



IntelliPack™ Series 851T
Intelligent Strain Gauge Transmitter/Alarm

Technical Reference

INTRODUCTION TO STRAIN
& STRAIN MEASUREMENT

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This information is provided as a service to our customers and to others interested in learning more about strain and strain measurement. Acromag assumes no responsibility for any errors that may occur in this document, and makes no commitment to update or keep this information current.

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The following information introduces the concept of strain as it relates to the Acromag Series 851T Strain Gauge module. Acromag manufactures a complete line of I/O modules that support a wide range of I/O types. Feel free to visit our website at www.acromag.com to obtain the latest information about these and other Acromag products.

Strain gauges are widely employed in sensors that detect and measure force and force-related parameters, such as torque, acceleration, pressure, and vibration. The strain gauge is the building block for strain sensors that often employ multiple strain gauges in their construction. A strain gauge will undergo a small mechanical deformation with an applied force that results in a small change in gauge resistance proportional to the applied force. Because this change in resistance with applied force is so small, strain gauges are commonly wired using a Wheatstone Bridge. The resultant output voltage of the bridge is directly related to any imbalance between resistances in each leg of the bridge and the bridge excitation voltage. The output of the bridge is normally specified in terms of millivolts of output voltage per volt of applied excitation (mV/V), and this is usually referred to as its rated output or *sensitivity*. The actual maximum or full-scale output of a strain gauge bridge at its full-rated load is the product of a bridge's sensitivity (mV/V) and the applied excitation voltage. This is referred to as the output span under full rated load.

ABOUT THE STRAIN GAUGE?

Strain is a measure of the deformation of a body when subject to an applied force. Specifically, strain (ϵ) is the fractional change in dimension (length, width, or height) of a body when subject to a force along that dimension. That is: $\epsilon = \Delta L / L$. Note that strain can be either positive (tensile), or negative (compressive). Further, the magnitude of a strain measurement is typically very small and is often expressed as a whole number multiple of 10^{-6} , or microstrain ($\mu\epsilon$). In most cases, strain measurements are rarely encountered larger than a few millistrain ($\epsilon * 10^{-3}$), or about $3000\mu\epsilon$, except for high-elongation applications.

When a body of material is subject to a force in one direction, a phenomenon referred to as *Poisson's Strain* causes the material to contract slightly in the transverse or perpendicular dimension. The magnitude of this contraction is a property of the material indicated by its Poisson's Ratio. The Poisson's Ratio (γ) is the negative ratio of the coincident compressive strain that occurs in the transverse direction (perpendicular to the applied force), to the strain in the axial direction (parallel to the applied force). That is:

Poisson's Ratio (γ) = $-\epsilon_T / \epsilon$. Likewise, the **Poisson's Strain (ϵ_T) = $-\gamma\epsilon$.**

Strain gauges are devices that change resistance slightly in response to an applied strain. These devices typically consist of a very fine foil grid (or wire grid) that is bonded to a surface in the direction of the applied force. The cross-sectional area of this device is minimized to reduce the negative effect of the shear or Poisson's Strain. These devices are commonly referred to as bonded-metallic or bonded-resistance strain gauges. The foil grid is bonded to a thin backing material or carrier which is directly attached to the test body. As a result, the strain experienced by the test body is transferred directly to the foil grid of the strain gauge, which responds with a linear change (or nearly linear change) in electrical resistance. As you can surmise, properly mounting a strain gauge is critical to its performance in ensuring that the applied strain of a material is accurately transferred through the adhesive and backing material, to the foil itself.

Most strain gauges have nominal resistance values that vary from 30 to 3000Ω, with 120Ω, 350Ω, and 1000Ω being the most common.

The relationship between the resultant fractional change of gauge resistance to the applied strain (fractional change of length) is called the Gauge Factor (GF), or *sensitivity to strain*. Specifically, the Gauge Factor is the ratio of the fractional change in resistance to the strain:

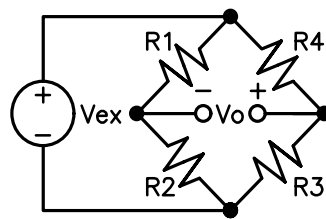
$$GF = (\Delta R / R) / (\Delta L / L) = (\Delta R / R) / \epsilon$$

The Gauge Factor for metallic strain gauges is typically around 2.0. However, it is important to note that this ratio will vary slightly in most applications and a method of accounting for the effective Gauge Factor of a strain measurement system must be provided (see Instrument Gauge Factor).

