University of California, Davis
Electrical and Computer Engineering

EEC 1/89D
Introduction to Electrical and Computer Engineering

Part 4: Digital Filters and Frequency Space
Frequency Domain via Sound and Noise Filtering

Lab 6

Introduction:

a. Purpose/ Scope

In the previous lab, you made a communications system with LEDs and photodiodes. In this lab, let's learn a new way to think of signals, the frequency domain. You will try to build an intuition for understanding the frequency domain and how it can be used to filter data.

b. Resources/Lab Materials

Useful Links:

Breadboard Tutorial Link.

Launchpad Tutorials: Link 1 and Link 2.

Lab Materials:

- Matlab w/ Signal Processing Toolbox
- 4x 330 Ohm resistor
- 4x LED
- 1x BreadBoard
- Wire Jumpers
- Launchpad
- Breadboard booster pack
- Microphone
- Headphones

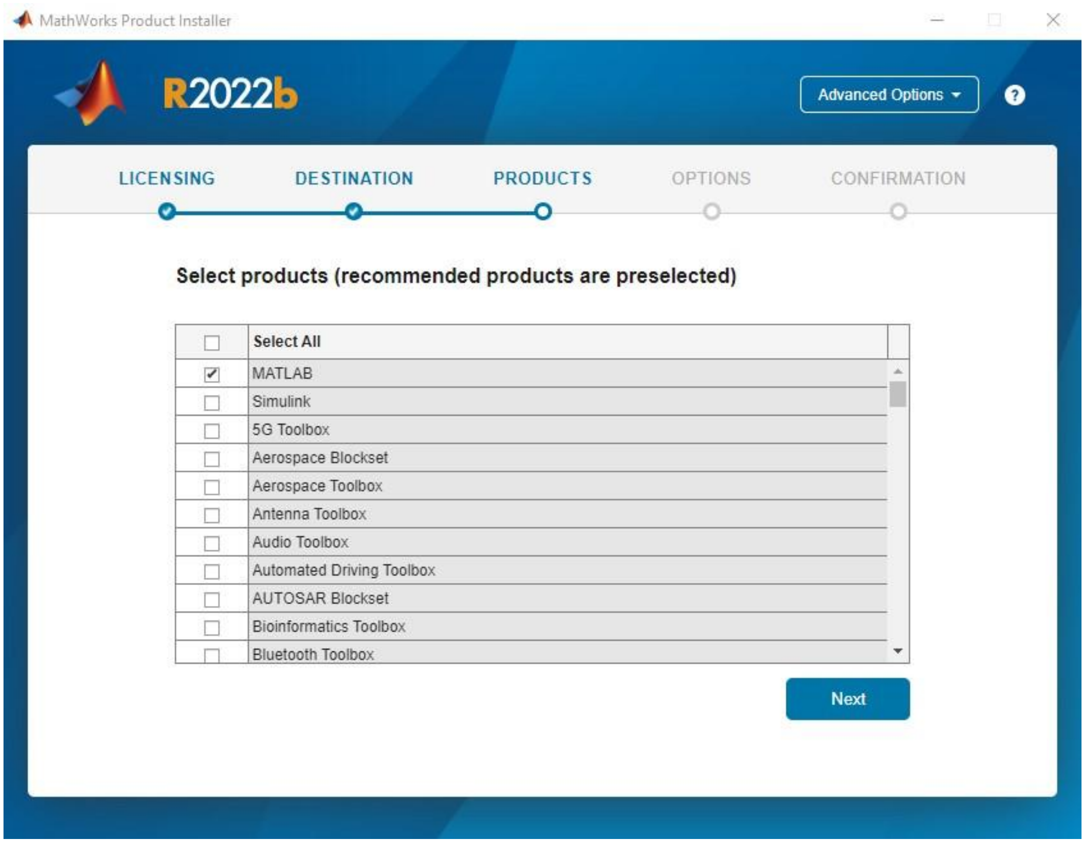
Lab Exercises:

You will need to use MATLAB software for this lab. You could either install the software on your laptop or use the lab computer (already installed). If neither of these methods work for you, please refer to the following files on Canvas:

MATLAB access through Virtual Computer Lab.pdf
MATLAB remote access guide.pdf

Part 0: Download and install MATLAB

Before proceeding with the lab you will need to download the most recent version of MATLAB. Go to the Mathwork website and install the MATLAB. You might need to register an account with Mathwork before installing (Use your ucdavis email so you have the license).



