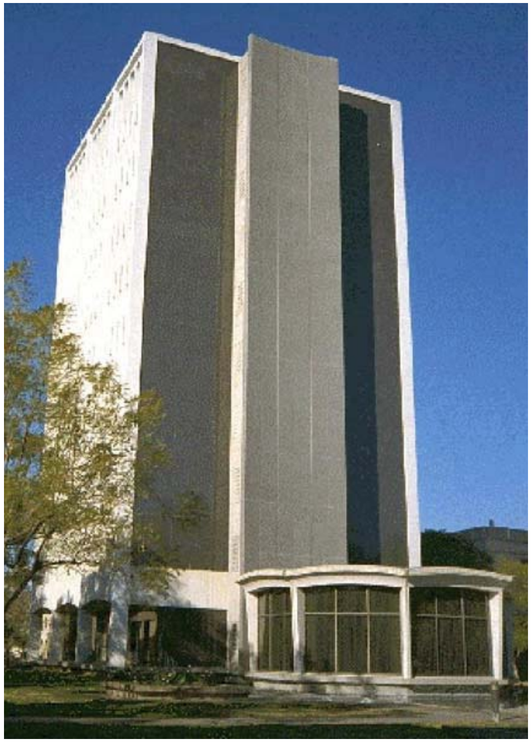
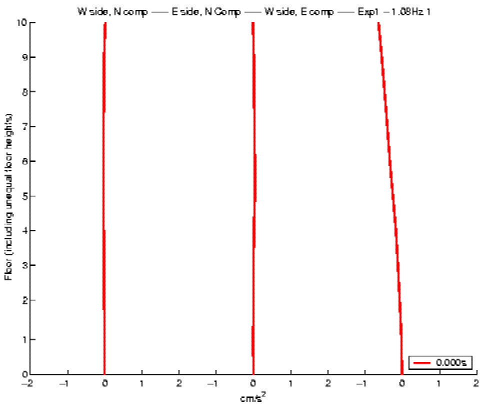
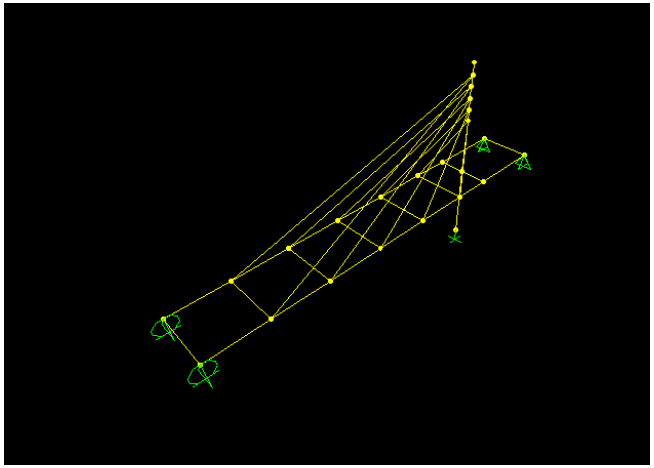
Structural Identification Project







Crossbow AD2012 Datalogger
(http://xbow.com)

Provides power for the sensors & performs the analog to digital conversion.

12-bit A/D Converter
8 Analog Inputs

Capable of Storing 540,000 Samples
Configurable Sampling Rate (1 – 500 Hz)

Crossbow CXL01L1 and CXL02L1 Accelerometers
(http://xbow.com)

Measurement Direction

CXL01L1 Capacitive Accelerometers

±1.25 g Measurement Range
DC – 100 Hz Measurement Range
0.000610 g Resolution on Channels 1-4
0.001221 g Resolution on Channels 5-8

CXL02L1 Capacitive Accelerometers

±2.50 g Measurement Range
DC – 100 Hz Measurement Range
0.001221 g Resolution on Channels 1-4
0.002441 g Resolution on Channels 5-8

Field-Testing

Using the Datalogger and accelerometers, you will need to go and record acceleration time histories at various locations on your structure.

You will need to choose these locations carefully (allowing you to capture the 1st couple of modes).

Once you have recorded your data, you will need to bring the datalogger back to the IT lab (SERF 154) and download the data.

We will then save the acceleration time histories onto a CD allowing you to perform the structural identification on your own.

Checking In and Out the Equipment

As there is only one set of testing equipment, we will set up a series of time slots. Each group will sign up for one of these and will be expected to do their testing during this time. If more time is needed, you may either trade times with another group or try to find and unused time slot.

Each group will be responsible for checking in the equipment before it is due back. This will allow us to service the equipment and ensure that everything is working for the next group.

Any data left on the datalogger will be erased once it is returned.

In order to allow sufficient time for analysis, all testing must be completed by February 28. The equipment cannot be checked out after this date!!!

One possibility: make the equipment available in 3 hour blocks

	Monday	Tuesday	Wednesday	Thursday	Friday
9:00 am-12:00 pm					
12:00 pm -3:00 pm					
3:00 pm -6:00 pm					

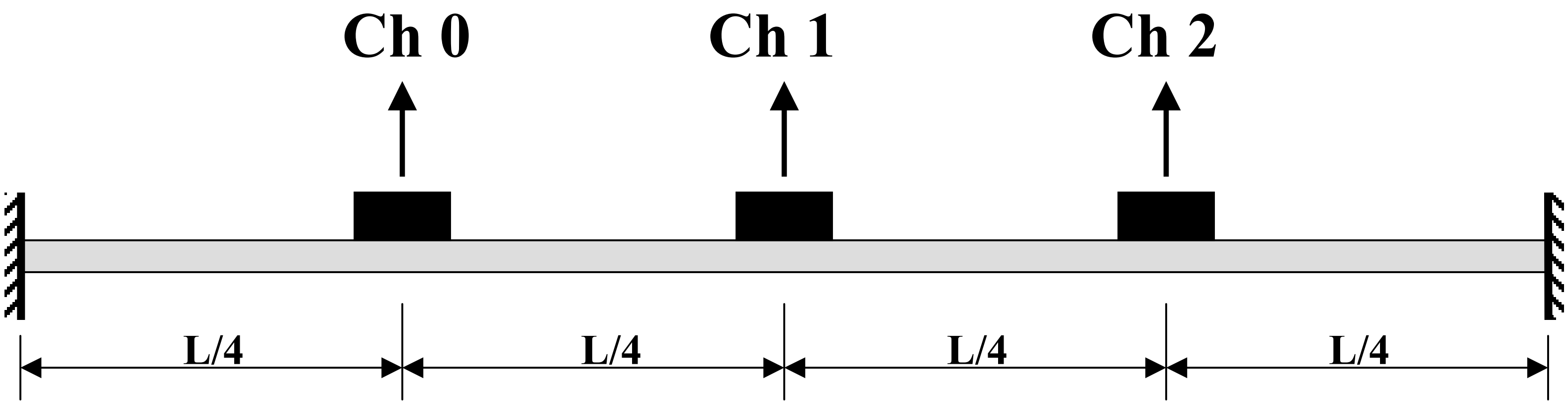
SERF Building Rm. 154

Crossbow AD2012 Datalogger

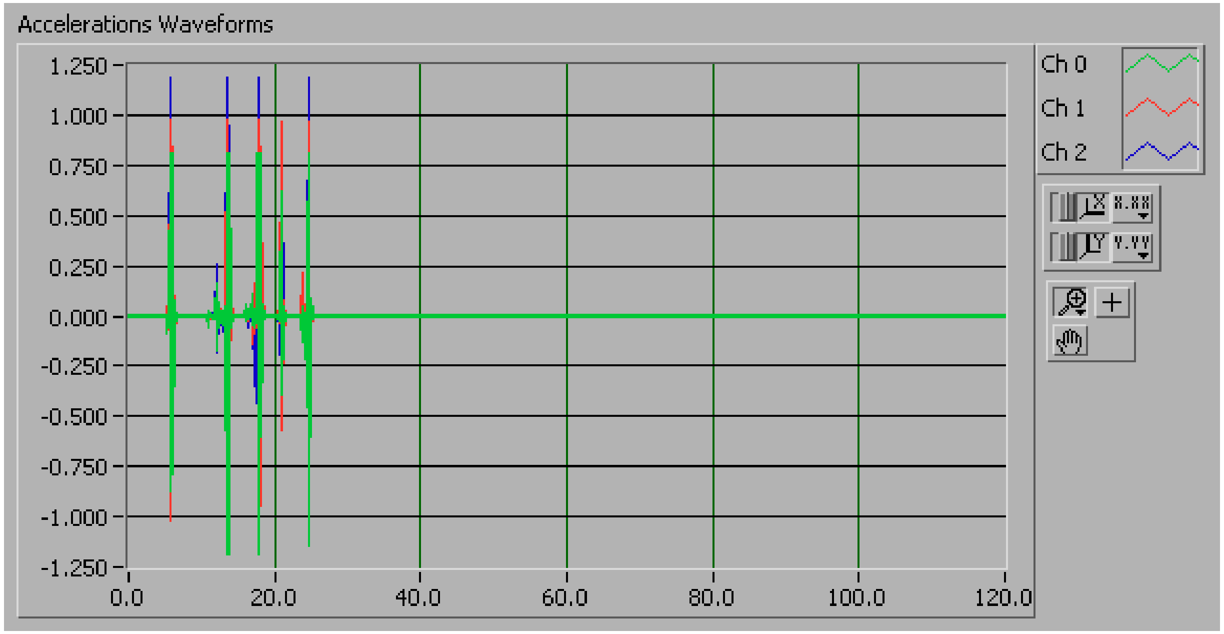
Crossbow CXL01L1 Accelerometer

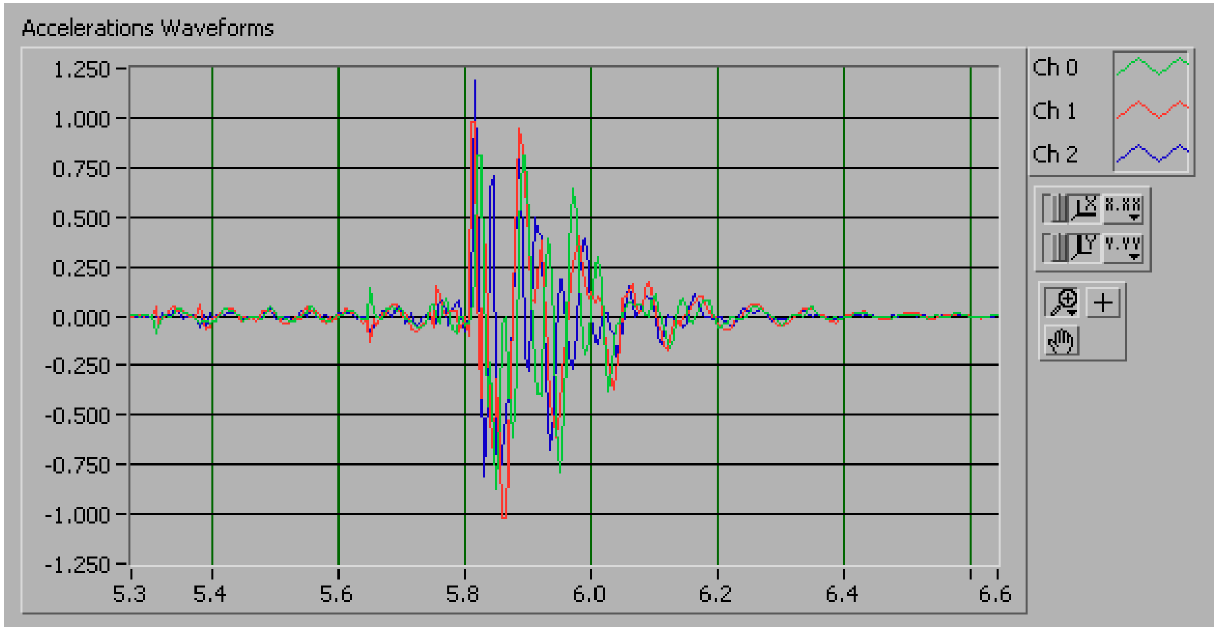
Canon A40 PowerShot Digital Camera

Example



Time Domain Data





Structural Identification Tools

The Fast Fourier Transform (FFT) and the Power Spectrum are powerful tools for analyzing and measuring signals.

FFTs and the Power Spectrum are useful for measuring the frequency content of stationary or transient signals. FFTs produce the average frequency content of a signal over the entire time that the signal was acquired.

Note: the frequency resolution $\Delta f = \dfrac{1}{N \cdot \Delta t}$

where, N is in the number of samples and Δt is the time increment.

Additional Resource: http://zone.ni.com/devzone/conceptd.nsf/webmain/C045A890751303A6862568650061EA98/$File/AN041.pdf

Power Spectrum

The power spectrum shows power as the mean squared amplitude at each frequency line but includes no phase information.

Because the power spectrum loses phase information, you may want to use the FFT to view both the frequency and the phase information of a signal.

The units of a power spectrum are often referred to as quantity squared rms, where quantity is the unit of the time-domain signal.

Fourier Transform

The FFT returns a two-sided spectrum in complex form (real and imaginary parts), which you must scale and convert to polar form to obtain magnitude and phase. The frequency axis is identical to that of the two-sided power spectrum. The amplitude of the FFT is related to the number of points in the time-domain signal.

The phase information the FFT yields is the phase relative to the start of the time-domain signal. For this reason, you must trigger from the same point in the signal to obtain consistent phase readings. In many cases, your concern is the relative phases between components, or the phase difference between two signals acquired simultaneously.

Cross Power Spectrum

The cross power spectrum is a useful tool for determining the phase difference between two signals.

The two-sided cross power spectrum of two time-domain signals A and B is computed as:

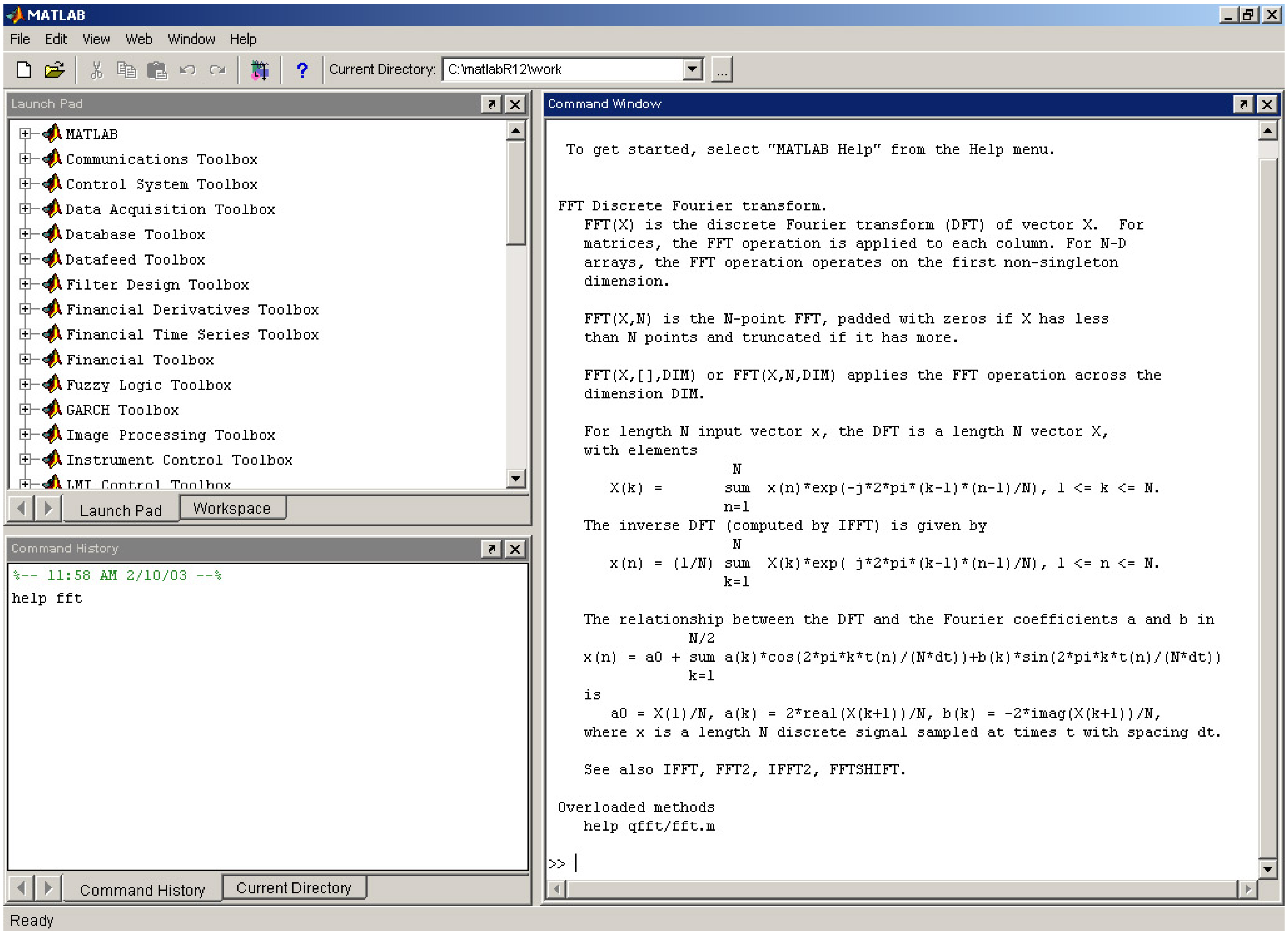
$$\text{Cross Power Spectrum } S_{AB}(f) = \frac{FFT(B) \times FFT^{*}(A)}{N^{2}}$$

These operations can be done in:

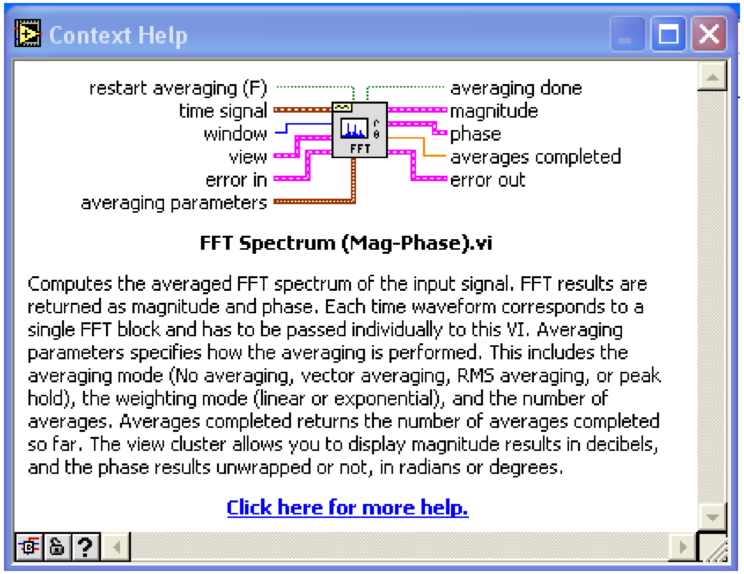
- Matlab
- LabVIEW
- Excel
- Fortran

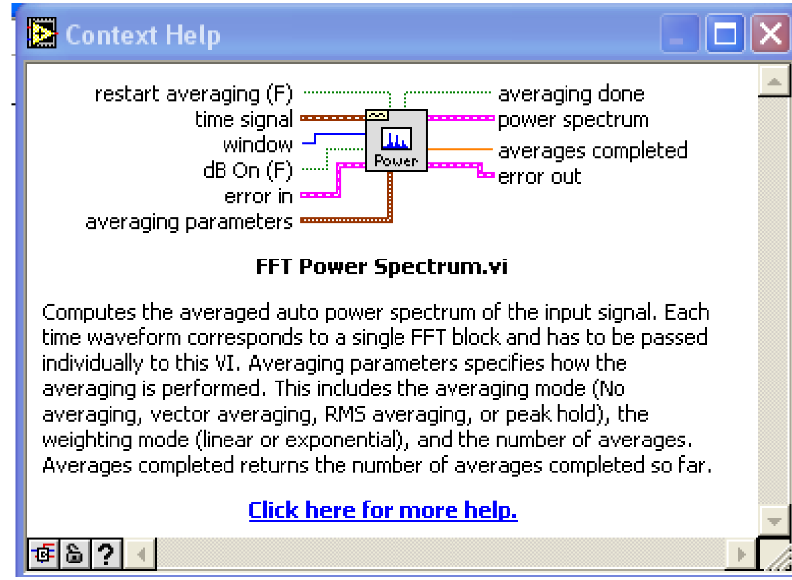
Matlab

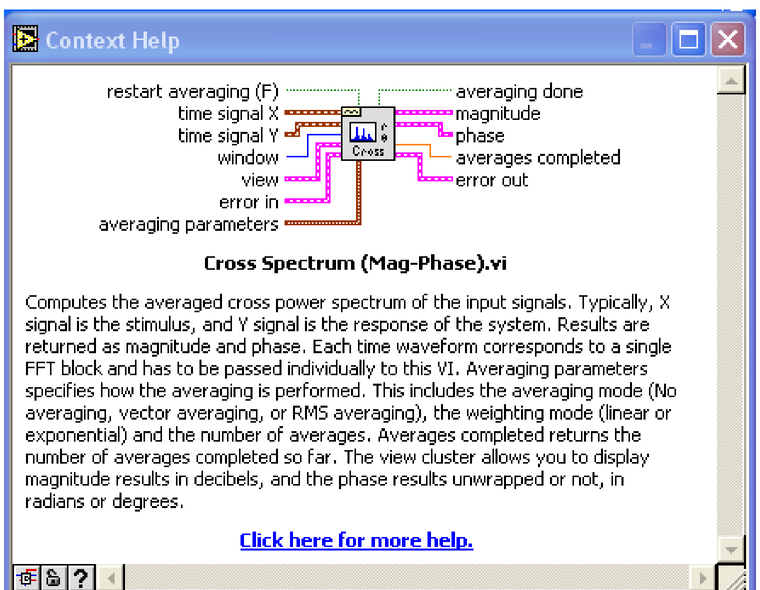
Type “help fft”

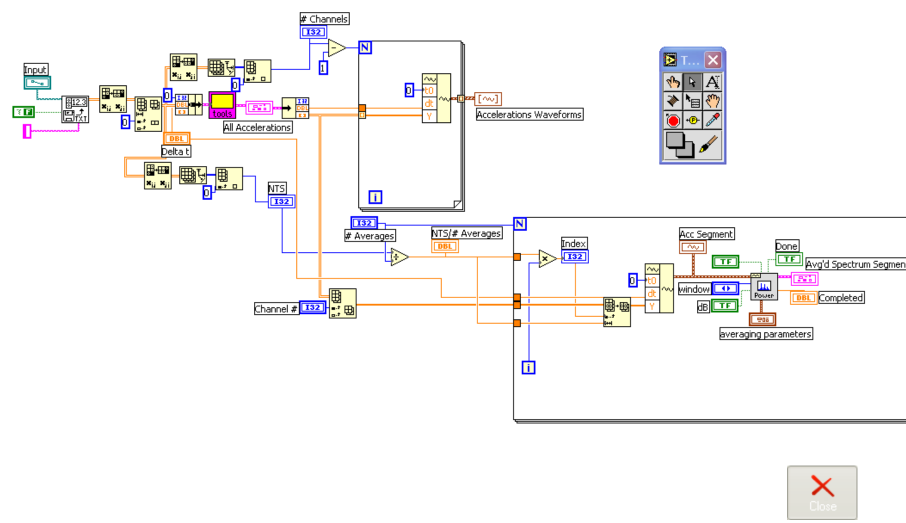


LabVIEW


Context Help
restart averaging (F)
time signal
window
view
error in
averaging parameters
averaging done
magnitude
phase
averages completed
error out
FFT
FFT Spectrum (Mag-Phase).vi
Computes the averaged FFT spectrum of the input signal. FFT results are returned as magnitude and phase. Each time waveform corresponds to a single FFT block and has to be passed individually to this VI. Averaging parameters specifies how the averaging is performed. This includes the averaging mode (No averaging, vector averaging, RMS averaging, or peak hold), the weighting mode (linear or exponential), and the number of averages. Averages completed returns the number of averages completed so far. The view cluster allows you to display magnitude results in decibels, and the phase results unwrapped or not, in radians or degrees.
Click here for more help.

