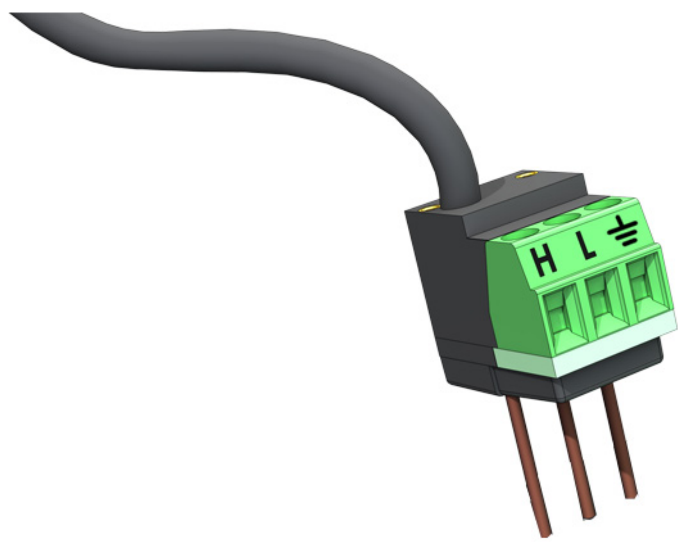
INSTRUCTION MANUAL

4WFBS120, 4WFBS350, 4WFBS1K 4 Wire Full Bridge Terminal Input Modules

Revision: 3/12



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About this manual

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

Some useful conversion factors:

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

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

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Table

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

1. Function

The 4WFBS120, 4WFBS350, and 4WFBS1K Terminal Input Modules (TIM) 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 a 120 ohm, 350 ohm, 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 ¼ bridge strain circuit (1 active element) using a dummy gage, or in a ½ bridge strain circuit (2 active elements).

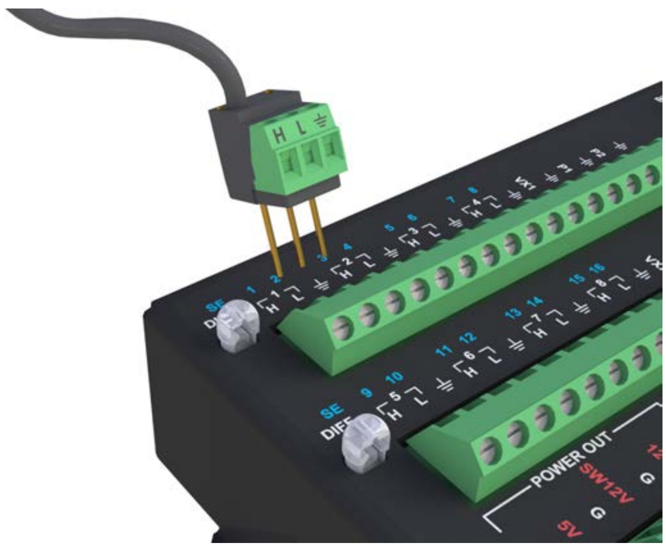


FIGURE 1-1. Terminal Input Module with CR1000

2. Specifications

2:1 Resistive Divider

Resistors:	1 kΩ/1 kΩ
Ratio tolerance @ 25 °C:	±0.01%
Ratio temperature coefficient:	0.5 ppm/°C (-55°C 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°C to 85°C)
Power rating:	0.25 W @ 70°C

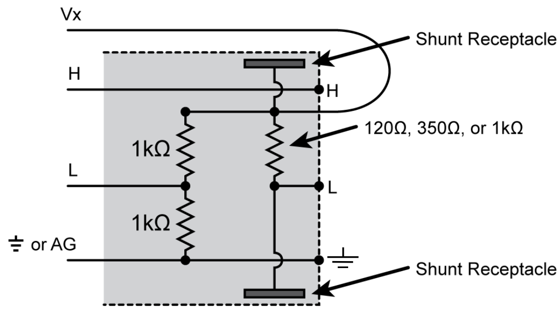


FIGURE 2-1. Schematic

3. 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 $\left(\varepsilon = \Delta L / L\right)$, and thus is dimensionless.

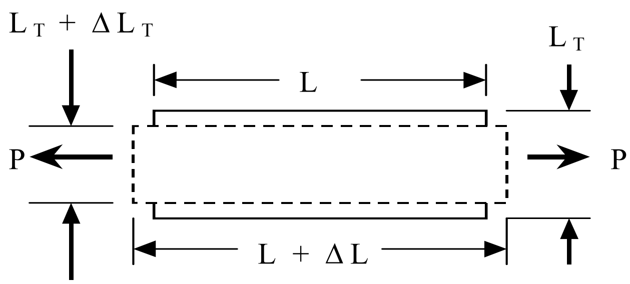


FIGURE 3-1. Strain definition

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 ratio (ν).

$$\nu = \frac{\Delta L_T / L_T}{\Delta L / L} \qquad 3.1$$

This Poisson 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 $(\mu\varepsilon)$. 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: $GF = \Delta R / R \big/ \Delta l / l$. For example, a gage factor of 2 means that if the length changes by one micrometer per meter of length $(1\,\mu\varepsilon)$, the resistance will change by two micro-ohms per ohm of resistance. A more common method of portraying this equation is:

$$\varepsilon = \frac{\Delta R_G}{GF \bullet R_G} \tag{3.2}$$

Or in terms of micro-strain:

$$\mu\varepsilon = \frac{(1 \times 10^6)\Delta R_G}{GF \bullet R_G} \tag{3.3}$$

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 4-1). There are two 1000 ohm precision resistors for the back plane 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 gauge, or to use two active gauges (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 datalogger 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 divided by the bridge excitation voltage: V_{out} / V_{ex}.

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

$$V_r = (V_{out} / V_{ex})_{Strained} - (V_{out} / V_{ex})_{Zero} \tag{3.4}$$

The result of the zero measurement, $\cdot(V_{out} / V_{ex})_{Zero}$, 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 ($1000 \cdot V_{out} / V_{ex}$). The StrainCalc function used in CRBasic uses this raw output as its input to calculate µstrain. See **Section 4.5** *Calculation of Strain for ¼ Bridge Circuits* for a detailed derivation of the equations used.

4. 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 2-Wire gauges, 3-Wire gauges, as well as a few circuits that utilize a dummy gauge for the arm opposite the arm holding the active gage instead of a resistor, R_D in Figure 4.1.-1 (See Figures 4.3-1, 4.3-2, and 4.3-3). The 4WFBS TIM modules can support all types of these ¼ Bridge Strain circuits.

4.1 Quarter Bridge Strain with 3 Wire Strain Element

A 3-wire quarter bridge strain circuit is shown in figure 4.1-1. 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 3-Wire circuit (e.g., the 4WFBS120 is used with a 120 ohm strain gage).

In Figure 4.1-1, R_1 and R_2 are 1000 ohm resistors making up the back plane 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.

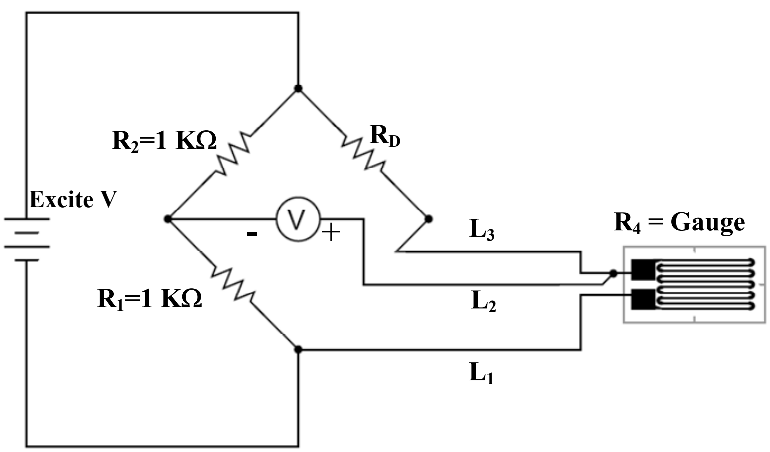


FIGURE 4.1-1. Three wire quarter bridge strain circuit

The 3-Wire gage alleviates many of the issues of the 2-Wire gage. As can be seen in Figure 4.1-1, 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 datalogger that has an input resistance greater than 1 Gohm, 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 gauge. See Section 4.4 for more on Lead resistance effects and methods to compensate for them.

4.1.1 Quarter Bridge Strain with 3 Wire Element Wiring

Figure 4.1-2 illustrates the wiring of the strain gage to the 4WFBS module and the wiring of the module to the datalogger. 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.

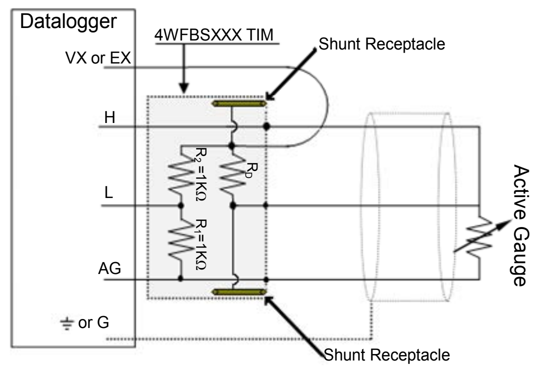
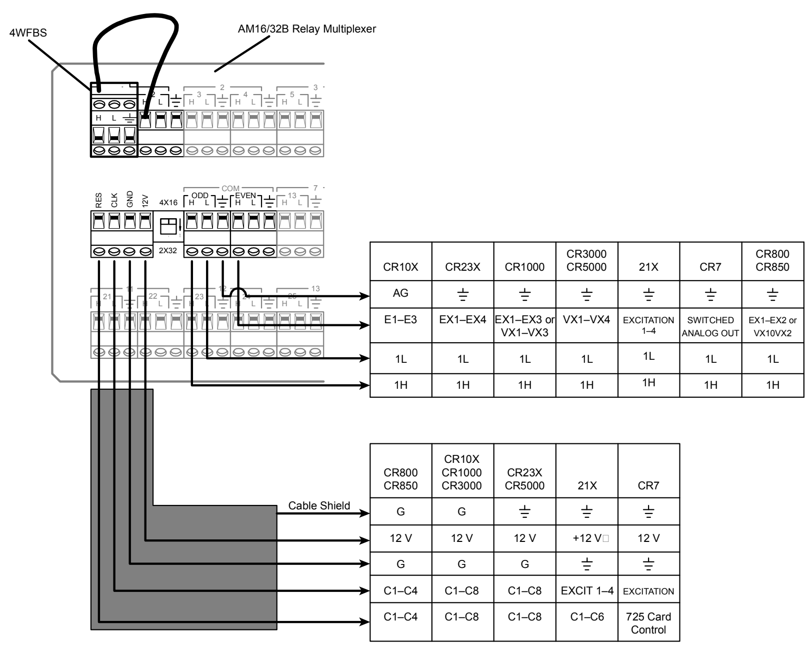


FIGURE 4.1-2. 3-wire ¼ bridge strain wiring

4.1.1.1 Quarter Bridge Strain with 3 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 4.1-3.



CR10X	CR23X	CR1000	CR3000 CR5000	21X	CR7	CR800 CR850
AG	⏚	⏚	⏚	⏚	⏚	⏚
E1–E3	EX1–EX4	EX1–EX3 or VX1–VX3	VX1–VX4	EXCITATION 1–4	SWITCHED ANALOG OUT	EX1–EX2 or VX1–VX2
1L	1L	1L	1L	1L	1L	1L
1H	1H	1H	1H	1H	1H	1H

CR800 CR850	CR10X CR1000 CR3000	CR23X CR5000	21X	CR7
G	G	⏚	⏚	⏚
12 V	12 V	12 V	+12 V	12 V
G	G	G	⏚	⏚
C1–C4	C1–C8	C1–C8	EXCIT 1–4	EXCITATION
C1–C4	C1–C8	C1–C8	C1–C6	725 Card Control

FIGURE 4.1-3. 3-wire ¼ bridge strain with multiplexer wiring

Although this 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 milli-Ohms. 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 gauges 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 ΔR_G = 40 mΩ). Inserting this into equation 3.3, using a 120 ohm strain gage with a gage factor of 2 results in an apparent strain of about 167 με.

$$167\mu\varepsilon = \frac{\left(1\times 10^{6}\right)\times 0.04\Omega}{2\times 120\Omega}$$

4.1.2 Quarter Bridge Strain with 3 Wire Element Calculations

As noted in Section 3, in real life applications the Wheatstone bridge starts out unbalanced. The strain gauge 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 gauge installed. This zero measurement can be incorporated into the datalogger 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_{ex}. (The actual result of the full bridge instruction is the millivolts output per volt of excitation, $1000 \cdot V_{out} / V_{ex}$) The result of the zero measurement, $1000 \cdot V_{out0} / V_{ex}$ 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.

$$V_r = (V_{out} / V_{ex}) - (V_{out0} / V_{ex}) \qquad 4.1.1$$

Using V_r from equation 4.1.1, the strain is calculated using equation 4.1.2.

$$\varepsilon = \frac{4V_r}{GF(1-2V_r)} \qquad 4.1.2$$

The calculations are covered in more detail in Section 4.5.

4.1.3 Quarter Bridge Strain with 3 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 datalogger's manuals and/or the CRBasic Editor's help files for detailed information on the program instructions used as well as additional program examples.

4.1.3.1 CRBasic Programming

Dataloggers 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 **Poisson ratio** parameter, which is not used with ¼ Bridge strain circuits.

Example Program 4.1. CR9000X ¼ bridge Strain with 3 reps

This example program 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 µstrain value. This program does not use a zero offset reading. See Example Program 4.2 for an example that performs a zero calibration.

```
'      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 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) = 2.1   :  GF(2) = 2.2   :  GF(3) = 2.3   'Initialize gauge 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
```

Example Program 4.2. CR9000X ¼ bridge Strain with 3 reps and zero offset

This example program starts out with Example Program 4.1 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 4.1.2.

The **LoadFieldCal** instruction facilitates the reloading of the calibration factors when the logger is powered up. In addition, the programmer should create a DataTable (we have called this DataTable 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 logger to store all of the calibration factors that are controlled using the FieldCalStrain instruction.

```
'     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 gauge 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 gauge 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
```

Example Program 4.3. CR1000 ¼ Bridge Strain with 3 reps and zero offset

This example program performs the same tasks as Example Program 4.2, 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.

```
'     Program name: STRAIN0.CR1
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
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 gauge 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,mV7_5,1,1,3,2500,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
```

Example Program 4.3. CR1000 ¼ Bridge Strain using an AM16/32B Multiplexer with 16 reps and zero offset

This example program has 16 strain gages multiplexed through an AM16/32 Multiplexer and uses FieldCalStrain for zeroing.

```
'      Program name: QuarterStrain with Zero and Mux.CR1
' This is only an example program and should be used only for help in creating a usable program
' ----------------------------------------------   WIRING   ---------------------------------------------------------
'  CR1000                    to        AM16/32 Multiplexer Control
' C1 (Control Port 1)                       Res (Reset)
' C2 (Control Port 2)                       Clk (Clock)
' G                                         GND (Ground)
' 12V                                       12V

'   CR1000      to        AM16/32 Common                     TIMs      to          AM16/32 Banks
' Diff 1H       to        Common Even Hi                     Blk Wire  to          Bank Odd Lo
' Diff 1L       to        Common Even Lo                     TIM H     to          Bank Even Hi
' EX1           to        Common Odd Lo                      Tim L     to          Bank Even Lo
' AG            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 gauge 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 (1 ,1 )                                   'Turn on AM16/32 using C1
   I = 1
   Delay (0,150,mSec)                                'required Delay for AM16/32 multiplexer
   SubScan (0,0,16)
      PulsePort (2,10000)                            'Pulse port C2 hi and low to clock the multiplexer
      BrFull(MVpV(I),1,mV7_5C,1,VX1,1,2500,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 (1 ,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
```

4.1.3.2 Edlog

The following examples for the CR10(X), 21X, and CR7 all have subroutines that measures the unstrained "zero" output of the strain gage. The examples calculate strain using equation 4.1.2 for a strain gage with a GF=2. These are just examples. Besides adding additional measurement instructions, the programs will probably need to have the scan and data storage intervals altered for actual applications. The instructions in the subroutine will also need to be modified for the actual gage factor.

Dataloggers that use Edlog include CR510, CR10(X), 21X, and CR7. The Edlog instruction that is used to measure strain gages is Instruction 6 – Full Bridge.

The Input Locations assignments used in CR10(X), 21X, and CR7 Examples are listed in Table 4-1.

