Model TT351-07x0, Bridge Input Transmitter (Strain Gauges, Load Cell, or ±4mV to ±165mV DC)

USB Programmable, DIN Rail Mount, DC-Powered Single Channel Transmitter w/ Sourcing Current or Voltage Output

USER'S MANUAL

ACROMAG INCORPORATED
30765 South Wixom Road
Wixom, MI 48393-2417 U.S.A.

Tel: (248) 295-0880
email: sales@acromag.com

8501140C

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IMPORTANT SAFETY CONSIDERATIONS
You must consider the possible negative effects of power, wiring, component, sensor, or software failure in the design of any type of control or monitoring system. This is very important where property loss or human life is involved. It is important that you perform satisfactory overall system design and it is agreed between you and Acromag, that this is your responsibility.

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This manual covers the TT351-0700 Strain Gauge Transmitter which converts a 4 or 6 wire strain gauge bridge or load cell sensor signal (or millivoltage signal) to an isolated voltage or current output signal. Acromag offers a complete line of other TT modules targeted to input signals that include current, voltage, thermocouples, frequency, thermistors, and resistance temperature detectors.

GETTING STARTED

DESCRIPTION

Symbols on equipment:

⚠

Means “Refer to User’s Manual (this manual) for additional information”.

The TT351-0700 is an ANSI/ISA Type IV (4-Wire) transmitter with an input that mates to a 4 or 6-wire strain gauge sensor or load cell wired as a Wheatstone bridge. It measures the ratio-metric bridge output Vo and bridge excitation Vex to resolve indicated strain or load of the sensor and linearly extrapolate an isolated DC voltage or current output signal. The ADC ratio-metrically converts the bridge signal relative to a reference derived from bridge excitation. Its input bipolar range varies with the product of gauge rated output (RO), excitation (Vex), and user-specified over-range limit. The unit is setup, calibrated, and scaled with USB configuration software and a connection to a Windows-based PC’s (Windows 7 and later versions only), or using a USB-OTG cable to an Android smartphone or tablet running our Agility mobile app. This model provides an adjustable and scalable input and output stage, null offset and automatic tare controls, plus drive capability for isolated voltage or current output, full 3-way isolation, variable excitation, and variable input filtering.

Key Features

- **USB configured and calibrated using** Windows software, or a wired USB-OTG connection to Android smartphones or tablets using the Acromag Agility app**.**
- **Thin 17.5mm wide enclosure** for high-density mounting**.**
- **Isolated Input/Exc, Output, & Power** – increases safety & noise immunity.
- **SG Bridge, Load Cell, or mV Input** w/support of sensor rated outputs from 1-10mV/V and 4-11V of excitation. Measures both sensor output Vo (ratio-metrically) and sensor excitation Vex to resolve corresponding strain or load (may optionally be used for ±4mV to ±165mV differential input signals).
- **Digitally Adjustable Internal Sensor Excitation** from 4-11V in ~111mV increments up to 120mA, turned OFF for use with external excitation.
- **Remote Sense of Bridge Excitation Vex** – Input samples coincident excitation via its ±SNS terminals allowing it to boost its internal excitation if needed to overcome voltage drop due to load, temperature, or excessive lead resistance.
- **Ratio-Metric Input Digitization of Ratio-Metric Sensor Vo** simultaneous and relative to an ADC reference derived from sensor excitation Vex for increased accuracy and immunity to changes in excitation and requisite noise.
- **Optional Auto Null-Compensation/Zero-Balance of Bridge Output Vo** – Initial bridge offsets can be automatically removed from sensor Vo measurements.
- **Optional Automatic Tare Removal** – Tare may be automatically removed from sensor Vo measurements and can be set via software control or remotely via an isolated digital input on the module.
- **Optional Half or Quarter Bridge Completion Built-In** – precision resistor pair ratio-matched to ±0.01% can be jump wired to IN± to accomplish half or quarter to full-bridge completion in either polarity (also useful to bias a millivolt input signal to keep it from floating).
- **Optional Custom Input Linearization** – can linearize a non-linear input signal (strain bridge, load cell, or millivolt signal) with up to 25 user-defined signal breakpoints for 24 piece-wise linear segments.
- **Separate voltage & current output terminals –** choice of nominal ±10V, ±5V, 0-10V, 0-5V, or 0-20mA/4-20mA isolated output or scaled sub-ranges of same.

Key Features...

- **Flexible I/O Scaling** with independently adjustable & scalable input and output.
- **Input Zoom Feature for Load Cells** that allows the sensor over-range limit specification to increase gain over a smaller portion of a load cell's rated range, potentially improving resolution & accuracy for some applications where a wide-input load sensor is used over a smaller application range.
- **Variable digital input filter (none, low, medium, or high) plus input averaging.**
- **Transparent Continuous ADC Background Self-Calibration** helps compensate the ADC for gain and offset error and drive a nearly flat output span with minimal drift over time and temperature.
- **Self-Diagnostics** are built-in and operate upon power-up to provide reliable service, easy maintenance, and trouble-shooting.
- **Normal or Reverse Acting Transmitter Output Signal.**
- **Wide Signal Range** supports sensor rated outputs from 1mV/V*4V to 10mV/V*11V with up to 50% of over-range (i.e. ±4mV to ±165mV).
- **High measurement accuracy & linearity** with 24-bit ADC & 16-bit DAC conversion.
- **LED Indication of power (green) and output fault (orange).**
- **Wide-range DC power input from 9-32V** is bus/redundant power ready.
- **Wide ambient temperature operation from -40°C to +70°C.**
- **Thoroughly tested and hardened for harsh environments.**
- **CE Approved.**
- **FCC Conformity Class A.**
- **Model TT351-0700 cULus Listed - Ordinary Location.**
- **Model TT351-0710 cULus Listed Class I/Division 2 - Haz. Loc., ATEX, & IECEx.**

Application

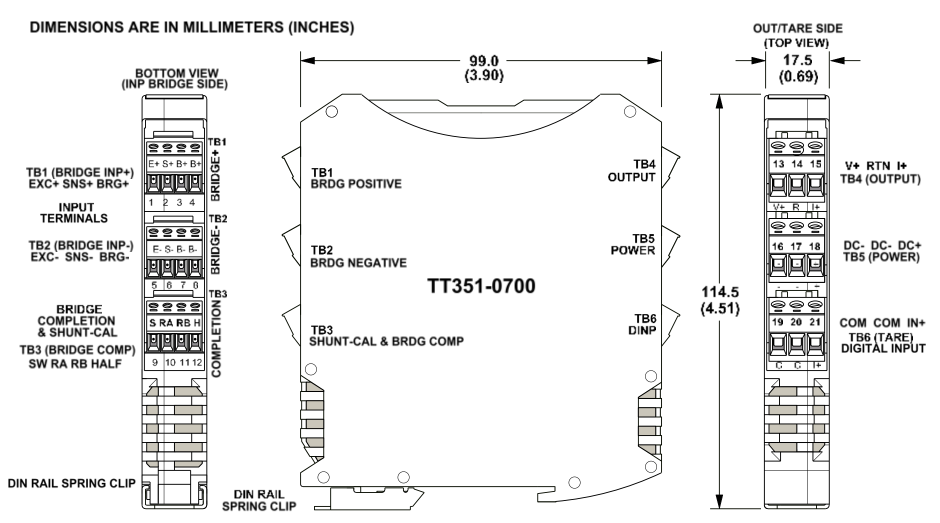
For additional information on these devices and related topics, please visit our web site at www.acromag.com. Also see whitepaper 8500-699: Introduction to Strain Measurement.

This model isolates and transmits a grounded or ungrounded strain gauge or load cell sensor wired to it as a Wheatstone bridge. It can optionally supply variable sensor excitation and will measure both sensor output Vo and coincident excitation Vex, which it uses to compute requisite strain or load and linearly drive an isolated sourcing output that supports 0-20mA or 4-20mA current, or ±10V, ±5V, 0-10V, 0-5V voltage ranges. It supports high-density mounting on T-type DIN rail, allowing units to be mounted side-by-side on 0.7-inch (17.5mm) centers with support for 9-32V DC power via terminals on the unit, or optionally wired to a DIN-rail bus connector.

Mechanical Dimensions

Units may be mounted to 35mm "T" type DIN rail (35mm, type EN50022), providing isolated I/O channels on 0.7-inch centers.

WARNING: *IEC Safety Standards may require that this device be mounted within an approved metal enclosure or sub-system, particularly for applications with exposure to voltages greater than or equal to 75VDC or 50VAC*

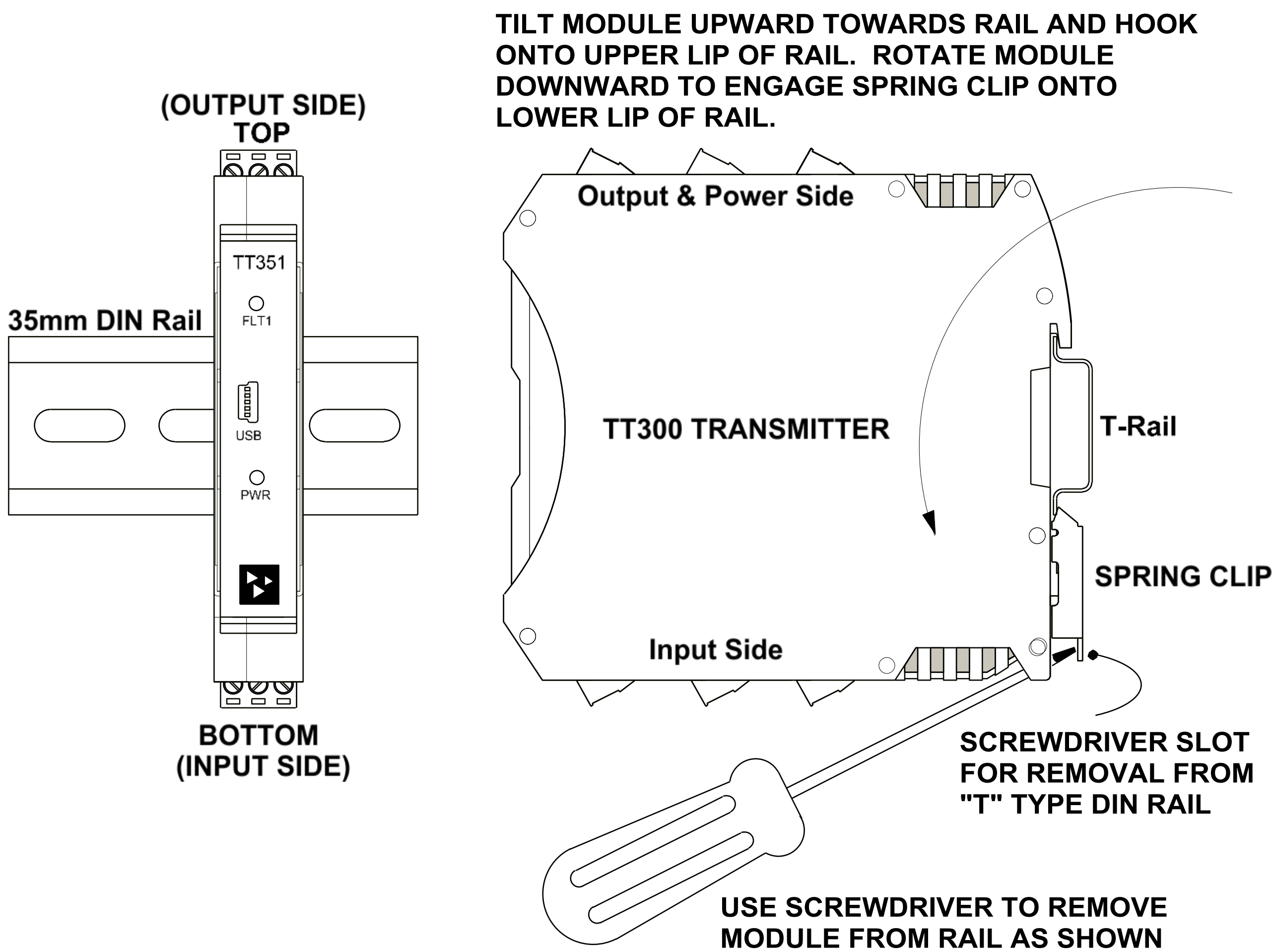


DIN Rail Mounting & Removal

NOTE: It is recommended that this unit be mounted upright on a DIN rail allowing free air flow intake from the bottom vent to flow through the unit and out the top vent. This will allow the unit to run cooler, perform better, and help to extend the life of the electronics.

Refer to the figure below for attaching and removing a unit from the DIN rail. A spring-loaded DIN clip is located on the input side bottom. The opposite rounded edge at the bottom of the output side allows you to tilt the unit upward to lift it from the rail while prying the spring clip back with a screwdriver. To attach the module to T-type DIN rail, angle the top of the unit towards the rail and place the top groove of the module over the upper lip of the DIN rail. Firmly push the unit downward towards the rail until it snaps into place. To remove it from the DIN rail, first separate the input terminal blocks from the bottom side of the module to create a clearance to the DIN mounting area. You can use a screwdriver to pry the pluggable terminals out of their sockets. Next, while holding the unit in place from above, insert a screwdriver into the lower path of the bottom of the module to the DIN rail clip and use it as a lever to force the DIN rail spring clip down while pulling the bottom of the module outward until it disengages from the rail, and lift it from the rail.

TT TRANSMITTER DIN RAIL MOUNTING AND REMOVAL



ELECTRICAL CONNECTIONS

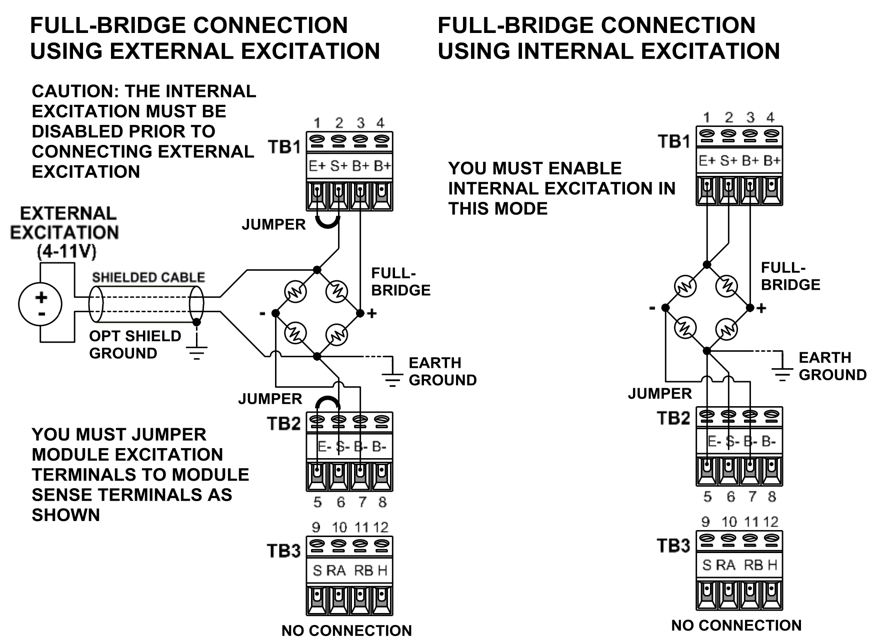
WARNING – EXPLOSION HAZARD – Do not disconnect equipment unless power has been removed or the area is known to be non-hazardous.
WARNING – EXPLOSION HAZARD – Substitution of any components may impair suitability for Class I, Division 2.
WARNING – EXPLOSION HAZARD – The area must be known to be non-hazardous before servicing/replacing the unit and before installing.

Wire terminals accommodate 14–28 AWG (2.08–0.081mm^2) solid or stranded wire with a minimum temperature rating of 90^{o}C. Input wiring may be shielded or unshielded type. Ideally, output wires should be twisted pair or shielded twisted pair. Use insulated wire to keep circuits isolated. Terminals are pluggable and can be removed from their sockets by prying outward from the top with a flat-head screwdriver blade. The TT351 models allows bridge sensors to be wired to TB1, TB2 and TB3. Strip back wire insulation 0.25-inch on each lead and insert the wire ends into the cage clamp connector of the terminal block. Use a screwdriver to tighten the screw by turning it in a clockwise direction to secure the wire (0.5-0.6Nm torque). Use adequate wire insulation and follow proper wiring practices, as common mode voltages can exist on signal wiring. As a rule, output wires are normally separated from input wiring for safety and low noise pickup.

Sensor Input Connections

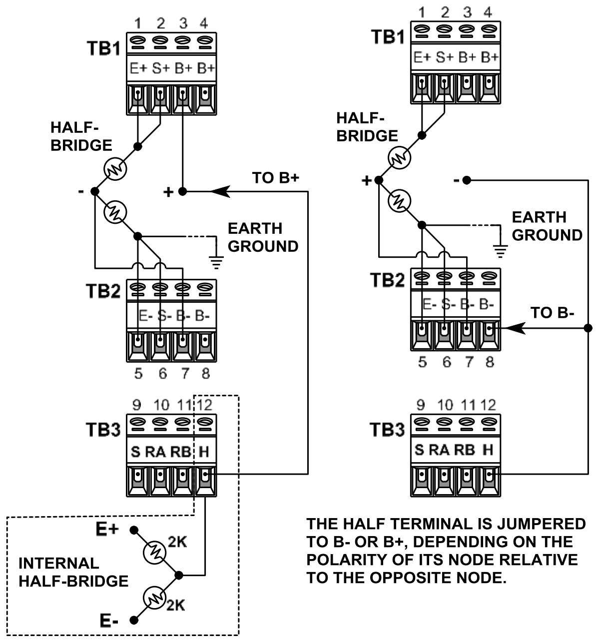
Input is wired as a Wheatstone Bridge directly to terminals TB1, TB2, and TB3 at the bottom of the module (spring-loaded DIN clip side). Follow proper polarity when making input connections.

- Sensor Excitation is isolated from unit power, the remote tare trigger, and the transmitter output. Excitation may be supplied internally or externally.
- You must disable internal excitation before connecting sensor to external excitation (use the config software to set Excitation to Ext).
- Complete input connections prior to power-up to avoid propagating input offset.



Sensor Input Connections...

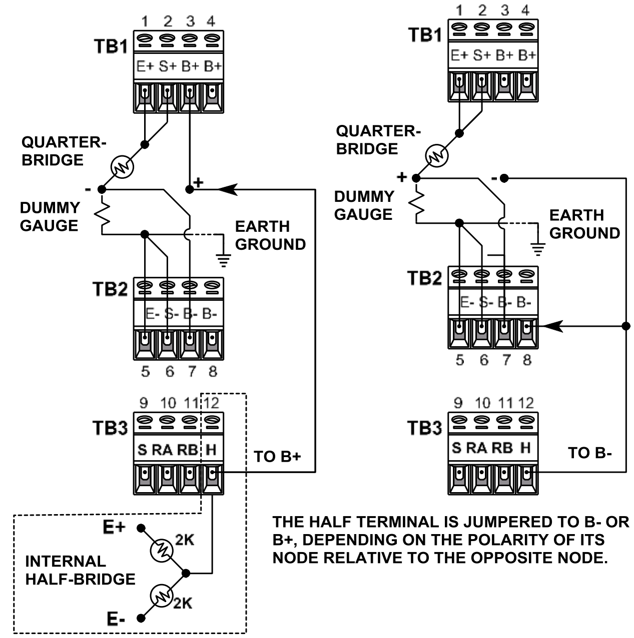
HALF-BRIDGE COMPLETION



THE INTERNAL HALF- BRIDGE USES TWO PRECISION RESISTORS RATIO MATCHED TO 0.01% AND WITH A LOW TC OF 2PPM/C.

THE HALF-BRIDGE TERMINAL IS ALSO REQUIRED TO PROPERLY BIAS A DIFFERENTIAL INPUT WHEN USING A MILLIVOLT SOURCE TO SIMULATE A BRIDGE SIGNAL.

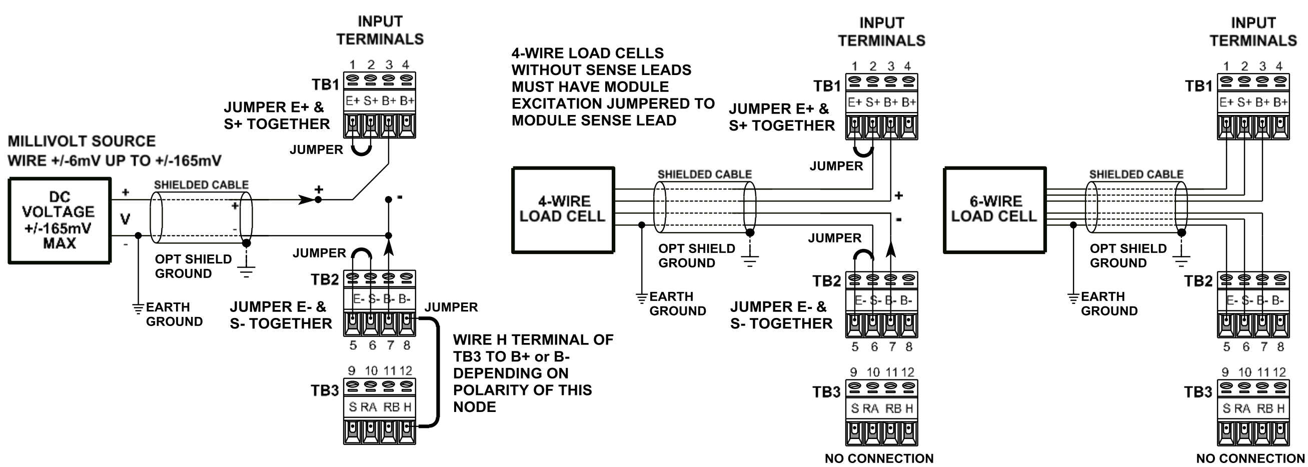
QUARTER-BRIDGE COMPLETION



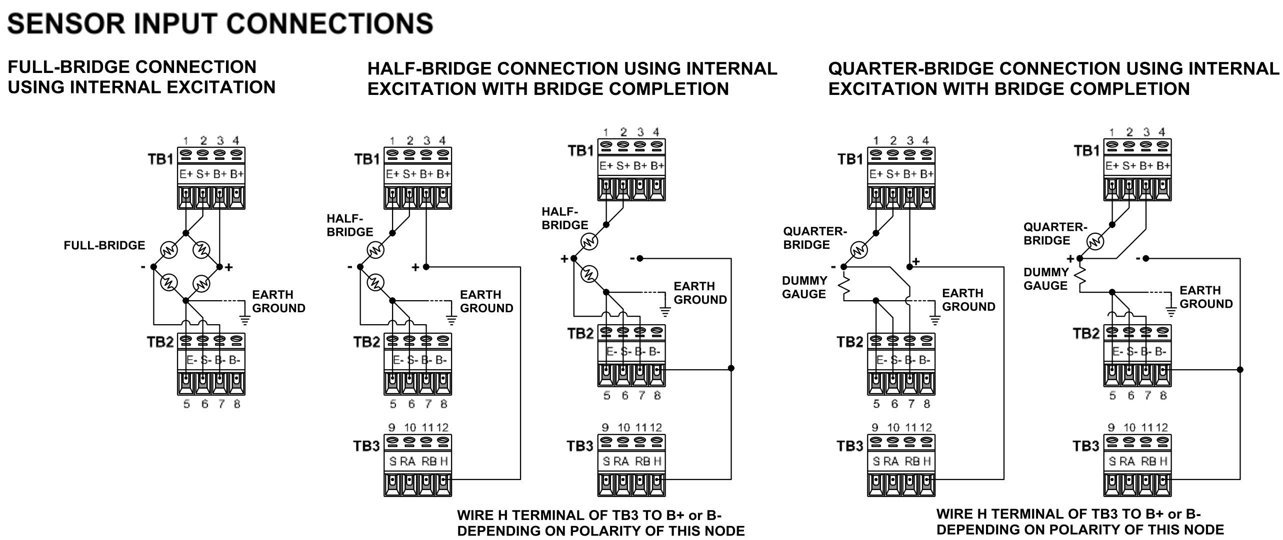
THE INTERNAL HALF- BRIDGE USES TWO PRECISION RESISTORS RATIO MATCHED TO 0.01% AND WITH A LOW TC OF 2PPM/C.

THE HALF-BRIDGE TERMINAL IS ALSO REQUIRED TO PROPERLY BIAS A DIFFERENTIAL INPUT WHEN USING A MILLIVOLT SOURCE TO SIMULATE A BRIDGE SIGNAL.

A "DUMMY" STRAIN GAUGE SHOULD BE USED TO COMPLETE A QUARTER BRIDGE AND SHOULD BE MOUNTED NEAR THE ACTIVE GAUGE TO MINIMIZE TEMPERATURE EFFECTS.



Sensor Input Connections...



Digital Input Connections (Tare)

Optionally used for remotely triggering a Tare measurement.

This unit can be setup to automatically remove or cancel “tare” weight in its measurement of sensor output Vo. Tare refers to a defined common weight between measurements that can be discounted from subsequent measurements (like the weight of a container or shipping materials). Do not confuse tare with offset null or zero balance, which is another control to correct Vo, but meant for smaller non-zero imbalances in the sensor application typically present when no load or strain is applied. Tare is established by triggering its measurement under software control, or remotely when the TARE digital input is asserted (asserted via a high 15-30V DC input, 200ms min pulse). Any application that requires frequent tare adjustment during operation should make provisions for wiring to the digital input TARE and COM as part of the installation. Note that a new Tare offset will take effect immediately but is only stored to non-volatile memory after 10 seconds of TARE trigger inactivity. If power is lost during a tare measurement, the tare offset may be lost and will have to be repeated. While this write delay may seem inconvenient, it is done to help preserve the life of non-volatile memory in the module if changing tare is triggered too frequently.

Output Connections

(To DC Current or Voltage Terminals)

Note: Your analog output is based on your Indicated measurement scaled using your Instrument Gauge Factor and Software Gain in place of the sensor Gauge Factor and a software gain of 1.

The transmitter output is modeled after an ANSI/ISA Type 4 transmitter (4-Wire) with unit power separate from the input and output.

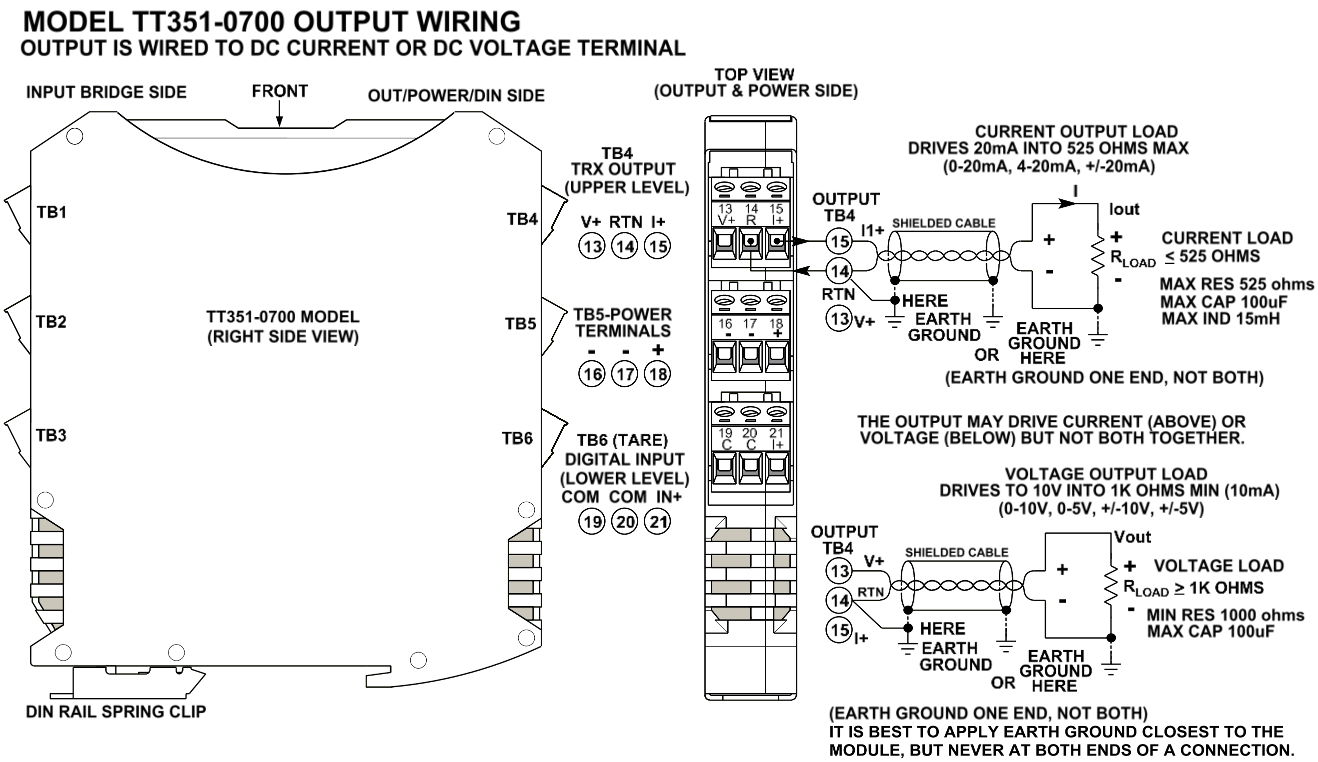
- **Sourcing/Active Output connections are polarized.** The sourcing transmitter current and voltage outputs at the TB4 terminals share a common return (RTN). Current is sourced from I Out+ and returned to RTN. Voltage is sourced positive at V Out+ with respect to RTN. Only one output terminal (V or I) may be loaded at one time.
- **Variations in output load resistance has negligible effect on output accuracy** when load limits are respected with respect to output type (see below).

Output Connections...

Observe proper polarity. Shielded twisted-pair wiring is recommended for best results to connect the longest distance between the field output and its remote load as shown above. An output connection to earth ground at the return terminal will help protect the isolated output circuit from damage in noisy environments.

WARNING: For compliance to applicable safety and performance standards, the use of twisted pair output wiring is recommended. Failure to adhere to sound wiring and grounding practices as instructed may compromise safety, performance, and possibly damage the unit.

TIP - Ripple & Noise: Place additional capacitance at the load to help reduce the 60Hz/120Hz ripple sometimes present in industrial applications. For large 60Hz ripple, connect an external 1uF or larger capacitor directly across the load to reduce excess ripple. For sensitive applications with high-speed acquisition at the load, high frequency noise may be reduced significantly by placing a 0.1uF capacitor directly across the load, and as close to the load as possible.



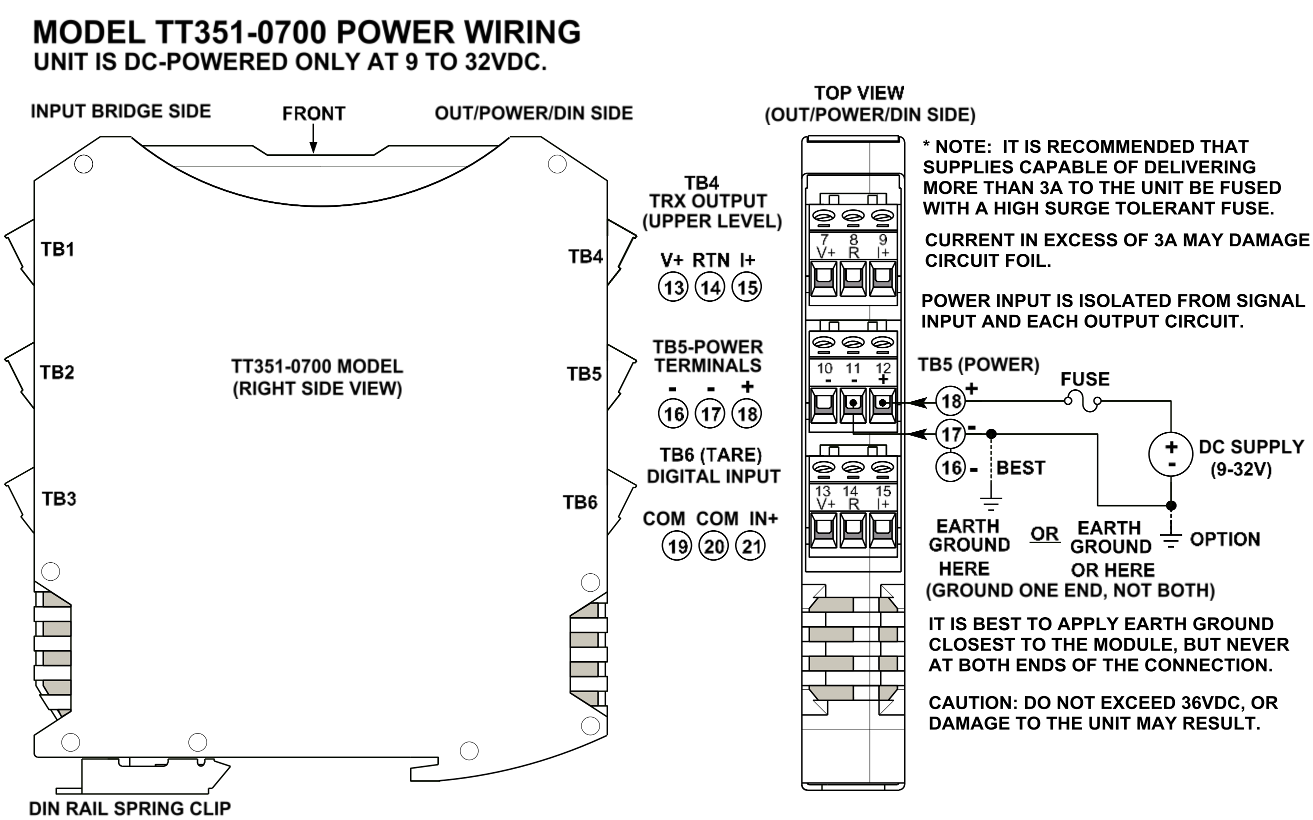
Power Connections

IMPORTANT – External Fuse: If this unit is powered from a supply capable of delivering more than 3A to the unit, it is recommended that potential fault current be limited via a high surge tolerant fuse rated for a maximum current less than 3A (for example, see Bel Fuse MJS or RJS fuse types).

The unit is powered from 9-32V DC (36V DC peak) by connecting power as shown below. This transmitter can be optionally powered (or redundantly powered) via the DIN rail bus when coupled to an optional DIN rail bus connector (Acromag Model 1005-063) with a bus terminal block (Acromag 1005-220 or 1005-221). This optional power connection method can allow several modules to share a single power supply connection without wiring power to each unit's power terminals.

- Power connections are isolated from the input and output. The supply voltage should be from 9-32V DC. This voltage must never exceed 36V DC peak, or damage to the unit may result.
- Variations in power supply voltage between the minimum required and 32V maximum, has negligible effect on transmitter accuracy.
- Note the placement of earth ground at power. The power cable shield and DC- should ideally be grounded closest to the module.

CAUTION: Risk of Electric Shock – More than one disconnect switch may be required to de-energize this equipment before servicing.

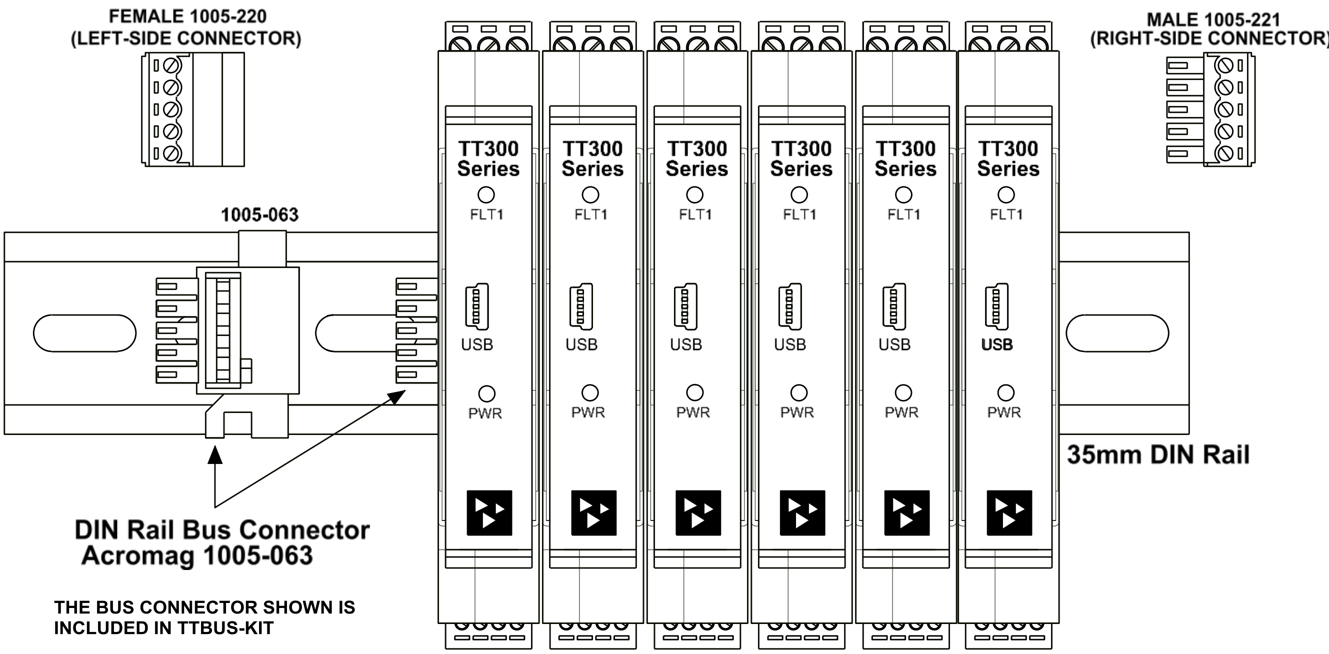


Optional Bus Power Connections

Power is normally wired to the TB5 terminals of the unit as shown on the previous page. However, this device is equipped to be optionally or redundantly powered via a DIN rail bus connector (Acromag 1005-063) mated to an optional plug-in terminal block (Acromag 1005-220 or 1005-221, depending on left side or right-side wire entry). Any power input via the bus connector is diode-coupled to the same point in the circuit as unit power connected at its power terminal TB5. You could power multiple units by snapping them together along the DIN rail bus using connector 1005-063, then connecting a mating terminal block (select a left side or right-side connector, see figure below). While the intent of the bus power connector is to allow several units to conveniently share a single supply, you could also use the bus power connector to redundantly power units (with local power also applied at TB5), allowing a backup supply to maintain power to the units should the main supply at TB5 fail.

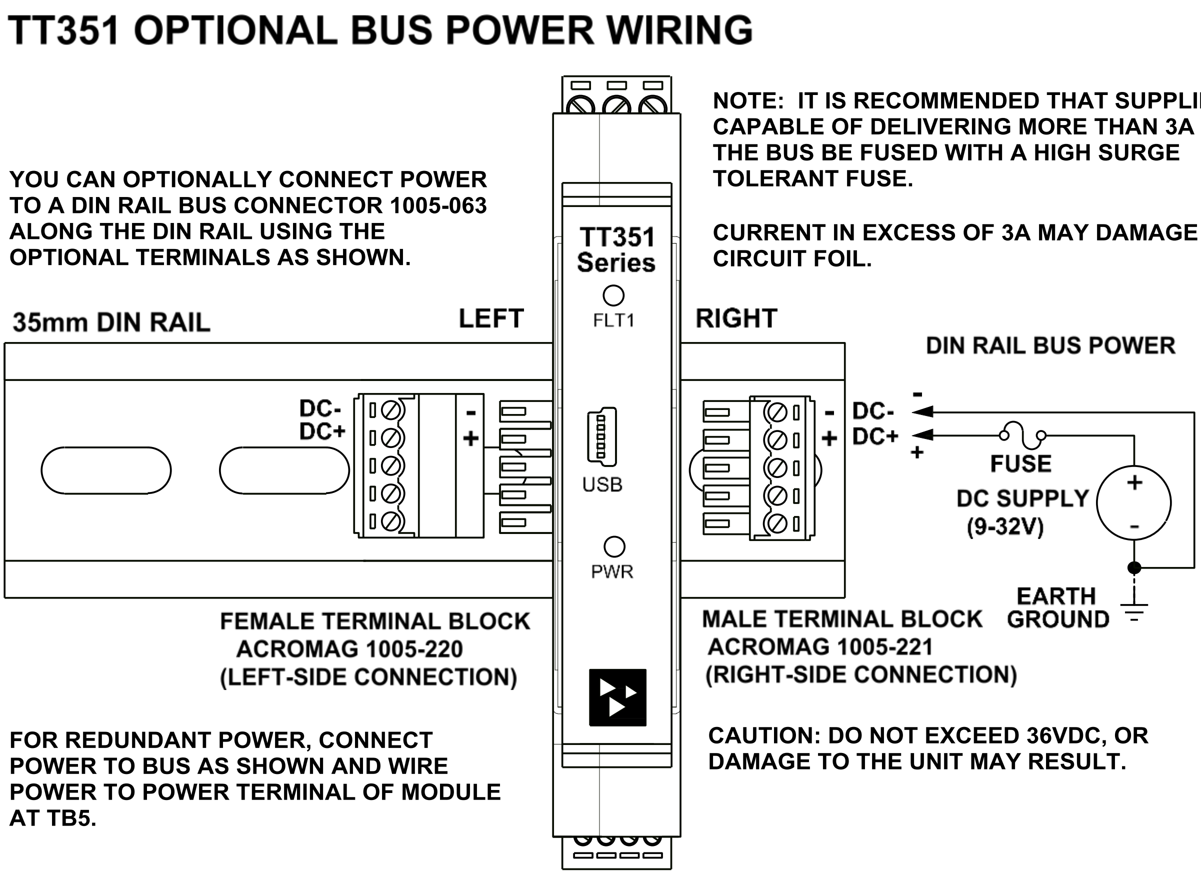
Acromag TTBUS-KIT connector kit contains bus connector 1005-063, plus left-side terminal 1005-220, and right-side terminal 1005-221, allowing units to snap together, side-by-side, along the DIN rail and share the power connection.

Important – End Stops: If this module uses the optionally powered (or redundantly powered) via the DIN rail bus for hazardous location installations (Class I, Division 2 or ATEX/IECEx Zone 2) it must use two end stops (Acromag 1027-222) to secure the terminal block and module (not shown).



Optional Bus Power Connections…

The figure below shows how to wire power to the optional bus terminal block when mated to the bus connector. Note power is wired to the rightmost bus terminals on the right, or the left-most terminals on the left. Observe proper polarity.



Earth Ground Connections

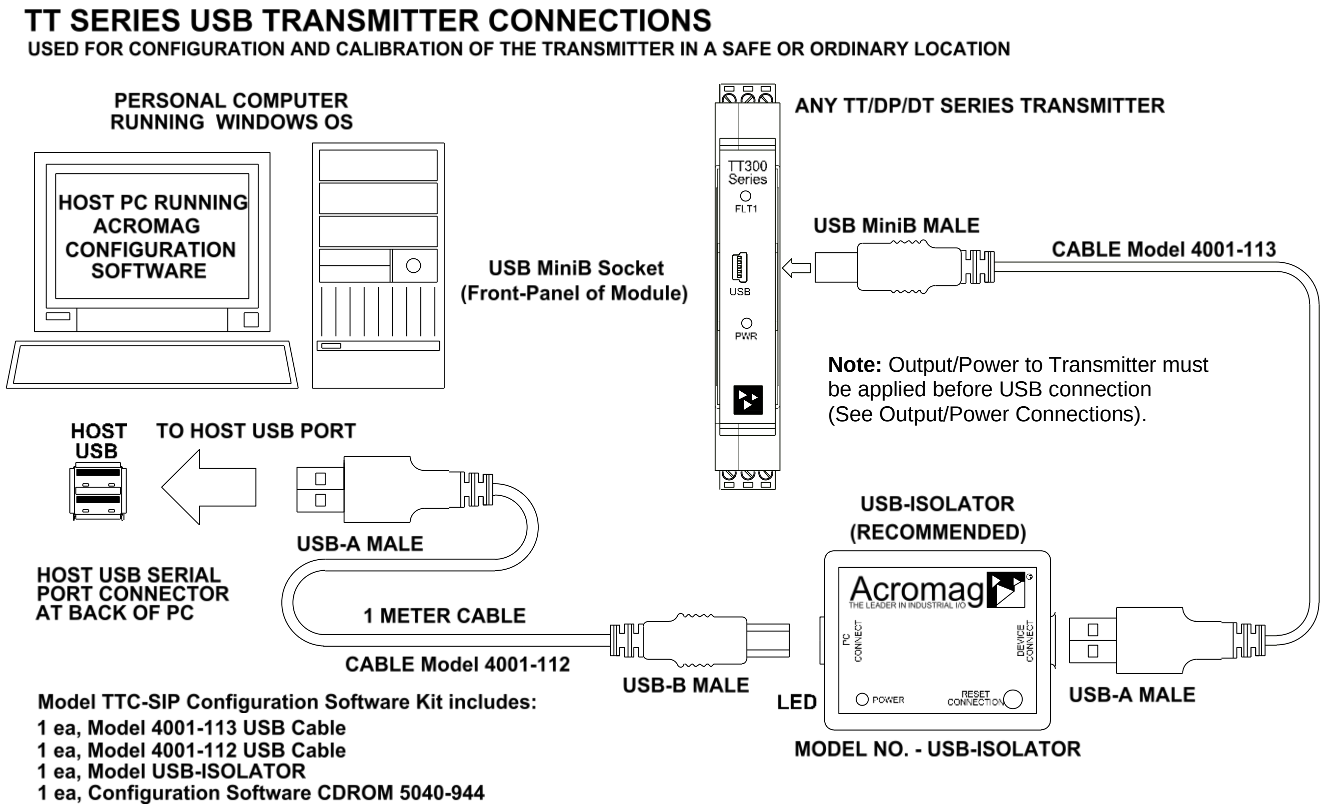
(To Protect Your Equipment, Lower System Noise, and Reduce Emissions)

This Transmitter’s input, output, and power circuits are electrically isolated from one another, allowing each of these circuits to be individually earth-grounded as indicated in their connection drawings (its housing is plastic and does not require an earth ground connection). Earth Grounding isolated circuits as shown is recommended for best results and to help protect the unit and its isolated circuits by giving each a low impedance path to ground for shunting destructive transient energy away from sensitive module circuitry. If the transmitter is mounted in a metal housing, a ground wire connection is usually required for the metal housing and you should connect that enclosure’s ground terminal (green screw) to earth ground using suitable wire per applicable codes. See the Electrical Connections Drawings for Input, Output, and Power, and note the position of earth ground for each isolated entity.

- Avoid inadvertent/extra connections to earth ground at other points in any isolated circuit than those indicated, as this could drive ground loops and negatively affect operation.
- A USB isolator is recommended when configuring or calibrating this unit to avoid the ground loop that occurs if your input is also earth grounded (A PC commonly earth grounds its USB port contacting both the USB signal and shield ground which are held in common to the input circuit ground of this transmitter).

USB Connections

This transmitter is configured and calibrated via configuration software that runs on a Windows-based PC connected to the unit via USB (Windows 7 or later required), or via a USB-OTG connection to an Android smartphone or tablet using the Acromag Agility mobile app. Refer to the drawing below to connect your PC or laptop to the transmitter to reconfigure or calibrate it using this software.



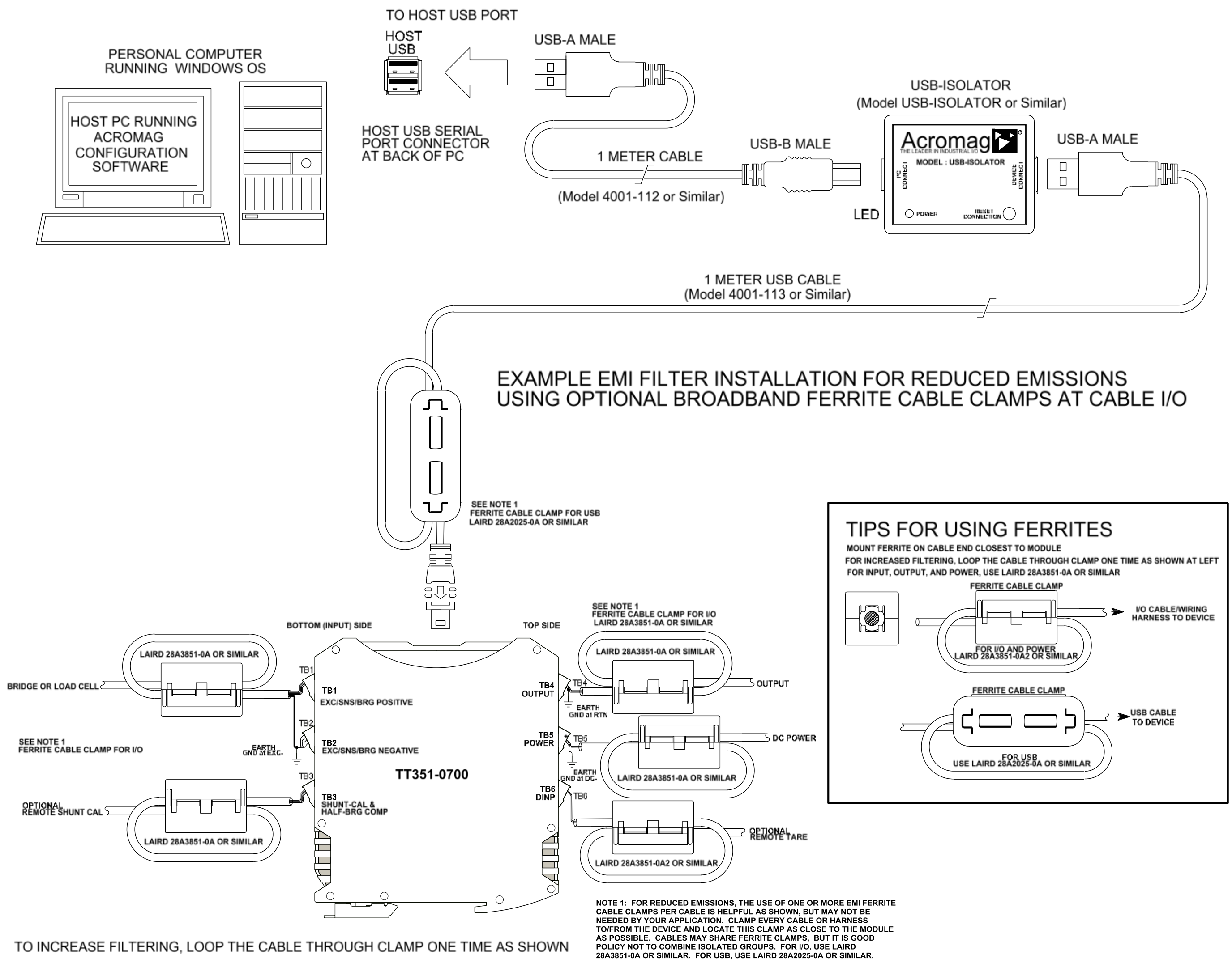
WARNING: The intent of mating USB with this transmitter is so that it can be conveniently set up and calibrated in a safe area, then installed in the field which may be in a hazardous area. Do not attempt to connect a PC or laptop to this unit while installed in a hazardous area, as USB energy levels could ignite explosive gases or particles in the air.

USB Signal Isolation is recommended as shown above and required when connected to a grounded input. The bridge input and USB connections are isolated from the output and power of this model. USB Isolation is recommended for safety and noise suppression and is required when the input bridge sensor or its excitation signal happens to already be earth grounded. You may use Acromag model USB-ISOLATOR to isolate your USB port, or you can optionally use another USB signal isolator that supports USB Full Speed operation (12Mbps).

IMPORTANT: USB logic signals to the transmitter are referenced to the potential of the transmitter's input circuit ground. Input ground is held in common with USB ground and USB cable shield ground. Thus, an isolator is required when the input signal is earth grounded and the unit is connected to the USB port of an earth-grounded PC. You could avoid the use of an isolator if a battery powered laptop was instead used to connect to the transmitter, and the laptop had no other earth ground connection, either directly or indirectly via a connected peripheral.

EMI Filter Installation

For low CE-rated radiated emissions, the use of one or two split/snap-on ferrite cores on I/O cables or harnesses to/from the device as shown in the drawing below is helpful. You can increase filtering by looping the cable one time through the ferrite as shown. Ferrites are also helpful for cables connected to the Host USB port. Use Laird 28A3851-0A or similar for inputs/outputs and power, and Laird 28A2025-0A or similar for USB cable. Locate ferrites by clamping them outside of I/O cables or wiring harnesses to/from the module (input, USB, output, DC power, remote tare, and remote shunt calibration connection groups), as close to the module as possible. While the use of these ferrites is helpful to obtain low CE-rated emissions, it may not be required for your application. Note that individual cables may share a ferrite, but it is not good practice to combine isolated circuits inside the same ferrite, but rather separate isolated circuits for safety and greater noise immunity.



INTRODUCTION TO STRAIN

Quick Overview of Strain Measurement

Strain gauges change their resistance in proportion to applied force that may result from loading, torque, pressure, acceleration, and vibration. Because their change in resistance to force is very small, they often connect in a Wheatstone Bridge of four elements. You can wire a bridge with one active strain gauge and 3 resistors (quarter bridge), two active strain gauges and two resistors (half-bridge), or 4 active strain gauges (full-bridge). The number of active gauges in a bridge and how they are oriented relative to applied force will determine the bridge type, its application, and relative strain computation.

An "active" gauge is oriented in a direction to measure the effect of an applied force on a material (usually in the same direction as the force or lateral to it).

The load cell is a simpler form of a Wheatstone Bridge based sensor, one whose output Vo is relative to percent of rated load and will correspond to the pressure or weight applied. Load cells are much simpler than strain gauge bridges because their relationship to load does not require additional detail of how its internal bridge elements are arranged, its Gauge Factor, or the Poisson's ratio of the material it is applied to. The only important considerations for resolving the load cell are its rated output (mV/V), excitation voltage, and rated capacity.

The output voltage of a Wheatstone Bridge is directly proportional to bridge excitation and very sensitive to the small mechanical deformations that drive resistance imbalances in one or more legs of a bridge. Because the mechanical deformation resulting from an applied force is a very small percentage, the corresponding strain it represents is often expressed as a multiple of 10^{-6} or micro-strain (micro-strain=$\triangle$L/L * 10^{-6}). Stress applied to an active bridge element will drive an unbalanced bridge condition that produces an offset in the bridge output voltage that can be related to the magnitude of the applied force. The electrical *sensitivity* of a bridge network or load cell is how much the bridge output voltage changes relative to 1V of bridge excitation and expressed in millivolts of Vo per volt of excitation Vex (mV/V). This is usually referred to as the gauge or cell Rated Output and denoted by Vr=Vo/Vex. The full-scale output of a strain gauge bridge or load cell sensor at its full rated load (100%) is the product of the gauge Rated Output (mV/V) and applied excitation voltage Vex.

*micro-strain ($\mu\varepsilon$) = $\triangle$L/L * 10^{-6}.*

$\varepsilon = \triangle L / L$

Strain (ε) is a measure of the mechanical deformation of a material and computed as a fractional change in dimension (length, width, or height) resulting from a force along that dimension ($\varepsilon = \triangle L / L$). Strain may be positive (tensile +ε), or negative (compressive -ε) and the magnitude of deformation it represents is a very small percentage such that it is often expressed as an integer multiple of 10^{-6}, or micro-strain ($\mu\varepsilon$).

In most real-world applications, strain measurements are rarely encountered larger than a few milli-strain (ε=0.003 or about 3000$\mu\varepsilon$).

There are normally two sensor measurements used to resolve strain or load: the sensor bridge output signal Vo and the sensor bridge excitation Vex. Using sensor specifications and these two measurements, the applied strain or load can be resolved from the bridge output signal.

Strain Measurement...

$GF = (\triangle R/R)/(\triangle L/L) = (\triangle R/R)/\varepsilon$

$\triangle R = R*GF*\varepsilon$

Like the sensitivity of a bridge reflects how much the magnitude its full-scale output changes per volt of excitation, the sensitivity of a strain gauge or Gauge Factor GF is how much its resistance changes in proportion to applied strain (its ratio of fractional change in resistance to applied strain ε). For common metallic strain gauges, the Gauge Factor is *typically* around 2.0, meaning its resistance change is about 2x its dimension change to an applied force ($\triangle R/R = 2x\ \triangle L/L$). However, GF varies slightly for most applications and this affects relative strain. For many instruments, sensor Gauge Factor will be used to compute *ideal* strain, but Instrument Gauge Factor will be used to compute *indicated* strain.

Poisson's Ratio $(\gamma) = -\varepsilon_T / \varepsilon$.
Poisson's Strain $(\varepsilon_T) = -\gamma\varepsilon$.
$-1.0 \leq \gamma \leq +0.5$

The effect of Poisson's strain is often ignored in strain calculations < 5000$\mu\varepsilon$ where it is small.

A material subject to a tensile or compressive uniaxial force in one direction will coincide with a lateral force referred to as Poisson's Strain. Most materials that undergo a tensile force or positive strain (when stretched or elongated) will contract slightly due to coincident negative strain in the lateral/transverse dimension (when its Poisson's ratio $\gamma = -\varepsilon_T / \varepsilon$ is a positive number). Less common, there are some materials with a negative Poisson's ratio that expand in the transverse direction ($+\varepsilon_T$) in response to being stretched ($+\varepsilon$) in the longitudinal direction. In general, the proportion of contraction or expansion is indicated by the application material's Poisson's Ratio. The Poisson's Ratio (γ) is the negative ratio of the simultaneous transverse strain that occurs in the perpendicular direction to the main strain parallel to the applied force.

Strain gauge sensors typically consist of a very fine foil or wire grid that is bonded to an application material surface in the direction of an applied force (uniaxial) or lateral to it (bending force). These are referred to as a bonded metallic or resistance strain gauges. They are designed to change their resistance *slightly* in proportion to stress. Most strain gauges have nominal resistance values that vary from 30 to 3000Ω, with 120Ω, 350Ω, and 1000Ω being the most common. Their cross-sectional area is minimized by design to reduce the negative effect of the corresponding shear or Poisson's Strain coincident to applied strain.

Example Calculation: *If you measured 3000$\mu\varepsilon$ with a 120Ω metallic strain gauge (GF=2.00), its corresponding fractional change in resistance $\triangle R/R = 2.00*3000*10^{-6} = 0.006$, implying that this 120Ω gauge changed its resistance by only 0.6% or 0.72Ω.*

The bonded metallic strain gauge has a foil grid attached to a thin backing material or carrier strip which is directly attached to the application material to help facilitate an efficient transfer of strain on the body to the foil grid of the gauge and allow it to respond with a linear or nearly-linear change in electrical resistance. Ideally, the strain gauge resistance should only change in response to applied strain, but unfortunately in practice, this is somewhat of an inexact science and it is difficult to make both the gauge material and application material expand and contract equally over temperature. As you can surmise, properly mounting the gauge is critical to ensure the application material strain is accurately transferred through the bonding adhesive and backing material to the gauge foil.

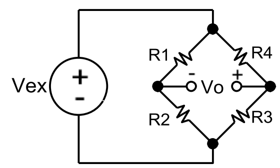
To curb potential problems caused by mismatched expansion and contraction rates between the gauge and application material, gauge manufacturers try to minimize sensitivity to temperature by selecting specific gauge materials for specific application materials. While this helps to minimize strain error, temperature remains a source of potential error and additional compensation is usually required. Adverse effects like this are the reason strain instruments provide additional parametric controls for rescaling their measurement as required, like utilizing Instrument Gauge Factor and Software Gain to help overcome application-induced skew in strain measurement.

The Wheatstone Bridge

△R = R*GF*ε implies that at 3000με, *△R/R ~ 2.00*3000*10⁻⁶ = 0.006 or 0.6%*

We stated that because strain measurement requires the detection of very small resistance changes resulting from very small mechanical deformations, we wire strain gauges as elements of a Wheatstone bridge which converts the signal to a bipolar output voltage that can be conveniently measured in proportion to the applied stress and its direction. Note that the magnitude of most strain measurement in stress applications is commonly between 2000με and 10000με, and rarely larger than about 3000με or ~0.6%. The Wheatstone Bridge offers an accurate method for measuring these very small changes in resistance and even provides an ability to compensate for the inherent sensitivity of the strain gauge relative to temperature.

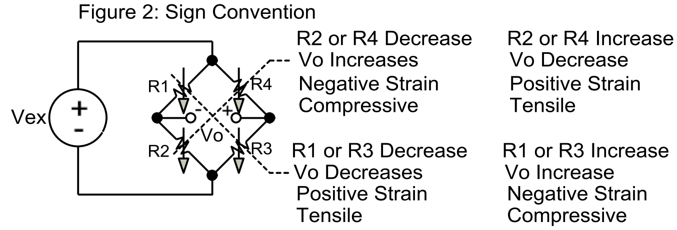
Figure 1: Wheatstone Bridge



The Wheatstone Bridge is comprised of four resistive arms or bridge elements arranged in the configuration of a diamond as shown at left. An excitation voltage Vex is applied vertically across the diamond or bridge input and an output voltage Vo can be measured horizontally across the diamond as shown in Figure 1.

From Kirchhoff's Voltage Law & Ohm's Law, the bridge output voltage Vo is the difference between two divided voltages with Vo = [R3/(R3+R4) – R2/(R2+R1)] * Vex. If the adjacent resistors of each divider match their ratios such that R1/R2 = R4/R3, then Vo=0 and the bridge is *balanced*. Note it is not required that R1=R4 and R2=R3 to achieve balance, just that the ratios of adjacent resistors R1:R2 and R4:R3 be equal (this also allows you to use half bridge completion resistors of a different value than the nominal gauge resistance). But for simplicity, if all four of the resistances in each leg of the bridge are equal, the two divider pairs will have equal ratios and the bridge will be balanced with a bridge output voltage Vo=0. Any change in resistance in any leg of the bridge will unbalance the bridge and produce Vo≠0. Remember that the same Vo offset can be obtained from adjacent pairs of different resistor values, if the ratios of the adjacent pairs are kept equal (R1/R2 = R4/R3).

