BME 301A Quantitative Physiology

Physical Lab #1: Biomedical Signal Acquisition

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Introduction:

This Physical Lab's Objectives can be broken down into 2 categories. The first is to development general skills with instrumentation equipment used in data acquisition of biomedical signals. This includes both oscilloscopes and digital software along with their associated filters and settings. Learning the function of an Oscilloscope 1x/10x probe and the functions of op-amps and amplifiers are present here. The second category is acquiring specific knowledge regarding signals. This includes understanding noise, where it comes from and how it affects our measurements along with aliasing and how to overcome it with sampling rates. It includes amplifier properties such as Common Mode Gain, Differential Gain, Common Mode Rejection Ratio and Input Impedance, and how to measure them in differential and instrumentation amplifier circuits. Lastly it also encompasses frequency responses, how to measure and interpret them in linear systems, and the effects of ac and dc coupling.

Materials and Methods:

During the course of the lab my group and I used the following materials: an oscilloscope and its probe, a thumb drive, a function generator, a bread board with semi-built circuits, a power supply for the circuit board, LabChart7 software, a PowerLab 26T unit, a resistor decade box, jumper cables and a myriad of connectors including BNC to BNC, banana to Minigrabber, BNC to DIN8, and BNC to Minigrabber.

For "Procedure 1: Oscilloscope Familiarization," my group and I began by familiarizing ourselves with the Oscilloscope and the functions of the 10x/1x probe. We did this by using the probe to connect the PROBE COMP terminal on the oscilloscope to channel 1 of the oscilloscope with a ground. We took a photo of the screen to document how the amplitude and frequency measured matched the printed values on the oscilloscope. We collected data with every combination of 1x and 10x on the probe itself and the scope menu of the oscilloscope. After that we connected the oscilloscope and the function generator to record the min and max peak to peak (p2p) output voltages possible from the generator at

frequencies from 20Hz to 20kHz. Lastly we experimented with finding noise using the oscilloscope to read out values from the free end of the probe as we placed it near objects and in contact with objects.

For “Procedure 2: Frequency Response,” my group and I established a sinusoidal output of 9.0V p2p from the function generator and proceeded to find the frequency response of the oscilloscope in AC and DC coupled modes. To do this we simply recorded voltages, shown on the oscilloscope, from the generator for the following frequencies (in Hz): 10, 103, 1002, 10k, 1M,2M.

For “Procedure 3: Amplifier Gain,” we started lab with two circuits nearly completed for us by the instructors. This procedure involved calculating the gain of both an INA137 differential amplifier along with an INA118 instrumentation amplifier. We finished assembling the circuits and hooked them up (one at a time) to the oscilloscope displaying input voltage and output voltage. We then applied a signal of 1V p2p And recorded values shown on the oscilloscope and using them to calculate each amplifiers differential gain. We supplied some of this data (including the value of the gain resistor for the INA 118) to the shared class spreadsheet.

For “Procedure 4: Common Mode Rejection Ratio (CMRR),” we wanted to find the CMRR. This required the differential gains we found in procedure 3 along with a common gain we had to calculate. Setting up this system involved the positive lead from the function generator connected to both pins of each amplifier and the negative lead connected to ground. Again using a 1V p2p from the function generator we recorded Vin and Vout using them to calculate the common-mode gain (Gc) of each amplifier. Using the 2 gains we could calculate the ratio between them.

For “Procedure 5: Measurement of Input Impedance,” we measured the input impedance of both amplifiers by connecting the function generator as the source voltage and the resistor decade box as the internal resistor. We varied the resistance of the decade box looking for the resistance that halved the output Voltage. For the INA137 this value was well within the range of the box, however for the INA118

we maxed out the resistance of the box without halving Vout. We noted this value as the resistance that caused a significant drop in Vout however it should be noted that this resistance introduced a lot of noise. To read the value of Vout from the oscilloscope we used the voltages from the internal peaks not including the added amplitude from the noise.

For "Procedure 6: Effect of Filtering," we used a PowerLab 26T unit along with LabChart7 software. We connected the output of the function generator to the input of the Powerlab, and also fed the signal to the oscilloscope. We set the function generator to 5Hz 10V p2p sine wave output. Then we used the software to record the actual frequency and amplitude of the signal as it measured on the oscilloscope. We sampled the waveform at each of the low pass filter frequency cutoff settings. This ranged from "none" to 100Hz.

For "Procedure 7: Sampling Rate," using the same setup as Procedure 6, we applied a 5Hz 10V p2p sine wave output. Then we changed the sampling rate in Lab Chart to record trials (each 15 seconds worth) at 4 samples/s, 40/s, 400/s,4k/s and 40k/s.

For "Procedure 8: Frequency Analysis," using LabChart and the 400/s signal from procedure 7, we selected several periods of a signal and opened them in the spectrum window. We manipulated the settings to show a clean FFT.

Results:

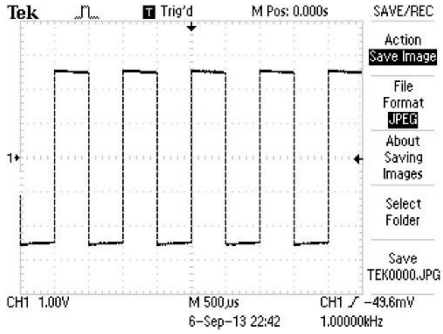


Figure 1: Procedure 1A's oscilloscope readout showing a 1V 1kHz signal coinciding with the scopes printed rating.

During procedure 1A our oscilloscope produced the same signal as the value printed on its face (See Figure 1). In 1B different combinations of probe and scope menu settings had expected results. This indicated that the probe attenuated the signal by the multiple of its setting and the scope menu prepared the scope to expect a certain attenuation equal to its settings. (See Table 1)

Probe Switch Setting	Scope Menu Setting	Signal Amplitude
1x	1x	5.12V-5.16V
1x	10x	51.2-51.6V
10x	1x	504mV-508mV
10x	10x	5.04V-5.08V

Table 1: Procedure 1B's results from each combination of probe switch and scope menu setting.

The measurements of maximum and minimum p2p output voltage from procedure 1C indicate that as frequency increased, the max and min output voltages increased slightly in a linear fashion. However the range (difference between max and min) stayed relatively constant (See Figure 2). For procedure 1D, noise interference was worst near anything with a current flow including biological tissue. The amplitude of the noise was very small at around 20.3mV from tissue and 4-5mV from air noise. The predominant frequency of the noise was ~50kHz. The bode plot (See Figure 3) demonstrates the difference between frequency responses of AC and DC coupled oscilloscopes from proc. 2.

Figure 2

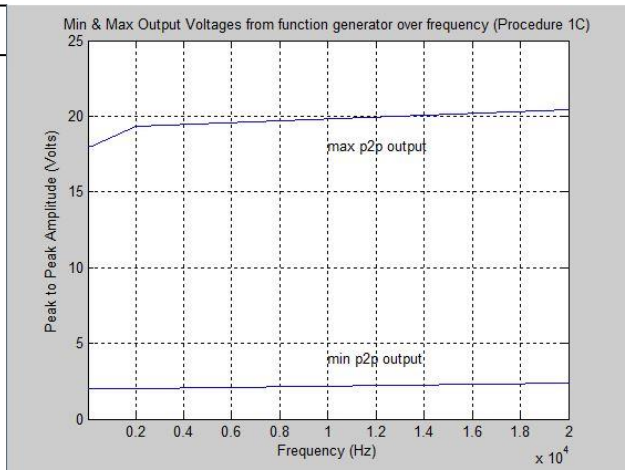
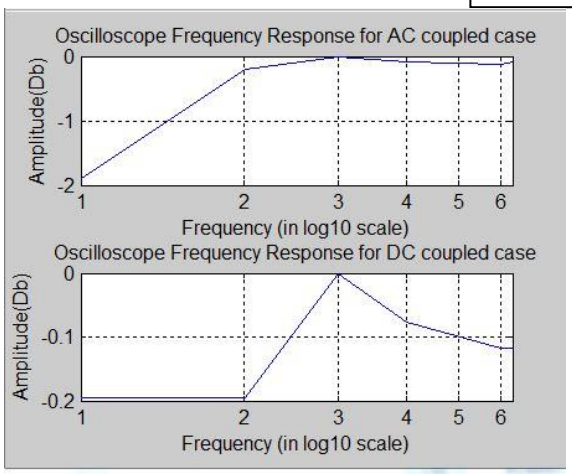


Figure 3



The data from proc.3 (See Table 2) was used to calculate the differential gain of both the differential and instrumentation amplifiers (See Figure 4).

Table 2

	INA137	INA118
Exact Value of V_in:	1.02V	1.03V
Exact Value of V_out:	1.98V	1.91V

$$For\ INA137:\ G_d = V_o/V_i = 1.98V/1.02V = 1.94$$

$$For\ INA118:\ G_d = V_o/V_i = 1.91V/1.03V = 1.85$$

Figure 4: Calculating differential gain

Procedure 4's data and calculations for Gc and CMRR are shown (See Figure 5).

Figure 5:

	INA137	INA188
Vin:	1.02V	1.02V
Vout:	690mv	5.20mv
Gd:	1.94V	1.85V
Gc:	$G_c = \frac{V_o}{V_i} = \frac{0.69}{1.02} = 0.68$	$G_c = \frac{V_o}{V_i} = \frac{0.0052}{1.02} = 0.0051$
CMRR:	$CMRR = \frac{G_d}{G_c} = \frac{1.94}{0.68} = 2.87$	$CMRR = \frac{G_d}{G_c} = \frac{1.85}{0.0051} = 360$

The equation relating Gd to Rg was calculated using a regression line, to all the class data, in matlab. Although 2 equations (a first order and a 2nd order) were of reasonable match, the 1st order was a better match. (See Figure 6)

$$G_d = (48,188/R_g) + 1$$

Figure 6

The data from procedure 5 (See Table 3) was used in combination with the equation and its reformation (see Figure 7) to calculate Ri (input impedance) for the INA 137 & INA 118 (See Figures 8 & 9 respectively).

Re:	20000	11,111,11(
Vs:	1.02V	1.02V
Vout:	0.99V	1.02V
Gd:	1.94V	1.85V

Table 3

$$V_o = G_d V_i = \frac{G_d R_i V_s}{R_i + R_e}$$

Figure 7

$$R_i = \frac{\frac{R_e V_o}{G_d V_s}}{1 - \frac{V_o}{G_d V_s}}$$

Figure 8

$$R_i = \frac{\frac{20k*0.99}{1.94*1.02}}{1 - \frac{0.99}{1.94*1.02}} = 2.0024 * 10^4$$

Figure 9

$$R_i = \frac{\frac{11111110*1.02}{1.85*1.02}}{1 - \frac{1.02}{1.85*1.02}} = 1.31 * 10^7$$

The procedure 6 plot of waveform amplitude as a function of Low-Pass Filter Cutoff Frequency is shown. (See Figure 10), as well as some qualities of the unfiltered signal (See Figure 11).

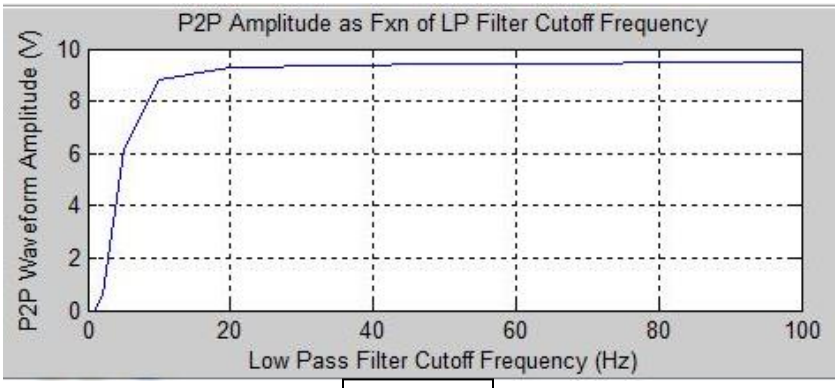
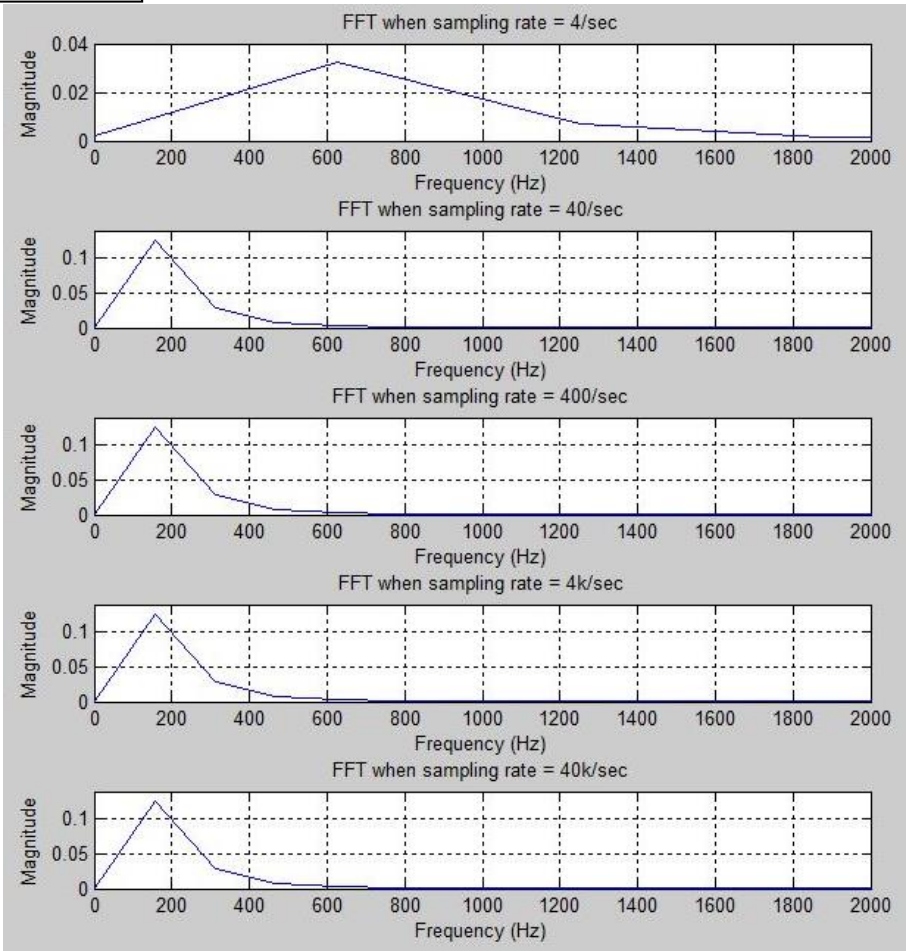


Figure 10

Max Amplitude	Mean Amplitude	Avg. Cyclic Frequency
4.6612 V	5.1575 Hz	(-0.2473 V)

Figure 11

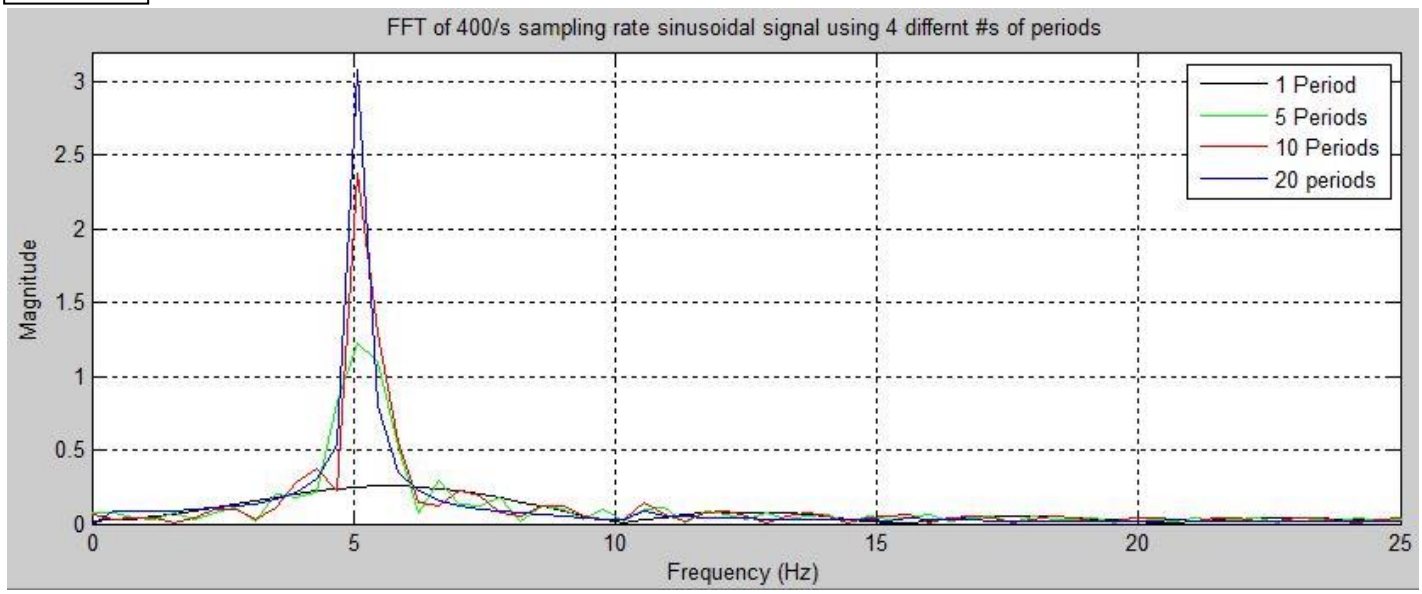
Figure 12



The procedure 7 data is slightly misleading. I have reason to think it was obtained without unchecking the "remove zero frequency" button on the settings in LabChart7. It therefore is not indicating all that it should. The subplots are provided nonetheless (See Figure 12). And the actual input frequency is 5.1597.

Procedure 8 combined plot comparing the FFT of the 400/s signal with 4 different period measurements is shown (See Figure 13).

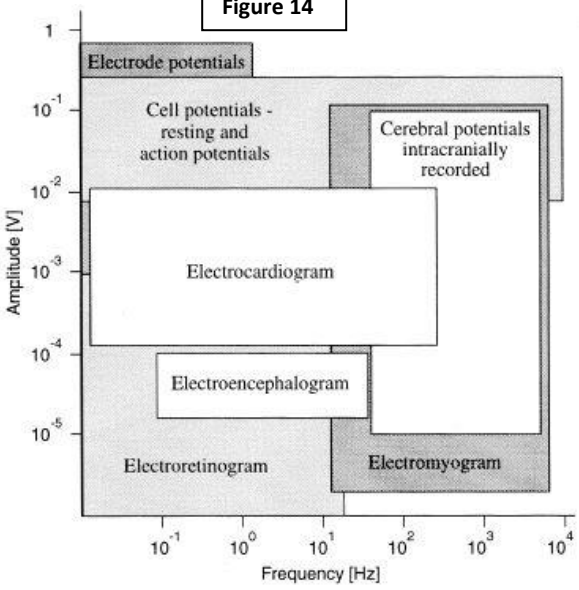
Figure 13



Discussion:

The Probe test signal used in procedure 1 is not a good test for biomedical signals because it is a 1V 1kHz signal. According to the diagram shown Module 1 Lecture 3 slides, the majority of biomedical signals fall under 1kHz and all fall below 1V. Both can be orders of magnitude lower (See Figure 14). When actually measuring biomedical signals I would recommend using the physical probe's switch on 1x because any attenuation to the signal will impact the recording of what is a very small amplitude signal already. Leaving the oscilloscope menu setting on 10x or 1x seems irrelevant to the quality of the data. However if 10x is set, the machine will expect an attenuated signal so the values will be read out 10x higher than they should be. This could be useful in easy calculations or readouts but one would have to remember to divide by 10 whenever they actually use the data. 1x/1x should be safe.

Figure 14



Moving on through the results, the output range of the function generator (difference between min and max) seems to stay constant, however the min and max are both increasing slightly (with the same slope) as frequency increases. This is ever so slight and I wouldn't expect it as the function generator is designed to supply a specific voltage signal at different frequencies. I attribute this phenomenon to the fidelity of the equipment.

Experimenting in procedure 1 showed the greatest noise occurred near anything with current. This definitely included human tissue. The amplitude of the noise was very small (20.3mV for tissue and 4-5mV for air). I expected the most prevalent frequency of noise to be ~60Hz, however this was not the case. We measured a most prevalent noise frequency of ~50kHz (a measurement I can't really explain). The T.A. seemed perplexed by this as well.

Moving on, the frequency response Bode Plots from procedure 2 showed somewhat expected results (See Figure 3). The AC coupling appeared to act like a high pass filter which an AC coupled setup should. The DC coupling appeared more constant despite how the graph makes it look. The amplitude range in the graph is so small compared to that of the AC graph that a change over its entirety can be considered almost constant. This would make sense as I expect a DC coupled setup to act like an all-pass filter (or no filter at all) allowing all frequencies to come through.

The analysis of the two amplifiers went smoothly. Consider the hypothetical situation where there was no resistor in the INA118 amplifier, but instead an open circuit of infinite resistance. According to the equation (See Figure 6) the differential gain would then approach 1 because the 48,188/Rg would go toward 0. This would make the amplifier act like an ideal amplifier with a gain of 1.

The INA 118 instrumentation amplifier also has the advantage over the differential amplifier in terms of CMRR. CMRR measures the ratio of differential gain to common mode gain where common mode gain can be thought of as noise. Since the CMRR for the INA118 was ~125 times larger than that of the INA137, and both calculations involved relatively similar differential gains (See Figure 5), it is clear the INA118 keeps the noise out of the signal. Additionally the input impedance of the INA118 was about 3 orders of magnitude greater than the input impedance of the INA137 (See Figures 8 & 9). Since a higher input-impedance allows more current to be directed through the amplifier, less signal loss will occur and a better recording will be amplified. The INA118 seems to be the better amplifier. On a side note, similar to the input impedance discussion for the INA118 amplifier, I would expect the oscilloscope to have a very high input-impedance to direct current through the oscilloscope instead of the resistor. This would allow better measurements of tiny signals.

Moving on to software based analysis, for the waveform in procedure 6 our measured frequency of the input signal was ~5.16 Hz. Looking at the graphs in LabChart7, I could only see degradation on Low Pass Filter settings below 10Hz. However looking at the plot I made using the data

captured from the spectrum view (See Figure 10), where changes might be more visible to the naked eye, I noticed degradation all the way up to almost 100Hz but with asymptotic behavior. Real notable degradation seemed to be occurring with LP filters 10-20Hz and below. And the amplitude was halved with the 5Hz filter.

Unfortunately my data for procedure 7 is convoluted and almost useless for the purpose of analysis and insight. In general if the Nyquist frequency is x, then the lowest sampling rate we could use is 2.5x. However in practice a 5-10 times greater sampling rate should be implemented. We overcame aliasing and achieved a clean signal at a sampling rate of 400 samples/s. Below that the signal wasn't complete. Although a greater sampling rate is not really posing any negative effects on the signal, it does require fancier equipment and a greater amount of storage making it bulky and more difficult to work with. For example the 40k/s signal didn't seem to hold any more relevant information to make a visibly accurate waveform than did the 4k/s. The reason why the data for this section was so bad may well be related to the zero frequency button. If you remove the zero frequency you are removing the DC offset and you lose the peaks that are present when the average of a p2p signal is above zero. For example consider peaks of -7 and 9 which average to 1, verses -8 and 8 which average to 0. This amplitude of 1 would show as a blip if the zero frequency component remains, but if the DC offset is removed, then no blip of amplitude would show and you would be losing information.

In an ideal sense an FFT shows the amplitude of your signal at any given frequency. Since a signal can be broken into many discrete sinusoids of different frequencies, some carry more amplitude (or more of the signal) than others do. The FFT shows the amount of amplitude (which can convey the amount of signal) carried at each frequency. The peak of the FFT should represent the amplitude of the signal; however that is in an ideal sense which would require the signal be broken into very discrete frequencies where each amplitude could be accurately deciphered. Our situation is a little more complicated because a triangular form, with a peak at the carrying frequency, presents itself as opposed

to a single skinny spike. In this case I estimate the area under that triangular form would be the amplitude of the signal at the frequency associated with the vertex/peak of the triangular waveform.

The amplitude of the FFT from procedure 8, in the case of the varying number of periods (See Figure 13), was increasing as I increased the number of periods used to form the FFT. It approached a magnitude of 3 but I assume, from the clear gap between the 10 period trial and the 20 period trial, that it had not peaked yet and more periods would result in an even higher peak. It seemed with each addition of more periods the peak grew, but at a decreasing rate. A 15 second run time at 400/s sampling rate did not yield enough periods to try higher numbers, but I can eyeball or estimate what it might peak at. I would guess it peaks at a magnitude of a little below 5 (using an infinite number of periods to construct the FFT) which is half the p2p amplitude from the original signal shown in lab chart which reads slightly under 10V. It seems then that a conclusion would be as follows: the longer the portion of data used to create an FFT of a periodic wave function, the higher the amplitude of the FFT at the frequency that carries that amplitude/majority of the signal. This will hold up to a maximum magnitude for the FFT (when using infinite number of periods) of 0.5*(p2p voltage of the original signal).

Clearly the 5-5.5Hz frequency range in procedure 8 carried a lot of the signals information, however I see slight bump in magnitude (See Figure 13) at just above 10Hz. This could be a harmonic, as it is close to double the original spike. Assuming the second blip is a harmonic I will say the Nyquist frequency is around 7 Hz where the main spike has died down.

The data present to draw the signal is a direct function of the sampling rate, meaning you simply don't have the data to smooth out artifacts and counter aliasing. There are likely interpolation-algorithms that can be applied based of an expected signal form. With algorithms like that, data could be estimated and inserted by the computer to predict what happens in the interim period between 2 points of data based on an indicated pattern. This is similar to anti-aliasing computer graphics technology that smooth lines of images or intelligent stereo headunits that fill in static gaps in low sample rate music.

But the LabChart7 software had no such option I could find. If one is experiencing bad aliasing or artifacts, they should really up the sampling rate and not try to correct for it after sampling.

References:

1. Enderle, John D., and Joseph D. Bronzino. *Introduction to Biomedical Engineering*. Amsterdam: Elsevier/Academic, 2012. Print.
2. Plab 1 Group Rg and Gain Value Spreadsheet

Unofficial Sources:

- Lab Manual
- Module 1 Lecture 3 Slides
- Blackboard Discussions
- Discussants: Lauren Bedell, Maeve Woeltje, Jodi Small, Paras Vora, Matt Everett