WORCESTER POLYTECHNIC INSTITUTE
MECHANICAL ENGINEERING DEPARTMENT

Engineering Experimentation
ME-3901, D'2012

Laboratory #4:

Vibration measurements with MEMS

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

<u>Please refer to posted handouts:</u>

"Laboratory 4: vibration measurements"

"Analog Devices: Single and dual Axis Automotive *i*MEMS"

Objectives

The objectives of this laboratory are to:

- use two-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

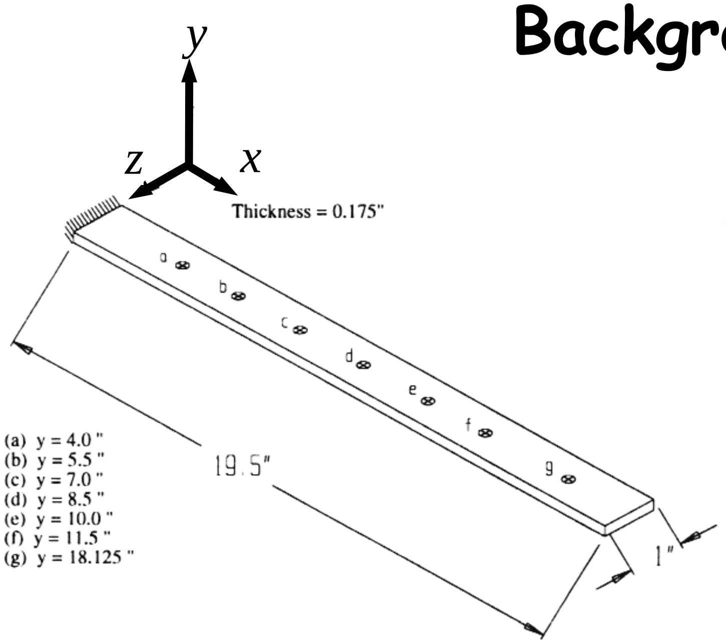


Fig. 3 Low carbon steel beam showing locations of interest

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: $$\omega_n = 3.5160 \sqrt{\frac{EI}{\overline{m} L^4}}, \quad \text{rad/s} \tag{3}$$

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: $$\omega_n = 22.0345 \sqrt{\frac{EI}{\overline{m} L^4}}, \tag{4}$$

Third: $$\omega_n = 61.6972 \sqrt{\frac{EI}{\overline{m} L^4}}, \tag{5}$$

Fourth: $$\omega_n = 120.0902 \sqrt{\frac{EI}{\overline{m} L^4}}, \tag{6}$$

Fifth: $$\omega_n = 199.8600 \sqrt{\frac{EI}{\overline{m} L^4}}, \tag{7}$$

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

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

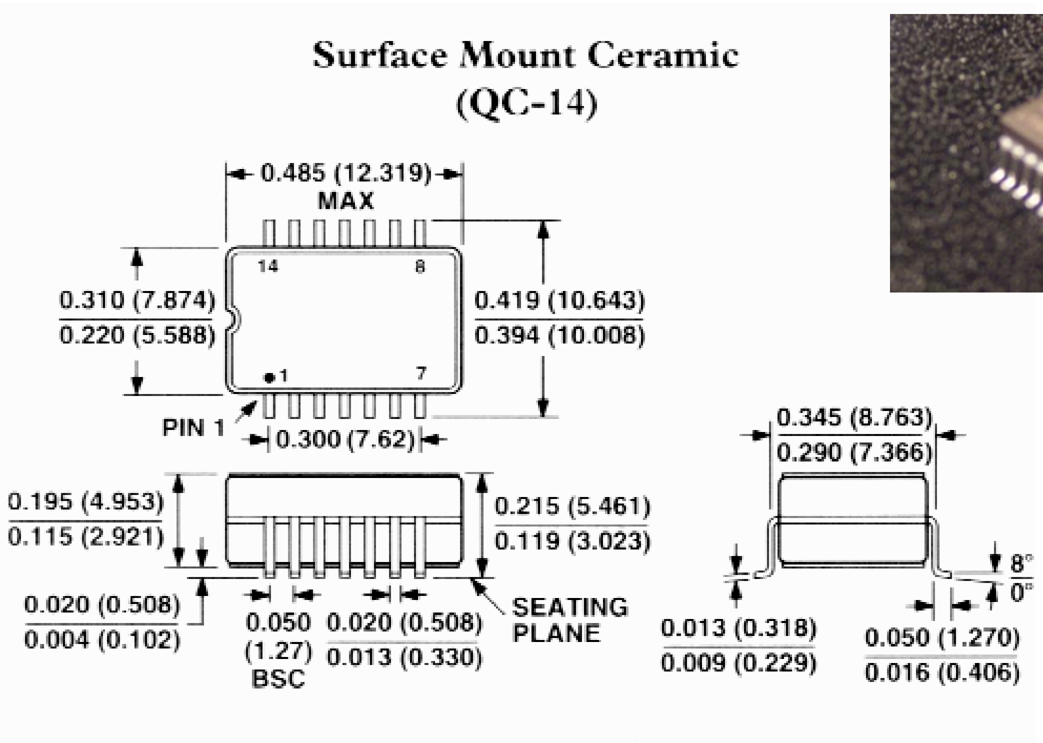
Natural Frequency	Magnitude, Hz
1	15.1270
2	94.8010
3	265.446
4	516.675
5	859.876

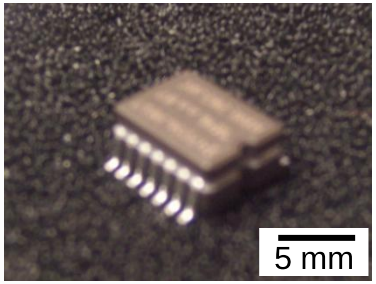
MEMS accelerometers

- In this laboratory Analog Devices ADXL276 (AD22237) dual-axes accelerometer will be utilized.
- The ADXL276 MEMS accelerometer is currently being used in a wide range of consumer, industrial, military, and automotive applications.
- The ADXL276 accelerometer has a measuring range of ±35 g (g = 9.81 m/s^2) and it provides analog output signals with sensitivity on the order of 55 mV/g.
- It requires 3 V to 5.25 V for operation and is capable of operating in a wide range of temperatures.
- Provides ~ 2.4 V output at zero-g (no motion)