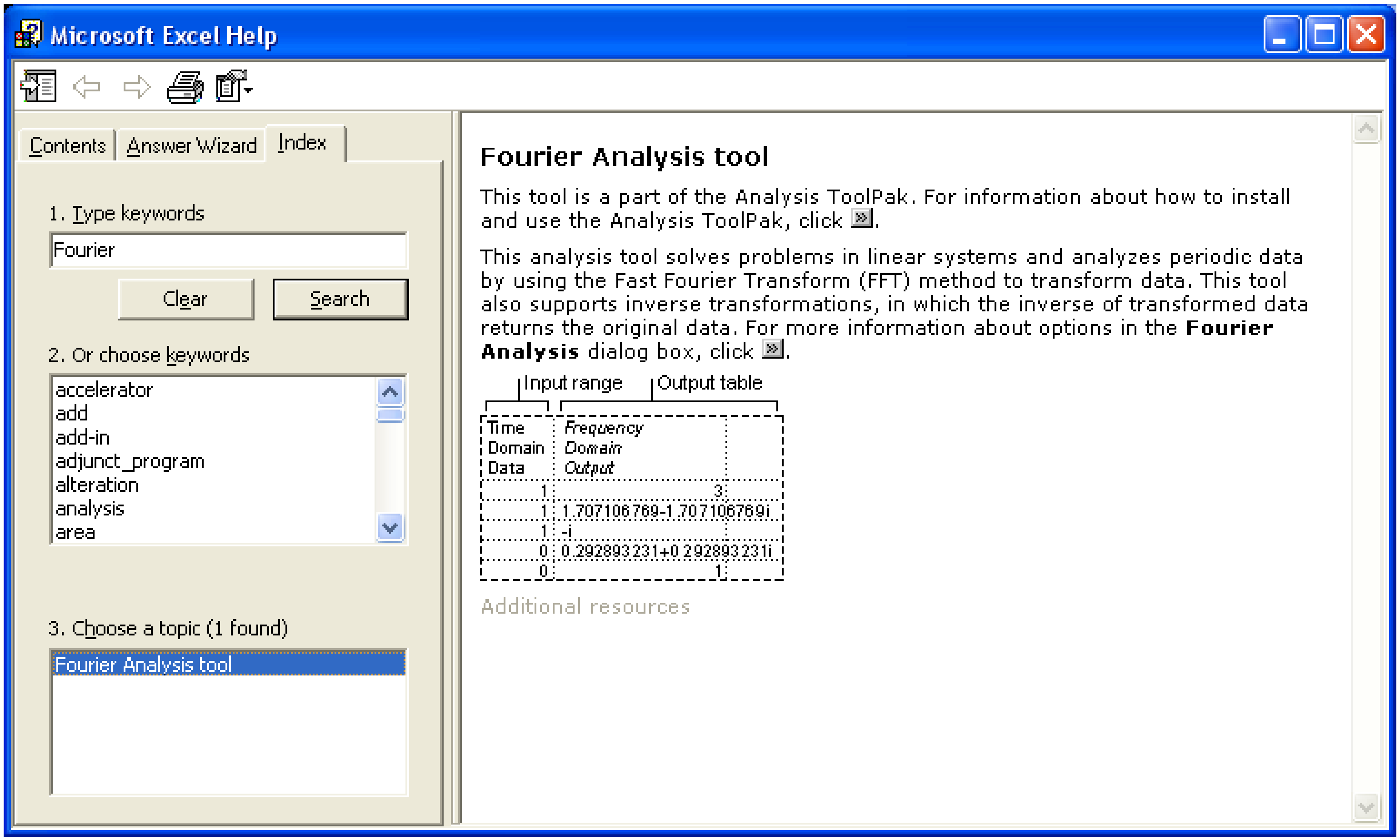

Context Help
restart averaging (F)
time signal
window
dB On (F)
error in
averaging parameters
averaging done
power spectrum
averages completed
error out
Power
FFT Power Spectrum.vi
Computes the averaged auto power spectrum of the input signal. Each time waveform corresponds to a single FFT block and has to be passed individually to this VI. Averaging parameters specifies how the averaging is performed. This includes the averaging mode (No averaging, vector averaging, RMS averaging, or peak hold), the weighting mode (linear or exponential), and the number of averages. Averages completed returns the number of averages completed so far.
Click here for more help.


Context Help
restart averaging (F)
time signal X
time signal Y
window
view
error in
averaging parameters
averaging done
magnitude
phase
averages completed
error out
Cross
Cross Spectrum (Mag-Phase).vi
Computes the averaged cross power spectrum of the input signals. Typically, X signal is the stimulus, and Y signal is the response of the system. Results are returned as magnitude and phase. Each time waveform corresponds to a single FFT block and has to be passed individually to this VI. Averaging parameters specifies how the averaging is performed. This includes the averaging mode (No averaging, vector averaging, or RMS averaging), the weighting mode (linear or exponential), and the number of averages. Averages completed returns the number of averages completed so far. The view cluster allows you to display magnitude results in decibels, and the phase results unwrapped or not, in radians or degrees.
Click here for more help.


Input
Channels
Accelerations Waveforms
All Accelerations
Delta t
NTS
Averages
NTS/# Averages
Channel #
Index
Acc Segment
Done
Avg'd Spectrum Segment
window
dB
Completed
averaging parameters
Close

Excel

This operation requires the Analysis ToolPak



Fortran (or similar)

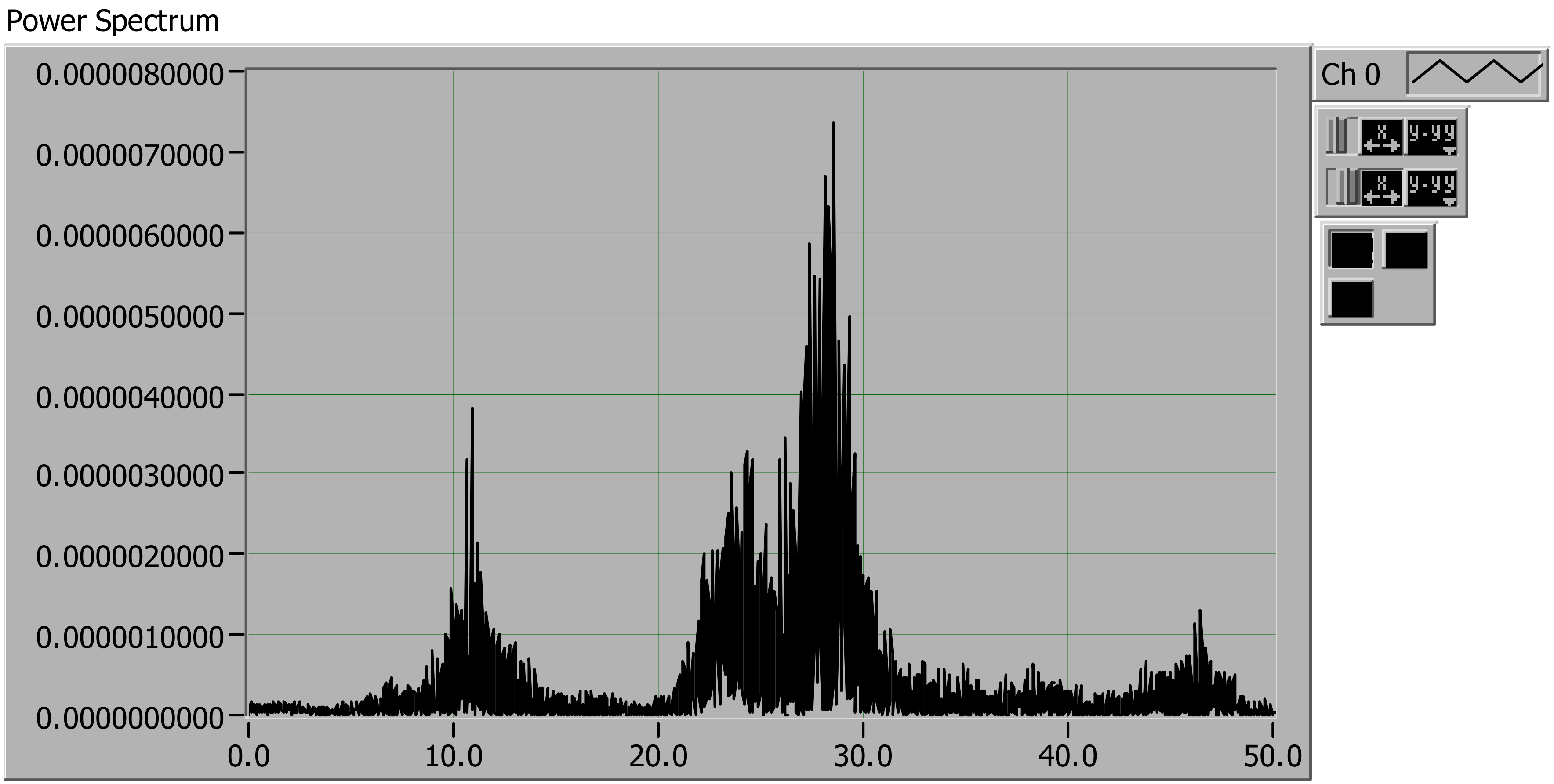
```
      program main
C MAIN PROGRAM CALLS SUBROUTINE FFT WHICH IS FROM
C JOHN F. HALL (1982). "AN FFT ALGORITHM FOR STRUCTURAL DYNAMICS",
C EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS, VOL.10, PP.797-81
        DIMENSION a(33000)
        INTEGER power,n,nn
        open(10,file='acc.txt',
     &     status='old')
        open(20,file='fft.txt',
     &     status='unknown')
        n=0
        a=0.0
        DO WHILE (.NOT. EOF(10))
         n = n + 1
           read(10,*) time,a(n)
           if (n.eq.1) time1 = time
           if (n.eq.2) time2 = time
      END DO
        dt = time2 - time1
        if (MOD(n, 2)/=0) then
           n = n+1
        endif
        nn = 2
        power = 1
        DO WHILE (nn < n)
           nn = 2*nn
           power = power + 1
      END DO
        L=2; M = power-1;
        CALL FFT(a,M,L,0,0,1.0 )
        df = 1/(nn*dt)
        f=0.0; amplitude=abs(a(1)); phase_angle = ATAN2D(0.,a(1))
        write(20,100) f, amplitude, phase_angle

.                          .
.                          .
.                          .
```

For more information see:

John F. Hall (1982). "AN FFT ALGORITHM FOR STRUCTURAL DYNAMICS", EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS, VOL.10, PP.797-811.

Example: Power Spectrum



Averaging

To smooth the spectrum, we need to average the data.

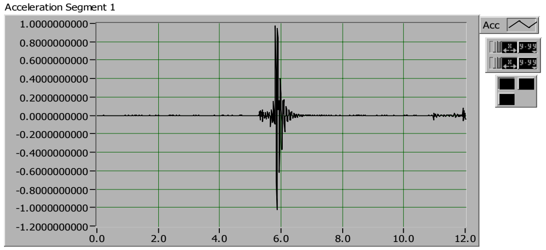
This can be done by:

1. **Splitting the time history into a number of equally sized segments.**
2. **Performing an FFT (or Cross Spectrum) on each of the segments.**
3. **Averaging each of these segments (Magnitude & Phase).** Start by converting to complex form (Real and Imaginary). Then sum the two real components at each increment of frequency and then divide by the number of averages. Do the same for the imaginary. When you are done, convert back to magnitude and phase.

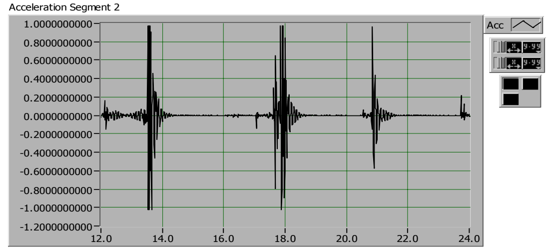
For our beam example:

1. Split the time history into 10 segments each 12 seconds long.

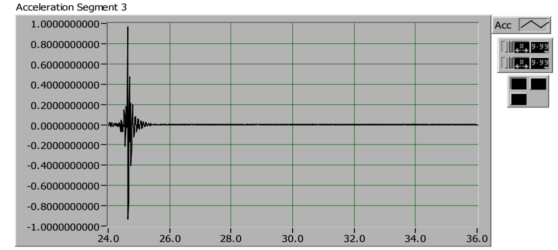
Acceleration Segment 1



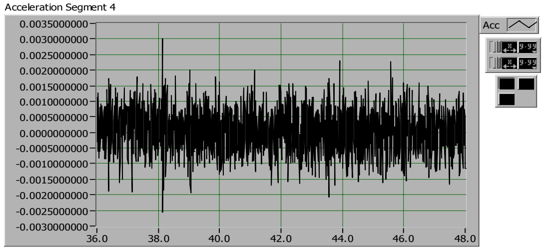
Acceleration Segment 2



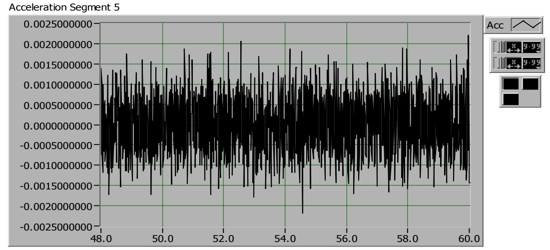
Acceleration Segment 3



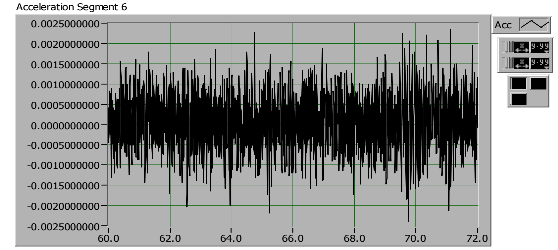
Acceleration Segment 4



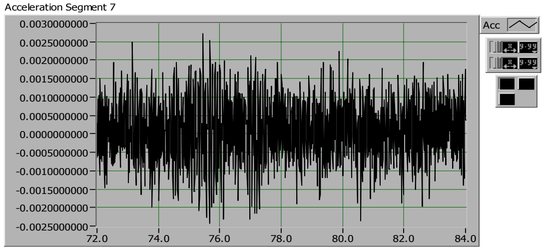
Acceleration Segment 5



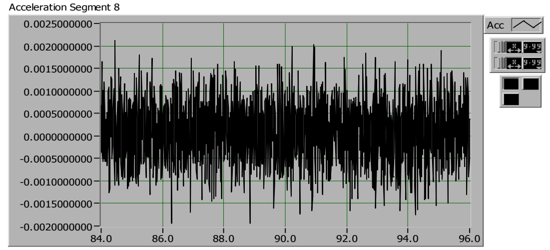
Acceleration Segment 6



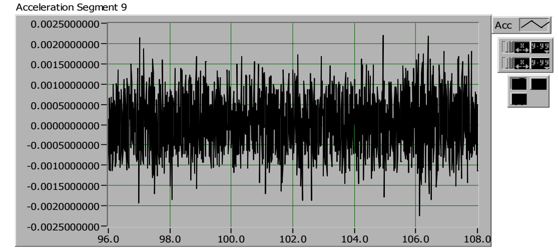
Acceleration Segment 7



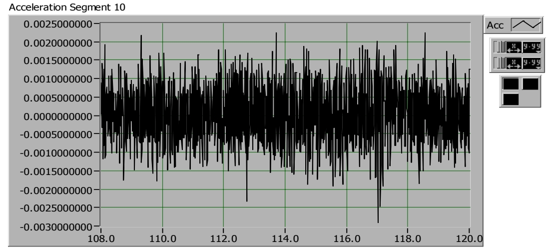
Acceleration Segment 8



Acceleration Segment 9



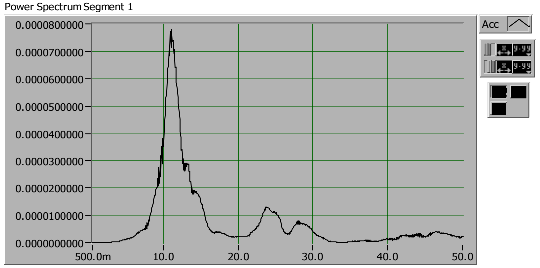
Acceleration Segment 10



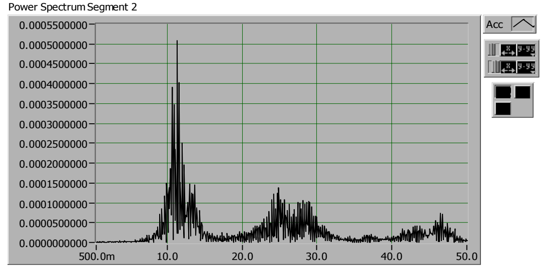
For our beam example:

2. Perform the Power Spectrum on each of the segments.

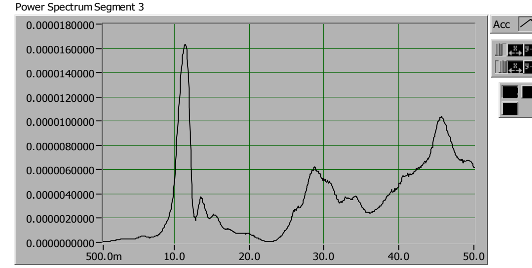
Power Spectrum Segment 1



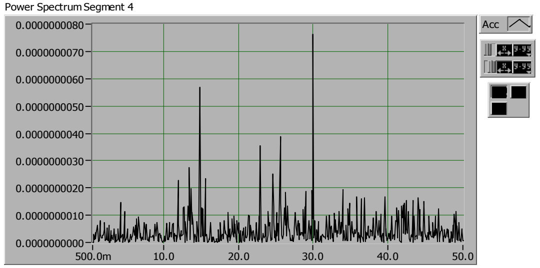
Power Spectrum Segment 2



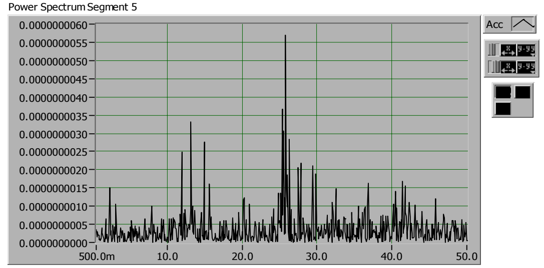
Power Spectrum Segment 3



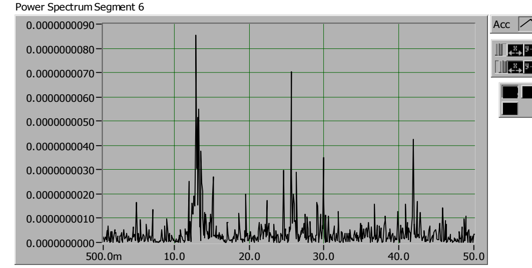
Power Spectrum Segment 4



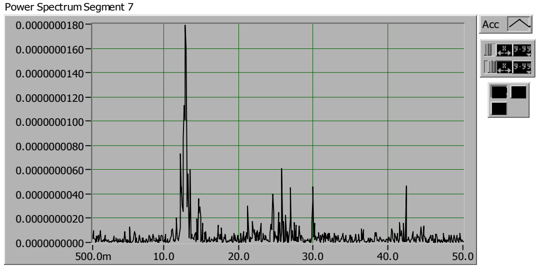
Power Spectrum Segment 5



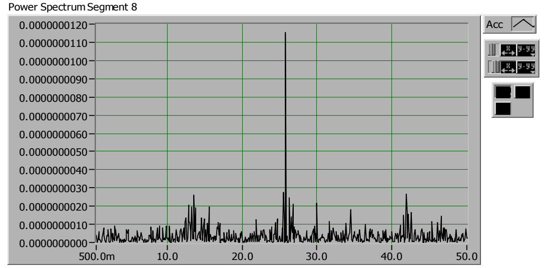
Power Spectrum Segment 6



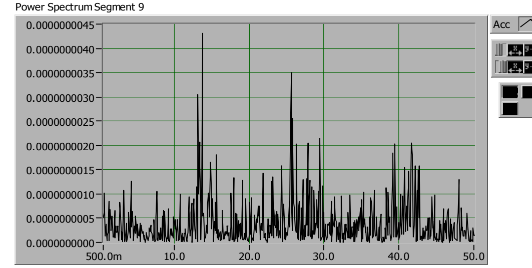
Power Spectrum Segment 7



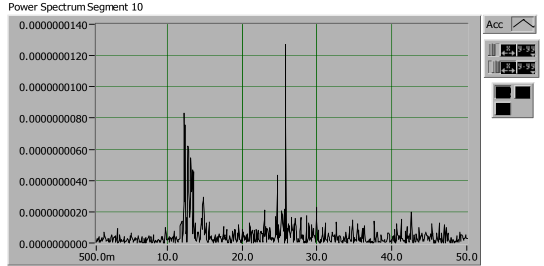
Power Spectrum Segment 8



Power Spectrum Segment 9



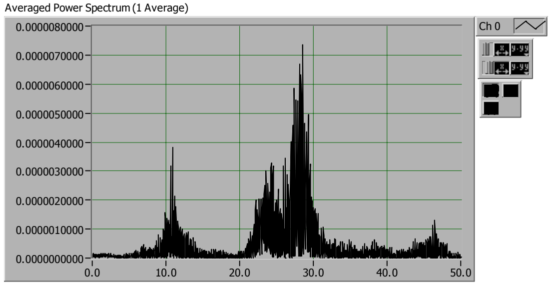
Power Spectrum Segment 10



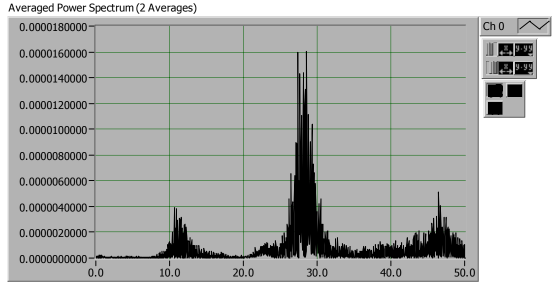
For our beam example:

3. Average each of the segments

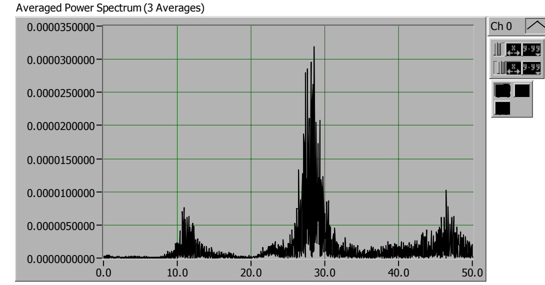
Averaged Power Spectrum (1 Average)



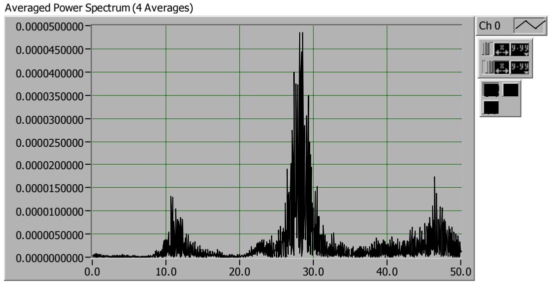
Averaged Power Spectrum (2 Averages)



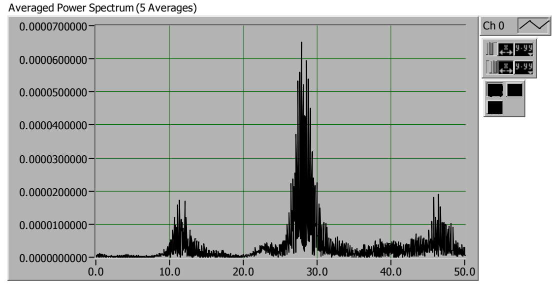
Averaged Power Spectrum (3 Averages)



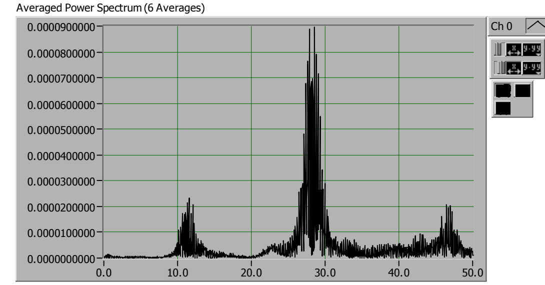
Averaged Power Spectrum (4 Averages)



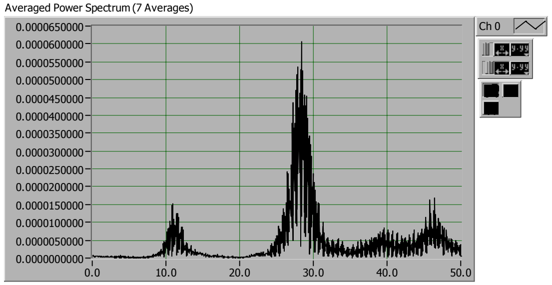
Averaged Power Spectrum (5 Averages)



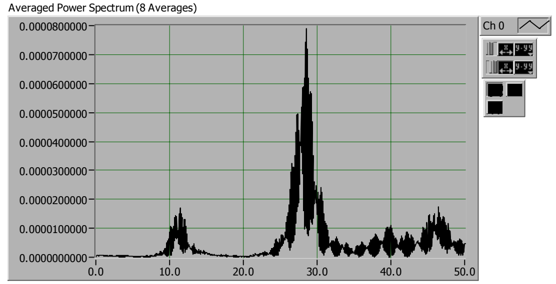
Averaged Power Spectrum (6 Averages)



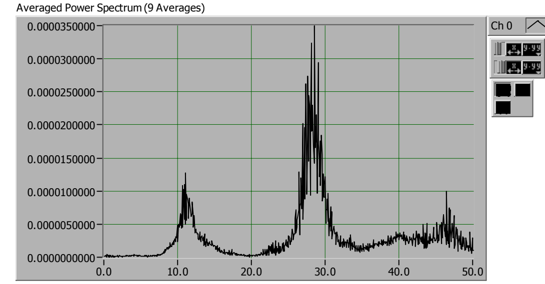
Averaged Power Spectrum (7 Averages)



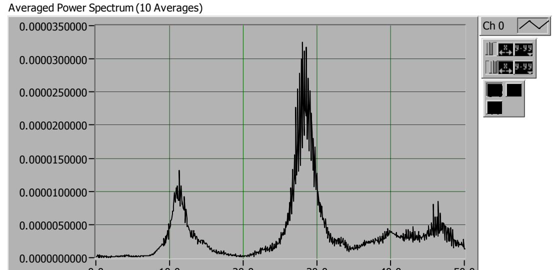
Averaged Power Spectrum (8 Averages)



Averaged Power Spectrum (9 Averages)