In the ideal sense, the resistance of a strain gauge should change only in response to the applied strain. Unfortunately, the strain gauge material, as well as the test material it is applied to, will expand or contract in response to changes in temperature. Strain gauge manufacturers attempt to minimize gauge sensitivity to temperature by design, selecting specific strain gauge materials for specific application materials. Though minimized, the equivalent strain error due to the temperature coefficient of a material is still considerable and additional temperature compensation is usually required.

THE WHEATSTONE BRIDGE

Because strain measurement typically requires the detection of very small mechanical deformations, and small resistance changes, the resultant magnitude of most strain measurements in stress analysis applications is commonly between 2000 and 10000μϵ, and rarely larger than about 3000μϵ. As such, an accurate method of measuring very small changes in resistance is required. Likewise, this method should also compensate for the strain gauge's inherent sensitivity to temperature. This is where the Wheatstone Bridge comes into play.



The Wheatstone Bridge is comprised of four resistive arms arranged in the configuration of a diamond as shown at left. An excitation voltage is applied across the diamond (or bridge input), and a resultant output voltage can be measured across the other two vertices of the diamond as shown.

From Kirchhoff's Voltage Law and Ohm's Law applied to the circuit above, we can show that $V_o = V_{R1} - V_{R4} = [R1/(R1+R2) - R4/(R3+R4)] * V_{ex}$. Note that when $R1/R2 = R4/R3$, the voltage output will be zero and the bridge is said to be balanced. That is, it is not required that $R1=R4$ and $R2=R3$ to achieve balance, just that the ratio of $R1$ to $R2$ and $R4$ to $R3$ be equal (this allows you to use bridge completion resistors that may have a different value than your nominal strain gauge resistance). For simplicity of illustration, if all four of the resistances in each leg of the bridge are equal, then the output voltage measured across the bridge will be zero, and the bridge is said to be balanced. Likewise, any change in resistance in any leg of the bridge will unbalance the bridge and produce a non-zero output voltage.

Note also that the same output can be obtained from two different sets of adjacent resistances, as long as their ratios are equivalent ($R1/R2 = R4/R3$).

Recall if $R1/R2 = R4/R3$, then the output will be zero and the bridge is balanced. A negative change in bridge output voltage will result from a decrease in $R1$ or $R3$ (decreasing $R1/R2$, increasing $R4/R3$). Likewise, a positive change in bridge output voltage will result by a decrease in $R4$ or $R2$ (decreasing $R4/R3$, increasing $R1/R2$). With the bridge output polarity shown, a decrease in resistance $R4$ will produce a positive change in bridge output voltage. The equivalent strain of a decrease in $R4$ resistance will be negative. The general convention is that positive strain is tensile, and negative strain is compressive. Thus, a positive bridge output voltage will result from a compressive stress that decreases resistance $R4$ which will produce a negative strain. This is the convention used throughout this manual.

If you were to replace $R4$ in the bridge with an active strain gauge (R_g), any change in the strain gauge resistance (ΔR) will unbalance the bridge and produce a non-zero output voltage proportional to the change in resistance. Note that the change in resistance due to the applied strain is

$$\Delta R = R_g * GF * \epsilon.$$

If $R1=R2$, & $R3=R_g$, then substituting $R_g+\Delta R$ for $R4$ in our earlier equation for V_o yields the expression: $V_o/V_{ex} = - GF * \epsilon / 4 * [1 / (1 + GF*\epsilon / 2)]$, which is the *sensitivity* of this quarter-bridge circuit. The presence of the $1/(1+GF*\epsilon/2)$ term in the this expression is representative of the small non-linearity of the quarter bridge output with respect to strain. However, the effect of this non-linearity is generally small and can be ignored for quarter-bridge strain levels below about 5000 microstrain.

Note that the active strain gauge (R_g) may occupy one leg of a Wheatstone Bridge (Quarter-Bridge Configuration), two legs of a bridge (Half-Bridge Configuration), or four legs of a bridge (Full-Bridge Configuration), with any remaining legs of the bridge occupied by fixed resistors or "dummy" gauges. In any case, the number of active gauges in a bridge is key to determining whether a bridge is a quarter, half, or full bridge type.

Recall that for the bridge circuit above and the polarities set as shown, tensile (positive) strains will produce a positive output voltage if located in cells 1 and 3, and a negative output voltage if located in cells 4 and 2. Compressive (negative) strains will produce a negative output if located in cells 1 and 3, and a positive output if located in cells 4 and 2. Changes of resistance in adjacent arms of the bridge are subtractive and tend to cancel each other out if they are of the same sign. If the adjacent cell resistance changes are of opposite sign, they are additive. Likewise, resistance changes in opposite cells are additive if of the same sign, and tend to cancel each other out if of the opposite sign.