MEMS accelerometers

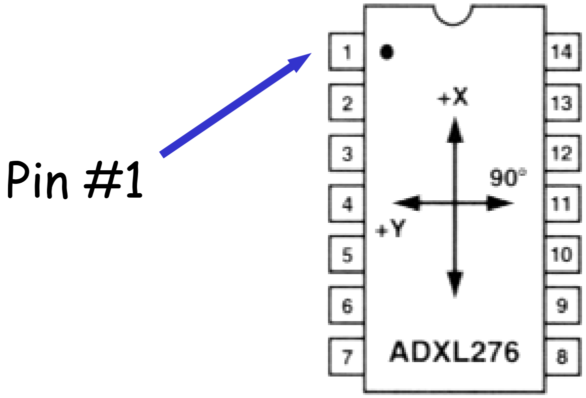
ADXL276 (AD22237) dual-axes accelerometer



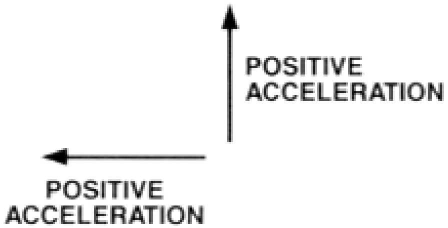


MEMS accelerometers

ADXL276 (AD22237): sensitivity axes



ADXL276 SENSITIVE AXIS
POSITIVE A => NEGATIVE V_{OUT}
(TOP VIEW)



ADXL276 (AD22237): specifications sheet (you have copy)

ADXL76, ADXL269, ADXL276–SPECIFICATIONS

(@ T_A = –40°C to +85°C, V_S = 5 V ± 5%, Acceleration = 0 *g*; unless otherwise noted)

Parameter	Conditions	ADXLxxQx 18[1] Min	ADXLxxQx 18[1] Typ	ADXLxxQx 18[1] Max	ADXLxxQx 38[1] Min	ADXLxxQx 38[1] Typ	ADXLxxQx 38[1] Max	ADXLxxQx 55[1] Min	ADXLxxQx 55[1] Typ	ADXLxxQx 55[1] Max	Unit
SENSOR											
Guaranteed Full-Scale Range	ADXL76 Only, Offset Adjusted[2]	±115									*g*
	ADXL76 Only, Offset Adjusted	±105									*g*
					±50			±35			*g*
					±45			±30			*g*
Nonlinearity						0.2					%
Package Alignment Error[3]						±1					Degrees
Sensor-to-Sensor Alignment Error	ADXL276, ADXL269					0.1					Degrees
Transverse Sensitivity[4]						±2					%
SENSITIVITY											
Sensitivity			18			38			55		mV/*g*
Sensitivity Tolerance[5, 6]	Ratiometric				–8		+8				%
Temperature Drift	From 25°C to T_{MIN} to T_{MAX}					±0.5					%
ZERO-*g* OFFSET LEVEL											
Output Zero-*g* Voltage[6, 7]	Offset from $V_S/2$	–198		+198	–418		+418	–605		+605	mV
Temperature Drift	From 25°C to T_{MIN} to T_{MAX}		3.6			7.6			11		mV
ZERO-*g* ADJUSTMENT											
Voltage Gain	$\Delta V_{OUT}/\Delta V_{ADJ\ PIN}$				0.45	0.5	0.55				V/V
Input Resistance					20	30	40				kΩ
Input Resistor Network Ratio %:1						±0.1					%
NOISE PERFORMANCE											
Noise Density	10 Hz to Nominal Bandwidth		4	12		1	3		1	3	mg/√Hz
Clock Noise	See Figure 18					5					mV p-p
FREQUENCY RESPONSE	Bandwidth Options: See Ordering Guide										
–3 dB Frequency[8]					–10		+10				%
Bandwidth Temperature Drift						20					Hz
Sensor Resonant Frequency	Q = 5					24					kHz
SELF-TEST[9]	@ 5 V										
Output Change		135	180	270	285	380	570	413	550	825	mV
Logic "1" Voltage					3.5						V
Logic "0" Voltage							1.0				V
Input Resistance	To GND				30	50					kΩ
OUTPUT AMPLIFIER											
Output Voltage Swing	I_{OUT} = +100 µA				V_S–0.25						V
	I_{OUT} = –100 µA						0.25				V
Capacitive Load Drive					1000						pF
POWER SUPPLY (V_S)											
Operating Voltage Range					4.75		5.25				V
Functional Voltage Range					4.0		6.0				V
Quiescent Supply Current	ADXL76, ADXL276,					18	3				mA
	ADXL269					3.5	5				mA
TEMPERATURE RANGE[10]					–40		+85				°C

NOTES

[1]For example: ADXLxxQx38 describes devices with a nominal sensitivity of 38 mV/*g*. See Ordering Guide for full part number.

[2]Trimmed at the factory to user specifications. May require 0-*g* adjust circuitry. Reference section on Zero-*g* Adjustment and Dynamic Range.

[3]Alignment error is specified as the angle between the true axis of sensitivity and the edge of the package.

[4]Transverse sensitivity is measured with an applied acceleration that is 90 degrees from the indicated axis of sensitivity.

[5]Ratiometric: V_{OUT} (accel, V_S) = $[V_S/2 \pm (a\ V_S/5\ V)] + [(accel)(b\ V_S + c\ V_S^2)(1 \pm 0.08)]$ where a = offset range in volts. For a 38 mV/*g* sensor: $b = 5.725 \times 10^{-3}$ 1/*g*, $c = 0.375 \times 10^{-3}$ 1/*g*/V. (For a 55 mV/*g* sensor: $b = 8.284 \times 10^{-3}$ 1/*g*, $c = 0.542 \times 10^{-3}$ 1/*g*/V. See Figures 5 and 13. Spec includes temperature drift, life drift, and nonlinearity. Test conditions: 100 Hz, ±50 *g* for the 38 mV/*g* and 18 mV/*g* sensor; 100 Hz ± 35 *g* for the 55 mV/*g* sensor.

[6]Error included in full-scale range specification.

[7]Proportional to $V_S/2$. See Figures 6 and 19.

[8]Includes Temperature Drift.

[9]ST pin from Logic "0" to "1." For the ADXL76: V_{OUT} change = (V_{OUT} change @ 5 V) × (V_S/5 V). For the ADXL269 and the ADXL276: V_{OUT} change = (V_{OUT} change @ 5 V) × $(V_S/5\ V)^3$.

[10]A higher temperature range available.

Specifications subject to change without notice.