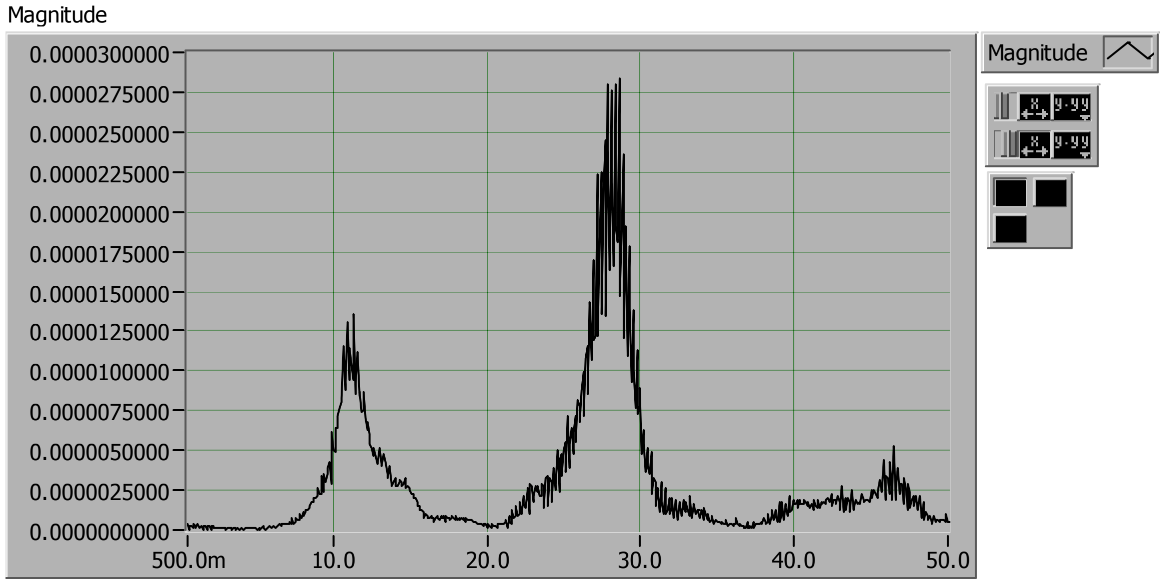


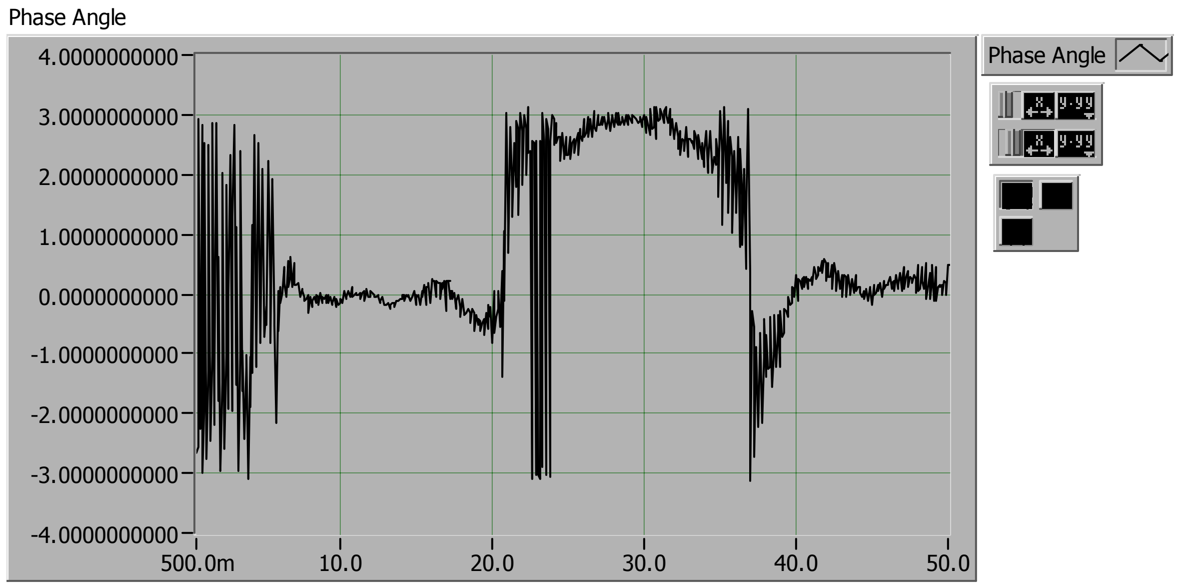
Averaged Power Spectrum (10 Averages)



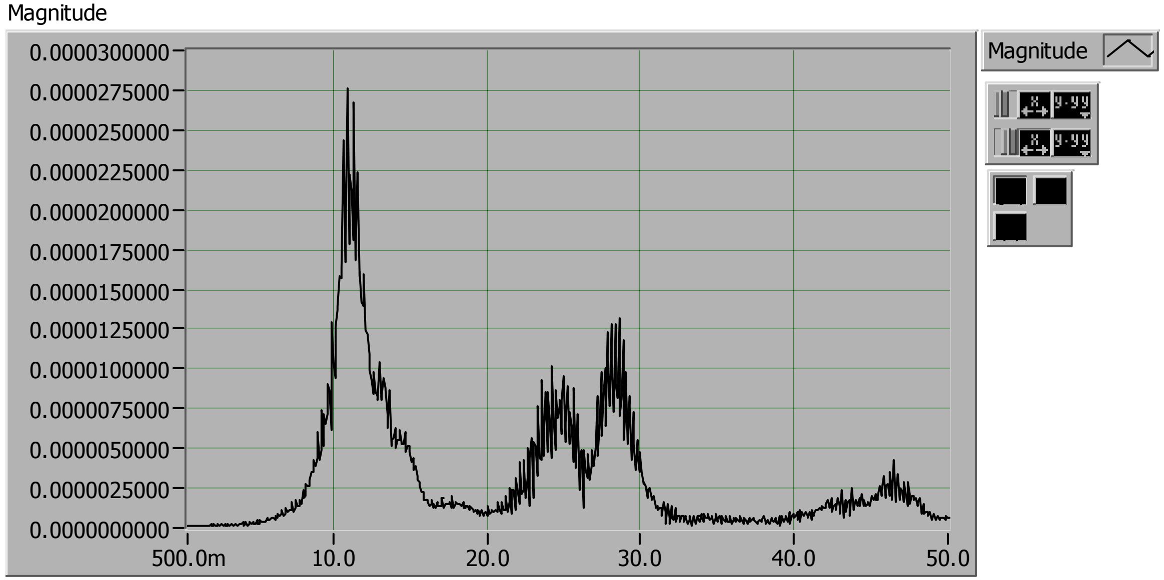
Do the Same for the Phase Angle

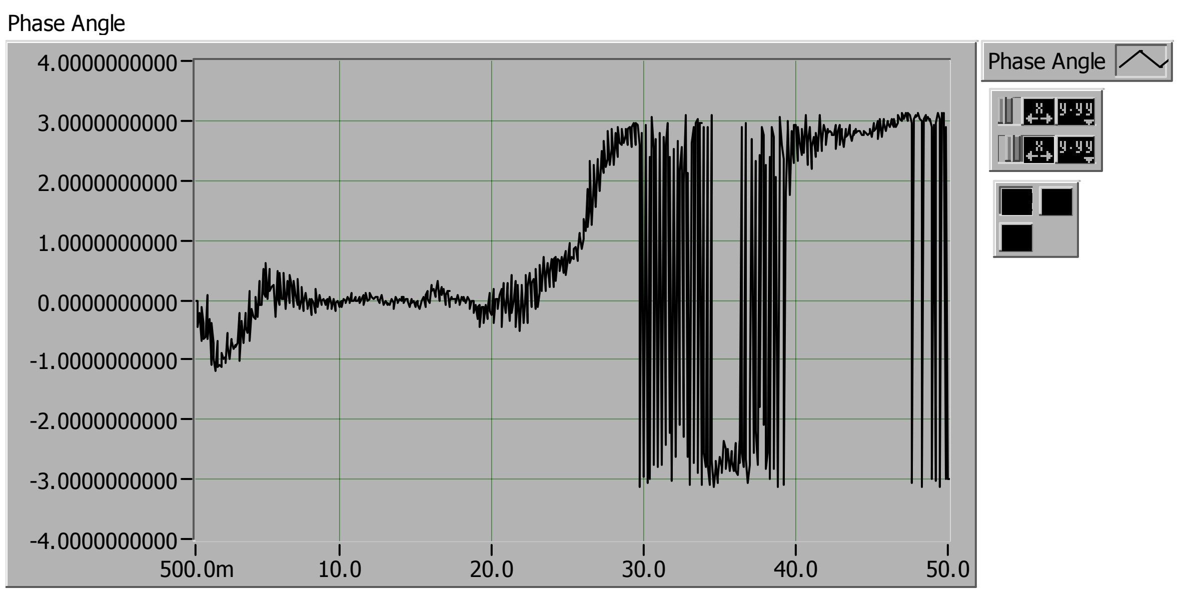
Cross Spectrum Channels 0 & 2





Cross Spectrum Channels 0 & 1



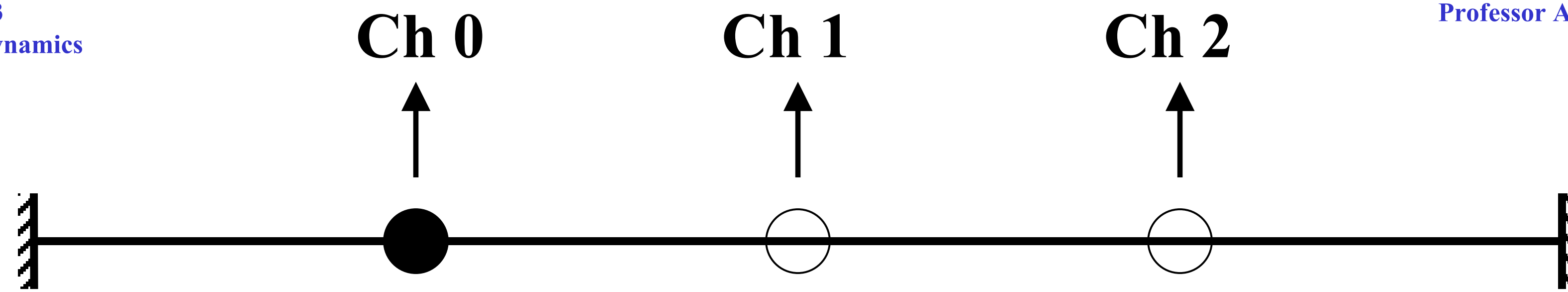


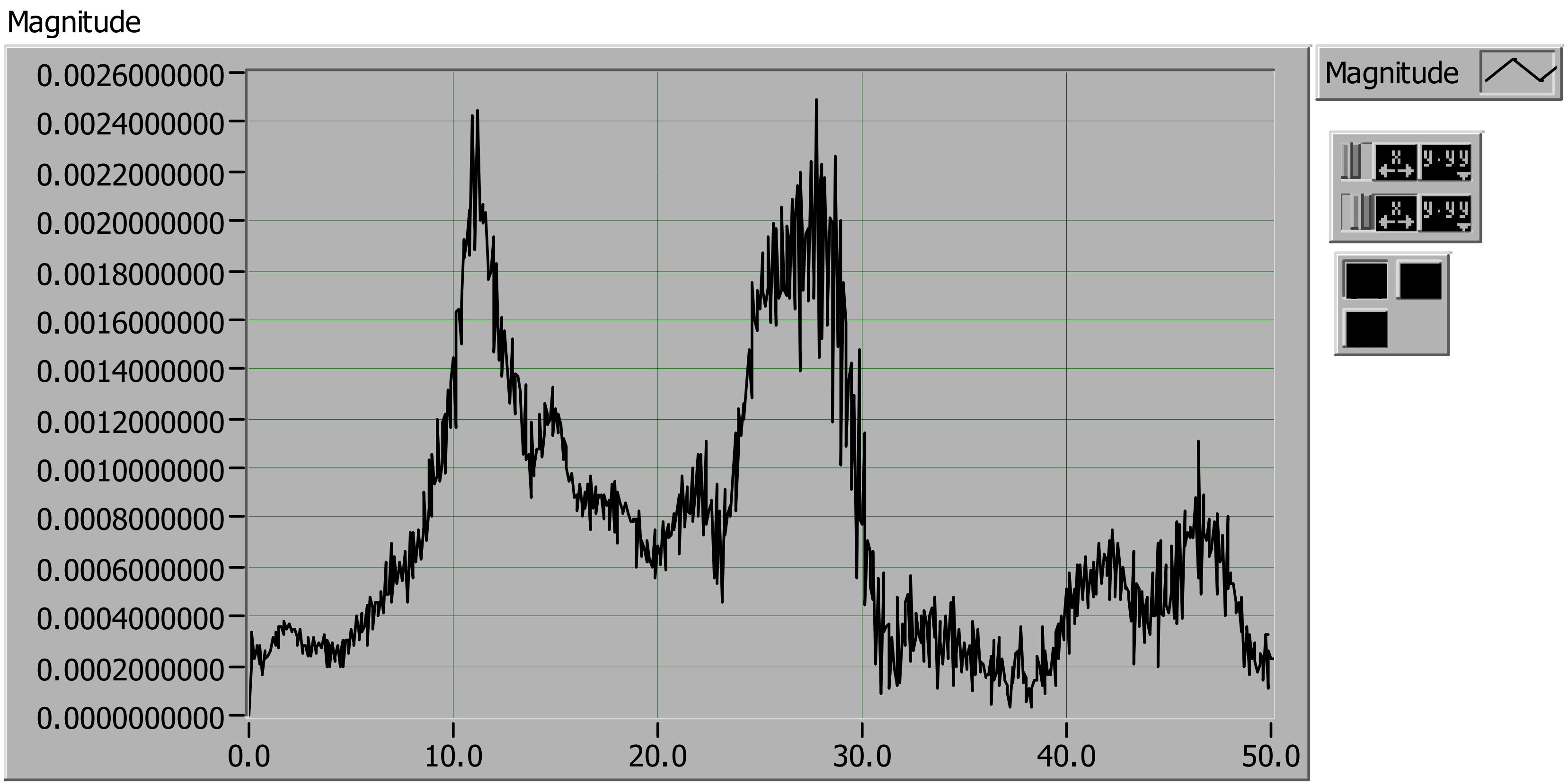
Construct the Mode Shapes

1. **From the Magnitude, determine the relative amplitude.**

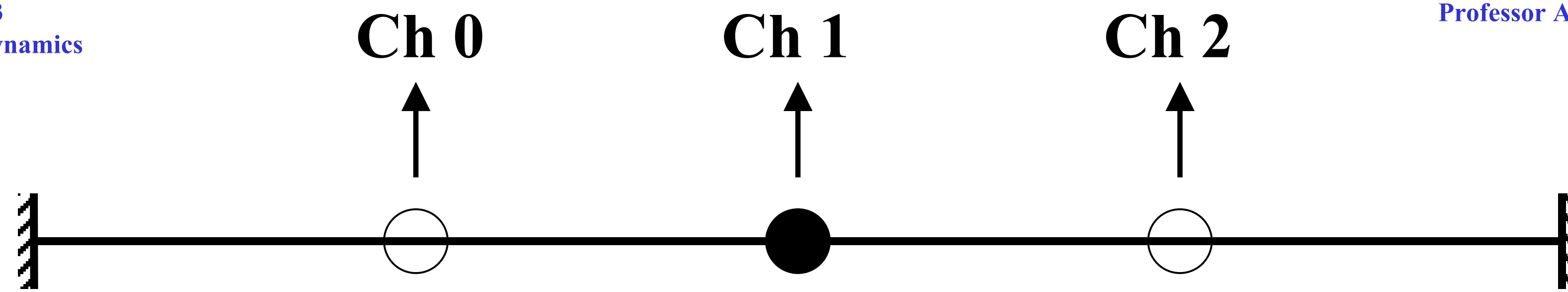
2. **From the Phase Angle, determine the sign.**

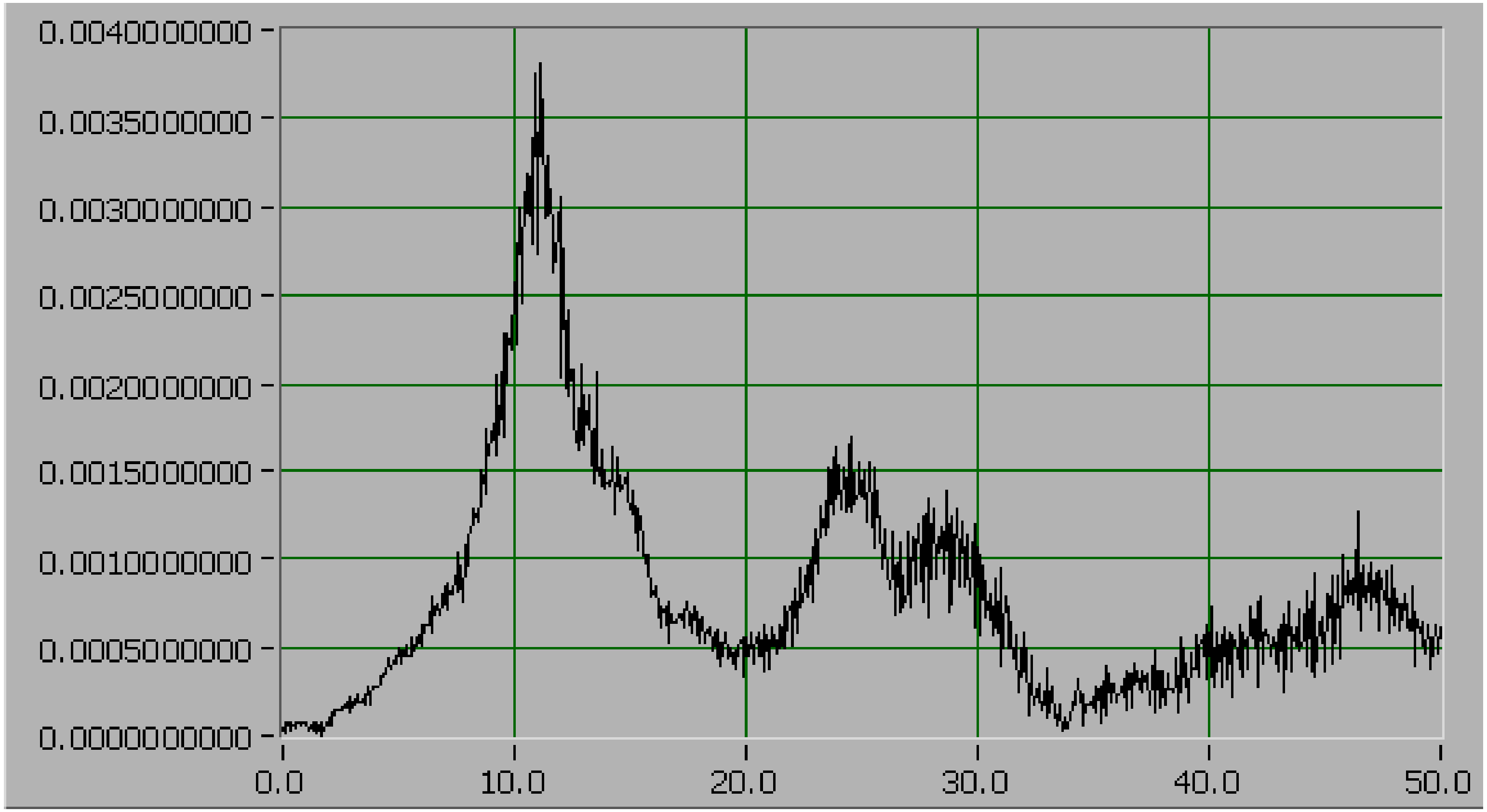
For our example, let's start with the 1^{st} mode



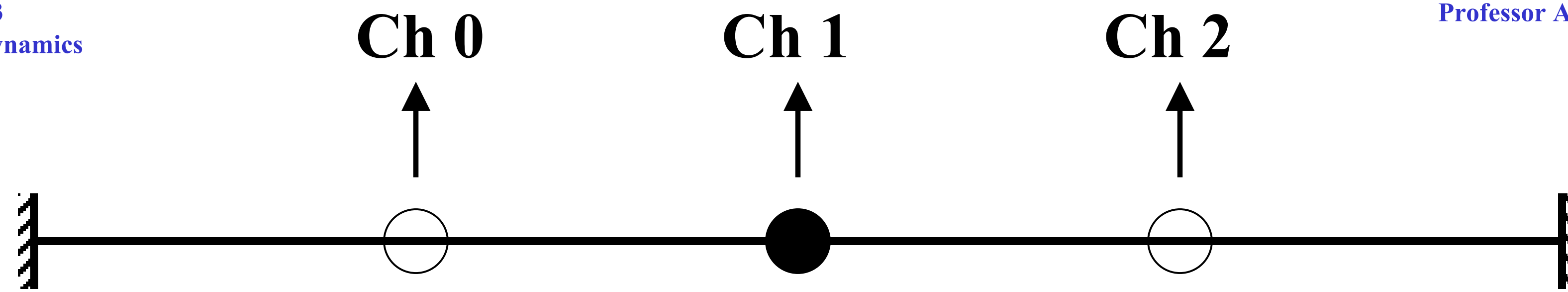


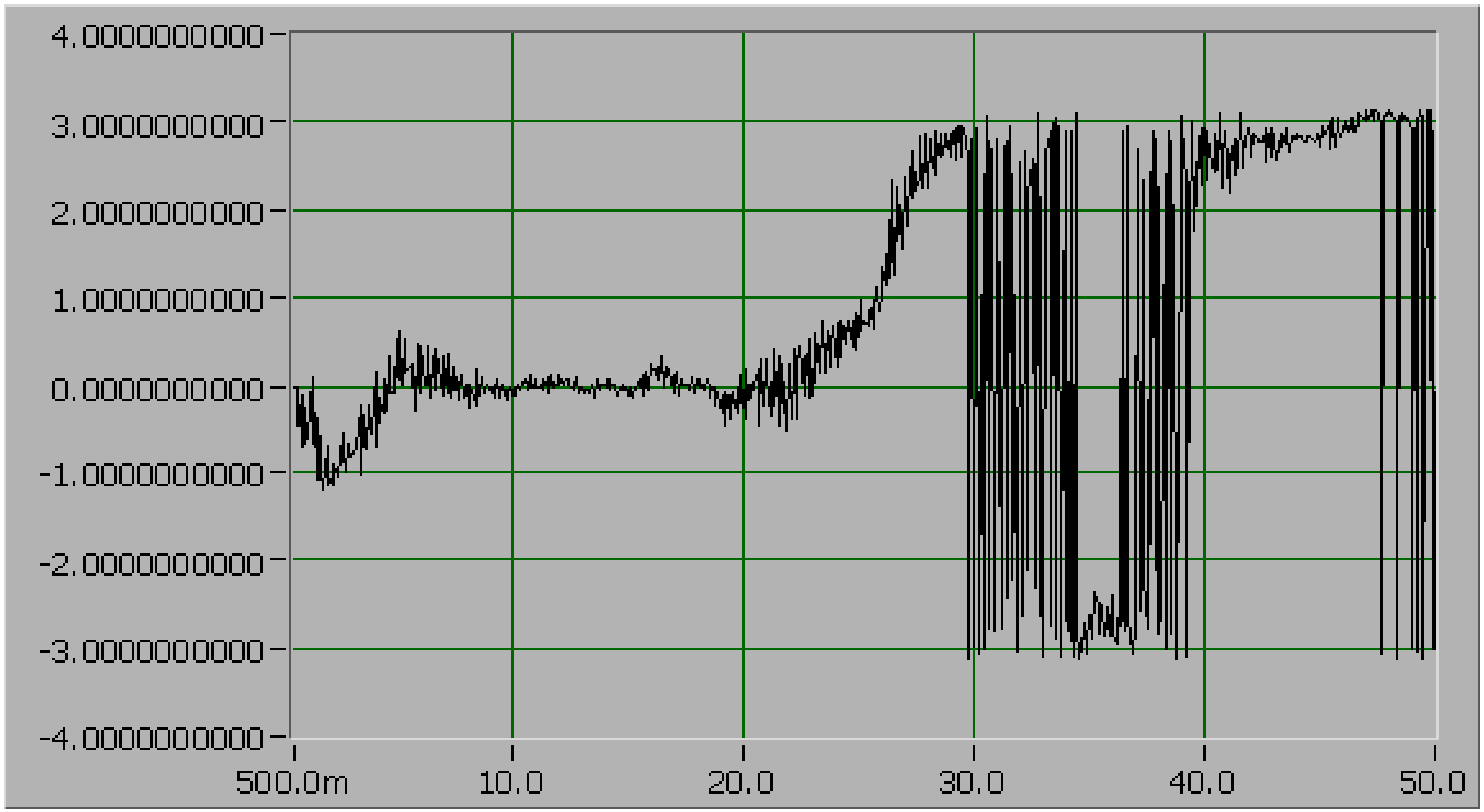
At 11 Hz, the amplitude at Ch 0 is 0.00245. We will let this location be our reference location.