Because changes in resistance at adjacent bridge resistors have the same (numerically additive) effect on the bridge output when those changes are of the opposite sign, and have the opposite effect (numerically subtractive) when changes in adjacent arms are of the same sign, then by placing similar gauges and lead-wires in adjacent arms and exposing them to the same temperature, they act together to nullify their individual thermal effects on the bridge output, effectively canceling the temperature induced strain error.

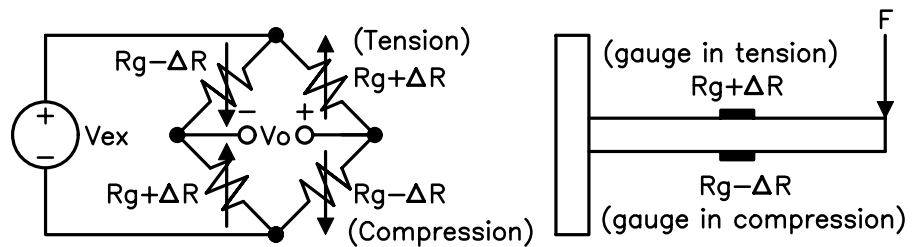
THE WHEATSTONE BRIDGE...continued

THE WHEATSTONE BRIDGE...continued

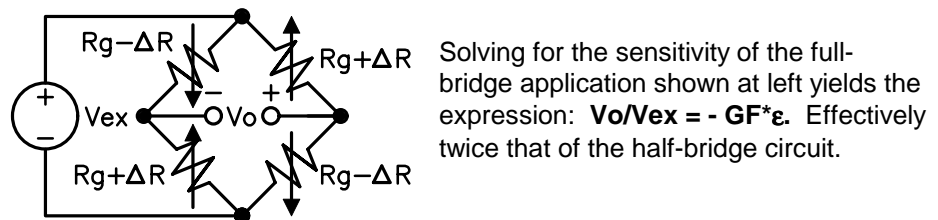
To illustrate, if you use two strain gauges in the bridge, the effect of temperature can be avoided. Substituting $R_g + \Delta R$ for R_4 (our active gauge), and R_g for R_3 (our “dummy” gauge), and by mounting the “dummy” gauge in the transverse direction with respect to the active gauge (perpendicular to the applied strain), the applied strain has little effect on the “dummy” gauge, but the ambient temperature will affect both gauges in the same way. That is, because their temperature effects are equal, the ratio of their resistance does not change, and the corresponding output voltage V_o does not change (effect of temperature is minimized).

If you choose to make the second gauge active, but in a different direction (e.g. one active gauge in tension, one active gauge in compression), you form a half-bridge configuration that effectively doubles the sensitivity of the bridge to strain. That is, the resultant output voltage is linear and approximately double the output of the quarter-bridge circuit for the same excitation.

Consider the balance beam application shown below. Solving for the sensitivity in this half bridge application yields: $V_o/V_{ex} = -GF\epsilon/2$. In the figure below, note that the direction of the arrows (opposing) depicts that the two active gauges are mounted such that one is in compression, and the other in tension, for the same applied strain.



You can further increase the sensitivity of this bridge circuit by making all four arms of the bridge active strain gauges, with opposite legs combined such that two legs are in compression, and two legs in tension. This forms a full-bridge circuit that has double the sensitivity of the half-bridge circuit, and four times the sensitivity of the quarter bridge circuit.



Solving for the sensitivity of the full-bridge application shown at left yields the expression: $V_o/V_{ex} = -GF\epsilon$. Effectively twice that of the half-bridge circuit.

The equations presented so far have been simplified in that they assume an initially balanced bridge that generates zero output when no strain is applied. This is rarely achieved in practice where resistance tolerances and strain errors induced by the application will almost always result in an initial offset voltage (unstrained). Further, these equations also fail to account for the lead wire resistances in the connections to the excitation supply and the measurement leads.

The following section reviews permutations of the three basic bridge configurations just presented that take into account the effects of unbalanced bridges, lead-wire resistance, and the coincident Poisson's Strain, where applicable.

The terms and nomenclature listed in the table below are used in the subsequent strain equations for the various bridge configurations. V_r is a new term that is used to account for the non-balance condition of most unstrained bridges.

