WORCESTER POLYTECHNIC INSTITUTE

MECHANICAL ENGINEERING DEPARTMENT

Engineering Experimentation
ME-3901, D'2012

Laboratory #4: Part 1

Vibration measurements with strain gauges

General information

Office hours

Instructors: Cosme Furlong

Office: HL-151

Everyday:

9:00 to 9:50 am

Christopher Scarpino

Office: HL-153

During laboratory sessions

Teaching Assistants: During laboratory sessions

General information

Please refer to laboratory description:
“Laboratory 4: vibration measurements”

Objectives

The objectives of this laboratory are to:

- use different types of motion transducers to measure the natural frequencies, damping characteristics, and elastic modulus of a cantilever

For each motion transducer, vibration data will be analyzed to:

1. Determine the vibration amplitude, velocity, and acceleration in various units of measure;
2. Determine natural frequencies;
3. Measure and express damping characteristics as logarithmic decrement and percentage of critical damping;
4. Compare measurements with analytical and/or computational models of a cantilever;
5. Determine elastic modulus of a cantilever via vibration measurements

Background: cantilevers

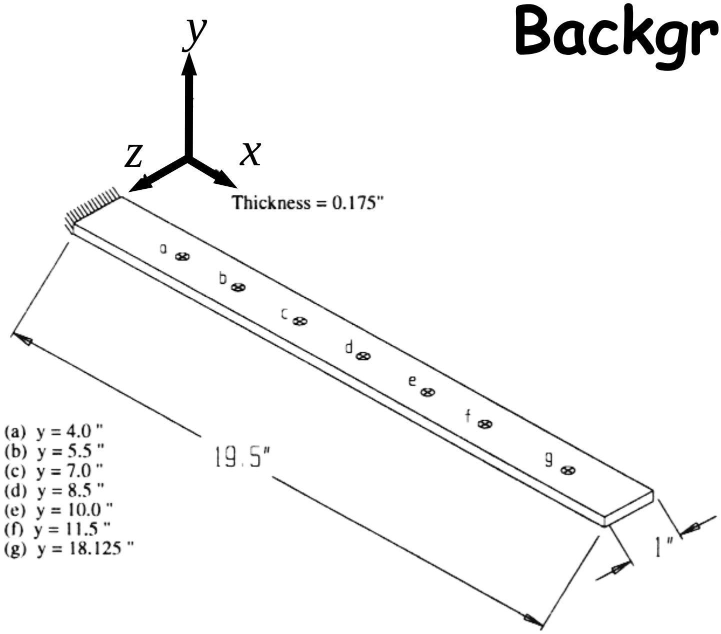


Fig. 3 Low carbon steel beam showing locations of interest

Show demo: modal analysis with FEM

Note: Frequencies can also be expressed as

$$\omega_n = \beta_n \frac{1}{\sqrt{12}}\sqrt{\frac{E}{\rho}}\left(\frac{t}{L^2}\right) \text{, rad/s}$$

Natural frequencies

First: $$\omega_n = 3.5160\sqrt{\frac{EI}{mL^4}}, \quad \text{rad/s} \qquad (3)$$

where,

E = Young's modulus = 30×10^6 psi,
I = Moment of inertia of the beam section = 4.46614×10^{-4} in^4,
$\overline{m}$ = mass per unit of length = 1.26805×10^{-4} lbf·s^2/in^2, and
L = length of the beam = 19.5 in,

Second: $$\omega_n = 22.0345\sqrt{\frac{EI}{mL^4}}, \qquad (4)$$

Third: $$\omega_n = 61.6972\sqrt{\frac{EI}{mL^4}}, \qquad (5)$$

Fourth: $$\omega_n = 120.0902\sqrt{\frac{EI}{mL^4}}, \qquad (6)$$

Fifth: $$\omega_n = 199.8600\sqrt{\frac{EI}{mL^4}}, \qquad (7)$$

$$EI\frac{\partial^4 y}{\partial x^4} + \overline{m}\frac{\partial^2 y}{\partial t^2} = 0 . \qquad (8)$$

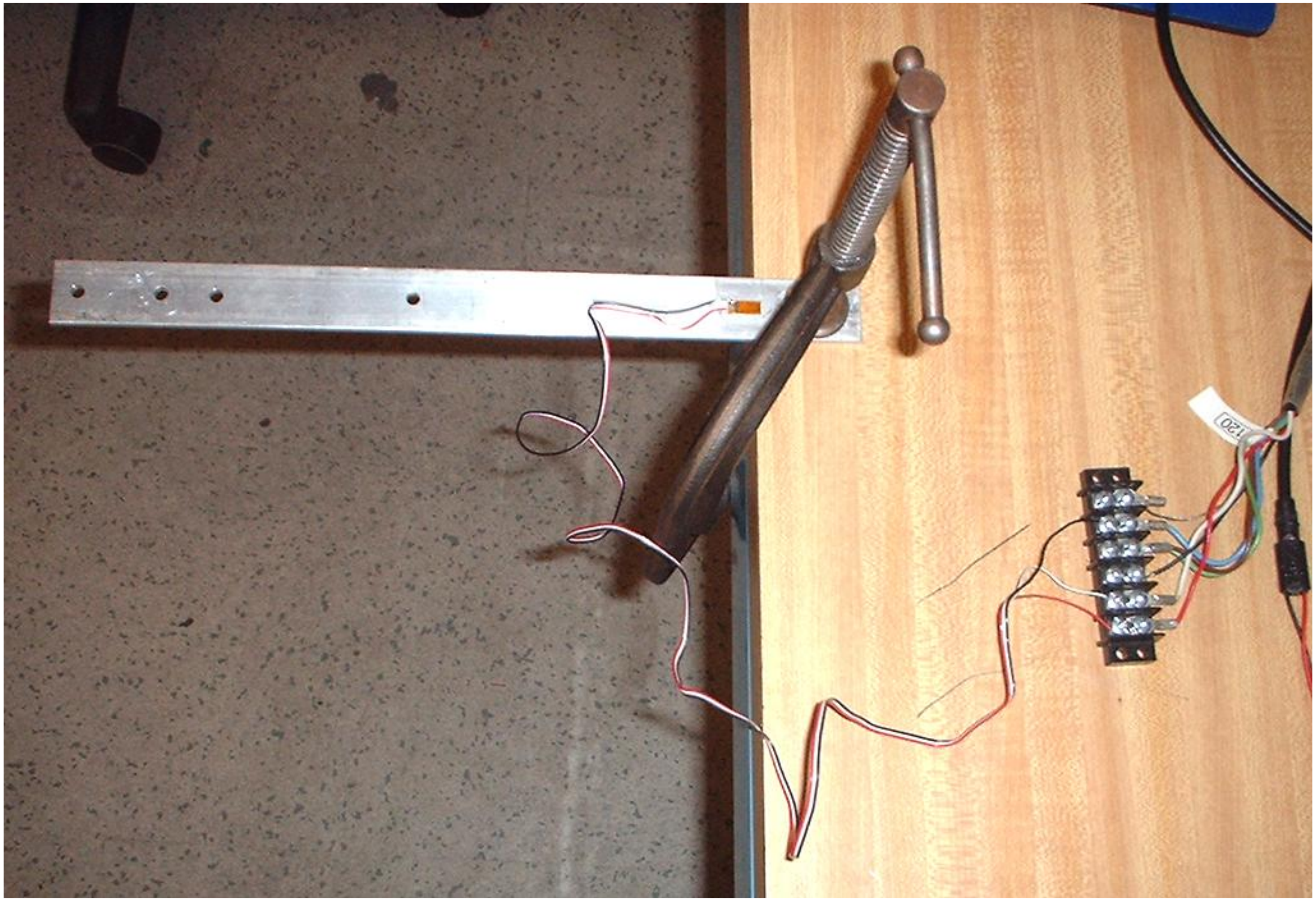
Table 4. Natural Frequencies obtained using Eq. 3 to 7

Natural Frequency	Magnitude, Hz
1	15.1270
2	94.8010
3	265.446
4	516.675
5	859.876

Strain gauges
Tasks

- Derive analytical solutions to determine:
  - a. Stresses and strains of a cantilever subjected to a concentrated load;
  - b. Fundamental natural frequencies and damping factors of a cantilever;
- Using a C-clamp, mount cantilever to the edge of a bench. Attach one strain gauge on the cantilever -- make sure to attach gauge at a location subjected to as much strain level as possible; check your analytical solutions;
- Calculate the necessary output gain for the gauge; use a 10 V bridge excitation; **recommended** filter level is 100; setup an analog input channel to the range of [-2,2] Volts;
- To determine an appropriate output gain consider loading the beam under static situation and with a known load;

Vibration measurements with strain gauges



Strain gauges

Tasks

- Use/modify/construct suitable LabView VI(s) to record time & frequency data;
- Pluck the end of the cantilever and record the vibration decay curve;
- Using the recorded data, determine modal parameters (i.e., natural frequencies and damping factors) and elastic modulus of the cantilever;
- Compare your results with analytical/computational models of a cantilever; and
- Do uncertainty analysis on the determined modal parameters and elastic modulus (including % contribution of uncertainties).

