ME 4005 Lab Report 1 – Measurements of Wave Signals and Related Uncertainty

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Introduction

Lab one covers the interpretation of noise and signals. This requires understanding of basic electrical circuits and signal filters. Specifically, the lab uses a Low-pass filter (LPF) which is a circuit comprised of a capacitor and resistor which has the objective of only allowing AC signals to pass or output if they are below a certain frequency threshold. The specific frequency threshold is typically called the cutoff frequency denoted as f_c. The main lab objectives were to understand, collect, and interpret noise readings from the MSP432 Data Acquisition System (DAQ); to determine the impact of noise on measurements and attenuate such noise; to learn about signal filters; to construct a first order LPF apply a sinusoidal and square wave signal to said LPF and describe and measure the output of the signals applied to the circuit, and to understand transfer functions and get an idea on how to derive the LPF transfer function [1].

Methods

In conducting lab one the student first opens the MSP432 DAQ Graphical User Interface (GUI) through the MATLAB command window. The student then sets up the MSP432 circuit board to connect to the GUI and shorts channel 1 to get the first of 3 noise readings (one for each channel). Only one noise reading will be interpreted in the student's results and discussion as directed in the lab manual directions. Figure 1 below shows the location of the MSP432 channels. For parts 2 and 3 a breadboard must first be constructed to create the following LPF circuit as denoted in figure 2 below [1].

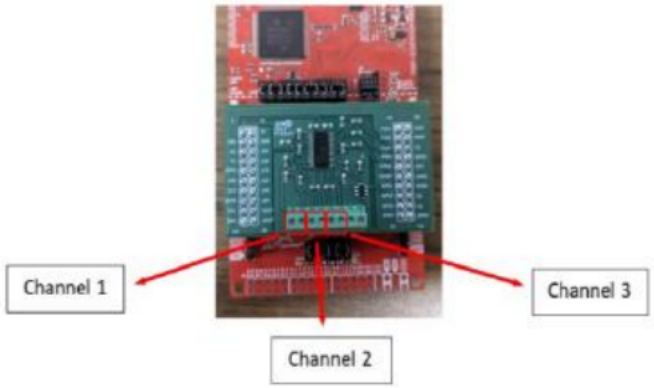


Figure 1

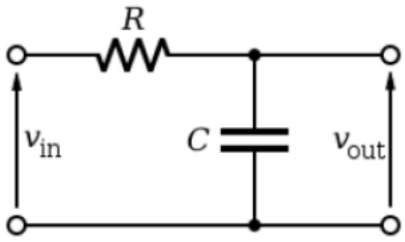


Figure 2

The resistor and capacitor values for the circuit are 3.3 kΩ and 0.33 µF respectively [1]. The breadboard is then connected to the provided PicoScope equipment. Specifically, the AWG channel and channel A are connected to the input and channel B is connected to the output of the breadboarded circuit. In the PicoScope software the student generates a set of specific frequency 1-Volt amplitude Arbitrary Waveform Generator (AWG) generated sinusoidal and square wave signals. To record data from the AWG signal in the PicoScope software the student will use the

measurement tools for peak-to-peak voltage and A-B channel phase angle. Figure 3 below shows some example measurements.



Figure 3

Following the collection of data as briefly described above and described in detail in the lab manual the student will analyze the collected data. For part one the student is required to use MALTAB to find statistical quantities for the noise in data collected. For part 2 the student is encouraged to use MATLAB but can use any software wanted to create designated graphs of calculated values from the experimentally collected data. Part 2 also requires the student to show in their graph the expected theoretical response as calculated in their Pre Lab 1 assignment. Part 3 consists of getting a screenshot containing specific measurements and does not require any specific data analytics although it is part of the required discussion in the following Results and Discussion section [1].

Results and Discussion

Data statistics for the short circuit noise are shown in Table 1 below (standard statistical symbols used to denote mean, standard deviation, and variance).

Table 1

$\mu = -1.04\ \mu V$	$\sigma = 30.5\ \mu V$	$\sigma^2 = 930.25\ pV^2$

Taking the data plotting a histogram for the number of occurrences for each voltage value and then overlaying a normal distribution curve yields the below plot in Figure 4.