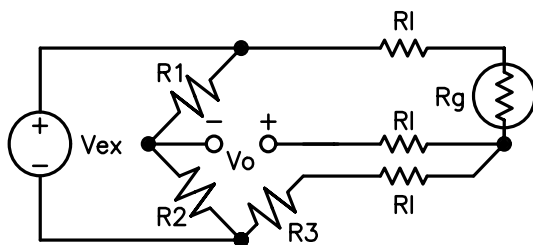
STRAIN GAUGE EQUATIONS

TERM	DEFINITION
V_o	Bridge Output Voltage: The convention used in this document assumes that a positive bridge voltage corresponds to a negative strain indication. V_o strained is the bridge output voltage under load. V_o unstrained is the bridge output voltage unloaded, or initial bridge offset.
V_{ex}	Bridge Excitation Voltage
γ	Poisson's Ratio
GF	Gauge Factor of Strain Gauge
ϵ	Strain (Multiply By 10^6 for micro-strain)
V_r	$(V_o \text{ strained} - V_o \text{ unstrained})/V_{ex}$
R_g	Nominal Strain Gauge Resistance
R_l	Lead-Wire Resistance
$+\epsilon$	Denotes <i>tensile</i> Strain
$-\epsilon$	Denotes <i>compressive</i> Strain
$-\gamma\epsilon$	Poisson's Strain (Transverse Strain)
N	Common Factor used To Account For Multiple Gauges In A Bridge (see Shunt Calibration)

In the examples presented in this manual for the polarities given, it is assumed that a positive strain is tensile and accompanied by a negative bridge output voltage. A negative strain is compressive and accompanied by a positive bridge output voltage. You can reverse this convention by removing the negative sign from the formulas provided and flipping the polarity of the bridge output voltage. Likewise, the internal bridge completion resistors may be taken to either IN- or IN+.

A quarter-bridge that uses one active gauge to make uniaxial tensile or compressive strain measurements has the following two general configurations:

Quarter-Bridge Equations



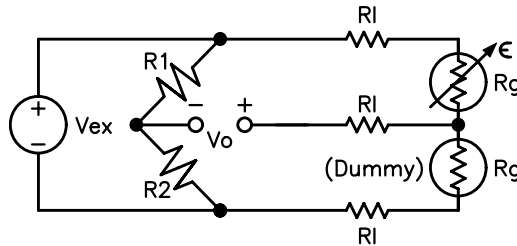
The first quarter bridge configuration (Type I) is most commonly used in experimental stress analysis, where ambient temperature is relatively constant. However, it is not

Quarter-Bridge Type I

recommended for real world applications as it does not compensate for changes in temperature. For the Type I configuration, the adjacent resistor in the lower arm is selected to have the same resistance as the strain gauge ($R_3=R_g$).

Quarter-Bridge Equations

Quarter-Bridge Type II (Compressive Strain)



The second quarter-bridge configuration (Type II) is commonly used to measure compression and you may find this type of bridge configuration in weigh-scale applications. This

configuration uses a single active, plus a passive or “dummy” gauge mounted transverse to the applied strain. The dummy gauge doesn’t measure any strain, it is provided for temperature compensation only. That is, the applied strain has little effect on the dummy gauge as it is mounted in the transverse (perpendicular) direction (the Poisson’s Strain is very small), but the ambient temperature will affect both gauges equally. Since both gauges are subject to the same temperature, the ratio of their resistances are the same, and V_o does not change with respect to temperature.

Note that the temperature compensated Quarter-Bridge (Type II) is sometimes incorrectly referred to as a half-bridge configuration due to the presence of the second gauge. But since the second gauge does not measure strain (it is not active), it is in fact a Quarter-Bridge Type II circuit and the quarter-bridge formulation applies. Note further that the quarter bridge technique cannot be used in applications where the direction of the stress field is unknown or changes.

If there is any force applied in the direction of the dummy gauge, then the measurement of strain along the direction of the active gauge will be in error.

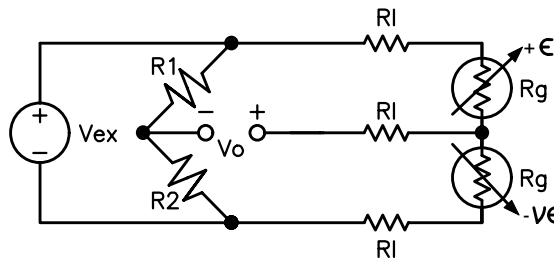
In either case, solving for the resultant strain of the Quarter-Bridge Type I or Type II configuration will yield the following expression (note the absence of Poisson’s Ratio):

$$\epsilon = -4V_r * (1 + R_I / R_g) / [GF*(1+2V_r)] \quad \text{(Quarter-Bridge Type I or II)}$$

Half-Bridge Equations

Half-Bridge Type I (Uniaxial Strain)

A Half-Bridge uses two active gauges to make strain measurements and has the following general configurations:

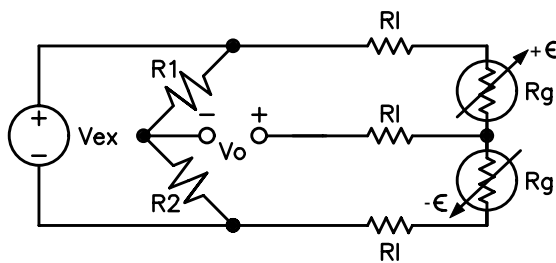


Solving for the resultant strain of the Half-Bridge Type I configuration at left yields the following expression (note that Poisson’s ratio is present where the transverse strain is considered):

$$\epsilon = -4V_r * (1 + R_I / R_g) / [GF*(1 + \gamma) - 2V_r*(\gamma - 1)] \quad \text{(Half-Bridge Type I)}$$

The Half-Bridge Type I circuit uses two active gauges in a uniaxial stress field with one gauge aligned in the direction of the applied strain, and the other gauge aligned in the transverse direction and subject to Poisson's strain. The Half-Bridge Type I circuit is similar to the Quarter-Bridge Type II circuit, except that in addition to temperature compensating the primary active gauge (the gauge mounted in the direction of the applied force), it also accounts for the effect of the transverse strain and Poisson's Ratio is included. This configuration is primarily used for uniaxial induced strain at higher levels of stress. That is, with higher stress levels come higher transverse strains. Thus, a second active gauge is mounted in the transverse direction to measure the increased level of Poisson's Strain that occurs as a result of the strain induced in the primary (axial) direction (the other active gauge measures the primary strain). The presence of the second gauge also corrects for the change in gauge resistance due to temperature, just as for the Quarter-Bridge Type II circuit.

Half-Bridge Equations



Solving for the resultant strain of the Half-bridge Type II configuration at left yields the expression (note the absence of Poisson's Ratio):

$$\epsilon = -2V_r \cdot (1 + R_I / R_g) / GF$$

(Half-Bridge Type II)

*Half-Bridge Type II
(Bending Strain)*

The Half-Bridge Type II configuration uses two active gauges with equal and opposite strains, typical of a bending-beam application. In these applications, a second active strain gauge is mounted in a position that causes it to compress, while the other strain gauge undergoes tension (review the balanced beam example presented earlier). Unlike the compressive transverse strain of the Half-Bridge Type I configuration, the second gauge of the Type II configuration does not measure transverse strain. However, like the Type I, the Type II does offer temperature compensation.

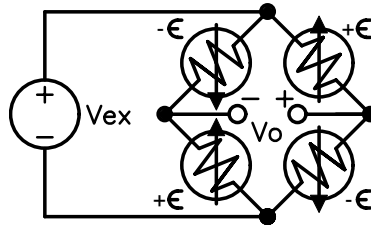
Another permutation of this arrangement would have two active gauges in opposite legs of a bridge, with equal strains, but of the same sign. For example, these gauges may be mounted on opposite sides of a column with a low thermal gradient.

The output signal of a half-bridge can be effectively doubled by substituting a full-bridge. A full-bridge configuration uses four active gauges to make strain measurements--two gauges measure compression, and two gauges measure tension. If opposing gauges are similarly strained, and adjacent gauges oppositely strained, the output of the full-bridge is twice that of the half bridge (and four times that of the quarter bridge). Thus, the full-bridge configuration offers twice the sensitivity of the half-bridge, but is more expensive due to the two additional gauges. Like the half-bridge, the full-bridge is balanced when all gauges undergo the same resistance change. It also compensates for changes in temperature. The Full-Bridge Type I circuit has the following configuration:

Full-Bridge Equations

Full-Bridge Equations

*Full-Bridge Type I
(Bending/Torsion)*

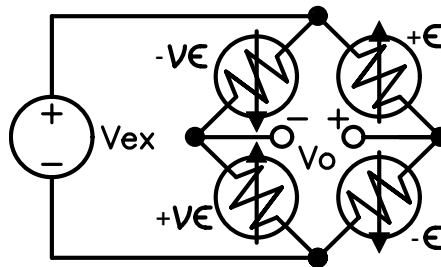


Solving for the resultant strain of the Full-Bridge Type I configuration at left yields the following expression (note the absence of Poisson's strain):

$$\epsilon = -V_r / GF \quad \text{(Full-Bridge Type I)}$$

The Full-Bridge Type I configuration utilizes four active gauges with adjacent gauge pairs subject to equal and opposite strains. This configuration is commonly applied to bending beam applications, or to shafts under torsion. These applications are arranged such that one opposite leg gauge pair is mounted to measure tensile strain, and the other opposite leg gauge pair is mounted in a position that causes it to compress, for the same applied stress (review the balanced beam example for an example of this type of mounting). In this configuration, the gauges that measure compression are not mounted to measure transverse strain.