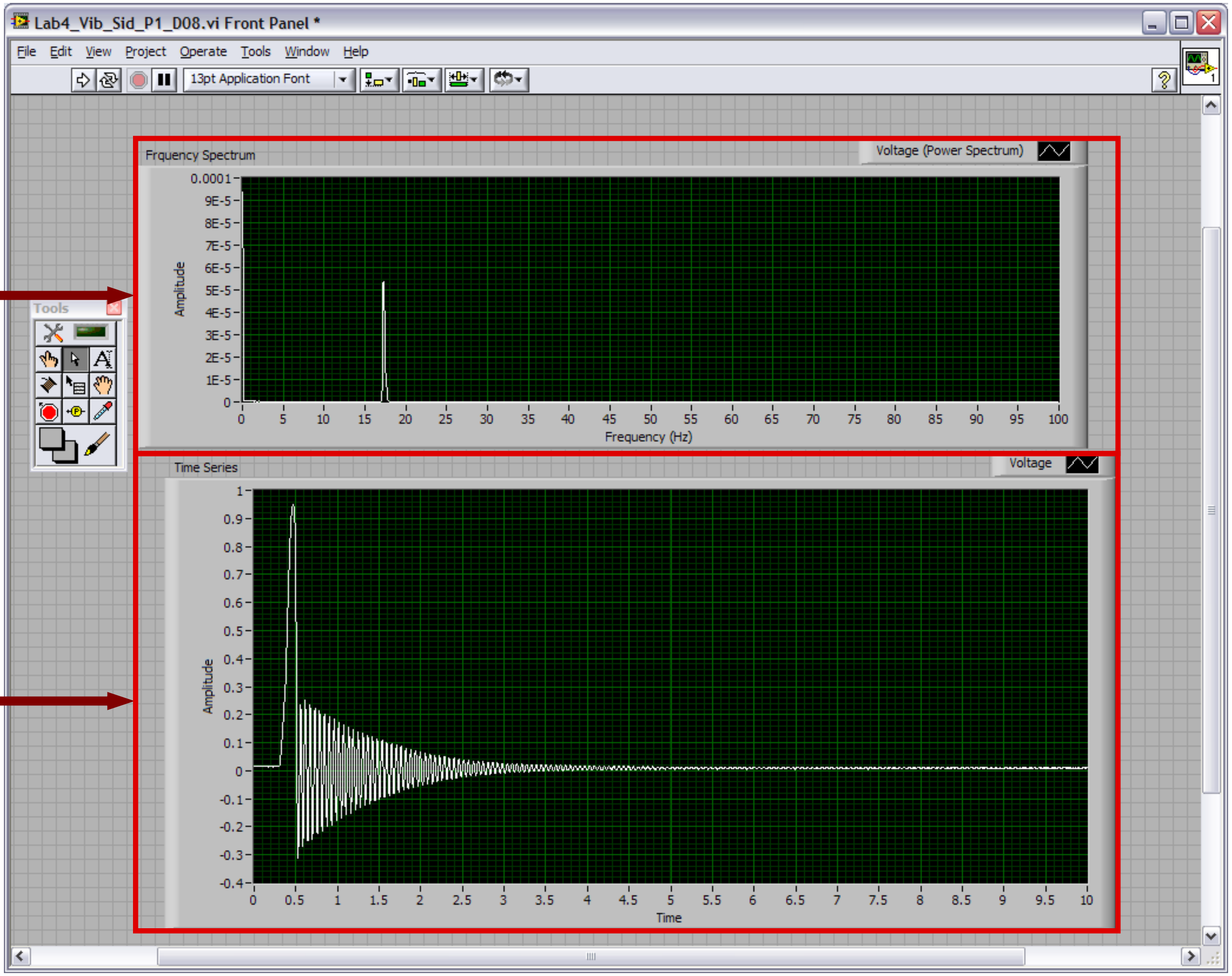
Vibration measurements with strain gauges and a VI

Frequency-domain

(Obtained by applying the "Fast Fourier Transformation (FFT)" on the time-domain data)

Time-domain data

(Obtained by plucking the beam)

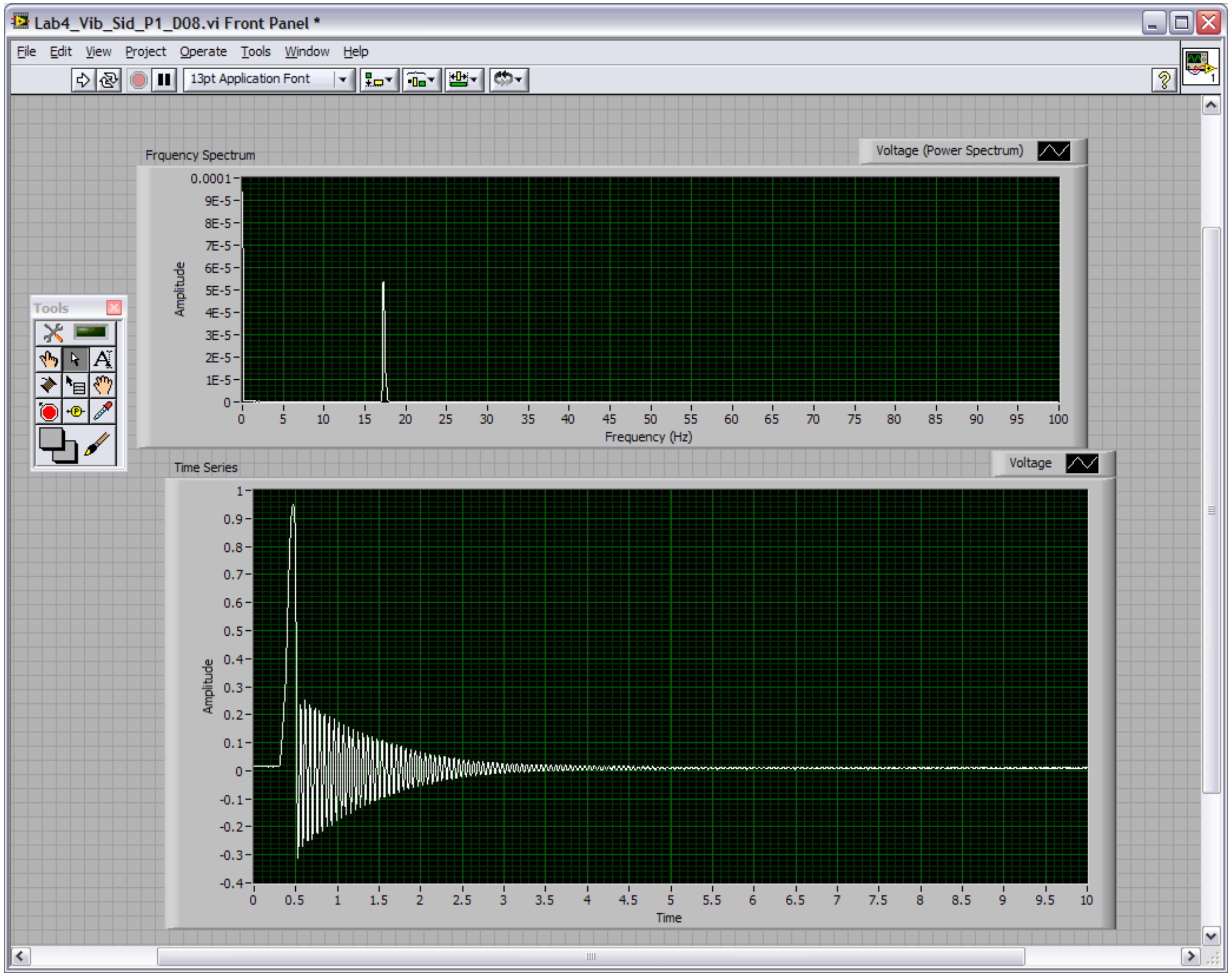


Vibration measurements with strain gauges and a VI

- You can construct a suitable LabView VI (to be shown next); or
- You can use and modify an existing LabView VI (available in our website).