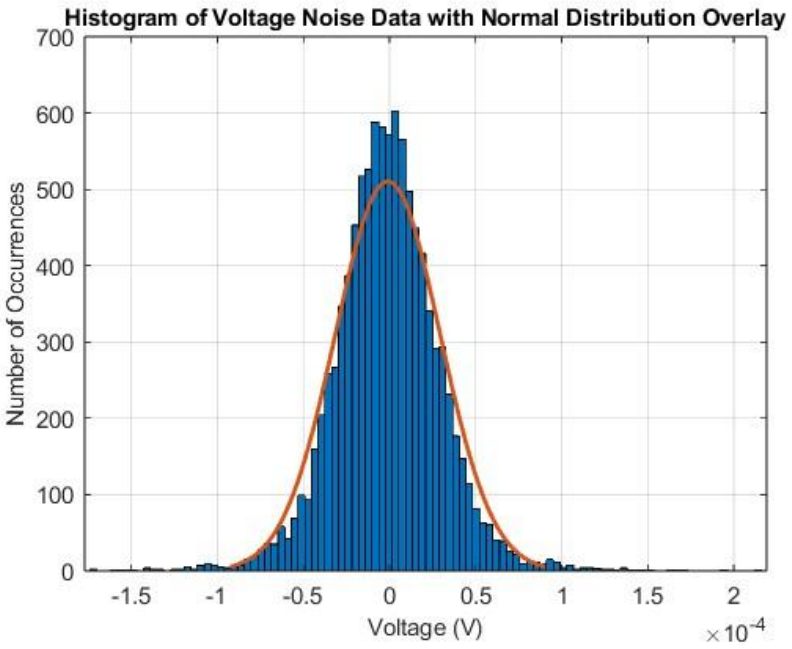


Figure 4

Lab instructions did not say to record open circuit noise and as such there is no open circuit noise histogram for comparison between open and short circuits. The noise seen roughly follows a normal distribution and as such can be concluded to be within expectations. Noise is most likely occurring from quantization, since voltage is continuous and the MSP432 is quantizing the voltage to a discrete digital value, this causes noise as digital quantization step size will never perfectly match the infinitely small continuous signal step size [2].

The data obtained from the PicoScope oscilloscope connected to the LPF is below in Table 2.

Table 2

Trial	V_{in} (V)	Frequency (Hz)	Frequency (Rad)	V_{out} (V)	Attenuation (dB)	Phaze Angle (Deg)
1	0.985	20	126	0.985	-0.00441	8.65
2	0.968	50	314	0.905	-0.58485	19.91
3	0.946	80	503	0.811	-1.33817	31.52
4	0.928	110	691	0.717	-2.24195	39.26
5	0.910	130	817	0.663	-2.75711	43.76
6	0.910	146.15	918	0.614	-3.42454	47.43
7	0.870	500	3142	0.224	-11.78930	74.77
8	0.848	1000	6283	0.115	-17.37153	81.69
9	0.843	5000	31416	0.023	-31.21428	88.70
10	0.839	10000	62832	0.012	-36.94089	92.59

The angular frequency and attenuation data was calculated from other measured data utilizing Eq.1 and Eq.2 as seen below.

$$\omega = 2\pi \tag{1}$$

$$\mathrm{dB} = 20\log_{10}\left(\left|\frac{V_{out}}{V_{in}}\right|\right) \tag{2}$$

As can be seen clearly in the data the input voltage remains relatively constant as compared to the output voltage, however both voltages drop as frequency is increased. This consistent drop in input voltage can be described by internal impedance within the PicoScope voltage source. The specific internal impedance as reported by PicoScope staff on a technical support forum is 600Ω on the AWG channel and 50Ω on both channel inputs [3]. This non-ideal real-world impedance is the most likely candidate for the cause of this observed behavior. The drop in output voltage is an expected and desired effect of passing voltage through the LPF circuit. Figures 5 and 6 seen below plot the experimental and theoretical results for filter attenuation and output phase angle as a function of frequency (Hz).