*Full-bridge Type II
(Uniaxial Bending-Beam Strain)*

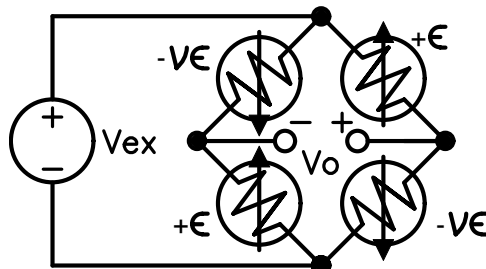


Solving for the resultant strain of the Full-Bridge Type II configuration at left yields the expression:

$$\epsilon = -2V_r / [GF*(\gamma + 1)]. \quad \text{(Full-Bridge Type II)}$$

The Full-Bridge Type II arrangement utilizes four active gauges subject to a uniaxial stress, with two gauges aligned to measure the maximum principal strain, and the other two aligned to measure the transverse Poisson's strain, an arrangement common to bending beam applications. Note that one half of the bridge measures the tensile and compressive strains, and the opposite half of the bridge measures the compressive and tensile Poisson's strain.

*Full-Bridge Type III
(Uniaxial Column Strain)*



Solving for the resultant strain of the Full-Bridge Type III configuration at left yields the expression:

$$\epsilon = -2V_r / [GF*(\gamma + 1) - Vr*(\gamma - 1)]. \quad \text{(Full-Bridge Type III)}$$

The Full-Bridge Type III arrangement utilizes four active gauges subject to a uniaxial stress, with two gauges aligned to measure the principal strain, and the other two aligned to measure the transverse Poisson's strain, an arrangement common to column stress applications.

Note that one half of the The Full-Bridge Type III configuration is used for axial strains where four active gauges are used with one opposite leg gauge pair mounted to measure the tensile strain, and the other pair of opposite leg gauges are mounted in a position to measure compressive Poisson's strain, for the same applied stress.

The Gauge Factor of a strain gauge is a characteristic transfer coefficient that relates the resistance change in a strain gauge to the actual strain that produced it. Specifically, the Gauge Factor is the ratio of the fractional change in resistance to the strain ($GF = (\Delta R / R) / (\Delta L / L) = (\Delta R / R) / \epsilon$). The Gauge Factor for metallic strain gauges is typically around 2.0, but may vary with temperature, strain level, and gauge mounting, and this variation will contribute to error in making strain measurements.

Instrument Gauge Factor

The concept of Instrument Gauge Factor is provided as an additional means of rescaling an instrument's strain measurement system via the process of shunt calibration. The other means of rescaling the instrument is by varying its measurement Gain (set to 1 by default). The need to rescale an instrument is largely driven by the inherent lack of precision in the strain gauge parameters, as well as variations in its application. For example, the rated output (mV/V) of a strain gauge may vary by as much as $\pm 10\%$ from the specification. Rescaling the instrument by varying its Gain or Instrument Gauge Factor allows us to account for these errors and more accurately reflect the strain.

During shunt calibration, the strain measurement is modified by varying the Instrument Gauge Factor until the reading matches a pre-calculated (simulated) strain. The calculation of the simulated strain is driven by the Gauge Factor of the strain gauge itself and a fixed gain of 1. The instrument's indicated strain is driven by the Instrument Gauge Factor and the Measurement Gain. Initially, the Instrument Gauge Factor is set equivalent to the Strain Gauge Factor, but may differ following shunt calibration. Thus, the Instrument Gauge Factor is simply an arbitrary transfer coefficient that can be changed "on the fly" to convert the input signal to an accurate indicated strain at the module. Any changes to the Gauge Factor must also be followed by changes to the Instrument Gauge Factor.

IMPORTANT: The Instrument Gauge Factor of the Acromag Model 851T is initially set equivalent to the strain Gauge Factor which is initially set to 2.000 by default. Thus, the indicated strain measurement will be considered equivalent to the measured strain for a strain gauge factor of 2. However, if the strain gauge factor $GF \neq 2$ and its value changes, the Instrument Gauge Factor must also change or the indicated strain will be in error. The Instrument Gauge Factor is normally set equivalent to the Gauge Factor, then fine tuned via shunt calibration. You need to be aware that changes in Gauge Factor only drive the calculation of simulated strain, but changes in the Instrument Gauge Factor drive the module's indicated strain. Alternately, the IntelliPack Configuration Software includes a Software Gain Factor that may be used to directly scale the indicated strain to the simulated strain during shunt calibration. The Software Gain Factor is initially set to 1.0 by default, but may be varied as required to rescale strain measurements following shunt calibration.

Instrument Gauge Factor

Note that with respect to the display of strain for bridge inputs via this module, the formulas presented are used internally by this module, except Instrument Gauge Factor is substituted for Gauge Factor, and the result is multiplied by a software Gain Factor for rescaling purposes (default gain is 1.000).

