalanced. The strain gage is never perfectly at its nominal resistance even prior to installation. The installation process can lead to even more deviation from this nominal state. In addition, lead resistance can cause an initial apparent strain reading. To remove this initial offset, a zero measurement can be made with the gage installed. This zero measurement can be incorporated into the data logger program and subsequent measurements can report strain relative to this zero basis point.

Strain is calculated in terms of the result of the full-bridge measurement. This result is the measured bridge output voltage divided by the bridge excitation voltage V_{out}/V_{in}. (The actual result of the full-bridge instruction is the millivolts output per volt of excitation, $1000 \bullet V_{out}/V_{in}$.) The result of the zero measurement, $1000 \bullet (V_{out}/V_{in})_{Unstrained}$, can be stored and used to calculate future strain measurements. The change in the full-bridge measurement from the zero state, V_r, is used in the calculation of the strain.

$$V_r = (V_{out}/V_{in})_{Strained} - (V_{out}/V_{in})_{Unstrained} \qquad 7\text{-}5$$

Using V_r from Equation 7-5, the strain is calculated using Equation 7-6.

$$\varepsilon = \frac{4V_r}{GF(1-2V_r)} \qquad 7\text{-}6$$

The calculations are covered in more detail in Section 7.2.5, *Calculation of Strain for Quarter-Bridge Circuits* *(p. 26)*.

7.2.1.3 Quarter-Bridge Strain with Three-Wire Program Examples

This section is broken out into CRBasic programs and Edlog programs. These programs are only to be used as examples. Besides adding additional measurement instructions, the programs will need to have the scan and data storage intervals altered for actual applications. Refer to the data logger's manuals and/or the *CRBasic Editor Help* files for detailed information on the program instructions used as well as additional program examples.

7.2.1.3.1 CRBasic Programming

Data loggers that use CRBasic include our CR800, CR850, CR1000, CR3000, CR5000, and CR9000(X). CRBasic uses the **StrainCalc()** instruction for calculating strain from the output of different full-bridge configurations:

```
StrainCalc(Dest,Reps,Source,BrZero,BrConfig,GageFactor,PoissonRatio)
```

Source is the variable holding the current result from the full-bridge measurement

BrZero is the zero measurement; this parameter uses the results of a previous full-bridge measurement instruction when the gage is at the zero condition (multiplier = 1, offset = 0, mV/V) directly.

BRCode for the bridge configuration used with the 4WFBS module should be set to **–1** for a quarter-bridge strain circuit.

Enter the actual gage factor in the ***GageFactor*** parameter.

Enter **0** for the ***PoissonRatio*** parameter, which is not used with quarter-bridge strain circuits.

CRBasic Example 7-1 measures the output from the Wheatstone bridge using the **BrFull()** instruction. The output from this instruction is input into the **StrainCalc()** instruction in order to calculate the raw microstrain value. This program does not use a zero offset reading. See CRBasic Example 7-2 for an example that performs a zero calibration.

CRBasic Example 7-1. CR9000X Quarter-Bridge Strain with Three Reps

```
'Program name: STRAIN.C9X
Public StrainMvperV(3) : Units StrainMvperV = mV_per_V  'Raw Strain dimensioned source
Public Strain(3)       : Units Strain = uStrain         'uStrain dimensioned source
Public GF(3)                                            'Dimensioned gage factor

DataTable(STRAIN,True,-1)                     'Trigger, auto size
  DataInterval(0,0,0,100)                     'Synchronous, 100 lapses, autosize
  CardOut(0,-1)                               'PC card , size Auto
  Sample (3,Strain(),IEEE4)                   '3 Reps, uStrain, Resolution
  Sample (3,StrainMvperV(),IEEE4)             '3Reps,Stain mVolt/Volt, Resolution
EndTable                                      'End of table STRAIN

BeginProg                                     'Program begins here
  GF(1) = 2.1  :  GF(2) = 2.2  :  GF(3) = 2.3 'Initialize gage factors for Strain( )

  Scan(10,mSec,100,0)                         'Scan once every 10 mSecs, non-burst
    BrFull(StrainMvperV(),3,mV50,4,1,5,7,1,5000,True,True,70,100,1,0)
    StrainCalc(Strain(),3,StrainMvperV(),0,-1,GF(),0)  'Strain calculation
    CallTable STRAIN
  Next Scan                                   'Loop up for the next scan

  SlowSequence                                'Slow sequence Scan to perform temperature
    Scan(1,Sec,0,0)                           'compensation on DAQ
      Calibrate                               'Corrects ADC offset and gain
      BiasComp                                'Corrects ADC bias current
    Next Scan
EndProg                                       'Program ends here
```

CRBasic Example 7-2 starts out with CRBasic Example 7-1 and adds instructions (highlighted) to perform a zero calibration. As all strain circuits have a zero or initial imbalance that is related to the circuit rather than the member undergoing strain, a zero reading is often used to offset or remove this apparent strain. Again, see the manual and CRBasic editor's Help file for more in-depth discussion on the instructions.

The **FieldCalStrain()** instruction takes care of the underlying math for the zeroing using Equation 7-6.

The **LoadFieldCal()** instruction facilitates the reloading of the calibration factors when the data logger is powered up. In addition, the programmer should create a **DataTable** (we have called this data table Calib in the example) to store the calibration factors each time a calibration is done.

The **NewFieldCal** is a Boolean flag variable that is only high during the scan that a calibration has been completed. It is used in the **DataTable()** instruction's trigger parameter to trigger the table to record a record.

The **SampleFieldCal()** output instruction is used to inform the data logger to store all of the calibration factors that are controlled using the **FieldCalStrain()** instruction.

CRBasic Example 7-2. CR9000X Quarter-Bridge Strain with Three Reps and Zero Offset

```
'Program name: STRAIN0.C9X
Public StrainMvperV(3)   :  Units StrainMvperV = mV_per_V  'Raw Strain dimensioned source
Public Strain(3)         :  Units Strain = uStrain         'uStrain dimensioned source
Public GF(3)                                               'Dimensioned gage factor
Public ZeromV_V(3), ZeroStrain(3)
Public ZReps, ZIndex, ModeVar

DataTable(STRAIN,True,-1)                       'Trigger, auto size
  DataInterval(0,0,0,100)                       'Synchronous, 100 lapses, autosize
  CardOut(0,-1)                                 'PC card , size Auto
  Sample (3,Strain(),IEEE4)                     '3 Reps, uStrain, Resolution
  Sample (3,StrainMvperV(),IEEE4)               '3Reps,Stain mVolt/Volt, Resolution
EndTable                                        'End of table STRAIN

DataTable (Calib,NewFieldCal,10)                'Table for calibration factors from zeroing
  SampleFieldCal                                'User should collect these to his computer
EndTable                                        'for future reference

BeginProg                                        'Program begins here
  GF(1) = 2.1  :  GF(2) = 2.2  :  GF(3) = 2.3    'Initialize gage factors for Strain( )
  ZReps = 3  :  ZIndex = 1                       'initialize cal reps and index pointer
  LoadFieldCal(True)                             'Load prior calibration factors
  Scan(10,mSec,100,0)                            'Scan once every 10 mSecs, non-burst
    FieldCalStrain(10,StrainMvperV(),ZReps,0,ZeromV_V(),ModeVar,0,ZIndex,1,0,Strain())
    BrFull(StrainMvperV(),3,mV50,4,1,5,7,1,5000,True,True,70,100,1,0)
    StrainCalc(Strain(),3,StrainMvperV(),ZeromV_V(),-1,GF(),0)  'Strain calculation
    CallTable STRAIN
    CallTable Calib
  Next Scan                                      'Loop up for the next scan

  SlowSequence                                   'Slow sequence Scan to perform
    Scan(1,Sec,0,0)                              'temperature  compensation on the DAQ
      Calibrate                                  'Corrects ADC offset and gain
      BiasComp                                   'Corrects ADC bias current
    Next Scan
EndProg                                          'Program ends here
```

CRBasic Example 7-3 performs the same tasks as CRBasic Example 7-2, only it is a CR1000 program instead of a CR9000X program. There are slight differences such as range codes and the fact that the CR1000 does not have a slot parameter for its measurement instructions. This program is more similar to what a CR800, CR3000, or a CR5000 program would look like than the CR9000X program.

CRBasic Example 7-3. CR6 Quarter-Bridge Strain with Three Reps and Zero Offset

```
'Program name: STRAIN0.CR6
Public StrainMvperV(3)  :  Units StrainMvperV = mV_per_V  'Raw Strain dimensioned source
Public Strain(3)        :  Units Strain = uStrain         'uStrain dimensioned source
Public GF(3)                                              'Dimensioned gage factor
Public ZeromV_V(3)
Public ZReps, ZIndex, ModeVar

DataTable(Strain,True,-1)                        'Trigger, auto size
  DataInterval(0,0,0,100)                        'Synchronous, 100 lapses, autosize
  CardOut(0,-1)                                  'PC card , size Auto
  Sample (3,Strain(),IEEE4)                      '3 Reps, uStrain, Resolution
  Sample (3,StrainMvperV(),IEEE4)                '3Reps,Stain mVolt/Volt, Resolution
EndTable                                         'End of table STRAIN

DataTable (Calib,NewFieldCal,10)                 'Table For calibration factors from zeroing
  SampleFieldCal                                 'User should collect these To his computer
EndTable                                         'For future reference

BeginProg                                        'Program begins here
  GF(1) = 2.1  :  GF(2) = 2.2  :  GF(3) = 2.3    'Initialize gage factors for Strain( )
  ZReps = 3  :  ZIndex = 1                       'initialize cal reps AND index pointer
  LoadFieldCal(True)                             'Load prior calibration factors
  Scan(100,mSec,100,0)                           'Scan once every 10 mSecs, non-burst
    FieldCalStrain(10,StrainMvperV(),ZReps,0,ZeromV_V(),ModeVar,0,ZIndex,1,0,Strain())
    BrFull(StrainMvperV(),3,mv5000,U1,U10,3,2500,True,True,450,500,1,0)
    StrainCalc(Strain(),3,StrainMvperV(),ZeromV_V(),-1,GF(),0)  'Strain calculation
    CallTable Strain
    CallTable Calib
  Next Scan                                      'Loop up for the next scan
```

CRBasic Example 7-4 has 16 strain gages multiplexed through an AM16/32 multiplexer and uses **FieldCalStrain** for zeroing.

CRBasic Example 7-4. CR6 Quarter-Bridge Strain Using an AM16/32B Multiplexer with 16 Reps and Zero Offset

```
'Program name: QuarterStrain with Zero and Mux.CR6
'This is only an example program and should be used only for help in creating a usable program
'------------------------------------  WIRING  ------------------------------------
'CR6                    to  AM16/32 Multiplexer Control
'C1 (Control Port 1)        Res (Reset)
'C2 (Control Port 2)        Clk (Clock)
'G                          GND (Ground)
'12V                        12V

'CR6   to  AM16/32 Common       TIMs      to  AM16/32 Banks
'U1    to  Common Even Hi       Blk Wire  to  Bank Odd Lo
'U2    to  Common Even Lo       TIM H     to  Bank Even Hi
'U10   to  Common Odd Lo        Tim L     to  Bank Even Lo
'G     to  Common Gnd           Tim AG    to  Bank Even AG
'\\\\\\\\\\\\\\\\\\\\\\\\DECLARE VARIABLES and CONSTANTS //////////////////////
Const REPS = 16                                 'Strain gage sensor count
Public MVpV(REPS)      :  Units MVpV = mV_V      'mV per Volt output from Bridge Measurement
Public STRAIN(REPS)    :  Units STRAIN = uStrain 'Variable where uS is stored,
Const BATCH_GF = 2.1   :  Public  GF(REPS)       'Batch gage factor
```

```
Public mV_VZero(REPS)  :  Units mV_VZero = mV_V   'Variable for Zero mV per V reading
Public CalReps, ZeroMode, ZeroStartIdx, ZeroCalAvgs  'Used by wizard for zeroing
Public CalFileLoaded As Boolean
Dim    I
'\\\\IF DESIRED (NOT REQUIRED): GIVE STRAIN VARIABLES UNIQUE ALIAS NAMES ////////
Alias STRAIN(1)  = Strain1  : Alias STRAIN(2)  = Strain2  : Alias STRAIN(3)  = Strain3
Alias STRAIN(4)  = Strain4  : Alias STRAIN(5)  = Strain5  : Alias STRAIN(6)  = Strain6
Alias STRAIN(7)  = Strain7  : Alias STRAIN(8)  = Strain8  : Alias STRAIN(9)  = Strain9
Alias STRAIN(10) = Strain10 : Alias STRAIN(11) = Strain11 : Alias STRAIN(12) = Strain12
Alias STRAIN(13) = Strain13 : Alias STRAIN(14) = Strain14 : Alias STRAIN(15) = Strain15
Alias STRAIN(16) = Strain16

'\\\\\\\\\\\\\\\\\\\\\\\ OUTPUT SECTION ///////////////////////
'Table STRAIN stores uStrain and raw mV per Volt measurements to the PC Card
DataTable(STRAIN,True,-1)           'Trigger, auto size
  DataInterval(0,0,0,100)           'Synchronous, 100 lapses
  CardOut(0,-1)                     'PC card , Autosize
  Sample (REPS,STRAIN(),IEEE4)      'Sample uStrain
  Sample (Reps,mVpV(),IEEE4)        'Sample raw mV per Volt values
EndTable                            'End of table

'Table CalHist uses SampleFieldCal which stores all of the Calibration constants
'When a calibration function is complete, user should always collect this Table as a record
DataTable(CalHist,NewFieldCal,50)
  SampleFieldCal
EndTable

'\\\\\\\\\\\\\\\\\\\\\\\\MAIN PROGRAM SECTION ///////////////////////
BeginProg                           'Program begins here
  For I = 1 To REPS                 'For the 16 gages
    GF(I) = BATCH_GF                'Assign default gage factor (2.1) to GF array elements
  Next I                            'Loop back up until complete
  CalFileLoaded = LoadFieldCal(1)   'Load the Cal constants if program signature matches

  Scan(1,Sec,10,0)                  'Scan once a  Second
    PortSet (C1,1  )                'Turn on AM16/32 using C1 ()
    I = 1
    Delay (0,150,mSec)              'required Delay for AM16/32 multiplexer
    SubScan (0,0,16)
      PulsePort (C2,10000)          'Pulse port C2 hi and low to clock the multiplexer
      BrFull(MVpV(I),1,mv5000,U1,U10,1,2500,True,True,250,500,1,0)  'Full-bridge measurement
      StrainCalc(Strain(I),1,MVpV(I),mV_VZero(I),-1,GF(I),0)  'Strain calculation
      I = I + 1                     'Increment I
    NextSubScan
    PortSet (C3,0 )                 'Turn on AM16/32 using C1
    FieldCalStrain(10,MVpV(),CalReps,0,mV_VZero(),ZeroMode,0,ZeroStartIdx,ZeroCalAvgs,0,STRAIN())
    CallTable CalHist
    CallTable STRAIN
  Next Scan                         'Loop up for the next scan
EndProg                             'Program ends here
```

7.2.2 Quarter-Bridge Strain with Two-Wire Element

NOTE Although a two-wire gage can be used with the 4WFBS TIM, due to the issues outlined in Section 7.2.4.3, *Lead Compensation using Quarter-Bridge Strain with Two-Wire Element* (p. 25), it is not recommended. An exception may be applications with short leads in a stable temperature environment.

A two-wire quarter-bridge strain circuit is shown in FIGURE 7-5.

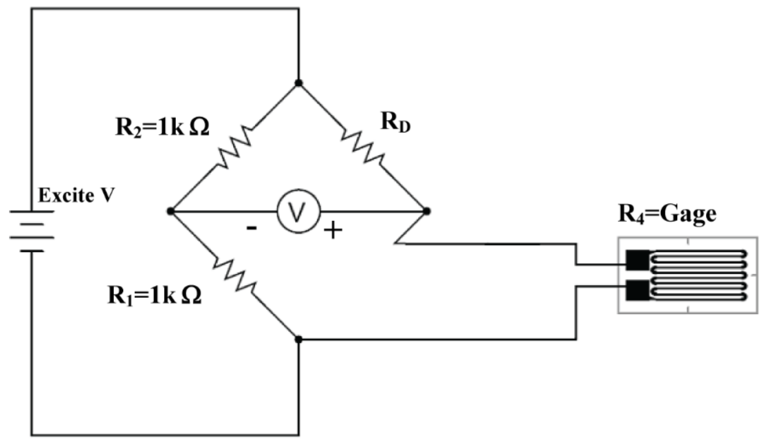

FIGURE 7-5. Two-wire quarter-bridge strain circuit

In this circuit, R_1 and R_2 are 1000 ohm resistors making up the backplane of the Wheatstone bridge, as is done in the TIM design. R_D is the complementary resistor, or dummy resistor, that has a nominal resistance of the unstrained gage. The 4th resistive element is the active strain gage. Strain gages are available in nominal resistances of 120, 350, and 1000 ohms. The 4WFBS model must match the nominal resistance of the gage (e.g., the 4WFBS120 is used with a 120-ohm strain gage).

As can be seen in FIGURE 7-5, both sensor leads are in the same arm of the Wheatstone bridge. Not only does this affect the sensitivity of the gage, the output from this circuit will include temperature-induced line resistance errors. See Section 7.2.4.3, *Lead Compensation using Quarter-Bridge Strain with Two-Wire Element (p. 25)*, for more information on issues with using two-wire gages.

7.2.2.1 Quarter-Bridge Strain with Two-Wire Element Wiring

To use a two-wire element strain gage with the 4WFBS TIM requires a jumper wire be placed between the **H** and **L** terminal of the TIM module as shown in FIGURE 7-6.

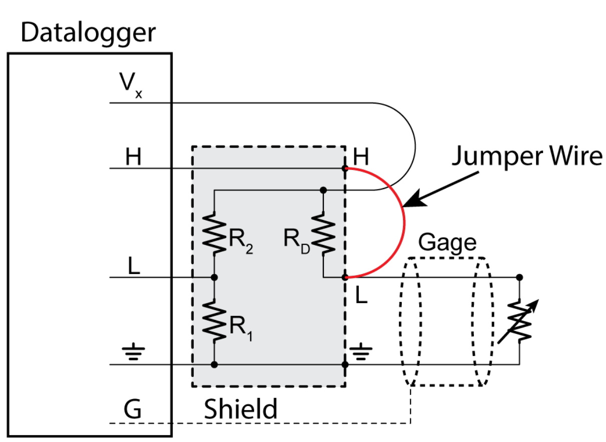

FIGURE 7-6. Wiring for two-wire gages

7.2.2.2 Two-Wire Quarter-Bridge use with Multiplexers and Equations

The equations to resolve the strain, programming of the data logger, and methods of using with multiplexers are the same as those covered in Section 7.2.1, *Quarter-Bridge Strain with Three-Wire Strain Element* *(p. 5)*, for the three-wire strain gage. The only variance is the wiring of the gage to the TIM.

7.2.3 Quarter-Bridge Strain with Dummy Gage

An undesirable property of strain gages is that of resistance change with changes in temperature. This is true even for the self-temperature compensating strain gages on the market today. Supplied with each package of strain gages are graphs and equations for the variance in the output of the strain gage due to thermal changes (referred to as thermal output or apparent strain) and for the variation of the gage factor with temperature. These graphs are based on the assumption that the gages are mounted on a material with the given thermal coefficient of expansion (TCE). The TCE value is included in the gage type nomenclature. Following are some typical equations supplied. Equation 7-7 is used to calculate the thermal output variance ($\mu\varepsilon_{TO}$) with the result in microstrain. Equation 7-8 is used to determine the change in the gage factor (GF) due to temperature changes. Both are based on temperature in degrees Celsius (T).

$$\mu\varepsilon_{TO} = -2.95 + 1.15T - 0.05T^2 + 3.25E^{-4}T^3 - 3.93E^{-7}T^4 \qquad \text{7-7}$$

$$GF_{adj} = GF_{raw} + 1.40E^{-4} \bullet (T - 24)GF_{raw} \qquad \text{7-8}$$

As an example, let us assume we use a gage with a GF of 2.00 in a test that started at 24 °C and 0 microstrain, and ended at 50 °C and a recorded strain value of 1000 microstrain. The thermal output strain, $\mu\varepsilon_{TO}$, at 50 °C would be –29.3 microstrain. The error in the gage factor would be 0.364% with a resultant GF_{adj} of 2.007. The corrected strain would be 967 microstrain:

$$\mu\varepsilon_{cor} = (1000\mu\varepsilon - 29.3\mu\varepsilon) \bullet 2.000/2.007 \qquad \text{7-9}$$

The uncorrected value had an error of approximately 3.3%. If the ending strain would have been 100 microstrain instead of 1000 microstrain, the error would have been around 30%.

Another temperature-induced error in a quarter-bridge strain circuit is due to the Temperature Coefficient of Resistance (TCR) of the completion resistor in the arm opposite the strain gage. The 4WFBS TIMs use a high-quality resistor having a TCR of 0.8ppm/°C to minimize these errors. For our example above, this could lead to an error in the reading of approximately 10 microstrain, assuming that the data logger experiences the same level of temperature variation. This error could be additive or subtractive to the other errors as the resistor manufacturer does not specify the polarity of the change in resistance, only the absolute magnitude.

These errors, with exception to the completion resistor's TCR, can be mathematically compensated for to some degree. It should be remembered that the curves and equations given are the average for the given batch of gages and are only applicable when mounting on the specified material. An alternative approach to eliminate the errors is to either use a dummy gage, from the same batch mounted on identical material, or to use a half or full-bridge strain circuit.

Dummy gages can be used to compensate for these false apparent strain readings. A strain gage that is mounted on a coupon that is not undergoing mechanical stress and is used as the resistive element for the Wheatstone bridge arm opposite the active gage is referred to as a dummy gage. This non-active gage in the other arm of the Wheatstone bridge is referred to as a dummy gage because it is not subjected to load-induced strains.

With the two opposing gages experiencing the same temperature conditions, the temperature effects on the active gage will be nullified by the equivalent temperature effects on the dummy gage. FIGURE 7-7 depicts a quarter-bridge strain circuit with a dummy gage.

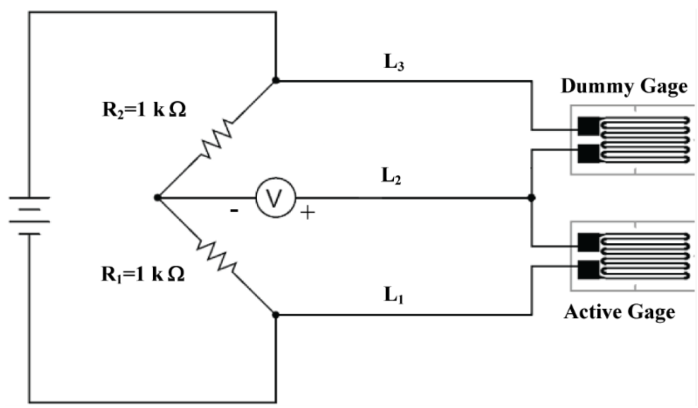

FIGURE 7-7. Quarter-bridge strain circuit with dummy gage

It should be noted that the coupon on which the dummy gage is mounted can still be subjected to temperature-induced strains. This can be used to null temperature-induced strains in the monitored member if the dummy gage is mounted to a coupon made up of material having the same TCR as the member that the active gage is mounted to. Conversely, the dummy gage could be mounted to a coupon with a negligible TCR allowing for the monitoring of temperature-induced stresses.

The 4WFBS modules can support quarter-bridge strain circuits using either the completion resistor built into the TIM, or a user supplied dummy gage, for the Wheatstone bridge arm's resistive element opposite of the active strain gage in the bridge. Wiring circuits using a dummy gage are covered in Section 7.2.3.1, *Quarter-Bridge Strain with Dummy Gage Wiring Setup* (p. 15).

7.2.3.1 Quarter-Bridge Strain with Dummy Gage Wiring Setup

FIGURE 7-8 illustrates the wiring of the strain gage with a dummy gage to the 4WFBS module, as well as the wiring of the module to the data logger. This shows the dummy gage out at the remote site along with the active gage. This is the best setup to achieve the best compensation for the apparent strain and gage factor variance due to temperature fluctuations, as it will be easier to keep the temperature of the two gages equivalent.

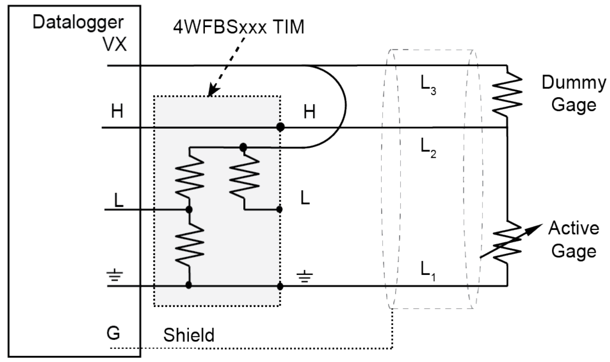

FIGURE 7-8. Quarter-bridge strain with remote dummy gage

FIGURE 7-9 illustrates the wiring of the strain gage to the 4WFBS module with the dummy gage at the data logger location. Apparent strain errors could result because of temperature variances between the two gages with this setup. This circuit is still utilized in some applications for ease of shunt calibration (can shunt across dummy gage at data logger location rather than at the remote gage location). Also, an existing, standard three-wire quarter-bridge strain circuit can easily be transformed into this circuit. If large temperature variances will exist between the active gage and the dummy gage located at the data logger, using the 4WFBS completion resistor can result in lower temperature-induced errors.

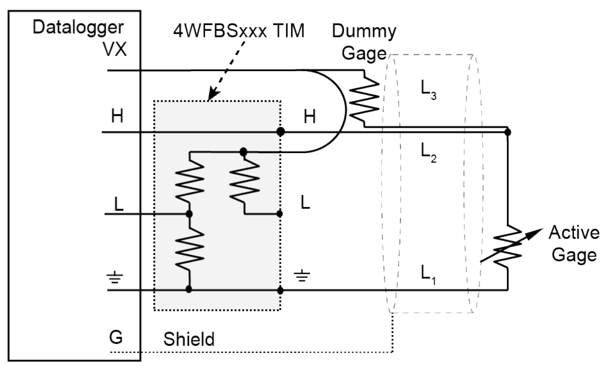

FIGURE 7-9. Quarter-bridge strain with dummy gage at data logger

With either circuit, one lead leg, L_1 or L_3, is in one of the two opposing arms of the Wheatstone bridge. It is important that the gage be wired such, and that these two leads be the same length, diameter and wire type. It is preferable to use a twisted pair for these two wires so that they will undergo the same temperature and electromagnetic field variations. With this configuration, changes in wire resistance due to temperature occur equally in both arms of the bridge with negligible effect on the output from the bridge.

7.2.3.2 Quarter-Bridge Strain with Dummy Gage Calculations

The calculations for this bridge setup are the same as for the three-wire quarter-bridge circuit. See Section 7.2.1.2, *Quarter-Bridge Strain with Three-Wire Element Calculations* *(p. 8)*, for details.

7.2.3.3 Quarter-Bridge Strain with Dummy Gage Example Programs

The programming for this bridge setup is the same as for the three-wire quarter-bridge circuit. See Section 7.2.1.3, *Quarter-Bridge Strain with Three-Wire Program Examples* *(p. 8)*, for details.

7.2.4 Quarter-Bridge Strain Lead Resistance Compensation

When using quarter-bridge strain (full-bridge with one active element) with long lead lengths, errors can be introduced due to the resistance of the leads. This section covers both mathematical and shunt calibration methods used to rectify these errors. The techniques covered in the section can be used with circuits using a 4WFBS's completion resistor or a dummy gage for the resistive element in the third arm of the Wheatstone bridge (arm opposite of active gage). The only difference is that when using a dummy gage, the 4WFBS module's gold shunt receptacles cannot be used. These receptacles are connected to the dummy resistor supplied by the 4WFBS module.

One potential error with long leads is due to the leads' resistance change from temperature fluctuations. When using a three-wire strain gage, wired as depicted in FIGURE 7-3, with the three leads all the same length and laid out together (all three experience the same temperature swings), the leads' resistance changes are self compensating. It is preferable to use a twisted pair for the two wires (L and G) carrying the current so that they definitely undergo the same temperature and electromagnetic field variations. With this configuration, changes in wire resistance due to temperature occur equally in both arms of the bridge with negligible effect on the output from the bridge.

Another error that is introduced when using long leads, is a sensitivity reduction of the system. There are two methods to rectify this error. The first is mathematical. The second is to perform a shunt calibration. Sections 7.2.4.1, *Mathematical Lead Compensation for Three-Wire, Quarter-Bridge Strain* *(p. 17)*, and 7.2.4.2, *Shunt Calibration Lead Compensation for Three-Wire, Quarter-Bridge Strain* *(p. 20)*, cover these methods for quarter-bridge strain circuits.

7.2.4.1 Mathematical Lead Compensation for Three-Wire, Quarter-Bridge Strain

The same equations pertain whether a completion (dummy) resistor or a dummy gage is used to complete the third arm of the Wheatstone bridge. So the material in this section is relevant for wiring setups shown in FIGURE 7-3, FIGURE 7-8, and FIGURE 7-9. The math and the programs used would be identical for all three of these circuits.

7.2.4.1.1 Mathematical Lead Compensation Circuit and Equations

If the lead resistance is known, the sensitivity error can be mathematically corrected for by multiplying the output by a simple factor $(1 + R_L / R_G)$ where R_L is the nominal resistance of one of the lead legs and R_G is the resistance of the strain gage. The gage factor can be multiplied by the inverse of this value, $R_G / (R_G + R_L)$, to derive an adjusted gage factor.

$$GF_{adj} = GF_{raw} \bullet \left(\frac{R_g}{R_g + R_L} \right) \qquad 7\text{-}10$$

The adjusted gage factor, GF_{adj}, would be used in the **StrainCalc()** function to derive the microstrain. The proof used to derive this adjusted gage factor is shown below:

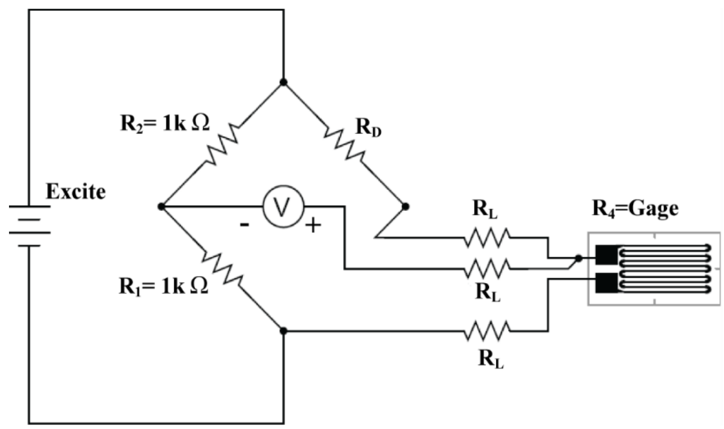

FIGURE 7-10. Three-wire quarter-bridge strain circuit

Balanced Bridge Condition

$$\left(\frac{E_O}{E_I} \right)_{BAL} = \frac{R_G + R_L}{R_G + R_L + R_D + R_L} - \frac{R_1}{R_1 + R_2} \qquad 7\text{-}11$$

Strained Bridge Condition

$$\left(\frac{E_O}{E_I} \right)_{STR} = \frac{R_G + R_L + \Delta R_G}{R_G + R_L + R_D + R_L + \Delta R_G} - \frac{R_1}{R_1 + R_2} \qquad 7\text{-}12$$

Change in Bridge Output (V_R)

$$V_R = \left(\frac{E_O}{E_I} \right)_{STR} - \left(\frac{E_O}{E_I} \right)_{BAL} = \frac{R_G + R_L + \Delta R_G}{R_D + 2R_L + R_G + \Delta R_G} - \frac{R_G + R_L}{R_D + R_G + 2R_L} \qquad 7\text{-}13$$

Assume $R_D = R_G$

$$V_R = \frac{R_G + R_L + \Delta R_G}{2R_L + 2R_G + \Delta R_G} - \frac{R_G + R_L}{2R_G + 2R_L} \qquad 7\text{-}14$$

Simplify

$$V_R = \frac{R_G \Delta R_G + R_L \Delta R_G}{(2R_G + 2R_L + \Delta R_G)(2R_G + 2R_L)} \qquad 7\text{-}15$$

Solve for $\Delta R_G/R_G$

$$\frac{\Delta R_G}{R_G} = \frac{4V_R}{(1-2V_R)}\left(\frac{R_G + R_L}{R_G}\right) \qquad \text{7-16}$$

Use the gage factor to calculate microstrain $\left(\mu\varepsilon = \frac{\Delta R \bullet 10^6}{R_G \bullet GF}\right)$

$$\mu\varepsilon = \frac{4V_R \bullet 10^6}{GF(1-2V_R)}\left(\frac{R_G + R_L}{R_G}\right) \qquad \text{7-17}$$

7.2.4.1.2 Mathematical Lead Compensation Programs

CRBasic Example 7-5 starts with CRBasic Example 7-2 and adds instructions to mathematically compensate for the leads resistances effects on the gage factor (sensitivity effect). Added instructions are highlighted.

CRBasic Example 7-5. CR9000X Quarter-Bridge Strain with Zero Offset and Lead Compensation

```
'Program name: StrainSH.C9X
Public StrainMvperV(3) :  Units StrainMvperV = mV_per_V  'Raw Strain dimensioned source
Public Strain(3)       :  Units Strain = uStrain         'uStrain dimensioned source
Dim GF(3)                                                'Dimensioned gage factor
Public ZeromV_V(3), ZeroStrain(3)
Public ZReps, ZIndex, ModeVar
Public Leadlength(3), Lead_R(3),GF_Adjusted(3),
Public I, LeadRper100ft, Gauge_R

DataTable(STRAIN,True,-1)                'Trigger, auto size
  DataInterval(0,0,0,100)                'Synchronous, 100 lapses, autosize
  CardOut(0,-1)                          'PC card , size Auto
  Sample (3,Strain(),IEEE4)              '3 Reps, uStrain, Resolution
  Sample (3,StrainMvperV(),IEEE4)        '3Reps,Stain mVolt/Volt, Resolution
EndTable                                 'End of table STRAIN

DataTable (Calib,NewFieldCal,10)         'Table for calibration factors from zeroing
  SampleFieldCal                         'User should collect these to his computer
EndTable                                 'for future reference

BeginProg                                'Program begins here
  GF(1) = 2.1  :  GF(2) = 2.2  :  GF(3) = 2.3  'Initialize gage factors for Strain( )
  LeadLength(1) = 1.25                   'load lead lengths  (100s of feet)
  LeadLength(2) = 1.50
  LeadLength(3) = 2.00
  LeadRper100ft = 2.5                    '24 gage copper wire lead R is 0.025 ohms/ft
  Gauge_R = 350                          'Load Strain gage Resistance
  For I = 1 To 3                         'Loop through calculate the adjusted gage factors
    Lead_R(I) = LeadLength(I) * LeadRper100ft
    GF_Adjusted(I) = GF(I) * (Gauge_R/(Gauge_R + Lead_R(I)))
  Next I
  ZReps = 3  :  ZIndex = 1               'initialize cal reps and index pointer
  LoadFieldCal(True)                     'Load prior calibration factors
  Scan(10,mSec,100,0)                    'Scan once every 10 mSecs, non-burst
    FieldCalStrain(10,StrainMvperV(),ZReps,0,ZeromV_V(),ModeVar,0,ZIndex,1,0,Strain())
    BrFull(StrainMvperV(),3,mV50,4,1,5,7,1,5000,True,True,70,100,1,0)
    StrainCalc(Strain(),3,StrainMvperV(),ZeromV_V(),-1,GF(),0)  'Strain calculation
    CallTable STRAIN
    CallTable Calib
  Next Scan                               'Loop up for the next scan

  SlowSequence                            'Slow sequence Scan to perform temperature
    Scan(1,Sec,0,0)                       'compensation on DAQ
```

```
      Calibrate                                 'Corrects ADC offset and gain
      BiasComp                                  'Corrects ADC bias current
    Next Scan
EndProg                                         'Program ends here
```

7.2.4.2 Shunt Calibration Lead Compensation for Three-Wire, Quarter-Bridge Strain

NOTE Although the following may seem complicated, the process of performing a shunt calibration is simple when using the *Calibration Wizard* utility found in Campbell Scientific's software packages.

Another method to compensate for sensitivity errors, and to calibrate the system (adjust system scaling), is to do a shunt calibration. This entails shunting a resistor across one of the arms of the bridge. The premise of a shunt calibration is that the shunted arm undergoes a reduction in resistance creating a simulated strain. The difference in strain reported by the system is checked against the actual simulated strain. Variance between the reported strain and the simulated strain can be corrected through adjusting the strain gage's gage factor (GF).

7.2.4.2.1 Three-Wire Gage Circuit with Shunt

There are two methods for performing a shunt calibration on a three-wire quarter-bridge strain circuit. The first is to shunt across the active gage remotely, and the second is to shunt across the dummy resistor or dummy gage (dependent on which is employed in the circuit) back at the data logger.

For either shunt method, the dummy resistor should be a 0.02% precision or better resistor to ensure that its resistance is the nominal resistance of the active gage. In addition, it should have a low TCR to limit the errors introduced by the change in its resistance due to temperature variations. The shunt resistor should also have a precision of 0.02% or better and a low TCR.

7.2.4.2.1.1 Three-Wire Gage Circuit with Remote Shunt across the Active Gage

A three-wire quarter-bridge strain circuit with a shunt calibration resistor ready to shunt across the arm that holds the strain gage is shown in FIGURE 7-11.

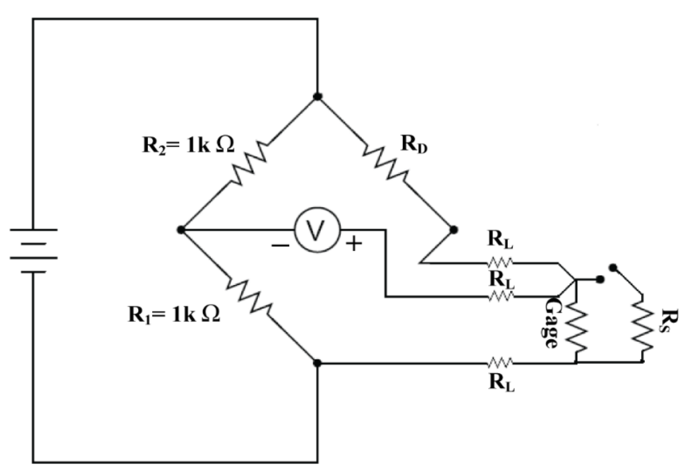

FIGURE 7-11. Shunting remotely across active gage

R_L represents the line resistances. R_D is the resistor in the arm next to the active gage which has a resistance equal to the nominal resistance of the strain gage and is referred to as the dummy resistor. R_s is the shunt resistor. This setup is the classical method for shunting a three-wire quarter-bridge strain circuit.

7.2.4.2.1.2 Three-Wire Gage Circuit with Shunt across the Dummy Resistor

Shunting across the active gage is frequently impractical due to inaccessibility or protective coatings across the gage and leads, which precludes getting an electrical contact across the gage. For these types of applications, it is more convenient to place a shunt resistor across the Wheatstone bridge arm that holds the dummy resistor, R_D. FIGURE 7-12 shows a three-wire quarter-bridge strain circuit for shunting across the dummy resistor.

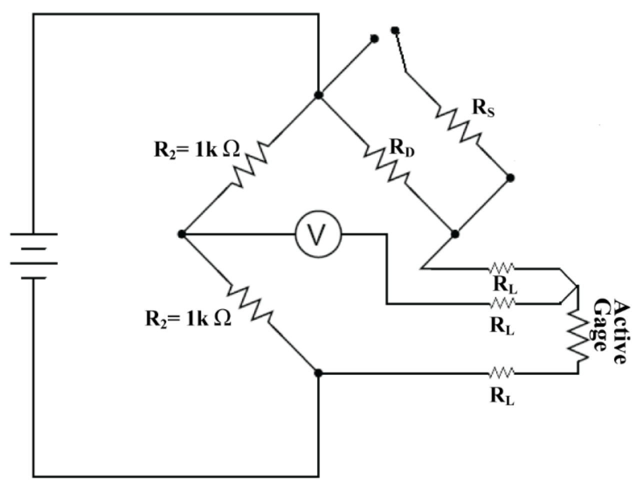

FIGURE 7-12. Circuit for shunting across dummy resistor

NOTE It should be noted that a shunt resistor should not be connected across the active gage's leads back at the completion portion of the Wheatstone bridge, as this would not correctly account for the leads resistances. If performing a shunt back at the instrumentation location, it must be done across the dummy resistor as shown in FIGURE 7-12.

The 4WFBS TIM modules include 2 gold plated, shunt pin receptacles to facilitate easy access to the internal dummy resistor. These receptacles, which accept 0.015 to 0.025 inch diameter pins, are depicted in FIGURE 7-13.

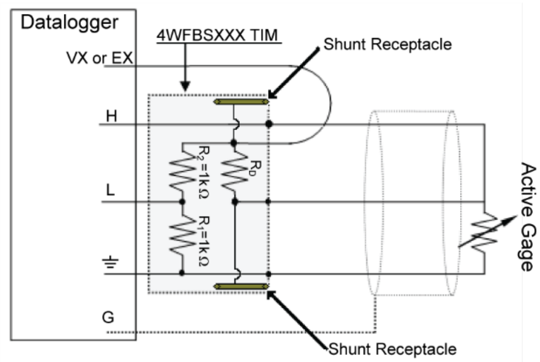

FIGURE 7-13. Wiring for shunt across dummy resistor

To shunt the dummy resistor, simply connect the resistor across the two gold plated shunt receptacles so that it is in parallel with the dummy resistor.

7.2.4.2.2 Math for Shunt Calibration of Three-Wire, Quarter-Bridge Strain Circuits

NOTE The math in this section is done automatically for the user by the data logger's operating system. It is included here mainly for reference and for users with our older data loggers that are not supported by the *Calibration Wizard* and higher end instructions. The *Calibration Wizard* utility which is installed with Campbell Scientific's software packages greatly simplifies the calibration process.

The premise is the same when shunting across either arm. The shunted arm undergoes a reduction in resistance creating a simulated strain. The change in resistance of the shunted arm is given by Equation 7-18:

$$\frac{\Delta R}{R_G} = \frac{-R_G}{R_G + R_S} \qquad \text{7-18}$$

Variable definitions:

ΔR = Change in arm resistance (ohms)

R_G = Nominal gage resistance (ohms)

R_S = Shunt resistor resistance (ohms)

If shunting across the active gage, the resistance of the active arm will decrease, reducing the output from the Wheatstone bridge simulating a compressive or negative strain. If shunting across the dummy resistor, the resistance of the inactive arm will decrease, increasing the output from the Wheatstone bridge simulating a tensile or positive strain. A precision resistor (0.02% or better) with an adequate temperature coefficient of resistance (~4 ppm/°C) should be used for the shunt resistor.

In order to perform a shunt calibration, first record an initial strain reading, next contact the leads of the shunt resistor to the gold-plated shunt receptacles, and record a secondary strain reading that will include the simulated strain.

Take the difference between the two readings to get this recorded simulated strain ($\mu\varepsilon_R$) created by the shunting process.

We will need to compare this recorded strain value with the calculated strain value. Equation 7-19 is the standard equation for calculating the microstrain from the change in the resistance of the gage:

$$\mu\varepsilon = \frac{\Delta R \bullet 10^6}{R_G \bullet GF} \qquad \text{7-19}$$

Variable definitions:

$\mu\varepsilon$ = microstrain

ΔR = change in arm resistance (ohms)

R_G = Nominal gage resistance (ohms)

GF = Gage factor

Combining Equations 7-18 and 7-19 results in Equation 7-20 that is used for calculating the simulated strain that is induced by the shunt resistor:

$$\mu\varepsilon_S = \frac{-R_G \bullet 10^6}{(R_G + R_S) \bullet GF} \qquad \text{7-20}$$

Variable definitions:

$\mu\varepsilon_S$ = Simulated microstrain created by shunt resistor

R_S = Shunt resistor value (ohms)

R_G = Nominal gage resistance (ohms)

GF = Gage factor

The calculated strain, $\mu\varepsilon_S$, is compared to the strain readout, $\mu\varepsilon_R$, from the instrumentation. A multiplier is derived from the ratio, $\mu\varepsilon_R/\mu\varepsilon_S$. The gage factor is multiplied by this factor to derive an adjusted gage factor for the system, $GF_{Adj} = GF_{Raw} \bullet \mu\varepsilon_R/\mu\varepsilon_S$, that is used to correct the output from the instrumentation.

When performing recursive shunt calibrations, the original, raw gage factor supplied by the gage manufacturer should always be used for GF_{Raw}.

In some applications a dummy or inactive gage is used in place of the dummy resistor (See Section 7.2.3.1, *Quarter-Bridge Strain with Dummy Gage Wiring Setup* *(p. 15)*). The scheme and underlying equations are the same for this type of circuit. The only difference is that you do not use the gold-plated shunt receptacles on the 4WFBS module to access the internal matching resistor, as this resistor is not used.

When performing a shunt calibration, it is usually preferable to use a resistor that will simulate a strain level within the range between 500 and 1000 uStrain.

NOTE When carrying out both a zero and a shunt calibration, always do a zero calibration after the shunt calibration is complete to ensure that the zero microstrain reading is calculated using the adjusted gage factor.

7.2.4.2.3 Example Programs for Shunt Calibration of Three-Wire, Quarter-Bridge Strain Circuits

CRBasic Example 7-6 starts out with CRBasic Example 7-2 and adds instructions to perform a shunt calibration. Added instructions are highlighted.

A **FieldCalStrain()** instruction takes care of the underlying math for the shunt calibration. Use the *Calibration Wizard* utility supplied with Campbell Scientific's software to simplify the shunt calibration process.

NOTE When carrying out both a zero and a shunt calibration, always do a zero calibration after the shunt calibration is complete to ensure that the zero microstrain reading is calculated using the adjusted gage factor.

CRBasic Example 7-6. CR9000X Quarter-Bridge Strain with Zero Offset and Shunt Calibration

```
'Program name: StrainSh.C9X
Public StrainMvperV(3)  :  Units StrainMvperV = mV_per_V  'Raw Strain dimensioned source
Public Strain(3)        :  Units Strain = uStrain         'uStrain dimensioned source
Public GF(3)                                              'Dimensioned gage factor
Public ZeromV_V(3), ZeroStrain(3) ZReps, ZIndex, ModeVar
Public  GF_Adjusted(3),  KnownRs(3), ShuntReps, ShuntIndex,ModeShunt
Dim I

DataTable(STRAIN,True,-1)                  'Trigger, auto size
  DataInterval(0,0,0,100)                  'Synchronous, 100 lapses, autosize
  CardOut(0,-1)                            'PC card , size Auto
  Sample (3,Strain(),IEEE4)                '3 Reps, uStrain, Resolution
  Sample (3,StrainMvperV(),IEEE4)          '3Reps,Stain mVolt/Volt, Resolution
EndTable                                   'End of table STRAIN

DataTable (Calib,NewFieldCal,10)           'Table for calibration factors from zeroing
  SampleFieldCal                           'User should collect these to his computer
EndTable                                   'for future reference

BeginProg                                  'Program begins here
  GF(1) = 2.1  :  GF(2) = 2.2  :  GF(3) = 2.3  'Initialize gage factors for Strain( )
  ZReps = 3  :  ZIndex = 1                 'initialize cal reps and index pointer
For I = 1 To 3                             'Initialize adjusted gage factors to raw gage factors
GF_Adjusted(I) = GF(I)
Next I
ZReps = 3  :  ZIndex = 1
  LoadFieldCal(True)                       'Load prior calibration factors

  Scan(10,mSec,100,0)                      'Scan once every 10 mSecs, non-burst
    FieldCalStrain(10,StrainMvperV(),ZReps,0,ZeromV_V(),ModeVar,0,ZIndex,1,0,Strain())
    FieldCalStrain (13,Strain(),ShuntReps,GF_Adjusted,0,ModeShunt,KnownRs,ShuntIndex,1,GF(),0)
    BrFull(StrainMvperV(),3,mV50,4,1,5,7,1,5000,True,True,70,100,1,0)
    StrainCalc(Strain(),3,StrainMvperV(),0,-1,GF(),0)  'Strain calculation
    CallTable STRAIN
    CallTable Calib
  Next Scan                                'Loop up for the next scan

  SlowSequence                             'Slow sequence Scan to perform temperature
    Scan(1,Sec,0,0)                        'compensation on DAQ
      Calibrate                            'Corrects ADC offset and gain
      BiasComp                             'Corrects ADC bias current
    Next Scan
EndProg                                    'Program ends here
```

7.2.4.3 Lead Compensation using Quarter-Bridge Strain with Two-Wire Element

NOTE If the leads become so long that lead resistance compensation calculations are required, then a two-wire gage should not be utilized. It would be difficult to mathematically compensate, and even though a shunt calibration is possible, false readings due to lead wire temperature changes would in most cases inject more error than the sensitivity change due to the leads resistances. Instead a three-wire gage should be utilized.

This section covers some of the errors introduced into the measurement using this type of circuit with long leads. This is not to show how to perform lead compensation using a two-wire gage, but to discourage its practice.

A two-wire quarter-bridge strain circuit is shown in FIGURE 7-14.

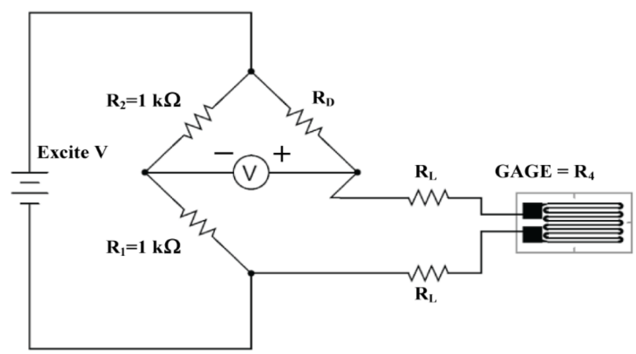

FIGURE 7-14. Two wire quarter-bridge strain circuit

In this circuit, R1 and R2 are 1000 ohm resistors making up the backplane of the Wheatstone bridge, as is done in the TIM design. R_D is the complementary resistor that has a nominal resistance of the unstrained gage. The 4th resistive element is the active strain gage. In most applications, the gage is some distance from the other components of the Wheatstone bridge. R_L represents the resistance of the wire leads returning from the two sides of the gage. It is normally assumed that the length of the two wires is equal and thus the two lead resistances are equal; R_L. As can be seen in this circuit, the two R_Ls are both included in the arm of the bridge containing the strain gage. This results in Equation 7-21 for solving the strain from the voltage ratio (V_r: reference Equation 7-4).

$$\varepsilon = \frac{4V_r\left(1 + {R_L}/{R_G}\right)^2}{\left(1 - 2V_r\left(1 + {R_L}/{R_G}\right)\right)GF} \qquad \text{7-21}$$

This results in a nonlinear relationship between the strain and the line resistance. In addition to this non-linear relationship in the gain, having both lines in the same arm of the bridge results in an offset error as the line resistance (R_L) changes due to temperature effects. These offset errors can easily outweigh any legitimate measurements.

Take for example a 120 ohm two-wire gage with 100 foot leads of 20 gage copper wire. Copper wire has a temperature coefficient of resistance of about +3930 ppm (or 0.393%) per °C. The initial resistance for the 200 foot combined leads is 2.000 ohms @ 24 °C. If the temperature were to drop 20 °C, the change in resistance would be 0.127 ohms:

$$0.127\Omega = 20°C \bullet \frac{0.00393\Omega/_{\Omega}}{°C} \bullet 2\Omega$$

Equation 7-2, from Section 7.1, *Measurement Concepts* *(p. 3)*, derives strain as a function of resistance:

$$\varepsilon = \frac{\Delta R_G}{GF \bullet R_G}$$

As mentioned before in Section 7.1, *Measurement Concepts* *(p. 3)*, strain is typically reported in microstrain (με). Microstrain is strain expressed in parts per million, i.e., a change in length by one millionth of the length. Equation 7-3, again from Section 7.1, *Measurement Concepts* *(p. 3)*, derives microstrain as a function of resistance.

$$\mu\varepsilon = \frac{10^6 \cdot \Delta R_G}{GF \bullet R_G}$$

Entering 0.127 Ω for ΔR_g, 2 for the gage factor (GF), and 120 Ω for R_g, the apparent or false strain reading indicated would be 529 με.

7.2.5 Calculation of Strain for Quarter-Bridge Circuits

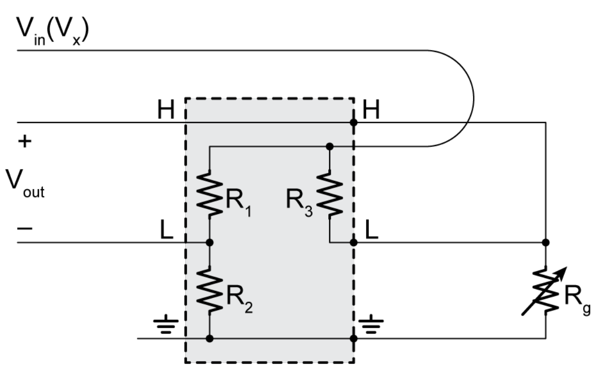

FIGURE 7-15. Strain gage in full-bridge

FIGURE 7-15 is the diagram of the strain gage in the full-bridge configuration provided by the terminal input module. The data logger full-bridge measurement, **BrFull()**, outputs the ratio X in mV/V as shown in the following equation:

$$X = 1000 \bullet \frac{V_{out}}{V_{in}} = 1000 \bullet \left(\frac{R_g}{R_3 + R_g} - \frac{R_2}{R_1 + R_2}\right) \qquad \text{7-22}$$

When strain is calculated, the direct ratio of the voltages (V/V, not mV/V) is used:

$$\frac{V_{out}}{V_{in}} = 0.001 \cdot X = \frac{R_g}{R_3 + R_g} - \frac{R_2}{R_1 + R_2} \qquad \text{7-23}$$

If the previous measurement is taken when the gage is unstrained, then when the gage is strained it will change resistance by ΔR_g. The equation for the bridge output is:

$$\left(\frac{V_{out}}{V_{in}}\right)_{Strained} = 0.001 \cdot X_{Strained} = \frac{R_g + \Delta R_g}{R_3 + R_g + \Delta R_g} - \frac{R_2}{R_1 + R_2} \qquad \text{7-24}$$

Subtracting the unstrained (zero) result from the strained result gives V_r:

$$V_r = \left(\frac{V_{out}}{V_{in}}\right)_{Strained} - \left(\frac{V_{out}}{V_{in}}\right)_{Unstrained} = 0.001(X_{Strained} - X_{Unstrained}) \qquad \text{7-25}$$

In *Short Cut* generated programs, this is:

```
Vr=0.001 (Vr1000-BrZero)
```

Solving for strain:

$$V_r = \frac{R_g + \Delta R_g}{R_3 + R_g + \Delta R_g} - \frac{R_g}{R_3 + R_g}$$

$$V_r = \frac{R_3 \bullet \Delta R_g}{(R_3 + R_g + \Delta R_g) \bullet (R_3 + R_g)}$$

Because the terminal input module is selected so that $R_3 = R_g$, we can substitute R_g for R_3:

$$\boldsymbol{V_r = \frac{R_g \bullet \Delta R_g}{(R_g + R_g + \Delta R_g) \bullet (R_g + R_g)} = \frac{R_g \bullet \Delta R_g}{4R_g^2 + 2R_g\Delta R_g} = \frac{\Delta R_g}{4R_g + 2\Delta R_g}}$$

$$(4R_g + 2\Delta R_g)V_r = \Delta R_g$$

$$4R_gV_r + 2\Delta R_gV_r = \Delta R_g$$

$$4R_gV_r = \Delta R_g - 2\Delta R_gV_r$$

$$4R_gV_r = \Delta R_g(1 - 2V_r)$$

$$\frac{4V_r}{1 - 2V_r} = \frac{\Delta R_g}{R_g} \qquad \text{7-26}$$

Strain is calculated by dividing Equation 7-26 by the gage factor. The units are converted to microstrain by multiplying by 10^6 µS/S.

$$\mu\varepsilon = \frac{4 \bullet 10^6 V_r}{GF(1-2V_r)} = \frac{10^6 \Delta R_g}{GF \bullet R_g} \quad \text{7-27}$$

7.3 Half-Bridge Strain Circuit

A half-bridge strain circuit is so named because two arms, half of the Wheatstone bridge, are composed of active gages. The other two arms of the bridge are composed of inactive elements. There are various Wheatstone bridge circuits that use two active elements, including setups that have the gages perpendicular to each other that require knowledge about the material's Poisson's ratio, circuits that have the gages residing adjacent to each other in the Wheatstone bridge (bending strain), and circuits that have the active gages diagonally opposed to each other in the Wheatstone bridge (axial strain).

Shunt Calibration: When performing a shunt calibration on a half-bridge strain circuit, it should be done remotely across one of the active gages. It could also be accomplished through running an extra pair of leads to be shunted at the data logger location. If this is done, it is recommended to take into account the resistance of the leads in addition to the shunt resistor's resistance.

7.3.1 Advantages/Strengths verses Disadvantages/Weaknesses

Compared to Quarter-Bridge Strain: The advantage of using the half-bridge strain is that the bridge output is almost doubled, and you can get better temperature compensation. Another advantage of the half-bridge strain is that the two active strain gages can be placed on the opposite sides of a member to measure only bending strains, removing the axial strain component.

It can be harder to install and is usually more expensive than a three-wire quarter-bridge strain gage.

Compared to Full-Bridge Strain: The main benefits include lower cost and the ability of measuring axial strain without using the Poisson's ratio. Also, you can remove the temperature-induced offset strains using dummy gages mounted on coupons of the same material, or, conversely, measure the temperature-induced stresses through using dummy gages mounted on coupons with a negligible thermo-coefficient of expansion.

The advantage of using the full-bridge strain is that the bridge output is almost doubled.

7.3.2 Half-Bridge Bending Strain

The half-bridge bending strain configuration is shown in FIGURE 7-16. It is used solely to measure bending strain. The two gages should be positioned on opposite sides of the member being measured such that they experience strains of equivalent magnitudes, but in opposite directions, as the member is bent. In other words, one gage would undergo compression while the other gage would experience tension. The backplane of the Wheatstone bridge (R_1 and R_2) can be made up of a matched pair as is done in the Campbell Scientific's 4WFBS TIM modules.

Using this configuration, axial strains would not be measured, as the resistance of Gage 1 and Gage 2 would move in the same direction, nulling the

Wheatstone bridge output. Axial induced temperature strains would also be nulled.

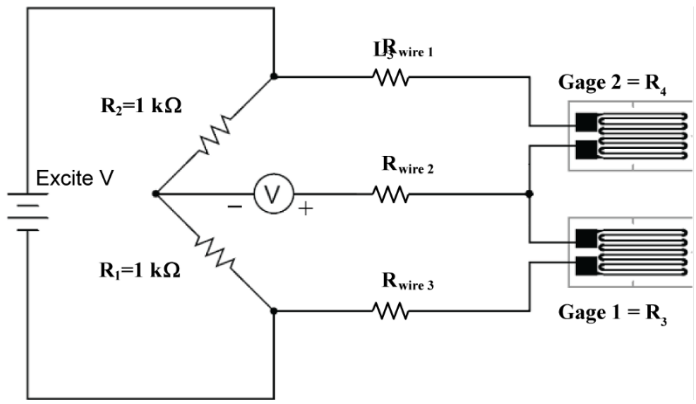

FIGURE 7-16. Half-bridge bending strain circuit

7.3.2.1 Half-Bridge Bending Strain Wiring

Campbell Scientific's 4WFBS terminal input modules can be utilized with this type of Wheatstone bridge circuit to supply the completion resistors on the back side of the Wheatstone bridge. FIGURE 7-17 depicts the wiring method to do so.

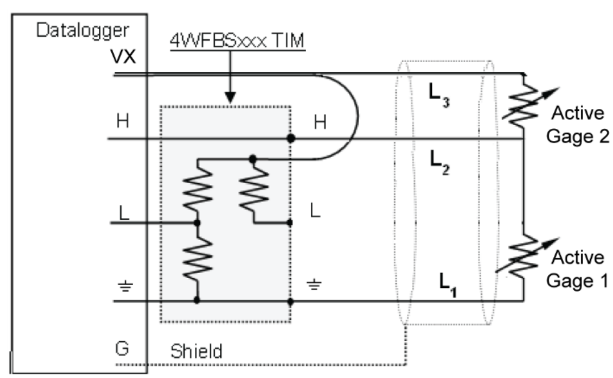

FIGURE 7-17. Half-bridge bending strain using a 4WFBS TIM

7.3.2.2 Half-Bridge Bending Calculations

The basic equation is the same as is used for quarter-bridge strain. The change in the full-bridge measurement from the zero state, V_r, is used in the calculation of the strain. From Equation 7-4:

$$V_r = (V_{out}/V_{in})_{Strained} - (V_{out}/V_{in})_{Zero}$$

The zero state equation looks very similar:

$$\left(\frac{V_{out}}{V_{in}}\right)_{Zero} = \frac{R_{G1}}{R_{G1} + R_{G2}} - \frac{R_1}{R_1 + R_2}$$

If the previous equation is taken as the result when the gages are unstrained, then when the gages are strained, they will change in opposite directions but with the same magnitude, ΔR_g. The equation for the bridge output is:

$$\left(\frac{V_{out}}{V_{in}}\right)_{Strained} = \frac{R_{G1} + \Delta R_{G1}}{(R_{G1} + \Delta R_1) + (R_{G2} + \Delta R_{G2})} - \frac{R_2}{R_1 + R_2}$$

Assume the $R_{G1} = R_{G2} = R_G$ and $\Delta R_{G1} = \Delta R_{G2} = \Delta R_G$, subtract the unstrained (zero) result from the strained result, and simplify to solve for V_r:

$$V_r = \left(\frac{V_{out}}{V_{in}}\right)_{Strained} - \left(\frac{V_{out}}{V_{in}}\right)_{Zero} = \frac{\Delta R_G}{2R_G}$$

or:

$$\frac{\Delta R_G}{R_G} = 2V_r \qquad \text{7-28}$$

From Equation 7-3 we know:

$$\mu\varepsilon = \frac{(1 \times 10^6)\Delta R_G}{GF \bullet R_G}$$

Substituting Equation 7-28 into Equation 7-2, we get:

$$\mu\varepsilon = \frac{(2 \times 10^6)V_r}{GF} \qquad \text{7-29}$$

Equation 7-29 is the equation used by the CRBasic **StrainCalc()** function when a **–3** is entered for the bridge configuration (***BrConfig***) parameter. Note that using a negative number for the bridge configuration code simply reverses the polarity of the output from the standard polarity.

Half-Bridge Bending CRBasic Programming: A program for measuring half-bridge bending strain, along with zeroing and shunt calibration functions, is very similar to a program for the quarter-bridge strain circuit covered in CRBasic Example 7-3. The only difference is the ***BrConfig*** option code should be set to **–3** for the circuit shown in FIGURE 7-16, and the function code for the **FieldCalStrain()** function should be set to **33**.

7.3.2.2.1 CR1000 Half-Bridge Strain with Three Reps Program Example

CRBasic Example 7-7 measures the output from the Wheatstone bridge using the **BrFull()** instruction. It uses the calibration sheet in FIGURE 7-4 (gage factor = 2.105). The output from this instruction is input into the **StrainCalc()** instruction in order to calculate the raw microstrain value. This program does not use a zero offset reading or shunt calibration.

CRBasic Example 7-7. CR6 Half-Bridge Bending Strain with Three Reps

```
'Program name: STRAINBend.CR6
Public StrainMvperV(3)   :  Units StrainMvperV = mV_per_V  'Raw Strain dimensioned source
Public Strain(3)         :  Units Strain = uStrain         'uStrain dimensioned source
Public GF(3)                                               'Dimensioned gauge factor

DataTable(Strain,True,-1)                                  'Trigger, auto size
  DataInterval(0,0,0,100)                                  'Synchronous, 100 lapses, autosize
  CardOut(0,-1)                                            'PC card , size Auto
  Sample (3,Strain(),IEEE4)                                '3 Reps, uStrain, Resolution
  Sample (3,StrainMvperV(),IEEE4)                          '3Reps,Stain mVolt/Volt, Resolution
EndTable                                                   'End of table STRAIN

BeginProg                                              'Program begins here
  GF(1) = 2.105 : GF(2) = 2.105 :  GF(3) = 2.105       'Initialize gauge factors for Strain( )
  Scan(100,mSec,100,0)                                 'Scan once every 10 mSecs, non-burst
    BrFull(StrainMvperV(),3,mV7_5,1,1,1,2500,True,True,500,500,1,0)
    StrainCalc(Strain(),3,StrainMvperV(),0,-3,GF(),0)  'Strain calculation
    CallTable Strain
  Next Scan                                            'Loop up for the next scan
EndProg                                                'Program ends here
```

The only change that is required for this measurement application from CRBasic Example 7-3 is to change the bridge configuration parameter from –1 to –3 (highlighted).

7.3.3 Half-Bridge Axial Strain

A half-bridge axial strain configuration is shown in FIGURE 7-18. This circuit will register tensile strain due to axial forces, as well as bending forces. It is a specialized circuit that is not as common as the other circuits covered in this text. It is covered because it is the circuit employed in the Hitec HBWF-35-250-6-XGP-NT strain sensor.

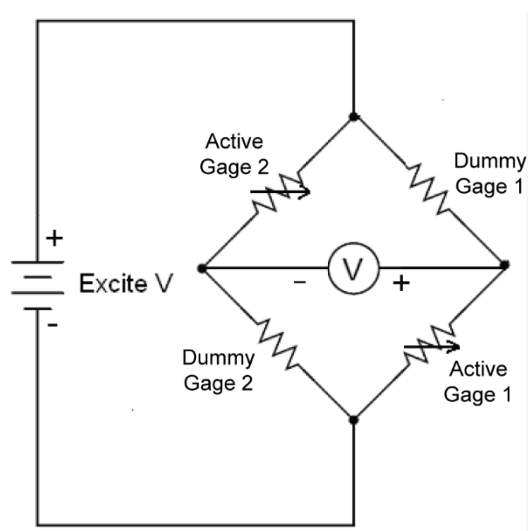

FIGURE 7-18. Half-bridge axial strain

As noted previously, an undesirable property of strain gages is that of resistance change with changes in temperature. (See Section 7.2.3, *Quarter-Bridge Strain with Dummy Gage* *(p. 14)*, for temperature-induced strain equations.) Dummy gages can be used to compensate for the majority of these false apparent strain readings.

7.3.3.1 Measurement Strain Sensor

Static strain sensors will usually have some method for removing the false temperature induced strain offset effects. These sensors can also be used successfully for dynamic strain measurement. With raw foil bonded gages, this can also be accomplished through the use of half-bridge strain or full-bridge strain Wheatstone bridge circuits.

7.3.3.1.1 Example of a Static Measurement Gage

The Hitec HBWF-35-250-6-XGP-NT is an example of a static strain sensor with a temperature compensating block. This design has two active gages diagonally opposed in the Wheatstone bridge. The two dummy gages are mounted on a coupon of the same material as the member being monitored. The coupon is designed to be non-constrained. This design compensates for the temperature-induced output of the gages. It should be noted that it also compensates for temperature-induced strains on the member. It does not remove temperature-induced stresses caused by the member being constrained during temperature-induced loading. In fact, it is one method employed to detect temperature-induced stresses, as the coupons with the dummy gages are free to expand/contract with temperature.

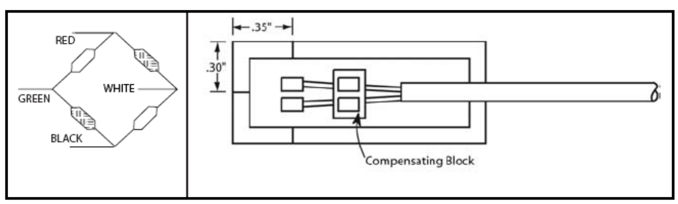

FIGURE 7-19. HBWF-35-250-6-XGP-NT Wheatstone bridge

7.3.3.1.1.1 Hitec HBWF-35-250-6-XGP-NT Calibration Sheet Example

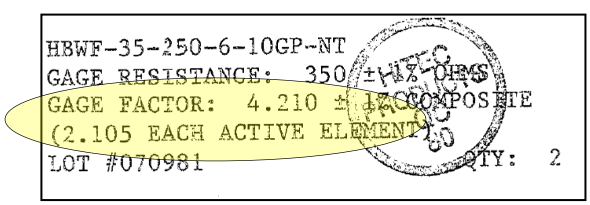

FIGURE 7-20. HBWF-35-250-6-XGP-NT calibration sheet

Hitec gages come with a calibration sticker on the box as shown in FIGURE 7-20. There is a composite gage factor (4.210 in example) to be used for measuring devices that can only be setup for measuring quarter-bridge strain (1 active element). This sensor actually consists of two active elements, but it should be measured as a quarter-bridge strain circuit with a multiplier of 0.5 for the **BrFull()** instruction. See 7.3.3, *Half-Bridge Axial Strain* *(p. 31)*. You will note that the individual gage factor is listed on this calibration sticker (2.105 EACH ACTIVE GAGE). This is the value that should be used for the gage factor in the **StrainCalc()** instruction.

7.3.3.1.1.2 HBWF-35-250-6-XGP-NT Example Program

CRBasic Example 7-8 was generated by the *Short Cut* program builder.

It measures a 350 Ohm half-bridge strain gage (two active elements) in a bending configuration (**StrainCalc** “3”). The **StrainCalc** parameter can be changed for other half bridge configurations.

FieldCalStrain instructions are incorporated in the program for shunt calibration of the gage (**Fieldcal** 33) or zeroing the gage offset (**FieldCal** 10). Both these calibration features are accessed with the Calibration Wizard in *LoggerNet* software. Calibration results are stored in the **CalHist** data table for reference.

CRBasic Example 7-8. CR6 Half-Bridge Strain with Zero Offset and Shunt Calibration

```
'CR6 Series
'Created by Short Cut (3.2)

'Declare Variables and Units
Public BattV
Public FCLoaded
Public PTemp_C
Public Strain
Public Vr1000
Public GFRaw
Public GFAdj
Public BrZero
Public CKnown
Public CReps
Public ZMode
Public QBSSMode
Public CIndex
Public CAvg

Units BattV=Volts
Units PTemp_C=Deg C
Units Strain=microstrain
Units Vr1000=mV/V
Units GFRaw=unitless
Units GFAdj=unitless
Units BrZero=mV/V

'Define Data Tables
DataTable(Table2,True,-1)
  DataInterval(0,1440,Min,10)
  Minimum(1,BattV,FP2,False,False)
EndTable

'Calibration history table
DataTable(CalHist,NewFieldCal,10)
  SampleFieldCal
EndTable

'Main Program
BeginProg
  'Initialize calibration variables for
  'Half Bridge Strain, 350 ohm with 4WFBS TIM measurement 'Vr1000'
  CIndex=1 : CAvg=1 : CReps=1 : GFRaw=2.0 : GFAdj=GFRaw
  'Load the most recent calibration values from the CalHist table
  FCLoaded=LoadFieldCal(True)
  'Main Scan
  Scan(5,Sec,1,0)
    'Default CR6 Data Logger Battery Voltage measurement 'BattV'
    Battery(BattV)
    'Default CR6 Data Logger Wiring Panel Temperature measurement 'PTemp_C'
    PanelTemp(PTemp_C,15000)
    'Half Bridge Strain, 350 ohm with 4WFBS TIM measurement 'Vr1000'
    BrFull(Vr1000,1,mV200,U1,U3,1,2500,True,True,500,15000,1,0)
    'Calculated strain result 'Strain' for
    'Half Bridge Strain, 350 ohm with 4WFBS TIM measurement 'Vr1000'
    StrainCalc(Strain,1,Vr1000,BrZero,3,GFAdj,0)
    'Bending half bridge strain shunt calibration for
    'Half Bridge Strain, 350 ohm with 4WFBS TIM measurement 'Vr1000'
    FieldCalStrain(33,Strain,1,GFAdj,0,QBSSMode,CKnown,CIndex,CAvg,GFRaw,0)
    'Zeroing calibration for
    'Half Bridge Strain, 350 ohm with 4WFBS TIM measurement 'Vr1000'
    FieldCalStrain(10,Vr1000,CReps,0,BrZero,ZMode,0,CIndex,CAvg,0,Strain)
    'Call Data Tables and Store Data
    CallTable Table2
    CallTable CalHist
  NextScan
EndProg
```

7.3.3.2 Half-Bridge Axial Strain Wiring

Campbell Scientific's 4WFBS terminal input modules CANNOT be utilized with this type of Wheatstone bridge circuit to supply the completion resistors on the back side of the Wheatstone bridge. This circuit is normally deployed in bridge sensors that will supply all of the legs of the Wheatstone bridge. If not, the user will have to supply them at the gage location. Do not complete the Wheatstone bridge at the data logger, as not only will this defeat the temperature compensation purpose of this circuit, but it can also lead to lead wire errors.

7.3.3.3 Half-Bridge Axial Strain Equations and Programming

The basic equation is the same as is used for half-bridge bending strain (see Section 7.3.2.2, *Half-Bridge Bending Calculations* *(p. 29)*). The change in the full-bridge measurement from the zero state, V_r, is used in the calculation of the strain. From Equation 7-4:

$$V_r = (V_{out}/V_{in})_{Strained} - (V_{out}/V_{in})_{Zero}$$

The zero state equation looks very similar:

$$\left(\frac{V_{out}}{V_{in}}\right)_{Zero} = \frac{R_{G1}}{R_{G1} + R_{D1}} - \frac{R_{D2}}{R_{D1} + R_{G2}}$$

If the previous equation is taken as the result when the gages are unstrained, then when the active gages are strained, they will change in the same direction with the same magnitude, ΔR_g. The equation for the bridge output is:

$$\left(\frac{V_{out}}{V_{in}}\right)_{Strained} = \frac{R_{G1} + \Delta R_{G1}}{(R_{G1} + \Delta R_G) + R_{D1}} - \frac{R_{D2}}{R_{D1} + (R_{G2} + \Delta R_G)}$$

Assume the $R_{G1} = R_{G2} = R_{D1} = R_{D1} = R_G$ and subtract the unstrained (zero) result from the strained result, and simplify to solve for V_r:

$$V_r = \left(\frac{V_{out}}{V_{in}}\right)_{Strained} - \left(\frac{V_{out}}{V_{in}}\right)_{Zero} = \frac{\Delta R_G}{2R_G + \Delta R_G}$$

Solve for $\frac{\Delta R_g}{R_g}$

$$\frac{\Delta R_G}{R_G} = \frac{2V_r}{1 - V_r} \qquad \text{7-30}$$

From Equation 7-3 we know:

$$\mu\epsilon = \frac{(1 \times 10^6)\Delta R_G}{GF \bullet R_G}$$

Substituting Equation 7-30 into Equation 7-3, we get:

$$\mu\varepsilon = \frac{2 \times 10^6 V_r}{GF(1 - V_r)} = \frac{10^6 \Delta R_g}{GF \bullet R_g} \qquad 7\text{-}31$$

Equation 7-31 is not one of the standard Wheatstone bridge equations and is not one that is directly supported by the CRBasic **StrainCalc()** function. But if we compare it to Equation 7-27:

$$\mu\varepsilon = \frac{4 \times 10^6 V_r}{GF(1 - 2V_r)} = \frac{10^6 \Delta R_g}{GF \bullet R_g} \qquad 7\text{-}32$$

We can see that if we enter $V_r/2$ into this equation in place of V_r, that it matches Equation 7-31. So we can simply enter 0.5 for the multiplier in the **BrFull()** measurement instruction and setup the **StrainCalc()** function as quarter-bridge strain. Zeroing and shunt calibration would all use the same settings as the quarter-bridge strain.

Half-Bridge Axial CRBasic Programming: A program for measuring half-bridge bending strain, along with zeroing and shunt calibration functions, is very similar to a program for the quarter-bridge strain circuit covered in Section 7.2.1.3.1, *CRBasic Programming* (p. 9), and Section 7.2.4.1, *Mathematical Lead Compensation for Three-Wire, Quarter-Bridge Strain* (p. 17). The only difference is that the **BrFull()** instruction's multiplier parameter should be set to 0.5 instead of 1.0.

7.3.3.3.1 Half-Bridge Axial Strain with Zero and Shunt Calibration Program Example

CRBasic Example 7-9 is set to measure three half-bridge axial strain circuits as depicted in FIGURE 7-18. It includes zeroing and a shunt calibration functions. A **FieldCalStrain()** instruction takes care of the underlying math for the shunt calibration. Use the *Calibration Wizard* utility supplied with Campbell Scientific's software to simplify the shunt calibration process. Note that it will refer to the shunt calibration as a quarter-bridge strain, even though there are two active gages in the circuit.

NOTE When carrying out both a zero and a shunt calibration, always do a zero calibration after the shunt calibration is complete to ensure that the zero microstrain reading is calculated using the adjusted gage factor.

CRBasic Example 7-9. CR6 Half-Bridge Strain with Zero Offset and Shunt Calibration

```
'Program name: StrainaxialhalfSh.CR6
Public StrainMvperV(3)                                'Raw Strain dimensioned source
Units StrainMvperV = mV_per_V
Public Strain(3)                                      'uStrain dimensioned source
Units Strain = uStrain
Public GF(3)                                          'Dimensioned gauge factor
Public ZeromV_V(3), ZReps, ZIndex, ModeVar,
Public  GF_Adjusted(3),  KnownRs(3), ShuntReps, ShuntIndex,ModeShunt
Dim I

DataTable(Strain,True,-1)                             'Trigger, auto size
  DataInterval(0,0,0,100)                             'Synchronous, 100 lapses, autosize
  CardOut(0,-1)                                       'PC card , size Auto
  Sample (3,Strain(),IEEE4)                           '3 Reps, uStrain, Resolution
  Sample (3,StrainMvperV(),IEEE4)                     '3Reps,Stain mVolt/Volt, Resolution
EndTable                                              'End of table STRAIN

DataTable (Calib,NewFieldCal,10)                      'Table for calibration factors from zeroing
  SampleFieldCal                                      'User should collect these to his computer
EndTable                                              'for future reference

BeginProg                                             'Program begins here
  GF(1) = 2.105 : GF(2) = 2.105 : GF(3) = 2.105       'Initialize gauge factors for Strain( )
  ZReps = 3 : ZIndex = 1                              'initialize cal reps and index pointer
  For I = 1 To 3                            'Initialize adjusted gage factors to raw gage factors
    GF_Adjusted(I) = GF(I)
  Next I
  ZReps = 3  :  ZIndex = 1
  LoadFieldCal(True)                                  'Load prior calibration factors

  Scan(100,mSec,100,0)                                'Scan once every 10 mSecs, non-burst
    FieldCalStrain(10,StrainMvperV(),ZReps,0,ZeromV_V(),ModeVar,0,ZIndex,1,0,Strain())
    FieldCalStrain (13,Strain(),ShuntReps,GF_Adjusted,0,ModeShunt,KnownRs,ShuntIndex,1,GF(),0)
    BrFull(StrainMvperV(),3,mV200,U1,U9,1,2500,True,True,500,500,0.5,0)
    StrainCalc(Strain(),3,StrainMvperV(),ZeromV_V(),2,GF_Adjusted(),0)  'Strain calculation
    CallTable Strain
    CallTable Calib
  Next Scan                                           'Loop up for the next scan
EndProg                                               'Program ends here
```

Limited Warranty

Products manufactured by Campbell Scientific are warranted by Campbell Scientific to be free from defects in materials and workmanship under normal use and service for twelve months from the date of shipment unless otherwise specified on the corresponding product webpage. See Product Details on the Ordering Information pages at *www.campbellsci.com*. Other manufacturer's products, that are resold by Campbell Scientific, are warranted only to the limits extended by the original manufacturer.

Refer to *www.campbellsci.com/terms#warranty* for more information.

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Assistance

Products may not be returned without prior authorization.

Products shipped to Campbell Scientific require a Returned Materials Authorization (RMA) or Repair Reference number and must be clean and uncontaminated by harmful substances, such as hazardous materials, chemicals, insects, and pests. Please complete the required forms prior to shipping equipment.

Campbell Scientific regional offices handle repairs for customers within their territories. Please see the back page for the Global Sales and Support Network or visit *www.campbellsci.com/contact* to determine which Campbell Scientific office serves your country.

To obtain a Returned Materials Authorization or Repair Reference number, contact your CAMPBELL SCIENTIFIC regional office. Please write the issued number clearly on the outside of the shipping container and ship as directed.

For all returns, the customer must provide a "Statement of Product Cleanliness and Decontamination" or "Declaration of Hazardous Material and Decontamination" form and comply with the requirements specified in it. The form is available from your CAMPBELL SCIENTIFIC regional office. Campbell Scientific is unable to process any returns until we receive this statement. If the statement is not received within three days of product receipt or is incomplete, the product will be returned to the customer at the customer's expense. Campbell Scientific reserves the right to refuse service on products that were exposed to contaminants that may cause health or safety concerns for our employees.

Safety

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.com. 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 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

- Protect from over-voltage.
- Protect electrical equipment from water.
- Protect from electrostatic discharge (ESD).
- Protect from lightning.
- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations.
- 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.
- Only use power sources approved for use in the country of installation to power Campbell Scientific devices.

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.

Internal Battery

- Be aware of fire, explosion, and severe-burn hazards.
- Misuse or improper installation of the internal lithium battery can cause severe injury.
- Do not recharge, disassemble, heat above 100 °C (212 °F), solder directly to the cell, incinerate, or expose contents to water. Dispose of spent batteries properly.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER 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.

INFO

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

Global Sales & Support Network

A worldwide network to help meet your needs

Campbell Scientific Regional Offices

Australia

Location: Garbutt, QLD Australia
Phone: 61.7.4401.7700
Email: info@campbellsci.com.au
Website: www.campbellsci.com.au

Brazil

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Email: vendas@campbellsci.com.br
Website: www.campbellsci.com.br

Canada

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Phone: 66.2.719.3399
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Website: www.campbellsci.asia

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Email: sales@campbellsci.co.uk
Website: www.campbellsci.co.uk

USA

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