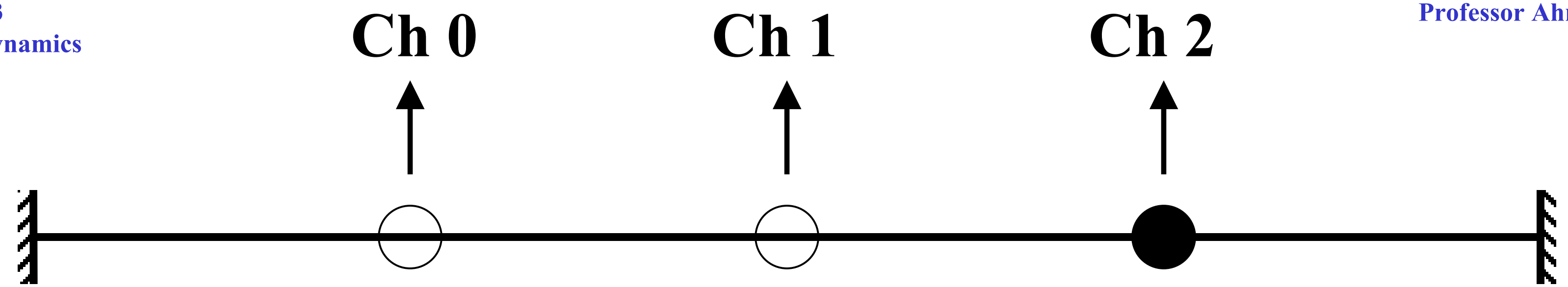


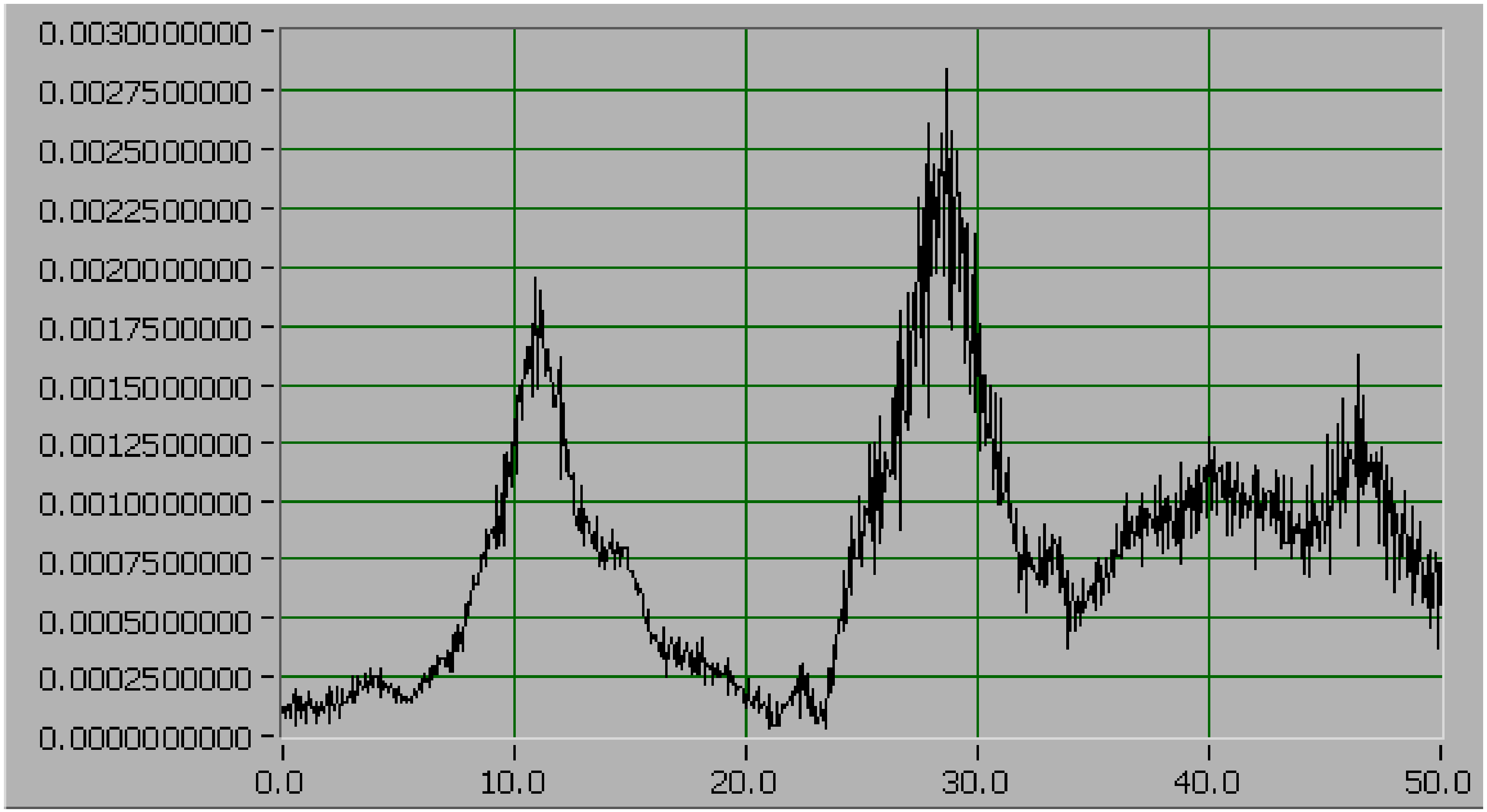
At 11 Hz, the amplitude at Ch 1 is 0.00382.



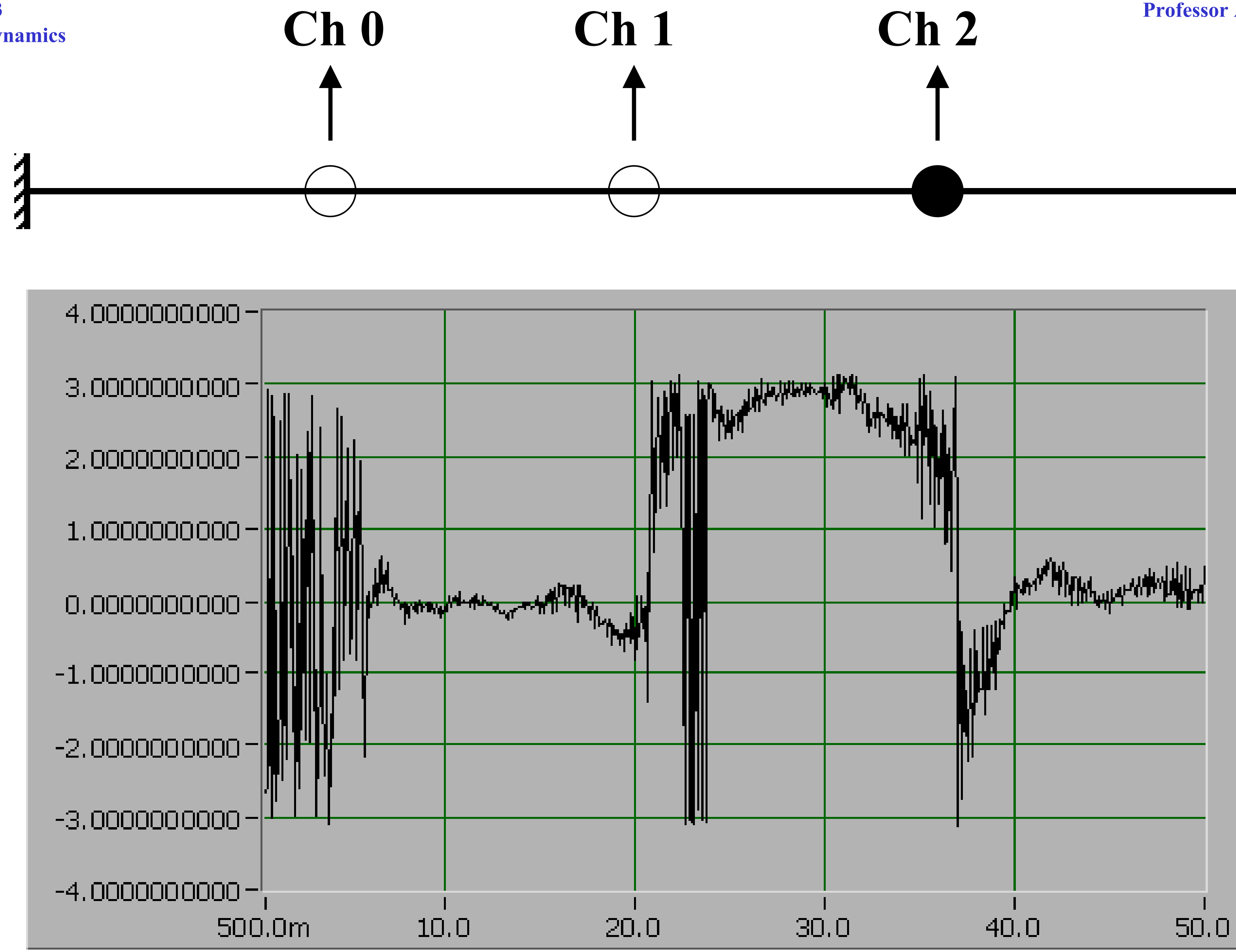


At 11 Hz, the Phase Angle is 0; therefore, locations 0 & 1 are in phase (we will define this as positive).



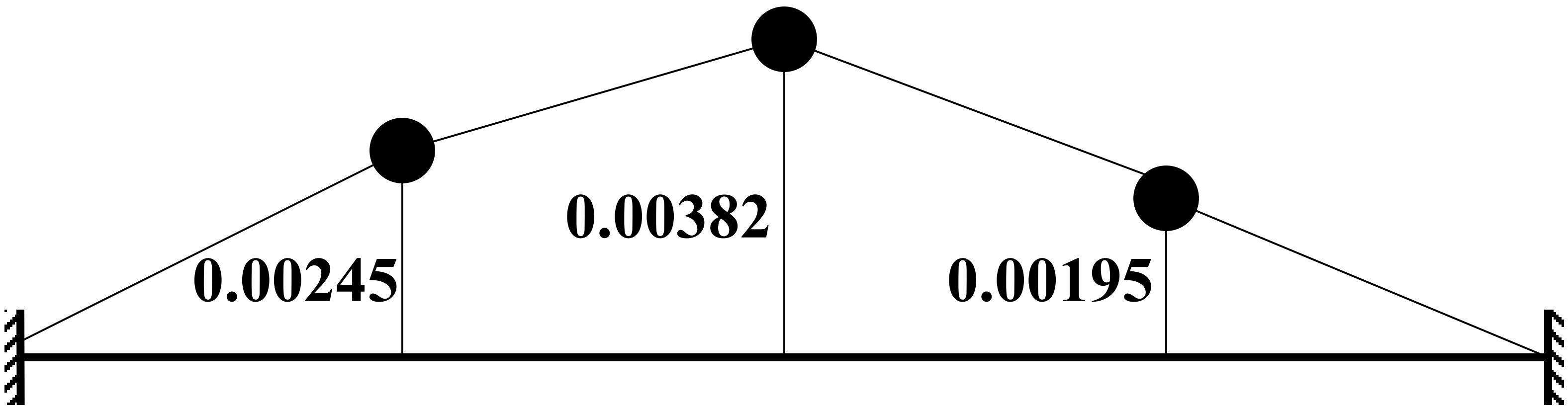


At 11 Hz, the amplitude at Ch 2 is 0.00195.

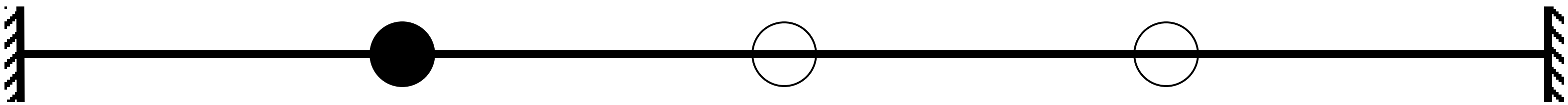


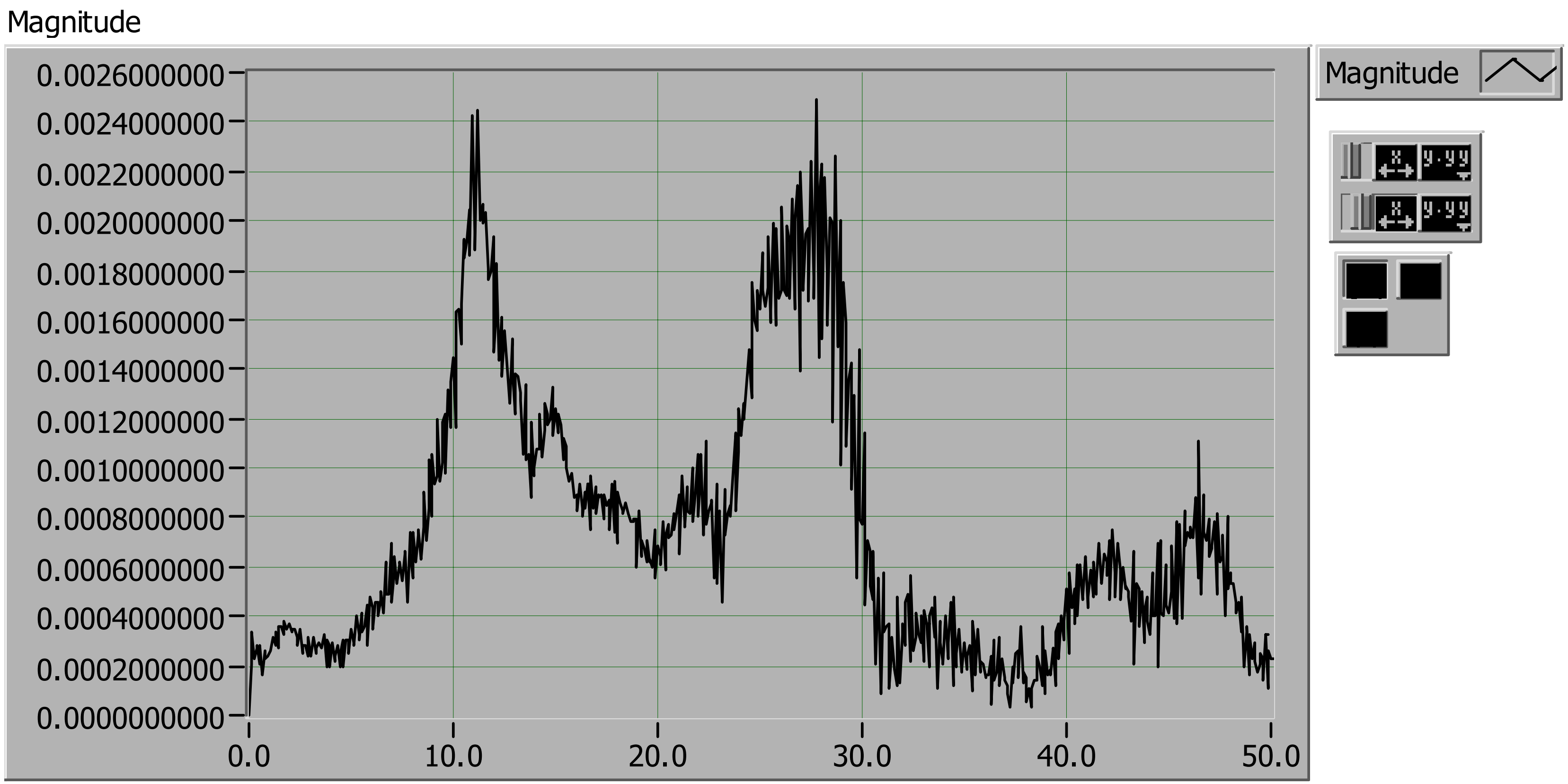
At 11 Hz, the Phase Angle is 0; therefore, locations 0 & 2 are in phase (positive sign).

First Mode Shape

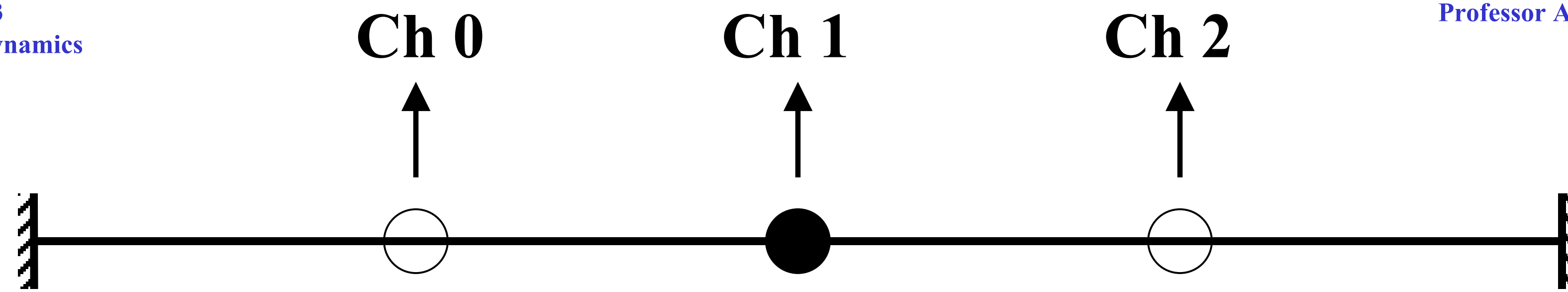


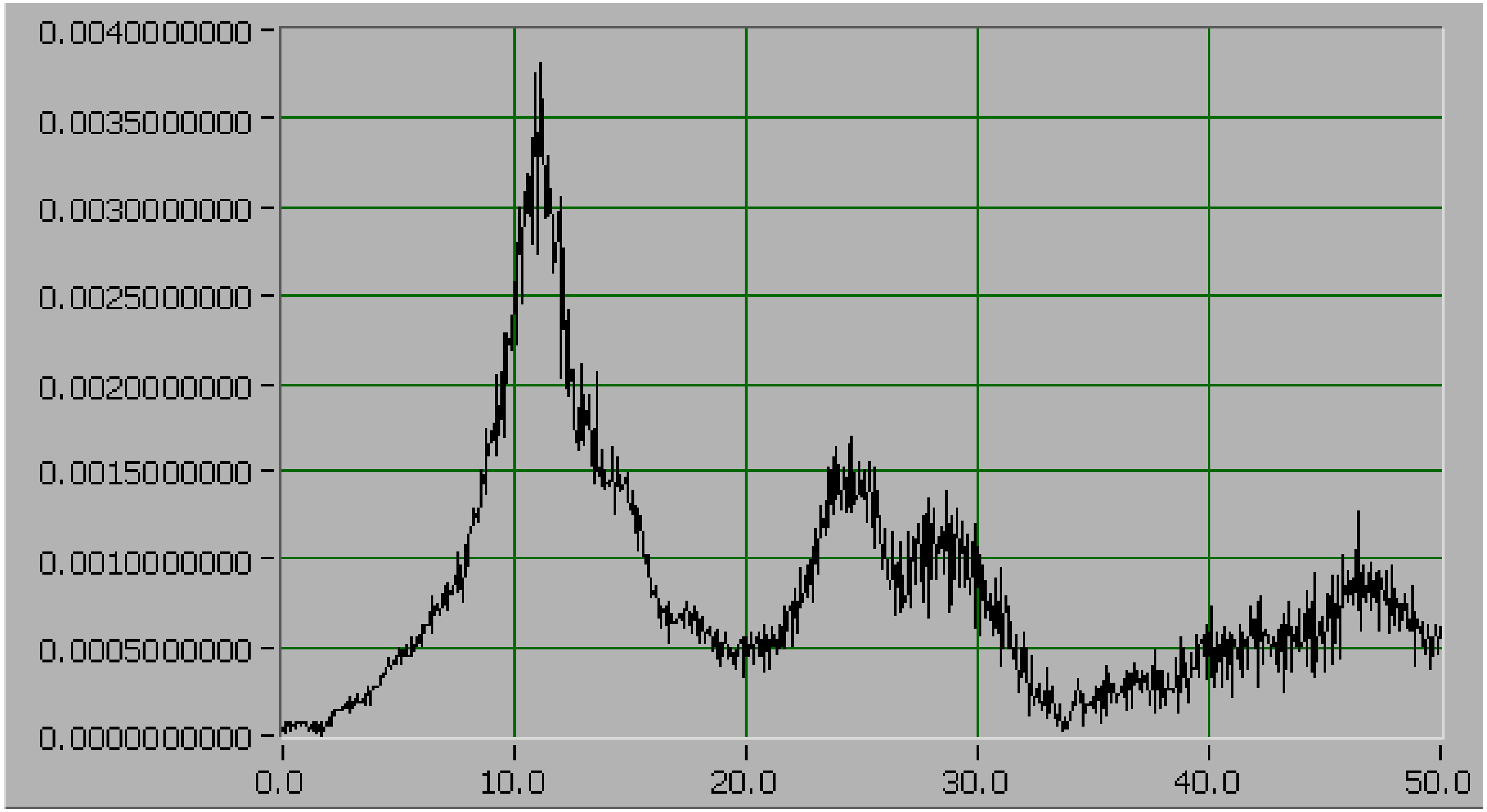
Repeat for the 2^{nd} Mode



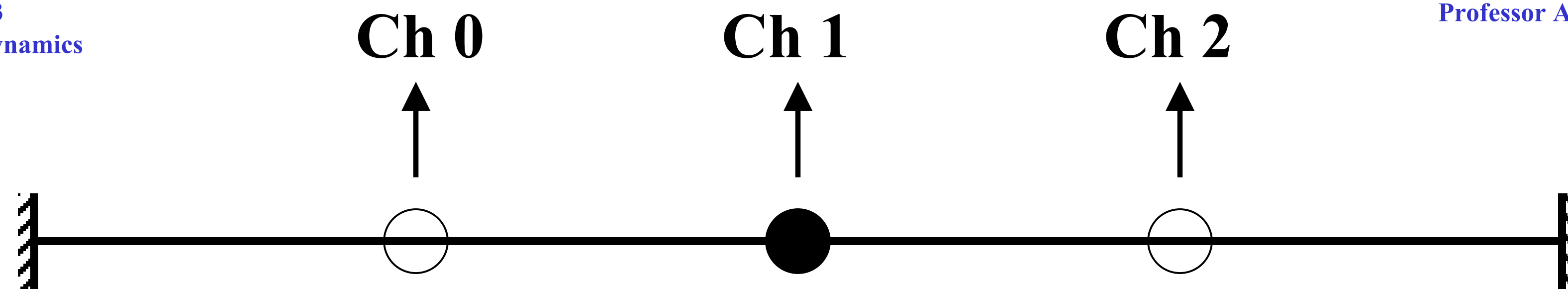


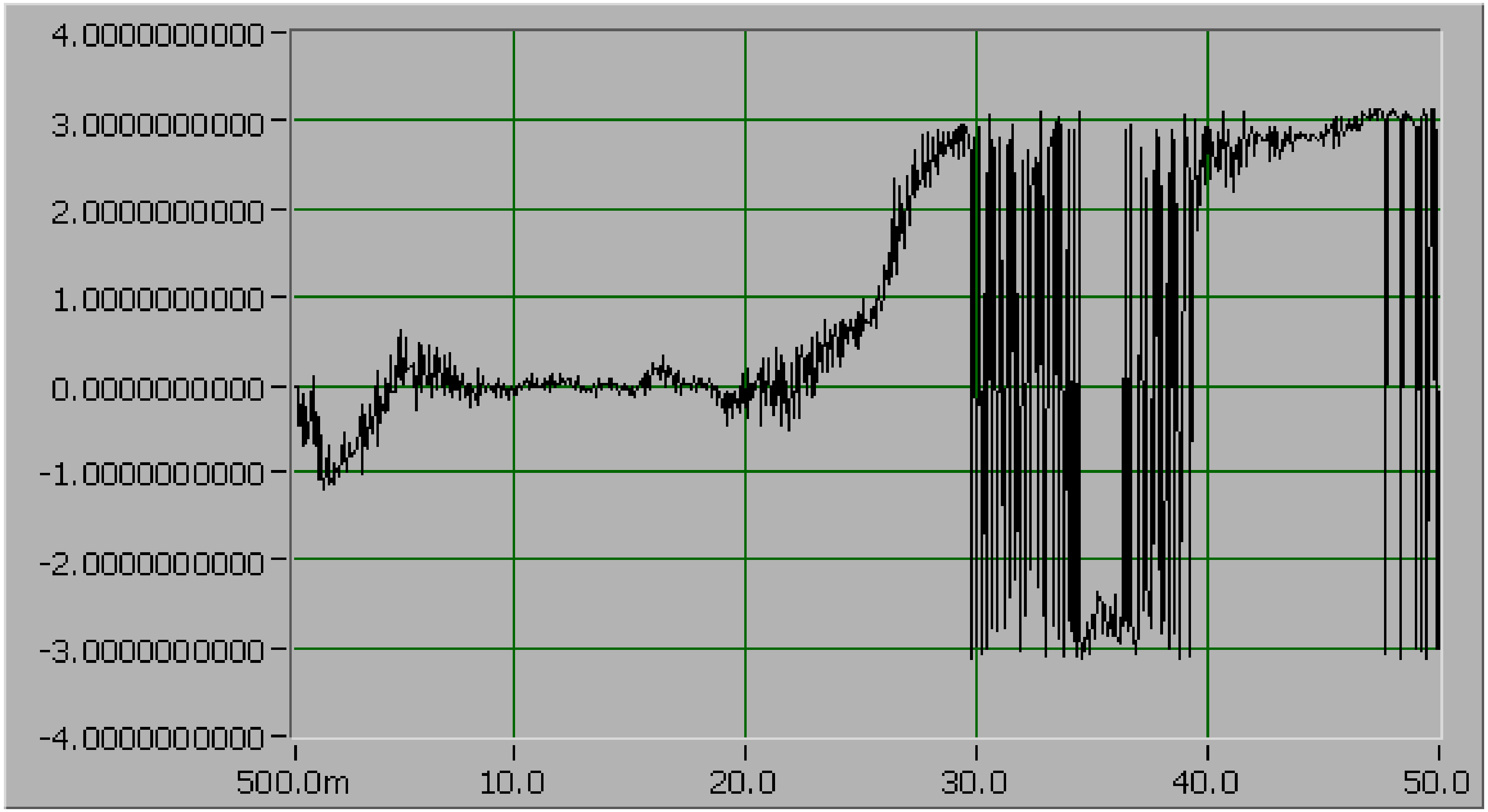
At 28 Hz, the amplitude at Ch 0 is 0.0022. We will let this location be our reference location.