DETERMINING YOUR SENSOR TYPE

The Acromag 851T modules support two input types: strain gauge bridge inputs for advanced strain measurement, or load cells for basic force measurements. Examples of load cell inputs include pressure transducers, torque converters, accelerometers, and vibration sensors. These devices may operate under compression and/or tension and yield bipolar or unipolar millivolt signals proportional to the applied force. Load cell signals are expressed in percent of span units for this module and do not require you to know any additional details of the internal bridge type, the gauge factor, or a materials Poisson's ratio, as may be required for strain gauge bridge inputs. Only the rated output and nominal excitation are considered for load cells. On the other hand, bridge inputs will use microstrain units and the formulation for strain is more complex and will require knowledge of these parameters and their application.

Bridge Inputs

The IntelliPack Configuration Software supports strain formulation for all quarter, half, and full bridge types described above. The following information is included to alleviate some of the confusion encountered in selecting the proper strain formulation for bridge input applications.

Note that all inputs to the 851T module are wired as complete full-bridge circuits with remote sense lines included. The number of active gauges, their purpose, and whether bridge completion is already provided or done internally will determine the applicable strain formula.

In any bridge configuration, it is the number of active load cells in the bridge that determine whether it is a half, quarter, or full-bridge. Additionally, the specific bridge type is determined by considering the mounting of any additional load cells in the bridge (i.e. their purpose), the presence of a "dummy" gauge, and whether or not half-bridge completion resistors are provided.

Thus, the first step to determine which bridge type applies to your application is to know how many *active* load cells are present. An "active" cell is mounted such that it will measure strain in the same direction as an applied force (either tensile or compressive). One active load cell will form a Quarter-Bridge, two active load cells will form a Half-Bridge, and four active load cells will form a Full-Bridge.

If your bridge has one active gauge and no additional dummy gauges or resistive elements present, then you select a **Quarter-Bridge Type I** formulation. However, If your sensor has one active gauge, plus a second passive or "dummy" gauge mounted transverse to the applied stress (to provide temperature compensation), then you select **Quarter Bridge Type II**. In any case, the same formula for calculating strain applies to both Quarter-Bridge types and the type distinction simply serves to specify whether the gauge is temperature compensated or not, and the steps that are necessary to complete the wiring for the full-bridge input of the 851T module.

Bridge Inputs

For example, both types will require half-bridge completion resistors (either external or internal), and Type I will require that a third resistor be connected in an adjacent arm to the active gauge and selected to match the resistance of the active gauge.

If your bridge has two active gauges, with the second active gauge mounted perpendicular to the applied force to measure the coincident transverse (Poisson's) strain and to temperature compensate the primary active gauge (the gauge mounted to measure strain in the same direction as the applied force), then you would select a **Half-Bridge Type I** formulation. This is commonly used to measure uniaxial strains at higher stress levels, where the effect of the transverse strain is greater and must be accounted for. Note that the Half-Bridge Type I circuit is similar to the Quarter-Bridge Type II, except that the transverse mounted gauge also measures the transverse Poisson's strain as well as temperature compensates the primary active gauge.

If your bridge has two active gauges, with both gauges mounted such that they are subject to equal and opposite strains for the same applied force, then you would select a **Half-Bridge Type II** formulation. This is commonly used in bending-beam applications, where one gauge is mounted in a position that causes it to compress while the other gauge undergoes tension. The presence of the second active gauge does provide temperature compensation, but does not measure transverse strain. Additionally, this type will require half-bridge completion resistors and these may be wired externally, or provided internally via the 851T module.

If your bridge has four active gauges, with adjacent gauge pairs subject to equal and opposite strains for the same applied stress, then you would select a **Full-Bridge Type I** formulation. This arrangement is inherently temperature compensated and does not require bridge completion.

If your bridge has four active gauges, with one half of the bridge (adjacent gauge pair) mounted to measure the tensile and compressive strain, and the opposite half mounted to measure the coincident transverse Poisson's Strains, then you would select a **Full-Bridge Type II** formulation. This type is commonly used to measure the uniaxial stress in bending beam applications. This arrangement is inherently temperature compensated and does not require bridge completion.

If your bridge has four active gauges, with one diagonal gauge pair mounted to measure the principal tensile strain, and the opposite diagonal gauge pair mounted to measure the transverse (compressive) Poisson's Strain, then you would select a **Full-Bridge Type III** formulation. This type is commonly used to measure the uniaxial stress in a column. This arrangement is inherently temperature compensated and does not require bridge completion.