TABLE 4-1. Input Locations Used in CR10(X), 21X, and CR7 Examples

Addr	Name
1	mVperV
2	mVperV_0
3	Vr
4	uStrain
5	Count
6	GF
7	_4e6
8	Mult
9	1_2Vr
10	Vr_1_2Vr

Example Program 4.4. CR10X ¼ Bridge Strain with 1 rep and zero offset

```
;{CR10X}
*Table 1 Program
  01:  1             Execution Interval (seconds)

1:  If Flag/Port (P91)                              ;On the first execution (Flag 1 is low)
  1:  21             Do if Flag 1 is Low            ;or when user sets Flag 1 low
  2:  1              Call Subroutine 1              ;call the zeroing subroutine

2:  Full Bridge (P6)                                ;Measure the strain gage
  1:  1              Reps
  2:  22             ± 7.5 mV 60 Hz Rejection Range
  3:  1              DIFF Channel
  4:  1              Excite all reps withExchan 1
  5:  2500           mV Excitation
  6:  1              Loc [ mVperV   ]
  7:  1              Mult
  8:  0              Offset

3:  X-Y (P35)                                       ;Subtract zero reading from the
  1:  1              X Loc [ mVperV   ]             ;measurement
  2:  2              Y Loc [ mVperV_0 ]
  3:  3              Z Loc [ Vr       ]

4:  X*F (P37)                                       ;Change Vr from mV/V to V/V
  1:  3               Loc [ Vr       ]
  2:  0.001
  3:  3               Loc [ Vr       ]
;The following instructions calculate microstrain
5:  Z=X*F (P37)
  1:  3              X Loc [ Vr       ]
  2:  -2             F
  3:  9              Z Loc [ 1_2Vr    ]

6:  Z=Z+1 (P32)
  1:  9              Z Loc [ 1_2Vr    ]

7:  Z=X/Y (P38)
  1:  3              X Loc [ Vr       ]
  2:  9              Y Loc [ 1_2Vr    ]
  3:  10              Loc [ Vr_1_2Vr ]

8:  Z=X*Y (P36)
  1:  10             X Loc [ Vr_1_2Vr ]
  2:  8              Y Loc [ Mult     ]
  3:  4              Z Loc [ uStrain  ]
; Output Section  : This example outputs an average of the 1 second readings ;once per minute.
09:  If time is (P92)
  1:  0              Minutes (Seconds --) into a
  2:  1              Interval (same units as above)
  3:  10             Set Output Flag High

10:  Set Active Storage Area (P80)
  1:  1              Final Storage Area 1
  2:  1              Array ID                       ;Set Array ID = 1 for measurement data

11:  Real Time (P77)
  1:  1110           Year,Day,Hour/Minute
```

```
12:  Average (P71)
   1:     1              Reps
   2:     4              Loc [ uStrain   ]

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

*Table 3 Subroutines

1:  Beginning of Subroutine (P85)                      ;Subroutine to measure "zero"
   1:     1              Subroutine 1

2:  Do (P86)                                           ;This prevents calling subroutine
   1:     11             Set Flag 1 High               ;until user sets flag 1 low again.

3:  Z=F (P30)                                          ;Set counter use for average to 0
   1:     0              F
   2:     0              Exponent of 10
   3:     5              Z Loc [ Count     ]

4:  Z=F (P30)                                          ;load 4 million (4*uS/S) into input location
   1:     4              F
   2:     6              Exponent of 10
   3:     7              Z Loc [ _4e6      ]

5:  Z=F (P30)                                          ;Load Gage Factor into input location
   1:     2              F                             ;Enter the actual Gage Factor here
   2:     0              Exponent of 10
   3:     6              Z Loc [ GF        ]

6:  Z=X/Y (P38)                                        ;calculate multiplier to use with strain
   1:     7              X Loc [ _4e6      ]           ;calculation
   2:     6              Y Loc [ GF        ]
   3:     8              Z Loc [ Mult      ]

7:  Beginning of Loop (P87)                            ;Loop through 5 times to obtain average
   1:     0              Delay                         ;zero reading
   2:     5              Loop Count

8:  Z=Z+1 (P32)                                        ;Increment Counter used to determine
   1:     5              Z Loc [ Count     ]           ;when to output

9:  Full Bridge (P6)                                   ;Measure Strain Gage
   1:     1              Reps
   2:     22             ± 7.5 mV 60 Hz Rejection Range
   3:     1              DIFF Channel
   4:     1              Excite all reps withExchan 1
   5:     2500           mV Excitation
   6:     1              Loc [ mVperV    ]
   7:     1              Mult
   8:     0              Offset

10:  IF (X<=>F) (P89)                                  ;Check for last pass through loop
   1:     5              X Loc [ Count     ]           ;to set output flag
   2:     3              >=
   3:     5              F
   4:     10             Set Output Flag High

11:  Set Active Storage Area (P80)                     ;Direct averaged "zero" reading
   1:     3              Input Storage Area            ;to input storage
   2:     2              Array ID or Loc [ mVperV_0  ]
```

```
12:  Average (P71)
   1:    1              Reps
   2:    1              Loc [ mVperV    ]

13:  If Flag/Port (P91)                                  ;When average is calculated,
   1:    10             Do if Output Flag is High (Flag 0)  ;also send it to Final Storage
   2:    10             Set Output Flag High

14:  Set Active Storage Area (P80)                       ;Direct Output to Final Storage
   1:    1              Final Storage Area 1
   2:    11             Array ID                         ;set Array ID = 11 for zero data

15:  Real Time (P77)
   1:    110            Day,Hour/Minute

16:  Sample (P70)
   1:    1              Reps
   2:    2              Loc [ mVperV_0  ]

17:  End (P95)

18:  End (P95)

End Program
```

Example Program 4.5. 21X ¼ Bridge Strain with 1 rep and zero offset

```
;{21X}
*Table 1 Program
   01:  1               Execution Interval (seconds)

;Other measurements could be inserted here or before the Output section

1:  If Flag/Port (P91)  ;On the first execution (Flag 1 is low)
   1:    21             Do if Flag 1 is Low              ;or when user sets Flag 1 low
   2:    1              Call Subroutine 1                ;call the zeroing subroutine

2:  Full Bridge (P6)    ;Measure the strain gage
   1:    1              Reps
   2:    2              ± 15 mV Slow Range
   3:    1              DIFF Channel
   4:    1              Excite all reps withExchan 1
   5:    5000           mV Excitation
   6:    1              Loc [ mVperV    ]
   7:    1              Mult
   8:    0              Offset

3:  Z=X-Y (P35)                                          ;Subtract zero reading from the
   1:    1              X Loc [ mVperV    ]              ;measurement
   2:    2              Y Loc [ mVperV_0  ]
   3:    3              Z Loc [ Vr        ]

4:  Z=X*F (P37)                                          ;Change Vr from mV/V to V/V
   1:    3              X Loc [ Vr        ]
   2:    0.001          F
   3:    3              Z Loc [ Vr        ]
```

```
;The following instructions calculate microstrain

5:  Z=X*F (P37)
   1:   3            X Loc [ Vr       ]
   2:   -2           F
   3:   9            Z Loc [ 1_2Vr    ]

6:  Z=Z+1 (P32)
   1:   9            Z Loc [ 1_2Vr    ]

7:  Z=X/Y (P38)
   1:   3            X Loc [ Vr       ]
   2:   9            Y Loc [ 1_2Vr    ]
   3:   10           Z Loc [ Vr_1_2Vr ]

8:  Z=X*Y (P36)
   1:   10           X Loc [ Vr_1_2Vr ]
   2:   8            Y Loc [ Mult     ]
   3:   4            Z Loc [ uStrain  ]

;Output Section
;This example outputs an average of the 1 second readings
;once per minute.

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

10:  Set Active Storage Area (P80)
   1:   1            Final Storage Area 1
   2:   1            Array ID                      ;Set Array ID = 1 for measurement data

11:  Real Time (P77)
   1:   1110         Year,Day,Hour/Minute

12:  Average (P71)
   1:   1            Reps
   2:   4            Loc [ uStrain  ]

*Table 2 Program
   01:  0.0000       Execution Interval (seconds)

*Table 3 Subroutines

1:  Beginning of Subroutine (P85)                  ;Subroutine to measure "zero"
   1:   1            Subroutine 1

2:  Do (P86)                                       ;This prevents calling subroutine
   1:   11           Set Flag 1 High               ;until user sets flag 1 low again.

3:  Z=F (P30)                                      ;Set counter use for average to 0
   1:   0            F
   2:   5            Z Loc [ count    ]

4:  Z=F (P30)                                      ;load 4000 into
   1:   4000         F                             ;input location
   2:   7            Z Loc [ 4e6      ]

5:  Z=X*F (P37)                                    ;Multiply by 1000 to get (4*uS/S)
   1:   7            X Loc [ 4e6      ]
   2:   1000         F
   3:   7            Z Loc [ 4e6      ]
```

```
6:  Z=F (P30)                                      ;Load Gage Factor into input location
    1:   2              F                          ;Enter the actual Gage Factor here
    2:   6              Z Loc [ GF       ]

7:  Z=X/Y (P38)                                    ;calculate multiplier to use with strain
    1:   7              X Loc [ 4e6      ]         ;calculation
    2:   6              Y Loc [ GF       ]
    3:   8              Z Loc [ Mult     ]

8:  Beginning of Loop (P87)                        ;Loop through 5 times to obtain average
    1:   0              Delay                      ;zero reading
    2:   5              Loop Count

9:  Z=Z+1 (P32)                                    ;Increment Counter used to determine
    1:   5              Z Loc [ count    ]         ;when to output

10:  Full Bridge (P6)   ;Measure Strain Gage
    1:   1              Reps
    2:   2              ± 15 mV Slow Range
    3:   1              DIFF Channel
    4:   1              Excite all reps withExchan 1
    5:   5000           mV Excitation
    6:   1              Loc [ mVperV    ]
    7:   1              Mult
    8:   0              Offset

11:  IF (X<=>F) (P89)                              ;Check for last pass through loop
    1:   5              X Loc [ count    ]         ;to set output flag
    2:   3              >=
    3:   5              F
    4:   10             Set Output Flag High

12:  Set Active Storage Area (P80)                 ;Direct averaged "zero" reading
    1:   3              Input Storage              ;to input storage
    2:   2              Array ID or Loc [ mVperV_0  ]

13:  Average (P71)
    1:   1              Reps
    2:   1              Loc [ mVperV    ]

14:  If Flag/Port (P91)                            ;When average is calculated,
    1:   10             Do if Output Flag is High (Flag 0)   ;also send it to Final Storage
    2:   10             Set Output Flag High

15:  Set Active Storage Area (P80)                 ;Direct Output to Final Storage
    1:   1              Final Storage
    2:   11             Array ID                   ;set Array ID = 11 for zero data

16:  Real Time (P77)
    1:   110            Day,Hour/Minute

17:  Sample (P70)
    1:   1              Reps
    2:   2              Loc [ mVperV_0  ]

18:  End (P95)

19:  End (P95)

End Program
```

