print name (first last): ______________________

course: ECET 337 2025-07-26

Second Order Butterworth Filters

Prelab Activity

_____ 1. Fabrication of the *full* circuit breadboard layout, as described on the following page (10%)

Prelab Video Demonstration Checks

_____ 1. Photo of the *full* circuit breadboard layout (5%)

_____ 2. $f_{\text{-3dB measured}}$ = _________ photo of generator & DMM from video (5%)

_____ 2. Transient responses peak overshoot = _______ % screen shot with cursors and data (5%)

Performance Checks

	In lab	or	Late
_____ 1. Noninverting Amp	(15%	or	8%)
_____ 2. Low Pass Quick Look	(30%	or	15%)

Lab Performance Scoresheet

Prelab Activity …	(10%)→	__________
Prelab video demonstration	(15%)	__________
All required signed ***Performance check offs*** ………………………………	(45%)→	___________
Total→	(out of 70%)	___________

Prelab Activity:

1. Build the circuit shown in the schematic Figure 1a, precisely as shown in the photo Figure 1b.

2. Locate and display on the far right of your protoboard the following parts.

Resistors

1 5.60 kΩ

2 2.2 kΩ

1 39 kΩ

3 10 kΩ

Capacitors

2 100 nF

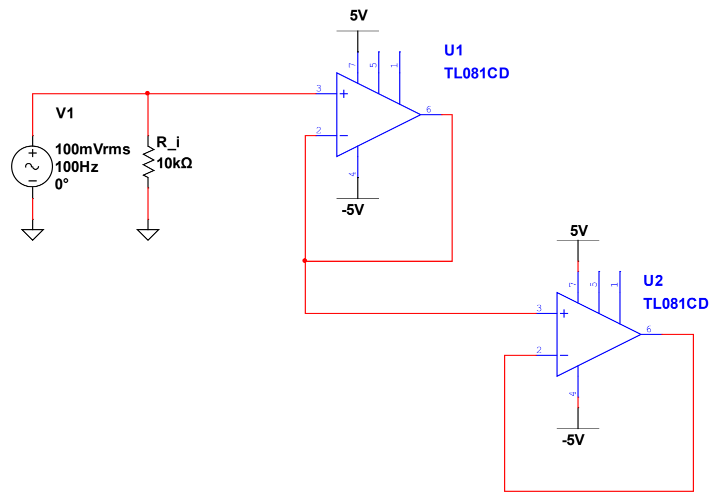


Figure 1a Schematic of two voltage followers

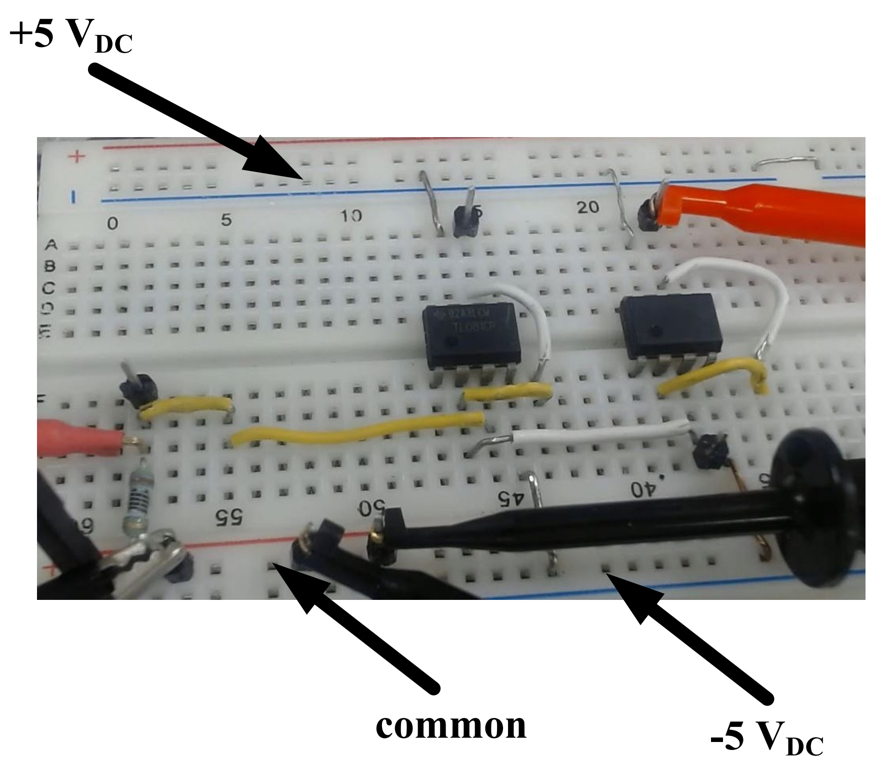


Figure 1b Protoboard build of two voltage followers

2. Build this circuit on your breadboard.

_____________ Instructor's initals

Objectives

Verify the frequency and transient responses of second order low pass Butterworth filters.