ADXL276 (AD22237): specifications sheet (you have copy)

Part number: ADXL276 (AD22237)

Standard Devices	Part Number	Sensitivity [mV/g]	Bandwidth (–3 dB) [Hz]	Package Description*	Package Option
ADXL76Q38	AD22215	38	400	Ceramic Dual-In-Line	Q-8
ADXL76QC38	AD22227	38	400	Surface Mount Ceramic	QC-14
ADXL76QC38-1	AD22229	38	1000	Surface Mount Ceramic	QC-14
ADXL76Q55	AD22224	55	400	Ceramic Dual-In-Line	Q-8
ADXL76QC55	AD22226	55	400	Surface Mount Ceramic	QC-14
ADXL276QC38	AD22235	38	400	Surface Mount Ceramic	QC-14
ADXL276QC38	AD22239	38	400X; 1000Y	Surface Mount Ceramic	QC-14
ADXL276QC55	AD22237	55	400	Surface Mount Ceramic	QC-14

Standard Devices	Part Number	Sensitivity [mV/g]	Bandwidth (–3 dB) [Hz]	Package Description*	Package Option
ADXL76QC18		18	400	Surface Mount Ceramic	QC-14
ADXL76Q38-1	AD22228	38	1000	Ceramic Dual-In-Line	Q-8
ADXL269QC38		38	400	Surface Mount Ceramic	QC-14
ADXL269QC55	AD22269	55	400	Surface Mount Ceramic	QC-14
ADXL276QC38-1	AD22236	38	1000	Surface Mount Ceramic	QC-14
ADXL276QC	AD22204	38X; 70Y	400	Surface Mount Ceramic	QC-14
ADXL276QC55-1	AD22238	55	1000	Surface Mount Ceramic	QC-14

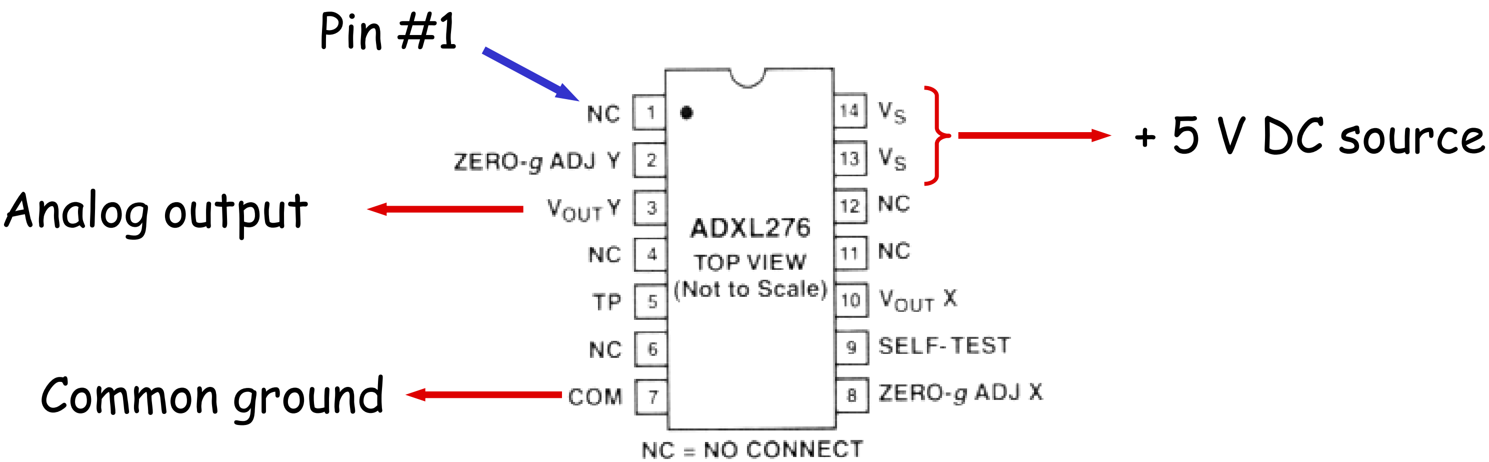
*Contact factory for availability.

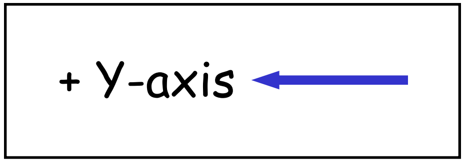
NOTE: Surface mount packages are shipped taped and reeled with a full reel quantity of 750 pieces. Dual-in-line packages are shipped in tubes (45 pieces per tube), 1080 pieces per box. Samples for preproduction development can be shipped in less than full box or full reel quantities.

MEMS accelerometers:wiring

ADXL276 (AD22237): wiring

We will be using only one axis (why?)

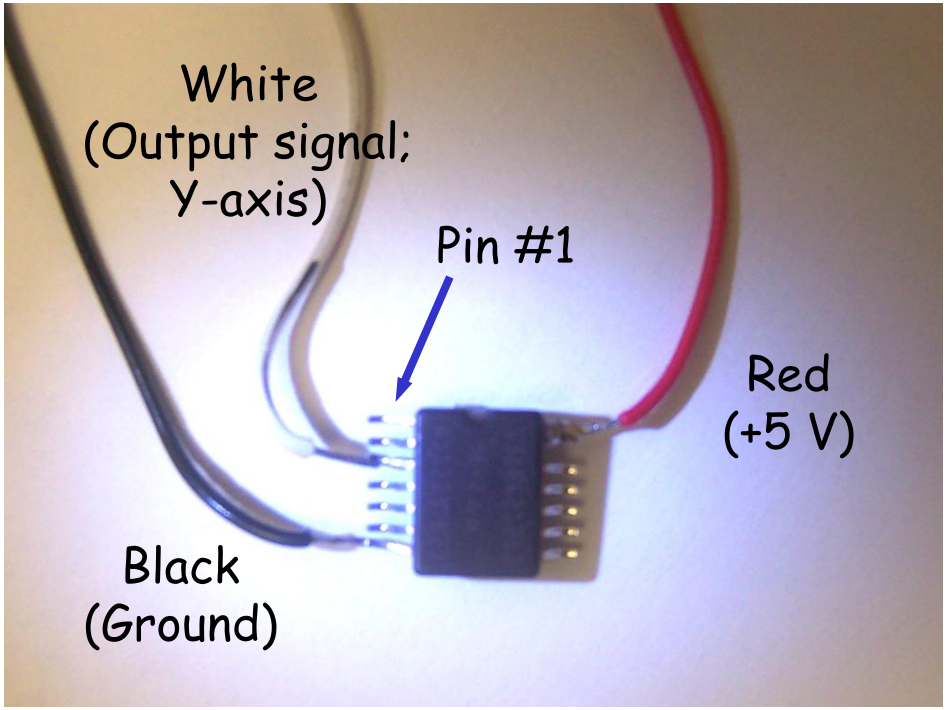




MEMS accelerometers:wiring

ADXL276 (AD22237): wiring. Use strain gage wire

<u>We will be using only one axis</u>

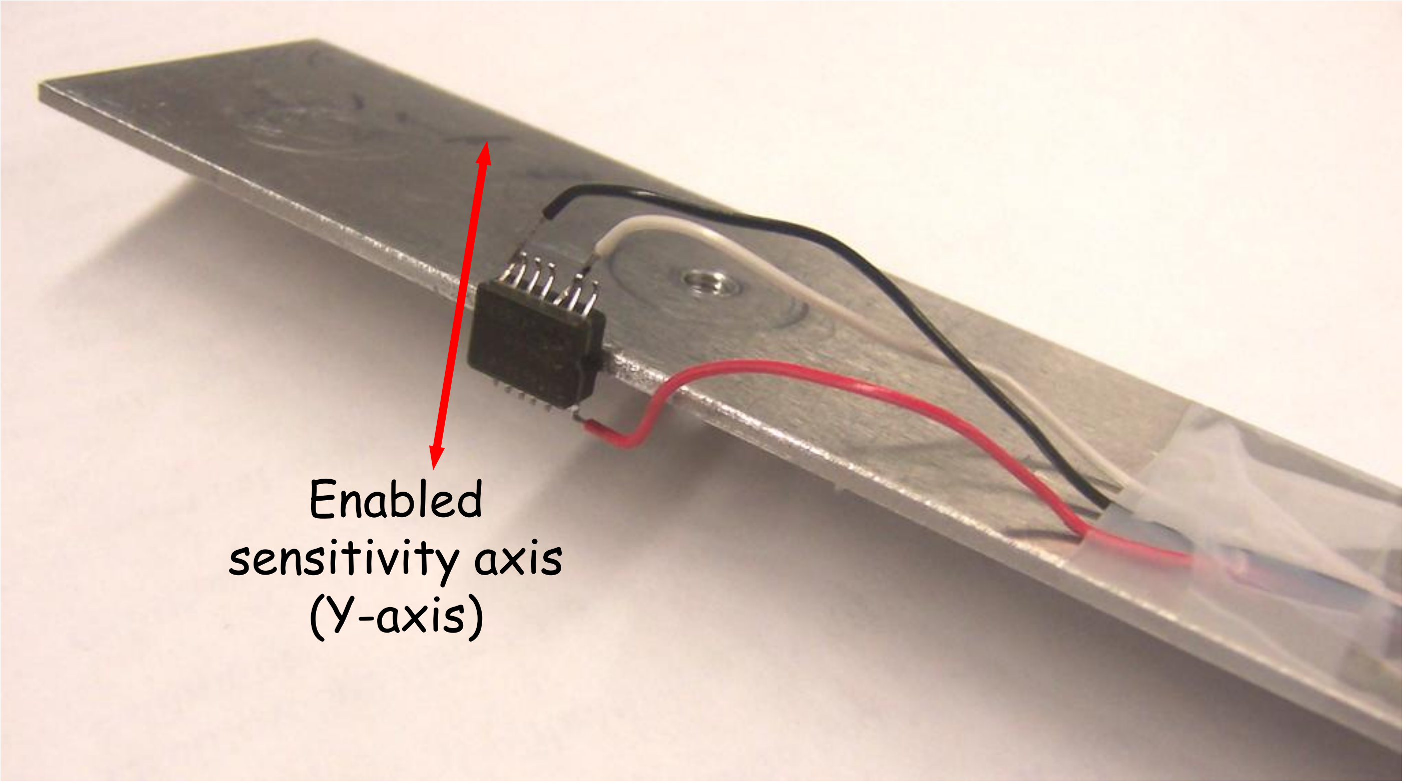


MEMS accelerometers: mounting

ADXL276 (AD22237): wiring. Use strain gage wire

<u>Use "super-glue" to attach accelerometer – secure wires w/tape</u>

Free end

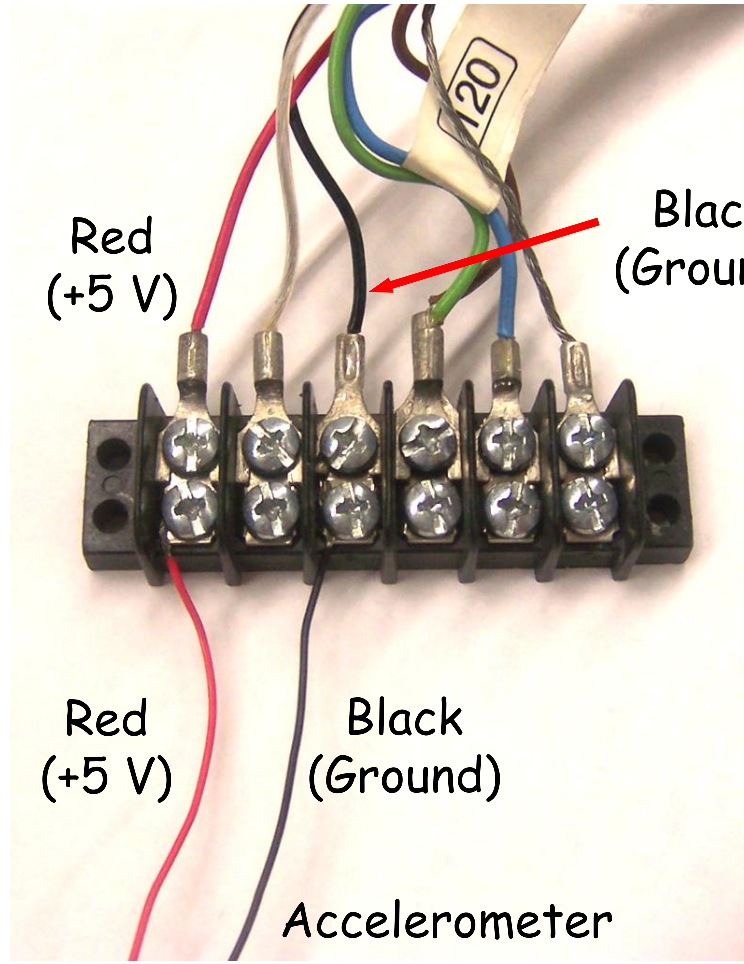


Clamped end

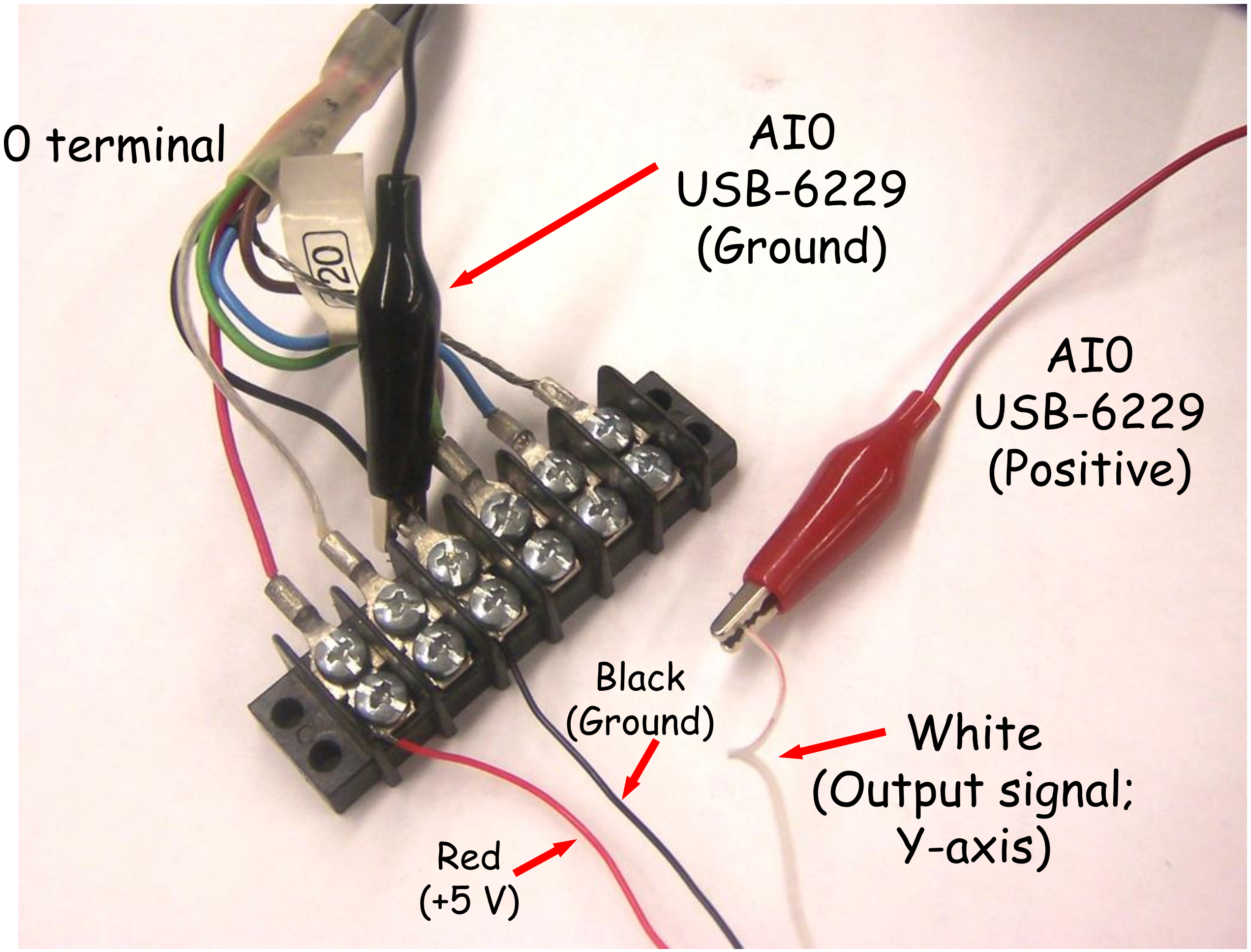
MEMS accelerometers: powering

Excitation output: 5 V DC

2310 terminal



MEMS accelerometers: analog output



Tasks: MEMS accelerometers

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

Record time & frequency data

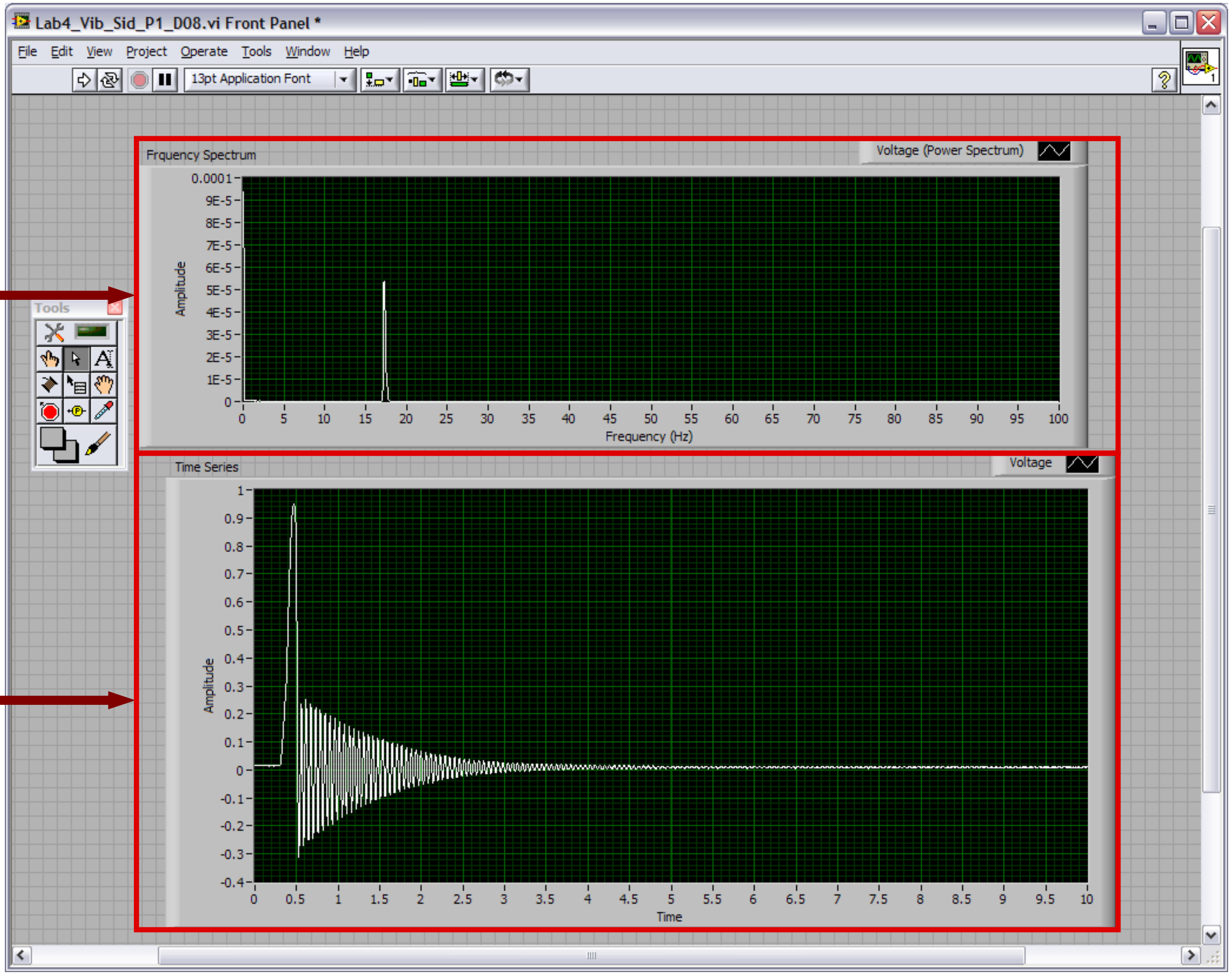
One **recommended** VI (available in our website)

Frequency-domain

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

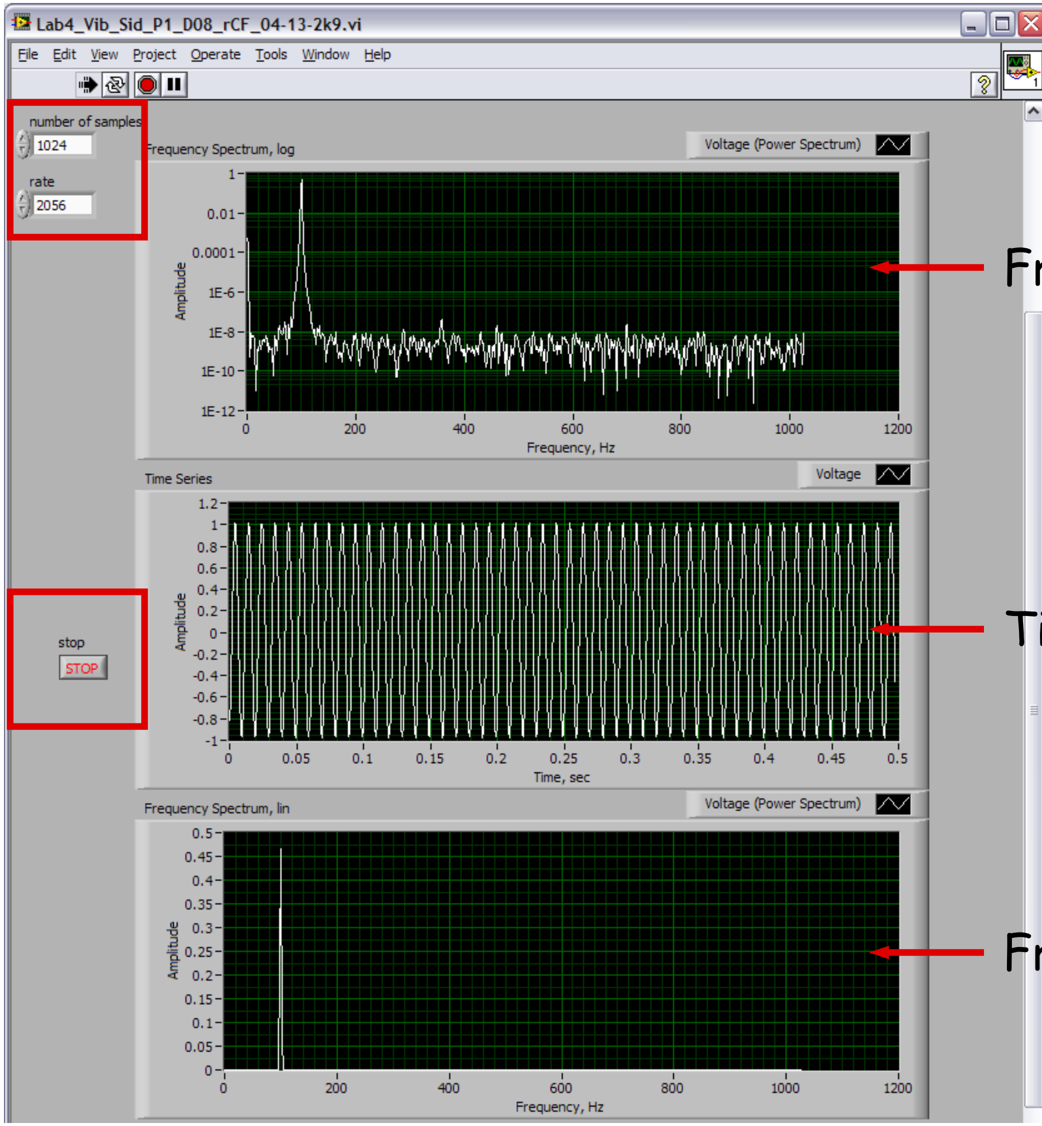
Time-domain data

(Obtained by plucking the beam)