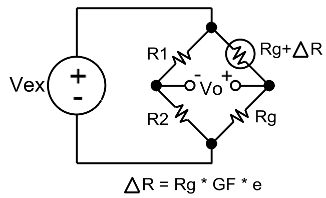
Figure 2: Sign Convention



As stated, if R1/R2 = R4/R3, then Vo=0 and the bridge is balanced. Examine the two Vex voltage dividers Vo- =R2/(R1+R2)*Vex and Vo+ =R3/(R4+R3)*Vex. Note a decrease in R4 or R2 increases Vo by increasing the +node voltage and decreasing the -node voltage. Likewise, a decrease in R1 or R3 will decrease Vo by increasing the -node voltage and reducing the +node voltage. The strain due to a decrease in resistance R4 or R2 will be negative and increase Vo (convention is that negative strain is compressive and positive strain is tensile). Thus, bridge Vo will grow positive for a compressive stress on R4 driving negative strain and decreasing its resistance. This is the convention used throughout this manual.

Wheatstone Bridge...

Figure 3: Strain Bridge w/ Gauge Factor



If you replace R4 in the bridge with an active strain gauge (Rg), then any change in the strain gauge resistance (△R) will unbalance the bridge and produce an offset in Vo proportional to the change in resistance △R. Using Gauge Factor, the change in resistance due to the applied strain is **△R = Rg * GF * ε.**

From our divider equation Vo=Vex*[R3/(R4+R3) – R2/(R1+R2)], substituting R1=R2, R3=Rg, and R4=Rg+△R yields: **Vo/Vex = - GF * ε / 4 * [1 / (1 + GF*ε / 2)].** This is the strain computation term Vr=Vo/Vex in mV/V and represents the *sensitivity* of the bridge network in mV/V (not to be confused with strain gauge sensitivity or Gauge Factor). The presence of the extra term **1/(1+GF*ε/2)** is representative of a small non-linearity in the output of the quarter bridge network with respect to strain. But for quarter-bridge strain levels below ~5000 micro-strain, the effect of this non-linearity is small and can be ignored in most applications.

Strain sensors formed from a bridge network may employ multiple strain gauges in their construction with 1, 2, or 4 active gauges in a bridge possible. Note that one active strain gauge (Rg) may occupy one leg of a four element Wheatstone Bridge (Quarter-Bridge), two legs of a bridge (Half-Bridge), or four legs of a bridge (Full-Bridge). Any remaining legs of a quarter or half bridge network are occupied by fixed resistors or "dummy" gauges, but it is the number of active gauges in the bridge that determines whether the bridge is a quarter (1), half (2), or full bridge (4) type.

Refer back to Figure 2 and note that tensile (positive) strain drives negative Vo for elements 1 and 3, and elements 4 and 2. Compressive (negative) strain drives Vo positive for 1 and 3, and elements 2 and 4. A change of resistance in the same direction for adjacent bridge resistors is subtractive and tends to cancel each other out, but a change of resistances in opposite directions for adjacent cells is additive and reinforces their effect on the output Vo. Similarly, resistance changes between diagonally opposite resistors are additive in same direction and reinforce their effect on output Vo, but subtractive in opposite directions and tend to cancel each other out.

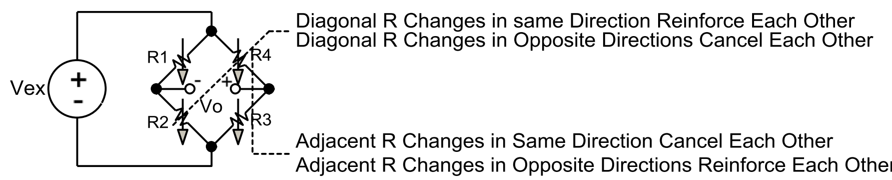
Because strain gauges are inherently sensitive to temperature, we can additionally arrange them in a bridge to compensate its Vo for temperature by making sure the adjacent element pair ratios R1:R2 and R3:R4 remain equal over temperature. Because opposite changes in resistance of adjacent bridge resistors R1 & R2 and R3 & R4 are numerically additive and reinforce each other, but numerically subtractive if in the same direction, then placing similar gauges and lead-wires in adjacent arms and exposing them to the same temperature will allow them to act together to null the net thermal effect on the bridge output Vo and effectively cancel temperature induced strain error.

That is, for an active strain gauge in one arm, use an identical strain gauge in the adjacent arm, subject to the same temperature but not the stress force. Then its temperature resistance change will track that of the primary gauge, and the ratio between them will stay the same, having no unbalancing effect on the bridge output Vo signal.

Wheatstone Bridge...

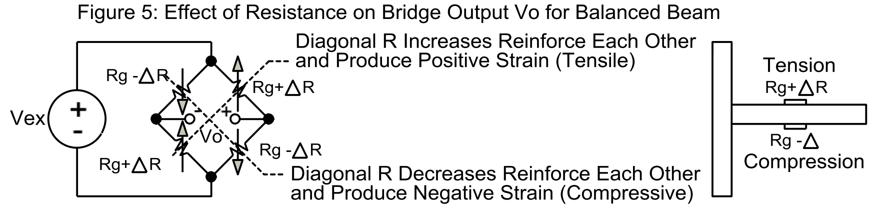
Returning to the prior example where we substituted R3=Rg and R4=Rg+△R in the bridge, their net effect with temperature on Vo was avoided by carefully mounting both gauges such that they are subject to the same temperature, but the "dummy" gauge R3=Rg mounted transverse to the axial strain (perpendicular to applied strain) such that strain on R4=Rg+△R has little or no effect on R3=Rg. Because the ambient temperature affects both gauges the same but not the force, they keep the same ratios and any temperature resistance changes cancel each other and Vo is not affected by temperature.

Figure 4: Effect of Resistance Changes on Bridge Output



Refer to Figure 4 and note opposite adjacent resistance changes reinforce each other. If you make the adjacent second gauge active by mounting it in the same axis as the applied strain, but of the opposite sign (e.g. one active gauge in tension, one active gauge in compression), you form a half-bridge configuration that doubles the sensitivity of the bridge to strain. That is, the output voltage Vo of the half-bridge is linear and approximately double the output of the quarter-bridge Vo for the same excitation Vex.

Figure 5: Effect of Resistance on Bridge Output Vo for Balanced Beam



Consider one half of the balance beam bridge application in Figure 5. Solving for the *sensitivity* Vr in a half bridge application of two adjacent active gauges would yield: **Vr = Vo/Vex = - GF*ε/2**. In Figure 5, note that adjacent arrows are opposite to depict the two elements are mounted such that one is in compression, and the other in tension, for the same applied strain. Now this bridge sensitivity can be further increased by making all four arms of the bridge active strain gauges, with diagonally opposite legs combined such that two diagonal legs are in compression, and two diagonal 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 a full-bridge balance beam application a shown, we get: **Vr = Vo/Vex = - GF*ε,** *effectively twice that of the half-bridge circuit.*

All the equations thus far have been simplified because they assume an initially balanced bridge with Vo=0 with no strain applied. This is rarely achieved in practice where resistance tolerance and application strain errors usually result in Vo≠0 with no strain applied. The equations also failed to account for lead wire resistance Rl in the measurement leads and connections to excitation. The equations that follow will be embellished to account for unloaded offset, sensor lead resistance, and material Poisson's ratio where applicable using permutations of the three basic bridge configurations: quarter, half, and full, where applicable.

Strain Bridge Equations

The strain bridge formulas that follow are used to compute both *ideal or simulated strain* and *indicated strain*. For Indicated Strain, the Instrument Gauge Factor will be substituted for Gauge Factor (initial IGF ~ 2) and/or your result may be subject to software gain that you specify to rescale Indicated Strain or Load during shunt or load calibration, typically to resolve application inefficiencies between the ideal and indicated strain or load. Note it is the indicated value of strain that is used to scale the analog output of this transmitter.

Bridge Figure Key:

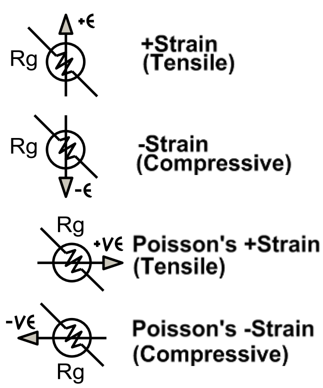


Table 1 reviews the terms and nomenclature used in the subsequent strain and load cell formulas for various strain gauge bridge configurations and for load cells.

Table 1: Strain and Load Parameters

Parameter	Definition
Vo *Bridge Output*	ADC Measurement 1 – Sensor Bridge Output Voltage Vo. To account for the non-balance Vo≠0 offset condition of an unstrained bridge, a distinction is made for Vo via Vo_strained for the bridge output under load, and Vo_unstrained for the bridge output unloaded (initial bridge offset). Likewise, for any non-zero tare, Vo=Vo_loaded -Vo-unloaded -Vo_tare.
Vex *Bridge Excitation*	ADC Measurement 2 - Bridge Excitation Voltage Vex. This is normally derived from a related ADC measurement.
Vr *Bridge Sensitivity*	Key strain computation term that represents the sensitivity of the strain bridge and is derived from ADC measurements of Vo & Vex with Vr = (Vo strained – Vo unstrained)/Vex. It is equal to the bridge output signal per volt of excitation and expressed as mV/V.
GF *(~2.00)*	*Input Specification - Gauge Factor is the gauge specification for its sensitivity to strain (not the bridge sensitivity), ~2.00 for Metallic Gauges. GF = (△R/R)/(△L/L) = (△R/R)/ε, then △R = R*GF*ε*
RO *(1-10mV/V)*	*Input Specification - Rated Output (1-10mV/V) is the gauge specification for its output voltage range under full-load (±100%) per volt of applied excitation voltage.*
ε *Strain* **+ε** Tensile[1] **-ε** Compr[1]	Strain (ε = △L / L, multiply by 10^6 for equivalent micro-strain). *tensile* Strain (ε = +△L / L) and compressive strain (ε = -△L / L)
γ	Poisson's Ratio, material constant w/ -1 < γ < 0.5 (γ = $-\varepsilon_T$ / ε)
$\varepsilon_T = -\gamma\varepsilon$	Transverse (Poisson's) Strain
+γε	A Tensile Poisson's strain $\gamma = \varepsilon_T/\varepsilon$ & $\varepsilon_T = \gamma\varepsilon$.
-γε	A Compressive Poisson's strain $\gamma = -\varepsilon_T/\varepsilon$ & $\varepsilon_T = -\gamma\varepsilon$.
Rg	Nominal Strain Gauge Resistance (120Ω, 350Ω, 1000Ω common).
Rl	Lead-Wire Resistance
N	Common Factor used to Account for Multiple Gauges in a Bridge (see Table 2 for N value)

In the following examples, the polarities indicated assume a positive strain +ε is tensile and negative strain - ε is compressive, but you can reverse this convention by removing the negative sign from the strain formulas and flipping the polarity of the bridge output voltage Vo. Reference to adjacent bridge elements refers to the relationship between the two elements on the left or two elements on the right of the bridge. Diagonally opposite bridge elements that change in the same direction reinforce each other's effect on Vo, while adjacent bridge elements that move in opposite directions reinforce each other's effect on Vo (they are additive to Vo). Adjacent gauges mounted transverse to primary ±ε gauges normally measure the coincident Poisson's strain ±νε. An active gauge measures axial strain when mounted in the same direction as the applied force and bending strain when mounted in a lateral direction to the applied force.

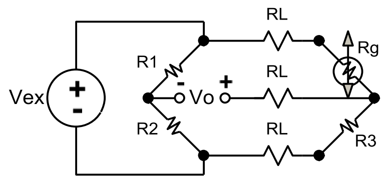
Strain Bridge Equations...

Quarter Bridge Type I, N=1
(For Axial or Bending Strain)

One Active Gauge Rg with Dummy Resistor R3=Rg and Half-Bridge Completion Resistors R1=R2 and R1/R2=Rg/R3.

Not Temperature Compensated

Quarter-Bridge Type I



A quarter-bridge uses one active gauge Rg to make a uniaxial tensile or compressive strain measurement with the gauge mounted in the direction of an axial strain or transverse to a bending strain.

The Quarter Bridge Type I is the most common in experimental stress analysis, where ambient temperature is relatively constant. It is not recommended for real world applications because it does not compensate for changes in temperature. In the Quarter bridge Type I configuration, the adjacent gauge resistor R3 is only selected to have the same resistance as the strain gauge (R3=Rg). The two resistors in the opposite half must equal each other (R1=R2), but do not have to equal to the gauge resistor Rg or R3, just their ratio (R1/R2=Rg/R3).

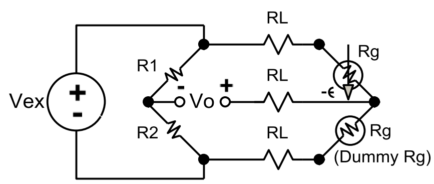
Quarter-Bridge Type II, N=1
(For Axial or Bending Strain)

One Active Gauge Rg with Passive Gauge R3=Rg and Half-Bridge Completion Resistors R1=R2 and R1/R2=Rg/R3.

Temperature Compensated

Good at lower levels of strain below ~5000$\mu\varepsilon$ where Poisson's Strain is small.

Quarter-Bridge Type II



A second Quarter Bridge is Type II and often used to measure compression, common to weigh-scale applications. This quarter bridge uses one active gauge Rg, plus a transverse mounted passive "dummy" gauge to compensate for temperature. The dummy gauge is not subject to strain and only provided for temperature compensation. Applied strain has little effect on a dummy gauge because it is mounted transverse/ perpendicular to the applied force and normally unbonded to the application material but mounted close enough to the active Rg such that the ambient temperature affects both gauges equally maintaining their ratio equivalency but not affecting output Vo over 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 while the second gauge matches its TC to Rg, it 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 the absence of Poisson's ratio). No quarter bridge formulation can be used in an application where the direction of the stress field is unknown or changes.

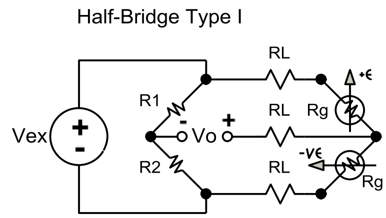
If any additional force is applied in the transverse direction of the dummy gauge, then the measurement of strain in the direction of the active gauge will be in error.

For Quarter-Bridge Type I or Type II, solving for the resultant strain will yield the following expression (note the absence of Poisson's Ratio because it is often ignored at lower levels of strain less than ~5000$\mu\varepsilon$):

$$\varepsilon = (1 + Rl/Rg) * -4Vr/[GF*(1+2Vr)]$$

Strain Bridge Equations...

Half-Bridge Type I, N=1+ γ (Single-Axis Strain Measurement at higher levels of stress)



A Half-Bridge uses two active gauges in a single-axis (uniaxial) stress field to make strain measurements, one mounted in same direction as applied strain and the other mounted transverse to applied strain to capture the effect of Poisson's strain.

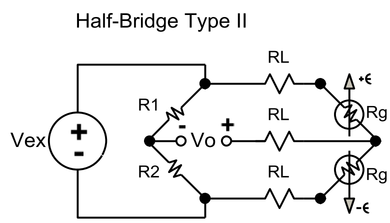
Solving for the strain of Half-Bridge Type I yields the following (note that Poisson's ratio is present because transverse strain is considered because of the generally higher stress levels): **ε = -4Vr * (1 + Rl / Rg) / [GF*(1+ γ) - 2Vr*(γ - 1)]**

The Half Bridge Type I resembles the Quarter-Bridge Type II, except that the transverse mounted gauge measures the transverse strain that results from its higher applicable stress levels where Poisson's strain is more significant. The secondary gauge still corrects for changing temperatures because of its matching temperature coefficient which keeps R3/R4 ratio constant over temperature.

Half-Bridge Type II, N=2 Bending Strain Only (Bending Beam Applications at Lower Strain Levels)

Two Active Gauges Rg with
R4 Meas Tensile Bending +ε
R3 Meas Compressive Bending -ε
R2 Half-Bridge Completion Res
R1 Half-Bridge Completion Res

Comp for Temperature
Good Sensitivity to Bending ε
No Comp for Poisson's (Lower ε)



The Half-Bridge Type II is typically used in bending beam applications. This bridge uses two active gauges with both subject to a bending stress, but mounted to measure equal and opposite strain, one in compression (bottom of beam), one in tension (top of beam). Because the adjacent gauge pair measures the same stress in opposite directions, their effect on Vo reinforces each other, doubling the output of the quarter bridge. The second gauge with a matching temperature coefficient also corrects for changes in temperature by keeping the gauge ratio R4/R3 constant. Solving for Half-Bridge Type II strain yields (note the absence of Poisson's Ratio suggests it is more applicable at lower levels of strain): **ε = -2Vr *(1 + Rl / Rg) / GF**

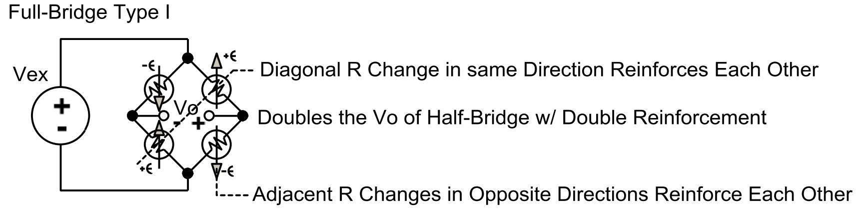
Another permutation of this arrangement would have the two diagonally opposite active gauges subject to equal strain in the same direction (also reinforcing each other). For example, each gauge could be mounted on opposite sides of a column with a low thermal gradient between them (both subject to same temperature). Recall that diagonally opposite gauges reinforce each other for resistance/strain changes in the same direction, while adjacent gauges tend to cancel each other for resistance/strain in the same direction.

Strain Bridge Equations...

Full-Bridge Type I, N=4
Bending Strain Only
(Bending Beams or Shafts Subject to Torsion at Lower Strain Levels)

Four Active Gauges Rg with
R4 Meas Tensile Bending +ε
R3 Meas Compressive Bending -ε
R2 Meas Tensile Bending +ε
R1 Meas Compressive Bending -ε

Comp for Temperature
Higher Sensitivity to Bending ε
No Comp for Poisson's (Lower ε)



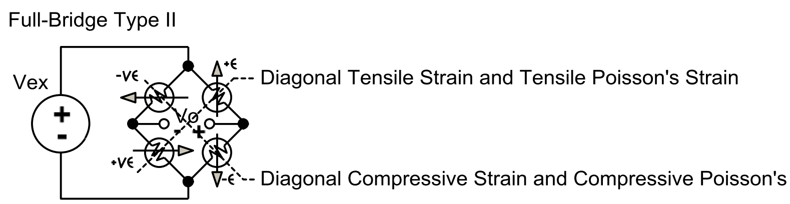
The Full-Bridge Type I is common to strain measurement of bending beams or shafts subject to torsion at lower levels of stress. This arrangement utilizes four active gauges with one diagonal pair measuring tensile bending strain and the opposite diagonal pair measuring compressive bending strain for the same applied stress (the diagonal gauge pairs in the same direction and adjacent gauge pairs in opposite directions reinforce each other making this bridge the most sensitive). While having greater sensitivity, it is generally used at lower levels of strain (no transverse mounted Poisson's strain gauges). The full-bridge is balanced with all gauges having the same resistance change with temperature, maintaining adjacent R1/R2=R3/R4 ratios equivalent over temperature.

Because the four gauges are arranged to reinforce their effects on Vo both diagonally and adjacent, the Full-Bridge Type I doubles the Vo signal of a half-bridge and quadruples that of a quarter bridge. But its greater 2x sensitivity than the half-bridge makes it more expensive because of two additional gauges. Solving for the Full-Bridge Type I strain yields (note the absence of Poisson's strain): **ε = - Vr / GF**.

Full-Bridge Type II, N= 2(1+ γ)
Bending Strain Only
(Bending Beam or Shaft Subject to Torsion at Higher Strain Levels)

Four Active Gauges Rg with
R4 Meas Tensile Bending +ε
R3 Meas Compressive Bending -ε
R2 Meas Tensile Poisson's +ε
R1 Meas Compressive Poisson's -ε

Comp for Temperature
Less Sensitive to ε than Type I
Comp for Poisson's (Higher ε)



Full-Bridge Type II is common to strain measurements for bending beams or shafts subject to torsion at higher stress levels (higher stress drives higher Poisson's strain). This arrangement utilizes four active gauges subject to bending stress, with one diagonal gauge pair aligned to measure tensile bending strain and transverse tensile Poisson's strain (i.e. top of beam), and the other diagonal pair aligned to measure the coincident compressive strain and transverse compressive Poisson's strain (i.e. bottom of beam). Solving for the Full-Bridge Type II strain yields:
ε = -2Vr / [GF*(γ + 1)].

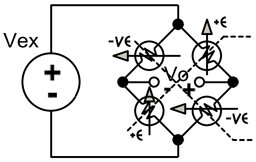
Strain Bridge Equations...

Full-Bridge Type III, N= 2(1+ γ)
Axial Strain Only
(Single-Axis Column Strain)

Four Active Gauges Rg with
R4 Meas Tensile +ε
R3 Meas Compressive Poisson's -ε
R2 Meas Tensile +ε
R1 Meas Compressive Poisson's -ε

Comp for Temperature
Comp for Poisson's (Higher ε)

Full-Bridge Type III



The Full-Bridge Type III is common to column stress measurement applications. This arrangement uses four active gauges subject to a uniaxial stress, with one diagonally opposite gauge pair measuring the principal axial strain in one direction (one mounted on top, one on bottom), and the other diagonal pair measuring the transverse Poisson's strain in the same direction (one mounted transverse on top and other transverse on bottom). Solving for the Full-Bridge Type III strain yields:

ε = -2Vr / [GF*(γ + 1) – Vr*(γ - 1)]

Because the Full-Bridge Type III configuration includes measurement of coincident Poisson's strain, it is suitable for measurement at higher stress levels above 5000με.

Sensor Gauge Factor and Instrument Gauge Factor

Example: *If measured strain ε=1000 micro-strain and GF = 2.00. Then, 2.00*1000*10^{-6}strain =0.002= (△R/R) and this implies a 350Ω gauge changes its resistance by only 0.2%, equivalent to 0.7Ω.*

The sensor Gauge Factor GF of a strain gauge is a characteristic transfer coefficient that relates the gauge element sensitivity to strain ε relative to its change in resistance △R. More specifically, GF is the ratio of the fractional change in resistance to the strain (**GF = (△R/R) / (△L/L) = (△R/R) / ε**). The Gauge Factor for metallic strain gauges is typically around 2.0, but may vary with temperature, strain level, and gauge mounting, and these application effects will contribute to error in making ideal strain measurements. Think of GF as a built-in scaling factor for the computation of ideal strain that is generally fixed to a value by the gauge manufacturer.

You can think of Instrument Gauge Factor IGF similarly, except it is controlled by you and used to rescale the Indicated Strain of an instrument to help overcome less than ideal application sensor irregularities that may skew strain from its ideal. That is, IGF is usually adjusted as required to make the indicated strain of the instrument converge to an ideal or simulated strain during the process of strain gauge bridge shunt calibration. Optionally, a second means of rescaling Indicated Strain is by using Software Gain. The need to rescale the indicated value of an instrument is largely driven by the inherent lack of precision in applying the strain gauge and the wide variation in its application, and sometimes even between sensors of the same type. Consider, the rated output (mV/V) of a strain gauge may vary by as much as ±10% from its manufacturer specification and between sensors. Rescaling the instrument's indicated value for a given sensor by varying its Software Gain and/or Instrument Gauge Factor allows you to account for this tolerance by trimming your response to more accurately reflect ideal strain in your application. Typically, during shunt calibration, the indicated strain measurement is modified by varying Instrument Gauge Factor and/or software gain to make its reading match a calculated ideal or simulated strain. The simulated strain is calculated using the sensor Gauge Factor specification and a fixed gain of 1, while indicated strain uses the Instrument Gauge Factor and/or Software Gain other than 1. The Instrument Gauge Factor is initially set to 2 (roughly equivalent to the sensor Gauge Factor) and this makes indicated strain roughly equivalent to ideal strain, insofar as much as the application induced error is kept to a minimum.

Resolving Strain or Load

Strain gauge elements are arranged in bridge networks to measure strain or load on a material relative to bending, axial, and shear or torsion forces. Bending stress results when a beam with a straight horizontal (longitudinal) axis is loaded by a lateral/transverse force such that its longitudinal axis bends into a curve and this strain is used to determine vertical loads. Axial stress/strain results when a body becomes shorter (compressive) or longer (tension) along the direction of an applied force and this strain is used to determine axial loads via material elongation (most materials under a tensile load in the direction of the stress also undergo a coincident transverse/lateral strain that causes it to contract (Poisson's strain).

How many active load cells?

One=Quarter Bridge QB
Two=Half-Bridge HB
Four=Full-Bridge FB

Is your strain measurement axial, bending, or torsional/shear?

The first step to determining which bridge formulation best fits your application is to identify the number of *active* load cells present or required. An "active" gauge means that it is mounted to <u>measure tensile or compressive strain in the same direction as an applied force (or transverse for bending strain)</u>. A dummy gauge refers to an adjacent matching gauge mounted transverse to the applied force or unbonded to the material such that it is subject to the same temperature, but not mechanically stressed (the ratio of adjacent elements will stay the same over temperature and not affect Vo). A bridge may have one, two, or four strain gauges present, but it is how they are positioned relative to one another and the applied force that will determine their application.

Which Type best fits the application?

Next you may wish to consider the measurement environment and the relative level of stress you intend to measure. If the environment temperature varies, you can dismiss Quarter Bridge Type 1 which is not temperature compensated. If the strain level you intend to measure is high (> 5000με), then you will want to capture the negative effect of Poisson's strain on your measurement and consider using Half-Bridge Type I, or Full-Bridge Type II or Type III, which take Poisson's ratio into account. A simple uniaxial force in one direction may only require one active gauge at lower strain levels, unless the ambient varies, then an adjacent active gauge may be added to temperature compensate the bridge output Vo. If you choose to mount the second gauge transverse to axial strain, then it may additionally capture Poisson's strain, which will be important at high levels of strain > 5000με where its contribution becomes significant. If your application needs more output signal (and higher signal to noise ratio), note the Half-Bridge Type II has twice the sensitivity of a Quarter-Bridge, and a Full-Bridge has twice the sensitivity as a Half-Bridge. One active gauge will form a Quarter-Bridge, two active gauges may form a Half-Bridge, and four active load cells may form a Full-Bridge—but the more active gauges you require, the higher your cost.

1 active/No Additional=**QB Type I**
1 active+1 Dummy=**QB Type II**

To determine its Type designation, I, II, or II, you must consider how gauges are mounted. If your bridge has <u>one</u> active gauge and no additional dummy gauges or resistive elements present, then you select a **Quarter-Bridge Type I** formulation. If your bridge has <u>one</u> active gauge plus a second passive or "dummy" gauge mounted transverse to the applied stress (for temperature compensation), then you select **Quarter Bridge Type II** formulation. Both Quarter-Bridge types use the same formula for calculating strain and their type distinction simply discerns whether the strain gauge is temperature compensated or not. Both quarter-bridge types also require half-bridge completion resistors (either external or internal) but Type I will require an adjacent fixed "dummy" resistor be connected, while Type II will require an adjacent "dummy" gauge be connected to closely match the temperature coefficient of the active gauge over temperature.

Resolving Strain or Load...

1 active+1 transverse=**HB Type I**

If your bridge has two active gauges, with the adjacent gauge mounted perpendicular to the applied force to measure coincident (Poisson's) strain as well as temperature compensate the primary active gauge, then you would select a **Half-Bridge Type I** formulation, common for measuring uniaxial strain at higher stress levels where the Poisson's strain should be accounted for. Note that the Half-Bridge Type I circuit is like the Quarter-Bridge Type II, except that the transverse mounted gauge is mechanically linked to the application material to measure Poisson's strain in addition to temperature compensate the primary active gauge.

1 active+1 opposite=**HB Type II**

If your bridge has two adjacent active gauges mounted such that they are subject to equal and opposite strains for the same applied force, you would select a **Half-Bridge Type II** formulation. This is common to bending-beam applications with one gauge is mounted to compress while the other undergoes tension for the same applied force. The presence of the second active gauge also temperature compensates Vo but does not measure Poisson's strain, making it more accurate at lower levels of strain < 5000με where Poisson's contribution can usually be ignored.

4 active w/opposite pairs=**FB Type I**

If your bridge has four active gauges with both 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 offers the largest output signal, is inherently temperature compensated, and does not require bridge completion.

1 active ±pair & 1 transverse pair=
FB Type II

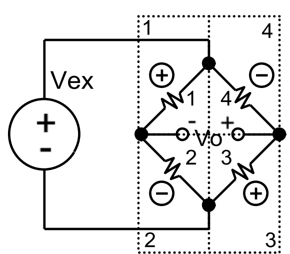
If your bridge has four active gauges, with one half of the bridge (adjacent gauge pair) mounted to measure the tensile and compressive strain, and the opposite half mounted to measure their coincident transverse Poisson's Strains, then you would select a **Full-Bridge Type II** formulation. This type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

1 active tensile pair diagonal +
1 active transverse pair diagonal=
FB Type III

If your bridge has four active gauges, with one diagonal gauge pair mounted to measure the principal tensile strain and the opposite diagonal pair mounted to measure its transverse (compressive) Poisson's Strain, then you would select a **Full-Bridge Type III** formulation. This is commonly selected to measure the strain in a column. This arrangement is inherently temperature compensated and does not require bridge completion and better suited for measuring higher levels of strain where Poisson's contribution is greater.

Use this figure to discern gauge positions and how they will affect the output signal magnitude and polarity.

BRIDGE POSITION AND POLARITY



Cell Polarity is Resistance Change that Increases Vo
Same Diagonal Cell Polarities Add to Vo
Opposite Adjacent Cell Polarities Add to Vo
Positive Strain is Tensile (Elongation)
Negative Strain is Compressive (Contraction)

Resolving Strain or Load...