4.2 Quarter Bridge Strain with 2 Wire Element

NOTE Although a two wire gage can be used with the 4WFBS TIM, due to the issues outlined in Section 4.4.3, it is not recommended. An exception may be applications with short leads in a stable temperature environment.

A 2-wire quarter bridge strain circuit is shown in figure 4.2-1.

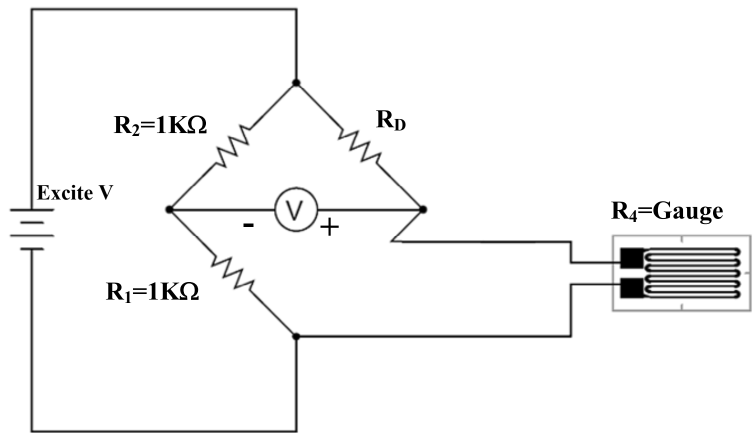


FIGURE 4.2-1. Two wire quarter bridge strain circuit

In this circuit, R1 and R2 are 1000 ohm resistors making up the back plane 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 un-strained gage. The 4^{th} 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 4.2-1, 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 4.4.3**, *Lead Compensation using ¼ Bridge Strain with 2 Wire Element* for more information on issues with using 2 wire gages.

4.2.1 Quarter Bridge Strain with 2 Wire Element Wiring

To use a two wire element strain gauge with the 4WFBS TIM requires a jumper wire be placed between the H and L terminal of the TIM module as shown in Figure 4.2-2.

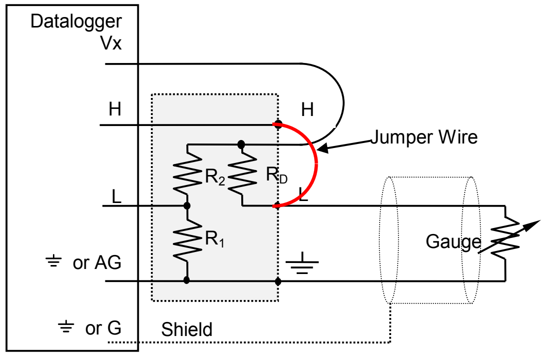


FIGURE 4.2-2. Wiring for 2-wire gauges

4.2.2 Two Wire ¼ Bridge use with Multiplexers and Equations

The equations to resolve the strain, programming of the logger, and methods of using with multiplexers are the same as those covered in Section 4.1 for the 3-Wire Strain gauge. The only variance is the wiring of the gage to the TIM.

4.3 Quarter Bridge Strain with Dummy Gage

An undesirable property of strain gauges 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 4.3.1 is used to calculate the thermal output variance ($\mu\varepsilon_{TO}$) with the result in µStrain. Equation 4.3.2 is used to determine the change in the gauge factor (GF) due to temperature changes. Both are based on temperature in degrees Celsius (T).

$$\mu\varepsilon_{TO} = -2.95 + 1.15T - 0.05T^2 + 3.25E^{-4}T^3 - 3.93E^{-7}T^4 \qquad 4.3.1$$

$$GF_{adj} = GF_{raw} + 1.40E^{-4} \times (T - 24)GF_{raw} \qquad 4.3.2$$

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

$$\mu\varepsilon_{cor} = (1000\mu\varepsilon - 29.3\mu\varepsilon) \times 2.000 / 2.007 \qquad 4.3.3$$

The uncorrected value had an error of approximately 3.3%. And if the ending strain would have been 100 µStrain instead of 1000 µStrain, 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 gauge. 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 µStrain, assuming that the datalogger 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 gauges can be used to compensate for these false apparent strain readings. A strain gauge 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 Gauge". This non-active gauge in the other arm of the Wheatstone bridge is referred to as a "dummy gauge" because it is not subjected to "load induced" strains.

With the two opposing gauges experiencing the same temperature conditions, the temperature effects on the active gage will be nullified by the equivalent temperature effects on the dummy gauge. Figure 4.3.1 depicts a Quarter Bridge Strain circuit with a Dummy gauge.

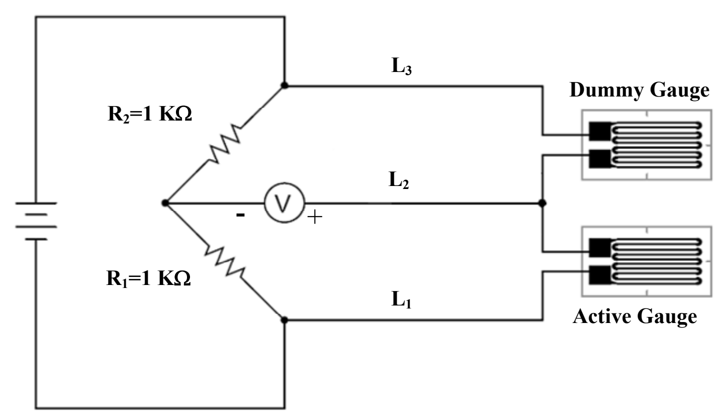


FIGURE 4.3-1. Quarter bridge strain circuit with dummy gauge

It should be noted that the coupon on which the dummy gauge 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 gauge is mounted to a coupon made up of material having the same Temperature Coefficient of Resistance (TCR) as the member that the active gauge 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" strain gauge, for the Wheatstone Bridge arm's resistive element opposite of the active strain gauge in the bridge. Wiring circuits using a dummy gage are covered in Section 4.3.1.

4.3.1 Quarter Bridge Strain with Dummy Gauge Wiring Setup

Figure 4.3-2 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 datalogger. This shows the dummy gauge 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 gauge factor variance due to temperature fluctuations, as it will be easier to keep the temperature of the two gages equivalent.

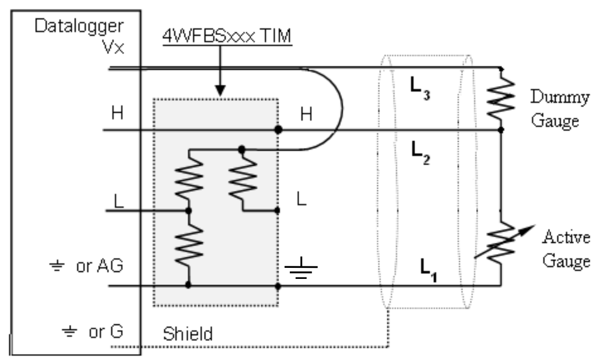


FIGURE 4.3-2. ¼ bridge strain with remote dummy gauge

Figure 4.3-3 illustrates the wiring of the strain gage to the 4WFBS module with the Dummy gauge at the logger location. Apparent strain errors could result because of temperature variances between the two gauges with this setup. This circuit is still utilized in some applications for ease of Shunt calibration (can shunt across Dummy gage at logger location rather than at the remote gauge location). Also an existing, standard 3-wire ¼ 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 datalogger, using the 4WFBS completion resistor can result in lower temperature induced errors.

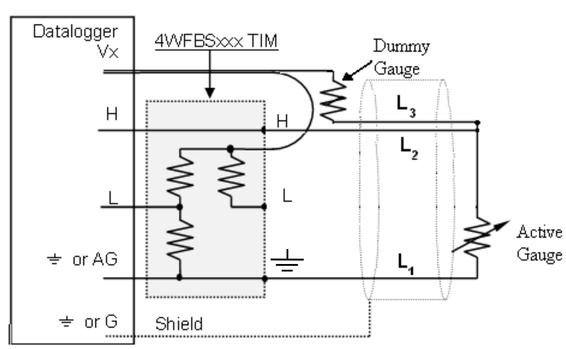


FIGURE 4.3-3. ¼ bridge strain with dummy gauge at datalogger

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.

4.3.2 Quarter Bridge Strain with Dummy Gauge Calculations

The calculations for this bridge setup are the same as for the 3-Wire Quarter Bridge circuit. See **Section 4.1.2** *Quarter Bridge Strain with3 Wire Element Calculations* for details.

4.3.3 Quarter Bridge Strain with Dummy Gauge Example Programs

The programming for this bridge setup is the same as for the 3-Wire Quarter Bridge circuit. See **Section 4.1.3** *Quarter Bridge Strain with3 Wire Program Examples* for details.

4.4 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 gauge for the resistive element in the third arm of the Wheatstone Bridge (arm opposite of active gauge). The only difference is that when using a dummy gauge, 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 gauge, wired as depicted in **Figure 4.1-2** *3-Wire ¼ Bridge Strain Wiring*, 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 4.4.1 and 4.4.2 cover these methods for ¼ Bridge Strain circuits.

4.4.1 Mathematical Lead Compensation for 3-Wire, ¼ Bridge Strain

The same equations pertain whether a completion (dummy) resistor or a dummy gauge is used to complete the third arm of the Wheatstone Bridge. So the material in this section is relevant for wiring setups shown in Figures 4.1-2, 4.3-2, and 4.3-3. The math and the programs used would be identical for all three of these circuits.

4.4.1.1 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 gauge. The Gauge Factor can be multiplied by the inverse of this value, $R_G/(R_G+R_L)$, to derive an adjusted Gauge Factor.

$$GF_{adj} = GF_{raw} \times \left(\frac{R_g}{R_g + R_L} \right) \qquad 4.4.1$$

The adjusted Gauge Factor, GF_{adj}, would be used in the StrainCalc function to derive the µStrain. The proof used to derive this adjusted Gauge Factor is shown below:

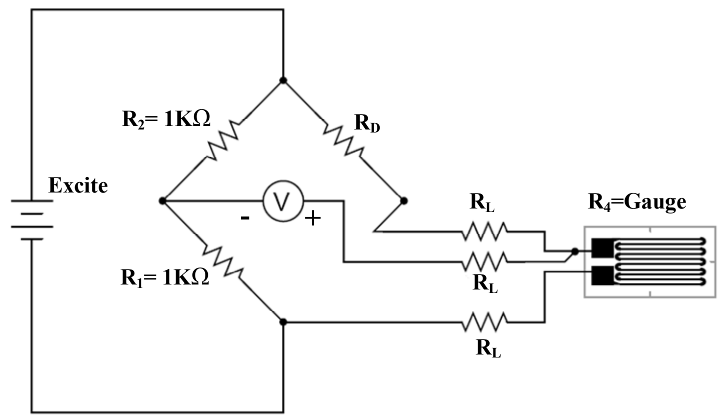


FIGURE 4.4-1. Three wire ¼ bridge strain circuit

Balanced Bridge Condition

$$\left(\frac{E_O}{E_I} \right)_{BAL} = \frac{R_G + R_L}{R_G + R_L + R_D + R_L} - \frac{R_1}{R_1 + R_2} \qquad 4.4.2$$

Strained Bridge Condition

$$\left(\frac{E_O}{E_I} \right)_{STR} = \frac{R_G + R_L + \Delta R_G}{R_G + R_L + R_D + R_L + \Delta R_G} - \frac{R_1}{R_1 + R_2} \qquad 4.4.3$$

Change in Bridge Output (V_R)

$$V_R = \left(\frac{E_O}{E_I} \right)_{STR} - \left(\frac{E_O}{E_I} \right)_{BAL} = \frac{R_G + R_L + \Delta R_G}{R_D + 2R_L + R_G + \Delta R_G} - \frac{R_G + R_L}{R_D + R_G + 2R_L} \qquad 4.4.4$$

Assume $R_D = R_G$

$$V_R = \frac{R_G + R_L + \Delta R_G}{2R_L + 2R_G + \Delta R_G} - \frac{R_G + R_L}{2R_G + 2R_L} \qquad 4.4.5$$

Simplify

$$V_R = \frac{R_G \Delta R_G + R_L \Delta R_G}{(2R_G + 2R_L + \Delta R_G)(2R_G + 2R_L)} \qquad 4.4.6$$

Solve for $\Delta R_G / R_G$

$$\frac{\Delta R_G}{R_G} = \frac{4V_R}{(1 - 2V_R)}\left(\frac{R_G + R_L}{R_G}\right) \qquad 4.4.7$$

Use the Gauge Factor to calculate micro-strain $\left(\mu\varepsilon = \frac{\Delta R \times 10^6}{R_G \times GF}\right)$

$$\mu\varepsilon = \frac{4V_R \times 10^6}{GF(1 - 2V_R)}\left(\frac{R_G + R_L}{R_G}\right) \qquad 4.4.8$$

4.4.1.2 Mathematical Lead Compensation Programs

Example Program 4.6. CR9000X ¼ Bridge Strain with zero offset and Lead Compensation

This program starts with Example Program 4.2 and adds instructions to mathematically compensate for the leads resistances effects on the Gauge Factor (sensitivity effect). Added instructions are highlighted.

```
'    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 gauge 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 gauge 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 gauge copper wire lead R is 0.025 ohms/ft
  Gauge_R = 350                                        ' Load Strain gauge Resistance
  For I = 1 To 3                                       ' Loop through calculate the adjusted gauge 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
```

Example Program 4.7. CR10X ¼ Bridge Strain with 16 reps, using multiplexer with zero offset and Lead Compensation Calculations using Lead resistance

Input Locations Used in CR10(X)Program Example X.X							
Addr	Name	Addr	Name	Addr	Name	Addr	Name
1	mVPerVG01	36	AdjGF01	70	LeadFt01	102	GF01
2	mVPerVG02	37	AdjGF02	71	LeadFt02	103	GF02
3	mVPerVG03	38	AdjGF03	72	LeadFt03	104	GF03
4	mVPerVG04	39	AdjGF04	73	LeadFt04	105	GF04
5	mVPerVG05	40	AdjGF05	74	LeadFt05	106	GF05
6	mVPerVG06	41	AdjGF06	75	LeadFt06	107	GF06
7	mVPerVG07	42	AdjGF07	76	LeadFt07	108	GF07
8	mVPerVG08	43	AdjGF08	77	LeadFt08	109	GF08
9	mVPerVG09	44	AdjGF09	78	LeadFt09	110	GF09
10	mVPerVG10	45	AdjGF10	79	LeadFt10	111	GF10
11	mVPerVG11	46	AdjGF11	80	LeadFt11	112	GF11
12	mVPerVG12	47	AdjGF12	81	LeadFt12	113	GF12
13	mVPerVG13	48	AdjGF13	82	LeadFt13	114	GF13
14	mVPerVG14	49	AdjGF14	83	LeadFt14	115	GF14
15	mVPerVG15	50	AdjGF15	84	LeadFt15	116	GF15
16	mVPerVG16	51	AdjGF16	85	LeadFt16	117	GF16
17	mVPerVZ01	52	uStrain01	86	OhmLead01	118	G01Ohms
18	mVPerVZ02	53	uStrain02	87	OhmLead02	119	G02Ohms
19	mVPerVZ03	54	uStrain03	88	OhmLead03	120	G03Ohms
20	mVPerVZ04	55	uStrain04	89	OhmLead04	121	G04Ohms
21	mVPerVZ05	56	uStrain05	90	OhmLead05	122	G05Ohms
22	mVPerVZ06	57	uStrain06	91	OhmLead06	123	G06Ohms
23	mVPerVZ07	58	uStrain07	92	OhmLead07	124	G07Ohms
24	mVPerVZ08	59	uStrain08	93	OhmLead08	125	G08Ohms
25	mVPerVZ09	60	uStrain09	94	OhmLead09	126	G09Ohms
26	mVPerVZ10	61	uStrain10	95	OhmLead10	127	G10Ohms
27	mVPerVZ11	62	uStrain11	96	OhmLead11	128	G11Ohms
28	mVPerVZ12	63	uStrain12	97	OhmLead12	129	G12Ohms
29	mVPerVZ13	64	uStrain13	98	OhmLead13	130	G13Ohms
30	mVPerVZ14	65	uStrain14	99	OhmLead14	131	G14Ohms
31	mVPerVZ15	66	uStrain15	100	OhmLead15	132	G15Ohms
32	mVPerVZ16	67	uStrain16	101	OhmLead16	133	G16Ohms
33	VR_1	68	Number4e3			134	GAndLOhms
34	One_2Vr	69	LeadOhms			135	AdjFactor
35	Vr_1_2Vr					136	

```
;{CR10X}
;16SGMux.CSI
;This program calculates the strain for 16 quarter strain bridges using4 wire bridge completion modules.
; It takes into account the sensitivity changes due to lead length resistance.
;(1) Sensors:
;    16 strain gauges multiplexed through an AM416
;(2) DataInfo:
;    Strain gauges will be measured every 5 seconds.
;    Only measurement at top of minute will be stored.
;(3) SubroutineDescrptions:
;    Subroutine01:   Measures the zero offset strain reading, sets the gauge factor.
;    Subroutine02:   Outputs processed values to FinalStorage
;(4) Wiring:
;    (a) Mux01:
;        10x_12V To AM416_12V                     10x_GND To AM416_GND
;        10x_C3  To AM416_ResetEnable             10x_C4  To AM416_Clock
;        10x_H4  To AM416_ComH1                   10x_L4  To AM416_ComL1
;        10x_E2  To AM416_ComH2                   10x_AG  To AM416_ComL2
;        First bank example:
;        SG+      To H1                           SG-      To L1
;        SGExcite To H2                           SGGnd    To L2
*Table 1 Program
01:  5   Execution Interval (seconds)
;Loop through the strain gages using the AM416:
1:  Do (P86)
  1: 43       Set Port 3 High ;              Reset and Enable the AM416.

2:  Beginning of Loop (P87)
 1:   0        Delay
 2:   16       Loop Count

   3:  Do (P86)
    1: 74       Pulse Port 4 ;               Clock forward to the next bank on the AM416.

   4:  Excitation with Delay (P22) ;         Delay to allow relay connection to settle.
    1: 2        Ex Channel
    2: 0        Delay WITHEx (units = 0.01 sec)
    3: 5        Delay After Ex (units = 0.01 sec)
    4: 0        mV Excitation

   5:  Full Bridge (P6)
    1: 1        Reps
    2: 2        7.5 mV Slow Range
    3: 4        DIFF Channel
    4: 2        Excite all reps withExchan 2
    5: 2500     mV Excitation
    6: 1     -- Loc [ mVPerVG01 ]
    7: 1.0      Mult
    8: 0.0      Offset

6:  End (P95)

7:  Do (86)
 1: 53       Set Port 3 Low ;                Deactivate the AM416.
;..
8:  If Flag/Port (P91) ;                     If first time through then call zero routine.
 1: 21       Do if Flag 1 is Low
 2: 1        Call Subroutine 1

9:  Beginning of Loop (P87) ;                This Loop calculates uStrain values:
 1: 0        Delay
 2: 16       Loop Count

   10:  Step Loop Index (P90)
    1: 1        Step
```

```
    11:  Z=X-Y (P35) ;                               Subtract zeroed value from measurement.
     1: 1     -- X Loc [ mVPerVG01 ]
     2: 17    -- Y Loc [ mVPerVZ01 ]
     3: 33       Z Loc [ Vr_1      ]

    12:  Z=X*F (P37)
     1: 33       X Loc [ Vr_1      ]
     2: -2       F
     3: 34       Z Loc [ One_2Vr   ]

    13:  Z=X+F (P34)
     1: 34       X Loc [ One_2Vr   ]
     2: 1000     F
     3: 34       Z Loc [ One_2Vr   ]

    14:  Z=X/Y (P38)
     1: 33       X Loc [ Vr_1      ]
     2: 34       Y Loc [ One_2Vr   ]
     3: 35       Z Loc [ Vr_1_2Vr  ]

    15:  Z=X/Y (P38)
     1: 35       X Loc [ Vr_1_2Vr  ]
     2: 36    -- Y Loc [ AdjGF01   ]
     3: 52    -- Z Loc [ uStrain01 ]

    16:  Z=X*Y (P36)
     1: 52    -- X Loc [ uStrain01 ]
     2: 68       Y Loc [ Number4e3 ]
     3: 52    -- Z Loc [ uStrain01 ]

17:  End (P95)

18:  If Flag/Port (P91)
 1: 12       Do if Flag 2 is High
 2: 30       Then Do

    19:  If time is (P92)
     1: 0        Minutes (Seconds --) into a
     2: 1        Interval (same units as above)
     3: 2        Call Subroutine 2 ;                 Outputs data to FinalStorage.

20:  End (P95)
*Table 2  Program
  02:   0
*Table 3 Subroutines
1:  Beginning of Subroutine (P85) ;                  Measures ZeroOffset strain reading and sets GF
 1: 1        Subroutine 1

    2:  Do (P86) ;                                   Setup so Subroutine does not get called again.
     1: 11       Set Flag 1 High

    3:  Z=F (P30) ;                                  Lead Length Resistance per 100 feet.
     1: 2.5      F ;                                 0.025 Ohms/Foot for 24 gauge copper stranded wire.
     2: 0        Exponent of 10
     3: 69       Z Loc [ LeadOhms  ]

    4:  Bulk Load (P65) ;                            Load lead length of the gages in 100s of feet:
     1: 3.0      F      ;                            Gage01
     2: 4.4      F ;                                 Gage02
     3: 8        F ;                                 Gage03
     4: 12       F ;                                 Gage04
     5: 14       F ;                                 Gage05
     6: 19       F ;                                 Gage06
     7: 15       F ;                                 Gage07
     8: 13       F ;                                 Gage08
     9: 70       Loc [ LeadFt01  ]
```

```
 5:  Bulk Load (P65)
  1: 5        F ;                                    Gage09
  2: 9        F ;                                    Gage10
  3: 12       F ;                                    Gage11
  4: 4        F ;                                    Gage12
  5: 8        F ;                                    Gage13
  6: 2        F ;                                    Gage14
  7: 8        F ;                                    Gage15
  8: 9        F ;                                    Gage16
  9: 78       Loc [ LeadFt09  ]

 6:  Beginning of Loop (P87) ;                       Calculate lead length resistance:
  1: 0        Delay
  2: 16       Loop Count

     7:  Z=X*Y (P36)
      1: 70    -- X Loc [ LeadFt01  ]
      2: 69       Y Loc [ LeadOhms  ]
      3: 86    -- Z Loc [ OhmLead01 ]

 8:  End (P95)

 9:  Bulk Load (P65) ;                               Load strain gauge Gage Factors:
  1: 2.095    F ;                                    Gauge01
  2: 2.095    F ;                                    Gauge02
  3: 2.095    F ;                                    Gauge03
  4: 2.095    F ;                                    Gauge04
  5: 2.095    F ;                                    Gauge05
  6: 2.095    F ;                                    Gauge06
  7: 2.095    F ;                                    Gauge07
  8: 2.095    F ;                                    Gauge08
  9: 102      Loc [ GF01      ]

 10:  Bulk Load (P65)
  1: 2.095    F ;                                    Gauge09
  2: 2.095    F ;                                    Gauge10
  3: 2.095    F ;                                    Gauge11
  4: 2.095    F ;                                    Gauge12
  5: 2.095    F ;                                    Gauge13
  6: 2.095    F ;                                    Gauge14
  7: 2.095    F ;                                    Gauge15
  8: 2.095    F ;                                    Gauge16
  9: 110      Loc [ GF09      ]

;                                                    Load strain gauge resistance values:
 11:  Bulk Load (P65)
  1: 350      F ;                                    Gage01
  2: 350      F ;                                    Gage02
  3: 350      F ;                                    Gage03
  4: 350      F ;                                    Gage04
  5: 350      F ;                                    Gage05
  6: 350      F ;                                    Gage06
  7: 350      F ;                                    Gage07
  8: 350      F ;                                    Gage08
  9: 118      Loc [ G01Ohms   ]

 12:  Bulk Load (P65)
  1: 350      F ;                                    Gage09
  2: 350      F ;                                    Gage10
  3: 350      F ;                                    Gage11
  4: 350      F ;                                    Gage12
  5: 350      F ;                                    Gage13
  6: 350      F ;                                    Gage14
```

```
   7: 350      F ;                                  Gage15
   8: 350      F ;                                  Gage16
   9: 126      Loc [ G09Ohms   ]

  13:  Z=F (P30) ;                                  Load in the large number, 4000.0
   1: 4        F
   2: 3        Exponent of 10
   3: 68       Z Loc [ Number4e3 ]
  14:  Beginning of Loop (P87) ;                    Loop through the strain gages using the AM416:
   1: 0        Delay
   2: 16       Loop Count

      15:  Z=X+Y (P33) ;                            Calculate GOhms+LeadOhms
       1: 118   -- X Loc [ G01Ohms   ]
       2: 86    -- Y Loc [ OhmLead01 ]
       3: 134      Z Loc [ GAndLOhms ]

      16:  Z=X/Y (P38) ;                            Calculate RG/(RG + RL)
       1: 118   -- X Loc [ G01Ohms   ]
       2: 134      Y Loc [ GAndLOhms ]
       3: 135      Z Loc [ AdjFactor ]

      17:  Z=X*Y (P36) ;                            Calculate adjusted Gauge Factor, GF*[RG/(RG + RL)]
       1: 135      X Loc [ AdjFactor ]
       2: 102   -- Y Loc [ GF01      ]
       3: 36    -- Z Loc [ AdjGF01   ]

      18:  Z=X (P31) ;                              Load last gauge measurements.
       1: 1     -- X Loc [ mVPerVG01 ]
       2: 17    -- Z Loc [ mVPerVZ01 ]
  19:  End (P95)
 ;..
  20:  Do (P86) ;                                   Store zero measurement values and adjusted GF.
   1: 10       Set Output Flag High (Flag 0)

      21:  Set Active Storage Area (P80)^15754
       1: 1        Final Storage Area 1
       2: 311      Array ID

      22:  Real Time (P77)^19880
       1: 1111     Year,Day,Hour/Minute,Seconds (midnight = 0000)

      23:  Sample (P70)^22627
       1: 16       Reps
       2: 17       Loc [ mVPerVZ01 ]

      24:  Sample (P70)^11346
       1: 16       Reps
       2: 36       Loc [ AdjGF01   ]

  25:  Do (P86)
   1: 20       Set Output Flag Low (Flag 0)

26:  End (P95)
;
27:  Beginning of Subroutine (P85) ;                Output data to FinalStorage.
 1: 2        Subroutine 2

  28:  Do (P86)
   1: 10       Set Output Flag High (Flag 0)

      29:  Set Active Storage Area (P80)^28949
       1: 1        Final Storage Area 1
       2: 321      Array ID

      30:  Real Time (P77)^16027
       1: 1111     Year,Day,Hour/Minute,Seconds (midnight = 0000)
```

```
        31:  Sample (P70)^16425
         1: 16       Reps
         2: 52       Loc [ uStrain01 ]

    32:  Do (P86)
     1: 20       Set Output Flag Low (Flag 0)

33:  End (P95)

End Program
```

4.4.2 Shunt Calibration Lead Compensation for 3-Wire, ¼ 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 CSI'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 gauge's Gage Factor (GF).

4.4.2.1 Three Wire Gage Circuit with Shunt

There are two methods for performing a shunt calibration on a 3-Wire ¼ 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 (dependant on which is employed in the circuit) back at the datalogger.

For either shunt method, the Dummy resistor should be a 0.02% precision or better resistor to insure that its resistance is the nominal resistance of the active gauge. In addition it should have a low Temperature Coefficient of Resistance (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.

4.4.2.1.1 Three Wire Gage Circuit with Remote Shunt across the Active Gage

A 3-wire quarter bridge strain circuit with a Shunt calibration resistor ready to shunt across the arm that holds the strain gauge is shown in figure 4.4-2.

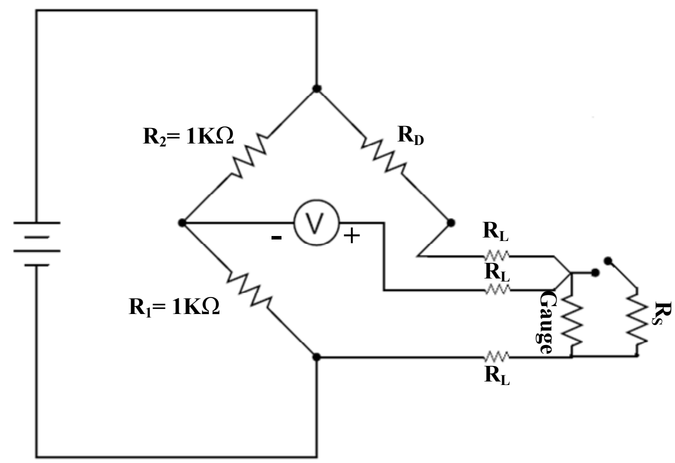


FIGURE 4.4-2. Shunting remotely across active gauge

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 gauge and is referred to as the **Dummy Resistor**. R_s is the Shunt resistor. This setup is the classical method for shunting a 3-wire ¼ bridge strain circuit.

4.4.2.1.2 Three Wire Gage Circuit with Shunt across the Dummy Resistor

Shunting across the active gauge is frequently impractical due to inaccessibility or protective coatings across the gage and leads, which precludes getting an electrical contact across the gauge. 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 4.4-3 shows a 3-wire ¼ Bridge strain circuit for shunting across the dummy resistor.

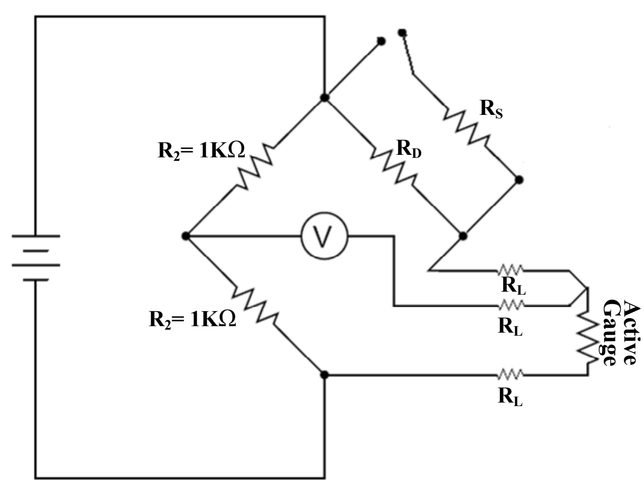


FIGURE 4.4-3. Circuit for shunting across dummy resistor

NOTE It should be noted that a shunt resistor should not be connected across the active gauge'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 4.4-3.

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 4.4-4.

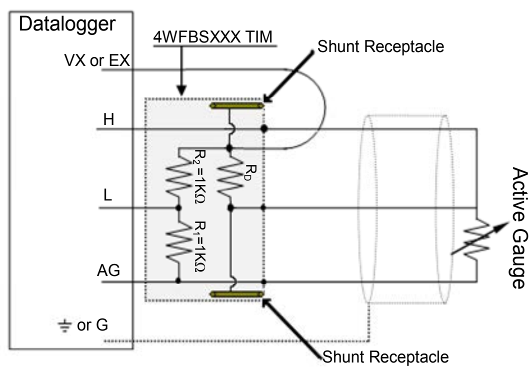


FIGURE 4.4-4. Wiring for shunt across dummy resistor

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.

4.4.2.2 Math for Shunt Calibration of 3-Wire, ¼ Bridge Strain Circuits

NOTE The math in this section is done automatically for the user by the Datalogger's Operating System. It is included here mainly for reference and for users with our older loggers that are not supported by the Calibration Wizard and higher end instructions. The Calibration Wizard utility which is installed with CSI'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 4.4.9:

$$\frac{\Delta R}{R_G} = \frac{-R_G}{R_G + R_S} \qquad 4.4.9$$

Variable definitions:

ΔR = Change in arm resistance (ohms)

$\mathbf{R_G}$ = Nominal gauge resistance (ohms)

$\mathbf{R_S}$ = Shunt resistor resistance (ohms)

If shunting across the active gauge, 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 **R**ecorded 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 4.4.10 is the standard equation for calculating the microstrain from the change in the resistance of the gauge:

$$\mu\varepsilon = \frac{\Delta R \times 10^6}{R_G \times GF} \qquad 4.4.10$$

Variable definitions:

$\mu\varepsilon$ = micro-strain

ΔR = change in arm resistance (ohms)

R_G = Nominal gauge resistance (ohms)

GF = Gauge factor

Combining equations 4.4.9 and 4.4.10 results in Equation 4.4.11 that is used for calculating the simulated strain that is induced by the shunt resistor:

$$\mu\varepsilon_S = \frac{-R_G \times 10^6}{(R_G + R_S) \times GF} \qquad 4.4.11$$

Variable definitions:

$\mu\varepsilon_S$ = Simulated micro-strain created by shunt resistor

R_S = Shunt resistor value (ohms)

R_G = Nominal gauge resistance (ohms)

GF = Gauge 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 gauge factor is multiplied by this factor to derive an adjusted gauge factor for the system, $GF_{Adj} = GF_{Raw} \times \mu\varepsilon_R / \mu\varepsilon_S$, that is used to correct the output from the instrumentation.

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

In some applications a Dummy or inactive gauge is used in place of the Dummy resistor (See **Section 4.3.1** *Quarter Bridge Strain with Dummy Gauge Wiring Setup*). 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 insure that the zero µstrain reading is calculated using the adjusted gauge factor.

4.4.2.3 Example Programs for Shunt Calibration of 3-Wire, ¼ Bridge Strain Circuits

Example Program 4.8. CR9000X with Zero and Shunt Calibration

This example program starts out with Example Program 4.2 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 CSI'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 insure that the zero µstrain reading is calculated using the adjusted gauge factor.

Example Program 4.7. CR9000X ¼ Bridge Strain with zero offset andShunt 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 gauge 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 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(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
```

4.4.3 Lead Compensation using Quarter Bridge Strain with 2 Wire Element

NOTE If the leads become so long that lead resistance compensation calculations are required then a 2-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 3-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 2 wire gage, but to discourage its practice.

A 2-wire quarter bridge strain circuit is shown in figure 4.4-5

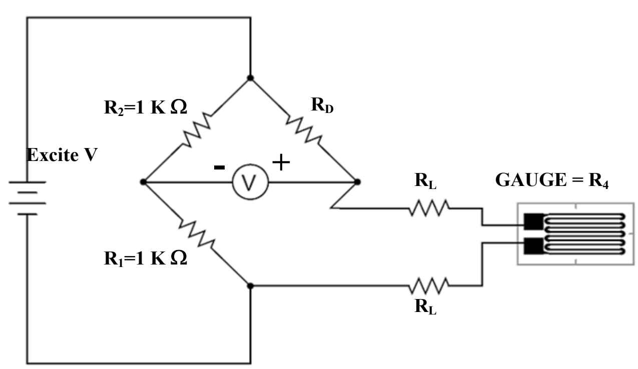


FIGURE 4.4-5. Two wire quarter bridge strain circuit

In this circuit, R1 and R2 are 1000 ohm resistors making up the back plane of the Wheatstone bridge, as is done in the TIM design. R_D is the complementary resistor that has a nominal resistance of the un-strained 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 4.4.12 for solving the strain from the voltage ratio (V_r :reference equation 3.14).

$$\varepsilon = \frac{4V_r\left(1+{R_L}/{R_G}\right)^2}{\left(1-2V_r\left(1+{R_L}/{R_G}\right)\right)GF} \qquad 4.4.12$$

This results in a non-linear relationship between the strain and 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 2 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 degree C. The initial resistance for the 200 foot combined leads is 2.000 ohms @ 24 degrees C. If the temperature were to drop 20 degrees C, the change in resistance would be 0.127 ohms:

$$0.127\Omega = 20°\mathrm{C} \times \frac{0.00393\Omega/\Omega}{°\mathrm{C}} \times 2\Omega$$

Equation 3.2, from Section 3, derives strain as a function of resistance:

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

As mentioned before in Section 3, strain is typically reported in microstrain $(\mu\varepsilon)$. Microstrain is strain expressed in parts per million, i.e: a change in length by one millionth of the length. Equation 3.3, again from Section 3, derives microstrain as a function of resistance.

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

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

4.5 Calculation of Strain for ¼ Bridge Circuits

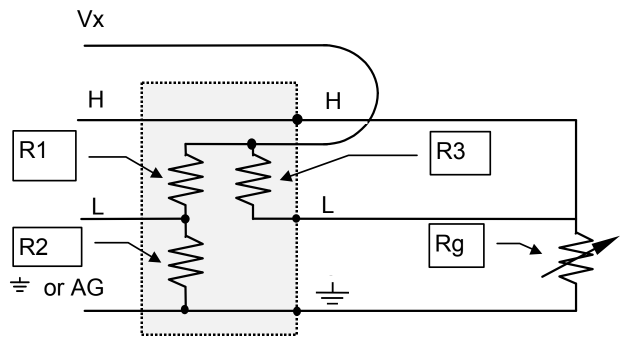


FIGURE 4.5-1. Strain gage in full bridge

Figure 4.5-1 is the diagram of the strain gage in the full bridge configuration provided by the terminal input module. The result of the datalogger's full bridge measurement when a multiplier of 1 and an offset of 0 is used is the measured bridge output in millivolts divided by the excitation in volts (1000 mV=1V):

$$1000 \cdot \frac{Vout}{Vin} = 1000 \cdot \left(\frac{R_g}{R_3 + R_g} - \frac{R_2}{R_1 + R_2} \right) \tag{4.5.1}$$

The result is output in the units of millivolts output per volt of excitation because the output voltage is small relative to the excitation voltage; these units allow the result to be a larger number easier for the datalogger to display and store (see data format discussion in the datalogger manual). The output is a ratio because: 1) the datalogger's ratio metric measurement technique allows this ratio to be more accurate than the measurement of the output voltage (errors in the excitation and measured output cancel). 2) This ratio can be used directly in the calculation of strain.

When strain is calculated, the direct ratio of the voltages (volts per volt not millivolts per volt) will be used:

$$\frac{Vout}{Vin} = \frac{R_g}{R_3 + R_g} - \frac{R_2}{R_1 + R_2} \tag{4.5.2}$$

If the previous equation is taken as the result 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:

$$\left.\frac{Vout}{Vin}\right._{strained} = \frac{R_g + \Delta R_g}{R_3 + R_g + \Delta R_g} - \frac{R_2}{R_1 + R_2} \tag{4.5.3}$$

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

$$V_r = \left(\frac{Vout}{Vin}\right)_{strained} - \left(\frac{Vout}{Vin}\right)_{unstrained} = \frac{R_g + \Delta R_g}{R_D + R_g + \Delta R_g} - \frac{R_g}{R_D + R_g} \quad 4.5.4$$

$$= \frac{R_D \times \Delta R_g}{\left(R_D + R_g + \Delta R_g\right) \times \left(R_D + R_g\right)}$$

The terminal input module is selected so that $R_D = R_g$; Substituting R_g for R_D:

$$V_r = \frac{R_g \cdot \Delta R_g}{(R_g + R_g + \Delta R_g) \cdot (R_g + R_g)} = \frac{R_g \cdot \Delta R_g}{4R_g^{\ 2} + 2R_g \Delta R_g} = \frac{\Delta R_g}{4R_g + 2\Delta R_g} \quad 4.5.5$$

Solving for strain:

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

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

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

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

$$\frac{4V_r}{1 - 2V_r} = \frac{\Delta R_g}{R_g} \quad 4.5.6$$

Strain is calculated by dividing equation 4.5.6 by the gage factor. The units are converted to microstrain by multiplying by 10^6 uS/S.

$$\mu\varepsilon = \frac{4 \cdot 10^6 V_r}{GF\left(1 - 2V_r\right)} = \frac{10^6 \Delta R_g}{GF \cdot R_g} \quad 4.5.7$$

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