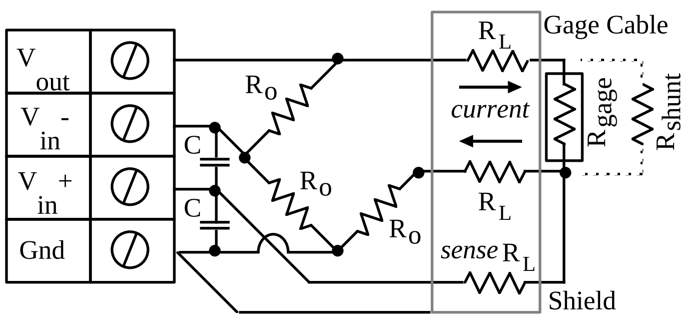
Quarter Bridge Strain Gage Measurement

This application note discusses the measuring of a quarter bridge strain gage using the instruNet measuring system. It discusses wiring issues involved in getting microVolt accuracy's with a gage 30meters from the instruNet measuring unit, and analyzes the various component errors, and their magnitudes. Please refer to the instruNet User's Manual for details involving the setting up of a strain gage measurement.

Hardware Setup

In this study, we wired a 350ohm gage (GF = 2.155) as shown below, with a 30 meter cable between the gage and the instruNet measuring unit. Each wire in the cable was measured with a DVM at 3.8 ohms (R_L), and the foil shield of the cable was tied to ground in one place, at the instruNet GND terminal. We added two 0.1uF capacitors to create a 4KHz low pass filter [Fc = 4000Hz = 1/(6.28 * R * C) = 1/(6.28 * 350ohms * .1e-6Farads)] to attenuate RFI energy that couples into the system. Without this filter, RFI energy can easily add several hundred uStrain of offset errors and noise. These capacitors, close to the instruNet terminals, are necessary in order to achieve microVolt accuracy's with a long gage cable (e.g. > 3meters). The bridge completion resistors were 350ohm 1/4Watt devices with a 0.1% initial accuracy and 5ppm/C temperature coefficient.



Strain Gage Wiring Guidelines

AM radio starts at 500KHz, and can induce many milliVolts of energy into a small loop of wire, and 30mV corresponds to approximately 10,000uStrain. To reduce the amount of RFI energy that enters the measurement path, the following wiring practices are recommended:

- The cable between the gage and measuring device must be shielded. Braided shield is better than foil; however, in most cases, foil is adequate.
- The cable shield must travel as close to the gage as possible, and as close to the measurement unit as possible, without shorting.
- The cable shield must be tied to ground at one place, preferably at the instruNet unit GND terminal.

- The bridge completion resistors must be as close to the measurement unit as possible.
- The filter capacitors must be as close to the measurement unit as possible.
- The strain gage wires should be twisted together whenever possible.
- In the previous figure, two wires route to the measurement unit from one side of a 3wire gage, one for current and one for sense (i.e. the two lower-most wires in the pictured gage cable). In some cases, RFI will couple into this loop of wire. The solution is to either attach these two wires together at the instruNet measurement unit to short out the RFI signal, or to install the pictured capacitors, to attenuate the RFI signal before it reaches the instruNet measurement unit.

Software Setup

The instruNet software settings were set as follows:

Measurement	Settings	Field	Value	Note
uStrain	General	Units Label	uStrain	
		Name	43R31	
	Hardware	Sensor	Strain Gage	
		Wiring	Q Bridge	
		Low Pass	Off	
		Integration	0.064	
		Range	+/-80mV	(or +-10mV, depends on max expected strain)
	Constants	Ro	350	
		Rlead	3.8	(depends on leads, must measure with DVM)
		GF	2.155	(depends on Strain Gage, see package label)
		Vout	5V or -5V	(alternates +5, -5, +5, -5...)
		Vinit	0.001273	
	Mapping	Scale	1,000,000	
uV Differential	*Same as above except:*			
	General	Units Label	uV	
	Hardware	Sensor	Volts	
		Wiring	Vin+-Vin-	
uV Vin+ Screw	*Same as above except:*			
	General	Units Label	uV	
	Hardware	Sensor	Volts	
		Wiring	Vin - GND	
uV Vin- Screw	*Same as above except go to corresponding Vin- channel and:*			
	General	Units Label	uV	
	Hardware	Sensor	Volts	
		Wiring	Vin - GND	
			Vin+	

The above settings show a voltage range of +/-80mV. This is necessary if the gage at its maximum strain puts out greater than +/-10mV; otherwise, a voltage range of +/-10mV is best. If you do your Rshunt verification at the maximum strain, and the measured reading is pegged at +/-10mV or +/-80mV, then you'll need to switch to a larger range.