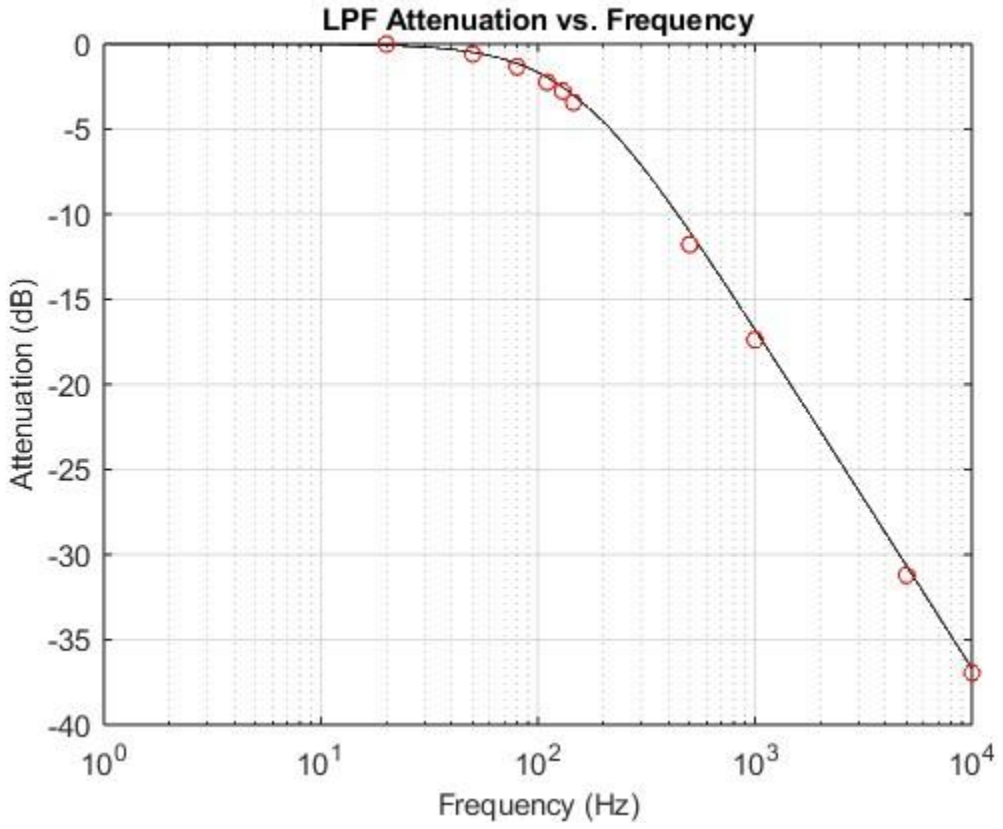


Figure 5

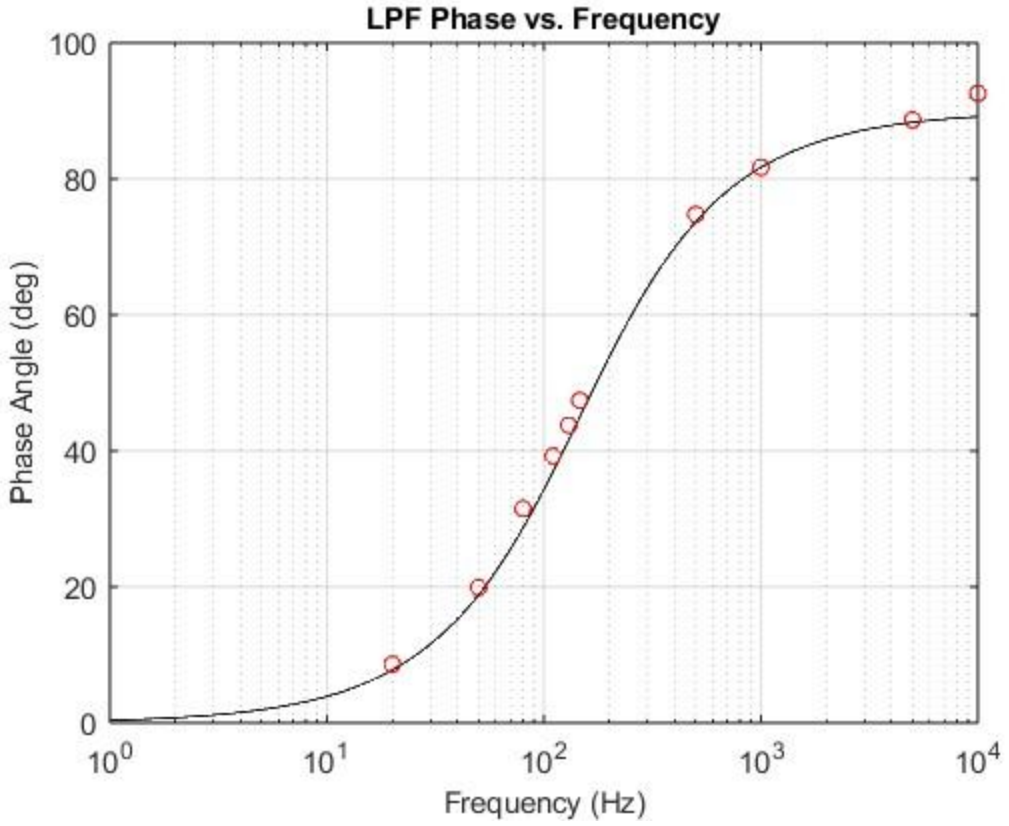


Figure 6

Discrepancies between the theoretical and experimental data points can be explained by small errors that come from real world impedances that do not exist in theoretical calculations. Another possible source for the small discrepancies is the time allotted before taking down the data as some samples have a two second experimental run time while others have more or less than that.

In part 3 of the experiment a square wave signal was applied to the LPF circuit. Figure 7 below shows the input and output response of the circuit to the square wave AWG signal.

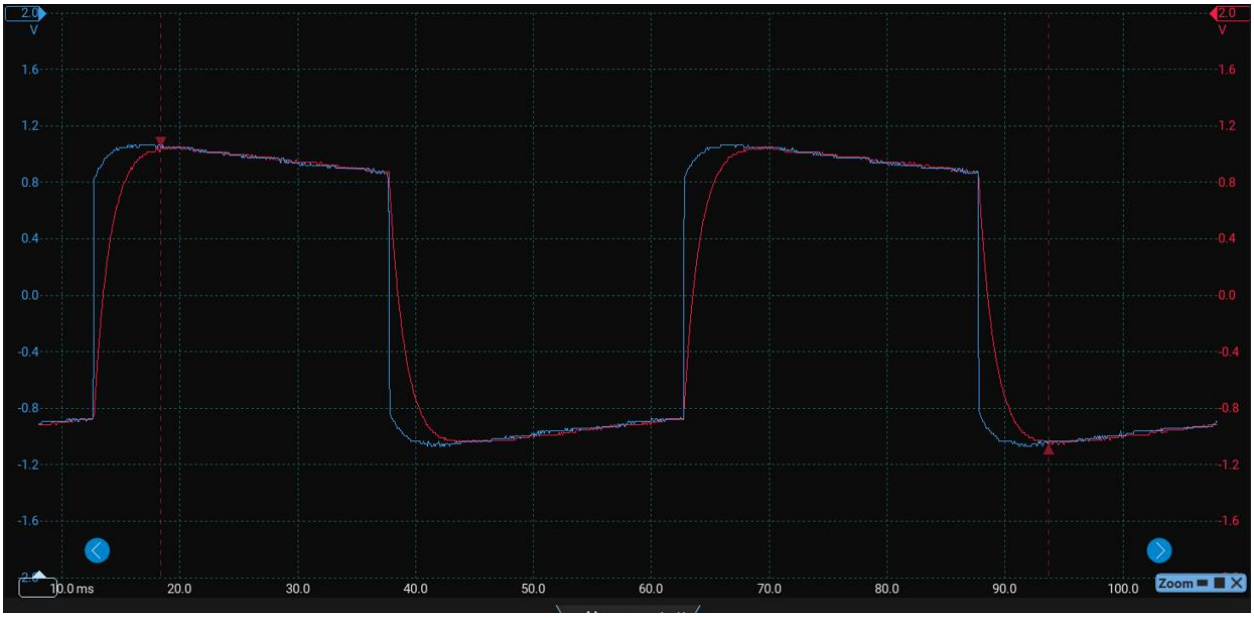


Figure 7

As seen above the circuit's response to the square wave signal (seen in red) has rounder curves as compared to the input (seen in blue). The output shape is similar to the input in flat sections of the wave but differs at the jumps up and down in voltage as it has a smother curve approach to the target voltage. The seen input signal frequency is below the LPF cutoff frequency. Differences seen between the input signal and output signal can be explained by the filtering out of higher frequency components of the square wave necessary for creating sharp corners. These higher frequency components to the fundamental frequency are explained by examining the Fouier Series of the square wave and given how LPF circuits work when the high frequency components are removed the resultant response is a rounder square wave as compared to the purer input wave. The input wave rounding can be explained by limitations of the AWG hardware.

References

[1] ME 4005 Course Materials. Available: https://canvas.vt.edu/courses/187828
[2] *MSP430 LaunchPad User's Guide*, Rev. A, Texas Instruments, Dallas, TX, 2013. [Online]. Available: https://www.ti.com/lit/ug/slau515a/slau515a.pdf

[3] Gerry (Pico Staff), "Re: Internal Resistance of Probes & 2206A," *Pico Technology Test & Measurement Forum*, Apr. 13, 2016. [Online]. Available: https://www.picotech.com/support/viewtopic.php?t=23461#:~:text=Re:%20Internal%20Resistance%20of%20Probes%20&%202206A&text=Hi%20tstauffer%2C,a%20channel%20input%20is%201M%CE%A9.. [Accessed: Feb. 19, 2026].