Table 2: Salient Features of The Seven SG Bridge Types and Their Strain Formulas

SUPPORT	**QB Typ I**	**QB Typ II**	**HB Typ I**	**HB Typ II**	**FB Typ I**	**FB Typ II**	**FB Typ III**
Axial	Yes	Yes	Yes	No	No	No	Yes
Bending	Yes	Yes	Yes	Yes	Yes	Yes	No
Active Gauges	1	1	2	2	4	4	4
Gauge R Positions & Function	R4 (+ε) R3 Fix R=Rg[2] R1,2 HB	R4 (+ε) R3=Dumb Rg[1] (Transverse) R1,2 HB	R4 (+ε) R3 (-γε) R1,2 HB	R4 (+ε) R3 (-ε) R1,2 HB	R1,3 (-ε) R2,4 (+ε)	R1 (-γε) R2 (+γε) R3 (-ε) R4 (+ε)	R1,3 (-γε) R2,4 (+ε)
[3]Sensitivity (Vr) @1000με	~0.5mV/V	~0.5mV/V	~0.65/V	~1.0mV/V *2x QB*	2.0mV/V *2x HB, 4x QB*	1.3mV/V	1.3mV/V
Comp Temp?	No	Yes	Yes	Yes	Yes	Yes	Yes
Comp Poisson's γ?	No	No	Yes	No	No	Yes	Yes
Strain High/Low	Low<5000με	Low<5000με	High	Low<5000με	Low<5000με	High	High

TYPE & N	**STRAIN FORMULA & PRIMARY APPLICATION**
QB Typ I **N=1**	$\varepsilon = -4Vr * (1 + Rl / Rg) / [GF*(1+2Vr)]$, Axial or Bending strain in a constant temperature environment because its output is not temperature compensated.
QB Typ II **N=1**	$\varepsilon = -4Vr * (1 + Rl / Rg) / [GF*(1+2Vr)]$, Axial or Bending strain in a variable temperature environment, common use in weigh-scale load cells and at lower levels of strain where the effect of Poisson's strain is small.
HB Typ I, **N=1+ γ**	$\varepsilon = -4Vr * (1 + Rl / Rg) / [GF*(1+ \gamma) - 2Vr*(\gamma - 1)]$, Uniaxial tensile or compressive strain in a temperature variant environment and good for higher stress levels where Poisson's strain is more significant.
HB Typ II **N=2**	$\varepsilon = -2Vr *(1 + Rl / Rg) / GF = -4Vr*(1 + Rl / Rg) / N*GF$, Bending beam strain with two strain gauges subject to equal and opposite strain for the same applied force.
FB Typ I **N=4**	$\varepsilon = -Vr / GF = -4Vr / (N*GF)$, Bending beam strain or a shaft under torsion with 4 active gauges arranged to measure equal and opposite strains. 2x the sensitivity of a half bridge, 4x the sensitivity of a quarter bridge. Used at lower levels of strain where the Poisson's effect is small.
FB Typ II **N= 2(1+ γ)**	$\varepsilon = -2Vr / [GF*(\gamma + 1)] = -4Vr / (N*GF)$, Axial column strain with one adjacent gauge pair measuring principal tensile and compressive strain and the opposite adjacent pair measuring the corresponding transverse Poisson's Strains, good for strain measurement at higher stress levels where Poisson's strain is significant.
FB Typ III **N= 2(1+ γ)**	$\varepsilon = -2Vr / [GF*(\gamma + 1) – Vr*(\gamma - 1)]$, Axial column strain with diagonal gauge pairs measuring tensile strain and the diagonally opposite gauge pair measuring the coincident transverse compressive Poisson's strain.

Symbols: +ε is positive or tensile strain and -vε is its compressive Poisson's strain, -ε is negative or compressive strain and +vε is its tensile Poisson's strain, HB refers to Half-Bridge completion resistors.

Notes (Table 2): [1]The quarter bridge resistor R3 is an inactive gauge that is mounted transverse or unbonded to the application material (thermally linked but not mechanically linked). [2]The quarter bridge resistor R3 matches the nominal active Rg resistance but is neither thermally linked or mechanically linked to the material that Rg attaches to. [3]The electrical sensitivity of a bridge network is measured in mV/V and represents the full-scale output Vo with Vex=1V and equivalent to Vr=Vo/Vex. Given strain, you can solve the strain equation for Vr to determine its sensitivity. [4]Equations apply for output in the polarities shown. If HB completion is included, you can connect the bridge completion resistors to IN+ instead of IN- to flip the polarity of the bridge output Vo and remove the negative sign preceding each equation.

How the TT351 Measures Strain and Load

The TT351-0700 input is wired to a Wheatstone-Bridge based sensor (pressure transducer, torque converter, accelerometer, or vibration sensor), or to individual strain gauges wired as a Wheatstone bridge. The input must be wired as a complete bridge (4 nodes) and include remote sense lines to bridge excitation (6 wires total). The TT351 utilizes a 24-bit ADC to take two measurements to resolve corresponding strain or load: sensor output Vo and sensor excitation (it measures REF1 =Vex*10K/73.2K). From Vo and Vex, it can compute the bridge sensors eklectrical sensitivity Vr =Vo/Vex and determine the imposed strain, the percent of full-scale load for the load cell, or the input millivoltage.

The TT351 can supply sensor excitation from 4V to 11V, up to 120mA, or excitation may be driven externally from 4 to 11V. In either case, Vo is measured ratio-metric to REF1=Vex*10K/73.2K and REF1 is itself measured relative to 1.8V to discern bridge excitation Vex.

The TT351 may be setup to automatically correct its Vo measurement for initial offset using its Zero Balance/Null-Offset calibration controls, and optional tare weight using its Tare controls (Input Calibration Page).

The TT351-0700 is considered an *indicator* for measured strain and load and internally refers to two values of strain or load—the ideal or simulated strain/load which is computed using the sensor Gauge Factor and a gain of 1, and the indicated strain/load which is computed after substituting Instrument Gauge Factor and/or optional Software Gain. For most applications, the indicated strain/load is driven to converge with the ideal or simulated strain/load during Bridge Shunt-calibration or Load Cell Load Calibration by adjusting Instrument Gauge Factor and/or Software Gain. The TT351 uses the *indicated* value to linearly extrapolate its analog output current or voltage range and will allow you to scale the input and output over smaller sub-ranges. Optionally, for sensor systems that are non-linear, the TT351 allows you to define up to 24 segments of the indicated input relative to the selected output range to accomplish I/O linearization.

Load cell sensors that operate under compression and/or tension and will yield bipolar or unipolar millivolt output voltage Vo directly proportional to applied force. Output readings are expressed in percent of full-load (span). Most load cell sensors will be internally compensated for temperature and do not require knowledge of their internal bridge type, sensor Gauge Factor, or the application material Poisson’s ratio. Rather, only rated output, nominal excitation, and capacity are considered for load cells.

Resolving a strain gauge bridge is more complex and requires knowledge of other parameters and the application. For any bridge, you must know the number of active load cells to determine whether it is a quarter (1), half (2), or full (4) bridge. Additionally, you must discern its specific type number by considering the way additional gauges are mounted in the bridge (their purpose), whether a “dummy” gauge is present, and whether half-bridge completion resistors are included or built into the sensor.

TT351-0700 Computation Summary:

ADC conversion uses a 24-bit bipolar converter with an Effective resolution that varies with gain and input filter (refer to Table 1 of Specifications for ENOB relative to ADC gain and input filter selection). Note that the bipolar resolution is found per Table 1 using ±10^[|ENOB-1|*LOG2]. ADC Count = |Resolution|*V*Gain/Vref + |Resolution-1|.
Sensor Rated Output RO user-specified 1mV/V to 10mV/V, Excitation Vex user-specified 4-11V, internal or external.
Input Over-Range OVR limit is user-specified up to 150% and Input Range is ±Vmax= RO*Vex*OVR/10.
ADC Measurement 1 is the bridge output Vo taken ratio-metric to Vref1

Vref1 = Vex*10K/73.2K for ADC Bridge Output Vo Conversion, Gain1 = 1, 2, 4, 8, 16, 32, 64, or 128 < Vref1/Vmax
ENOB1 per Gain1 and Input Filter per Specifications Table 1 and Resolution = ±10^[|ENOB-1|*LOG2]
ADC Count 1 = |Resolution|*Vo*Gain1/Vref1 + |Resolution-1|

ADC Measurement 2 is of the ratio-metric reference Vref1 taken with respect to Vref2 and Vex= Vref1 * 73.2/10.

Vref2 = 1.8V±0.003V, Gain2 = 1
ENOB2 per Gain2=1 and Input Filter from Specifications Table 1 and Resolution = ±10^[|ENOB-1|*LOG2]
ADC Count 2 = |Resolution|*Vref1/Vref2 + |Resolution-1|

Strain Computation Term Vr=Vo/Vex (see Strain formula per Bridge Type)

Example Calculation for a Strain Gauge

A 120Ω strain gage is wired in a quarter-bridge circuit to measure the strain imposed on a beam under stress. The bridge excitation voltage is Vex=10V. The sensor gauge Factor GF is 2.0. The bridge output is balanced with no load applied (Vo_unstrained = 0) and the gauge leads are short with negligible lead resistance. When loaded, the bridge output Vo_strained=3.500mV and no tare applies. What is the strain imposed on this beam under load?

First, refer to Table 2 on page 27 to determine the Quarter-Bridge *Type* designation, I or II – A single gauge with no adjacent dummy gauge forms a Quarter-Bridge Type I circuit and strain **ε = -4Vr * (1 + Rl / Rg) / [GF*(1+2Vr)].**

Note Rg=120Ω, Rl=0, and GF=2.0. With Vo=0.0035 and Vex=10V, we can calculate the strain computation term Vr= Vo/Vex = 0.0035/10 = 0.00035 which represents the sensitivity of the strain bridge. That is, using Vr, the calculation of requisite strain is straight-forward using ε = -4Vr * (1 + Rl / Rg) / [GF*(1+2Vr)] = -4*0.00035 / [2*1.0007] = -699.5 micro-strain (negative strain is compressive).

In a nutshell, the TT351 measures Vo relative to a ratio-metric divided reference derived from bridge excitation Vex as REF1=10/73.2*Vex. The TT351 also measures the REF1 voltage relative to a 1.8V fixed reference. From REF1, it derives the excitation applied Vex=REF1*73.2/10. It then combines the Vo & Vex voltages to determine the strain computation term Vr = Vo/Vex used in its strain formulation of the Quarter-Bridge output signal Vo. While the TT351 knows Rg=120Ω, Rl=0, and GF=2.0, it does not know the actual voltages Vo and Vex—rather, it measures these voltages digitally using a 24-bit ADC and calculates the corresponding strain ε as follows:

The ADC measures REF1 digitally using a bipolar count = ±10^[|ENOB-1|*LOG2] relative to a fixed voltage reference of 1.8V and a gain of 1. Refer to Specifications Table 1 to find ENOB with gain=1 and your input filter. Then REF1_count = REF1*|Resolution|/1.8 + |Resolution-1|. The excitation voltage Vex is related to REF1 voltage by a voltage divider as Vex=REF1*73.2K/10K. From the expression for REF1_count, we can solve for REF1 = (REF1_count -|Resolution-1|) *1.8, then calculate Vex=REF1*73.2K/10K (for Vex=10V, the REF1 voltage = 10/73.2*10 = 1.3661V). For medium filtering and gain of 1, ENOB from Specifications Table 1 is 19, and ±100% =±10^[18*LOG2] = ±262144 yielding REF1_count = 262144*1.3661/1.8 + 262143 = 461096. From 461096, the unit derives the actual REF1 voltage by solving REF1_count = REF1*Resolution/1.8 + |Resolution-1| for REF1, leading to REF1 = (461096-262143) *1.8/262144 = 1.3661V. With REF1=1.3661V, we know that Vex=REF1*73.2K/10K=10V.

To determine the bridge output Vo from its ADC count, one additional gauge specification is needed--the gauge Rated Output RO (its output voltage at a maximum load per 1V of excitation). For this example, the RO is 5mV/V. Thus, for a full load with Vex=10V, the bipolar ±100% input signal is ±10V*5mV/V=±50mV. The TT351 over-scales its input up to ±150% of rated load, or over-range OVR = ±1.5*0.050=±0.075. We calculated the ratio-metric ADC reference voltage REF1=10/73.2*Vex or 1.3661V. The TT351 applies the largest gain from 1, 2, 4, 8, 16, 32, 64, or 128 < (±REF1/±OVR = ±1.3661/±0.075=18). In this case, the ADC PGA gain is set to 16 < 18. At a gain of 16 with a medium filter setting, the ADC ENOB=19 and its bipolar count is ±10^(18*LOG2)=±262144 for ±100%, or as a function of Vo_count = Vo*16*262144 + 262143. Solving for Vo itself, we get Vo = (Vo_count – 262143) / (16*262144). The ADC measurement of Vo=3.5mV produced a count = 0.0035*16*262144/1.3661+262143=272889. From this digital count, the unit derives the actual input voltage by solving the expression Vo_count = Vo*16*262144/1.3661 + 262143 for Vo, leading to Vo = (272889-262143) *1.3661 / (16*262144) = 0.0035V. Using both the Vo and Vex voltages derived from their ADC counts, the unit can calculate bridge computation term Vr= Vo/Vex to resolve the indicated quarter-bridge strain using its equation.

Note: The Vo term has been used in this example to represent the sensor output voltage under strain or load, but Vo = Vo_strained – Vo_unstrained (for simplification, this example assumed Vo_unstrained = 0). When Vo_unstrained ≠ 0, then Vo under load must have this offset removed in subsequent calculations.

For the TT351, imprecision in the ratio-metric input divider of 10K/73.2K is calibrated out. Additionally, imprecision in its fixed 1.8V reference has also been factory-calibrated and precise values for both terms are substituted in the formulation.

Additionally, for the indicated strain by this module (versus ideal strain) used to drive the transmitter output, your own Instrument Gauge Factor is substituted for Gauge Factor and a software gain different than 1 may be applied to scale the unit’s computed load or strain as required by your application, set during shunt-calibration or load cell calibration.

Example Calculation for a Load Cell

The load cell is a device principally used in weighing systems that utilizes strain gauge technology internally, but whose output is expressed in equivalent units of force or percent, not micro-strain.

Most load cells will have 4 or 6 leads and already have bridge completion and temperature compensation built-in. Internally, a load cell will contain some permutation of quarter, half, or full-bridge circuitry, but this detail is irrelevant to the load computation and is not usually provided by the load cell manufacturer.

IMPORTANT – NULL OFFSET: Load cells rarely indicate exactly 0% with no load applied which will offset its load measurement and you should null the unloaded offset using module controls prior to taking measurements and prior to Load Calibration. Null offset will automatically remove the offset from subsequent measurements. Null offsets after changing load cells or changing between Load Cell and Bridge input types. Do not combine Tare with Offset by using Null Offset to remove Tare weight, or subsequent load cell measurements will be in error.

TIP: *When selecting a load cell for a weighing application, better service life can be obtained by keeping the full application load inside ~2/3 of the load cell capacity (esp scales). Likewise, you should respect the load cell division and keep resolution above its minimum/ incremental load (commonly 1/3000 to 1/10000) for stable and repeatable incremental measurements (see Minimum Load specification).*

The load cell is a simpler form of Wheatstone Bridge based sensor, whose output reading is not expressed in $\mu\varepsilon$, but in units of measure related to pressure or weight (typically percent of full rated load). Unlike SG inputs, processing a load cell signal does not require additional detail of its internal bridge, Gauge Factor, or material Poisson's ratio. Only rated output (mV/V), excitation, and capacity are important.

Note that the TT351 may connect to 6-wire or 4-wire load cells, but for 4-wire load cells, you must add two jumpers from EXC+ to SNS+ and EXC- to SNS-.

Example: *A compression load cell with six connection wires: sense±, excitation±, and signal ±, is specified by its manufacturer as follows (bold specs are required):*

- ***Rated Output: 2.0mV/V (sometimes referred to as electrical sensitivity)***
- ***Rated Excitation: 10V DC (15V Maximum)***
- ***Rated Capacity: 50,000 lbs/square-inch***
- ***Safe Over-Range Level: 150% of Full-Scale***
- *Operating Temperature Range: -65°F to 200°F*

The cell output Vo = 0.0035V w/no offset or tare, what is the indicated load?

Note: Based on these specifications, you can additionally conclude this load cell is temperature compensated by its wide-ambient and because it has 6 leads, it already includes half-bridge compensation resistors built-in.

Manual Calculation: The load cell's rated output is 2mV/V and its excitation is 10V. This means that 100% of load corresponds to 10V*2mV/V = 20mV. With rated capacity = 50000lbs/in^2 and Vex=10V, Vo=20mV at 100% load corresponding to 50000psi. For Vo=3.5mV, this corresponds to 3.5/20*50000psi = 8750lbs/square-inch. With software gain=1 the indicated load would be 100% *(3.5mV/20mV or 8750/50000) =17.50%. Additionally, this load cell may be safely over-loaded up to 150% of full-scale or 75000psi at Vo =30mV and Vex=10V. For the load cell, the load computation is straight-forward as shown and only Vex, Rated Output, and rated capacity were required to determine its percent load corresponding to Vo.

TT351: Just as for a strain gauge, the TT351 measures both Vo and Vex to resolve the load using a bipolar count related to its ENOB =Vin*Gain*32768/Reference + 32767. It first measures REF1 relative to REF2=1.8V with Gain=1. From the REF1 count, it solves for REF1 = (REF1_count -32767) *1.8, then derives Vex through its divider with REF1 =10K/73.2K*10V =1.3661V. The ADC returns REF1_count =32768*1.3661/1.80 + 32767 =57636. From 57636, the TT351 derives REF1 voltage by solving REF1_count for REF1, leading to REF1 = (57636-32767) *1.8/32768 = 1.3661V. Then from REF1=1.3661V, it would derive Vex=REF1*73.2/10=10V. Second, the TT351 measures Vo wrt REF1. From Vex and cell Rated Output, it computes Vo at 100%. It adds overrange up to 150% of full-scale. For this example, the rated output=2mV/V and Vo_max = 1.5*2mV/V*Vex at 150%. Thus, it sets its input gain to the largest of 1, 2, 4, 8, 16, 32, 64, or 128 < REF1/Vo_max = (Vex*10/73.2)/(3mV/V*Vex) = 10/73.2*0.003=45, or 32. The ADC would return Vo_count =Vo*32*32768 + 32767. Using this count, it solves for Vo = (Vo_count – 32767)/(32*32768). At Vo=3.5mV, the ADC count = 0.0035*32*32768/1.3661 + 32767 = 35453. Using this count, the unit solves for the Vo voltage, leading to Vo = (34110-32767) *1.3661/(32*32768) = 0.0035V for our example.

Optimizing Resolution

You can use your specification of Over-Load Limit to increase the effective resolution of the conversion for some applications by limiting the over-range limit below 150% to increase signal gain.

The resolution of your measurement system refers to the smallest amount of load or strain that the system can measure. Some Load Cell applications may additionally require that their incremental application weight produce an accurate and repeatable output response for each increment. To accomplish this, your load cell must have a division less than or equal to the incremental load and the digital instrument it connects to must have a resolution greater than the incremental load—in reality, the instrument resolution must usually be orders of magnitude greater to ensure that it can always distinguish one increment of load from its noise. That is, you must have a resolution equal or greater than the minimum required resolution of the ADC converter for noise-free operation. This allows the increment of measurement to overcome the noise floor of the digital weighing system. The Input Resolution specification at the back of this manual shows you how to determine the effective input resolution for your application and the applicable ADC gain. Use the resolution and gain you determined and pick a filter setting and refer to Table 3 of the Minimum Load specification to make sure your input resolution is equal or better than the minimum required resolution for noise free operation at your gain and filter setting. Note that input resolution can be optimized by increasing the signal (improved signal to noise ratio) or increasing the filter rate (reducing the sampling rate). You can increase the signal by increasing excitation and/or rated output, or by increasing the ADC signal gain using a smaller over-range limit specification (see below).

If your effective input resolution is less than the value in Specification Table 1 for your gain and filter setting, then you will have a hard time discerning an increment of load from potential noise. To remedy this, you can try the following to improve resolution:

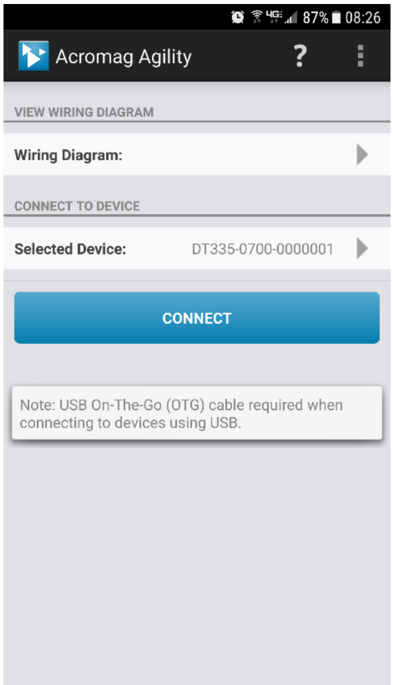
- Increase the Signal (increase rated output and/or excitation voltage)
- Increase the Filter Level (refer to Specification Table 1)
- Increase the ADC gain (see below)

<u>How to Increase ADC Gain to Improve Effective Resolution</u>: For the sensor input signal, the ADC_gain is set to the highest available gain of 1, 2, 4, 8, 16, 32, 64, or 128 just below REF1/Vin_max = REF1/[RO*Vex*(OVR%/100)]. While your choice of input sensor will usually determine the Vex and RO specification, you can indirectly raise the ADC gain by setting an over-range limit (OVR) less than the 150% default. The ADC_gain is set to the highest available gain of 1, 2, 4, 8, 16, 32, 64, or 128 below REF1/Vin_max (you are reducing Vin_max to raise the signal gain). Note that if “Enforce OVR” is not also enabled, the input range will limit at ±REF1/ADC_gain. If “Enforce OVR” is enabled, the input range will limit at ±(OVR%/100)*RO*Vex.

Note that typically a load cell is selected such that the maximum load of an application is less than 2/3 of the cell capacity to enhance its service life. In general, you also select a load cell with a load division greater than your application’s minimum incremental load. If your application maximum load is well below the capacity of the load cell, you can utilize the gain zoom feature to limit your application to a smaller portion of the cell capacity to raise the applied gain (being careful to keep your application incremental load above the system noise by making sure your effective resolution is at least as good as the noise-free level specified in Specification Table 3).

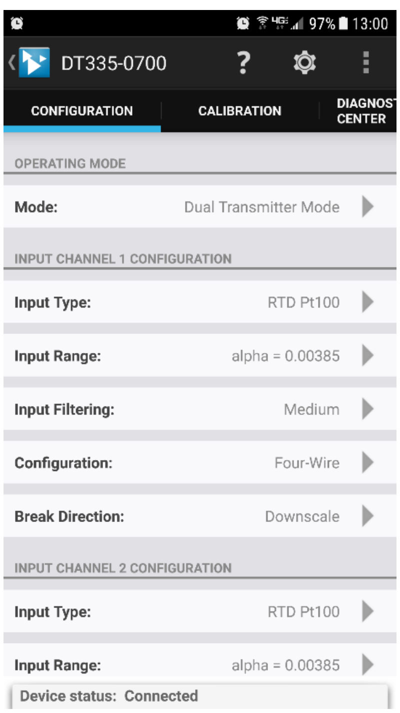
CONFIGURATION SOFTWARE

Quick Overview – Android



This transmitter can be setup & calibrated via the Acromag Agility™ Config Tool. This software APP can be downloaded free of charge from play.google.com. To connect to this transmitter, a USB OTG (On-The-Go) cable (5028-565) and USB A to Mini-B cable (4001-113) are required. This app is compatible with Android devices using Ice Cream Sandwich (4.0) or later.

The initial connection screen of the app is shown at left. Once a device is connected, the main portion of the app will launch. The screen is divided into three tabs for this model. A short description of each tab follows.



Connection Screen Set up – DEVICE SELECT (First Connect to Unit Here)

- Select from connected transmitters by tapping the **[Select Device]** button. This will bring up a list of attached devices. Select the desired device and tap the Connect button to open the device.
- To view wiring diagrams of a transmitter, tap the **[Wiring Diagram]** button and select the desired model. Swipe left or right to view more diagrams. No connection is required to view the diagrams.
- Android requires user permission to access external hardware. If the Device List displays "No Device Permission", select this device and when prompted to give permission to access the USB device, tap **[OK]**.

Configuration Tab – CONFIGURE I/O

- Once connected, the app will automatically read your transmitter and display its current configuration.
- Changing any option on this page will send the changes to the transmitter instantly. The device status at the bottom of the page will report if the changes were sent successfully.

Calibration Tab – (Calibrate the module's Input or Output or perform sensor Null-Offset, sensor Shunt Calibration, or sensor load calibration as Needed)

- On screen instruction guides the set up to properly calibrate the transmitter. After completing instructions, tap the **[Calibrate]** button.
- The device status at the bottom of the page will report if the calibration was sent successfully.

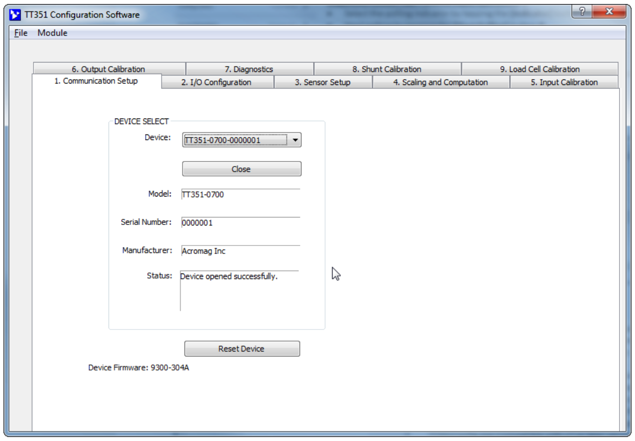
Diagnostic Center Tab – (Verify Input operation)

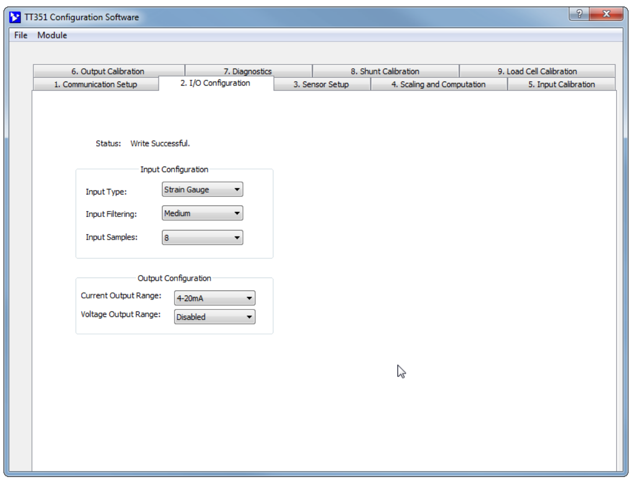
- Select the polling indicator by tapping the **[Indicator]** button.
- Start polling by tapping the **[Start Polling]** button.

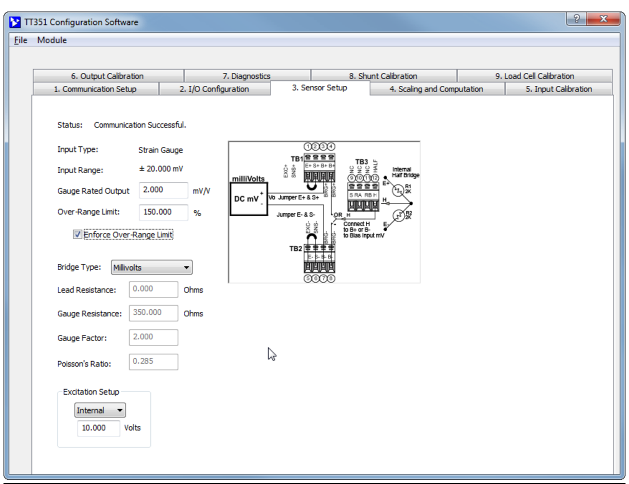
Utility Page – (Reboot or Restore Settings)

- Tap the **[Gear]** in the Action bar to access the Utility Page.
- You can tap the **[Restore/Reset Factory]** utility buttons to get out of trouble if you ever misconfigure or improperly calibrate a transmitter.

Quick Overview – Windows







HELP – Press F1 for Help on a selected or highlighted field or control or click the [?] button in the upper-right hand corner of the screen and then click to point to a field or control to get a Help message pertaining to the item you pointed to.

This transmitter can be setup and calibrated with a USB connection and Configuration Software running on your Windows PC/laptop. The USB software can be downloaded free of charge from our web site at www.acromag.com, and is included on a CDROM bundled in the TTC-SIP Configuration Kit (see Accessories). For this model, look for the program TT351Config.exe (compatible with v7 or later versions of the Windows OS).

The initial USB config software screen for this model is shown at left. Configuration info is divided across nine separately tabbed pages as follows: Communication Set up, Configuration, Sensor Setup, I/O Scaling, Input Calibration, Output Calibration, Shunt Calibration, load Cell Calibration, and Diagnostics. A short description of each of these configuration pages follows:

1 Communication Set up (First Screen at Left)

- Select from USB connected transmitters and Open/Close communication with them.
- Display Model, Serial, and Manufacturer of the connected transmitter and report the status of communication with it.

2 Configuration (Second Screen at Left)

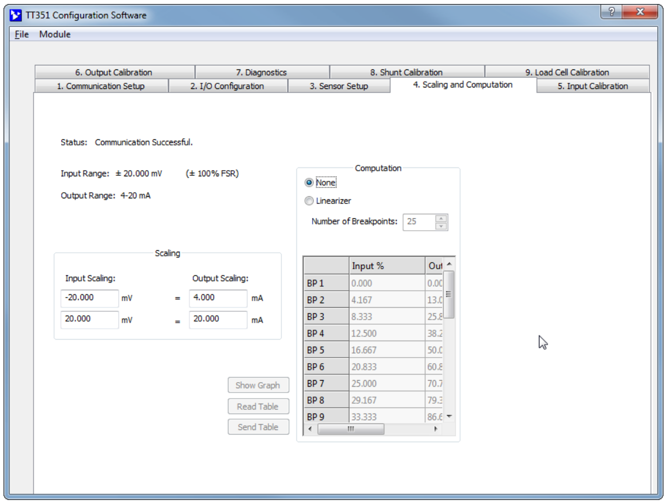
- Set your Input Type and Output Type and input filtering here.

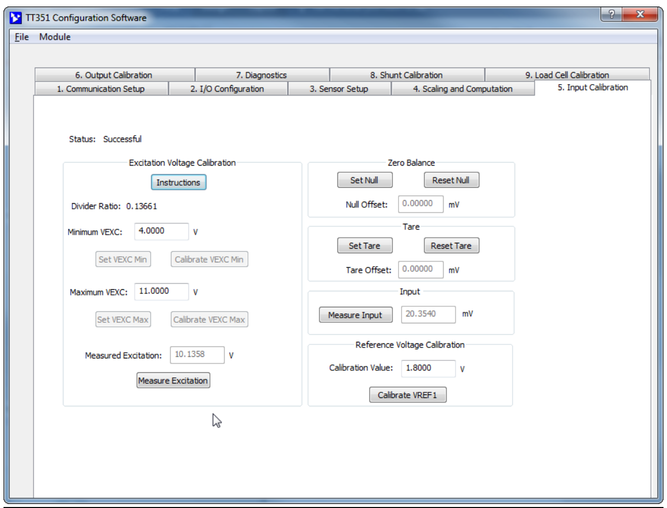
3 Sensor Setup (Third Screen at Left)

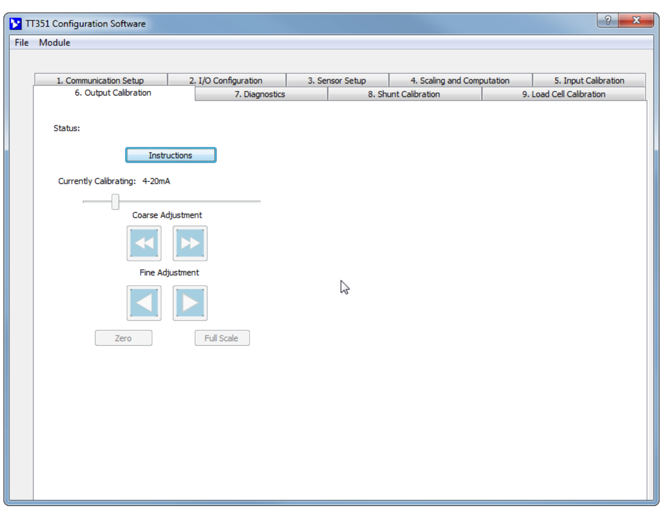
- Set strain gauge or load cell parameters relative to your sensor input. Disable or Enable internal excitation and set its level here. You can also enable an over-range limit to affect gain or impose your own range limits. By enabling an over-range below 100%, you can zoom the ADC gain to focus on a smaller portion of the sensor range. Keep in mind that the analog output uses the indicated value to extrapolate its output range and the over-range level limits the indicated value.

*Please use the **Module** pull-down menu selection **Send Configuration** to write your configuration page changes to the connected module before changing to the next page.*

Quick Overview – Windows...







4 Scaling & Computation (First Screen at Left)

- Specify the input range endpoints (or sub-range of) to map to nominal output range endpoints (or a sub-range of) for zero and full-scale, or setup up to 25 input breakpoints to piece-wise linearize a non-linear sensor response here.

5 Input Calibration (Second Screen at Left)

- Calibrate Excitation adjustment and the ratio-metric divider for the ADC reference. Null any unloaded sensor offset here (zero-balance). Set a Tare value to automatically correct the Indicated Value for tare. Sample excitation and display its level. Also sample the input and display the Indicated Value.

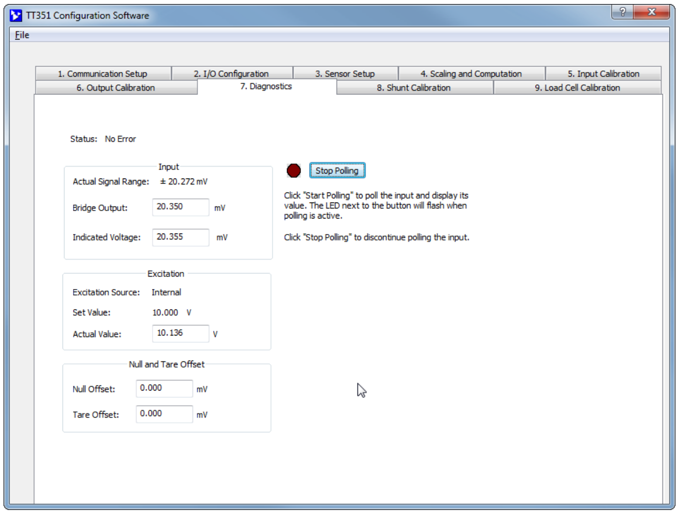
6 Output Calibration (Third Screen at Left)

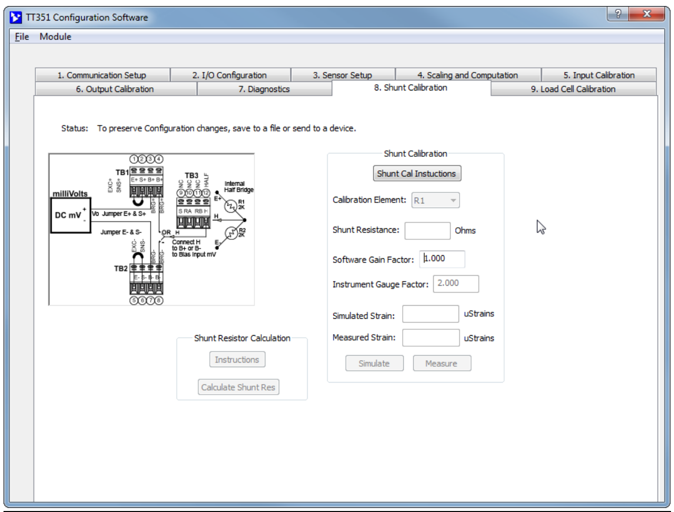
- Calibrate the transmitter's nominal voltage or current output range (controls the output independent of the input signal).

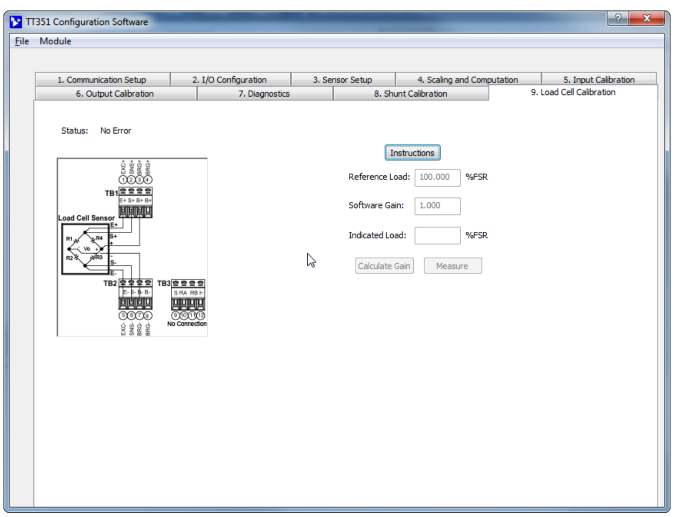
HELP – You can press F1 for Help on a selected or highlighted field or control. You can also click the [?] button in the upper-right hand corner of the screen and then click again to point to a field or control to get a Help message pertaining to the item you pointed to.

*Please use the **Module** pull-down menu selection **Send Configuration** to write your configuration page changes to the connected module before changing to the next page.*

Quick Overview – Windows...







7 Diagnostics (Optional, to Test/Verify Unit Operation)

- Poll the unit to verify communication, strain or load computation, problems with input/sensor wiring or excitation. Both sensor output and Indicated Value are reported.
- Measure/monitor sensor excitation.
- Report any non-zero offset or tare correction in place (the Indicated Value is inclusive of this correction).

8 Shunt Calibration (SG Input Only)

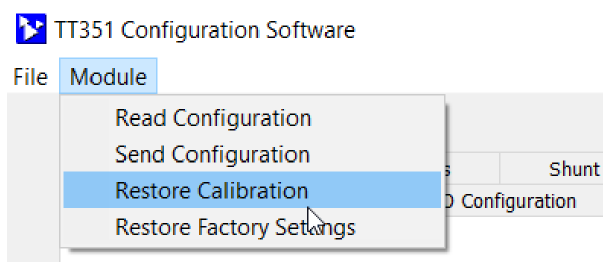
- Perform strain bridge shunt calibration of your bridge sensor application here. You can set Instrument Gauge Factor and Software Gain for the Indicated Value here. You can adjust software gain for Indicated mV input here.

9 Load-Cell Calibration (Load Cell Inputs Only)

- Perform reference load calibration for your load cell sensor here. You can adjust Software Gain here to affect the value of Indicated Load.

The communication status of any pages that set configuration information will be indicated in a status field of the page and can be helpful to troubleshoot connection problems.

Likewise, from calibration or configuration pages, if you ever need to restore a calibration (or configuration), you can click on the Module-Restore pull-down menu.



*Please use the **Module** pull-down menu selection **Send Configuration** to write your configuration page changes to the connected module before changing to the next page.*

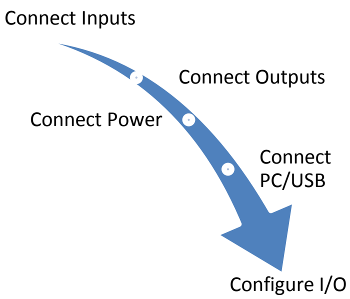
HELP – You can press F1 for Help on a selected or highlighted field or control. You can also click the [?] button in the upper-right hand corner of the screen and then click again to point to a field or control to get a Help message pertaining to the item you pointed to.

TECHNICAL REFERENCE

OPERATION STEP-BY-STEP

Wired Connections

This section will walk you through the Connection-Configuration-Calibration process step-by-step. But before you attempt to reconfigure or recalibrate this transmitter, please make the following electrical connections.



Note: Your input source (bridge simulator, strain indicator calibrator, strain simulator, weights/dummy loads) or optional millivolt source, output meter, and load resistor (current output) must be accurate beyond the unit specifications, or better than ±0.1%. A good rule of thumb is that your equipment accuracy should be four times better than the rated accuracy you are trying to achieve with this transmitter (better than 0.025%).

Calibration Connections (Transmitter Input):

1. **Connect Input:** Connect your input source to TB1-TB3 as required for your application (Refer to Sensor Input Connections). Your sensor source/simulator must be adjustable over your desired range of zero and full-scale plus over-range.
2. **Connect your Load to the Voltage or Current Output:** Wire your output load to the transmitter output appropriate for either current or voltage (not both), as required by your application. You will need to measure output current or voltage accurately to calibrate the output. You could connect a current meter in series with a load to read the output current directly, or a digital volt meter in parallel with a load to measure output voltage. Alternatively, you could simply connect a voltmeter across a precision load resistor to accurately read output current as a function of the IR voltage drop produced in the load resistor (recommended for current outputs).
3. **Connect Power:** Wire 9-32VDC power to the unit at TB5 as shown in the Electrical Connections section. Optionally, you may wire power to the bus terminal as shown in the optional power connections drawing. But in either case, never exceed 36VDC peak, or damage to the unit may result.

   Apply power to the transmitter before connecting to USB. You will not be able to configure or calibrate the unit without power applied, as this device does not draw power from USB.

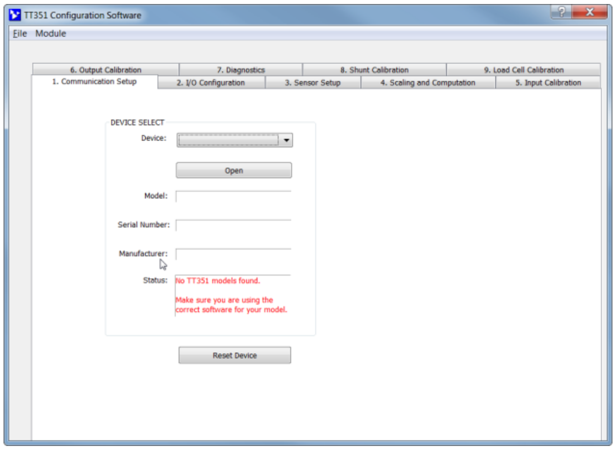
4. **Connect to PC via USB:** Connect the transmitter to the PC using the USB isolator and cables provided in Configuration Kit TTC-SIP (refer to Accessories). You may only omit the isolator if you are using a battery powered laptop to connect to the unit, or your input signal source is not already earth grounded (USB ground and input return share common).

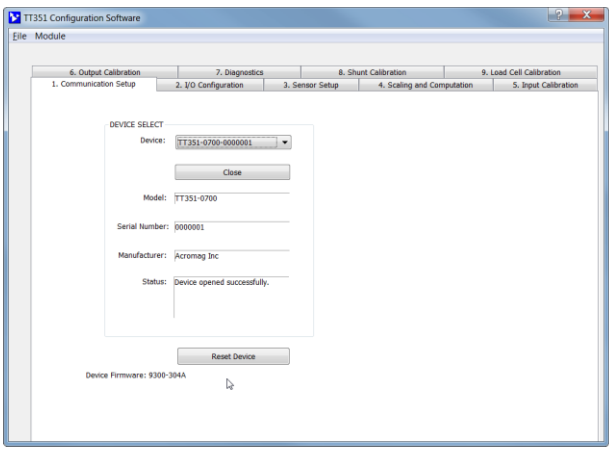
Now that you have made your connections and applied power, you can execute the TT351Config.exe software to begin configuration and testing (software is compatible with v7 or later versions of the Windows operating system).

TT351-0700 USB CONFIGURATION PARAMETERS AT A GLANCE WITH DEFAULT SETTINGS INDICATED

I/O CONFIGURATION								
Input Type	Strain G	*Load Cell*						
Input Filter	High	*Medium*	Low	None				
Input Samples	*1*	2	4	8	16			
Current Output Range	Disable	4-20mA	0-20mA					
Voltage Output Range	Disable	0-5V	±5V	*0-10V*	±10V			
SENSOR SETUP								
Rated Output	*3.000*	mV/V						
Over-Range Level	*150*	%						
Enforce Over-Range Limit	*Disable*	Enable						
Bridge Type	millivolt	Qtr Typ I	Qtr Typ II	HB Typ I	HB Typ II	Full Typ I	Full Typ II	Full Type III
Lead Resistance	*0.000*	Ohms						
Gauge Resistance	*350.000*	Ohms						
Gauge Factor	*2.000*							
Poisson's Ratio	*0.285*							
Excitation	*Int*	Ext						
	10.000	Volts						
SCALING AND COMPUTATION								
Zero	*0%*	*0.000*						
Full	*100%*	*10.000*						
Computation	*None*	Linearizer						
Number of Breakpoints			Input%	Output%				
		BP1	*0.000*	*0.000*				
		BP2	*4.167*	*13.053*				
		BP3	*8.333*	*25.882*				
		BP4	*12.500*	*38.267*				
		BP5	*16.667*	*50.000*				
		BP6	*20.833*	*60.876*				
		BP7	*25.000*	*70.711*				
		BP8	*29.167*	*79.335*				
		BP9	*33.333*	*86.604*				
		BP10	*37.500*	*92.387*				
		BP11	*41.667*	*96.593*				
		BP12	*45.833*	*99.144*				
		BP13	*50.000*	*100.000*				
		BP14	*54.167*	*99.144*				
		BP15	*58.333*	*96.593*				
		BP16	*62.500*	*92.387*				
		BP17	*66.667*	*86.604*				
		BP18	*70.833*	*79.335*				
		BP19	*75.000*	*70.711*				
		BP20	*79.167*	*60.876*				
		BP21	*83.333*	*50.000*				
		BP22	*87.500*	*38.267*				
		BP23	*91.667*	*25.882*				
		BP24	*95.833*	*13.053*				
		BP25	*100.000*	*0.000*				
INPUT CALIBRATION								
MIN Measured EXC	*4.000*	V						
MAX Measured EXC	*11.000*	V						
Null Offset	*0.000*							
Tare Offset	*0.000*							
Measured Vref1	*1.800*	V						
SHUNT CALIBRATION								
Calibration Element	*R1*	R2	R3	R4				
Shunt Resistance		Ohms						
Software Gain	*1.000*							
Instrument Gauge Factor	*2.000*							
LOAD CALIBRATION								
Reference Load	*100.000*	%FSR						
Software Gain	*1.000*							
Indicated Load	*100.000*	%FSR						

1 Communication Setup





- *Select Device*
- *Identify Unit*
- *Open USB Communication*
- *Reset Unit*

Note that you should have power connected to the transmitter at this point or you will not be able to configure, calibrate, or test the unit (TT300 models do not draw power from USB).

After executing the Acromag Configuration software for the TT351, the screen shown at left will appear, if you have not already connected to your transmitter via USB (note the red status message and that its fields are blank under these conditions).

Connect your PC to the unit via USB, and the unit's model-serial information will appear in the Device field as shown in the second screen at left.

If you happen to be connected to more than one unit via a USB hub, you can use the Device scroll field to the right of the Device field to select another unit of the same model using the serial suffix of the Device model to discern one unit from another.

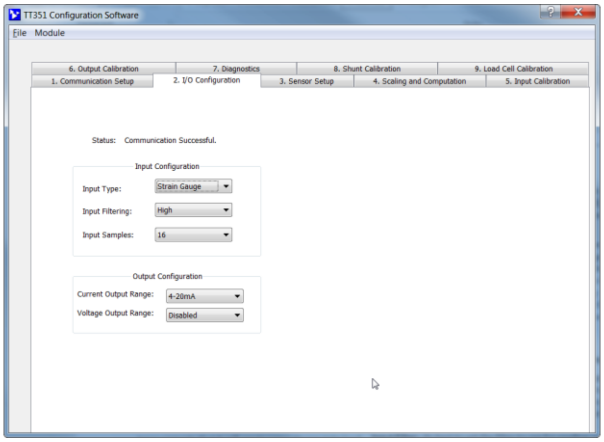
Once you have selected a device, click the **[Open]** button to open communication with the selected unit.

After clicking [Open] of the Connection screen and with USB connected, the selected unit's Model, Serial Number, and Manufacturer will be displayed as shown in the third screen at left. Additionally, the communication Status field indicates "Device opened successfully".

TIP: Always Close a connection with one device before selecting another device and make sure that you have booted the correct model software for the model device you are trying to connect to.

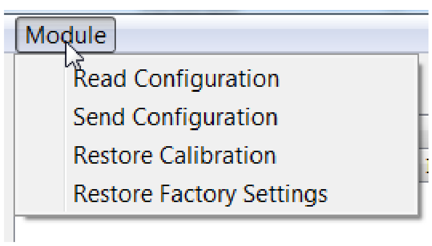
Note that configuration tabs are numbered in relative order of reconfiguration. At this point, you can click the **"2. I/O Configuration"** tab and "**3. Sensor Setup**" to begin configuring the unit, "**4. Scaling & Computation**" to map the input range to the output range, "**5. Input Calibration**" to calibrate the input excitation supply and ADC references (or to zero balance the sensor or set tare), "**6. Output Calibration"** to calibrate the output DAC range end-points, **"7. Diagnostics"** to optionally test module operation, "**8. Shunt Calibration**" to perform shunt calibration of your input bridge, or "**9. Load Calibration**" to calibrate your load cell to a reference load.

2 I/O Configuration

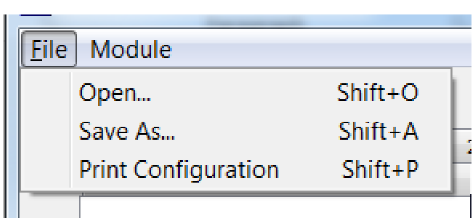


HELP – You can press **[F1]** for Help on a selected or highlighted field or control. You may click the **[?]** button in the upper-right hand corner of the screen then click to point to a field or control to get a Help message pertaining to the item you pointed to.

To reload the module's current configuration, write a new configuration, restore a module's factory calibration, or to restore original factory settings, refer to the "Module –" pull-down menu shown below:



To optionally save your configuration to a file, load from a saved file, or print the configuration, refer to the **"File – "** pull-down menu below.



When you click the "I/O Configuration" tab, the software retrieves the current input type (strain gauge or load cell), filtering level, samples for averaging, plus the selected output type and nominal output range and displays the screen at left.

Status (Communication): *This field displays configuration status messages like "No Error", "Transfer Error", and "Timeout Error" during reconfiguration. If you encounter a Transfer or Timeout Error, your reconfiguration did not complete and you may have to click Module - Send Configuration again for it to take effect (another remedy may be to restart this program).*

Input Configuration

- **Input Type**
- **Input Filtering**
- **Input Samples**

Input Type ([1]Strain Gauge or [2]Load Cell): For Strain Gauge, the module will compute Indicated Strain in micro-strain units (millivolt input is a sub-function of Strain gauge). For Load Cell, the module will compute Indicated Load in percent of full scale. Additional details specific to your input type are configured on the Bridge/Load Cell Setup page.

Input Filter (None, Low, Medium, or High): Set the filter level to use for reading sensor Vo and REF1/Vex. Increased filtering helps to filter transients, but the effective response time also increases (see Specifications).

Input Samples (1, 2, 4, 8, or 16): You can specify the number of bridge output Vo and REF1/Vex samples to average together as an additional method of input filtering. As with Input Filter level, increasing the number of ADC samples helps to filter transients, but the effective response time will also increase (see Specifications).

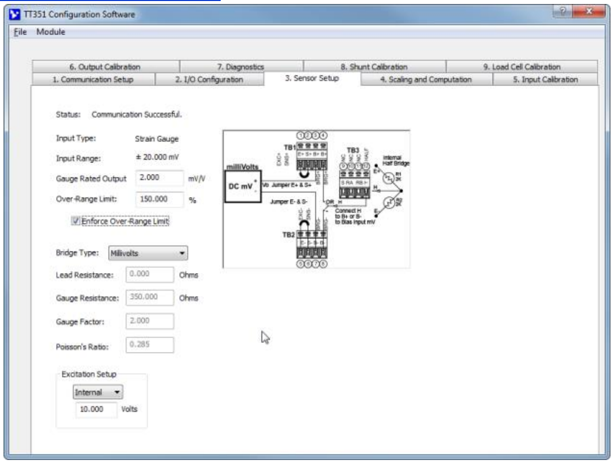
Output Configuration

- **Current Output Range**
- **Voltage Output Range**

Nominal Range (Current <u>or</u> Voltage): This transmitter has separate sourcing DC voltage and DC current output terminals that share return (only one output type may be loaded at a time). The current output will nominally drive 0-20mA or 4-20mA into 525Ω (or select Disabled). The voltage nominal output will drive ±10V, ±5V, 0-10V, or 0-5V into a 1KΩ or higher load (or select Disabled). Output ranges are sub-ranges of 16-bit nominal ±10V (voltage) or 0-24mA (current) ranges and may be scaled smaller (each halving of the nominal range reduces output resolution 1 bit).

After making changes, refer to the **"Module – Send Configuration"** pull-down menu command to write your settings to the module. The only other way to preserve changes you make is to optionally save them to a reference file by using the **"File – Save As..."** pull-down menu command.

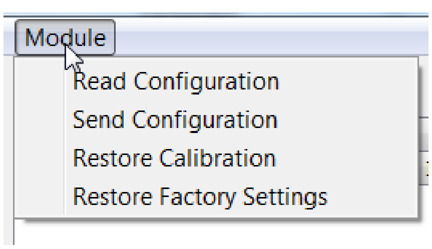
3 Sensor Setup



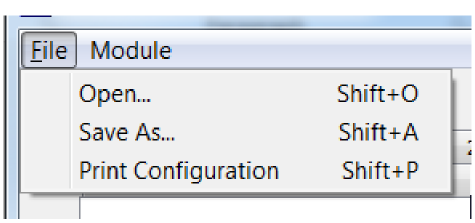
HELP – You can press **[F1]** for Help on a selected or highlighted field or control. You can also click the **[?]** button in the upper-right hand corner of the screen and click to point to a field or control to get a Help message pertaining to the item you pointed to.

Note that this module will use *Indicated Strain* to linearly extrapolate its analog output current or voltage range. The Indicated value differs from the ideal value because its computation utilizes your own settings of Software Gain (other than 1) and/or Instrument Gauge Factor (initial set to 2) for computing the load or strain.

To reload the module's current configuration, write a new configuration, restore a module's factory calibration, or to restore original factory settings, refer to the "Module " pull-down menu shown below:



To optionally save your configuration to a file, load from a saved file, or print the configuration, refer to the **"File – "** pull-down menu below.



This page content varies according to your I/O Configuration (see input type & range indicated in the first two fields). When you clicked the "Sensor Setup" tab, the software retrieves the current configuration before your changes. The only way to preserve any changes is to write them to the device by clicking **[Send I/O Config]** or saving them to a reference file by clicking **"File"** in the upper left-hand corner of the screen.

Strain Gauge Type Only (First screen shown at Left)

- **Gauge Rated Output RO**
- **SG Bridge Type**
- **Gauge Resistance Rg**
- **Poisson's Ratio**
- **Excitation Int/Ext?**
- **Over-Range Limit**
- **Lead Resistance Rl**
- **Gauge Factor GF**
-
- **Excitation Voltage**

***Status*:** This field displays configuration status messages like "No Error", "Transfer Error", and "Timeout Error" during reconfiguration. If you encounter a Transfer or Timeout Error, your reconfiguration did not take effect and you may have to click File - Send I/O Configuration again. For "Timeout Error", you may have to close the program and restart.

Input Type Strain Gauge or Load Cell: *Displays your input type selection set in the Input Configuration Page.*

Input Range: *The ±product of measured excitation Vex and gauge Rated Output mV/V (all ranges are bipolar) which corresponds to ±100% of the input (not including over-range). The transmitter output signal may be separately scaled to a smaller sub-range of its nominal setting if desired.*

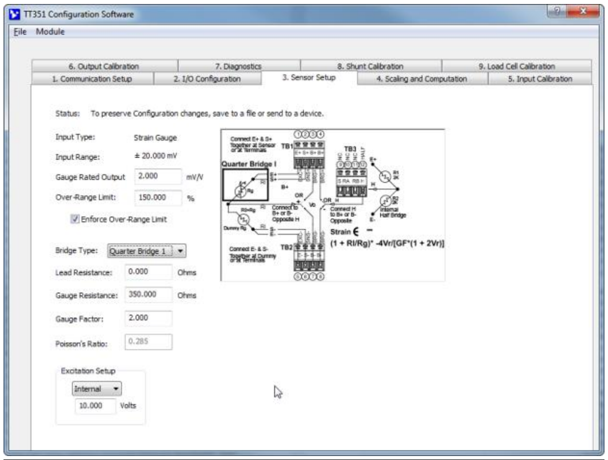
Gauge Rated Output RO (1mV/V to 10mV/V): The sensor's Rated Output in millivolts/volt of excitation as specified by the manufacturer. The ±product of RO and measured excitation Vex determines your ±100% input signal range. Changes in RO or Excitation will also drive changes to your scaling (next page).

Over-Range Limit (% portion of input range up to ±150%): Normally set per cell specification and represents a safe level of over-capacity for the sensor. It can also be useful for setting your own application limit different from the sensor if your application does not utilize the full rated Vo range of the sensor. Setting it below 100% can increase the ADC signal gain and allow some applications to have improved resolution and accuracy over a smaller portion of rated capacity (improving resolution of small signals relative to sensor capacity).

Enable Over-Range Limit: Click this option to enforce the over-range limit specified for the indicated value (the analog output is extrapolated from the indicated value).

*Please use the **Module** pull-down menu selection **Send Configuration** to write your configuration page changes to the connected module before changing to the next page.*

3 Sensor Setup...



__Note:__ The selection of quarter or half SG Bridge types also requires installation of the HALF jumper from TB3 – H to TB1 IN+ or TB2 IN- if the internal half-bridge completion resistors are used. A millivolt input also requires that this jumper be installed to bias the voltage to the differential signal ground. In addition, quarter bridge conversion also requires the installation of an external resistor or "dummy gauge" (not supplied). See Bridge Completion section for additional details.

***IMPORTANT:** You must set Excitation Source to "Ext" <u>**before**</u> connecting an external excitation source to the module or damage to the unit's internal excitation supply may occur.*

***Note:** The excitation supply was designed to drive up to 10V at the bridge, with up to 5Ω of lead resistance Rl at currents up to 125mA.*

*Please use the **Module** pull-down menu selection **Send Configuration** to write your configuration page changes to the connected module before changing to the next page.*

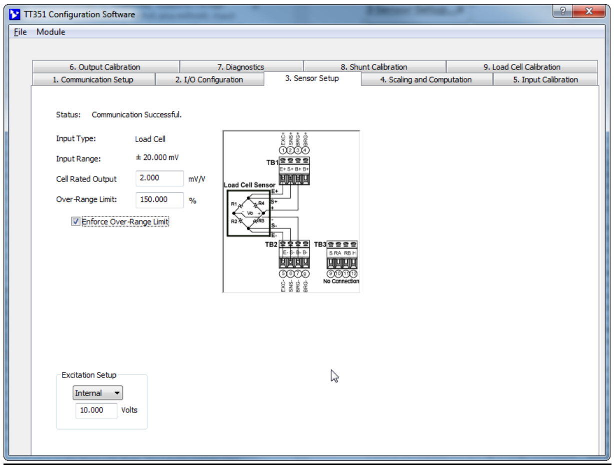
Bridge Type ([1]SG Bridge or **[2]Load Cell)**. Supports 7 bridge types: two Quarter, two Half, three Full, plus millivolt. Input must be wired in Wheatstone-Bridge format and the indicated output will be in units of micro-strain (or mV units for millivolt input type). For Load Cell, a full 4 or 6-wire connection to the sensor is assumed and the computed output will be expressed in percent-of-full load. A graphic of sensor wiring and applicable formula is displayed with reference designators.
RL Lead Resistance Ω: The lead resistance of the excitation and sense leads to the gauge in ohms (all RL leads are assumed equal in gauge and length).
Rg Gauge Resistance Ω: The nominal gauge resistance specified by the manufacturer. For strain indication, it is assumed that all gauges and/or resistors of quarter and full-bridge applications have the same Rg base resistance.
Gauge Factor (Default is 2.0): The Gauge Factor (GF) of the strain gauge (its resistance sensitivity expressed as the ratio of its change in resistance to applied strain GF=△R/R*ε). <u>Do not confuse Gauge Factor with the Instrument Gauge Factor of the module which you control to rescale the Indicated value</u>. GF is primarily used to calculate the ideal or simulated strain during shunt calibration. Note that Instrument Gauge Factor is initially set to 2 but may be varied following SG Bridge shunt calibration to affect the Indicated Value while holding the Gauge Factor constant.
Poisson's Ratio: For the material the strain gauge(s) are applied to if other than 0.285 (default value). For example, the Poisson's Ratio for steel varies from 0.25 to 0.30. *Note that this value is ignored for Quarter-Bridge, Half-Bridge Type II, and Full-Bridge Type I applications.*

Excitation Setup

Source (Internal/External): Select Internal (default), or External to disable the internal supply and connect one externally (new setting is assumed following download). Use of External will also require you to wire jumpers between EXC+/SNS+, and between EXC-/SNS- terminals.
Selected Excitation: With internal excitation, use this field to specify a <u>nominal</u> level from 4V to 11V. The ADC measures Vex with every Vo sample via its remote sense lines and displays its actual value on the Diagnostic Page. Your measured Vex may differ from this Nominal selection due to limitations of adjustment resolution and/or larger than expected lead resistance. The unit will utilize the Vex read value in its computation for resolving indicated strain or load and can adjust Vex as needed to boost its level if it droops too far below the nominal you select here.

The remaining information varies according to the Input Type selection, SG Bridge type or Load Cell. Parameter fields that do not apply to your type selection will be grayed out on-screen.

3 Sensor Setup...



Load Cell Type Only (See Screen above)

- **RO (Rated Output)**
- **Over-Range (OVR)**
- **Enforce OVR Limit**
- **Excitation**

Status: *Displays configuration status messages like "No Error", "Transfer Error", and "Timeout Error" during reconfiguration. If you encounter a Transfer or Timeout Error, your reconfiguration did not take effect and you may have to use File- Send I/O Configuration again.*
Input Type: Displays **Load Cell** for the load cell input type selection on the Input Configuration Page.
Input Range: Displays the ±product of Rated Output RO, Excitation Vex corresponding to ±100% of input signal range for your sensor. The ADC input sets its signal range using the product of input range and the Over-Range Level/100%.
Cell Rated Output RO (mV/V): Sometimes referred to as electrical sensitivity and normally specified by the load cell manufacturer. Set this from 1mV/V to 10mV/V. The ±product of RO and Excitation Vex will determine ±100% of input signal. Over-range OVR is set up to 150% of this. The ADC gain sets its gain to 1,2,4,8,16,32,64, or 128 < REF1/[(OVR/100)*RO*Vex]. If OVR is not enabled, the ADC signal range is limited to ±REF1/Gain. If OVR is enabled, then the input signal is limited to (OVR%/100)*RO*Vex.
Over-Range Limit OVR (default 150%): Typically set per cell specification up to 150% and represents the cell sensors safe over-capacity. By specifying this limit, you ensure that the ADC input will process sensor input signals up to this level. It is used to affect ADC gain and resolution as the ADC input signal gain is set to 1,2,4,8,16,32,64, or 128 < REF1/|RO*Vex*OVR%/100|.

You can lower the OVR limit to raise Gain and improve input resolution for some applications. This is also useful to limit the analog output level if you also choose to enforce the input OVR Limit (see below).

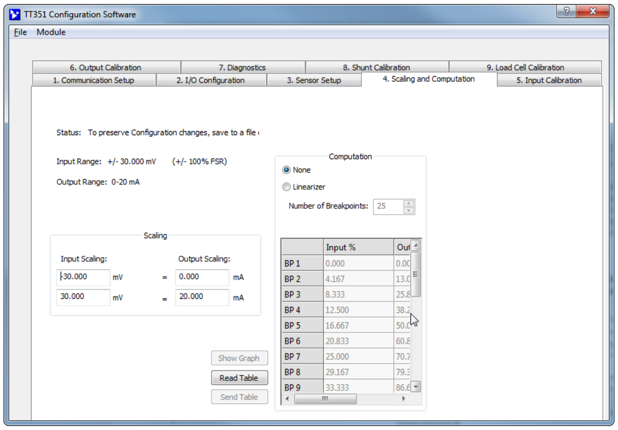
<u>Tip (OVR and ADC Gain)</u>: *ADC input Gain is set to the highest of 1, 2, 4, 8, 16, 32, 64, or 128 < REF1/Vin_max = REF1/|Vex*RO*(OVR%/100)|. While your choice of input sensor usually determines the Vex and RO specifications, you can indirectly affect the ADC gain selection by setting an OVR limit less than the ±150% default according to this formula. This may be useful to improve resolution for some applications with a maximum load below cell capacity or to help ensure that resolution is suitable for minimum load detection by driving it above the noise-free level (see Minimum Signal specification). You may separately Enforce the OVR over-range limit to only allow inputs up to this signal level and limiting the output.*

Enforce Over-Range Limit: The input range is constrained within its hardware limit of ±REF1/[(OVR/100)*RO*Vex] if this option is not selected. Checking this option will enforce an input range limit of ±RO*Vex*OVR/100.
Excitation Source: Set to Internal to have the module drive sensor excitation from its EXC+ and EXC- input terminals. Set to External to turn off the internal supply and connect excitation externally to the sensor and also wire it to the input SNS+ and SNS- terminals of this module.
Excitation Level: Use this field to set the Internal excitation voltage to a nominal level from 4V to 11V (internal excitation is is 4-11V at up to 120mA).

Note: *The internal excitation supply was designed to drive up to 10V at the bridge, with up to 5Ω of lead resistance Rl at currents up to 120mA.*

If set to External, then sensor excitation must be driven externally between the input sense leads from an external 4-11V source. Note that for mV input, the input EXC± terminals are jump-wired to their adjacent SNS± terminals and the input mV range is set by adjusting the EXC level as a product of Vex and the RO specification. This module measures Vex with every Vo sample between its remote sense lines and displays its value on the Diagnostic Page of this software. The measured Vex may differ from your Nominal selection due to limitations of adjustment resolution and/or a larger than expected lead resistance. The unit utilizes the read Vex value in its computation to resolve indicated strain or load and can adjust Vex as needed to boost its level if it droops too far below the nominal you select here.

4 Scaling/Computation



The analog output current or voltage of this transmitter is linearly extrapolated from the indicated input load (%) or strain (micro-strain). The indicated load/strain refers to its computed value using your own software gain (other than 1.0 used for ideal strain) and/or instrument gauge factor (other than sensor Gauge Factor for ideal strain).

Nominal Range (Current or Voltage): This transmitter drives separate DC voltage and current sourcing output terminals that share a return (only one signal type may be loaded at a time). The nominal current output will drive up to 525Ω with your choice of 0-20mA or 4-20mA (or select Disabled). The nominal active voltage output will drive 1KΩ or higher loads and supports your choice of ±10V, ±5V, 0-10V, 0-5V ranges (or select Disabled). Output ranges are scaled sub-ranges of 16-bit nominal ±10V (voltage) or 0-24mA (current) ranges. When scaling smaller, be careful not to reduce the range too much, as resolution decreases and noise/error goes up (each halving of the nominal range reduces its output resolution 1 bit).

IMPORTANT: If you choose Linearize for Computation and setup your I/O breakpoints, it is only sent to the module by clicking [Send Table], it is not sent to the module via the menu Module - Send Configuration.

*Please use the **Module** pull-down menu selection **Send Configuration** to write your configuration page changes to the connected module before changing to the next page.*

Indicated strain or load is linearly scaled from the input to an output current or voltage according to range endpoints you specify on this page. Optionally, for sensor systems that may be non-linear, this page allows you to define up to 24 segments of the indicated input relative to the output to accomplish piece-wise I/O linearization.

Scaling or Computation

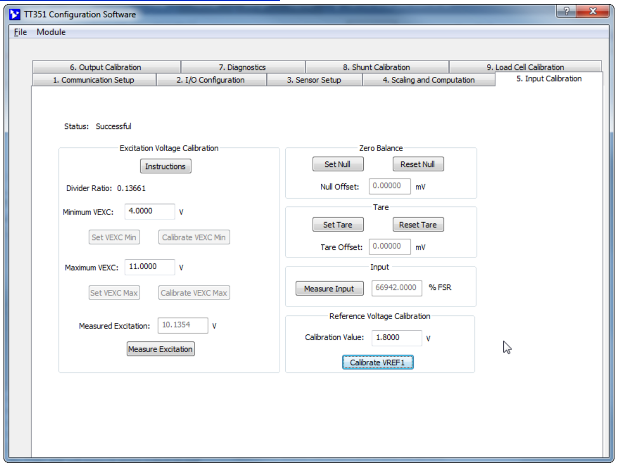
- **Input Range Endpoint 1**
- **Input Range Endpoint 2**
- **Linearizer**
- **Output Range Endpoint 1**
- **Output Range Endpoint 2**
- **Breakpoints**

***Status*:** Displays configuration status messages like "No Error", "Transfer Error", and "Timeout Error" during reconfiguration. If you encounter a Transfer or Timeout Error, your reconfiguration did not take effect and you may have to click File - Send I/O Configuration again.
Input Range: The product of Rated Output RO and measured Excitation Vex corresponding to ±100% sensor input range.
Output Range: Displays the nominal output current or voltage range selected.

Scaling

In the I/O scaling fields, set the input and output signal endpoint min/zero and max/full-scale values inside their nominal ranges to correspond (or optionally swap min/max input zero/full-scale levels to configure a reverse acting output response if desired).
Scaling Input: Output (Not for Linearized Computation): Scaling allows any portion of the selected input range (indicated value) to be scaled to any portion of the transmitter analog output using these fields to map high/low I/O range endpoints together. It is performed using the indicated value with filtering applied and converts the input range (or a portion of the nominal range) to the nominal output range or portion of the nominal output range. When you rescale the nominal input/output ranges to smaller sub-ranges, be careful not to reduce an I/O range too much, as resolution diminishes in proportion and noise/error increases (each halving of range reduces respective resolution by 1 bit). For rated performance, try to maintain an effective I/O resolution of 12-bits or better after scaling.
Computation (for None or Linearize): Select None (default) for a proportional linear scaled I/O response in mapping indicated load/strain to the output current or voltage. Otherwise select Linearize to enter a specified "linearized" response and you may define up to 25 indicated input-to-output break points to facilitate your own 24-segment linearization of the sensor's indicated load/strain.

5 Input Calibration



Use the tools of this page to calibrate the ratio-metric excitation divider used to drive REF1 for measurement of sensor Vo, the Internal excitation adjustment, and to zero-balance or null any unloaded sensor offset prior to shunt or load cell calibration.

The TT351 ADC will measure sensor output Vo and excitation Vex to compute requisite strain or load. It uses a precision resistive divider of 10K/73.2K (~0.13661x) of Vex between the input ±SNS terminals for the ratio-metric reference REF1 used by the ADC to measure Vo. It also measures REF1 on a separate channel relative to REF2=1.8V to derive the excitation Vex coincident with Vo. Internal excitation Vex is digitally controlled in a 4-11V range and calibration helps to overcome resistor divider error as well as determine the Vex adjustment increment such that it can extract Vex precisely and quickly servo its adjustment of Vex. The unit divides the Vex min/max span by 63 to get the Vex/lsb increment and its measurement of Vex will allow it to determine Vex when it measures Vo & REF1.

You must use an accurate DVM to independently measure the min/max excitation levels between the input SNS± terminals (ideally at your application sensor), then input your measured values into the Min & Max Calibration fields of the Input Calibration screen and click the Calibrate button to store the measured values, calculate the ratio-metric reference divider, and set the Vex adjustment increment/lsb. The corrected divider ratio (default ~0.13661) will be indicated along with the Vex MIN (~4V) and MAX (~11V) detent levels. The relative accuracy of your module is strongly dependent on the accuracy of your DVM measurements, so be careful to accurately measure and record the MIN/MAX excitation levels to 4 decimal places.

Excitation Voltage Calibration

- **Divider Ratio**
-
- **Internal Vex Minimum**
- **Internal Vex Maximum**

In general, after reconfiguring a unit, you may install it in the field after nulling any unloaded offset because the input ADC, input divider, and output DAC circuit has already been factory calibrated with a high degree of precision. But if at some point you encounter excessive module error not related to your sensor, or you must satisfy company maintenance requirements for your application, you can optionally click the **Input Calibration** tab to display the input Excitation, Divider, and Zero Balance controls as shown at left.

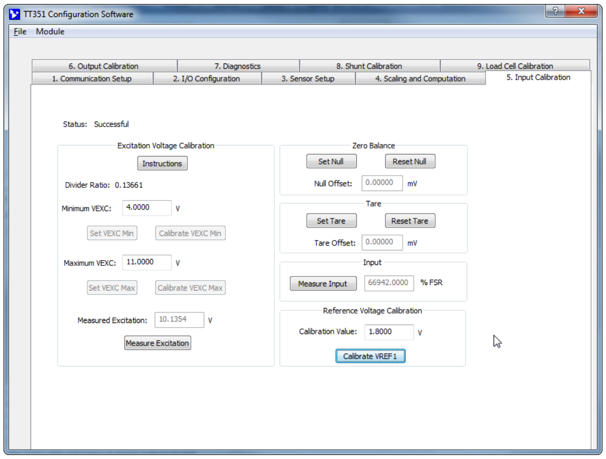
Status: *Displays configuration status messages like "No Error", "Transfer Error", and "Timeout Error" during reconfiguration. If you encounter a Transfer or Timeout Error, your reconfiguration did not take effect and you may have to click File - Send I/O Configuration again.*
[Instructions]: Click this button to initiate excitation calibration, receive instructions and enable the Set and calibrate Vex Min/Max buttons.
Divider Ratio Indication: *Indicates the current divider ratio derived from your calibration using a DVM measurement coincident to the module's REF1 measurement (def ~0.13661).*

MIN Vexc: Enter the DVM minimum level measured between the SNS± terminals in this field after clicking [Set Vexc MIN].
MAX Vex: Enter the DVM max level measured between the SNS± terminals in this field after clicking [Set Vexc MAX].
[Set Vex...]: Click this button to send Vex to its MIN or MAX setting, where you will measure the level on a DVM.
[Cal Vex...]: Click this button after you have measured the MIN or MAX Vex level and entered it into the MIN or MAX Vex field (the ADC simultaneously measures REF1 to derive the reference divider and displays it along with the measured minimum Vex (this min/max Vex should converge with your measured Vex following calibration).

Excitation Voltage MIN/MAX Indication: Indicates the ADC's measurement of Vex updated each time the [Calibrate vex...] button is pressed.
[Measured Excitation]: Click this button to have the module sample the input excitation

IMPORTANT: For best accuracy, the input divider should be calibrated with internal Vex loaded as required by the application (your sensor connected) or an equivalent load.

5 Input Calibration...



This module measures sensor output voltage. For many applications, SG Bridge and Load Cell sensors commonly fail to indicate exactly zero output with no strain or load applied. This is often due to small application induced stresses driven by variations in lead resistance among bridge elements, or between leads, and other application-induced stresses. It may also occur from small thermoelectric voltages generated in the circuit wiring or from induced noise generated by nearby equipment. The Null Offset controls of this page allow you to remove any unloaded/unstrained SG Bridge or Load Cell offsets from subsequent Vo measurements of the sensor output voltage.

IMPORTANT: Do not use Null Offset controls to remove tare weight from the sensor Vo measurement or you will generate measurement error and not be able to discern real tare from a measurement of load. Tare is controlled separately from offset using controls found on the Diagnostics page. *Tare is typically much larger than unloaded offset and can take any value within the range of an input. If you note a large unloaded sensor offset, there may be a problem with your sensor. If you inadvertently combine tare with the offset measurement, then your Vo measurement will never return to zero with the load removed. You need to be able to discern large bridge offsets separate from tare to detect potential sensor problems, and because tare values change more frequently for a sensor, while initial offset usually remains constant for the application sensor.*

IMPORTANT: Null Offset should be done prior to SG Bridge Shunt Calibration or Load Cell Load Calibration and always after changing sensors.

Zero Balance/Offset Null (Do Not Use for Tare)

- Null the Offset Value
- Reset any Nulled Offset

The Zero Balance controls allow you to measure and store any offset in Vo when no load or stress has been applied and subsequent measurements of Vo will have this offset automatically removed before computing the corresponding load or strain. The unloaded offset is generally sensor-specific and may vary between sensors and sometimes between SG Bridge types. You should null your sensor's unloaded offset if you change sensors or bridge types and before attempting SG Bridge Shunt Calibration or Load Cell Load Calibration, or your load or strain measurements will be in error.

[Set Null]: Click this button to measure the current unloaded bridge signal, store the value, treat it as an offset and automatically remove it from subsequent Vo measurements.
[Reset Null]: Click this button to remove any existing offset correction if you plan to change your sensor or input type as offset is usually sensor specific.
Null Offset Field: Indicates the current sensor offset that will be removed from Vo measurements before computing strain or load.

Tare (Do Not Use for Zero Offset)

- Measure Tare
- Reset Tare

The tare controls allow you to take a measurement and store this value which will be removed from subsequent Vo measurements. For example, tare may refer to a common weight between measurements that doesn't change, like a container or skid. Always null unloaded offset before taking a tare measurement.

[Set Tare]: Click this button to cause the Vo measured to be stored and subtracted from subsequent Vo measurements.
[Reset Tare]: Click this button to remove any existing tare.
Tare Offset Field: Indicates the current tare weight removed from Vo measurement. This Null Offset voltage will be automatically removed from Vo measurements before computing strain or load and is tracked separate from tare (see the Diagnostics page for software Tare controls).

5B ADC Calibration (Factory Only)

ADC 1.8V Reference 2 Calibration ***REF2 is measured between socket X1-8 and X1-1 located behind the front panel.*** ***Note:*** *Factory Calibration Only, this is not a field calibration procedure. Recalibration of this reference in the field is not normally required and this information is included here as a reference for factory service only.*	**ADC Reference Voltage (Initial Calibration done from the Factory):** For voltage measurement of REF1 (the reference used by the ADC to measure Vo), the ADC uses a fixed 1.8V ±0.003V, ±30ppm/°C reference. VREF1 is measured each time it samples the bridge output signal Vo and it uses this measurement for precisely determining the ratio-metric excitation divider to generate the reference for measuring Vo. The initial tolerance of this reference can be compensated for by measuring the reference voltage and down-loading the measured value to the module using special software at the factory. The reference voltage is nominally 1.8 ±0.003V (1.797V to 1.803V). Simply measure the REF2 voltage at the reference test-points of the circuit board (X1-8 to X1-1) with an accurate DVM and enter the measured value into the software field and click **[Calibrate]** to store it in non-volatile memory within the module. This is a factory procedure that can only be done without the enclosure using special factory software and strict ESD handling procedures.

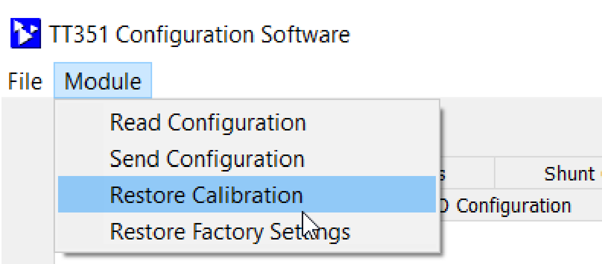
Ongoing field calibration requirements for the module itself involve calibration of its input ADC circuit (its ratio-metric input divider and its internal adjustment of sensor excitation Vex), and its output DAC circuit range zero and full-scale. Input Calibration must follow the factory calibration of the fixed 1.8V±0.003V±30ppm/°C ADC REF2 noted above. REF2 is used by the ADC to measure the ratio-metric input reference REF1 that is used by the ADC to measure the sensor output voltage Vo. The coincident excitation at the bridge Vex is derived from the REF1 measurement. REF2 can be measured between socket X1-8 and X1-1 located behind the front panel.

The TT351 also provides additional calibration tools that are generally application sensor-specific and include Zero-Balance/Offset-Null, SG Bridge Shunt-Calibration (SG Bridge input only), and Load-Cell Calibration (Load Cell input only). These additional tools do not calibrate the instrument, only its treatment of the sensor signal.

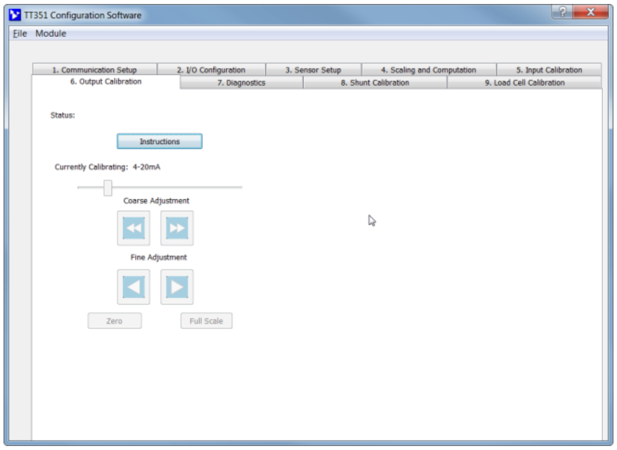
The following sub-sections review each of these calibration tools in more detail.

Note: Keep in mind that this module uses its *indicated* value of strain or load to linearly extrapolate its analog output current or voltage (not the computed or ideal load or strain). The indicated value of strain or load differs from the ideal computation of strain or load for a sensor because it optionally utilizes your own settings of software gain (other than 1) and/or instrument gauge factor (instead of sensor gauge factor) for computing the indicated load or strain. Keep this in mind when scaling the transmitter output, as changes to Software Gain and Instrument Gauge Factor that affect indicated strain or load will drive proportional changes to the transmitter analog output current or voltage. Note that from the factory, for computation of indicated strain or load, Software Gain is initially set to 1 and the Instrument Gauge Factor is set to 2 by default. For computation of ideal or simulated strain values, the gain is 1 and the Gauge Factor of the sensor is used.

In the calibration pages that follow, if you ever need to restore a calibration (or just the configuration), you can click on Module Restore…



6 Output Calibration

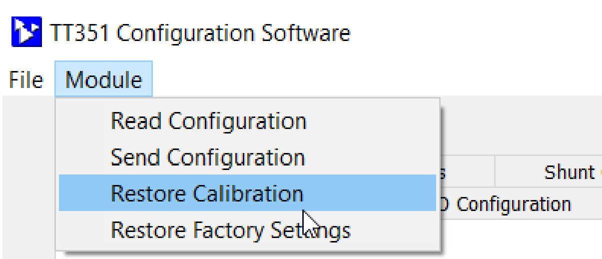


If your output acts erratic and appears imprecise relative to your expected accuracy, you may need to repeat calibration of the nominal output DAC range zero and full-scale. First check that your rescaled I/O range has adequate resolution (12-bit or better), as an input or output span set too-tight will have diminished resolution and appear to magnify output error.

IMPORTANT: Consider your decision to recalibrate carefully. The unit has already had its output factory calibrated with high precision. If you attempt to recalibrate the output, you may inadvertently degrade transmitter performance if you don't do it properly, or you do it using low grade measurement equipment.

Before calibrating the selected nominal output voltage or current range, be sure to select the correct range for your application, connect to the right output terminal, load the output properly, and take accurate output measurements. For current output, if you are measuring a voltage across an output load resistor, make sure that you use the exact load resistance when calculating the load current being measured.

To restore a calibration, click on Module Restore…



Use these controls to calibrate the transmitter output current or voltage range.

Transmitter Output Calibration for Nominal Selected Range

- **DAC Output Zero**
- **DAC Output Full-Scale**

Wire your output signal monitoring equipment to the correct terminal, voltage or current of the unit and make sure to preset the nominal output range for your application. Be sure to measure the zero and full-scale output levels very accurately, or output performance will be degraded.

Status: Displays calibration status messages like "No Error", "Transfer Error", and "Timeout Error" during calibration. If you encounter a Transfer or Timeout Error, your calibration did not take effect and you may have to repeat calibration.
[Instructions]: Click this button to initiate output calibration, receive instructions, and enable the Zero/Full-Scale buttons and adjustment controls (the output is controlled independent of the input signal during output calibration).

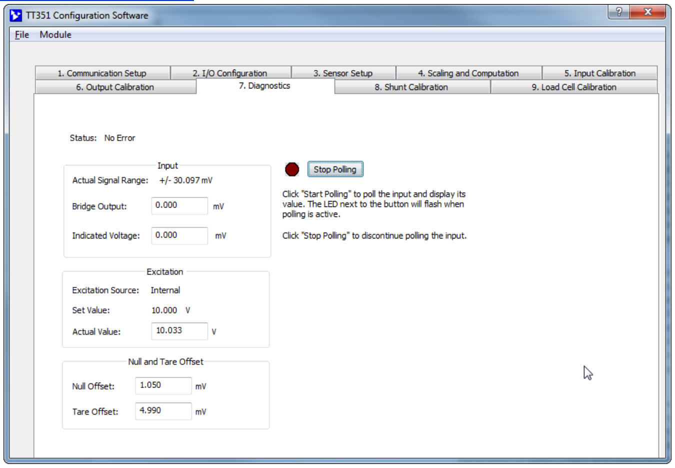
Slide Control: Use this slider along with the course/fine adjustment controls to drive the output independent of the input to its precise nominal output range zero level as measured by your output meter (i.e. 0mA, 4mA,-10V, -5V, or 0V according to your nominal output range selection). With output level at the precise output range zero, click **[Zero]** to set the output DAC digital range zero position (corresponding to -100% or 0% according to bipolar/unipolar range).

Next, use the output slider along with the course/fine adjustment controls to drive the output independent of the input to its precise nominal output full-scale level (i.e. 20.000mA, 5.000V, or 10.000V) as measured by your output meter. At the precise output range full-scale, click **[Full-Scale]** to set the output DAC digital range full-scale position (corresponding to +100%).

[Zero]: Click this button after you have set the output to its nominal output zero level as measured on your DVM.
[Full-Scale]: Click this button after you have set the output to its nominal full-scale level as measured on your DVM.

[Restore Factory Calibration] Use to restore the original factory output calibration if you make an error during calibration and have degraded performance, or if the transmitter output acts erratic.
[Restore to Factory Default] Use to return the unit to its original factory configuration settings (does not restore calibration, only configuration). Useful as a sanitation tool to restore initial configuration when decommissioning a module.

7 Diagnostics

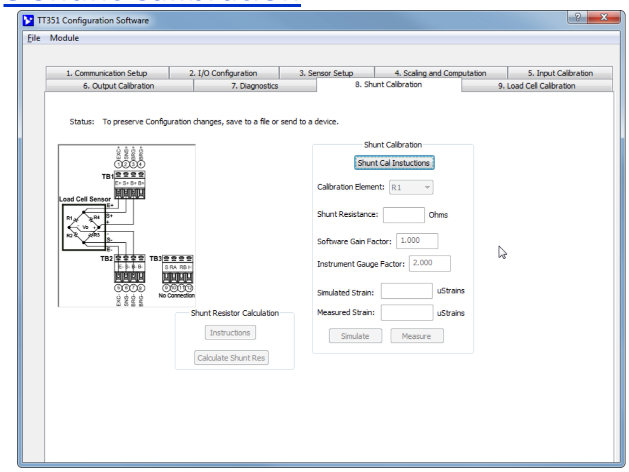


You can access the Diagnostics page 7 at left to check the operation of your module and review its operating parameters. Here you can poll the sensor output voltage Vo, its indicated value, the measured excitation, any non-zero offset and tare (note that offset and tare can be set by controls of the Input Calibration page 5). The indicated value of load, strain, or millivolts on this page will have offset and tare automatically removed. This page returns both a simulated load, strain, or mV (using sensor Gauge Factor and gain of 1) and the Indicated load, strain, or mV (using Instrument Gauge Factor and/or Software Gain). Although the Indicated Value on this page is inclusive of offset and tare, this page returns those offsets separately for review.

Simply click **[Start Polling]** to trigger the software to periodically read the sensor Vo, its indicated value, excitation Vex, offset, and tare and display their values (the Indicated value of load, strain, or mV will have any offset already nulled and/or tare removed from it). Note the simulated lamp next to the polling button flashes slowly each time it samples Vo and Vex. Click **[Stop Polling]** to stop polling the input before moving onto another tab/page.

The polled value is indicated in its native units of both micro-strain (Strain Gauge), or percent of full-scale load (Load Cell), or millivolts (millivolt input). Note that the actual ±100% signal range is indicated and is based on the product of Rated Output and measured excitation (the measured excitation may differ slightly from your specified value due to limitations of adjustment resolution). The "Status" line will typically display "No error" in the Communication status field while polling.

8 Shunt Calibration



Shunt Calibration does not calibrate the instrument itself, but the SG Bridge sensor it connects to, allowing you to rescale the transmitter's Indicated strain by modifying Software Gain and/or Instrument Gauge Factor.

Through the process of Shunt-Calibration, a sensors ideal strain (its simulated strain) and indicated strain are typically driven to converge by adjusting the Instrument Gauge Factor and/or Software Gain to affect the Indicated value. For some applications, deliberate adjustments to Instrument Gauge Factor and/or Software Gain is done instead to simply rescale the Indicated strain to alter the transmitter output current or voltage signal, as it is the Indicated strain value that is used to linearly extrapolate the analog output of this transmitter inclusive of any unstrained offset and tare correction.

IMPORTANT-NULL FIRST: Be sure to null any unloaded sensor offset in its Vo before applying a bridge shunt and attempting Shunt Calibration. For best results, it is recommended you allow the module to warm-up several minutes prior to shunt calibrating an SG Bridge sensor.

Note: *The Indicated strain and Simulated Strain of this page does not include any defined tare measurement for the application.*

Note: If your input is millivolts, this page will only allow you to modify software gain to affect the corresponding Indicated millivoltage.

IMPORTANT: Always Null unloaded SG Bridge offsets to zero before attempting Shunt Calibration.

Shunt Calibration (SG Bridge Input Type Only)

- **Bridge Element**
- **Shunt Resistance**
- **Instrument Gauge Factor**
- **Software Gain Factor**

Bridge Element: Refer to the graphic and identify bridge element R1, R2, R3, or R4 to be shunted with Shunt R.
Shunt R Field: Enter the Shunt Resistance and click [Simulate] to compute the corresponding Simulated Strain (Ideal strain) using the sensor Gauge Factor and a software gain of 1. Alternately, you could choose to specify the Simulated micro-Strain value and click [Simulate] to calculate the required Shunt R resistance to obtain the Simulated Strain specified.
[Simulate]: Click to either calculate the Shunt R required to produce the Simulated Strain value you specify, or the Simulated Strain value that corresponds to the Shunt R value specified. Simulated Strain does not measure Vo but is calculated with Shunt R parallel to Cal Element while using the sensor Gauge Factor and gain of 1 when [Simulate] is clicked.
Sim Strain Field: Displays Simulated Strain calculated using Shunt R in parallel with Bridge Element and the sensor Gauge Factor and a gain of 1 when you click [Simulate]. Alternately, you can type in a Simulated micro-strain value and click [Simulate] to have the software calculate the required Shunt R.
Software Gain: Initially set to 1 and used for computing the Indicated Strain displayed. You can vary this gain to affect Indicated Strain during shunt calibration, typically to make it converge with the Simulated Strain as a function of Shunt-R.
Instrument Gauge Factor: Initially set to 2 by default but may be varied here to affect Indicated Strain during shunt calibration, typically to make it converge with Simulated Strain after you click [Measure] with the specified Shunt R applied to the Cal Element during shunt calibration.
[Measure]: Click [Measure] to measure Indicated strain with Shunt R applied to the SG Bridge Cal Element. Indicated strain measures sensor Vo and is computed using the Instrument Gauge Factor and/or Software Gain you specify.
Indicated Strain: Measured strain updated by clicking [Measure] and computed using your Instrument Gauge Factor and Software Gain settings.

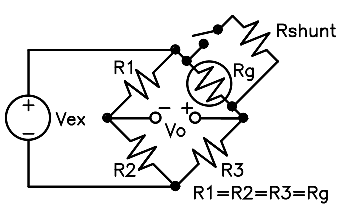
Normally, you vary Instrument Gauge Factor and/or Software Gain and click [Measure] until Indicated Strain converges with the Simulated Strain setup as a function of Shunt R. Or simply re-scale Indicated Strain as required by adjusting these factors for your application, as the Indicated Value is used to drive the transmitter output current and voltage range.

More About Shunt Calibration...

Any strain gage instrument that utilizes constant voltage sensor excitation will commonly use Shunt-Calibration to affect its Indicated Strain measurement by adjusting Instrument Gauge Factor and/or Software Gain to make its reading converge with an ideal or simulated strain. This is accomplished by temporarily connecting a precision resistance in parallel with an arm of the Wheatstone Bridge (usually a dummy resistance) to stimulate the instrument's response to a decrease in resistance corresponding to a known strain (or simulated ideal strain). The use of the term "calibration" is somewhat of a misnomer here because Shunt Calibration does not calibrate the measurement accuracy of the instrument itself to any known standard, but rather the strain bridge sensor it connects to, allowing its Indicated Strain to be scaled to correct engineering units and to overcome excitation and gain error due to tolerance, temperature changes, and other sources of measurement system error (the sensitivity of the sensor-transducer strain measurement system).

Shunt-calibration is the most common approach used to verify the operation of a strain measurement system to detect important changes that may occur over time. Traditionally, some strain gage instrument manufacturers collect and supply shunt calibration data for their instruments to a known shunt-resistor as a feature to facilitate monitoring the integrity of their measurement over time (this data/reference resistor is not a component of the sensor, but the instrument).

A key strain gauge parameter is its sensitivity to strain or Gauge Factor (GF) equivalent to its fractional change in resistance to fractional change in dimension (strain). The GF of common metallic strain gauges is typically ~2.0. Like sensor Gauge Factor represents a gauge's sensitivity to strain, Instrument Gauge Factor is used to relate the instrument's sensitivity to the sensor output. Initially, Instrument Gauge Factor is commonly set to 2.0, approximately equivalent to sensor Gauge Factor and its indicated strain will be roughly equal to ideal measured strain. Generally, if the strain sensor Gauge Factor GF $\neq$ 2 or its value changes, the Instrument Gauge Factor also changes accordingly. Adjustments are typically made to IGF to get the indicated strain to converge with an ideal or simulated value to help overcome application errors that result from less than ideal conditions in applied strain measurement.



Recall that an unloaded bridge is balanced with Vo=0 when R1/R2 = Rg/R3. Shunting a bridge element with Rshunt reduces its resistance. Likewise, a decrease in Rg or R2 will drive an increase in Vo (raising Vo+ and reducing Vo-) and simulate negative strain or compression (positive strain is tensile & negative strain compressive). At simulated strains ≤ 2000 micro-strain, the Rshunt value and its simulated micro-strain (Es) are related by the expression: **Rs = [Rg * 10^6 / (GF * N * Es)] – Rg.**

Shunt-calibration does not have to shunt the active-gauge Rg of the bridge and it is often more convenient to shunt another bridge element, usually a dummy resistor. The magnitude of response is normally the same, but its sign varies according to the element (refer to Figure on page 7). If the indicated measurement differs from the ideal or simulated value for the applied reference-shunt, the instrument's gain and/or sensitivity (Instrument Gauge Factor) is adjusted until the Indicated Value values converges with an ideal simulated value.

Rg refers to the resistance of the shunted gauge arm. Nominal bridge resistances are typically 120Ω, 350Ω, or 1000Ω and N is a factor used to account for the presence of multiple active gauges in a bridge circuit (see table below). Es refers to the simulated strain in micro-strain units (its sign is often omitted because it's always negative). Note that GF refers to the sensor Gauge Factor--not the Instrument Gauge Factor used to calculate indicated strain.

N	**Bridge Type**
1	Quarter Bridge Type I & II
$1 + \gamma$	Half-Bridge Type I
2	Half-Bridge Type II
$2 * (1 + \gamma)$	Full-Bridge Type II & III
4	Full-Bridge Type I

The factor N can be used to correct the strain simulated via a strain indicator calibrator (you typically divide the calibrator's "dial" indication by N to get the actual strain seen by the module with its configuration set to the corresponding bridge type). To calculate **simulated strain** (Es) in micro-strain units, solve the equation for Es as follows:
Es (micro-strain) = - Rg * 10^6 / (GF* N* (Rs+Rg).

More About Shunt Calibration...

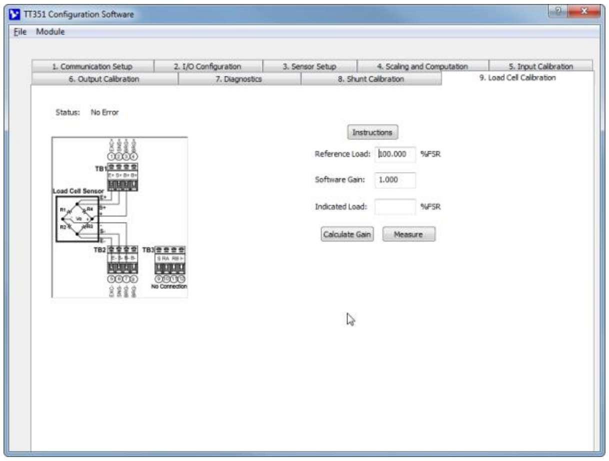
If the lead-wire resistance Rl happens to be sufficiently large compared to shunt resistance Rs such that 100*Rl/Rs >0.1* (*required calibration precision in percent*), then the following calculation for Rs is more precise (note the additional term): **Rs = [Rg * 10^6 / (GF * N * Es)] – Rg – 2 * Rl.** For these equations to be used, it is assumed the resistance of each bridge leg is equal and the bridge is *balanced* prior to performing shunt calibration. Because simulated strain results from Rg shunted by Rs to lower its resistance, this simulates negative strain (compressive) and the sign is sometimes omitted.

IMPORTANT: Shunt Calibration should only be performed on unstrained sensors after nulling any unloaded offsets and without including tare. Unloaded bridge offsets should be nulled and the instrument allowed to warm up several minutes prior to performing shunt calibration.

Ideally, the shunt resistor should be applied at the bridge, not at the instrument, but in most applications, it's not convenient to apply the shunt right at the sensor and the shunt resistor is applied local to the instrument with its remote connection to the bridge element along separate wired leads of equal length and gauge. Shunt EXC+ to BRG+ for tension/positive, or EXC+ to BRG- for compression/negative). Refer to Shunt-Calibration Connections for the TT351 and note that you connect a shunt calibration resistor between two terminals and wire a SPST switch to a third terminal that is used to remotely enable/disable its connection across a bridge element to unbalance the bridge and simulate a mechanical load. Because the shunt-calibration resistor is generally high in value relative to the bridge resistor, the effect of the remotely wired lead resistance connecting it to the bridge element is usually negligible. If the output of the module is found to have shifted from its initial record following this check, then the instrument sensitivity (Instrument Gauge Factor and/or Software Gain) may be readjusted to precisely re-set the output as required. By using the same reference resistor to verify operation over time, you can detect if the module's gain or span has changed.

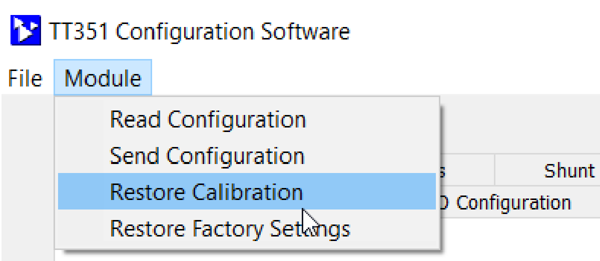
The TT351 software Shunt-Calibration tools provide an entry field for Shunt Resistance (Rs), plus a field to identify the specific leg of the bridge to apply the shunt (Bridge Element). A graphic figure is indicated with reference designators for standard quarter, half, and full bridge configurations. Additional fields for Instrument Gauge Factor and Software Gain are provided that affect the computation of the module's Indicated strain. A simulation calculator is included to optionally calculate the required Shunt Resistance of a Simulated Strain value, or the Simulated Strain value that results from a specified Shunt Resistance (Simulated Strain is calculated using the sensor Gauge Factor and a fixed gain of 1, but its relative accuracy will diminish at values > 2000 micro-strain). With the Shunt Resistance applied to the sensor Bridge Element, you click [Measure] to compute the Indicated strain using the Software Gain and/or Instrument Gauge Factor (the Indicated Value is used to drive the transmitter's analog output). You typically adjust Instrument Gauge Factor and/or Software Gain and click [Measure], until your indicated measurement closely matches the ideal or72 Simulated Strain.

9 Load Cell Calibration



Note that Load Calibration does not calibrate the instrument itself, but only this instrument's computation of indicated load for the connected load cell by allowing you modify its Software Gain. That is, normally the indicated load is driven to converge with the reference load by making small adjustments to a software gain factor. It is always the indicated load that drives the transmitter output current or voltage signal inclusive of any unloaded offset and tare correction. The indicated load value displayed on this page does not include any tare correction.

To restore a calibration, click on Module Restore…



IMPORTANT-NULL FIRST: Always null unloaded load cell offsets to zero before attempting Load Calibration. For best results, it is recommended you also allow the module to warm-up several minutes while connected to your load cell prior to attempting Load Calibration.

Note that Load measurement on this page does not include any defined Tare weight for the application (it does include Null Offset correction).

Load Cell Calibration (Load Cell Input Type Only)

- **Reference Load**
- **Software Gain**

Reference Load: Enter the reference or calibration load applied to your load cell in percent of full-scale capacity (% span). Ideally, select a reference load greater than or equal to 60% of full-scale. Before you adjust gain, always make sure that the Indicated Load is zero with no load applied. If not zero without a load applied, you should zero balance the load cell first (Zero Balance controls are accessed on the Input Calibration page).

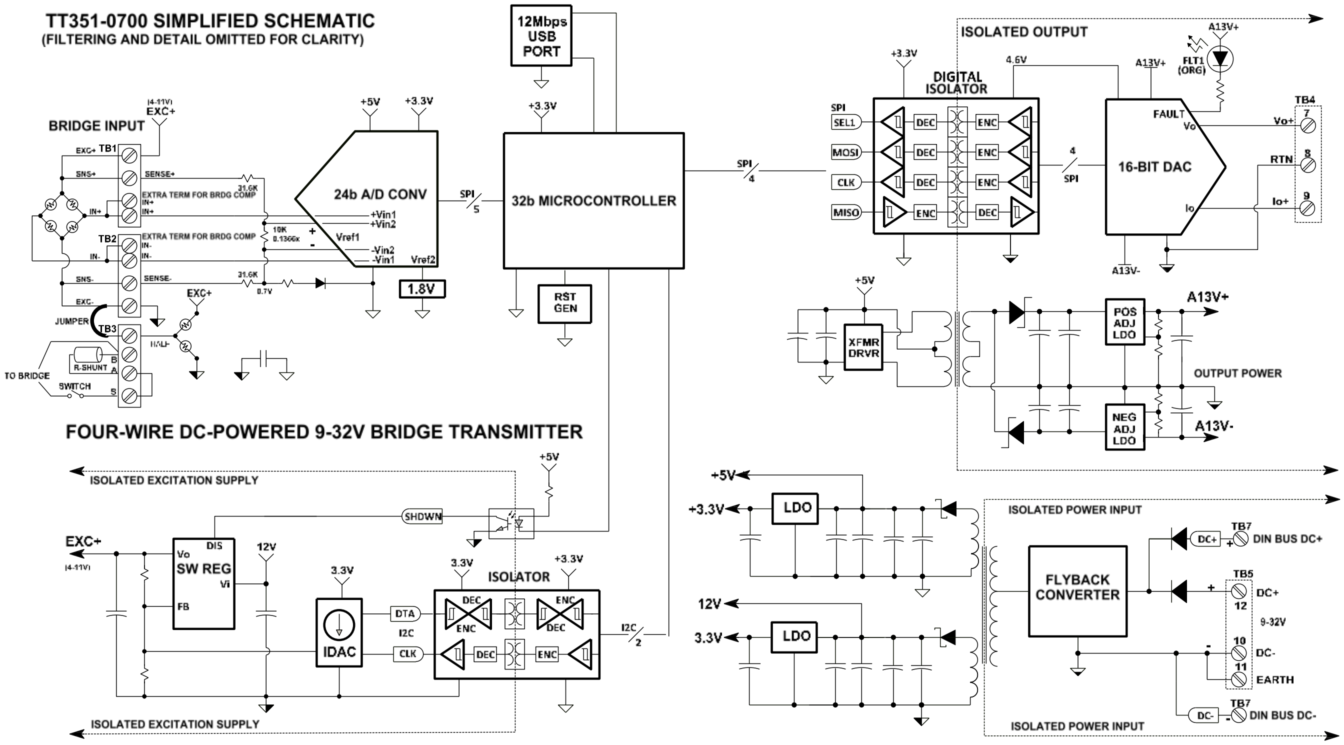
Software Gain: Gain is initially set to 1 and gain may be adjusted for computing Indicated Load. Normally, you vary the gain as required to rescale the Indicated Load to make it converge with your Reference Load. Alternatively, click [Calc Gain] to trigger the software to determine the required gain that equates the Indicated Load with the Reference Load.

Indicated Load Field (%FSR): Indicates the measured value of load as a percent of the full-scale range without tare applied and computed using Software Gain each time **[Measure]** is clicked. The idea is to rescale Indicated Load until it converges with the Reference Load by adjusting Software Gain.

[Calc Gain]: Click this button to have the software calculate the required Software Gain to equate Indicated Load with Reference Load.

[Measure]: Click this button to utilize Software Gain and take a new measurement of Indicated Load.

BLOCK DIAGRAM



How It Works

Key Points of Operation

- Unit is DC powered and its input, output, and power circuits are isolated.
- The bridge input is measured ratio-metric to bridge excitation using a 10K/73.2K resistive divider on the excitation level.
- The ratio-metric reference voltage is measured relative to a fixed 1.8V voltage reference.
- The isolated output has both current and voltage output terminals.
- The ADC input ground is common to USB ground and bridge isolation is kept isolated from input ground.

This transmitter digitally conditions a single strain gauge bridge or load cell by measuring both sensor output and sensor excitation to drive a proportional voltage or current output signal. This unit reads the sensor bridge output Vo relative to a reference that is simultaneously derived from bridge excitation (ratio-metric), helping to make the input conversion more immune to transient changes in excitation voltage or noise. The unit also reads the ratio-metric reference divider voltage REF1. Both signals are serially transmitted to a 32-bit microcontroller and the microcontroller will remove any defined bridge offset and/or tare from Vo and compute the excitation level Vex from its REF1 measurement. It will divide Vo by the excitation Vex to get the computational term Vr that is used in the formulation for strain related to the bridge type. The indicated strain or load is computed in micro-strain units (SG Bridge inputs), or percent-of-span units (Load Cell) and used to drive a proportional isolated output current or voltage signal.

A wide input switching regulator (isolated fly-back) provides both an isolated excitation supply and isolated input power. Bridge excitation may be connected externally or be provided internally via a DAC controlled adjustable switching regulator. Internal excitation is digitally controlled by the microcontroller and its output level is measured by the ADC, allowing it to boost the regulator output as needed to closely match the required excitation and this helps overcome droop at the bridge.

How it Works...

Embedded configuration and calibration parameters are stored in non-volatile memory integrated within the micro-controller. This transmitter measures both the bridge output Vo and bridge excitation Vex to resolve indicated strain or load. New functionality can be downloaded to it via USB Configuration Software and a USB isolator. The input/USB, output, and power circuits are all isolated from each other.

This module's ADC measures the sensor bridge output signal Vo ratio-metrically, meaning its measurement reference REF1 is derived from the bridge excitation at the same time (REF1 = Vex*10K/73.2K) and REF1 is measured on a second ADC channel relative to a fixed ADC reference REF2=1.8V. The internal excitation level may be varied from 4 to 11V and its level is derived from the REF1 measurement. The sensor or gauge rated output RO is set from 1-10mV/V by sensor specification. The ADC measures the input differentially using a bipolar conversion scheme at a resolution equal to ±10^(|ENOB-1|*LOG2) for ±100% (ENOB is found in Specifications Table 1 per gain and filter setting). The TT351 sets its input over-range to user-specification up to OVR=150% and input ±Vmax= ±Vex*RO*(OVR/100). ADC gain is set to 1, 2, 4, 8, 16, 32, 64, or 128 just below ±REF1/Vmax.

For example, if Vex=10V, RO=2mV/V, and medium filtering is set with OVR=150% enforced, then ±100%=±10V*2mV/V= ±20mV and the input will accommodate over-range up to ±1.5*20mV=±30mV. Its full-scale input is ±ADC reference REF1 or ±10V*10K/73.2K = ±1.36612, or ±(OVR/100)*RO*Vex if OVR is also enforced. The ADC GAIN is capped to the closest available gain to ±REF1/±Vmax=±1.36612/±0.030 = 45, or 32 for this example. The ADC measures the signal via a bipolar count based on ENOB=18 (see Specifications Table 1) which resolves to ±10^[|ENOB-1|*LOG2]= ±131072. Thus, the ADC count is represented by an unsigned integer = 131072*Vin*GAIN/ADC_ref + 131071, or 131072*±0.030*32/1.36612 + 131071 = ±92107 + 131071 or 38964 at -30mV, to 223178 at +30mV, yielding a resolution of 1 part in 184214 for ±30mV, or 1 part in 92107 for 0-100%/0-30mV, and 1 part in 61405 for 0-20mV.

Nominal ratio-metric input reference REF1 = Vex*divider=Vex*10K/73.2K (the divider is precisely pre-calibrated via a DVM measurement of EXC between the input SNS± leads while also measuring it through the ADC). The calibrated divider is used to derive the actual excitation voltage Vex for each Vo sample using the ADC CH2 measurement of REF1 relative to a fixed ADC reference REF2=1.8V (REF2 is precisely pre-calibrated at the factory). For example, if while calibrating the input divider the DVM measured voltage between ±SNS at 9.9V while the ADC measured a divider voltage of 1.3V, the calibrated divider would be 1.3/9.9=0.1313 instead of its ideal default 10K/73.2K=0.13661 and the actual ratio-metric input reference used to resolve the indicated strain is Vex*0.1313.

The unit measures Vo between ±BRG and REF1 via its ±SNS divider of bridge Vex (divider is precisely determined to be 0.1313x via prior calibration). Bridge excitation level Vex is derived from (REF1 measurement)/divider=REF1/0.1313. The TT351 resolves Vex to ~0.111V and measures it relative to VREF2=1.8V each time Vo is measured (VREF2 value is precisely set via factory calibration). REF1 varies from ~4(10/73.2) to ~11(10/73.2), or REF1=0.5464V-1.5027V and is measured relative to REF2=1.8V (no gain is applied to REF1 measurement). Its measurement resolution is computed via its ENOB at gain=1 and filter level with count= ±resolution*REF1/1.8 + |resolution-1|).

TROUBLESHOOTING

Diagnostics Table

Before attempting repair or replacement, be sure that all installation and configuration procedures have been followed and that the unit is wired properly. Verify that power is applied to the unit and that your supply voltage is at least 9V. Verify that your load is appropriate to your output type, current or voltage.

If your problem still exists after checking your wiring and reviewing this information, or if other evidence points to another problem with the unit, an effective and convenient fault diagnosis method is to exchange the questionable unit with a known good unit.

Acromag's Application Engineers can provide further technical assistance if required. Repair service is also available from Acromag.

POSSIBLE CAUSE	**POSSIBLE FIX**
Cannot Communicate with Unit via USB…	
Output shifts off-range when you connect USB…	
Output Erratic, Not operational, or at Wrong Value…	
Unit fails to operate or exhibits an output shift…	
A missing USB Isolator could cause a ground loop between a grounded input sensor or excitation supply and earth ground at the connected Personal Computer's USB port because USB and input share a common ground connection.	Without USB isolation, a ground loop is possible between a grounded input and earth ground of the PC USB port. The input ADC of the channel is normally ratiometrically biased off input ground to process the input signal. A grounded signal source could inadvertently short this reference to earth ground and prevent operation with a non-isolated USB connection. For this reason and for increased safety and noise immunity, it is best to connect to USB via a USB isolator. Use an isolator like the Acromag USB-ISOLATOR. Otherwise, use a battery powered laptop to configure the transmitter, which does not normally earth ground its USB port.
Software Fails to Detect Transmitter…	
Bad USB Connection	Recheck USB Cable Connection.
(Agility) Your smart device needs permission to connect to the Acromag transmitter the first time.	When you first connect to a smart device, it will prompt for permission. Be sure to grant permission or Agility will not discern your device connection. You may have to unplug/ replug the USB connection to your tablet/ phone to get this prompt.
USB has not enumerated the device.	Use the Acromag USB isolator reset button to trigger renumeration of the unit, or simply unplug/re-plug the USB cable to the transmitter.
Software Fails to Detect Transmitter…	
Communication or power was interrupted while USB was connected and the configuration software running.	Close the current connection with the software, then select & re-open the unit for communication (or simply exit the configuration software and reboot it).
For an input step, the output appears to make 2 steps to reach its final value…	
For a step change in the input, the A/D needs 2 input conversions to ramp up to its final level.	For an input step, it takes two conversions for the A/D to transition to its final output level, evident when using a scope to examine the output in response to a step change of the input which may appear to make two steps in its transition to its final level.

Diagnostics Table…

For Service & Repair: This unit contains solid-state components and requires no maintenance, except for periodic cleaning and transmitter calibration (zero and full-scale) and verification. Its enclosure is not meant to be opened for access and can be damaged easily if snapped apart. It is highly recommended that a non-functioning transmitter be returned to Acromag for repair or replacement. Acromag has automated test equipment that thoroughly checks and calibrates the performance of each transmitter and can restore firmware. Please refer to Acromag's Service Policy and Warranty Bulletins or contact Acromag for complete details on how to obtain repair or replacement.

POSSIBLE CAUSE	POSSIBLE FIX
Output goes right to Over-Range or Under-Range Limit…	
This indicates that either the input signal is out of range, scaling is incorrect, or a sensor lead has broken. It can also occur due to contention between earth ground at the PC USB port and the input sensor.	Check the input wiring. Check and adjust the input signal as required to drive the output within its linear operating range. A fully up/down-scale output can be driven by a sensor fault, such as an open/broken lead. Check input sensor wiring and if not isolating USB, check for a ground loop between the sensor & USB port earth ground.
Cannot Calibrate Input Channel…	
Is input wired properly? *All inputs to this module require 6 wired terminal connections, or 4 wired terminal connections plus two terminal jumpers.*	Check that the input is wired to the input terminals using the correct polarity. Have you remembered to connect the excitation and remote sense leads to the bridge? If you are using external excitation, have you connected the sense leads and excitation leads to your excitation at the bridge and disabled the internal excitation supply?
Changing Input Filter Setting Affects Input Calibration…	
You may notice a small shift in the input value when changing input filter level.	This is normal. It is best to calibrate the input at the desired application filter level and desired number of samples.
Cannot Measure Input Strain or Load…	
Have you wired the input to the correct terminals at the input as a complete bridge?	Refer to Sensor Input Connections and verify the input is wired as a complete bridge with 6 lines or 4 lines (plus ±EXC & ±SNS jumpers).
Output Noise Seems Excessive…	
Scaled input or output range is too small.	Scaling I/O to very small spans will diminish resolution and signal to noise ratio, potentially magnifying error. Every halving of a nominal range reduces resolution by 1-bit. Its best to ensure your range span is large enough to maintain a minimum 12-bits of resolution.
An orange output fault LED is ON...	
Corresponding current output load is too large to drive it accurately, or you have an open-circuit, or the output driver has over-heated.	Indicates the current load is open-circuit or too large to maintain its output accurately (≥525Ω), or the IC die temperature has exceeded 142°C (resets upon cooling below 124°C). It may also occur if the loop supply voltage is too low to support the load.
Cannot measure millivolt input type...	
Your input across BRG± is floating (this is a differential input).	You must add a half-bridge jumper from the input H terminal to either BRG- or BRG+, essentially biasing the differential measurement within its common-mode range and keeping it from floating.

Diagnostics Table…

POSSIBLE CAUSE	POSSIBLE FIX
Polling or Read Data appears corrupt...	
Does Communication Status field report a Timeout Error?	If communication status reports timeout error and page data is in error, one remedy is to exit the software program, reboot, and reconnect.
Input Signal Noise appears excessive or erratic...	
Is your effective resolution less than the noise-free level required at your selected filter and ADC gain?	Refer to Input Resolution and Minimum Resolution specification to discern if your application resolution is less than the minimum required for low noise. You can potentially improve resolution by enforcing your own over-range limit to increase ADC gain and improve resolution.
Have you applied Filtering	You can reduce noise by increasing the filter level and/or number of input samples.
Cannot read Input with External excitation...	
Did you connect EXC± and SNS± terminals to your external excitation supply?	The input must be able to read the excitation level via its SNS± divider to generate REF1 and the external supply must also connect to ±EXC to reference itself to the ADC input ground reference.
Did you turn the internal excitation supply OFF before connecting the input EXC±/SNS± to the external supply?	You must disable the internal excitation supply by setting the module to Ext Excitation BEFORE connecting it to an external supply or the two voltage supplies will be in contention and damage to the unit may result.
Cannot trigger Tare via the Digital Input...	
Input pulse asserted high?	The input pulse on the digital input must exceed 15V for at least 200ms to trigger a Tare conversion. This is done to help prevent noise from repeatedly writing Tare.

Service & Repair Assistance

This unit contains solid-state circuitry and requires no maintenance, except for periodic cleaning and transmitter calibration and verification. Its enclosure is not meant to be opened for access and can be damaged easily if snapped apart. It is highly recommended that a non-functioning transmitter be returned to Acromag for repair or replacement. Acromag has automated test equipment that thoroughly checks and calibrates the performance of each transmitter and can restore firmware. Please refer to Acromag’s Service Policy and Warranty Bulletins or contact Acromag for complete details on how to obtain repair or replacement.

ACCESSORIES

Software Interface Package

Software Interface Package/Configuration Kit – Order TTC-SIP

- USB Signal Isolator
- USB A-B Cable 4001-112
- USB A-mini B Cable 4001-113
- Configuration Software CDROM 5040-944

This kit contains the essential elements to configure TT/SP/DT family Transmitters. Isolation is recommended for USB port connections to these transmitters and will block a potential ground loop between your PC and a grounded input. A software CDROM is included that contains the Windows software used to program TT/DT/SP transmitters.

USB Isolator

USB Isolator – Order USB-ISOLATOR

- USB Signal Isolator
- USB A-B Cable 4001-112
- Instructions 8500-900

This kit contains a USB isolator and a 1M USB A-B cable for connection to a PC. This isolator and cable are also included in TTC-SIP (see above).

USB A-B Cable

USB A-B Cable – Order 4001-112

USB A-B Cable 4001-112

This is a 1 meter, USB A-B replacement cable for connection between your PC and the USB isolator. It is normally included with the TTC-SIP Software Interface Package and with the isolator model USB-ISOLATOR.

USB A-mini B Cable

USB A-mini B Cable – Order 4001-113

- USB A-mini B Cable 4001-113

This is a 1-meter, USB A-miniB replacement cable for connection between the USB isolator and the DT/SP/TT33x transmitter. It is normally included in TTC-SIP.

Note that Windows-USB or Android-USB OTG software for all DT/TT/SP Series models is available free of charge, online at www.acromag.com.

USB OTG Cable

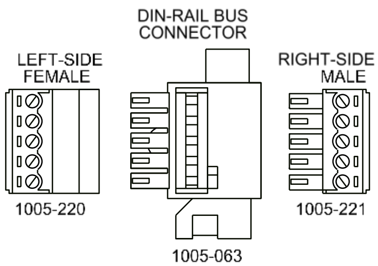
USB OTG Cable – Order 5028-565

- USB OTG Cable 5028-565

This is a 6 inch, USB On-The-Go cable for connection between the USB A-mini B Cable and a mobile phone or tablet. It is required to use the Acromag Agility™ Config Tool App on an Android smartphone or tablet to configure the unit.

Note that the Acromag Agility ™ Config Tool is available free of charge, online at the Google Play store.

DIN Bus Connector Kit



Bus Connector Kit for DIN Rail Connection to Power – Order TTBUS-KIT

This kit contains one each of the following terminals
- DIN Rail Bus Connector 1005-063 for 17.5mm TT/SP/DT Modules.
- Left Side terminal block, female connector 1005-220.
- Right Side terminal block, male connector 1005-221.
- Two End Stops for 35 mm DIN Rails 1027-222 (not shown).

Series SP Splitters and DT transmitters are shipped with their bus port plugged. Remove this plug and insert DIN Rail Bus Connector 1005-063 shown at left, which allows multiple units to snap together along a DIN rail bus. Then add a left-side or right-side terminal block at an end to connect the bus to power. These terminals can be used to optionally (or redundantly) drive power to Series TT/DT/SP modules via the DIN rail bus connector and allowing modules to neatly and conveniently share a connection to Power. Two end stops 1027-222 are used to secure the terminal block and module for hazardous location installations and are not shown

End Stops

Two End Stops – Order 4001-252
- Two 1027-222 End Stops for 35 mm DIN Rail mounting

For hazardous location installations (Class I, Division 2 or ATEX/IECEx Zone 2), you can use two end stops (Acromag 1027-222) to help secure modules to 35mm DIN rail (not shown).

SPECIFICATIONS

Model Number

TT351-0700 (CE & cULus) or TT351-0710 (CE & cULus CI/D2 & ATEX/IECEx Zone 2)

Signal Transmitter
Isolated Strain Gauge or Load Cell
Four-Wire DC Powered
CE Approved
Includes cULus Class I, Div 2, ATEX/IECEx approvals

Custom calibration to your specification can be added as a separate line item at time of purchase.

The TT351 model prefix denotes a Thin Transmitter targeted to a load cell or strain gauge input sensor (or millivoltage input) packaged as part of our DIN-Mounted four-wire TT300 transmitter family. The trailing “-0700” model suffix denotes DC powered with CE Approved & cULus Listed - Ordinary Location, and “-0710” denotes DC power with cULus Listed Class I/Division 2 – Haz. Loc. plus ATEX/IECEx approvals.

Factory configuration to your application may be ordered as a separate line item at the time of purchase on a per unit basis. This will require the specification of input bridge type/wiring configuration/excitation/gauge rated output/units, input filter level, nominal output range, and scaled range zeros and full-scale values. You can also specify a normal or reverse acting transmitter output signal.

A standard model without adding custom factory calibration is calibrated by default to reference test conditions with its transmitter output mapped to normally acting 4 to 20mA output.

Models can be mounted on standard 35mm “T” Type DIN rail. Recalibration of any model will require use of the TTC-SIP configuration kit, ordered separately (see Accessories section).

Input

IMPORTANT: Complete your input connections prior to applying power. If the module is powered up prior to completing the input connections, an initial self-calibration routine will cause an offset error to be generated once the input connections are completed post-power. You may correct this error by resetting the module or cycling power with completed input connections.

Reference Test Conditions: RO=1mV/V, Vex=10V, OVR=150% enabled, medium filtering, input 350ΩSG Bridge or millivoltage yielding ±10mV (±100%); Output is 4 to 20mA, normal acting; Power is 24VDC; ambient temperature is 25°C and the unit is mounted upright on a DIN rail allowing free air flow from the bottom vent to pass through the unit and out the top vent.

Input ADC (24-bit): Utilizes the ENOB bits according to Gain and Filter selection for its 24-bit, Σ-Δ A/D converter (Texas Instruments ADC LMP90100MHE/NOPB) to measure both sensor bridge output Vo and ratio-metric reference voltage REF1, used to resolve indicated strain or load (Vex is derived from REF1). The ADC uses the ENOB in bipolar mode to determine a relative digital count. Refer to Resolution for ENOB and Minimum Signal for Noise-Free Resolution. Note that your selection of Filter level will determine the ADC sampling rate. Vo is measured ratio-metric to ADC_ref =REF1 =Vex*10K/73.2K. REF1 is measured relative to ADC_ref =REF2 =1.8V at ADC_gain=1. But for Vo, the ADC_gain is set dynamically to 1, 2, 4, 8, 16, 32, 64, or 128 < REF1/Vo_max. Vo_max is set by user-specification up to 150% of full-scale as the ±product of Rated Output, Excitation, and Over-Load%/100. Vex is related to REF1 by a voltage divider with Vex=73.2K*REF1/10K.

Input Span/Range: Unless otherwise specified, the ADC uses an Over-Load Level specification up to 150% to help set its relative input range as the ±product of Excitation Vex, Rated Output RO, and Over-Load%/100 (see above).

Input Units: micro-strain ±με (SG Bridge), ±100% (Load Cell), or millivolts (mV Input).

Input Gauge or Cell Rated Output (mV/V): Accepts sensor Rated Output from 1mV/V to 10mV/V (RO is sometimes referred to as sensor electrical sensitivity). The ADC sets its input range for the sensor Vo signal as the ±product of excitation Vex, Rated Output, and user-specification for Over-Load%/100.

Input...continued

IMPORTANT: Do not connect the input terminals to an external excitation source unless you have first used its USB Configuration Software to set its excitation source to Ext (external), which disables internal excitation. Failure to do this first will drive power contention and damage the internal excitation supply when connected to an external supply before setting the unit to external excitation.

Input Accuracy: Better than ±0.05% of span typical for bipolar sensor ranges ≥ ±10mV and scaled resolutions ≥ 12-bits (1/4096). This includes the effects of repeatability and terminal point conformity, but not sensor/load cell, offset, or application error. Noted accuracy refers to strain/load measurement not including potential output inaccuracy.

Input Ambient Temperature Effect: Better than ±0.008% of input span per °C (±80ppm/°C), or ±1.0uV/°C, whichever is greater.

Input Excitation Vex (Internal): Internal excitation is adjustable to 64 points from 4V to 11V in ~111mV increments, up to 1.2W (i.e. 10V & 120mA). It is OFF on power-up and disabled by selecting Ext excitation. It is turned ON by selecting Int excitation. Vex is derived from an ADC measurement of REF1 each time the bridge Vo signal is measured ratio-metric to REF1 (REF1 =Vex*10K/73.2K). Low bridge resistance could cause internal excitation Vex to thermal limit and shut-down if load current exceeds 120mA. You must never set the unit to Int with external excitation connected (set it to Ext excitation before connecting to your bridge). The internal excitation voltage will be automatically boosted if it drops more than ~111mV.

Input Excitation Vex (External): Connect 4V to 11V up to 120mA (internal excitation is limited to 120mA maximum current, some applications may need to use external excitation if more than 120mA is required). <u>Internal excitation must be turned OFF prior to connecting the unit to an external excitation supply by selecting Ext. To allow the unit to monitor external excitation, you must also connect the module's ±EXC terminals to their adjacent ±SNS terminals</u>. The unit will not operate in any mode without an excitation voltage measurement.

Input Load Cell: You will need the cell Rated Output (mV/V), excitation Vex, its rated capacity at 100%, and a safe over-range level or application range limit up to ±150%. Accepts 4 or 6-wire load cells with outputs up to ±100mV with lead terminations for and BRG± (differential bridge output), SNS± (remote sense lines), and ±EXC (internal variable sensor excitation). For 4-wire load cells, you must jumper the module's ±EXC terminals to their adjacent ±sense leads (see Electrical Connections).

Input SG Bridge (7 supported sub Types): For SG Bridge, you will need to specify the Bridge Type, its Rated Output (mV/V), its excitation, the gauge resistance Rg, the lead resistance Rl, sensor Gauge Factor, and application material Poisson's Ratio (for some Bridge types). You may choose internal or external excitation. The unit provides lead terminations for BRG± (differential input), SNS± (remote sense), and ±EXC (internal variable supply), and support for seven standard types of bridges (two versions of quarter-bridge, two versions of half bridge, and three versions of full-bridge supported), plus optional millivolt input. Optional half-bridge completion connections for a half bridge sensor is also built-in. This unit is not suitable for high-elongation strain indication.

Input as Millivolt (±4mV to ±165mVDC): For convenience with SG Bridge Input type, you may optionally select millivolt and connect a millivolt signal source to the differential BRG± input with the input type set to SG Bridge. Its corresponding millivolt input range will be set via the product of ±Rated Output (mV/V), Excitation Vex, and Over-Range Limit (up to 150%). For mV input, you must wire the ±EXC terminals to their adjacent ±SNS sense leads to enable millivolt connection to the input BRG± terminals. The mV input is differential and must not float, so you must add a HALF bridge completion jumper from input H to BRG- to bias the differential input signal or measurement error may result (see Electrical Connections). You may modify software gain on the Shunt Calibration page to scale your mV input.

Input...continued

Input Tare (Automatic): Set tare via the Input Calibration page, or optionally via the digital input on the unit. This correction is built-into the Indicated Value. To set tare remotely, you can trigger it via the TRIG digital input of the unit (200ms minimum active pulse > 15V). Automatic Tare correction is typically used to remove the weight of a load container from subsequent load measurements until tare is reset or a new tare conversion is triggered. The Tare offset correction takes effect immediately but only written to non-volatile EEPROM memory after 10 seconds of TRIG input inactivity to help preserve the life of internal memory while still allowing tare to change on the fly. Tare measurement is not inclusive of itself and does not include any prior tare offset—always reset tare before triggering a new tare measurement.
Input Impedance (Minimum): ±BRG at 1MΩ, ±SNS at 73.2KΩ.
Input Bias Current: 1nA typical at ±BRG.
Input Lead Resistance: Module has overdrive to guaranty 10V minimum of bridge excitation with 5Ω/lead and 120mA of excitation current. Larger lead resistances or higher currents will limit the maximum bridge excitation that can be achieved.
Input Lead Break Detection w/Internal Excitation: Output will be driven upscale for failure of the wire harness (all 4 or 6 leads open). Output moves upscale for a single IN+ lead break and downscale for a single IN- lead break. The output moves upscale for all other individual and combinational wire failures, except SNS- alone, and SNS- combined with BRG+.
Input Lead Break Detection w/ External Excitation: If you are using an *external excitation supply*, you must jumper the module's ±EXC excitation terminals to their adjacent ±SNS sense terminals to allow the unit to measure the external excitation level and properly detect lead breakage. Note that sense lead wiring is still required with external excitation, as excitation level and the input ADC reference is derived from the sensor excitation measured via the ±SNS leads
Input Overvoltage Protection: Uses bipolar Transient Voltage Suppressors (TVS) up to 18V working voltage, capacitive filtering, series resistance, and diode clamps.
Input Response Time: See output response time.
Input Filter: Normal mode RC filtering, digital filtering within the Σ-Δ ADC, and averaging.
Input Bandwidth: Output -3dB occurs at ~15Hz, typical with no filter. See Normal Mode Noise Rejection and Output Response Time.
Input Sampling Rate (A/D): The bridge input is sampled at a variable rate according to the input filter setting as follows:

Filter >	None	Low	Medium	High
Rate >	214.65sps	53.6625sps	13.42sps	1.6775sps

Noise Rejection (Common Mode): 136dB, typical at 60Hz with 100Ω input unbalance.
Noise Rejection (Normal Mode): Varies with input filter. Table below indicates the typical rejection at 60Hz for SG bridge input per filter rate.

Filter >	None	Low	Medium	High
TT351	-19dB	-34dB	*> 80dB[1]*	*> 80dB[1]*

[1]**Note:** At medium and high filter settings, the heavily attenuated 60Hz signal cannot be measured due to 4^{th} order filtering by the input ADC which adds 80dB minimum of rejection at frequencies between 47Hz and 61Hz.

Input...continued

Input Resolution & ENOB: While a 24-bit ADC is used to convert the input signals, its effective resolution will be limited by internal noise and distortion to a lower level that varies with gain and input sampling rate (per Digital Filter setting) as follows:

Table 1: ENOB (Effective Number of Bits) per Input Gain A_v & Input Filter

INPUT FILTER	RATE (sps)	A_v 1	A_v 2	A_v 4	A_v 8	A_v 16	A_v 32	A_v 64	A_v 128
None	*214.6500*	19	18.5	18	17.5	18.5	17.5	17	16
Low	*53.6625*	20	19.5	19	18.5	19.5	18.5	17.5	17
Med	*13.4200*	19	18.5	18	17.5	19	18	17.5	16.5
High	*1.6775*	20.5	20.5	19.5	19	20.5	19.5	19	18

Because the converter utilizes its full range ENOB in bipolar ±100% mode, the applicable resolution can be computed via Resolution = ±10^[(ENOB-1)*LOG2] as the ENOB msb is utilized as a sign bit. Likewise, LOG |Resolution| = (ENOB-1)*LOG(2), or ENOB=LOG (Resolution)/LOG(2)+1. The ADC count for the input signal can be computed as Resolution*V*Gain/REF + |Resolution|-1. To determine the input resolution for your application, calculate ±Vmax=(OVR%/100)*RO*Vex and REF1 = Vex*10K/73.2K, to find gain = 1, 2, 4, 8, 16, 32, 64, or 128 < REF1/Vmax. With Gain and Filter setting, refer to Table 1 to get ENOB. Then ±100% = ±10^[(ENOB-1)*LOG2] and sensor Vo count = Resolution1*Gain*Vo/REF1 + |Resolution1| - 1. REF1 is measured relative to REF2=1.8V at gain=1 and REF1 count = Resolution2*REF1/1.8 + |Resolution2| -1. Because REF1=Vex*10K/73.2K, Vex =73.2*REF1/10. The following Table gives relative ADC count for sensor Vo from minimum and maximum RO and Vex product with its over-range limit set to 150% and Medium Filtering:

Table 2: Resolution from Min to Max Input w/Medium filter & 150% Over-range

Vex	RO	±Vmax[1]	REF1[2]	A_v[3]	ENOB	LoCount[4]	HiCount[4]	Res[5]
4V	0.001/V	±0.006	0.546V	64	17.5	27498	157864	130366
11V	0.010/V	±0.165	1.503V	8	17.5	87748	97614	9866

[1]**Notes (Table 2)**: [1]±Vmax =Vex*RO*150%/100 [2]REF1= Vex*10K/73.2K. [3]Gain A_v = 1,2, 4, 8, 16, 32, 64, or 128 < REF1/[V_{max}]. [4]An ENOB of 17.5 has a bipolar resolution of ±10^[16.5*LOG2] = ±92682 parts and the bipolar ADC count is calculated from 92682*Vo*Gain/REF1 + 92681. [5]Resolution is High count – Low count.

Example Resolution Calculation: For a millivolt input and MED filter rate, Vex=10V, RO=1mV/V, and OVR=150% and over-load protection enabled, here is how you derive resolution: REF1=10V*10K/73.2K=1.3661V. Vin_max=+/-1.5*1mV/V*10V=+/-15mV for +/-150%. Av is potentially 1.3661/0.015=91x, so ADC Gain is set to 64. Use Av=64 and MED filter and refer to Table 1 to find the full-range ENOB=17.5 bits for entire bipolar span, or ±16.5bits for ±150% range. At 16.5bits, the ADC resolves to 10^(16.5*LOG2) = ±92682 parts for ±150% @ ±15mV. Then the 16.5bit bipolar ADC count = 92682*Av*V/REF1 + 92681 = 92682*64*V/1.3661 + 92681. At -10mV, count =92682*64*-0.01/1.3661 + 92681 = 49261. At 0mV, count=92681. At +10mV, count = 92682*64*0.01/1.3661 + 92681 = 136101. Thus, the 0-100% resolution = 136101 – 92681 = 43420 and the -100% to 0 resolution = 92681-49261 = 43420. Note that this refers to input resolution, the effective I/O resolution for the transmitter will be the lowest of input ADC or output DAC (see output resolution). To calculate the equivalent number of bits of resolution corresponding to 0-100% of range having 43420 parts, NOB=LOG(Resolution)/LOG(2) = LOG(43420)/LOG(2)=15.4 bits.

Input...continued

[1]**Computation Summary**:
ADC CH0 Measures Sensor Vo wrt REF1.
ADC CH0 Range = ±Vmax = (OVR%/100)*RO*Vex
ADC CH0 REF1 = Vex*10K/73.2K
ADC CH0 Gain = Largest of 1,2,4,8,16,32,64, or 128 < REF1/|Vmax|
ADC CH0 ENOB varies with Gain and Filter and can be found in Specifications Table 1.
ADC CH2 Measures REF1 wrt REF2=1.8V.
ADC CH2 Gain=1 and its Filter matches ADC CH0 setting.
ADC CH2 ENOB is determined via Table 1 at Gain=1 and Filter setting.
CH ±Resolution = ±10^[(ENOB-1)*LOG2] for ±100%
CH0 count = |Resolution1|*Vo*Gain/REF1 + |Resolution|-1.
CH2 count = |Resolution2|*REF1/1.8V + |Resolution|-1.
NOB (Number of Bits) for 100% of Resolution = LOG|Resolution| / LOG2.
<u>Example</u>: Medium filter, OVR enabled at 150%, Vex=10V, RO=2mV/V.
±Vmax = ±1.5*10V*0.002=±0.030V.
REF1= Vex*10K/73.2K=1.3661V.
Gain =1, 2, 4, 8, 16, 32, 64, or 128 < REF1/Vin_max=1.3661/0.03=45, or <u>32</u>.
ENOB from Table 1 at Medium filter and Gain=32 is 18 bits
±100% = ±10^[17*LOG2] = ±131072. ADC count = 1310782*Vo*32/REF1 + 131071
Count (-20mV) = 131072*-0.02*32/1.3661 + 131071=69665, Count (0mV) =131071, Count (+20mV) = 192477.
Resolution 0-100%=0-20mV= 192477-131071=61406 (±61406 for ±20mV).
The effective resolution will further depend on the sensor type as follows:

> <u>If this is a Load Cell</u>: 0-100% is 1 part in 61406 (0.00163%), but the indicated resolution for the load cell is limited to <u>two digits after the decimal point</u> in percent (±0.01%) and the measurement resolution becomes 1/10000 (i.e. < 1/61406 of input ADC). Note that the TT351 Load Cell Display resolution limited the resolution to 1 part in 10000.
>
> <u>If this is a SG Bridge</u>: The ADC count = 1310782*Vo*32/REF1 + 131071. Substitute REF1=Vex*10K/73.2K for REF1 and count can be solved the Vr=Vo/Vex computation term. That is, Vr=Vo/Vex=(192477-131071)*10/73.2/(131072*32). At Vo=+20mV, count=192477. Then 192477=131072*Vex*RO*32/1.3661 + 131071 and solving for Vr (at count for 20mV) = 0.002, then a Quarter-Bridge (N=1) with Rl=0Ω and GF=2, the relative strain ε = -4 * Vr / [GF*(1+2Vr)] = -4*0.002/2*(1+0.004) =3984x10^{-6}, or 3984 micro-strain at +20mV (100%). The effective resolution is 1 part in 3984 or 0.0251% because the indicated value in micro-strain resolves to 1με. If from a Half-Bridge Type II (N=2), then ε = -2*Vr/GF =0.002 = 2000με with an effective resolution of 1 part in 2000. If from a Full-Bridge Type I (N=4), strain ε= -4Vr/(N*GF) = -Vr/2 = 0.001 = 1000με, and its effective resolution is reduced to 1 part in 1000 for this example. Note that the effective resolution of indicated strain for FB Type I=1/1000 < HB Type II=1/2000 < Quarter-Bridge=1/3984 < Load Cell=1/10000 < 1/15351 (the ADC) for the same +20mV signal and same sensitivity Vr= 2mV/V. Note that it is the Indicated Value of the input that is used to drive the transmitter output and its type will affect I/O resolution.

The TT351 has a unique feature built into its Over-Range OVR specification that can be used to increase input resolution for some applications by limiting the application over-range below 150%, and this is explained below:

Input...continued

How to Zoom ADC Gain (useful for application ranges below cell capacity): As noted, the choice of ADC gain is set via input Vmax = Vex*RO*(OVR%/100). While your choice of input sensor will determine the Vex and RO specification, you can indirectly affect the gain by setting by enforcing an over-range limit (OVR) less than the default ±150% as ADC_gain is set to the highest available gain of 1, 2, 4, 8, 16, 32, 64, or 128 just below REF1/Vin_max.

Minimum Signal (Min Noise Free Resolution Level): The TT351 ADC converter is 24-bits and digitizes the input signal using bipolar conversion and ENOB. ENOB is inclusive of all parts of the input signal including noise. Consider that very-low signal levels of some applications will drive high levels of gain in the converter, which magnifies noise and that noise is additionally magnified at higher sampling rates relative to the input filter setting. As such, there is a lower number of bits where the resolution is considered relatively noise-free and a signal can be reliably resolved every time. The following table represents the relative minimum noise-free resolution of the ADC conversion relative to its ADC gain and sampling rate per filter setting:

Table 3: Minimum Required Noise Free Input Resolution w/ Gain and Filter

INPUT FILTER	RATE (sps)	A_v 1	A_v 2	A_v 4	A_v 8	A_v 16	A_v 32	A_v 64	A_v 128
None	214.6500	16.5	16	15.5	15	16	15	14.5	13.5
Low	53.6625	17.5	17	16.5	16	17	16	15	14.5
Med	13.4200	16.5	16	15.5	15	16.5	15.5	15	14
High	1.6775	18	18	17	16.5	18	17	16.5	15.5

The point of providing this information is to help you avoid input configurations that might result in an effective input resolution below the minimum required for optimum performance relative to input noise. For example, some load cell applications must resolve a minimum increment of weight with a stable/repeatable output. If you review the Input Resolution specification, you can see how your choice of filter, rated output, excitation, and over-range setting may truncate your noise-free resolution. For load cell applications, you normally want to avoid an input resolution below these numbers to ensure that your minimum incremental load always produces a stable/repeatable output response (i.e. relatively noise-free).

Output

Output Range: Separate voltage and current terminals that share a return connection. Only one output terminal, voltage or current, may be loaded at one time. See Table 4 for supported output ranges with over-range.

Output Accuracy: Better than ±0.05% of span, typical, and ±0.1% combined for nominal input and output ranges. This includes the effects of repeatability, terminal point conformity, and linearization, but does not include sensor error.

Output Ambient Temperature Drift: Better than ±80ppm/°C (±0.0080%/°C) over the ambient temperature range. This includes the combined effect of zero and span drift for reference test conditions (see Input Specifications).

Output Resolution: Output 16-bit DAC is a Texas Instruments DAC8760IPWPR with both voltage & current output. Its resolution per nominal output range is indicated in Table 4 below. Nominal output ranges may be rescaled in the unit and its resolution will drop 1 bit for every halving of this range. The actual I/O resolution is the lowest resolution of the input A/D and output D/A relative to the I/O range.

Output...continued

IMPORTANT: Output range may be scaled smaller than nominal range shown at right and this can increase potential error as resolution and signal to noise ratio will diminish for very small spans. Each halving of the nominal range lowers its bit resolution by 1 bit. In general, rated accuracy can be achieved for an effective resolution equal or better than 12 bits (1/5096).

16b DAC	Table 4: Output Ranges and Resolution w/Over-Range					
COUNT	**0-5V**	**0-10V**	**±5V**	**±10V**	**0-20mA**	**4-20mA**
0	**0V**	**0V**	-5.5V	-11V	**0mA**	0mA
2979			**-5.0V**	**-10V**		
10923					4mA	**4mA**
54612					**20mA**	**20mA**
59577	**5.0V**	**10.0V**				
62556			**+5.0V**	**+10V**		
65535	5.5V	11.0V	+5.5V	+11V	24mA	24mA
RESOL	**1/59577**	**1/59577**	**1/59577**	**1/59577**	**1/54612**	**1/43689**
1 lsb	83.925uV	167.8uV	167.8uV	335.7uV	0.34132uA	0.34132uA
%Span	0.001678%				0.001707%	0.002133%

Output Noise/Ripple: Less than ±0.1% of output span with ±0.05% (current output) and ±0.02% (voltage output), typical. RMS Noise: 0.025% (voltage); 0.05% (current), typical.

Note (High Speed Acquisition of current output): Added filtering at the load is recommended for sensitive applications with high-speed acquisition rates. For excessive 60Hz ripple, a 1uF or larger capacitor is recommended at the load. Placing a 0.1uF or 0.01uF capacitor directly across the load can reduce or eliminate high frequency noise and raise RF immunity.

Output Load: The voltage outputs can drive loads down to 1KΩ minimum. The current outputs can drive 21mA DC into 0-525Ω minimum.

Output Response Time: The maximum time measured for the output signal to reach 98% of its transition for a step change in the input driving its current output into a 250Ω load with input filtering as follows:

FILTER	NONE	LOW	MED	HIGH
Tr (98%)	264ms	292ms	472ms	2547ms

Power

Power Supply (Connect at TB5 or via DIN Rail Bus Terminal): 9-32V DC SELV (Safety Extra Low Voltage), 3.1W maximum. Observe proper polarity. Reverse voltage protection included. Current draw varies with input voltage, output current, and internal excitation load and can be calculated for an application load by computing total power: P_{TOT} =Pbase@0.7W +Pout@20mA*0.0175W/mA +Pexc @(Vex*Iex)/0.6 = 3.05W with Io=20mA and Vex=10V at Iex=120mA. Divide P_{TOT} by the input voltage to get its supply current as follows:

SUPPLY	P_{TOT}	CURRENT DRAW
9V	3.05W	339mA Max
12V		254mA Max
15V		203mA Max
24V		127mA Max
32V		95mA Max

CAUTION: *Do not exceed 36VDCpk to avoid damaging the unit. Terminal voltage at or above 9V minimum must be maintained across the unit during operation.*

Power Supply Effect: Less than ±0.001% of output span effect per volt DC change.

USB Interface

⚠ **IMPORTANT – USB Isolation is Required:** The input is isolated from its output and power circuits and may connect to grounded or un-grounded input sensors and/or excitation. The input circuit ground connects in common to the USB power/ signal/shield ground which will also make a connection to earth ground at a PC if connected to its USB port without a USB isolator. Failure to make a USB connection without isolation would short the input ratio-metric reference to ground if the sensor is also earth grounded, interfering with operation. For this reason, USB isolation is recommended when connecting to a PC while also connecting to a grounded input sensor or excitation. Otherwise, a battery-powered laptop could replace the PC, which does not normally connect to earth ground.

USB MINI-B socket for temporary connection to a PC or laptop for reconfiguration and calibration. External USB isolation is required when input is connected to a grounded input sensor at the input (see "IMPORTANT" below). During reconfiguration & recalibration, the transmitter receives its power from its DC power connection (via DIN rail bus or power terminal TB5), not USB. As such, you must connect power to the unit when you connect USB.

CAUTION: Do not attempt to connect USB in a hazardous environment. Transmitter should be set up and configured in a safe environment only.

Data Rate: USB v1.1 full-speed only, at 12Mbps. Up to 32K commands per second. USB 2.0 compatible.

Transient Protection: Adds transient voltage protection on USB power & data lines.

Cable Length/Connection Distance: 5.0meters maximum.

Driver: No special drivers required. Uses the built-in USB Human Interface Device (HID) drivers of the Windows Operating System (Windows XP or later versions only).

USB Connector: 5-pin, Mini USB B-type socket, Hirose UX60SC-MB-5S8(80).

USB PIN	DEFINITION
1	+5V Power (Transient Protected, but not used by the module)
2	Differential Data (+)
3	Differential Data (-)
4	NC – Not Connected
5[1]	Power Ground (Connects directly to input Signal Ground)
SHLD[1]	Signal Ground (Connects directly to input Signal Ground)

[1]**Note:** Most Host Personal Computers (except battery powered laptops) will connect earth ground to the USB shield and signal ground.

Enclosure & Physical

General purpose plastic enclosure for mounting on 35mm "T-type" DIN rail.

Case Material: Self-extinguishing polyamide, UL94 V-0 rated, color light gray. General purpose NEMA Type 1 enclosure.

Circuit Board: Military grade fire-retardant epoxy glass per IPC-4101/98.

Unit Weight: 0.35 pounds (0.16 Kg).

Dimensions: Width = 17.5mm (0.69 inches), Length = 114.5mm (4.51 inches), Depth = 99.0mm (3.90 inches). Refer to Mechanical Dimensions drawing.

I/O Connectors: Removable plug-in type terminal blocks rated for 12A/250V; AWG #26-12, stranded or solid copper wire.

Program Connector: 5-pin, Mini USB B-type socket, Hirose UX60SC-MB-5S8(80).

DIN-Rail Mounting: Unit is normally mounted to 35x15mm, T-type DIN rails. Refer to the DIN Rail Mounting & Removal section for more details.

LED Indicators (Front-Panel)

Power PWR (Green) – Channel Green ON indicates power is applied to unit (this LED is sourced from isolated internal 3.3V rail).

Fault FLT (Orange, FLT1, Current Output Only) - For the current output with ON indicating the selected current output is open-circuit, or the current load resistance is too high to drive accurate current to it (resistance is greater than 525Ω). ON may also indicate over-temperature if the output die temperature has exceeded 142°C.

Environmental

These limits represent the minimum requirements of the applicable standard, but this product has typically been tested to comply with higher standards in some cases.

Operating Temperature: -40°C to +70°C (-40°F to +158°F). It is recommended this unit be mounted upright on a DIN rail, allowing free air to flow into the bottom vent, pass through the unit and out the top vent.
Storage Temperature: -40°C to +85°C (-40°F to +185°F).
Relative Humidity: 5 to 95%, non-condensing.
Isolation: Input/USB/excitation, output, and power circuits are all isolated from each other for common-mode voltages up to 250VAC, or 354V DC off DC power ground, on a continuous basis (will withstand 1500VAC dielectric strength test for one minute without breakdown). Complies with test requirements of **UL 61010C-1 First Edition, August 9, 2002 "UL Standard for Safety for Process Control Equipment"** for the voltage rating specified.
Shock & Vibration Immunity: Conforms to: IEC 60068-2-6: 10-500 Hz, 4G, 2 Hours/axis, for sinusoidal vibration; IEC 60068-2-64: 10-500 Hz, 4G-rms, 2 Hours/axis, for random vibration, and IEC 60068-2-27: 25g, 11ms half-sine, 18 shocks at 6 orientations, for mechanical shock.
Installation Category: Suitable for installation in a Pollution Degree 2 environment with an Installation Category (Over-voltage Category) II rating per IEC 1010-1 (1990).

Electromagnetic Compatibility (EMC)

Minimum Immunity per BS EN 61000-6-2:

1) Electrostatic Discharge Immunity (ESD), per IEC 61000-4-2.
2) Radiated Field Immunity (RFI), per IEC 61000-4-3.
3) Electrical Fast Transient Immunity (EFT), per IEC 61000-4-4.
4) Surge Immunity, per IEC 61000-4-5.
5) Conducted RF Immunity (CRFI), per IEC 61000-4-6.

This is a Class A Product with Emissions per BS EN 61000-6-4:

1) Enclosure Port, per CISPR 16.
2) Low Voltage AC Mains Port, per CISPR 16.

WARNING: In a domestic environment, this Class A product may cause radio interference in which the user may be required to take adequate measures. Refer to the EMI Filter Installation drawing in the Electrical Connections section of this manual to install ferrite cable clamps that help to reduce radiated emissions. Proper grounding and the use of shielded cable is also helpful in curbing emissions.

Agency Approvals

Electromagnetic Compatibility (EMC): CE marked, per EMC Directive 2014/30/EU.
FCC Conformity: This device complies with Part 15, Class A of the FCC rules.
Safety Approvals: cULus Listed – Ordinary Location only (TT351-0700). cULus Listed Class I, Division 2, Groups A, B, C, D Hazardous Location or Nonhazardous Locations only (TT351-0710). These devices are open-type devices that are to be installed in an enclosure suitable for the environment.

ATEX/IECEx Certified: Model TT351-0710 is ATEX/IECEx Certified for Explosive Atmospheres per ATEX Directive 2014/34/EU which complies with standards EN IEC 60079-0:2018, EN IEC 60079-7:2015 +A1:2018, IEC60079-0 Edition 7, and IEC 60079-7 Edition 5.1.

II 3 G Ex ec IIC T5 Gc -40°C ≤ Ta ≤ +70°C
UL 20 ATEX 2416**X** IECEx UL 20.0088**X**

X = Special Conditions

1) The equipment shall only be used in an area of not more than pollution degree 2, as defined in EN/IEC 60664-1.

2) The equipment shall be installed in an enclosure that provides a degree of protection not less that IP 54 and only accessible with the use of a tool in accordance with EN/IEC 60079-0.
3) Transient protection should be provided and set to a level not exceeding 140% of the peak rated voltage value at the supply terminals to the equipment.

Reliability Prediction

Reliability Prediction

MTBF (Mean Time Between Failure) & Failure Rate: MTBF in hours using MIL-HDBK-217F, FN2. *Per MIL-HDBK-217, Ground Benign, Controlled, G_BG_C*

Temperature	MTBF (Hours)	MTBF (Years)	Failure Rate (FIT)
25°C	916,960 hrs	104.7 years	1,090.6
40°C	614,360 hrs	70.1 years	1,627.1

Configuration Controls

Configuration Method – Software Reconfiguration Only

Refer to Operation Step-By-Step in the Technical Reference section of this manual for detailed information on available software control of this model

Software Configuration Only via USB or USB-OTG: This transmitter drives a current or voltage output linearly proportional to its input measurement of sensor voltage and excitation from a sensor wired as a Wheatstone bridge (bridge signals are wired to TB1-TB3) without the use of switches or potentiometers. Its behavior as an isolated signal amplifier/transducer is instead determined via programmed variables set using a temporary USB connection to a host computer or laptop running a Windows-compatible configuration software program specific to the transmitter model. This software provides the framework for digital control of all configuration and calibration parameters, and this information is stored in non-volatile memory. In addition to configuring all module features, the USB Configuration Software has additional capabilities for testing and control of this module:

- Measures differential bridge output Vo and excitation Vex to compute relative strain in micro-strain or load in percent according to input type. May also automatically null bridge offsets and remove tare weight. Allows USB polling to be turned on or off to test operation.
- Allows a configuration to be uploaded/downloaded to/from the module and provides the means to rewrite a module's firmware if the microcontroller is replaced or the module's functionality is updated.
- Provides controls to separately calibrate the input, excitation, and output circuits. Adds controls to perform shunt or load calibration and to restore the original factory input or output calibration in case of error.
- Provides controls to zoom gain over a smaller portion of sensor capacity for load cell applications that utilize only a portion of their rated capacity (improving application resolution/accuracy).
- Provides controls to enable and adjust internal bridge excitation voltage 4-11V.
- Provides controls to null initial bridge or load cell offsets or remove tare.
- Provides controls to perform shunt or load calibration and to re-scale the instrument's indication by modifying its gain and/or instrument gauge factor.
- Provides two controls to trigger a tare conversion of the input signal: via its software interface or remotely via a wired digital input on the module.
- Provides controls to reset the module.
- Provides controls to adjust the output independent of the input signal.

- Allows module configuration to be printed in an easy to read, 2-page format, including user documentation (includes fields for tag number, comment, configured by, location, and identification information). This info can also be uploaded from a module, replicated to another, and printed via this software.

REVISION HISTORY

The following table shows the revision history for this document:

Release Date	Version	EGR/DOC	Description of Revision
04-NOV-2019	A	BC/ARP	Updated Revision A Manual.
17-JAN-2020	B	BC/ARP	Added MTBF, Bandwidth, changed Filter Default to Medium.
15-SEP-2020	C	CAP/ARP	Added cULus, ATEX, IECEx, and FCC approvals.