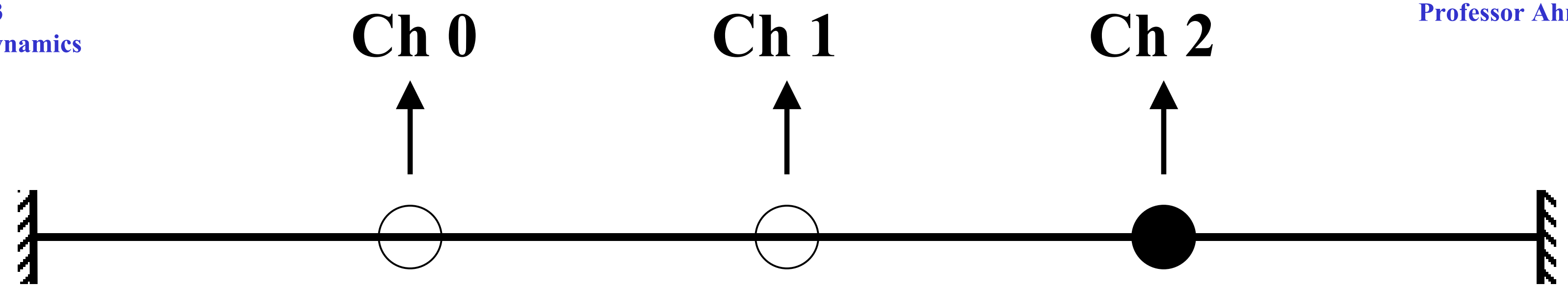


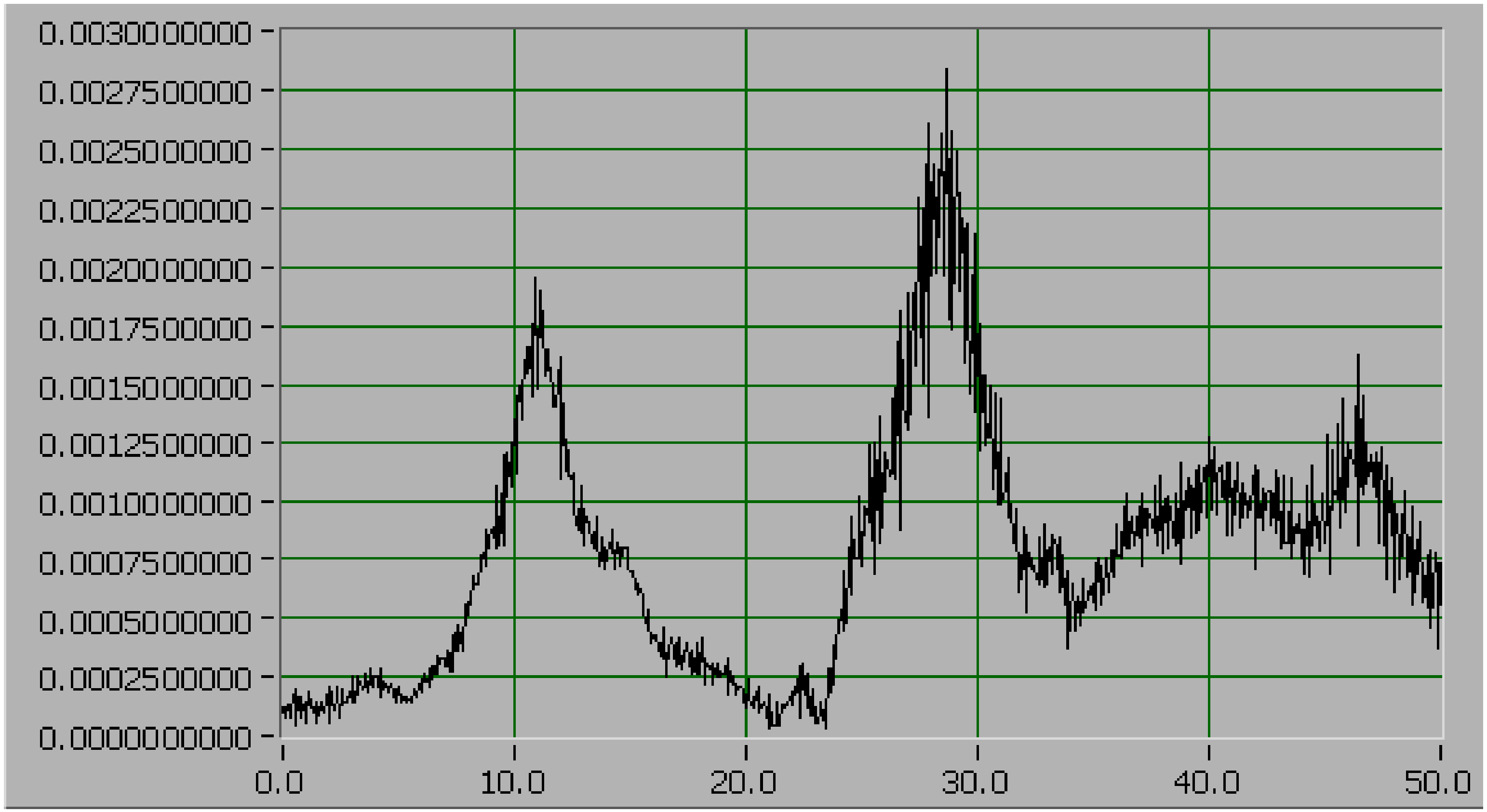
At 28 Hz, the amplitude at Ch 1 is 0.0013.



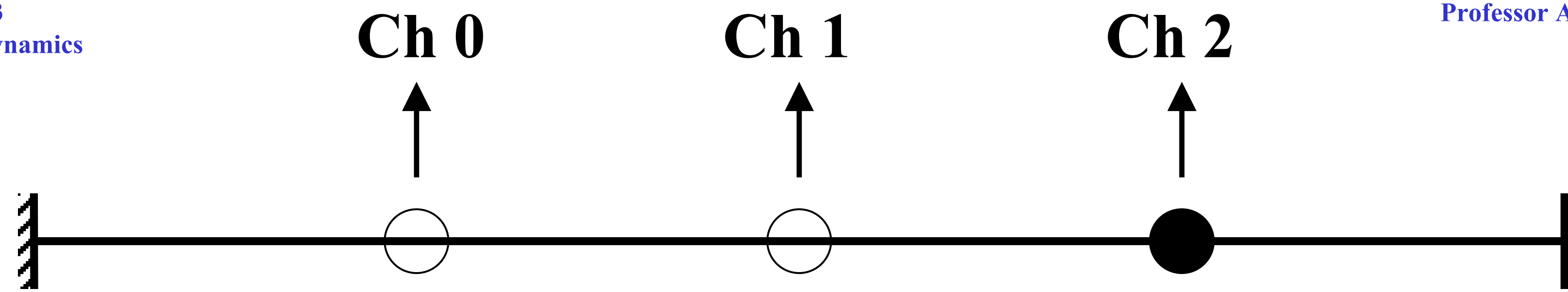


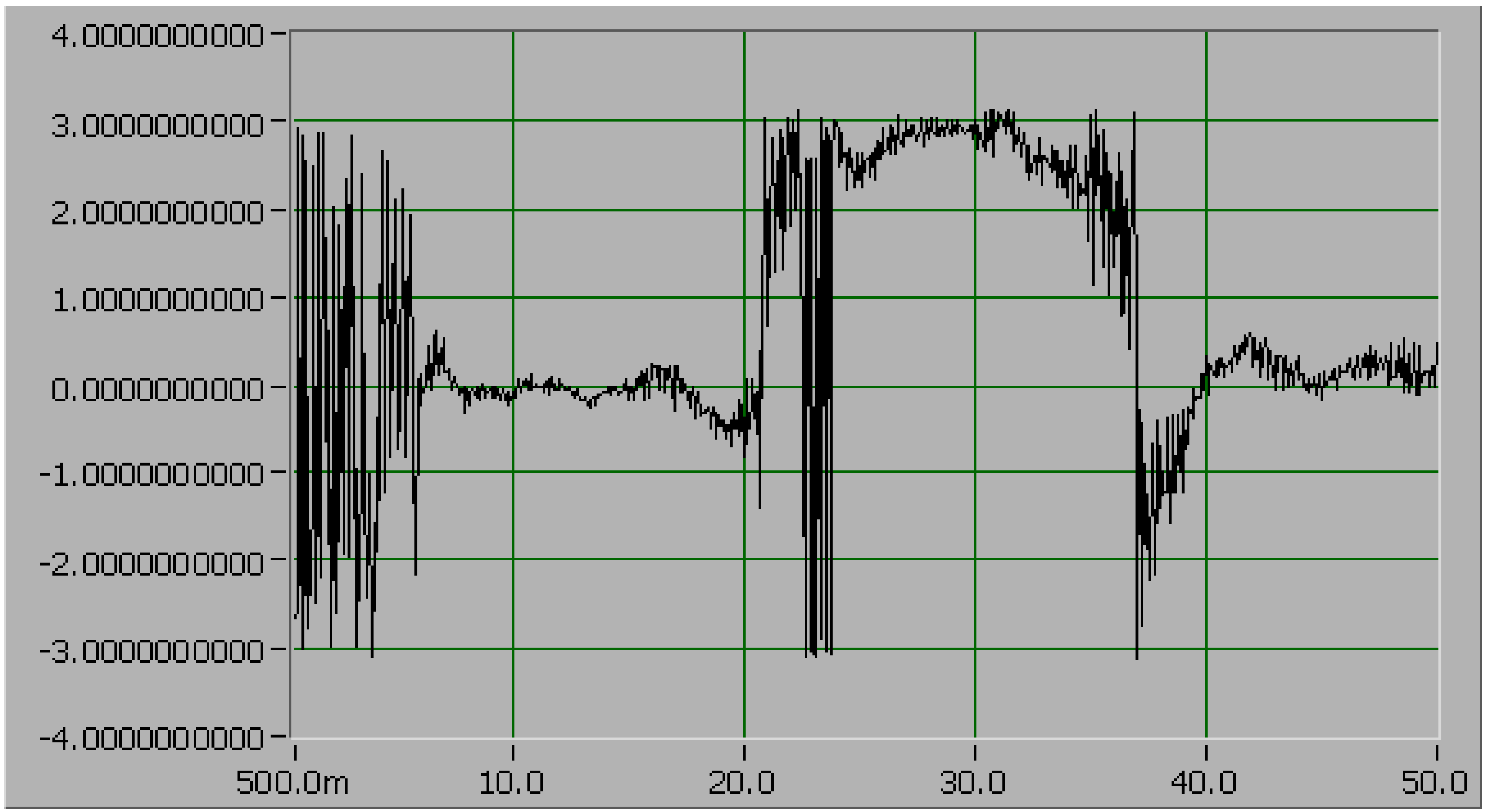
At 28 Hz, the Phase Angle is π; therefore, locations 0 & 1 are out of phase (we will define this as negative).





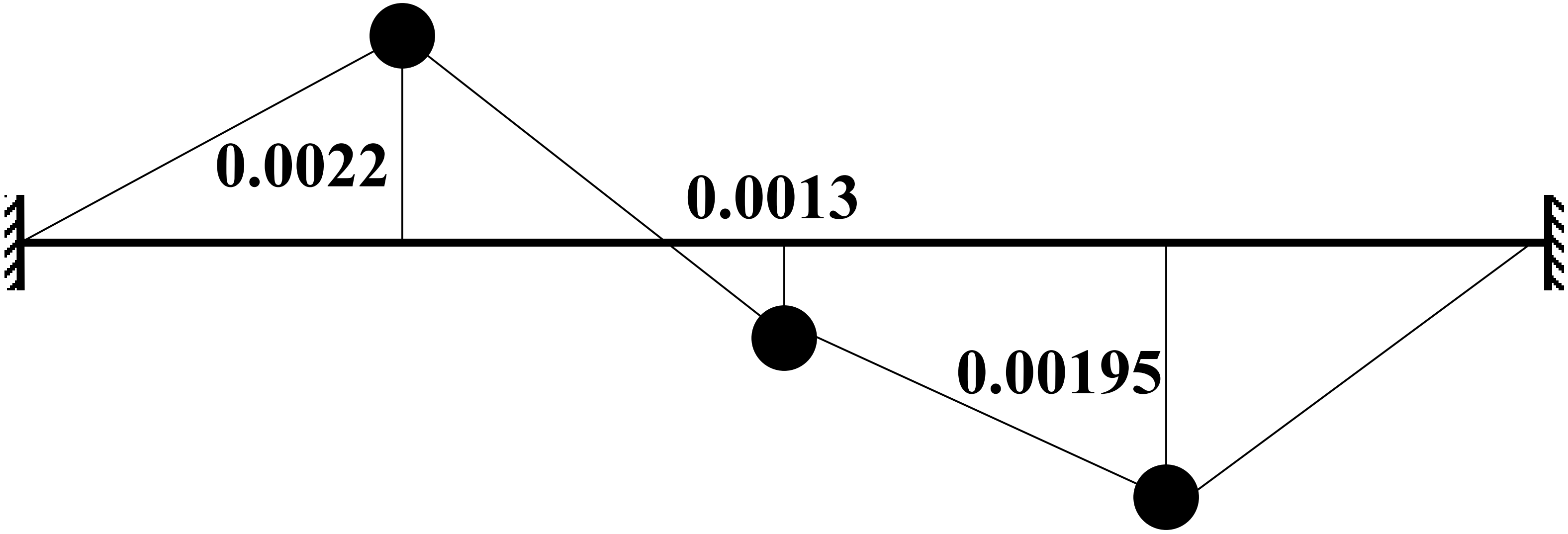
At 28 Hz, the amplitude at Ch 2 is 0.0026.





At 28 Hz, the Phase Angle is π; therefore, locations 0 & 2 are out of phase (negative sign).

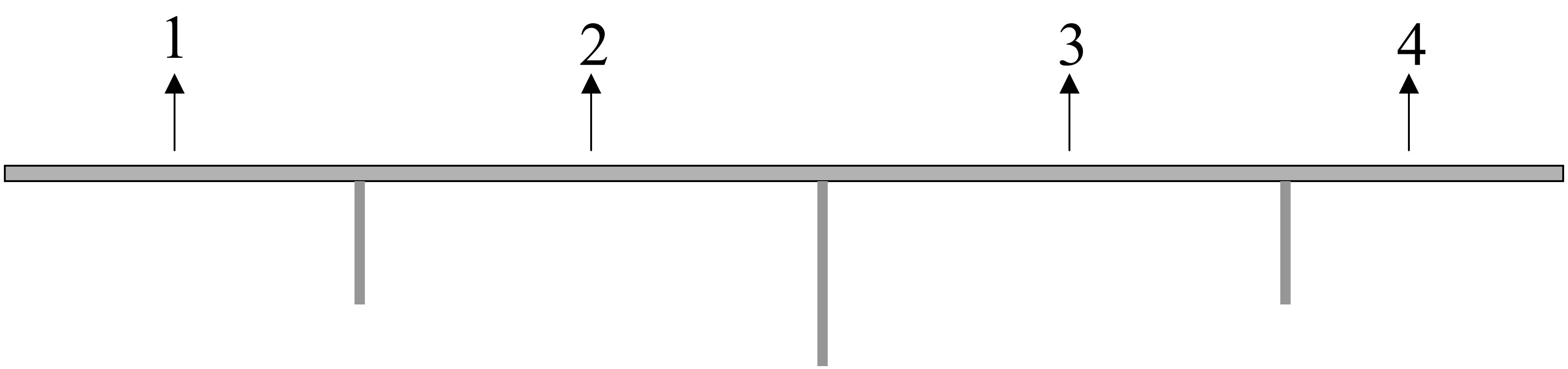
Second Mode Shape



Hints

1. In order to determine the mode shape, you will need to establish a reference location on your structure.

Depending on the geometry of the structure, you may not be able to keep the same reference point. In this case, you will need to use a moving reference. For example on the bridge below, you would probably need to take a data sets with a repeated sensor location. One possibility is to record at 1&2, then 2&3, and finally 3&4.



Hints (continued)

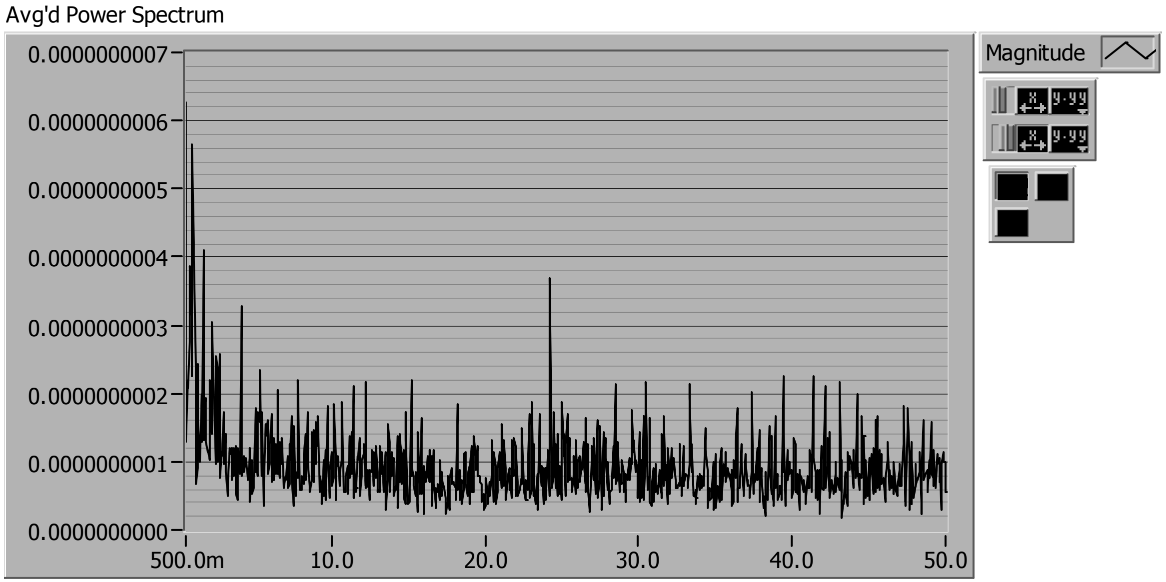
The Crossbow CXL01L1 and CXL02L1 are capacitive accelerometers. Therefore, they will record a DC signal when used for measuring vertical acceleration. In a vertical configuration, the CXL01L1 has only a 0.25 g measurement range.

Measurement Direction

When measuring vertical acceleration on a horizontal surface, you may need to use one of the anchor plates.

Hints (continued)

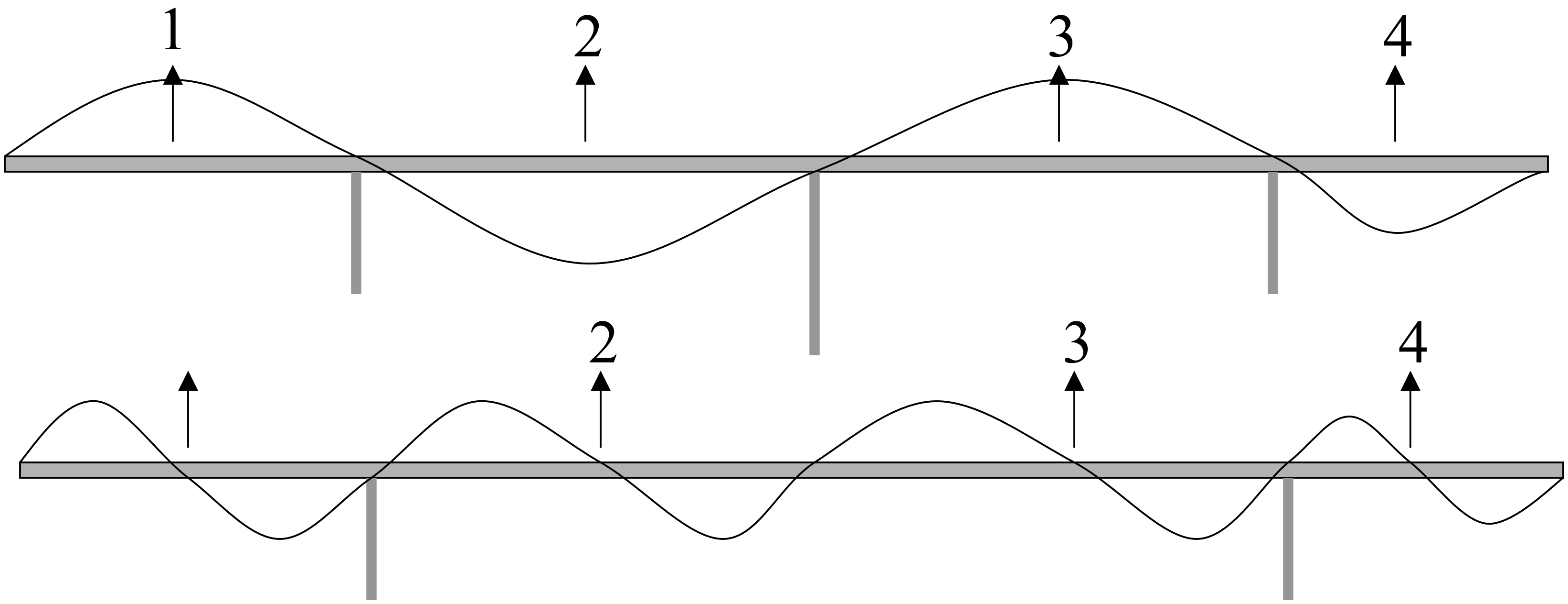
Before you get very far into your testing, you may want to check to ensure that you are measuring a meaningful signal. This can be done by making a simple preliminary test at one or two locations and checking the Power Spectra of the data.



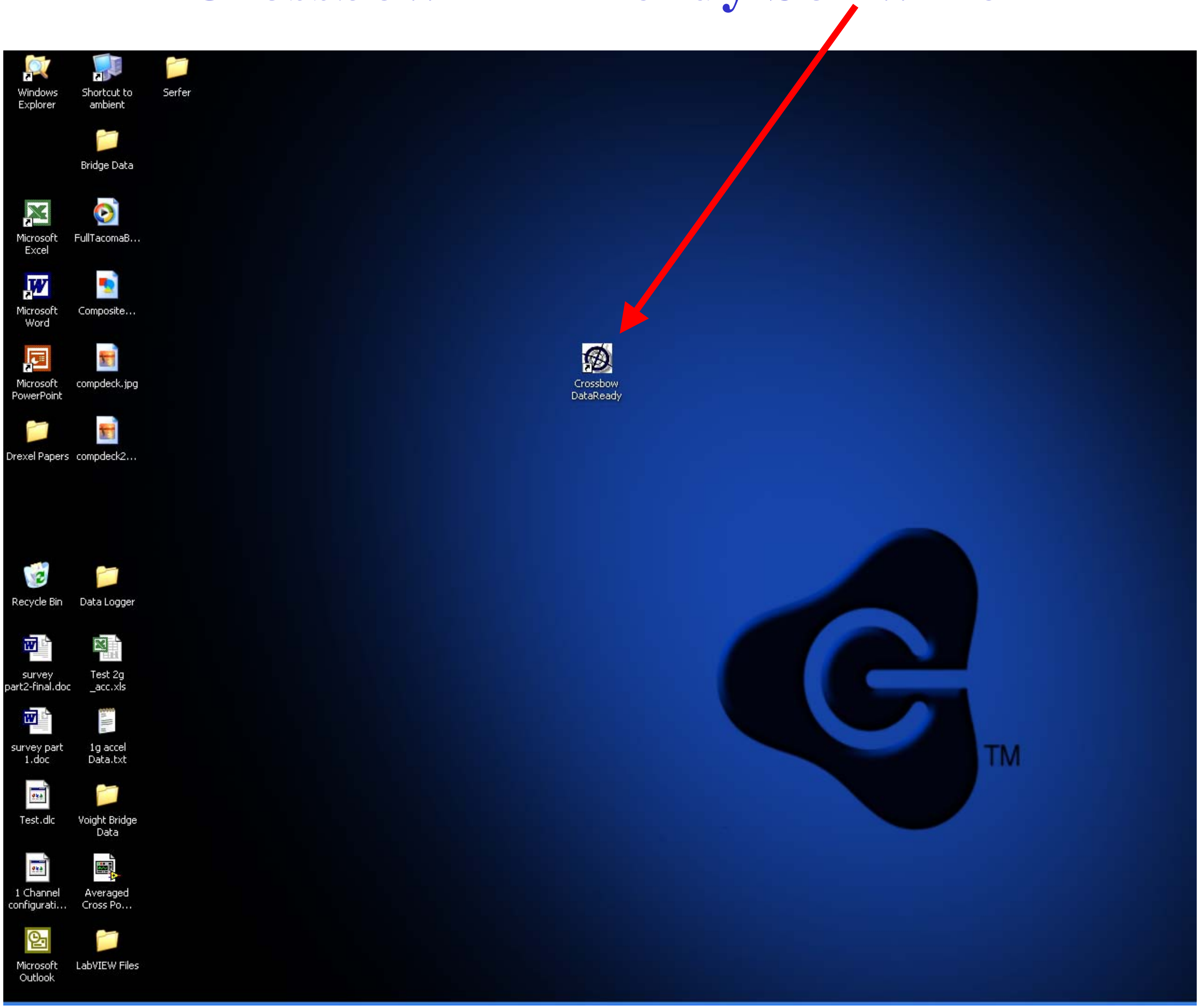
Hints (continued)

When choosing the location for your sensors, make sure you choose locations that will allow you to capture the first few modes.