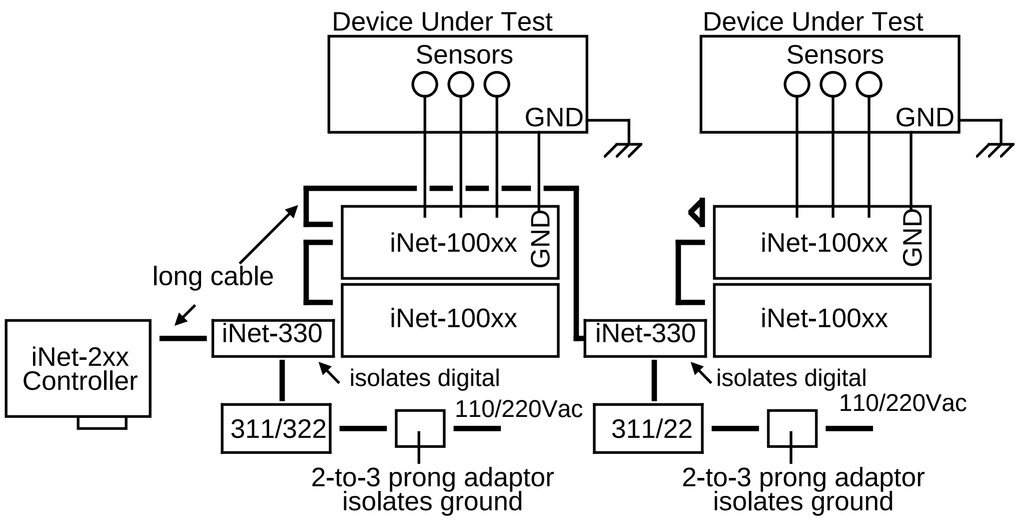
Low Pass Filter Issues

A low pass filter consisting of two capacitors, labeled "C" in the previous diagram, is often used to attenuate RFI that is not stopped with the previously mentioned Wiring Guidelines. The capacitors are strongly recommended, since even a small loop of wire in the measurement path will pick up some RFI. The cutoff frequency of the low pass filter is a function of the capacitor value, as shown in the following table. If you are not interested in signals greater than 1KHz, then 0.1uF is recommended; otherwise, you'll need a smaller capacitor and a larger cutoff frequency.

Capacitor	R	C	Freq Cutoff
100pF	350	1.00E-10	4,549,591
.001uF	350	1.00E-09	454,959
.01uF	350	1.00E-08	45,496
.1uF	350	1.00E-07	4,550

Grounds and Power Supply Wiring

If multiple instruNet units are connected together, with multiple power sources, then ground loops can develop. This involves currents that pass through the measurement circuit, on their way to earth ground, from the various power sources in the region. And these currents can induce voltage offsets. And these might be large compared to the microVolts accuracy's we are looking for. The best, and lowest risk solution is to isolate the instruNet measurement system with the #iNet-330 Optical Isolators. These isolators, the transformer in an external power supply, and a 2-to-3 prong power adapter fully isolate the instruNet measurement box. Once isolated, one can attach 220VAC power directly to the instruNet box (i.e. the GND terminal) while performing a measurement without adverse effects (assuming all wires to the box are floating). Once isolated, it is recommended, however, that the instruNet box be attached to earth ground, close to your sensors. This will keep the instruNet box from picking up RFI and radiating. A large #18 gage wire from the instruNet GND terminal to a nearby local earth ground is recommended. An example of an isolated system with 4 instruNet Devices, without ground loops, is illustrated below:



Balancing the Bridge

To balance the bridge, we place the gage in an unstrained position, tell instruNet to measure the voltage put out by the bridge (i.e. we change the channel settings to "Voltage" Sensor with "Vin+ - Vin-" Wiring), write down the measured voltage, switch back to "Strain Gage" Sensor with

"Quarter Bridge" Wiring, and then set the "Vinit" Field in the Constants Settings area to the measured voltage. After entering this initial voltage value, the measured strain on the computer screen should be close to 0 uStrain. Notice that we have set the "Scale" field in the Mapping settings area to 1e6, to facilitate the displaying of uStrain and uV, instead of Strain and Volts.