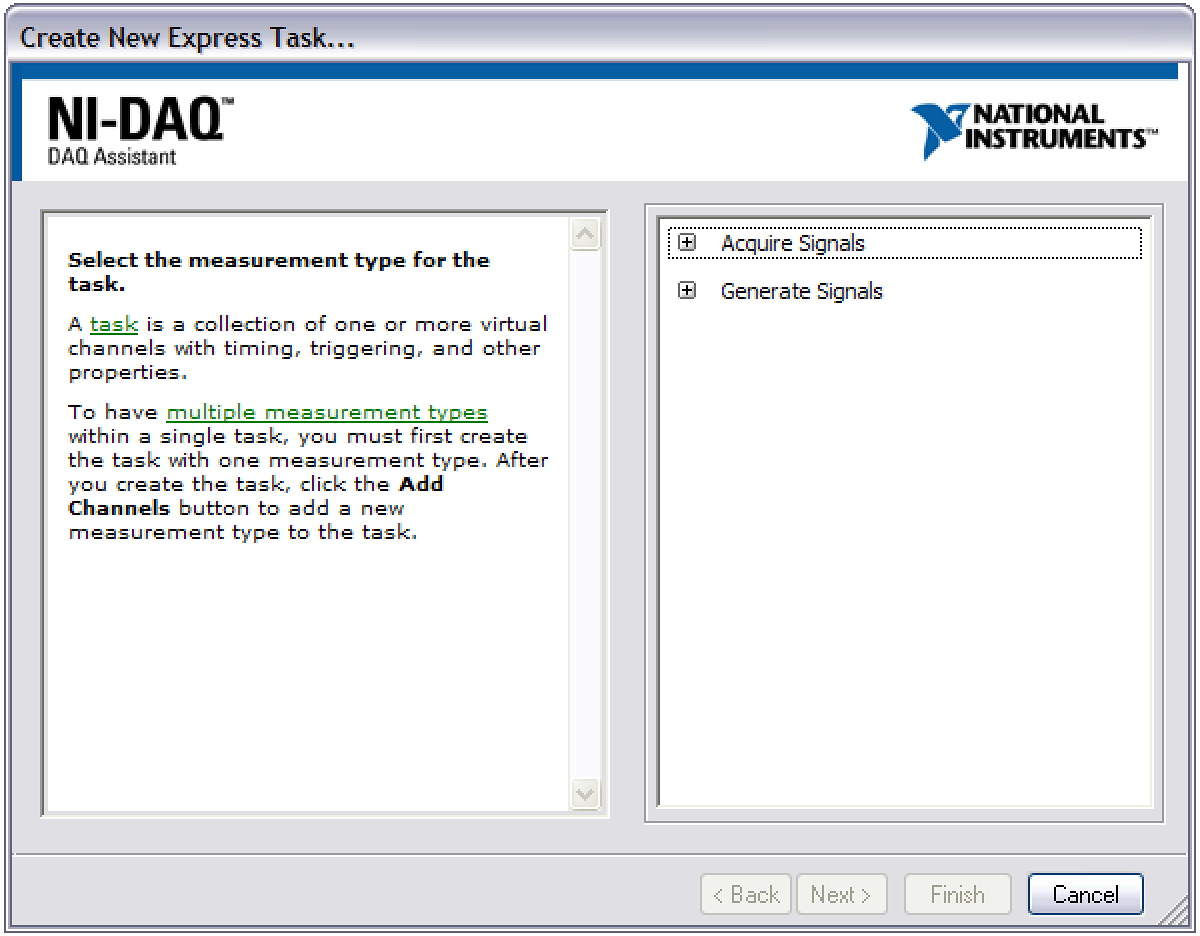
Example time & frequency domains VI

Let's build it !



Setting up the DAQ assistant (1)

Open a new VI project & set one AI channel

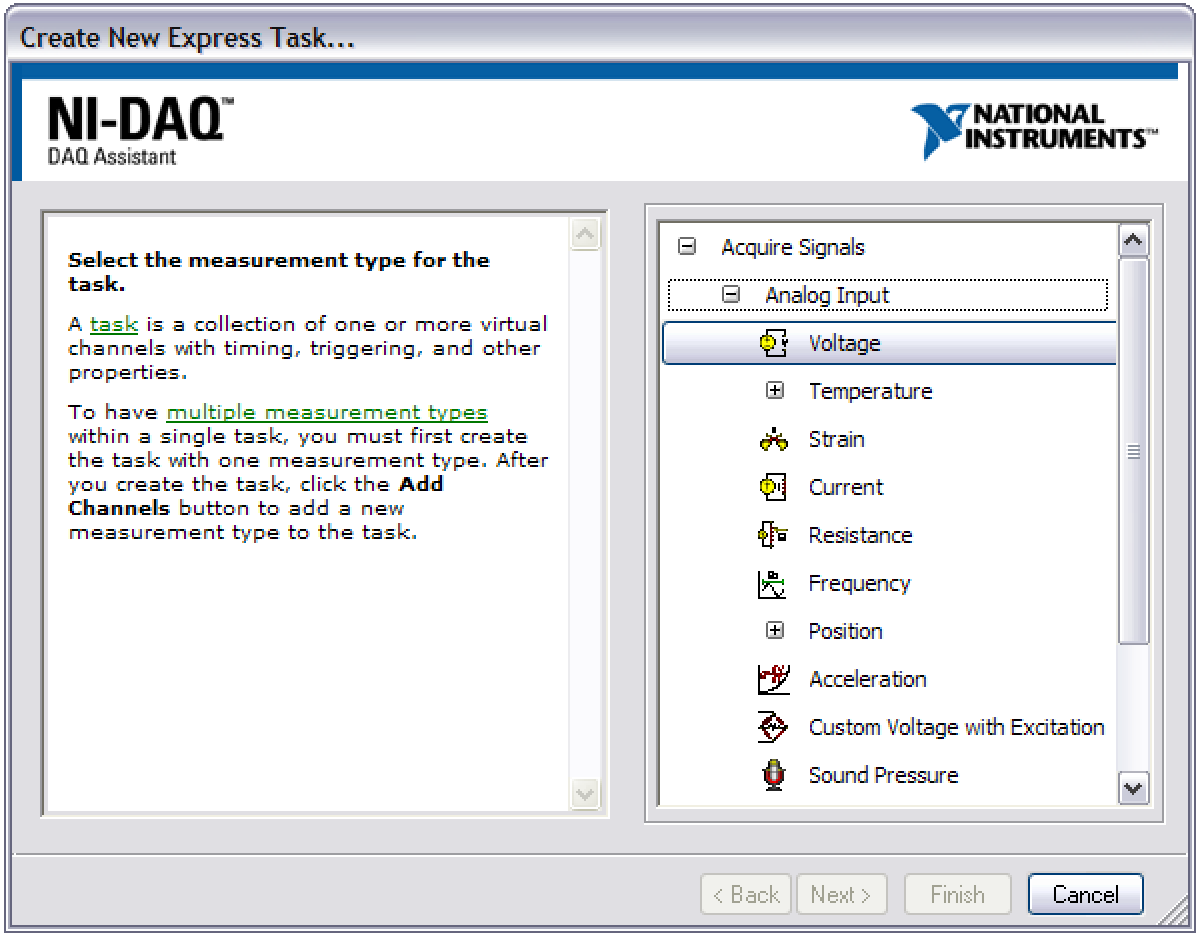


Select the measurement type for the task.

A task is a collection of one or more virtual channels with timing, triggering, and other properties.

To have multiple measurement types within a single task, you must first create the task with one measurement type. After you create the task, click the **Add Channels** button to add a new measurement type to the task.

Setting up the DAQ assistant (2)

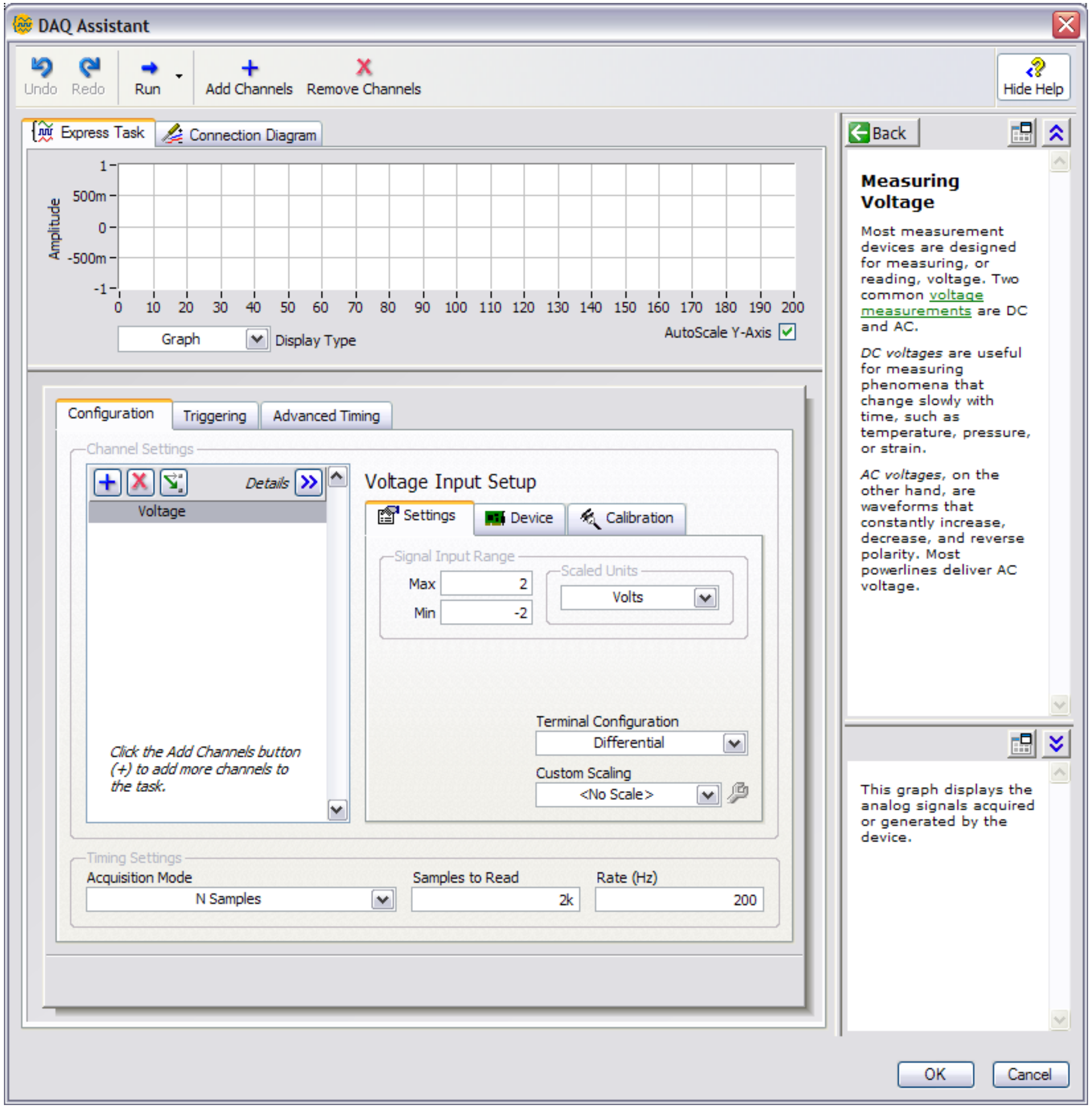


Select the measurement type for the task.