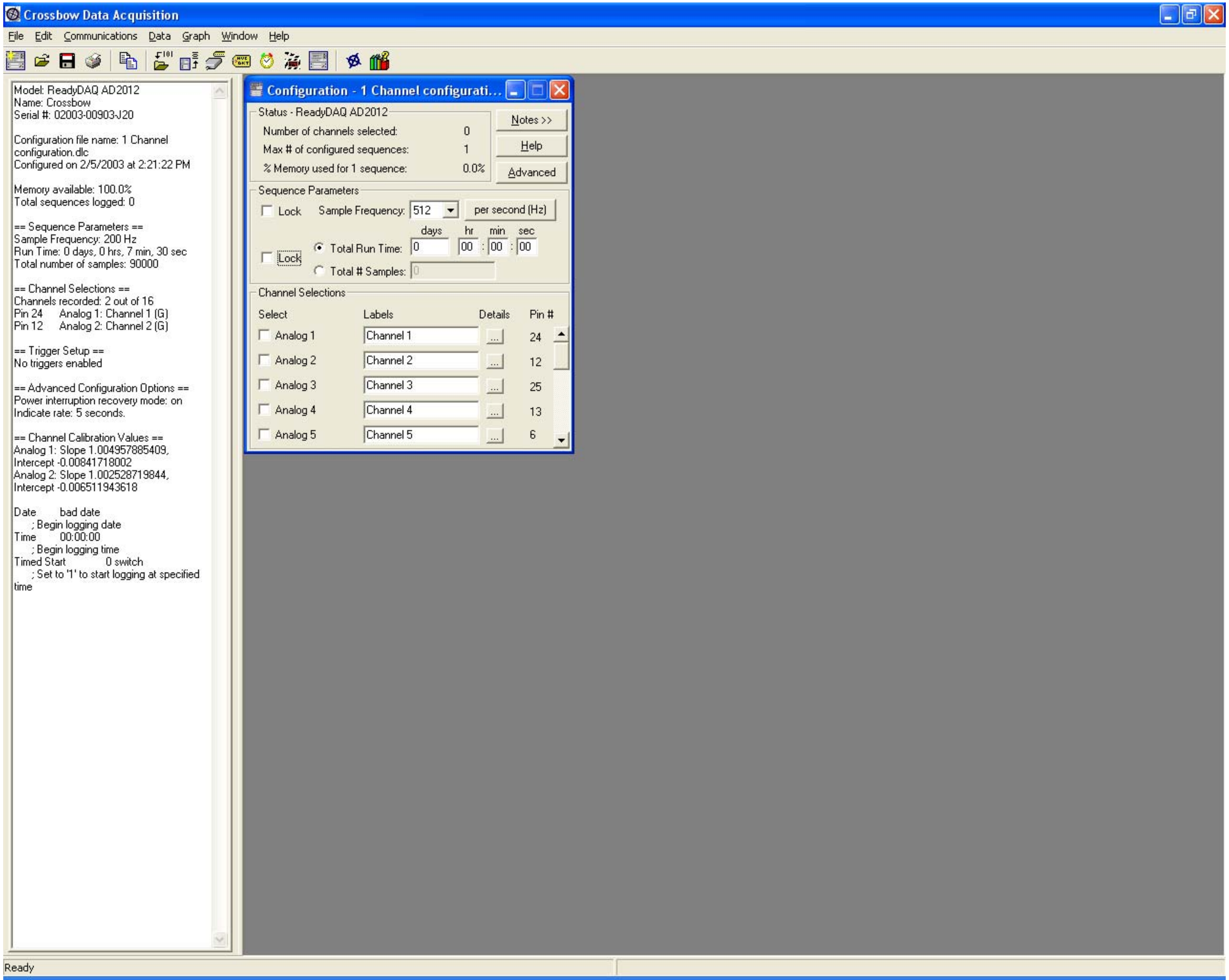
While the configuration shown below may work well for the 1st Mode, it may not work for higher modes.



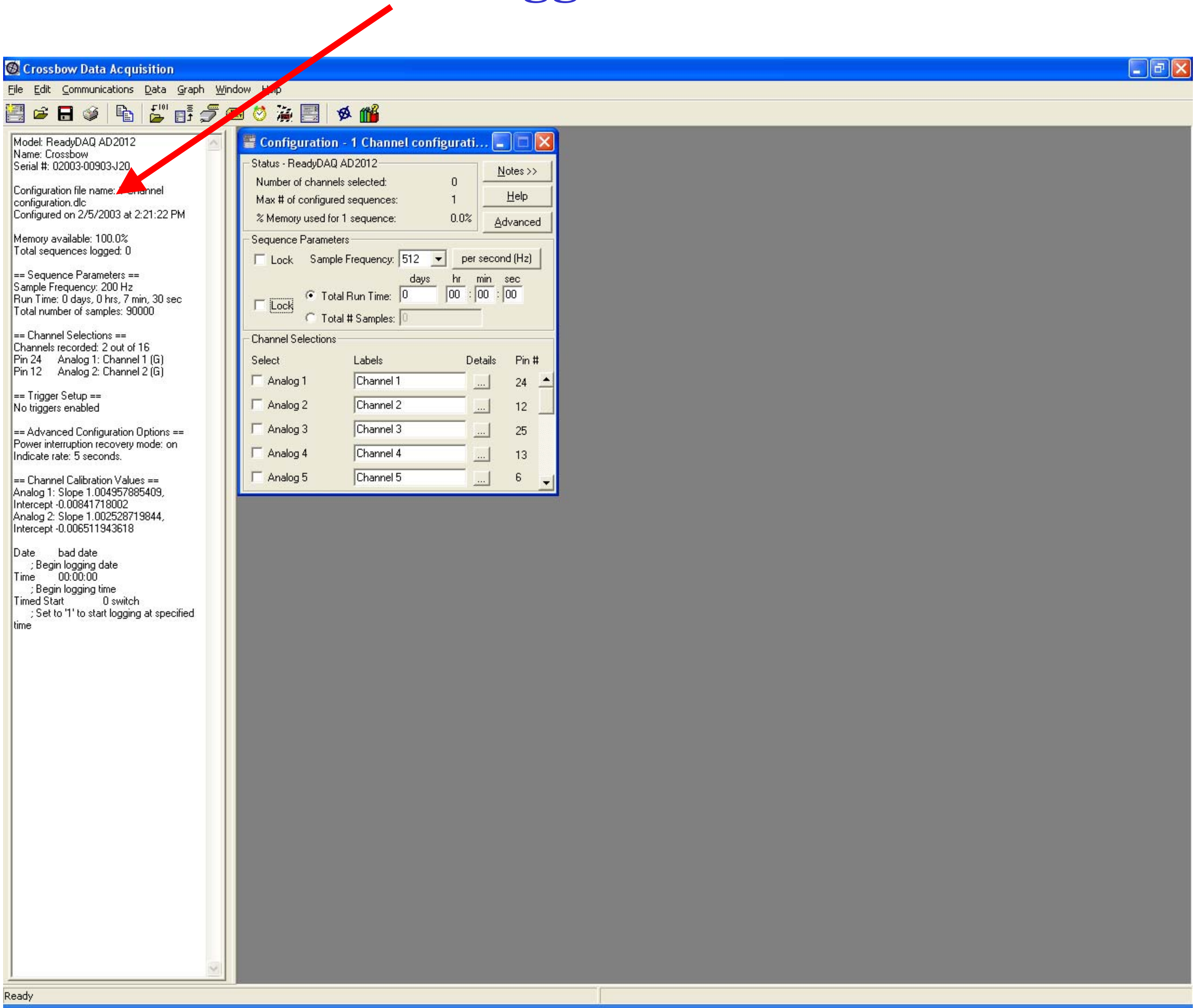
Running the Crossbow DataReady Software



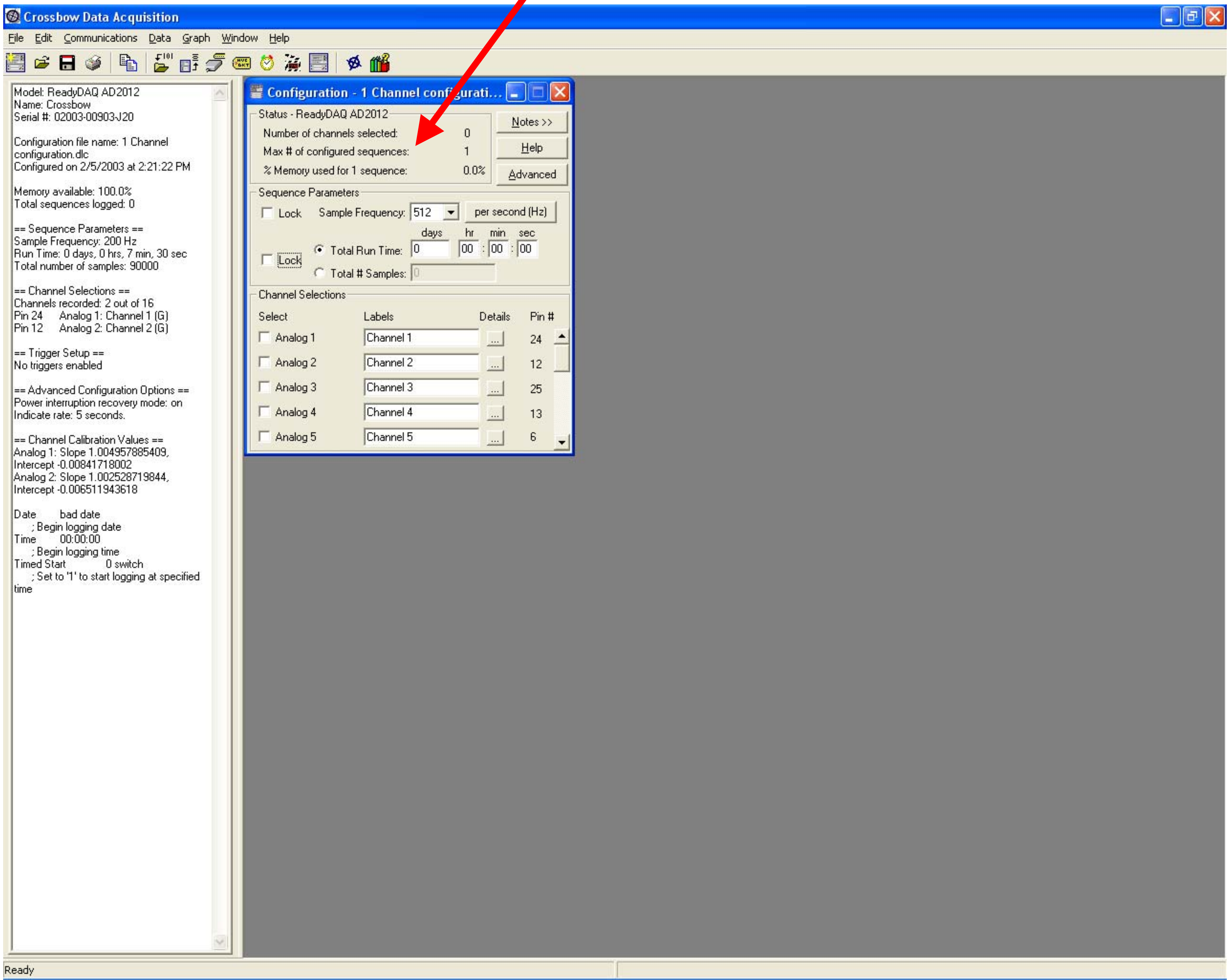
Crossbow DataReady Startup Window



Datalogger Status



Current Datalogger Configuration



Configuring the Datalogger

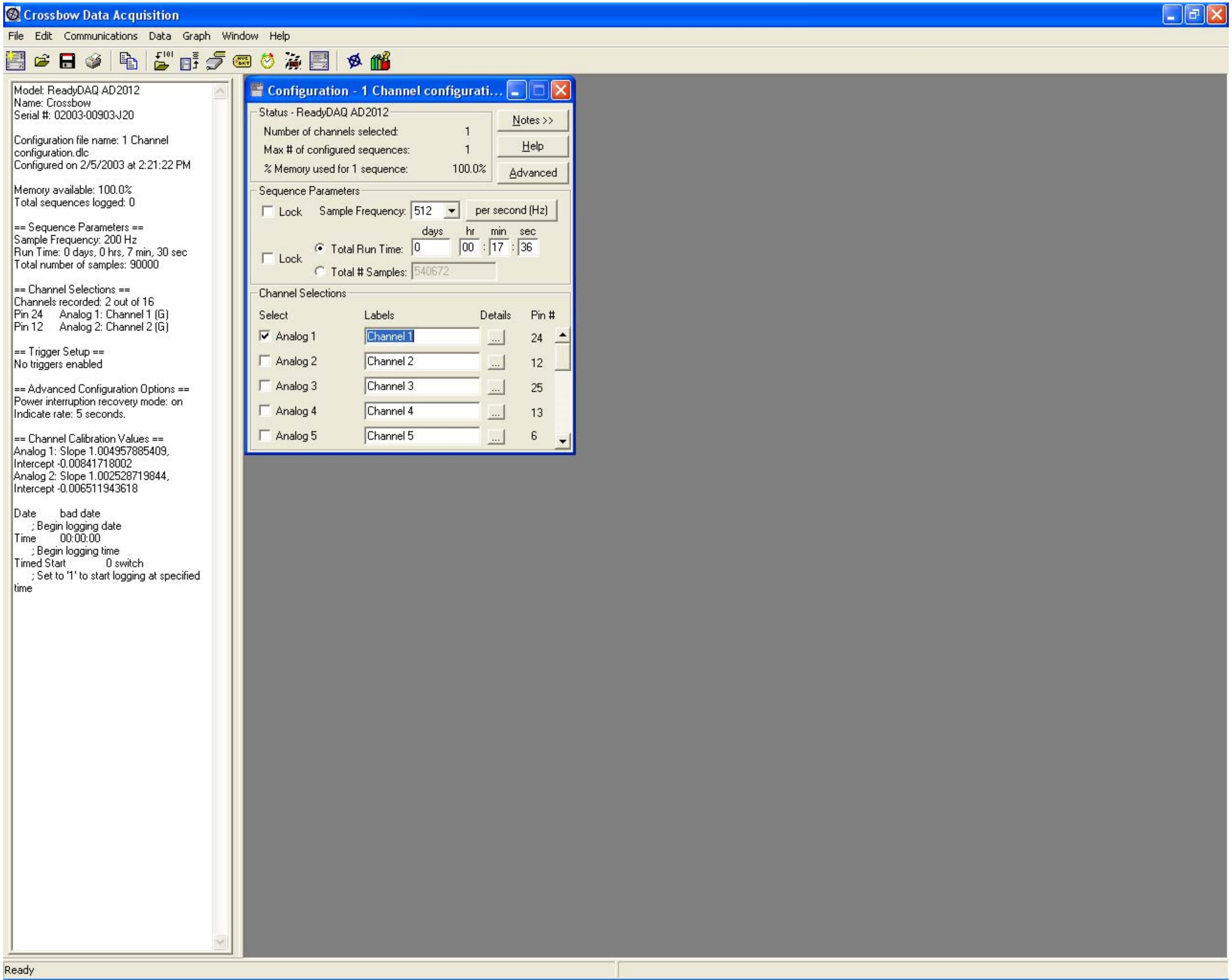
Select Active Channels

Configure each of the channels

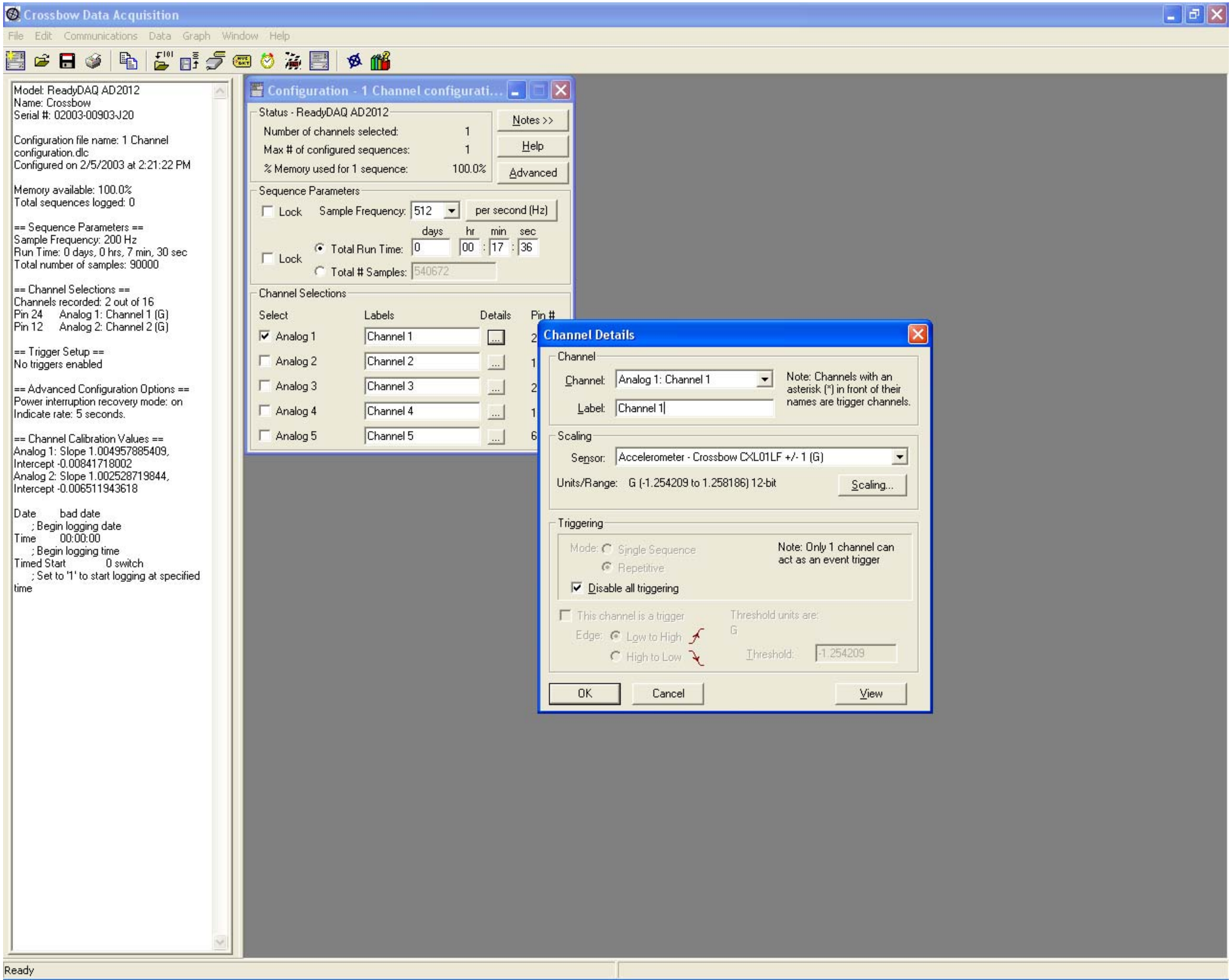
Set Sampling Frequency

Set Total Run Time

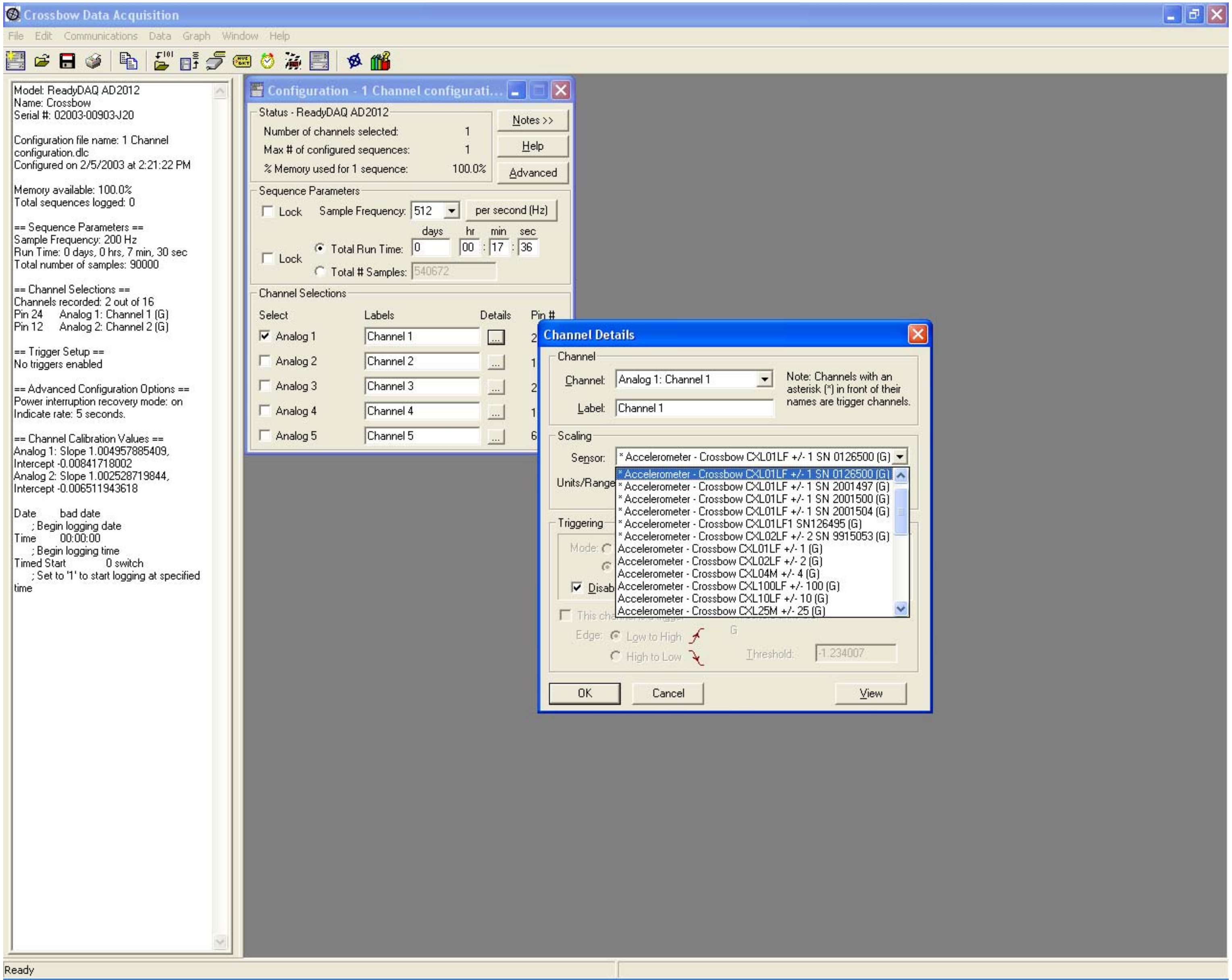
Step 1 – Activate Channel 1



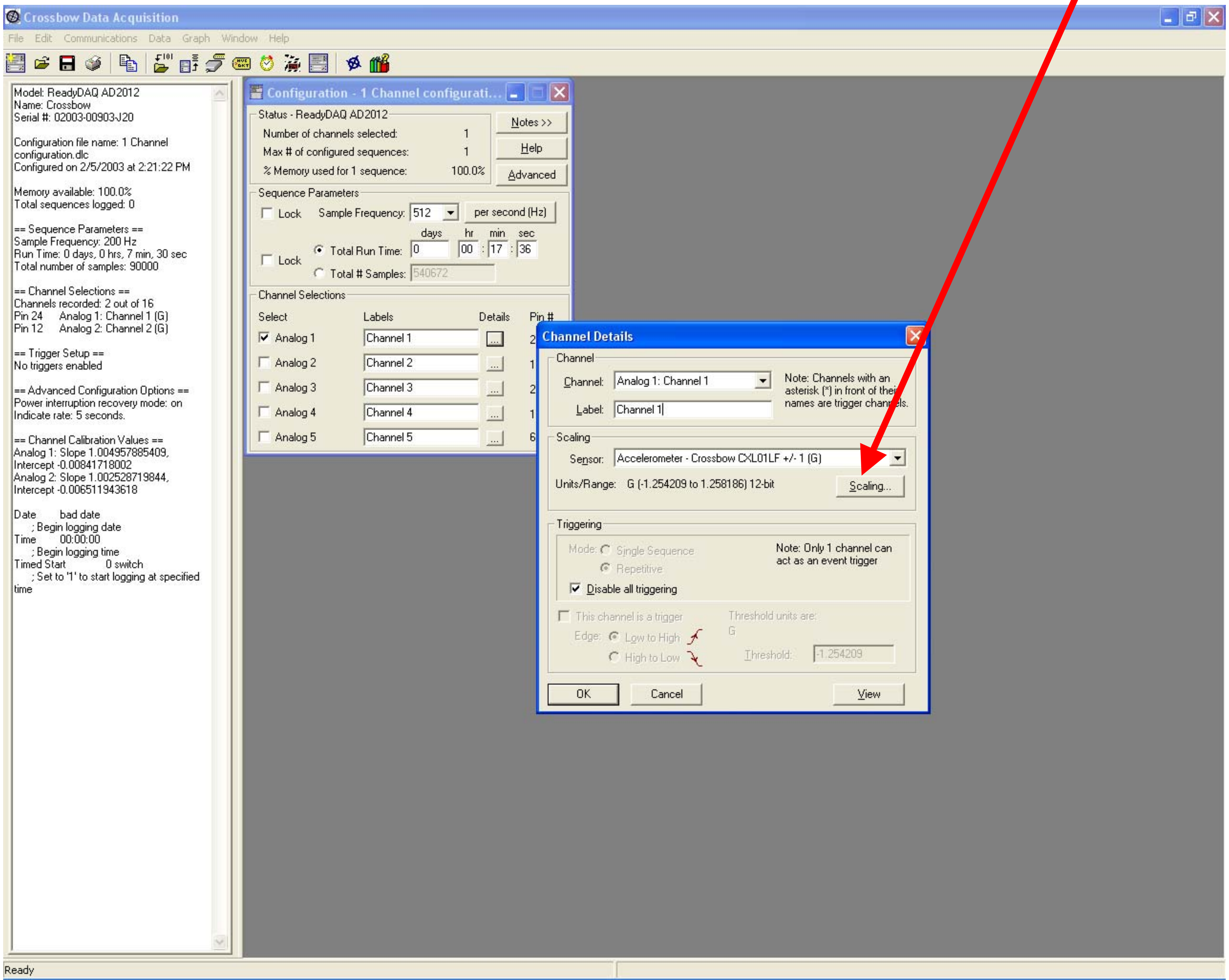
Step 2 – Enter Channel 1 Details



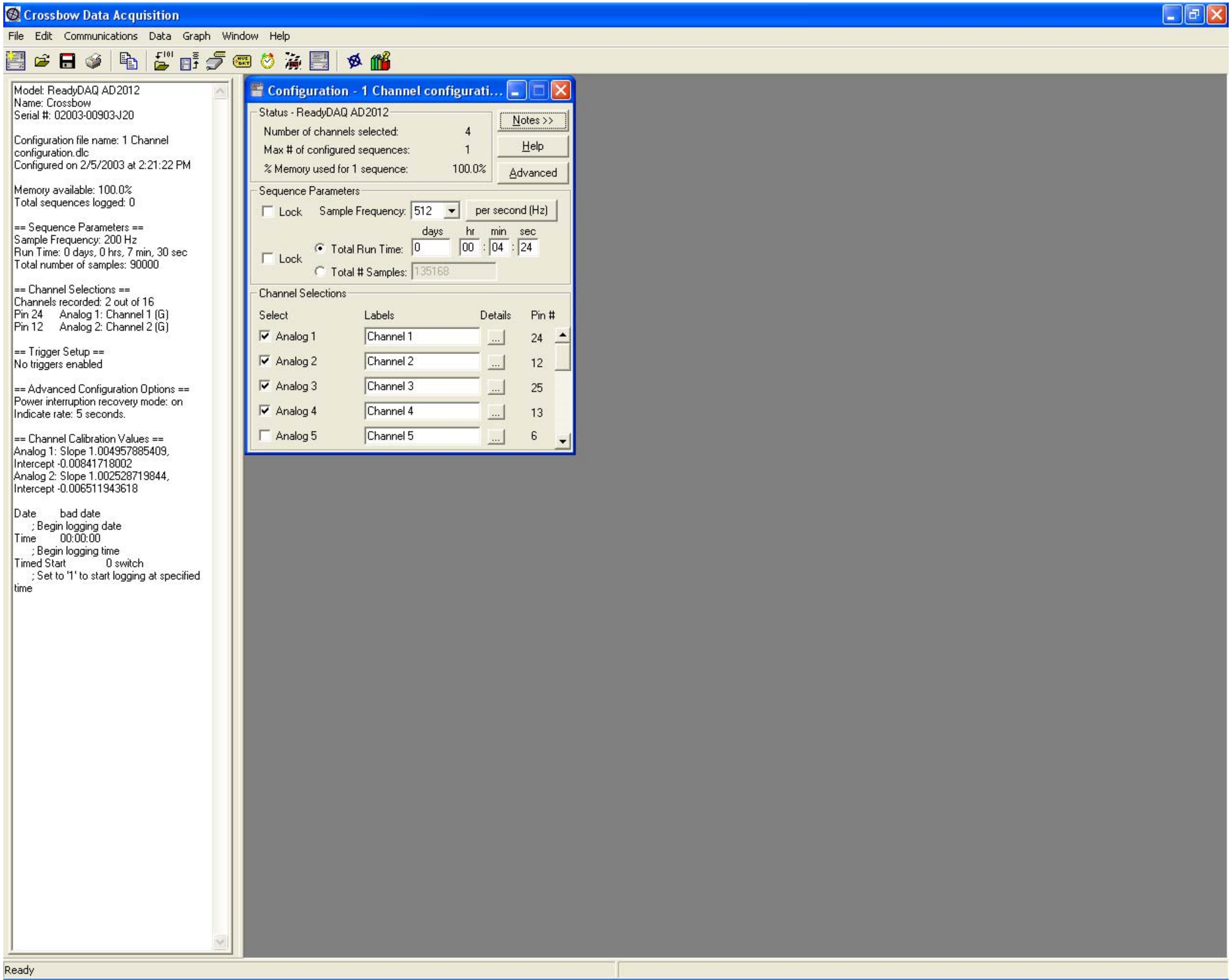
Step 3 - Select the Appropriate Sensor Type & Serial Number from the Drop Down Window



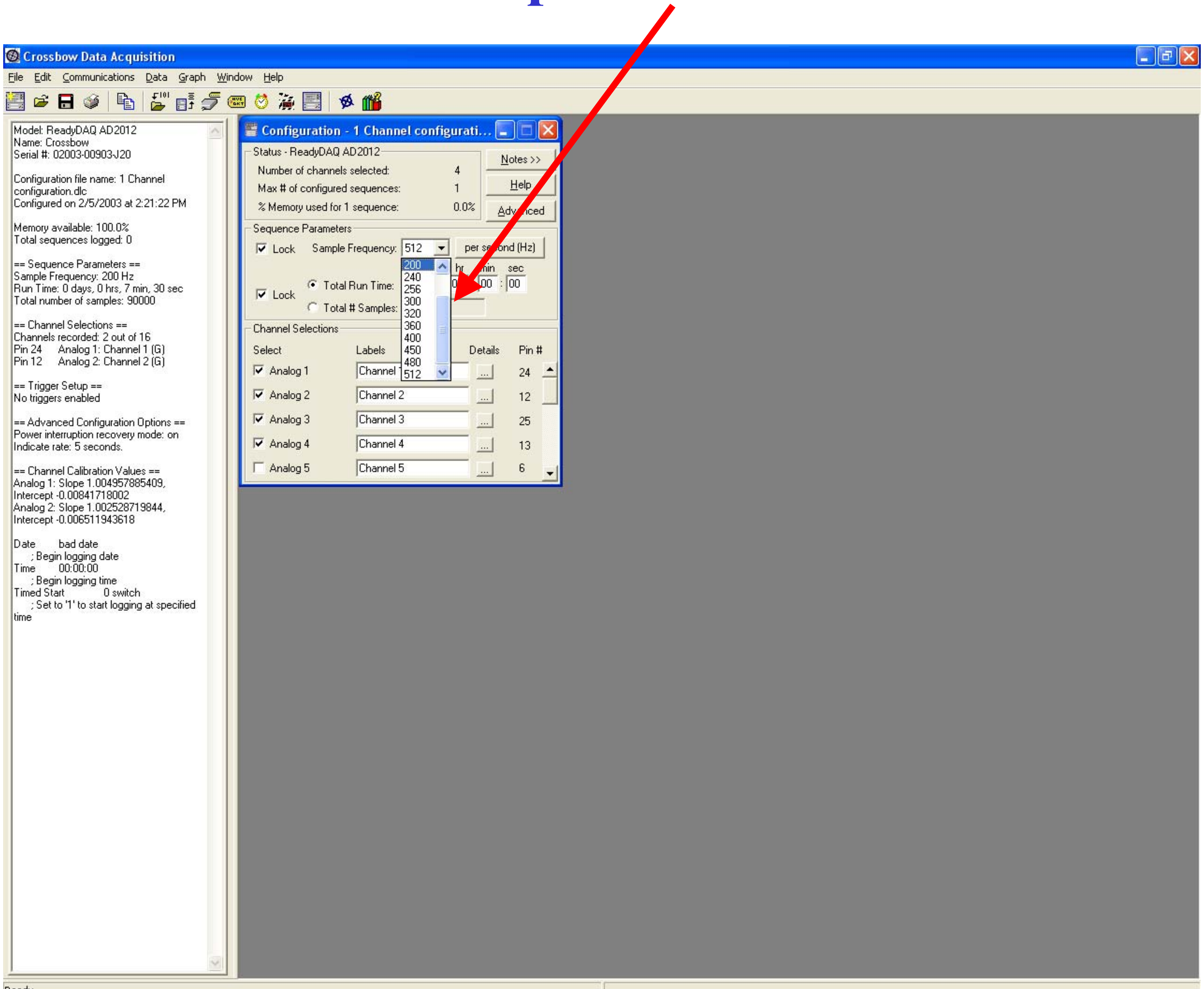
If you select a serial number from the drop down window, you do not need to worry about the “scaling” tab.



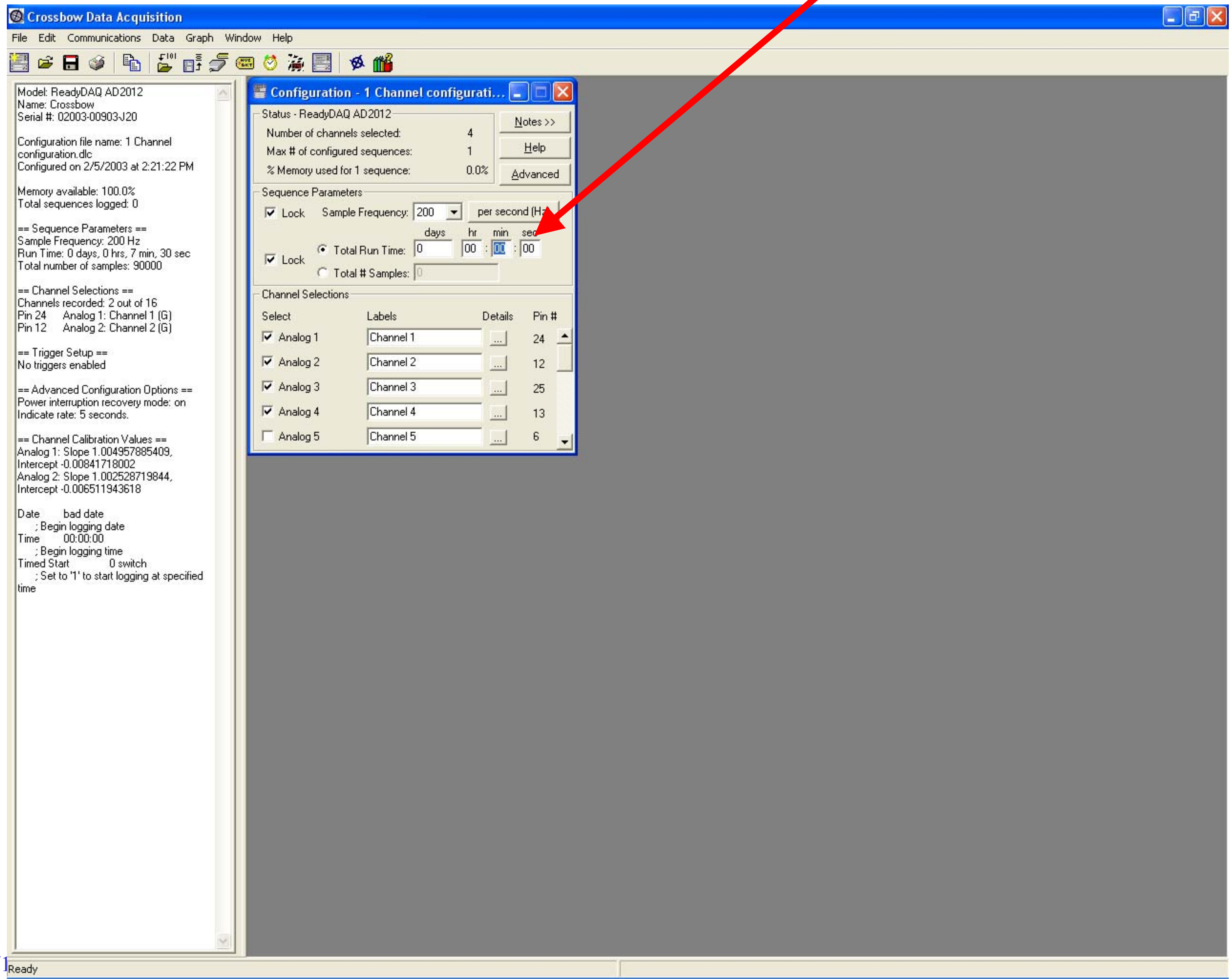
Step 4 – Select Additional Channels (Repeat Steps 1-3 For Each Additional Channel)



Step 5 – Set Desired "Sample Frequency" In the Drop Down Window

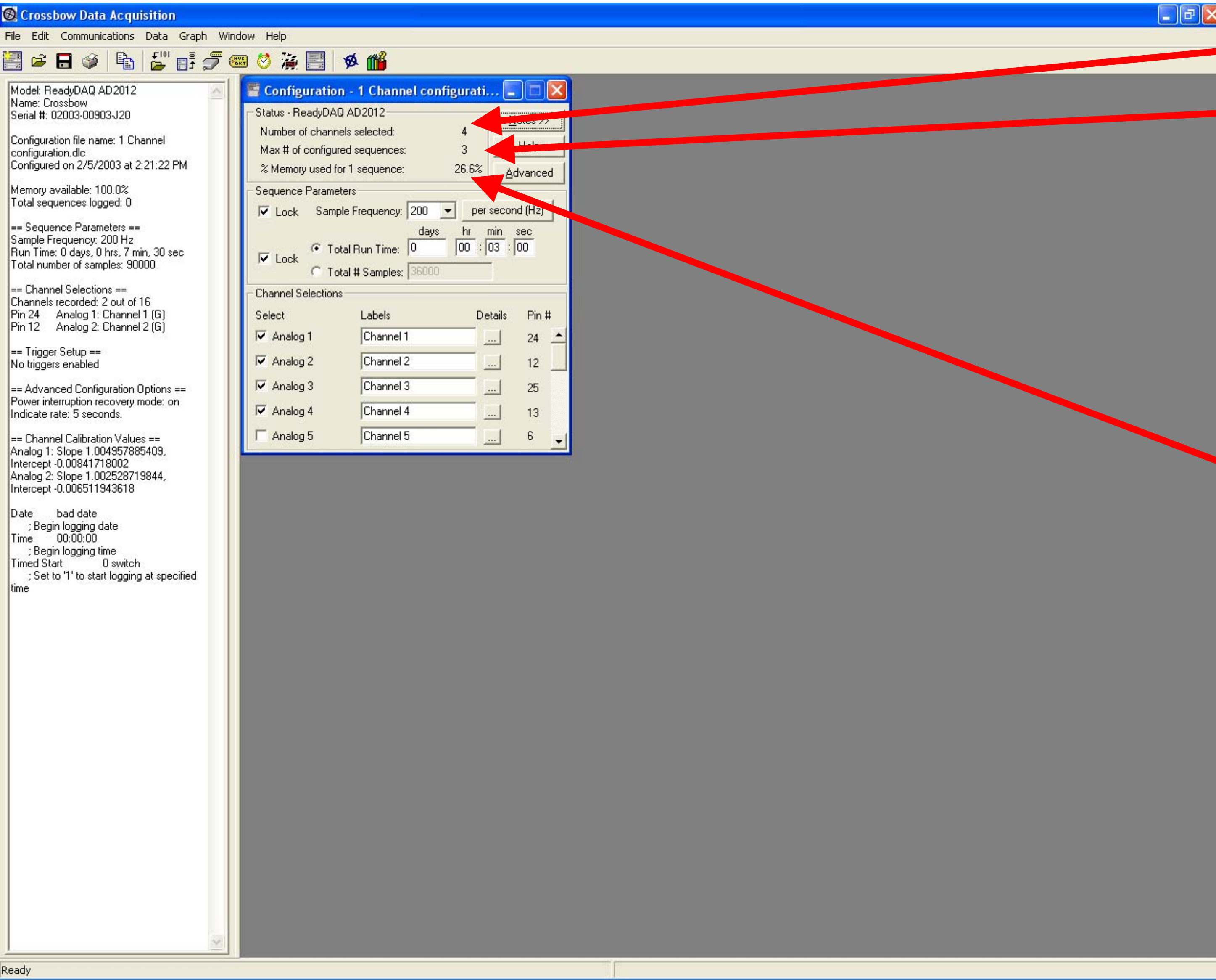


Step 6 – Enter “Total Run Time”



The “Total Run Time” is limited by the maximum number of samples that the data logger can store.

Configuration Details



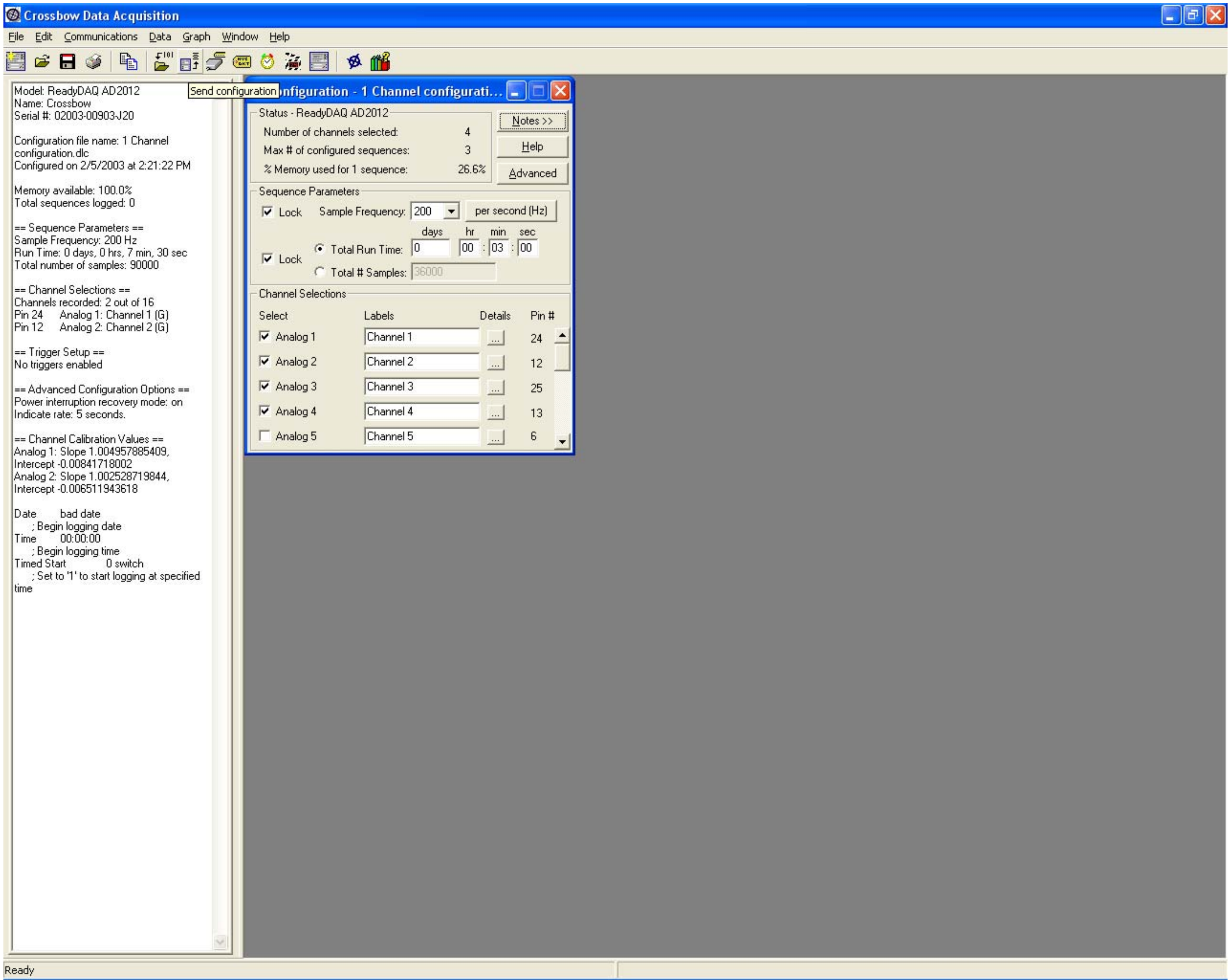
 # Active Channels

Max # of configured sequences that can be run before the memory on the datalogger is filled.

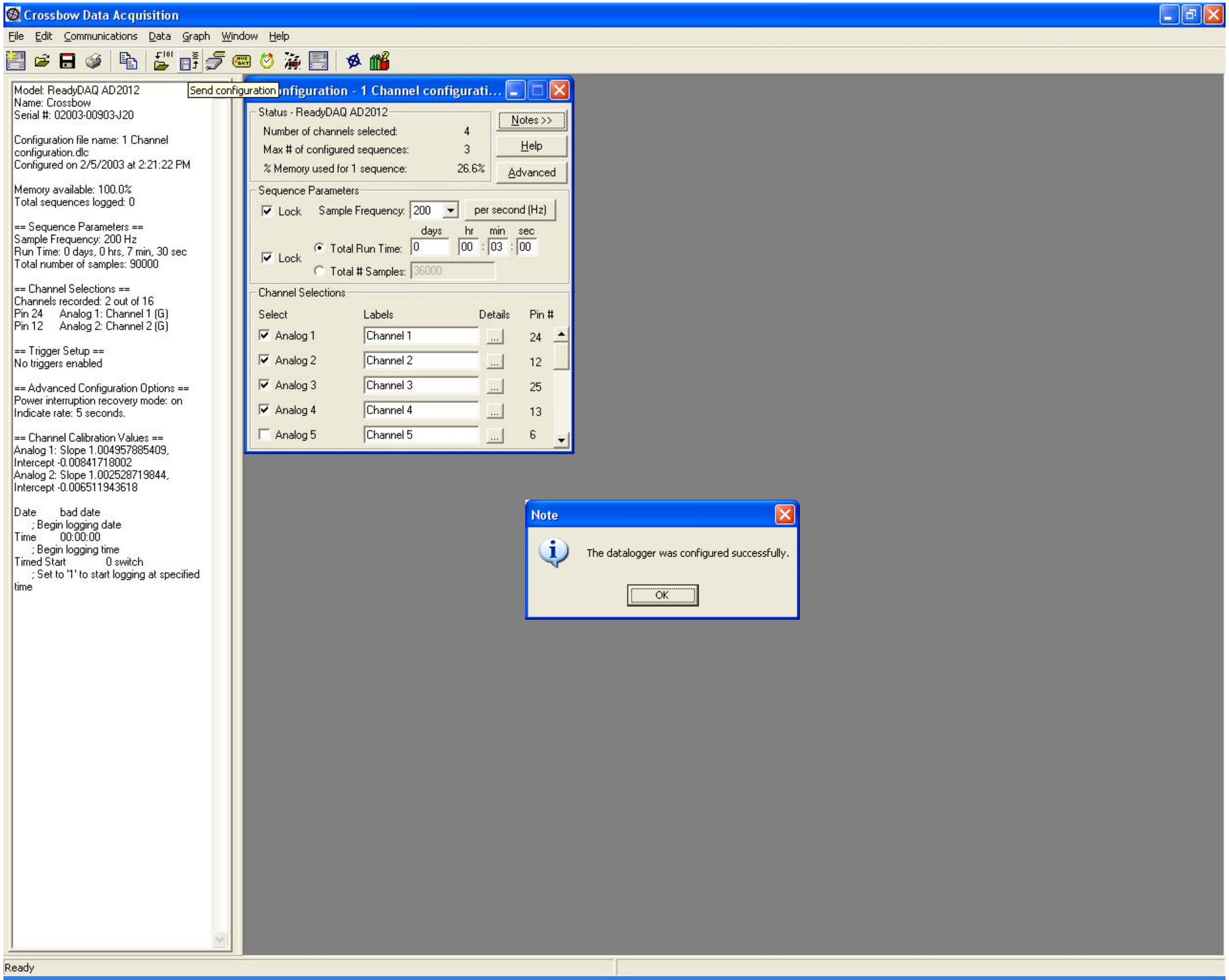
% of datalogger memory used by each sequence.

Click "Send Configuration" to Datalogger and Then Click "OK".

Note: this will erase any data stored on the logger.

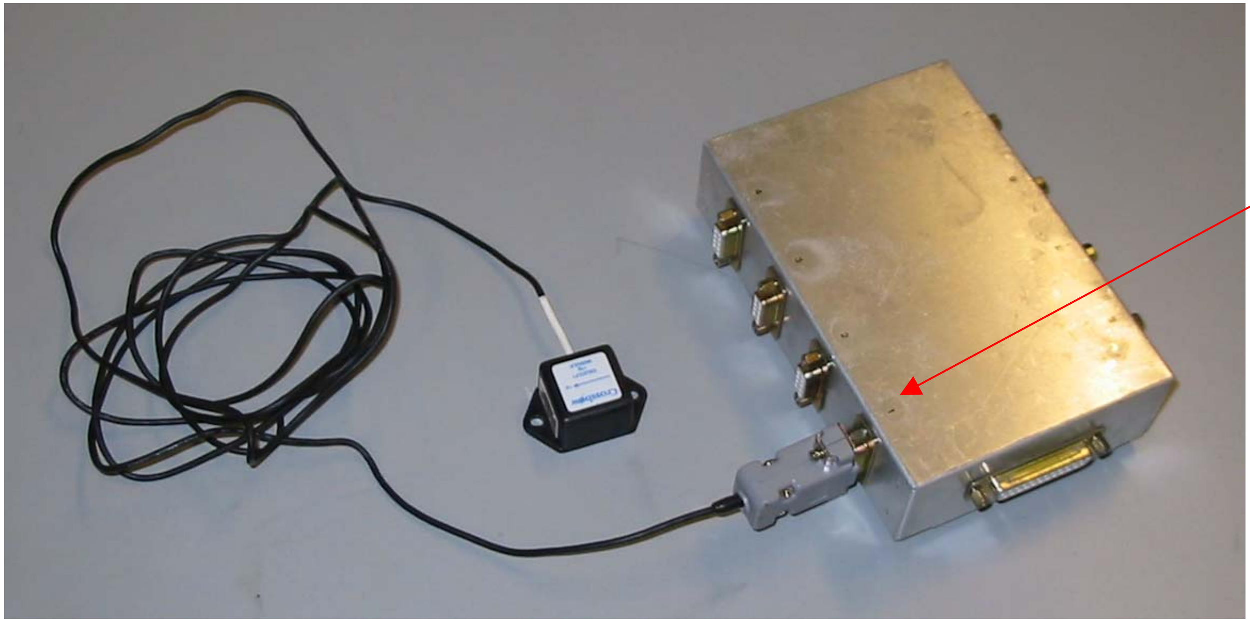


When the upload is complete it will display "The datalogger was configured successfully"



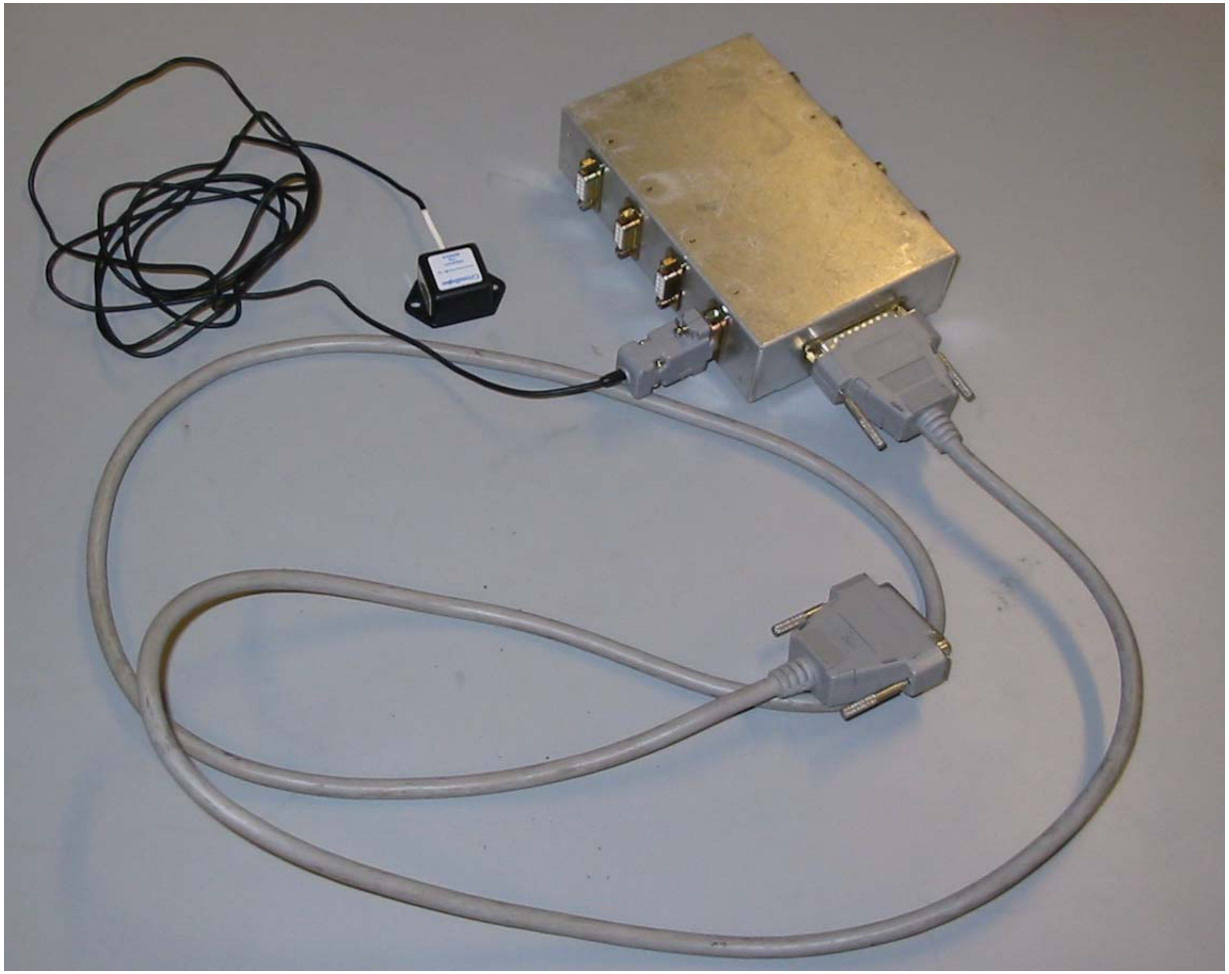
Connecting the Accelerometers to the Datalogger

Plug the accelerometer into the desired port on the junction box.



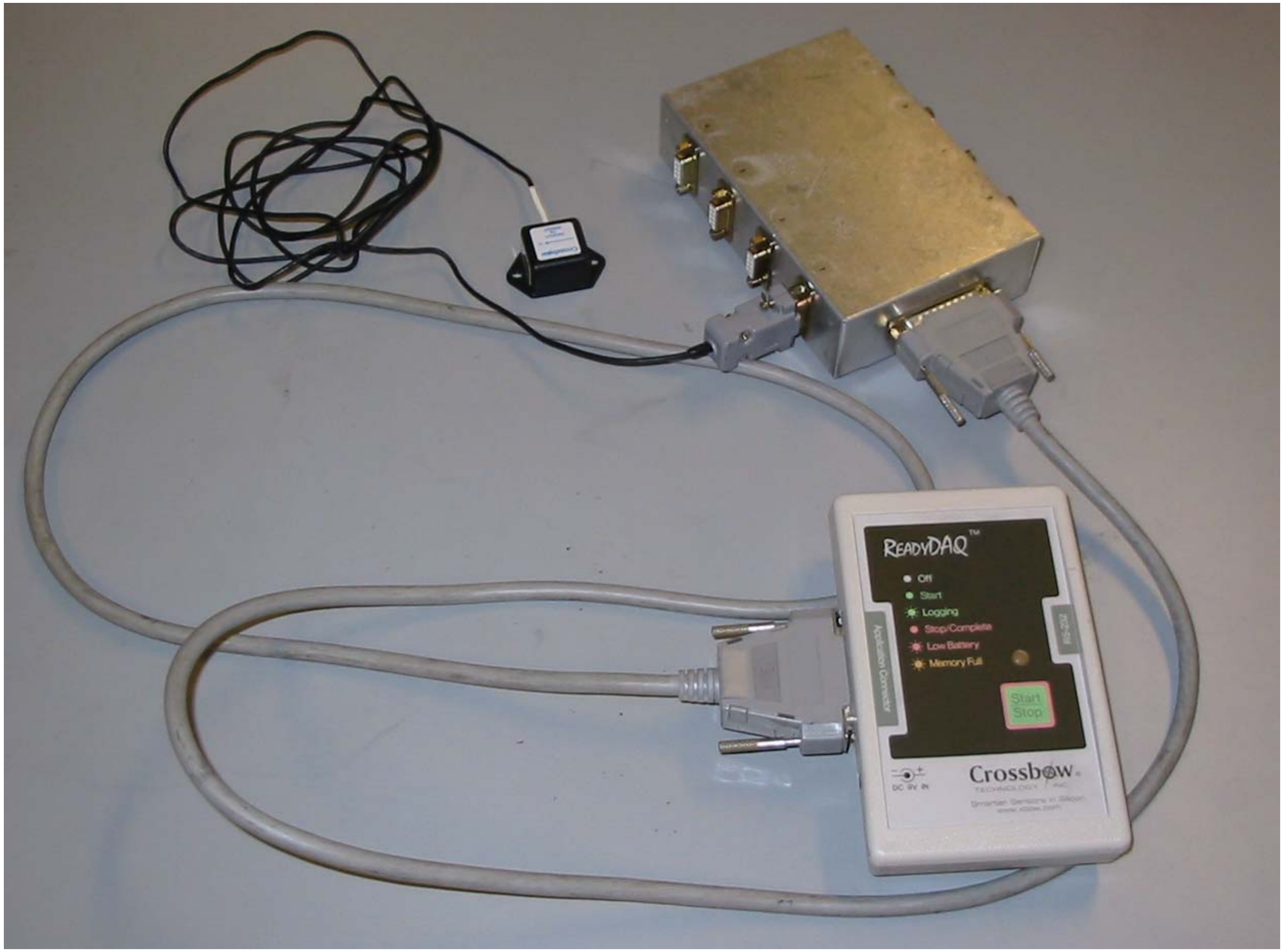
Ports on the junction box are numbered

Plug the 25 pin cable into the junction box.



Plug the 25 pin cable into the datalogger.

Note: Once the datalogger is connected to the junction box, the datalogger will start supplying power for the sensors. Please conserve the battery by not connecting to the datalogger until you are ready to start taking measurements.



To start collecting data, press the green "Start/Stop" button.

Once, the "Start/Stop" button is pushed once, the indicator light will turn green. When the measurement is complete this light will turn off.

Indicator Light

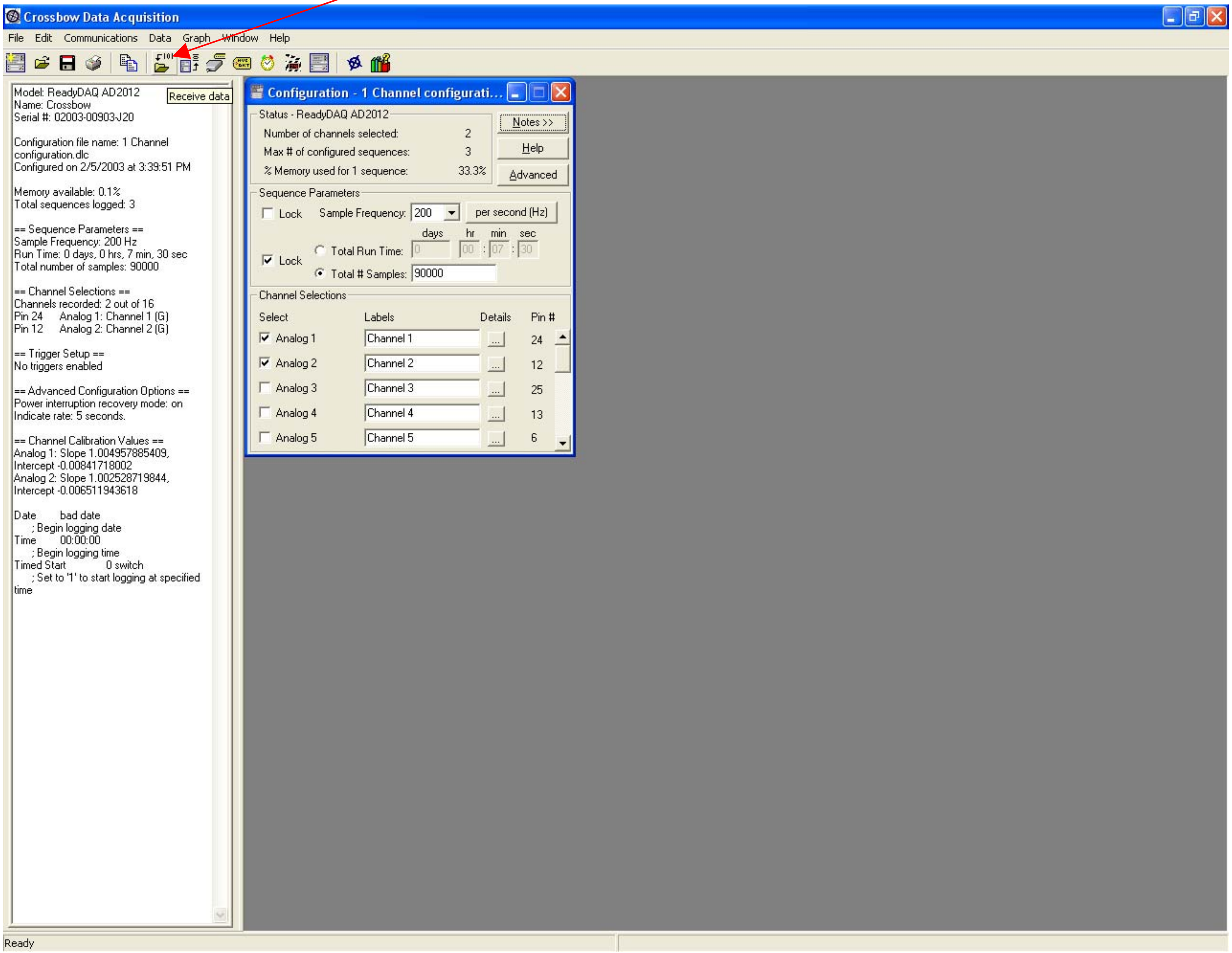
Start/Stop Button

Uploading Recorded Data

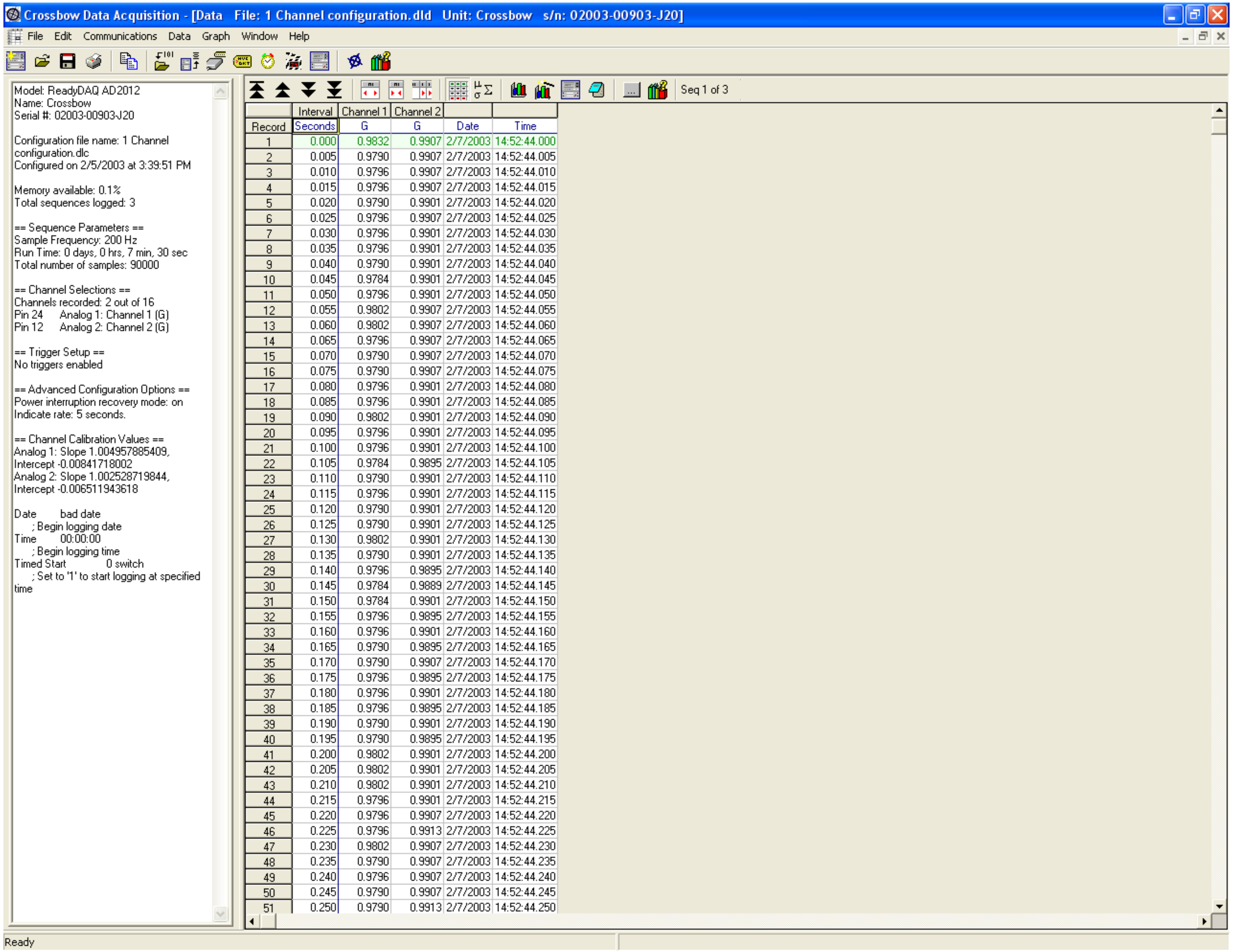
1. Connect the datalogger to a PC using the RS-232 cable

2. Run the Crossbow DataReady Software

Click on the "Receive Data" Button

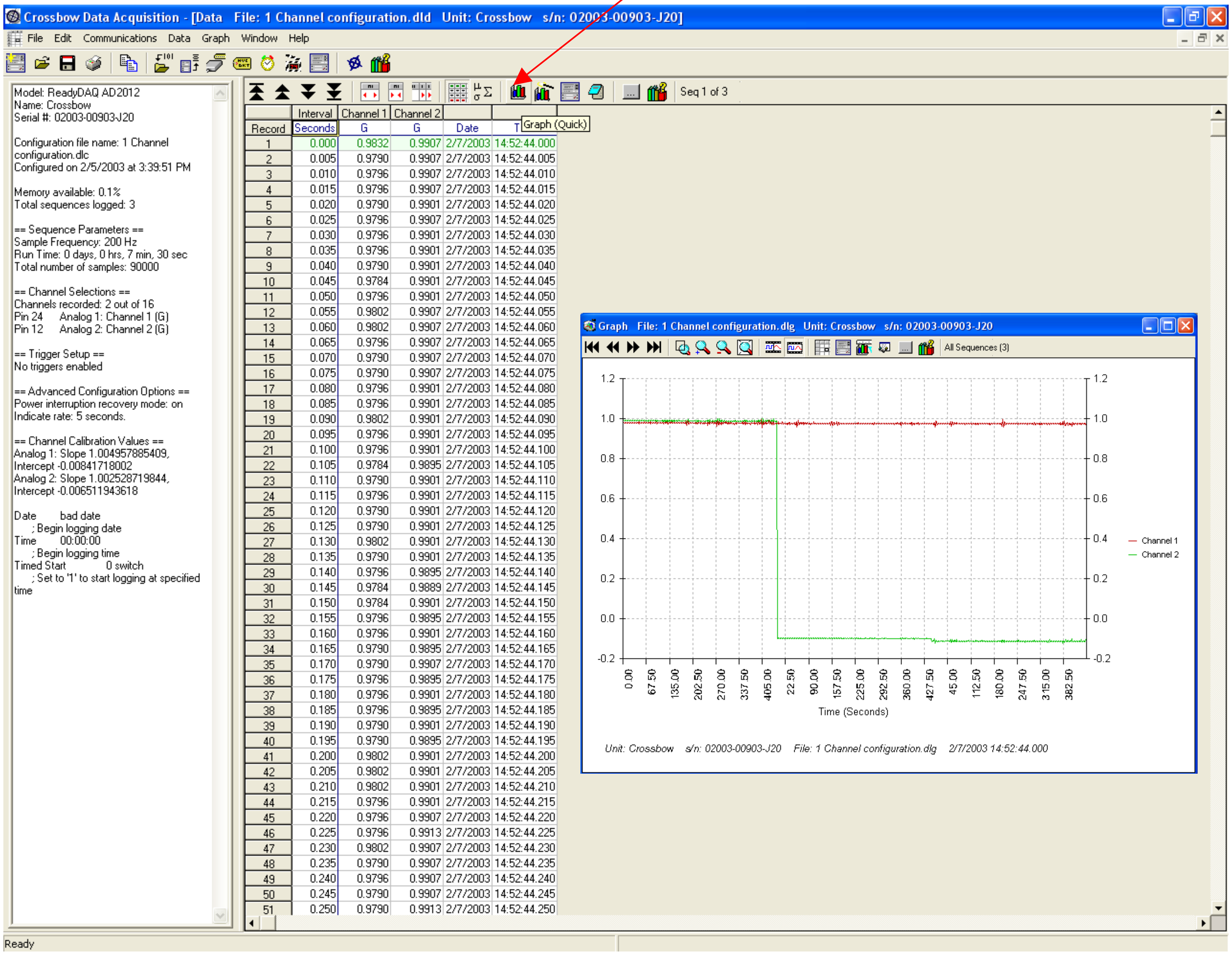


Recorded Data

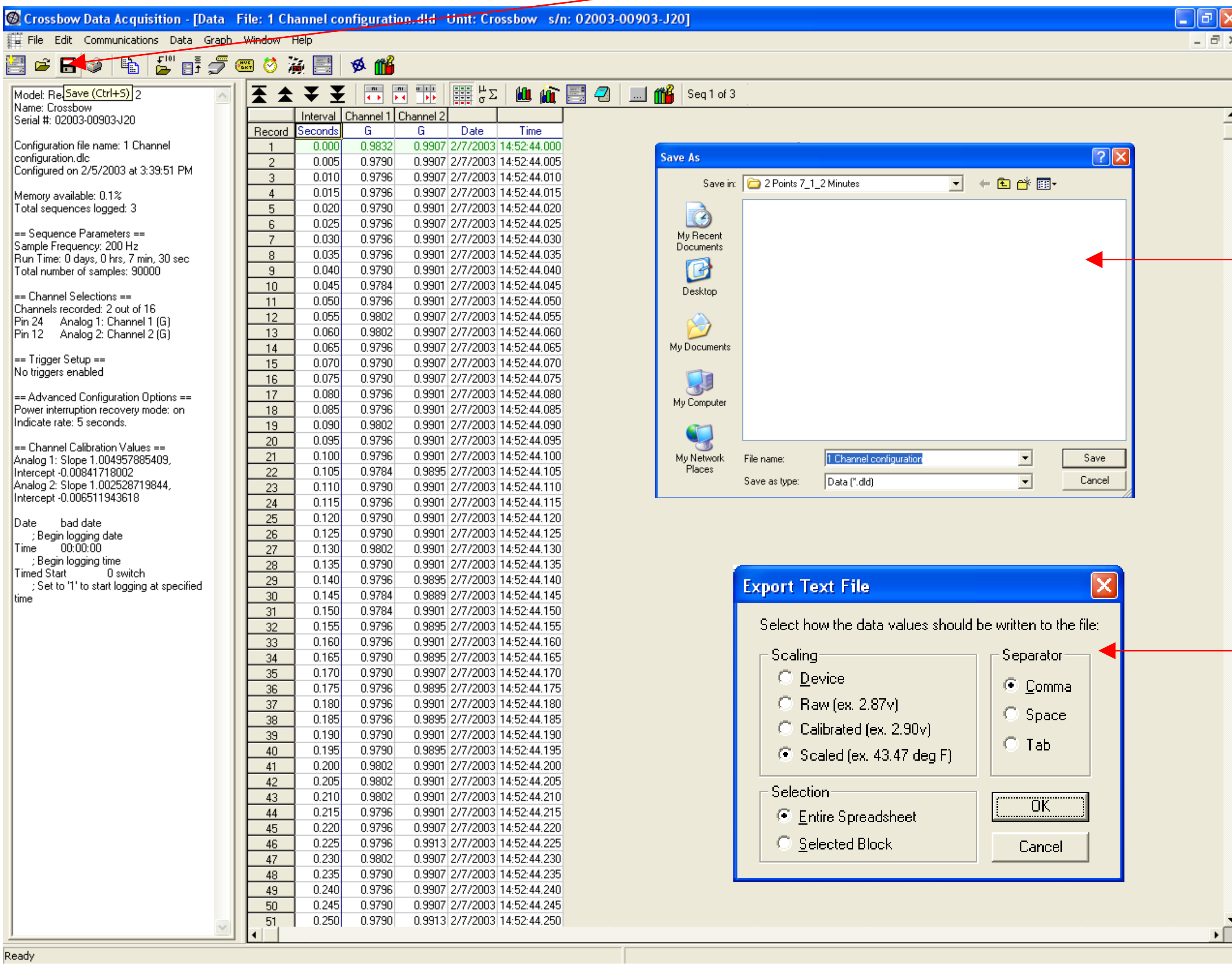


	Interval	Channel 1	Channel 2		
Record	Seconds	G	G	Date	Time
1	0.000	0.9832	0.9907	2/7/2003	14:52:44.000
2	0.005	0.9790	0.9907	2/7/2003	14:52:44.005
3	0.010	0.9796	0.9907	2/7/2003	14:52:44.010
4	0.015	0.9796	0.9907	2/7/2003	14:52:44.015
5	0.020	0.9790	0.9901	2/7/2003	14:52:44.020
6	0.025	0.9796	0.9907	2/7/2003	14:52:44.025
7	0.030	0.9796	0.9901	2/7/2003	14:52:44.030
8	0.035	0.9796	0.9901	2/7/2003	14:52:44.035
9	0.040	0.9790	0.9901	2/7/2003	14:52:44.040
10	0.045	0.9784	0.9901	2/7/2003	14:52:44.045
11	0.050	0.9796	0.9901	2/7/2003	14:52:44.050
12	0.055	0.9802	0.9907	2/7/2003	14:52:44.055
13	0.060	0.9802	0.9907	2/7/2003	14:52:44.060
14	0.065	0.9796	0.9907	2/7/2003	14:52:44.065
15	0.070	0.9790	0.9907	2/7/2003	14:52:44.070
16	0.075	0.9790	0.9907	2/7/2003	14:52:44.075
17	0.080	0.9796	0.9901	2/7/2003	14:52:44.080
18	0.085	0.9796	0.9901	2/7/2003	14:52:44.085
19	0.090	0.9802	0.9901	2/7/2003	14:52:44.090
20	0.095	0.9796	0.9901	2/7/2003	14:52:44.095
21	0.100	0.9796	0.9901	2/7/2003	14:52:44.100
22	0.105	0.9784	0.9895	2/7/2003	14:52:44.105
23	0.110	0.9790	0.9901	2/7/2003	14:52:44.110
24	0.115	0.9796	0.9901	2/7/2003	14:52:44.115
25	0.120	0.9790	0.9901	2/7/2003	14:52:44.120
26	0.125	0.9790	0.9901	2/7/2003	14:52:44.125
27	0.130	0.9802	0.9901	2/7/2003	14:52:44.130
28	0.135	0.9790	0.9901	2/7/2003	14:52:44.135
29	0.140	0.9796	0.9895	2/7/2003	14:52:44.140
30	0.145	0.9784	0.9889	2/7/2003	14:52:44.145
31	0.150	0.9784	0.9901	2/7/2003	14:52:44.150
32	0.155	0.9796	0.9895	2/7/2003	14:52:44.155
33	0.160	0.9796	0.9901	2/7/2003	14:52:44.160
34	0.165	0.9790	0.9895	2/7/2003	14:52:44.165
35	0.170	0.9790	0.9907	2/7/2003	14:52:44.170
36	0.175	0.9796	0.9895	2/7/2003	14:52:44.175
37	0.180	0.9796	0.9901	2/7/2003	14:52:44.180
38	0.185	0.9796	0.9895	2/7/2003	14:52:44.185
39	0.190	0.9790	0.9901	2/7/2003	14:52:44.190
40	0.195	0.9790	0.9895	2/7/2003	14:52:44.195
41	0.200	0.9802	0.9901	2/7/2003	14:52:44.200
42	0.205	0.9802	0.9901	2/7/2003	14:52:44.205
43	0.210	0.9802	0.9901	2/7/2003	14:52:44.210
44	0.215	0.9796	0.9901	2/7/2003	14:52:44.215
45	0.220	0.9796	0.9907	2/7/2003	14:52:44.220
46	0.225	0.9796	0.9913	2/7/2003	14:52:44.225
47	0.230	0.9802	0.9907	2/7/2003	14:52:44.230
48	0.235	0.9790	0.9907	2/7/2003	14:52:44.235
49	0.240	0.9796	0.9907	2/7/2003	14:52:44.240
50	0.245	0.9790	0.9907	2/7/2003	14:52:44.245
51	0.250	0.9790	0.9913	2/7/2003	14:52:44.250

To plot the data, press the “Graph (Quick)” button



To save your data, press the "Save" button.



Location

(Choose save as .txt type)

Export File Option