On the Products page, please select the "MATLAB" and "Signal Processing Toolbox" (not shown in this screenshot). You could add more toolbox later if you are interested.

Part A: Open MATLAB GUI

First you must download the .zip folder containing the GUI and unzip the folder "FFT_Visualization" into your MATLAB workspace and make it your current folder in your workspace. You should be able to see the "FFT_GUI.m" in the folder. Double click it and it should open it in the Editor. Once it opens, click the "Run" button and the GUI should open in a new window.

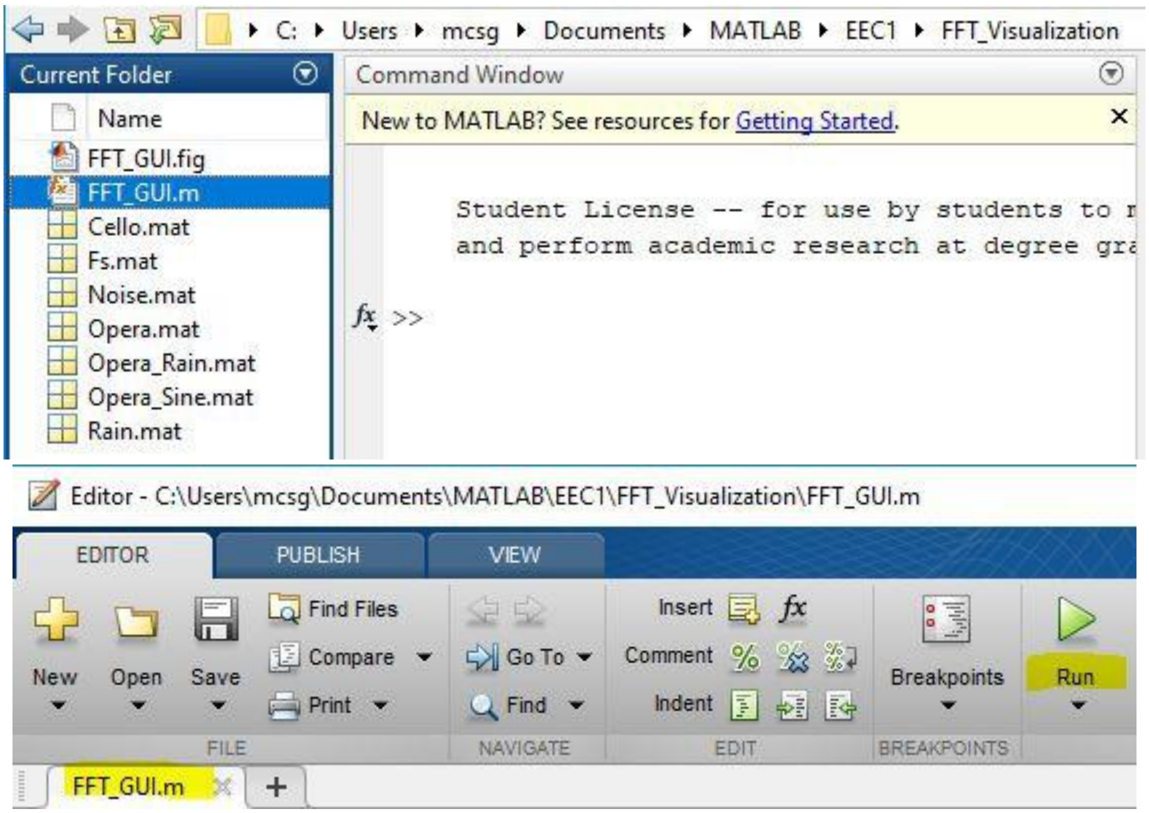


Fig. 1. MATLAB interface showing the location of the GUI program

Part B: Tones and frequency space

In Part B, we will be exploring how sine waves map into the frequency space, and how they add together. Make sure your GUI is in the tone section.

NOTE: ***PLEASE USE HEADPHONES FOR THESE EXCERCISES. IF YOU DON'T HAVE YOUR OWN, WE HAVE A FEW EXTRAS IN LAB.***

Create the following sine waves by entering the table data into the into the MATLAB GUI using either the slider bars or the edit text. Press the "Play" button to hear the sounds wave. It may be loud, so start at low volume and increase it until it is a comfortable level. Try to take note of how each combination in the table sounds and how it looks in the frequency domain as you answer the questions in the Challenge. Feel free to spend some time playing with the tone generator.

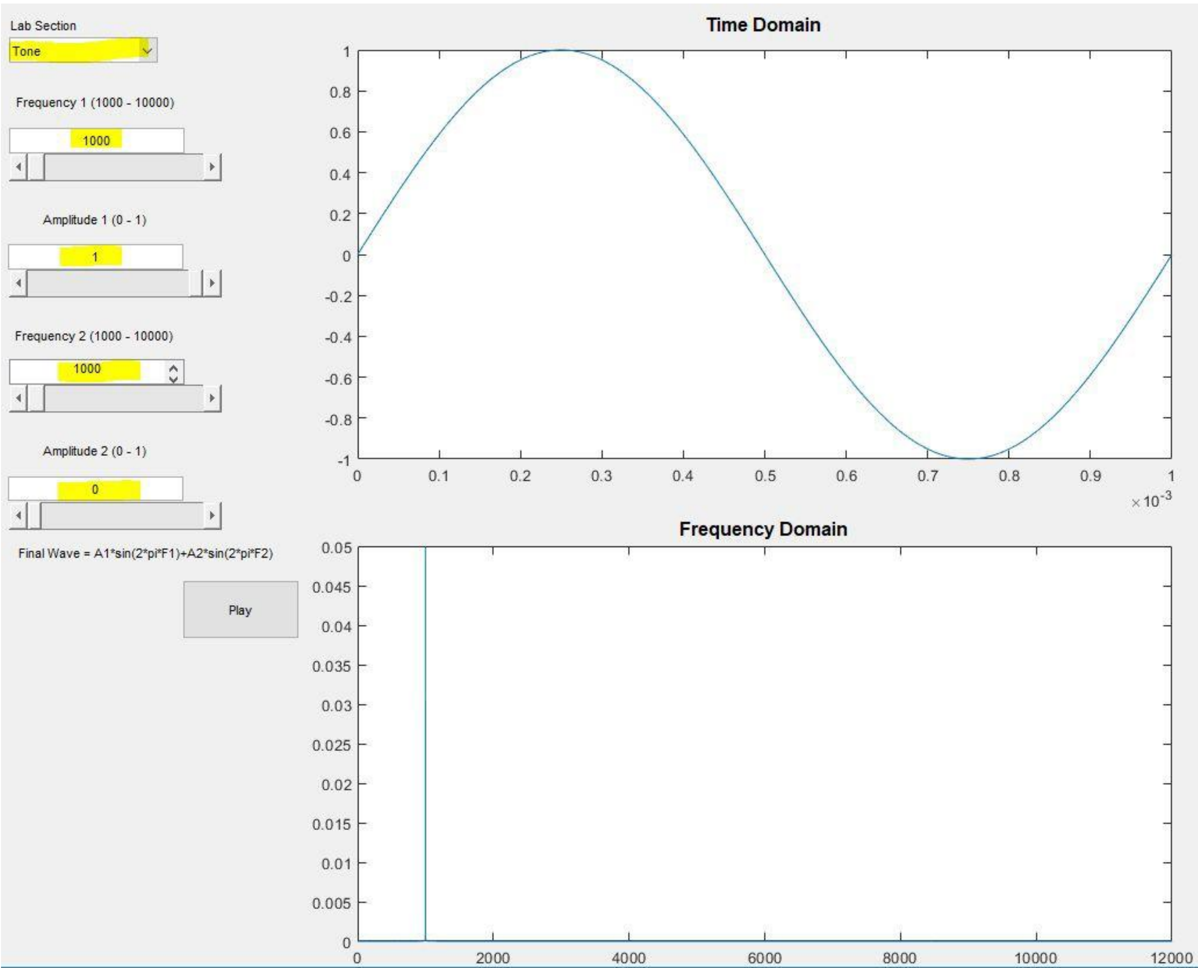


Fig. 2. MATLAB program showing a waveform in the time (top) and frequency (bottom) domains

Frequency 1	**Amplitude 1**	**Frequency 2**	**Amplitude 2**
1000	1	1000	0
1000	.5	1000	0
3000	1	1000	0
6000	1	1000	0
1000	1	1000	.5
1000	1	3000	.5
1000	1	6000	.5

Questions: Submit answers to the following questions on Canvas.

1. How does the amplitude of the sine wave affect the height of the peak in the frequency domain and the volume of the sound?
2. When only one sine wave is playing, how is the frequency of the sine wave related to the peak in the frequency domain?
3. When only one sine wave is playing, what is the relationship between the frequency and the pitch of the sound?
4. What effect does adding two sine waves with the same frequency have in the frequency domain and on the volume of the sound?
5. How would you describe the sounds when you have different frequencies added together? How does it compare to the individual sounds?

<u>Part C:</u> Music

For this part you need to change the drop-down bar in the top left of the GUI to “Music”. You need to listen to the four sound samples and answer the questions below. Again, take note of the sounds you hear and how they are represented in the frequency domain.

Questions: Submit answers to the following questions on Canvas.

1. When comparing the Opera singer and the Cello, which would you say is lower pitch? Does the frequency domain agree with you?
2. How does the sound of the rain compare with the random noise signal? Are there any similarities in their frequency domains?
3. What advantages does the frequency domain offer over the time domain when watching the various sounds?

Some sounds fit well into a limited range of frequencies while others don’t. Using the table below, try to set a lower and upper frequency limit that contains the majority of the sound’s signal. (Remember the graph is logarithmic so be careful to accurately determine the frequency).

Audio Clip	Low Frequency Limit	High Frequency Limit
Opera		
Cello		
Rain		
Noise		

<u>Part D:</u> Adding sounds

For this part you need to change the drop down bar in the top left of the GUI to "Adding Sound". You need to listen to the four sound samples and answer the questions in the Challenge. Again, take note of the sounds you hear and how they are represented in the frequency domain?

Questions: Submit answers to the following questions on Canvas.

1. How does the frequency domain graph of the two sound clips added together compare to the frequency domain graphs of the individual sound clips? Is it the same or different than when adding two tonal signals? Why or why not?
2. Imagine you can choose to make parts of the frequency graph louder and other parts quieter. If you wanted to make the Opera louder, which range of frequencies would you make louder?
3. If you wanted to hear only the Opera, what range of frequencies would you make quieter?
4. Would that work for all of the clips that contain the Opera?
5. Rank how well you think you could turn down the non-Opera sounds in the table below (1 = best, 3 = worst)

Audio Clip	Rank (1-3)
Opera + Cello	
Opera + Rain	
Opera + Noise	

<u>Part E:</u> Filtering sounds

For this part you need to change the drop down bar in the top left of the GUI to "Filters". As it turns out, there are devices that can suppress (decrease the amplitude) different ranges of frequencies. These are called filters. In this section we will be dealing with a band-pass filter. A band-pass filter takes one frequency band (a continuous range of frequencies) and allows them to pass through undisturbed, while suppressing all frequencies outside of that band. You can set your frequency band by changing the Bandpass Low/High Frequency Limits. When you do, a box will show up in the Frequency Domain Before Filters graph. This will help you visualize your bandpass filter.

<u>NOTE:</u> *<u>IF YOU CHANGE THE FILTER IN THE MIDDLE OF PLAYING A CLIP, IT WILL NOT TAKE EFFECT UNTIL A NEW CLIP IS PLAYED.</u>*

Questions: Submit answers to the following questions on Canvas.

Adjust the filters so that only the Cello or the Opera is heard. You probably won't be able to filter out all of the rain/noise, but do your best. If you use too small of a band you may distort the sound you are trying to keep, try to compromise as little of the sound you want as possible.

Audio Clip	**Bandpass Low Frequency Limit**	**Bandpass High Frequency Limit**
Opera + Rain		
Opera + Noise		
Cello + Rain		
Cello + Noise		
Opera + Cello (Get Opera Music)		
Opera + Cello (Get Cello Music)		

1. Is the noise signal or the rain harder to filter out of the Opera music? Why do you think this is?
2. Is the noise or the rain harder to filter out of the Cello? Why do you think this is?
3. What do you notice about the different settings of the filters when trying to separate the Opera and Cello music from one another?

<u>Part F:</u> Frequency domain and the launchpad

For the last part of this lab we will be using the Launchpad to take in a signal generated from a the microphone in the previous lab, and perform a Fourier Transform (time domain to frequency domain), and turn on LEDs according to the frequency of the input.

Here, the LEDs will signify various frequency ranges. Each LED will be connected to an analog output pin. This will allow us to change the intensity of the light based on the amplitude and the frequency of the applied signal. To generate this signal we will use a microphone, headphones, and the tone generator website used in the previous lab.

Step 1: Connect the launchpad to multiple LEDs (use pins 31, 32, 34 and 35). Connect the other end of the diodes to a 330 Ω resistor and connect the other end of the resistor to ground to create this circuit.

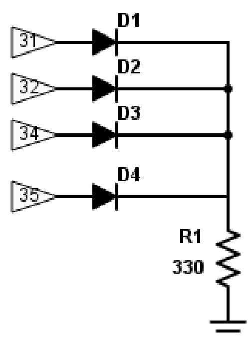


Fig. 3. Schematic for LED connections to MCU

Step 2: Construct the microphone circuit shown below with a wire running between the output and Pin 12 of the MCU.

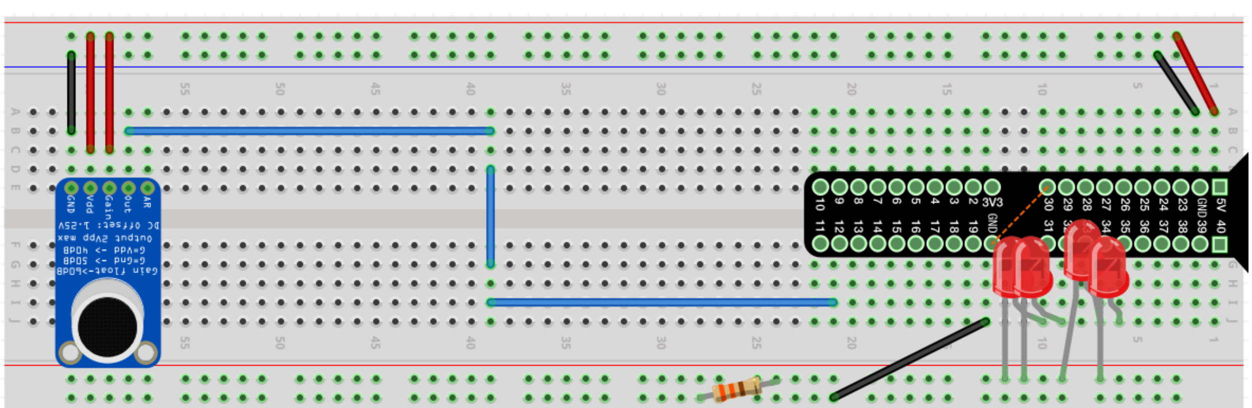


Fig. 4. Diagram of circuit for frequency domain analysis

Step 3: Upload the “Lab4PartF.ino” code from canvas onto our Launchpad. Download and open it in Energia. Then upload the code into your Launchpad. You may need to make sure that your Board and COM port is correct in the Tools section.

Step 4: Now go to the website to generate a tone at a given frequency (Link). Connect your headphones to your computer and place them against the microphone. You should now be able to see different LEDs turn on based on the frequency selected. Use the circuit and tone generator to complete the following questions.

Questions: Submit answers to the following questions on Canvas.

1. Incrementally change the frequency from 500 Hz to 5 kHz (5000 Hz). Write down the frequency range or “band” that each LED operates in.

2. Are there some frequencies where more that 1 LED lights up? Are there frequency gaps where no lights are bright? Write down frequencies where you observe this phenomena. What do you think is happening at these points?

3. Describe what you think is happening with the system to light up an LED in each frequency range.

4. Adjust the frequency bands to work in a different set of ranges, and test your modifications (line 40 of the program). What are the lowest set of ranges you can adjust to? What are the highest bands you can still get? What do you think limits the system?