A task is a collection of one or more virtual channels with timing, triggering, and other properties.

To have multiple measurement types within a single task, you must first create the task with one measurement type. After you create the task, click the **Add Channels** button to add a new measurement type to the task.

Setting up the DAQ assistant (3)



Display Type: Graph

AutoScale Y-Axis ☑

Click the Add Channels button (+) to add more channels to the task.

Signal Input Range

Max: 2

Min: -2

Scaled Units: Volts

Terminal Configuration: Differential

Custom Scaling: <No Scale>

Acquisition Mode: N Samples

Samples to Read: 2k

Rate (Hz): 200

Measuring Voltage

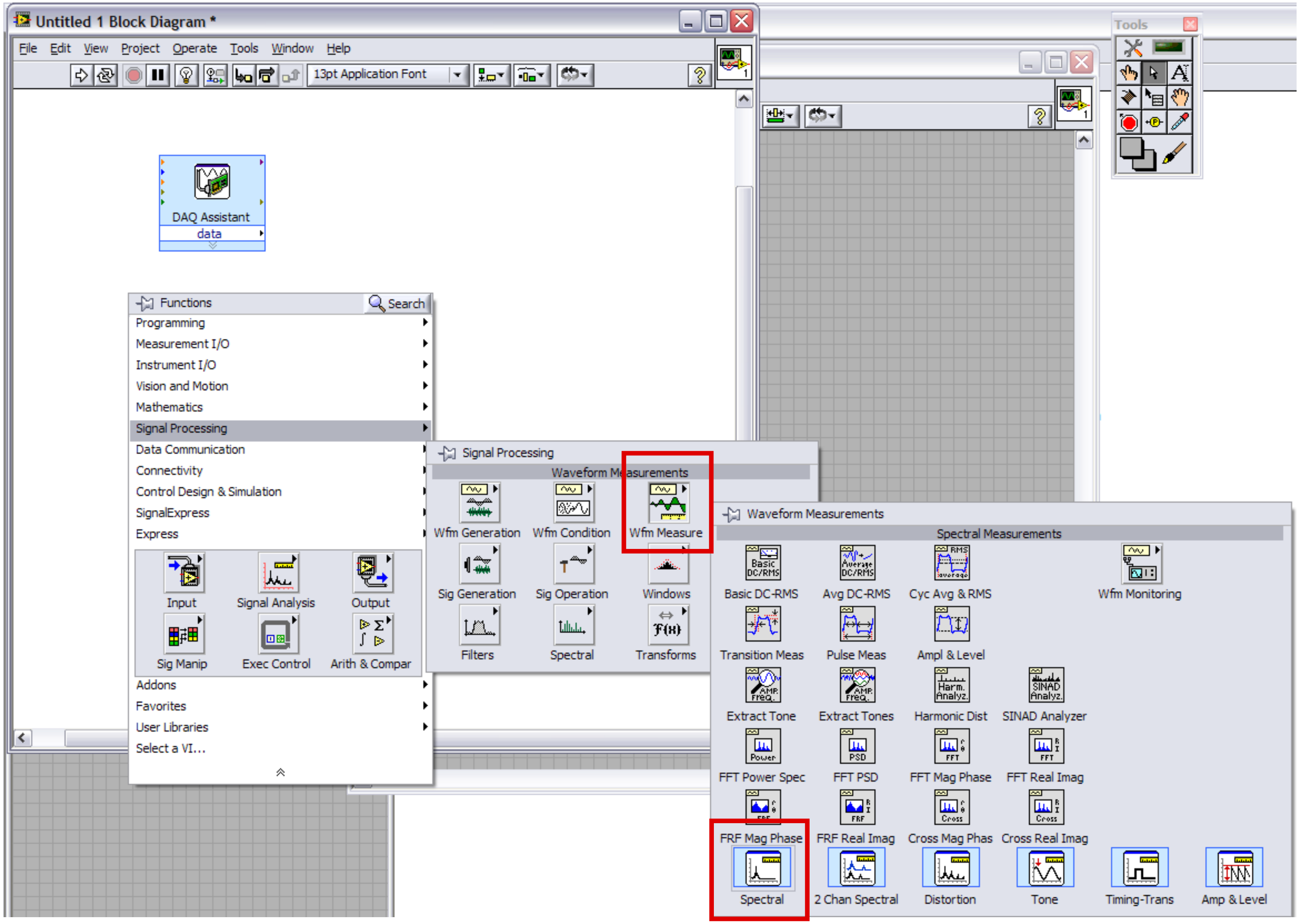
Most measurement devices are designed for measuring, or reading, voltage. Two common voltage measurements are DC and AC.

DC voltages are useful for measuring phenomena that change slowly with time, such as temperature, pressure, or strain.

AC voltages, on the other hand, are waveforms that constantly increase, decrease, and reverse polarity. Most powerlines deliver AC voltage.

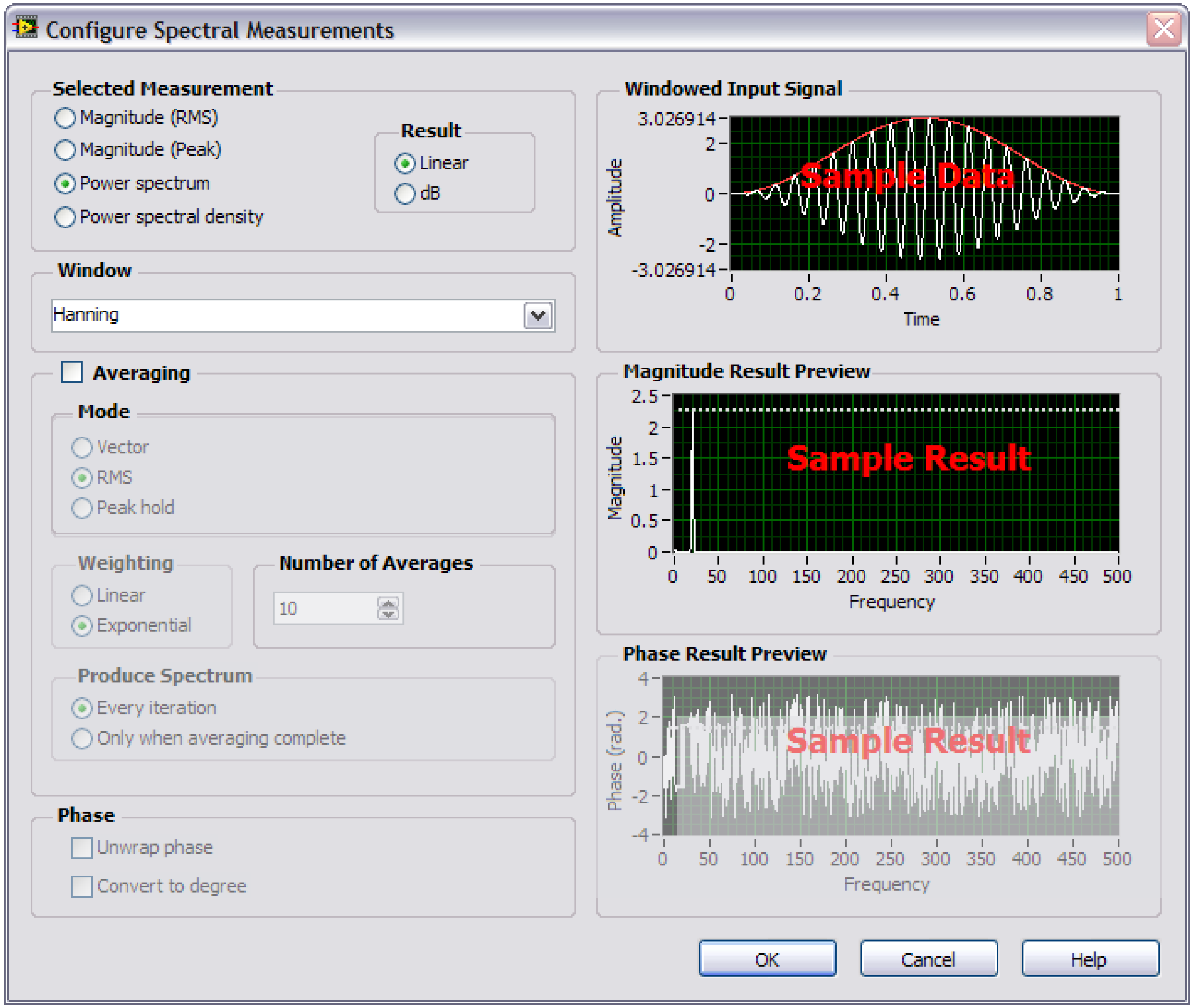
This graph displays the analog signals acquired or generated by the device.

Adding spectral measurements tool to block diagram



Settings in the spectral measurements tool

Can be modified later, if necessary



Configure Spectral Measurements

Selected Measurement

- ○ Magnitude (RMS)
- ○ Magnitude (Peak)
- ● Power spectrum
- ○ Power spectral density

Result

- ● Linear
- ○ dB

Window

Hanning

☐ **Averaging**

Mode

- ○ Vector
- ● RMS
- ○ Peak hold

Weighting

- ○ Linear
- ● Exponential

Number of Averages

10

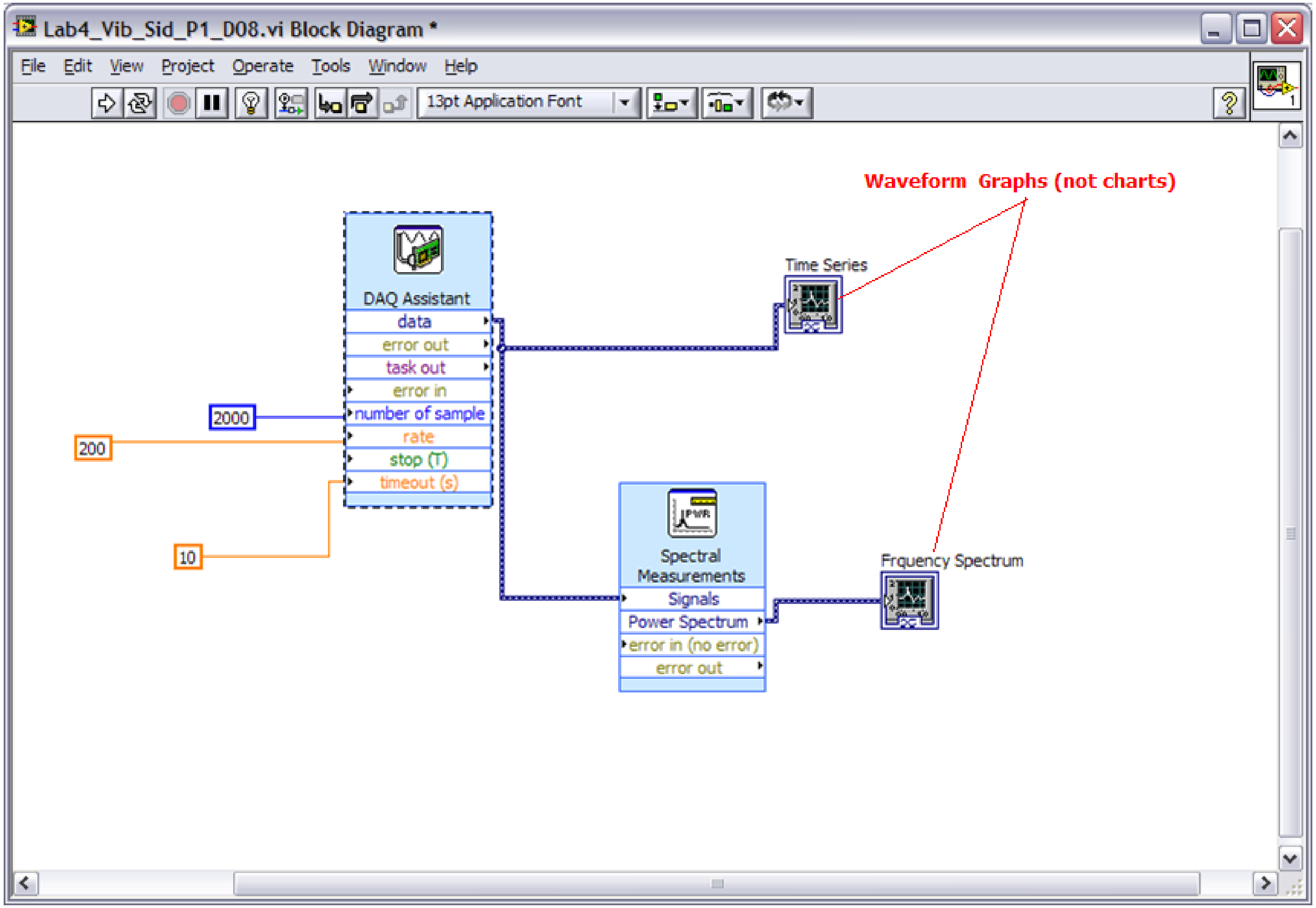
Produce Spectrum

- ● Every iteration
- ○ Only when averaging complete

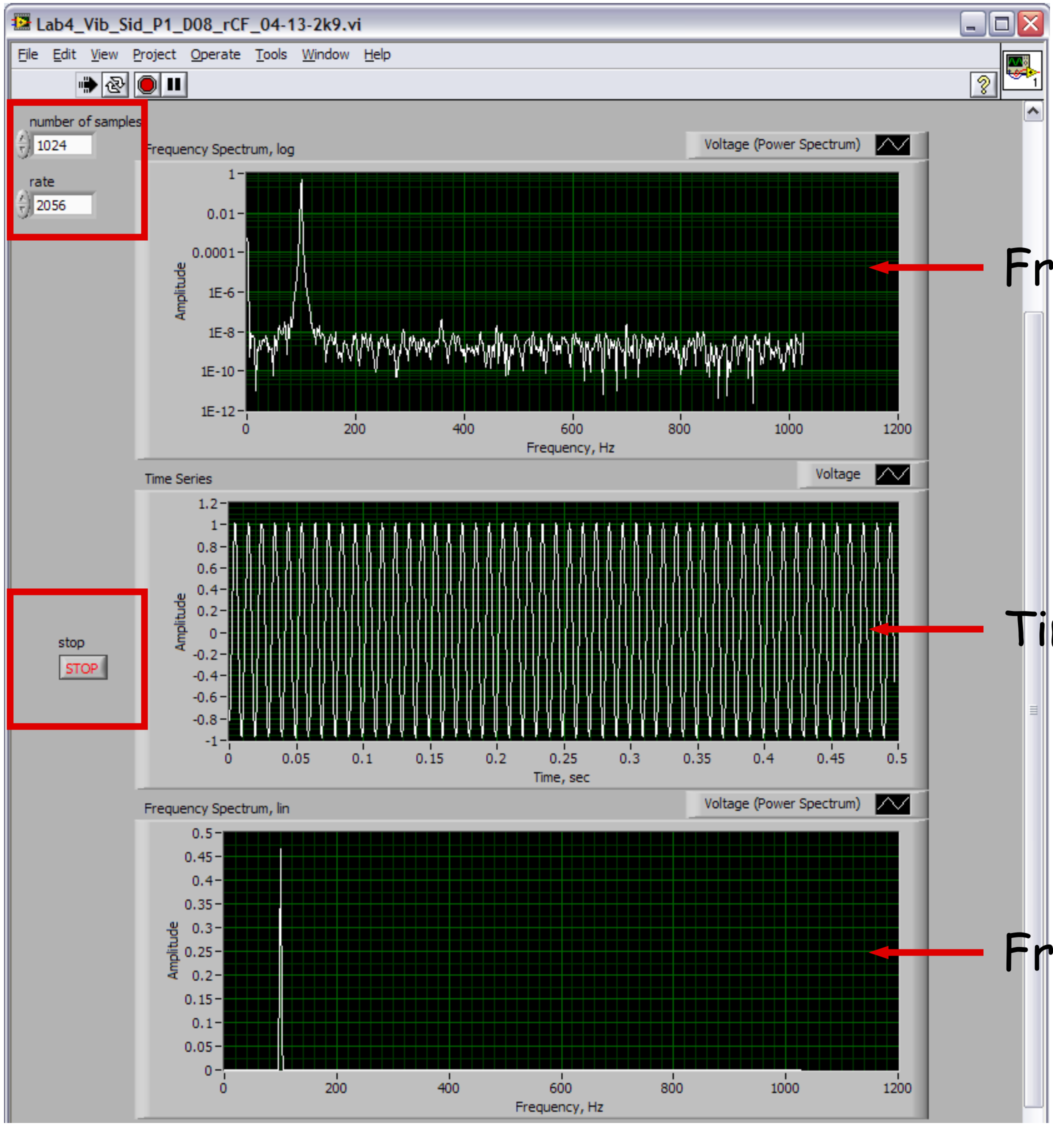
Phase

- ☐ Unwrap phase
- ☐ Convert to degree

Add controls, graphs, and wire as shown



Modify to add suitable controls, shown here



Lab4_Vib_Sid_P1_D08_rCF_04-13-2k9.vi

number of samples: 1024

rate: 2056

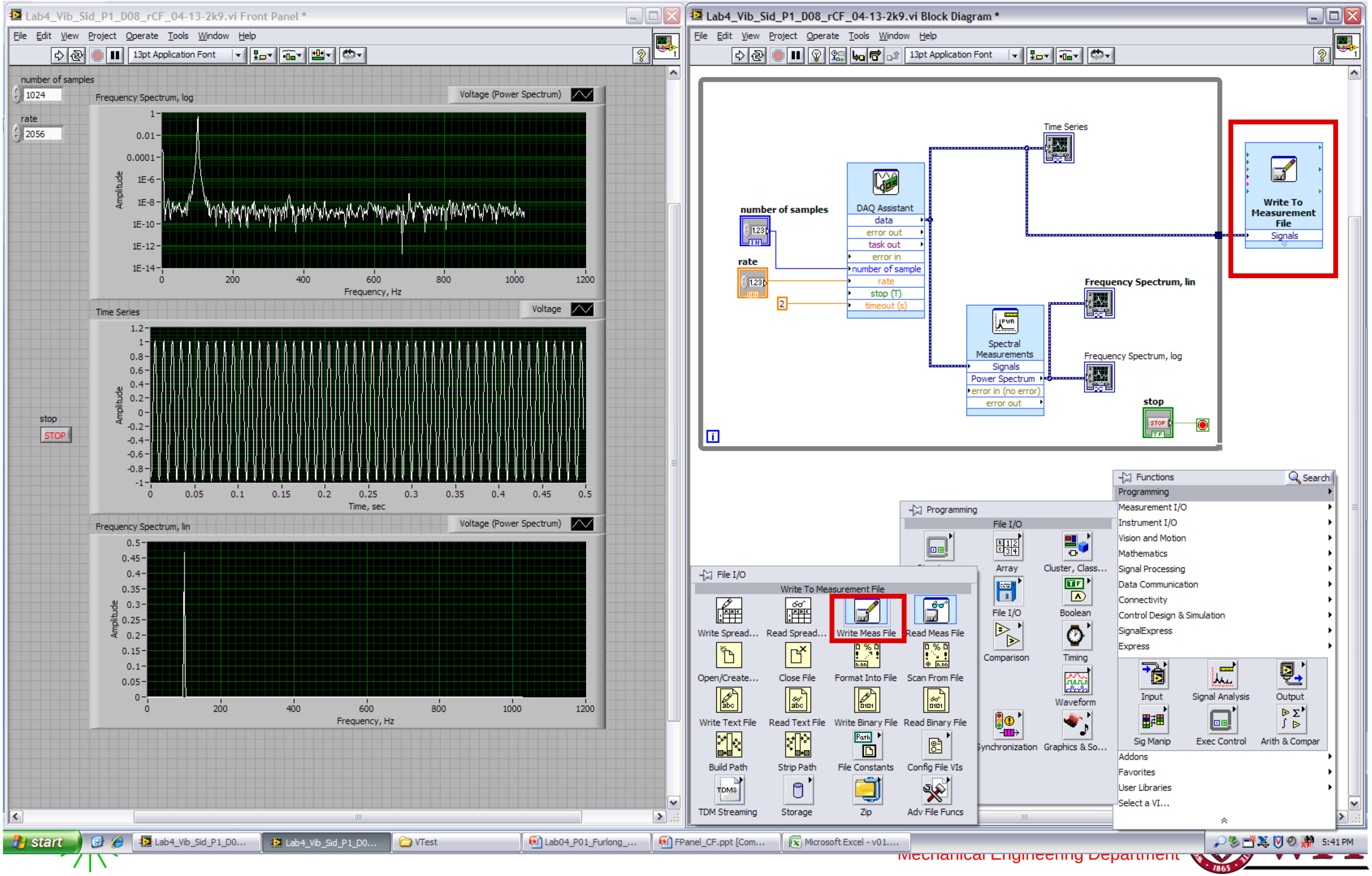
Multiple of 2^n

Frequency domain (lin-log)

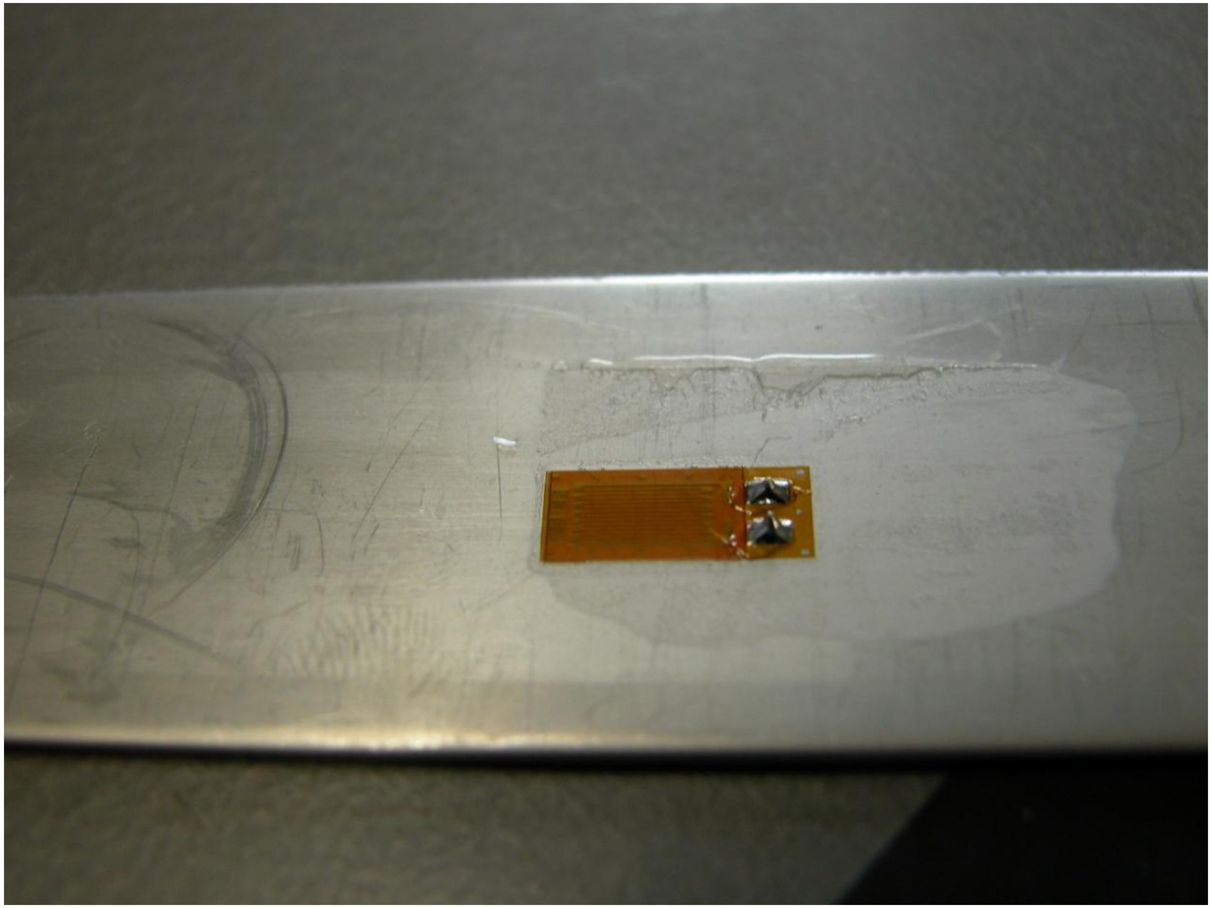
Time domain

Frequency domain (lin-lin)

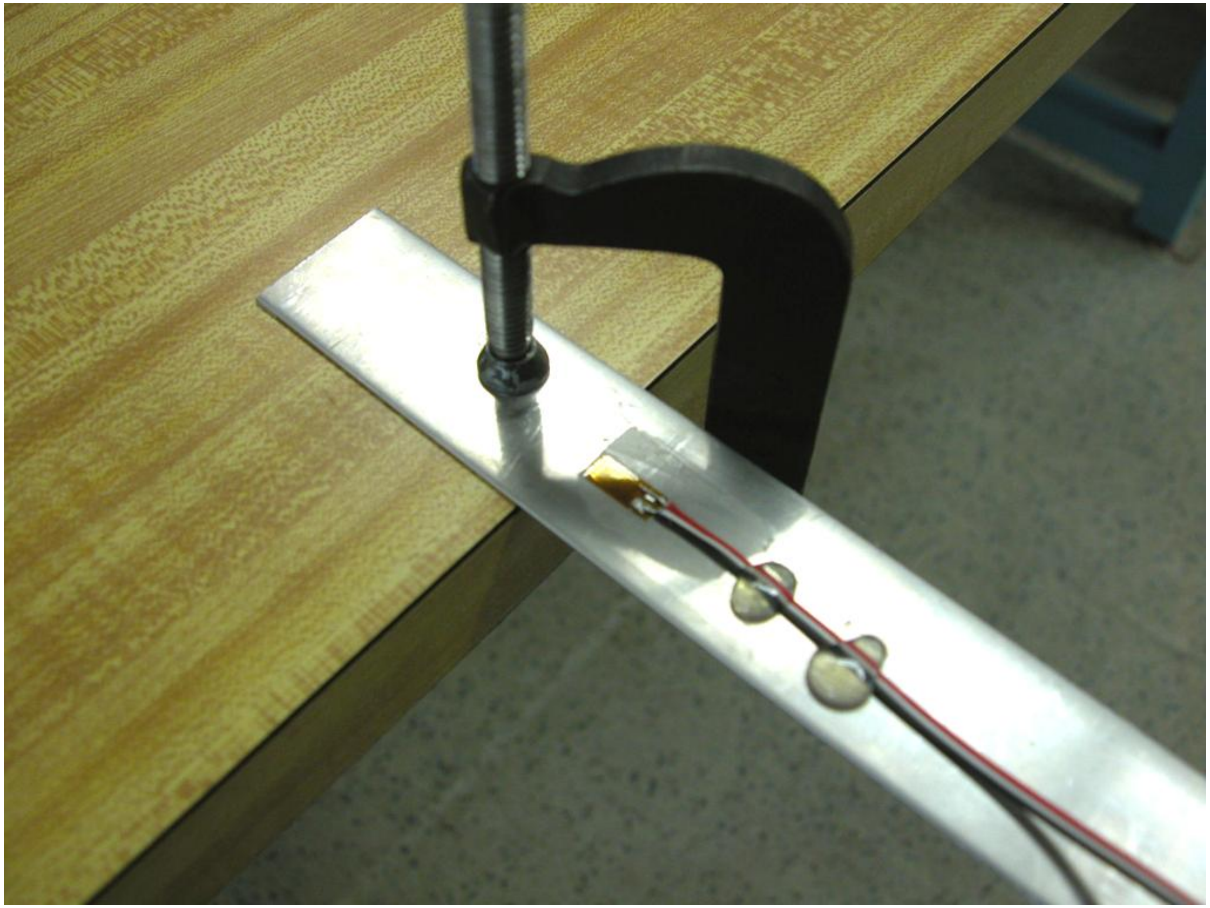
Modify to add suitable functionality, shown here (while loop and write data into file)



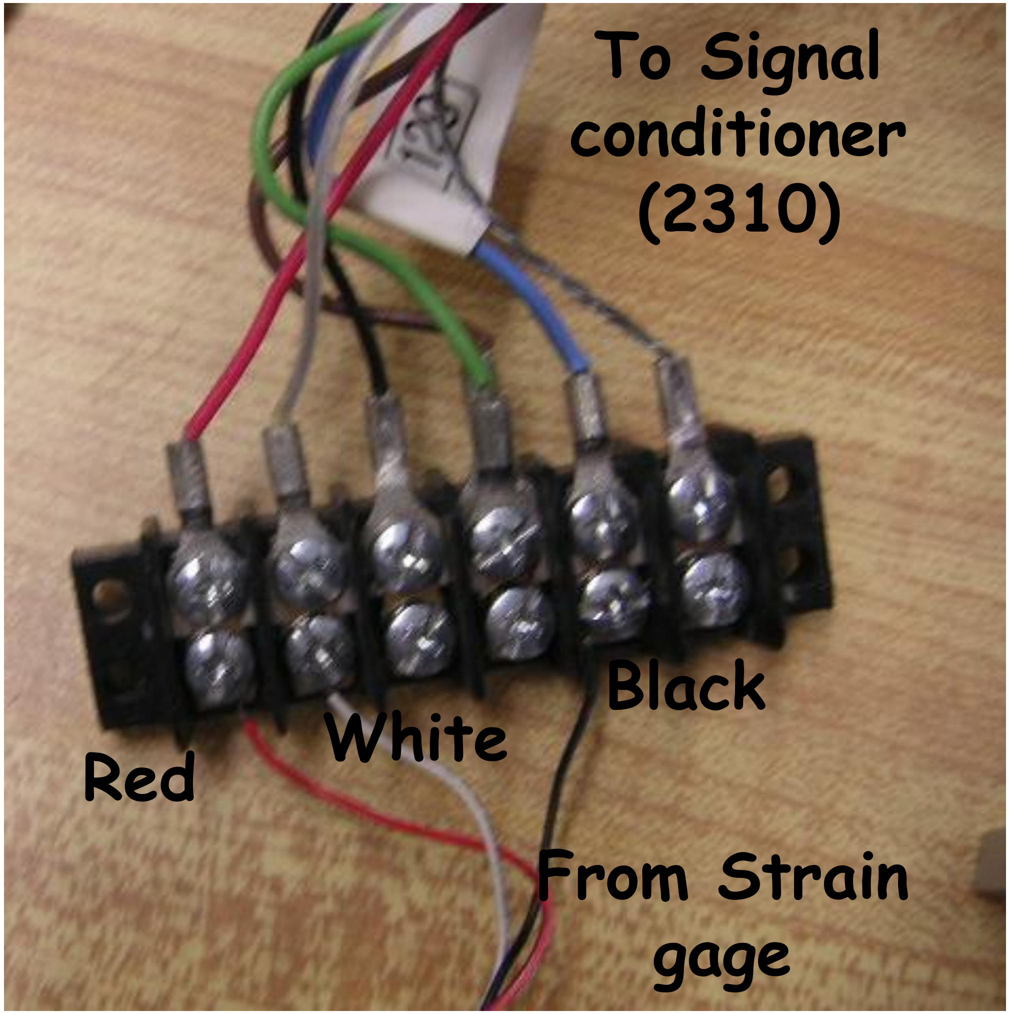
Setting up the hardware (1): attaching strain gauge



Setting up the hardware (2): clamping



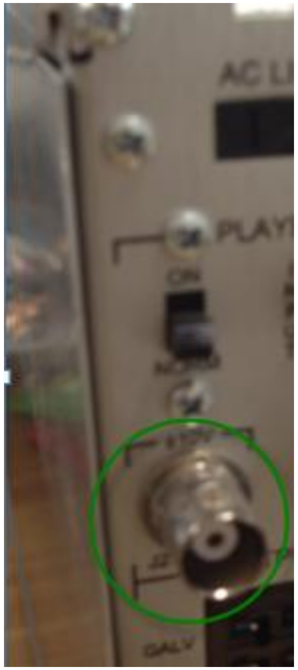
Setting up the hardware (3): bridge completion

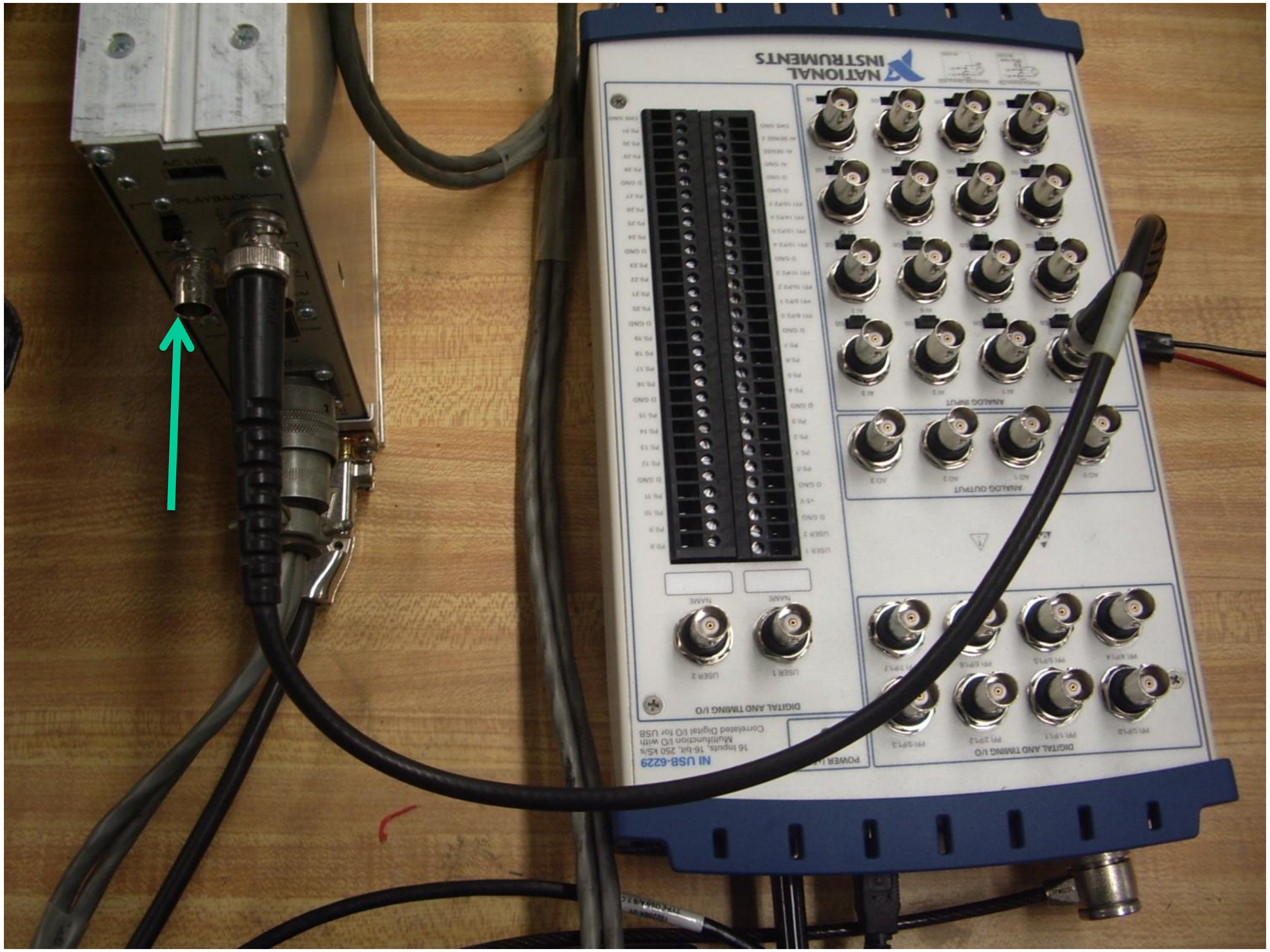


Term.	Strain Gage
Red	Red
White	White
Blue	Black

Setting up the hardware (4): read amplified signal

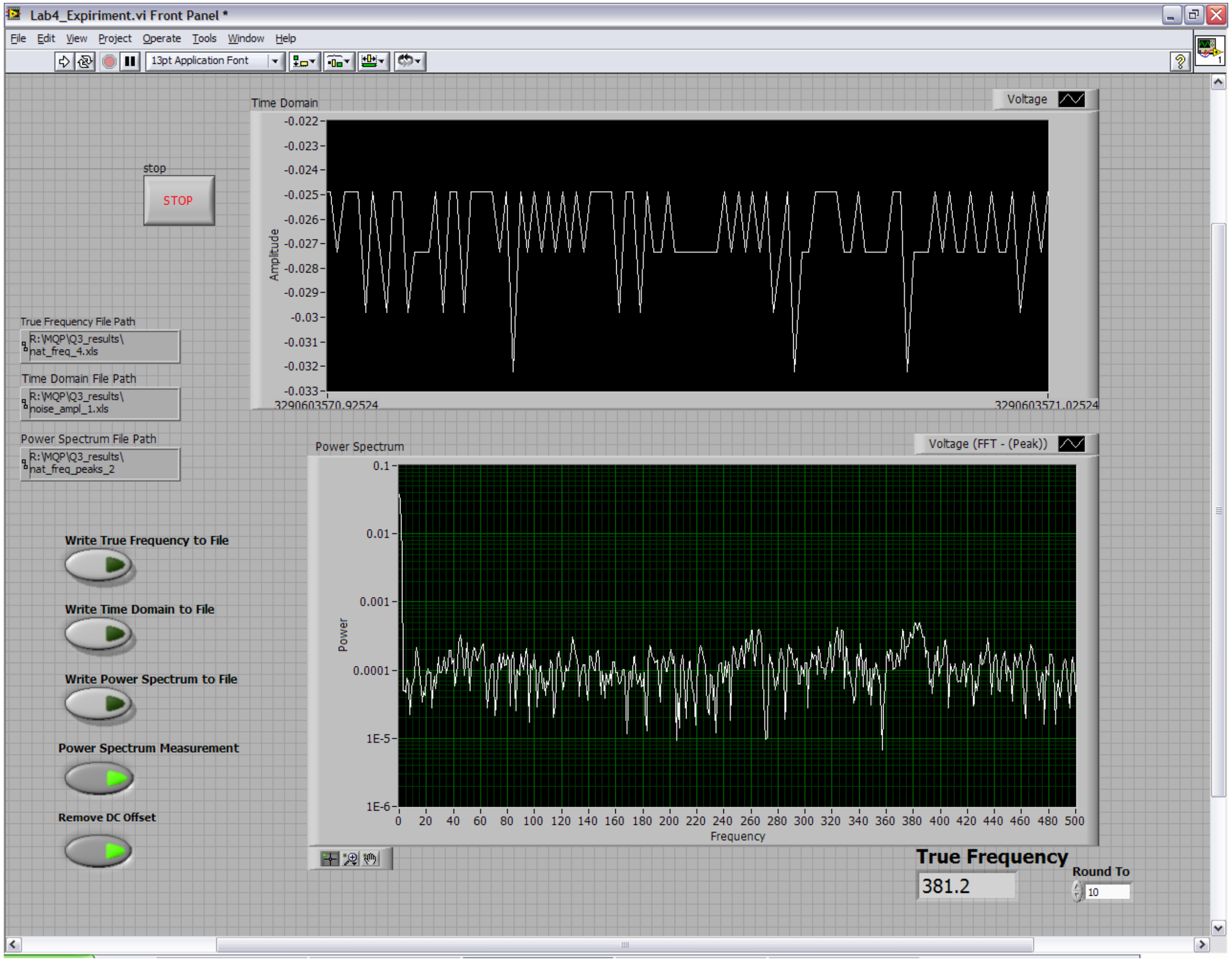
BNC cable from 2310's output (see ±10 terminal)





You can try another VI - available in our website

(enabled with writing to file capabilities)



True Frequency File Path: R:\MQP\Q3_results\nat_freq_4.xls

Time Domain File Path: R:\MQP\Q3_results\noise_ampl_1.xls

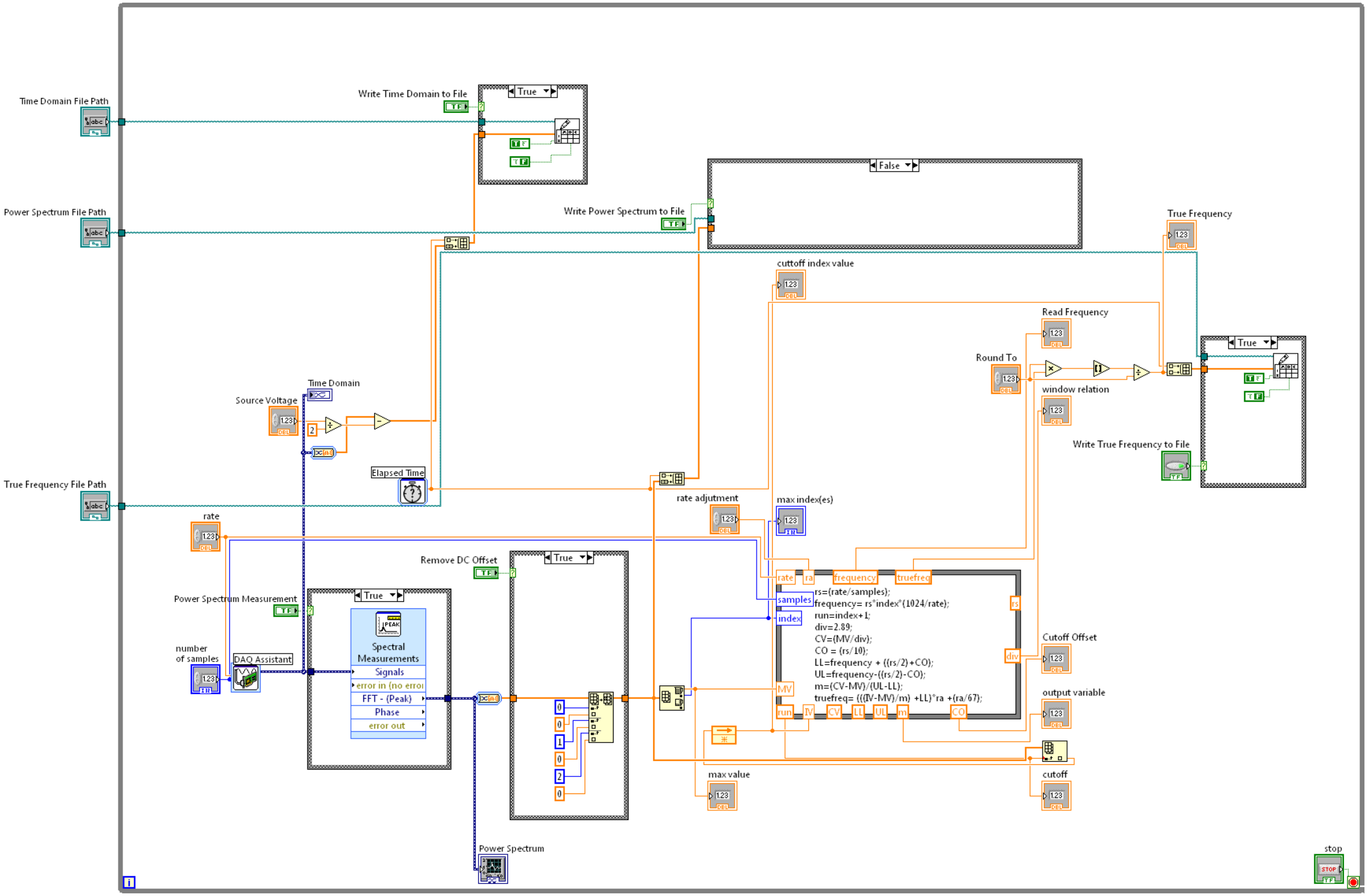
Power Spectrum File Path: R:\MQP\Q3_results\nat_freq_peaks_2

True Frequency: 381.2

Round To: 10

You can try another VI – available in our website

(enabled with writing to file capabilities)



```
rs=(rate/samples);
frequency= rs*index*(1024/rate);
run=index+1;
div=2.89;
CV=(MV/div);
CO = (rs/10);
LL=frequency + ((rs/2)+CO);
UL=frequency-((rs/2)-CO);
m=(CV-MV)/(UL-LL);
truefreq= (((IV-MV)/m) +LL)*ra +(ra/67);
```

Basic principle of accelerometers

- Recall that the RMS value of a function $i(t)$ is calculated as:

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T [i(t)]^2\,dt}$$

- For a pure sinusoidal function with zero offset:

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} [I_p \sin(\omega t)]^2\,dt} = \sqrt{\frac{I_P^2}{2\pi}\int_0^{2\pi} \sin^2(\omega t)\,dt}$$

$$\boxed{I_{RMS} = \frac{I_p}{\sqrt{2}}}$$

Basic principle of accelerometers

- Also, recall that for a position function given by:

$$y(t) = A\sin(\omega t + \phi) \qquad [\omega, \text{rad/sec}]$$

$$[f = \frac{\omega}{2\pi}, \text{Hz}]$$

- Velocity function is:

$$\dot{y}(t) = \omega A \cdot \cos(\omega t + \phi)$$

- Acceleration function is:

$$\ddot{y}(t) = \underbrace{-\omega^2 A}_{\substack{\uparrow \\ \text{Magnitude of} \\ \text{acceleration}}} \cdot \sin(\omega t + \phi)$$