Verifying that RFI is not inducing Noise or an Offset Error
To verify that RFI (i.e. Radio Frequency Interference) is not inducing noise or an offset error, one must move the gage cable and gage about and watch the effect this has on the measured uStrain value. This value should not vary by more than +/-10 uStrain as the cables are moved about. If it does, it is recommended that you follow the Wiring Guidelines more closely, optically isolate your instrumentation and/or add more capacitance across your voltage measurement input terminals. To simulate an electrically hostile environment, move the gage cable into a computer and wrap it around a video board. This can be done while the gage is at 0 uStrain, or when it is connected to R_{shunt}. Any loop of wire in the voltage measurement path (i.e. from Vin+, to the gage, and back to Vin-) is a directional antenna. RFI energy that passes through the loop induces a voltage, which can then be seen as an offset or as noise. Moving the cables around changes the RFI fields that enter the loop, and therefore changes what is viewed on the computer. The two capacitors close to the instruNet screw terminals attenuate most of this effect. Without these capacitors, one can typically see hundreds of uStrain of effect from moving the cables, even with only a 10cm diameter loop of exposed wire. Notice that loops are most prevalent at the gage, and at the bridge completion resistors; therefore, careful wiring at these positions, as noted earlier, is important.

Verifying that the Measured Value is Correct
To verify the accuracy of the system, we attach a shunt resistor (R_{shunt}) in parallel with the gage, near the gage (not 3.8 ohms away at the instruNet screw terminals), to change its resistance (to simulate a bend), and look for a specific uStrain value on the computer screen. In our study, we calculated that if our gage resistance decreased 3.017 ohms, then the measured strain would decrease 4000 uStrain, and a 40,252 ohm Rshunt in parallel with a 350 ohm Rgage facilitates this 3.017 ohm change (R_L = 3.8, GF = 2.155). In our study, we measured 4001.7 uStrain via the computer, with about +/-1uStrain of noise with 0.064sec integration and +/-5uStrain of noise with 0.001sec integration.

delta_Rgage = Rgage * strain * GF
*-3.017 = 350 * -0.004 * 2.155*

Rshunt = -Rgage / (1 - Rgage / (Rgage - delta_Rgage))
40,252 = -350 / (1 - 350 / 346.983)

An Analysis of Measurement Errors
There are several sources of errors which we will explore in detail. Errors are characterized as Temperature Drift, General Measurement Errors and Noise.

<u>There are 4 sources of Temperature Drift (errors caused by a change in temperature):</u>

1a. Ro Temperature Drift
If one Ro resistor (i.e. a bridge resistor) drifts 5ppm/C max, and the temperature changes 6C after balancing the bridge, then the Ro will drift 30ppm max, which will cause (Vin+-Vin-) to change 40uV max, which corresponds to 15 uStrain (GF=2, Vexc=5V, quarter bridge bending).

Three resistors could cause more drift in the measured uStrain, especially if their actual temperature coefficients were different. To see this, note the change in uStrain on the computer screen before and after one Ro is heated with 2 warm human fingers. The uStrain reading while the fingers are on the resistor will not be accurate since the fingers change the resistance (yet it is accurate before and after the fingers). Typically, one will see a 5 uStrain variation when one Ro is heated several degrees.

1b. Rgage Temperature Drift
This situation is similar to the Ro scenario, described above. The strain gage resistance changes with temperature to induce an error. One can see this by heating the gage, and noticing the effect on the measured strain. Typically, a heat gun on the gage for 4 seconds can induce a 200 uStrain change. Obviously, this heat can change the strain of the material as well. Please consult the strain gage package label for more information on temperature effects.

1c. instruNet Temperature Drift
This typically induces a 2uV/C offset measurement error (e.g. 10uV after 5C instruNet hardware temperature change) since the last instruNet auto-calibration. In typical cases, auto-calibration is run every 5 minutes in the background (even while digitizing) to null this error to 0uV. 10uV corresponds to about 4uStrain with a quarter bridge bending configuration with GF of 2 and Vexc of 5V. To see this, press the instruNet Calibrate button, change the instruNet box temperature 5C with a heat gun, press the Calibrate button again, and note the change in measured uStrain change right after the second button press. This change (e.g. 4uStrain after a 5C change) is the amount of correction that occurred when the instruNet unit calibrated the 2nd time and corrected for the internal Voltage measurement temperature drift.

1d. Material being measured Temperature Drift
If the temperature of the material being measured for strain changes after balancing the bridge, it will expand or contract, causing the strain to change. This is difficult to measure, since it is often difficult to heat the material without heating the gage itself, yet if one characterizes a specific gage for temperature before attaching it to the material, and then corrects for this after being affixed to the material and heated, then one can get a fix on the strain temperature drift of the material itself.

<u>There are several sources of General Measurement errors:</u>

2a. Rshunt Accuracy
If the Rshunt verification resistor is off by 20ohms, the effect in microstrain is about 2 uStrain. This is often negligible, yet a 5-digit DVM to verify the resistance value with a low temperature coefficient Rshunt (e.g. 5 to 25ppm/C) is recommended. Also note that a 40K Rshunt with a 100ppm/C temperature coefficient that changes 10C will result in a 40K * 0.0001 * 10 = 40ohm change in resistance.

2b. instruNet Voltage Measurement Error
With the #iNet-100xx on the +/-10mV range one can expect +/-10uV of absolute accuracy (e.g. approx +/-3uStrain with GF=2, 5Vexc, quarter bridge bending) and on the +/-80mV range one can expect +/-15uV of absolute accuracy, assuming integration is set to at least 0.001sec. 0.01666 secs is better, and 0.064 secs is outstanding. Also, this assumes that the instruNet device temperature has not changed since the last time it did its auto-calibration.

2c. Strain Gage Errors

Please see your strain gage data sheet for information on GF and related accuracy's. For example, if the initial GF is accurate to 0.5%, then this error would yield a 20uStrain error at 4000uStrain.

There are several sources of Noise errors:

3a. instruNet Measurement Noise
This is noise within the instruNet measuring device itself. To measure this noise, attach Vin+ and Vin- to instruNet GND, and digitize. You should see one number come back (0Volts), yet if you digitize 100 points, they will not all be the same. The amount of variation is the internal noise within instruNet. The noise figure is often described as Volts-Peak-To-Peak, or Volts-Root-Mean-Square, and is a function of the "Range" and "Integration" fields. Typical noise levels with 0.016secs of integration on a +/-10mV range are 0.8uVrms (0.3uStrain RMS) or +/-3uVpp (+/-1uStrain peak-to-peak with GF=2, Vexc=5, quarter bridge bending).

3b. Noise from RFI
Radio Frequency Interference (RFI) can very easily be picked up by the strain gage, the gage cable, and the bridge wires; and this additional energy sometimes appears as a random signal, or sometimes as a fixed offset error. AM radio produces strong signals beginning at 500KHz, and a 50KWatt transmitter 10KM away can induce a 50mV signal in a 1meter diameter loop of wire. This high frequency signal can produce fixed offset errors on the order of ten's of milliVolts within the instruNet measurement unit. And this is when we're trying to get microVolt accuracy's! And one radio station is just one of many sources of RFI -- all sources (e.g. radio, TV, cellular phones, etc) add up to beat up on your measurement. The best way to kill RFI is to place capacitors at the instruNet input terminals. The capacitor lets low frequencies pass, and stops high frequencies. For information on low pass filters and capacitors, please see the previous "Low Pass Filter" discussion. For information on how to diagnose and fix an RFI problem, please see the previous "Verifying that RFI is not inducing noise or an offset" discussion. In summary, two .1uF capacitors are strongly recommended if the signal you are measuring is <1KHz; and the measured reading should not change as you move your cables around, and if it does, you have an RFI induced error that must be addressed with methods discussed in the application note.

3c. Noise from AC Power Lines
Noise from AC power lines is easily attenuated with the instruNet integration feature. If instruNet measures the voltage at the bridge for an even number of power cycles (e.g. 16ms or 64ms for 60Hz power), then the effects of the positive and negative parts of the power line sine wave cycle will cancel.

Maximizing uV per uStrain
The number of microVolts measured per unit of microstrain relates to measurement accuracy. One wants a large number, if possible, and this is achieved with a large Vexcitation, and a large GF.

The number of uV per unit of microstrain with a Quarter Bridge in Bending configuration is summarized as uV/uStrain = Vexcitation * GF / 4. For example, 5Volts of excitation and a GF of 2 correspond to 2.4uV per uStrain. Below are several Quarter Bridge Bending configurations:

Ro	Vexc	Gf	uV/uS
350	1	2	0.5
350	1	10	2.4
350	5	2	2.4
1000	5	2	2.4
350	5	10	12.4
1000	5	10	12.4
350	10	2	4.94

Summary
Good shielding, good ground wiring, capacitors at the instruNet screw terminals to kill RFI, verification via an R_{shunt} resistor, and verification that RFI energy is not effecting your measurement (by moving cables and watching the effect on the computer screen) will all insure that you have a positive measurement experience.