The table of the following page summarizes each of the bridge configurations discussed, along with their respective strain formulation, applications, and wiring. These equations apply for the bridge output voltage in the polarity shown. Where applicable, if the bridge completion resistors connect to IN+ instead of IN- you effectively flip the polarity of the bridge output voltage and you may remove the negative sign preceding each equation. The convention illustrated in this document assumes a positive strain is tensile and will correspond to a negative bridge output voltage.

Load Cell Inputs

A simpler form of the Wheatstone bridge is the load cell. The load cell is a device principally used in weighing systems that utilizes strain gauge technology internally. Unlike the strain gauge, the output of a load cell will be expressed in equivalent units of force (not microstrain). As a result, processing a load cell signal does not require intimate knowledge of its bridge type, gauge factor, or Poisson's ratio. Rather, the important considerations of a load cell are its rated output (mV/V), its excitation, and its rated capacity.

Note that even though the load cell itself will contain permutations of quarter, half, or full-bridges, this detail is irrelevant and rarely provided by the manufacturer. Further, most load cells have bridge completion and temperature compensation already built-in.

Example 1: A compression load cell has six connection wires (sense \pm , excitation \pm , and signal \pm) and is specified as follows:

Rated Capacity: 50,000 lbs/inches
Full-Scale Output: 2.0mV/V
Rated Excitation: 10V DC, 15V Maximum
Safe Overload: 150% Full-Scale
Operating Temperature Range: -65°F to 200°F

From these specifications, we can conclude the following:

- This load cell is temperature compensated (wide ambient).
- The cell already includes half-bridge compensation resistors internally (note the wiring—most common for this cell type).
- The output of this load cell is +20mV at full rated load of 50000psi with 10V of excitation (2.0mV/V * 10V).
- The output may be over-driven to +30mV at a load of 75000psi with 10V of excitation (safe overload limit).

Bridge Types, Their Strain Formula, Applications, and Wiring

Active Gauges	Bridge Type (N)	ϵ Strain Formulation (Primary Application)	BRIDGE WIRING
1	Quarter-Bridge Type I N=1	$-4V_r * (1 + R_l / R_g) / [GF*(1+2V_r)]$ Uniaxial Compressive Strain In Constant Temperature Environments	A Single Gauge Paired With A Matching Resistor and Half-Bridge Completion Resistors.
1	Quarter-Bridge Type II N=1	$-4V_r * (1 + R_l / R_g) / [GF*(1+2V_r)]$ Uniaxial Compressive Strain With Changing Ambient Environmental Temperatures, most common in weigh-scale load cells	A Single Gauge Paired With A Transverse Mounted "Dummy" Gauge for Temperature Compensation and Half-Bridge Completion Resistors.
2	Half-Bridge Type I N=1+γ	$-4V_r * (1 + R_l / R_g) / [GF*(1+ \gamma) - 2V_r*(\gamma - 1)]$ Uniaxial Strain at Higher Stress Levels	A Primary Gauge Paired with a Transverse Gauge To Measure Poisson's Strain and Provide Temperature Compensation. Requires Half-Bridge Completion Resistors.
2	Half-Bridge Type II N=2	$-2V_r *(1 + R_l / R_g) / GF = -4V_r*(1 + R_l / R_g) / N*GF$ Bending Strain with Two Gauges Subject to Equal and Opposite Strains	One Gauge Measures Compression and Other Gauge Measures Tension For Same Applied Force. Requires Half-Bridge Completion Resistors.
4	Full-Bridge Type I N=4	$-V_r / GF = -4V_r / (N*GF)$ Bending Beam Strain or Shafts Under Torsion with Gauge Pairs Measuring Equal and Opposite Strains	One Opposite Leg Pair Measures Compression, While Other Opposite Leg Pair Measures.
4	Full-Bridge Type II N= 2(1+ γ)	$-2V_r / [GF*(\gamma + 1)] = -4V_r / (N*GF)$ Uniaxial Column Strain with One Gauge Pair Measuring the Principal Tensile and Compressive Strains and the Opposite Gauge Pair Measuring the Corresponding Transverse Poisson's Strains	One Half of Bridge Measures the Principal Tensile and Compressive Strain, Other Half Measures the Coincident Compressive and Tensile Poisson's Strains.
4	Full-Bridge Type III N= 2(1+ γ)	$-2V_r / [GF*(\gamma + 1) - V_r*(\gamma - 1)]$ Uniaxial Column Strain with One Gauge Pair Measuring the Principal Tensile Strain and the Opposite Gauge Pair Measuring the Compressive Transverse Poisson's Strain	One Opposite Gauge Pair (Diagonal) Measures Principal Tensile Strain and Other Opposite Gauge Pair Measures the Compressive Transverse Poisson's Strain.

Notes: