



COLDFIRE® DSP HANDS-ON WORKSHOP MANUAL

Introduction: The scope of these experiments have been designed to familiarize and educate the attendees on the signal processing capabilities of the M5222x ColdFire® class of microprocessors, with an embedded Multiply and Accumulate (MAC) unit. The demonstrations are limited to simple examples on the effects of sampling and filter implementations of Infinite Impulse Response (IIR) filters of different types.

The experiments are designed to enable students realize experimentally some of the digital signal processing concepts that had been taught during the lecture.

Hardware: Mechanical resonator, sensor, ColdFire® evaluation board, laptop and impact hammer.

Note: If you do not have the mechanical resonator and sensor, you can still do the lab with just the ColdFire board. See Appendix for details.

Software: Freescale CodeWarrior 6.4 and LabVIEW® graphic display.

Experiments

1. Digital filter Demo: Low Pass and High Pass Filter Demonstration

WALK-IN DEMO !!

Introduction: The scope of this experiment is to generate a signal sampled at 3030 Hz, pass it through a 4th order low pass filter ($f_c= 120$ Hz) and 4th order high pass filter ($f_c= 350$ Hz), respectively. The effects of filtering should be evident on the displayed signals. Also, the computational efficiency, in terms of processor cycles should be emphasized

Procedure:

- a. Strike the beam with the metal impact hammer provided.
- b. Stop the display when the signal is in full view
- c. Zoom on a section of each plot

Observation:

- d. The tab labeled “Z, Z2” displays the raw signal and the low pass filtered signal (Figure 1a), with frequency content less than 120 Hz.
- e. The tab labeled “Z, Z1” displays the raw signal and the high pass filtered signal (Figure 1b), with frequency content greater than 350 Hz
- f. The tab labeled “Z1, Z2” displays the low pass filtered and the high pass filtered signals (Figure 1c).
- g. The arms on the gauge labeled “T1,T2” should indicate the number of CPU cycles needed to process each filter operation.

Conclusions:

- h. The tab labeled “Z2, Z1” displays signals with frequencies less than 120Hz (low pass filtered signal) and greater than 350Hz (high pass filtered signal). The high pass filter eliminates the signal offset that is apparent on the raw signal.
- i. The effect of time delay on the filtered signals is evident in Figures 1a and 1b.
- j. The indicators on the gauge should read the same, since the filters are of the same order.

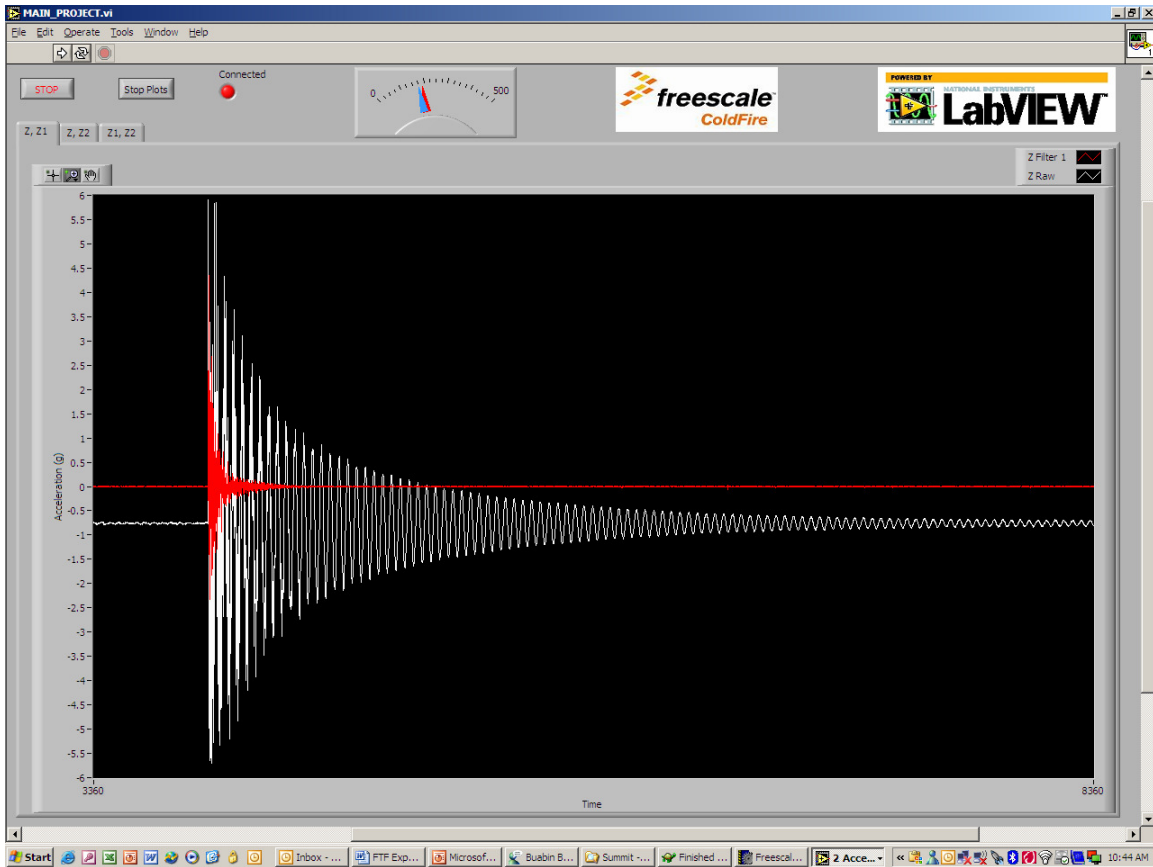


Figure 1a: Original and high pass filtered signals

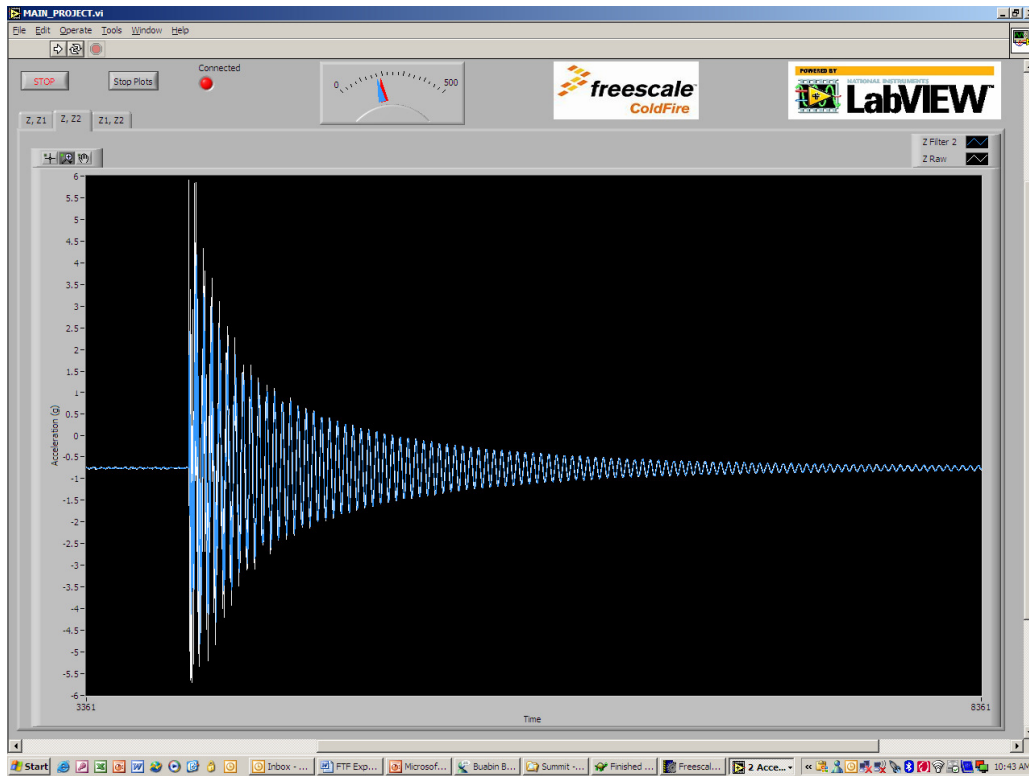


Figure 1b: Original and low pass filtered signals

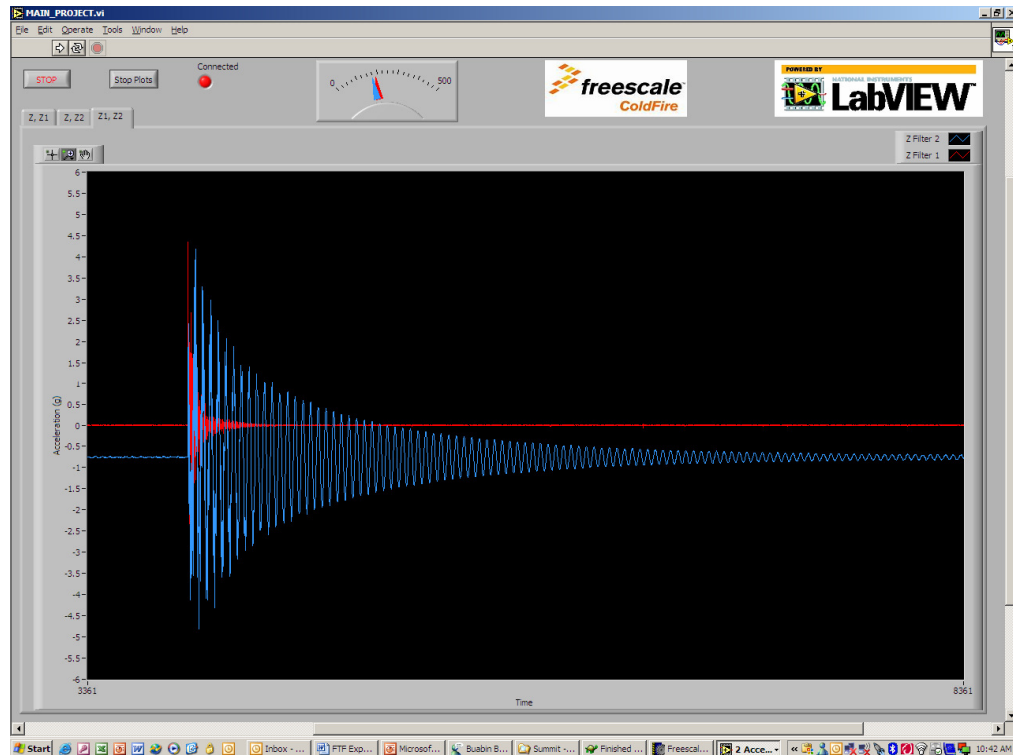


Figure 1c: Low and high pass filtered signals

2. Digital filter design: High Pass Digital Filter Design

Introduction: The scope of this experiment is to generate a signal sampled at 3030 Hz, pass the measured signal through two high pass filters. The filters will be designed during the course of the experiment. The selected filters should be of the same order but different cut off frequencies. The effects of filter cut-off frequencies on filter performance should be evident on each filtered signal.

Procedure:

- a. Scroll to the subheading “EXPERIMENT 2”, in the file *hands_on_lab_exercises.c*.
- b. Select a 4th order high pass filter with a cut-off frequency (f_c) of 350Hz on channel Z2 (data path 2) and a high pass 4th order filter with cutoff frequency of 900Hz on channel Z1 (data path 1). The filter selection process is explained in the “Software Initialization Procedure”.
- c. Perform “*Software Initialization Procedure*” as stated in the appendix.
- d. The default sampling frequency is set to 3kHz
- e. Strike the beam with the impact hammer and stop the display when the generated signal is in full view.

Observation:

- f. The tab labeled “Z, Z1” displays the raw signal and the high pass filtered signal (Figure 2a), with frequency content greater than 900 Hz.
- g. The tab labeled “Z, Z2” displays the raw signal and the high pass filtered signal (Figure 2b), with frequency content greater than 350 Hz.
- h. The tab labeled “Z1, Z2” displays the both high pass filtered signals (Figure 2c).
- i. The gauge labeled “T1,T2” is an indication of the number of CPU cycles needed to process each filter operation

Conclusions:

- j. The tab labeled “Z1, Z2” displays two signals, with frequencies higher than 900Hz and 350Hz, respectively. The high pass filters eliminate the signal offset that is apparent on the raw signal.
- k. The effect of time delay on the filtered signals is evident in Figures 2a and 2b.
- l. The indicators on the gauge should read the same for both signals, since the amount of CPU cycle is proportional to the filter order.

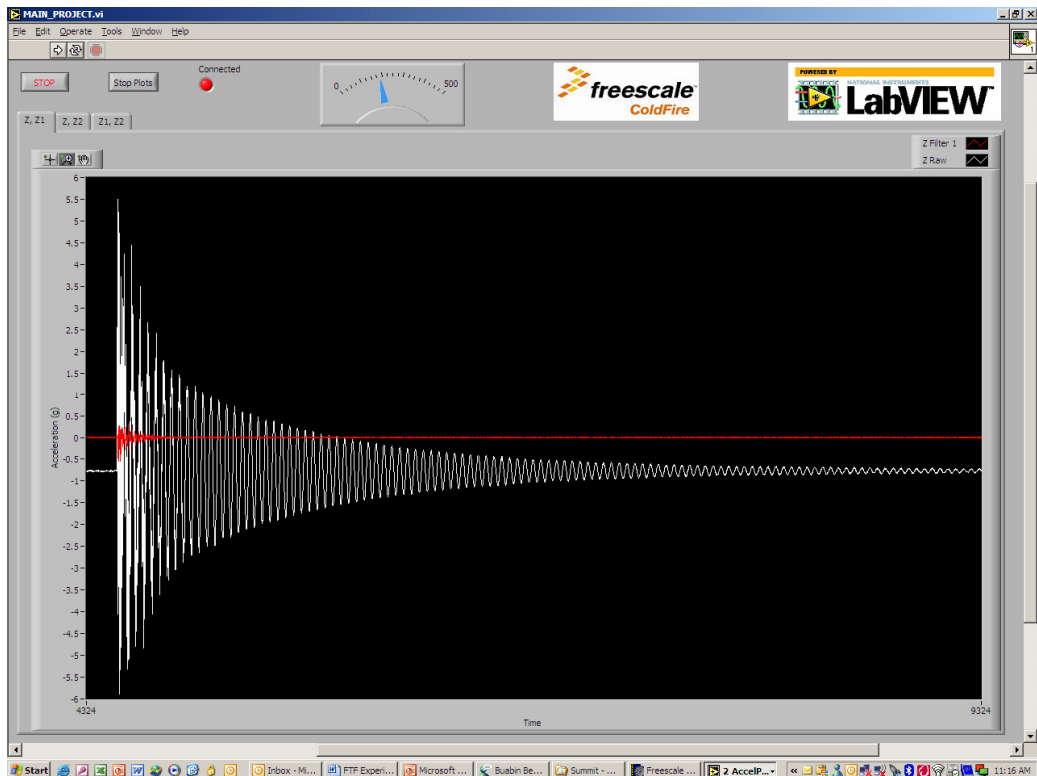


Figure 2a: Measured and High pass filtered signals ($f_c=900$ Hz)

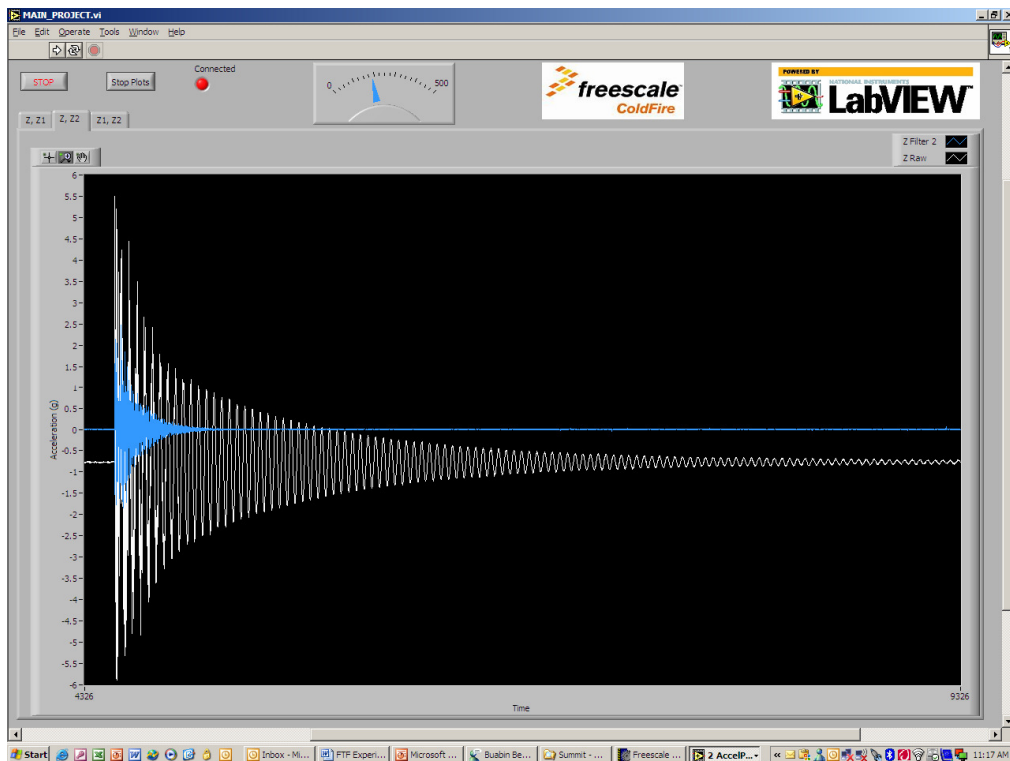


Figure 2b: Measured and high pass filtered signals ($f_c=350$ Hz)

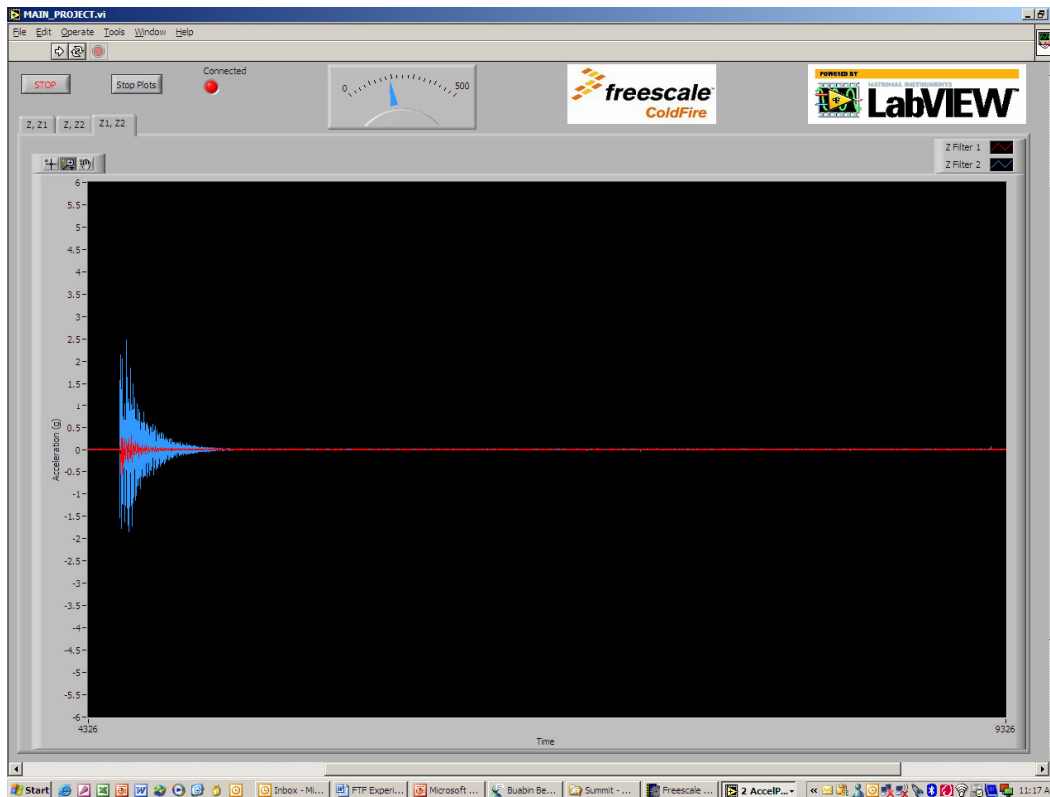


Figure 2c: High pass filtered signals with cut off frequency at 900 Hz and 350Hz

3. Digital filter design: Cascaded Filter design

Introduction: The scope of this experiment is to generate a signal sampled at 3030 Hz, pass it through 4th order, low pass filter ($f_c=350\text{Hz}$) cascaded to a 3rd order, high pass filter ($f_c=100\text{Hz}$). The signal from the cascaded channel is compared to the filtered signal from a 4th order, band pass filter ($f_c=350\text{Hz}$). The comparative effects of filtering on signal frequency content, time delay, processor cycle count and elimination of low frequency offset, should be evident.

Procedure:

- Scroll to the heading “Timer Settings” in the file *hands_on_lab_exercises.c*
- Scroll up to the heading “CASCADED FITLER DESIGN: EXPERIMENT 4”, delete the first set of block comments “/*” and “*/”.
- This automatically selects the filters for the cascade filer design experiment.

- d. Look for the subheading “data path 1: CASCADED FILTERS” and uncomment the line of code “*iir(&filter0)*” under this subheading, as explained in step 7 of the “Software initialization procedure”.
- e. Deselect all the filters in subheading “NON-CASCADED FILTER DESIGN” as explained in step 7 of the “Software initialization procedure”.
- f. Set sampling frequency to 3030 Hz by initializing the variable “*sample_rate_reduction_log2*” to the value 0, in the file “*hands_on_lab_exercises.c*”. This divides the base ADC sampling rate of 3030 kHz by a factor of 2^0 , or 1.
- g. Repeat *Software Initialization Procedure*, starting at step 8.
- h. Strike beam with the impact hammer and stop the display when the generated signal is in full view.
- i. Zoom on an area of the plot to demonstrate the presence of selected frequency bands on the filtered signal.

Observation:

- j. The tab labeled “Z, Z1” displays the raw signal and the signal at the output of the cascaded filters (Figure 4a).
- k. The tab labeled “Z, Z2” displays the raw signal and the band pass filtered signal (Figure 4b).
- l. The tab labeled “Z1, Z2” displays the band pass filtered signal and the signal at the output of the cascaded filters (Figure 4c).
- m. The gauge labeled “T1,T2” is an indication of the number of CPU cycles needed to process each filter operation

Conclusions:

- n. The tab labeled “Z1, Z2” displays signals with frequencies more than 100Hz (high pass filtered signal) and less than 120Hz (low pass filtered signal). The high pass and the band pass filters eliminate the signal offset that is apparent on the raw signal.
- o. The effect of time delay on the filtered signals is evident in Figures 4a, 4b and 4c.
- p. The indicators on the gauge should read higher for the cascaded filters, since the amount of CPU cycle is proportional to the filter order.

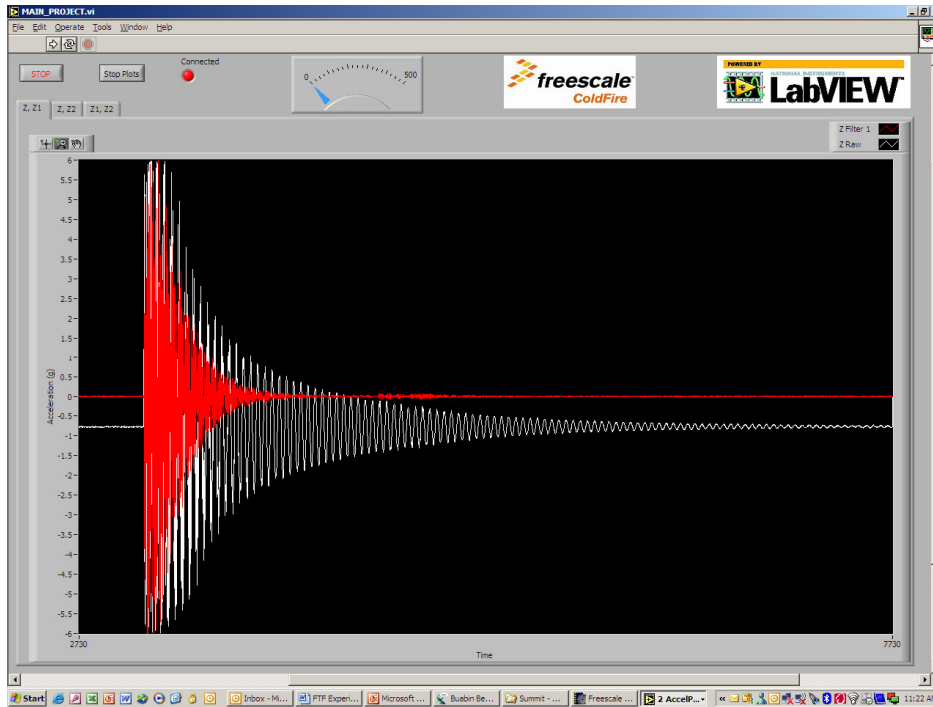


Figure 4a: Measured and filtered signal from cascaded filters

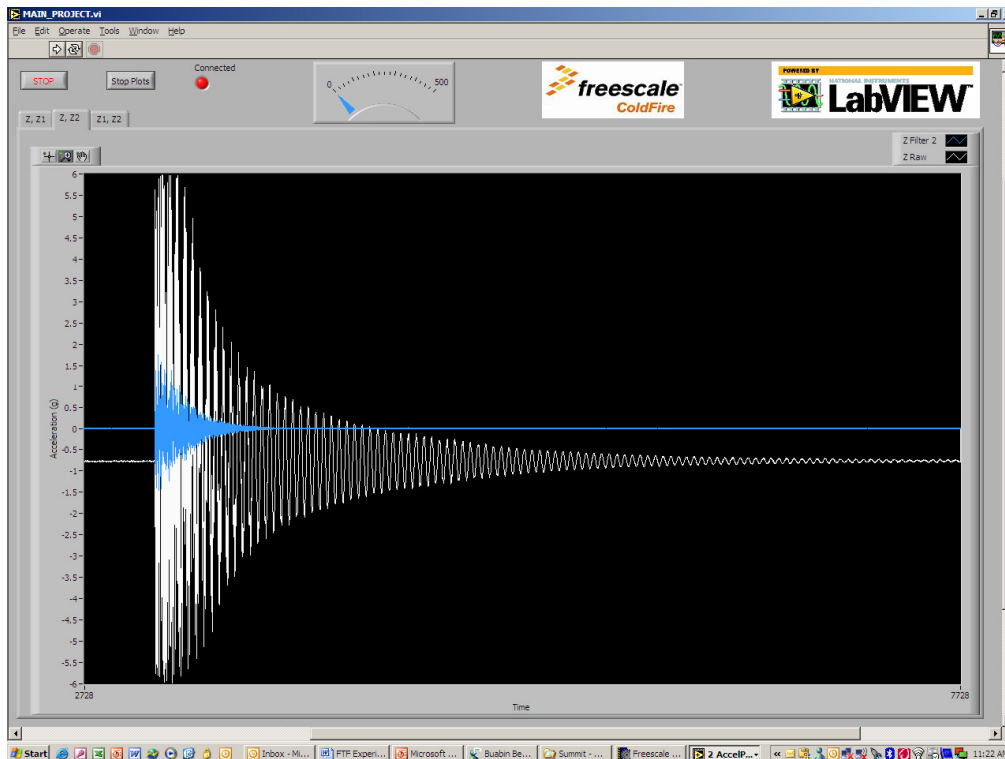


Figure 4b: Measured and band pass filtered signal

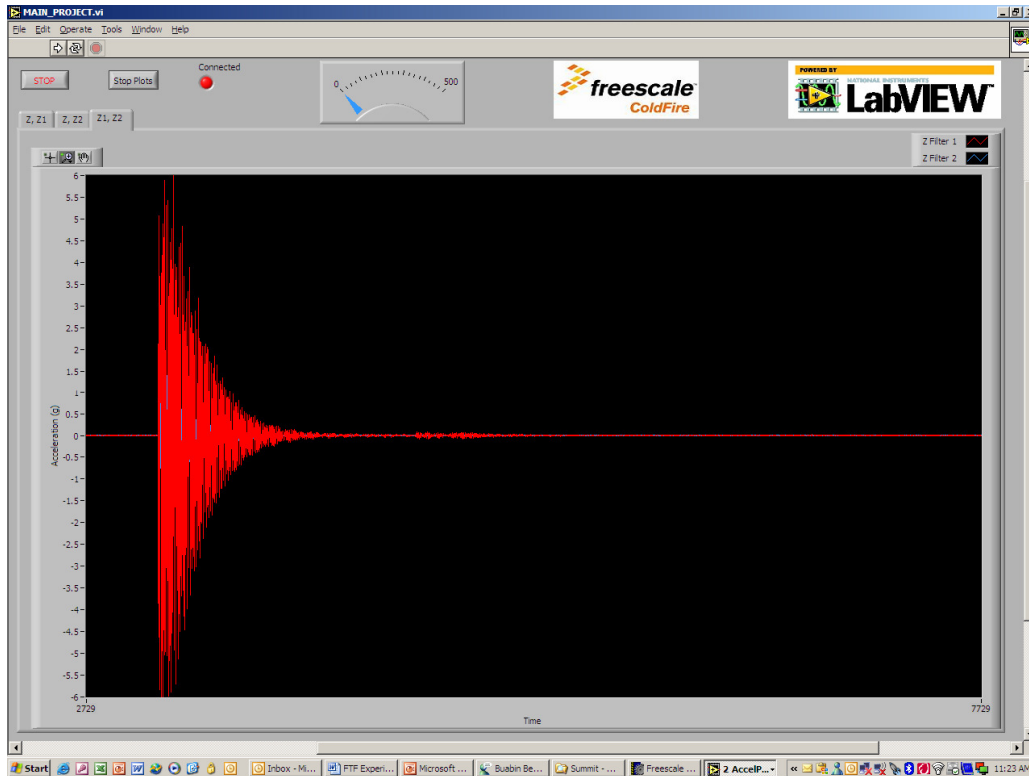


Figure 4c: Band pass and cascaded filtered signal

4. Digital filter design: Interactive Filter Design

Introduction: The scope of this experiment is to generate a signal sampled at 3030 Hz, and pass it through any filter of choice. A desired performance is predicted and a filter is selected that can best deliver the predicted performance. The selected filters could be of any order or type. The effects of filter type, order and structure on filter performance should be evident on the filtered signals.

Procedure:

- a. Select any combination of filters of choice.
- b. Set sampling frequency to 3 kHz.
- c. Repeat *Software Initialization Procedure*.
- d. Strike the beam with the impact hammer and stop the display when the generated signal is in full view.
- e. Examine the displayed signal and determine if the selected filter performance matches the predicted output.
- f. Repeat the above procedure until the predicted performance is met.

5. Signal Aliasing

Introduction: The scope of this experiment is to generate a signal that is sampled at a frequency lower than the base sampling rate of 3030 Hz. The effects of time domain aliasing should be evident on the displayed signals.

Procedure:

- a. Set sampling frequency to 758 Hz by initializing the variable “*sample_rate_reduction_log2*” to the value 2, in the file “*hands_on_lab_exercises.c*”. This divides the base ADC sampling rate of 3030 kHz by a factor of 2^2 , or 4.
- b. Perform the *software Initialization procedure*, starting at step 6.
- c. Strike beam with the impact hammer and stop the display when the generated signal is in full view.
- d. Zoom on an area of the displayed signals

Observation:

- e. The tab labeled “Z, Z1” displays the raw signal and the low pass filtered signal (Figure 2a).
- f. The tab labeled “Z, Z2” displays the raw signal and the High pass filtered signal (Figure 2b).
- g. The tab labeled “Z1, Z2” displays the low pass filtered and the high pass filtered signals (Figure 2c).

Conclusions:

- h. The tab labeled “Z1, Z2” displays signals with frequencies less than 120Hz (low pass filtered signal) and greater than 900Hz (high pass filtered signal). The high pass filter eliminates the signal offset that is apparent on the raw signal.
- i. The effects of signal aliasing are evident on a zoomed view of each display. The raw and high passed filtered signals have been aliased. The signals seem to be of the same frequency as the low pass filtered signal and the jagged signal peaks on the raw and high pass filtered signals are characteristic of aliased signals. Hence signal have been aliased to frequencies below the Nyquist frequency, $f_{nyq}=376$ Hz.
- j. The effect of time delay on the filtered signals is evident in Figures 3a and 3b.
- k. The indicators on the gauge should read higher for the 5th order filtered signal, since the amount of CPU cycle is proportional to the filter order.

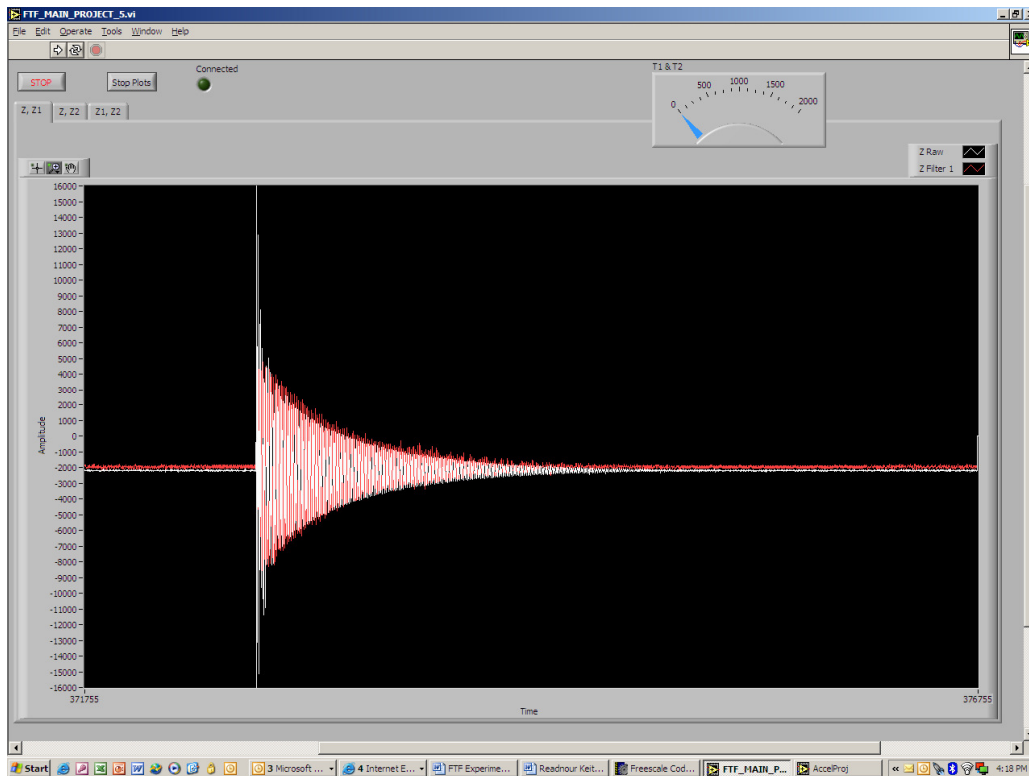


Figure 3a: Aliased measured signal and low pass filtered signal

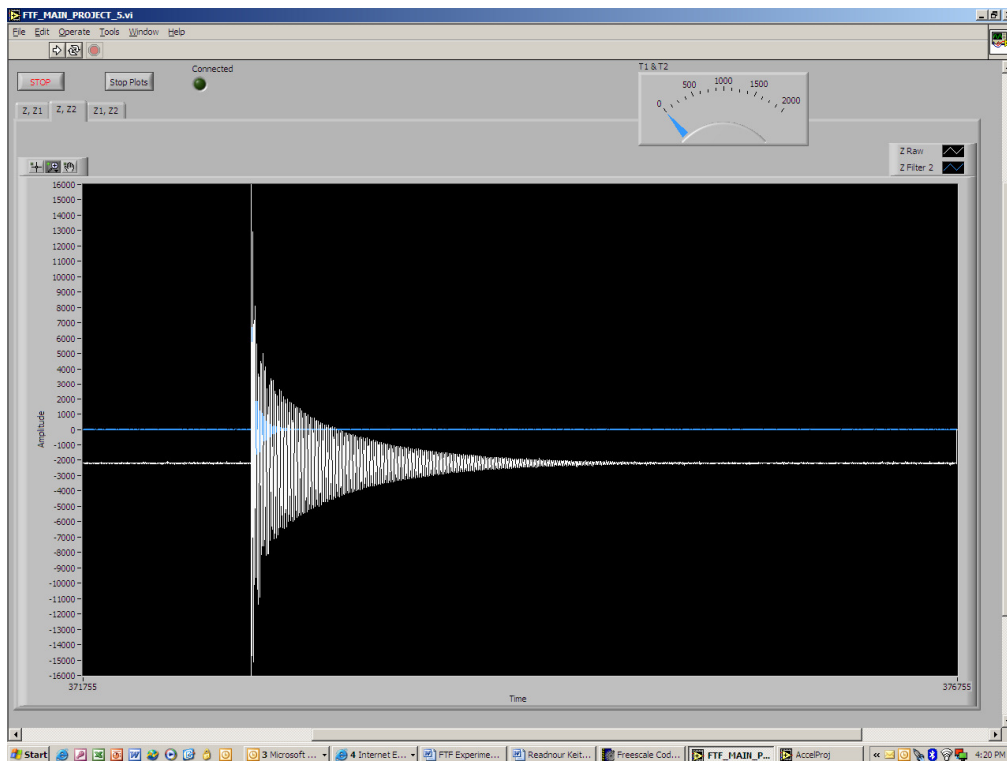


Figure 3b: Aliased measured signal and high pass filtered signal

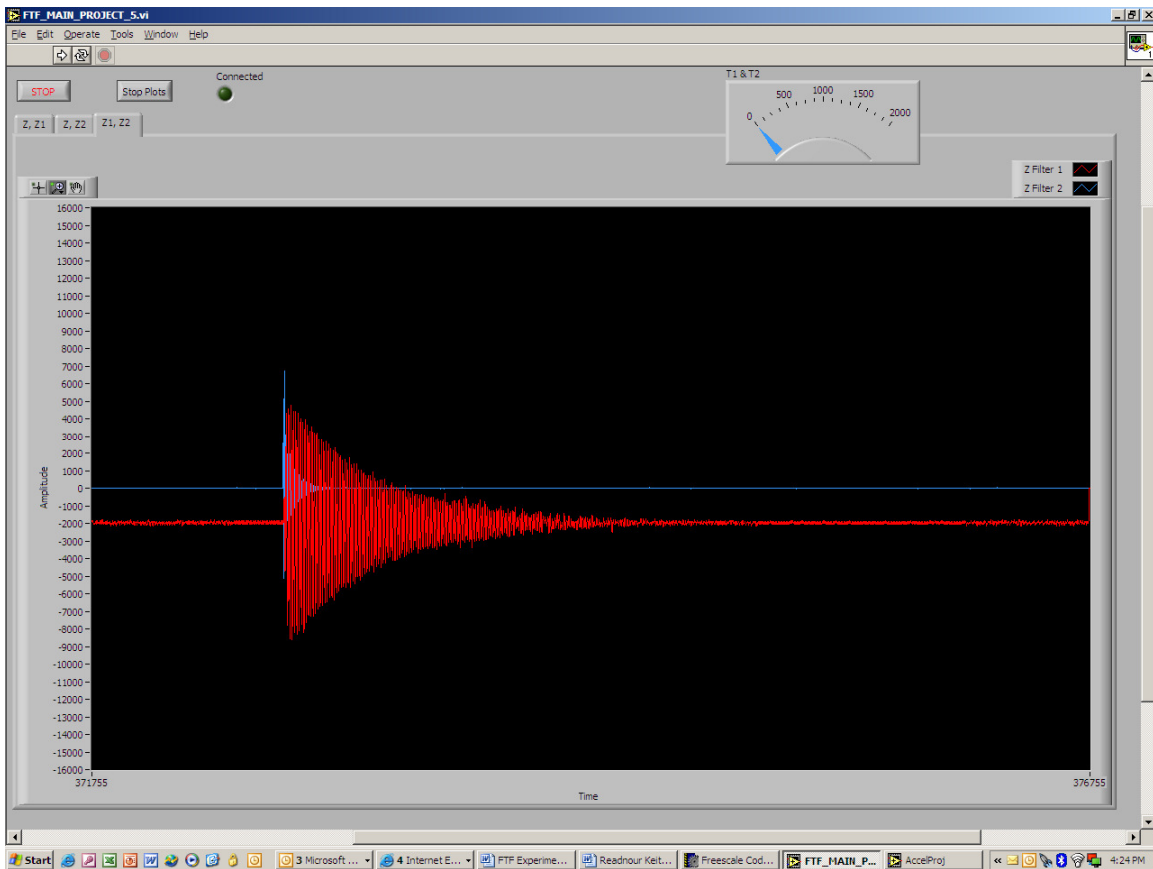


Figure 3c: Low and high pass (aliased) filtered signals

APPENDIX

Software Initialization Procedure: Repeat this procedure as necessary.

- 1) Close **LabVIEW**
- 2) Launch **CodeWarrior** version 6.4 from your desktop
- 3) Open the project **dsp_library_project.mcp**, select target **m5222x_Ruler_demo** and open the file “*hands_on_lab_exercises.c*”. If you do not have the mechanical resonator, you can use the accelerometer mounted on the ColdFire board. In this case, use target **m5222x_demo_flash** or **m5221x_demo_flash** depending on which board you have.
- 4) Scroll to the sub heading “Filter design Experiments”.
- 5) For Non-cascaded filter design, scroll to the subheading, “Non-Cascaded Filter Design” and select a filter in each of the subgroups “data path 1” and “data path 2”, respectively.
- 6) For cascaded filter design, scroll to the subheading, “Cascaded Filter Design”, select 2 filters in the “data path 1” subgroup and a filter in the “data path 2” subgroup.
- 7) Select a desired filter by deleting the characters “//” preceding the function “iir_init”. This should uncomment the text, which will be highlighted in *blue*. This means the filter has been selected and is active in the data path. Effectively, this procedure changes the filter coefficients.
- 8) Deselect a filter by typing the characters “//” preceding the function “iir_init”. This should comment the text, which will be highlighted in *red*. This means the filter has been deselected and is inactive in the data path.
- 9) **Save** the file (**Ctrl S**) and **Make** (**F7**) the code.
- 10) Select “**Flash Programmer**” from the tools menu and highlight the “**target configuration**” option in the menu page on the left. Then click on the “**load settings**” button and select “**CFM_MCF52221.xml**” in the ColdFire® folder, and click **Open**. (The complete path is **C:\Program Files\CodeWarrior for ColdFire V6.4\bin\Plugins\Support\Flash_Programmer\ColdFire**)
- 11) Select the “**Erase/ blank check**” option in the menu page, and click the “**Erase**” tab. This erases the current software on the board.
- 12) When the **status bar** reads “**Erase command succeeded**”, select the “**Program /Verify**” option on the menu page and select the “**Program**” tab to download software to the board.
- 13) When the status bar reads “**Program command Succeeded**”, click “**OK**” and the board is now programmed with software containing resent changes.
- 14) Run the code on the board by clicking the Run button (green play arrow) or cycling the power switch to the board
- 15) Launch **LabVIEW** from the desktop and maximize the screen
- 16) The system defaults to the START simulation state.
- 17) When the system starts running, STOP the display and START it again. This should display captured data on the screen. If not, STOP the display, cycle power to the board and START the display again.

18) NOTE: This step may need to be repeated as often as necessary to initialize the COM port and get data streaming to the display.

A1.

FREQUENCY RESPONSE PLOTS OF DEMO FILTERS

Sample Filters for Demos

Blue: 3rd LP, 120 Hz

Red: 4th LP, 120 Hz

Green: 5th LP, 120Hz

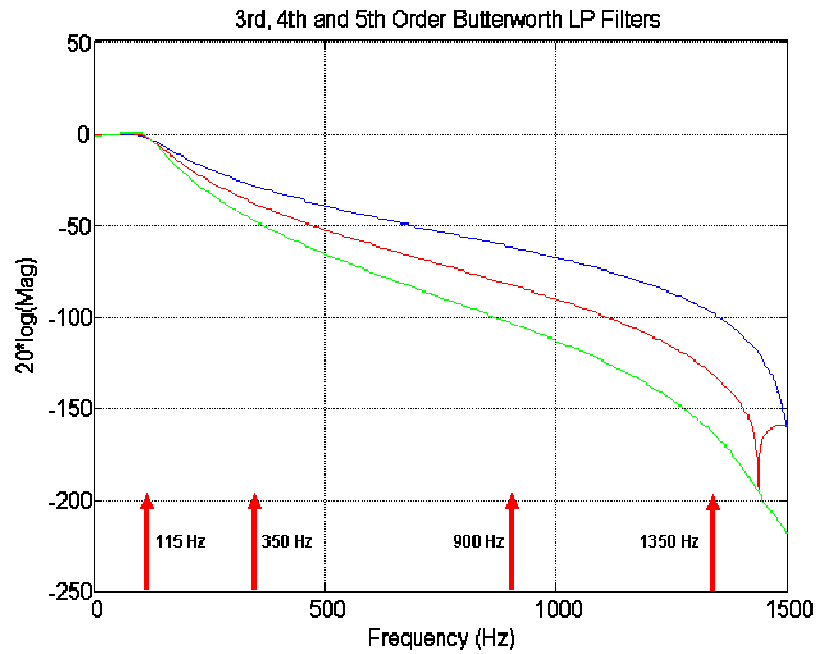


Figure A1: Frequency response of low pass filters

Sample Filters for Demos

Magenta: 3rd HP, 100 Hz

Blue: 3rd LP, 120 Hz

Red: 4th LP, 120 Hz

Green: 5th LP, 120 Hz

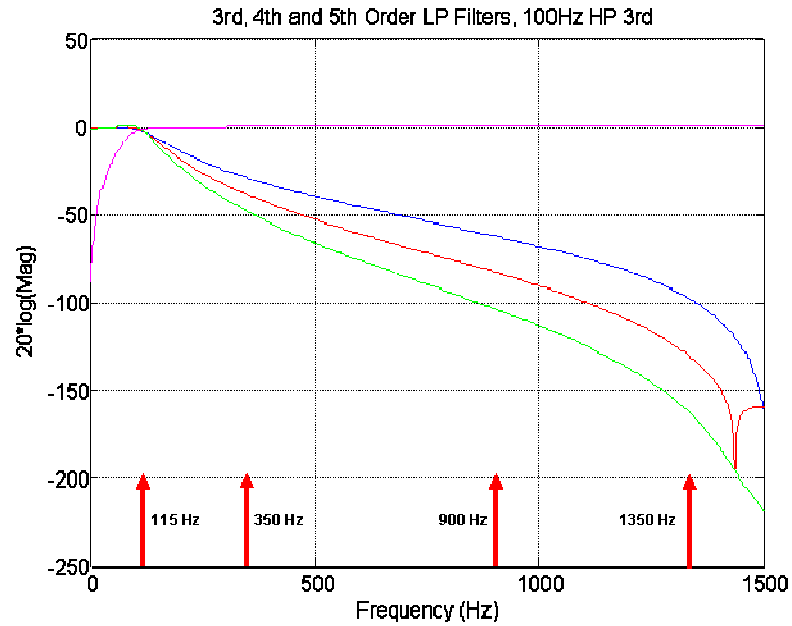


Figure A2: Frequency response of high and low pass filters

Sample Filters for Demos

Blue = 3rd Butterworth 100 Hz HP

Red = 4th Butterworth 350 Hz HP

Green = 4th Chebychev 350 Hz HP

Mag. = 4th Chebychev 900 Hz HP

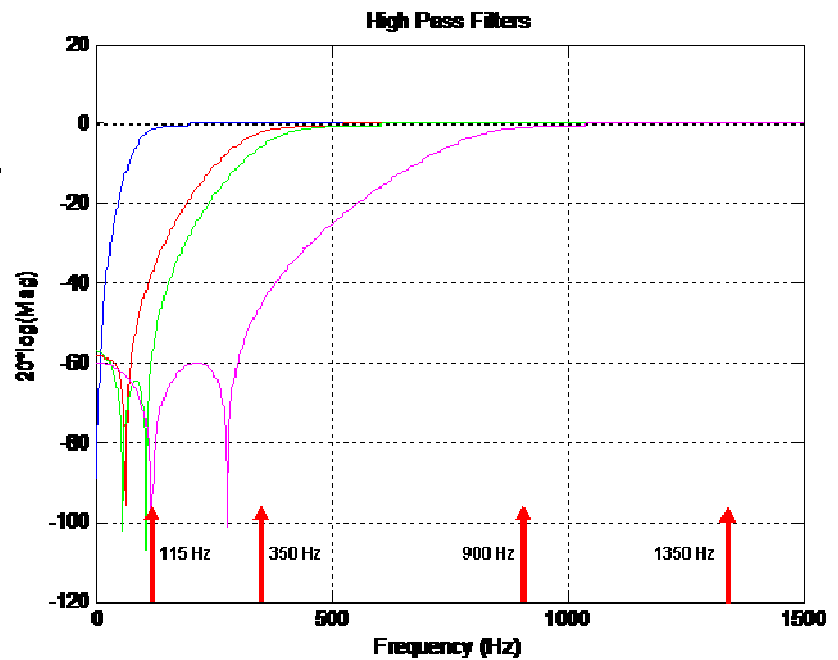


Figure A3: Frequency response of high pass filters

Sample Filters for Demos

Blue = 4th Order Chebyshev 350 Hz BP

Red = 4th Order Chebyshev 900 Hz BP

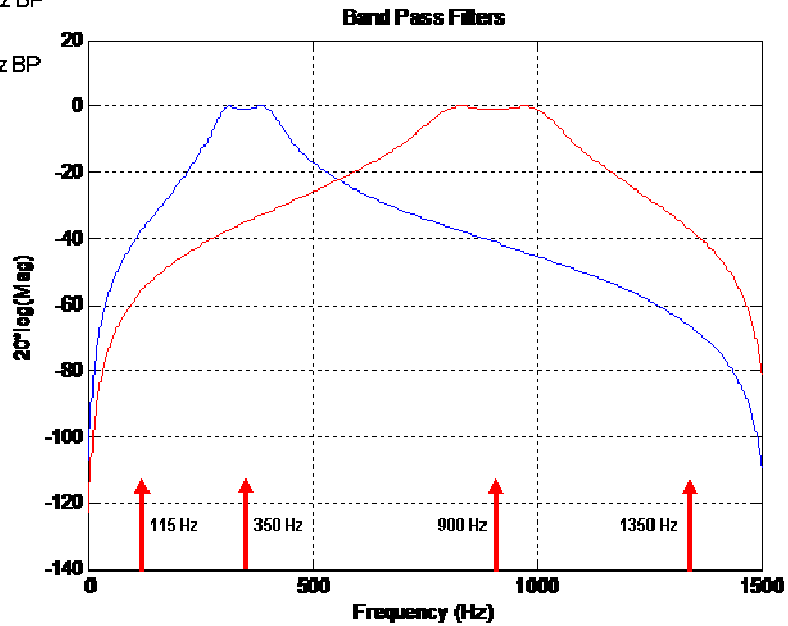


Figure A4: Frequency response of Band pass filters

Accelerometer Frequency Response

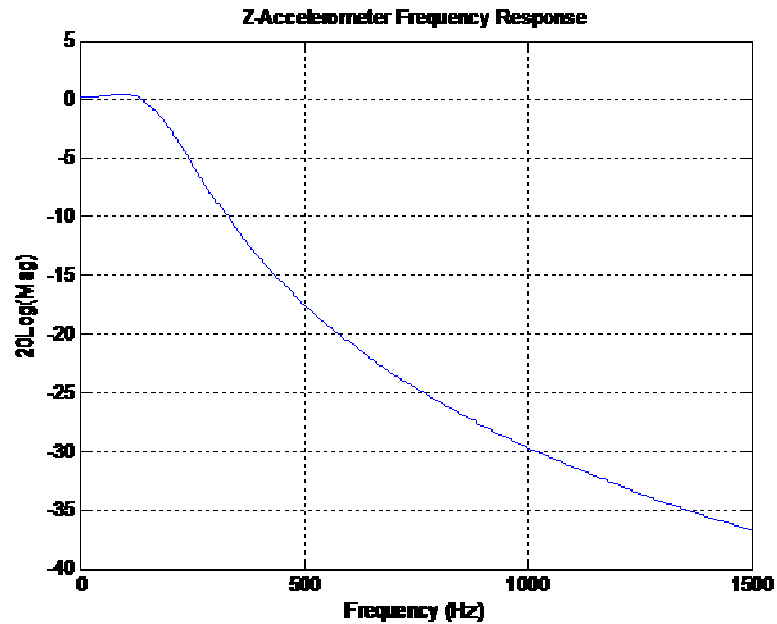


Figure A5: Frequency response of demo accelerometer