Modify to add suitable controls, shown here

Multiple of 2^n

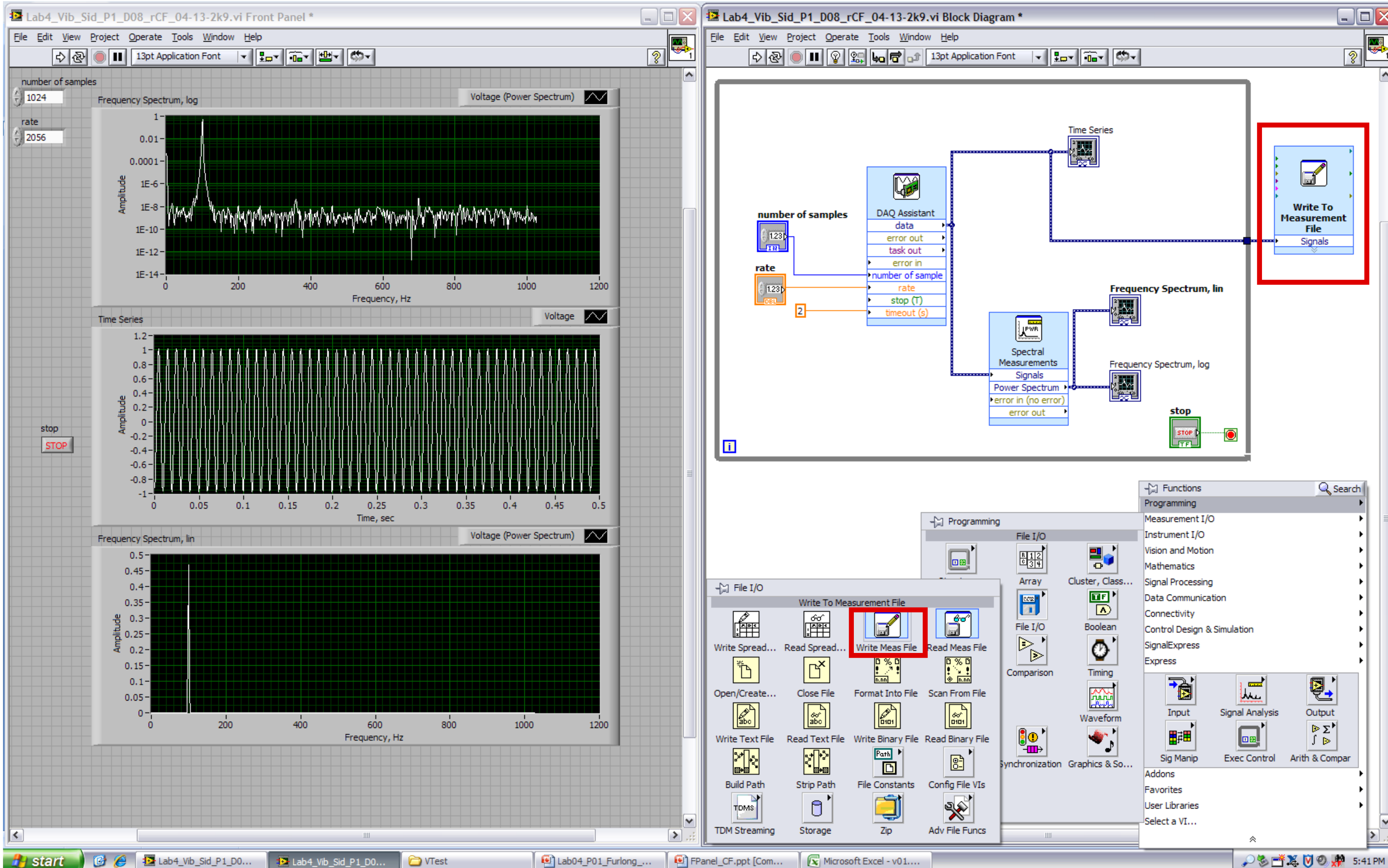


Frequency domain (lin-log)

Time domain

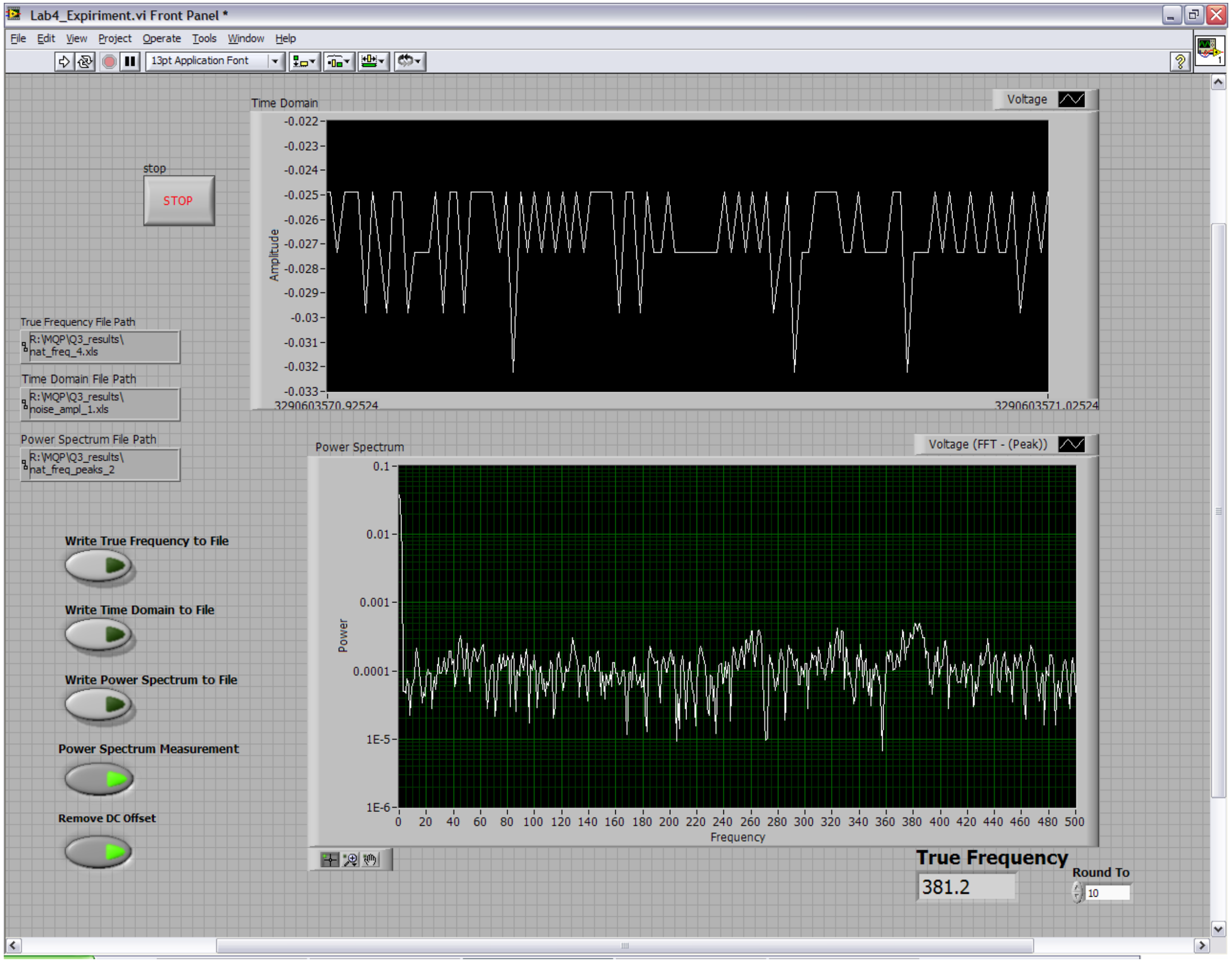
Frequency domain (lin-lin)

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



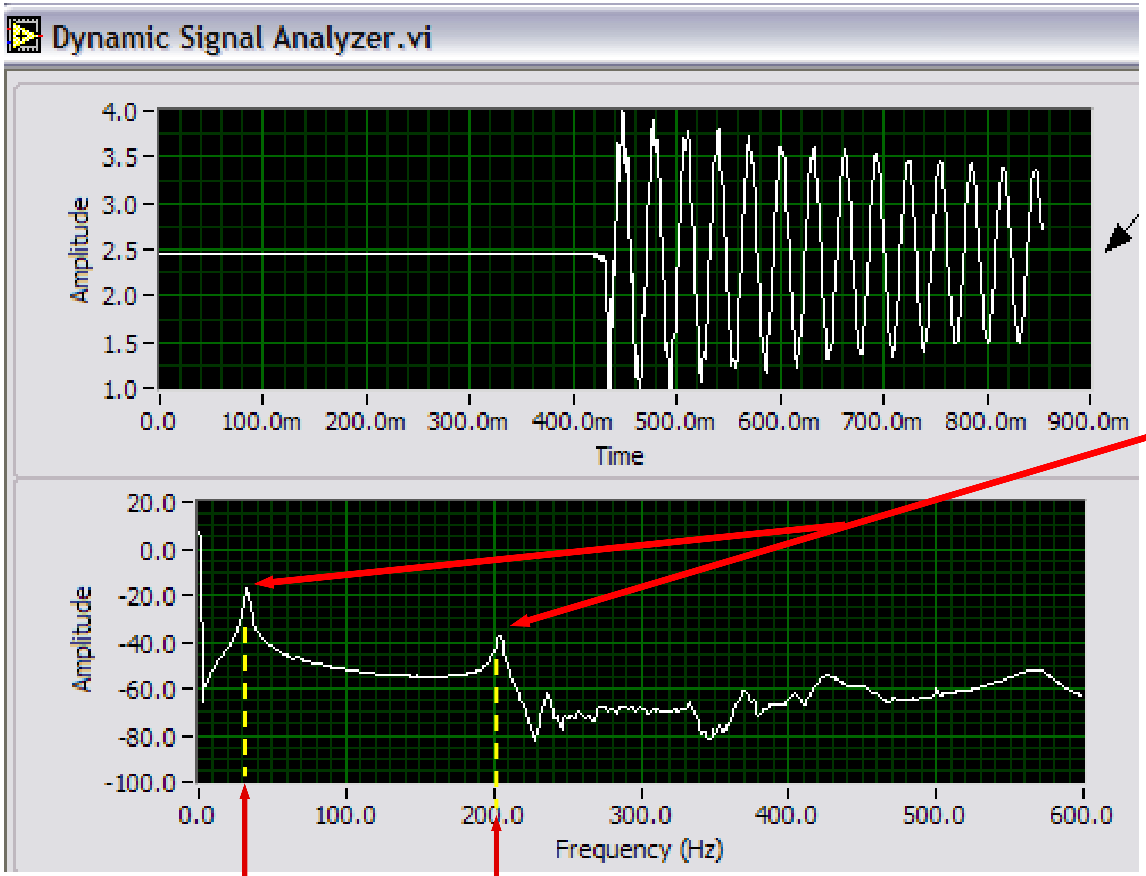
Record time & frequency data

Another **recommended** VI (available in our website)



Frequency-time domain: dynamic signal analyzer

Sample: single pluck (two frequencies are identified)



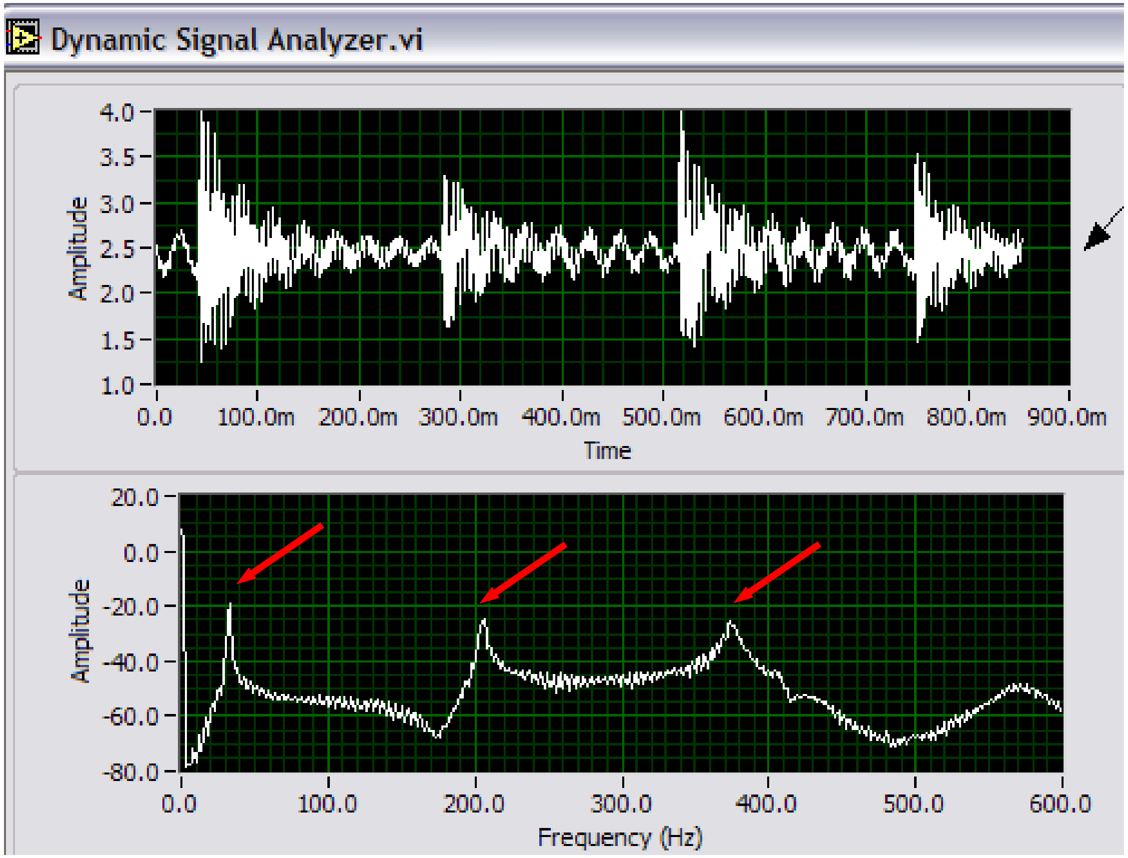
Note "peaks," which correspond to natural frequencies of vibration

Read horizontal location of peaks to identify frequency components

Frequency-time domain: dynamic signal analyzer

Sample: rapid plucking

(increases frequency resolution, three frequencies are identified here)



Do these frequency "peaks" correspond to bending, torsion, or in-plane modes of vibration?

Please identify, if possible.

Hint: see equations that predict bending frequencies

Make note on:

Measuring resolutions/sensitivities obtained with MEMS

&

Strain gauges