Approach and Results

A. Amplifier Fabrications

Voltage Followers

1. For the voltage followers of Figure 1, replace the signal generator with a direct connection to common.

2. Turn the power supplies *on*.

3. Measure the VDC at the output of U1. It should be < $\pm$0.1 V_{DC}. Do not continue until the output of U1 is very small (< $\pm$0.1 V).

4. Measure the VDC at the output of U2. It should be < $\pm$0.1 V_{DC}. Do not continue until the output of U1 is very small (< $\pm$0.1 V).

5. Set the signal generator to produce a 100 mV_{RMS}, 100 Hz, 0 V_{DC} sine wave.

6. Without connecting it into the op amp, verify with the multimeter that the V_{RMS}, V_{DC}, and frequency are correct. Adjust the signal as necessary.

7. Connect the sine wave to the input of U1.

8. Connect CH 1 of the oscilloscope to display that signal. Adjust the oscilloscope to place the wave across the middle of the screen, covering more than half of the screen vertically, displaying one to two cycles, well triggered.

9. Move CH1 of the oscilloscope to the output of U1. Verify that that signal is an undistorted sine wave. Do not continue until that waveshape is correct.

10. With the multimeter, measure the V_{DC} at the output of U1. Continue when that V_{DC} is < $\pm$0.1 V.

11. With the multimeter, measure the V_{RMS} at the output of U1. It should be the same size as U1's input, 100 mV_{RMS}. Continue when the $V_{U1\ out}$ is correct within 5 %.

12. With the multimeter, measure the V_{DC} at the output of U2. Continue when that V_{DC} is < $\pm$0.1 V.

13. With the multimeter, measure the V_{RMS} at the output of U2. It should be the same size as U1's input, 100 mV_{RMS}. Continue when the $V_{U2\ out}$ is correct within 5 %.

14. Disable the generator's output, then turn the power supplies off.

Noninverting Amplifiers

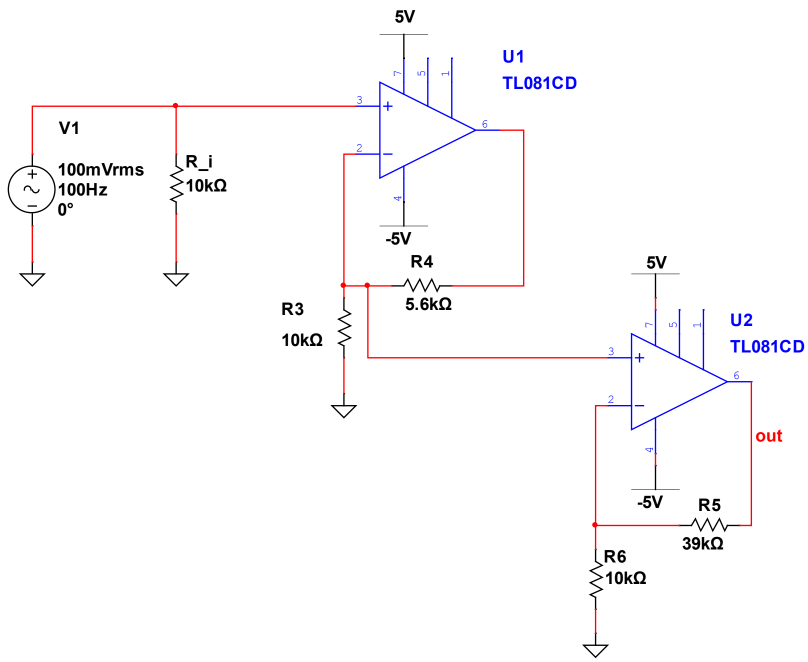


Figure 2 Noninverting amplifiers

1. Build the circuit shown in Figure 2. Set R4 = 5.6 k Ω, and R5 =39 kΩ.

2. Turn the power supplies *on*.

3. Measure the VDC at the output of U1. It should be < $\pm$0.1 V_{DC}. Do not continue until the output of U1 is very small (<$\pm$0.1 V).

4. Measure the VDC at the output of U2. It should be < $\pm$0.1 V_{DC}. Do not continue until the output of U1 is very small (< $\pm$0.1 V).

5. Connect the sine wave to the input of U1.

6. With the multimeter, measure the V_{DC} at the output of U1. Continue when that V_{DC} is < $\pm$0.1 V.

7. With the multimeter, measure the V_{RMS} at the output of U1. It should be 156 mV_{RMS}. Continue when the $V_{U1\ out}$ is correct within 10 %.

8. With the multimeter, measure the V_{DC} at the output of U2. Continue when that V_{DC} is < $\pm$0.1 V.

9. With the multimeter, measure the V_{RMS} at the output of U2. It should be 500 mV_{RMS}. Continue when the $V_{U2\ out}$ is correct within 5 %.

10. Disable the generator's output, then turn the power supplies off.

Sallen Key Low Pass Filter

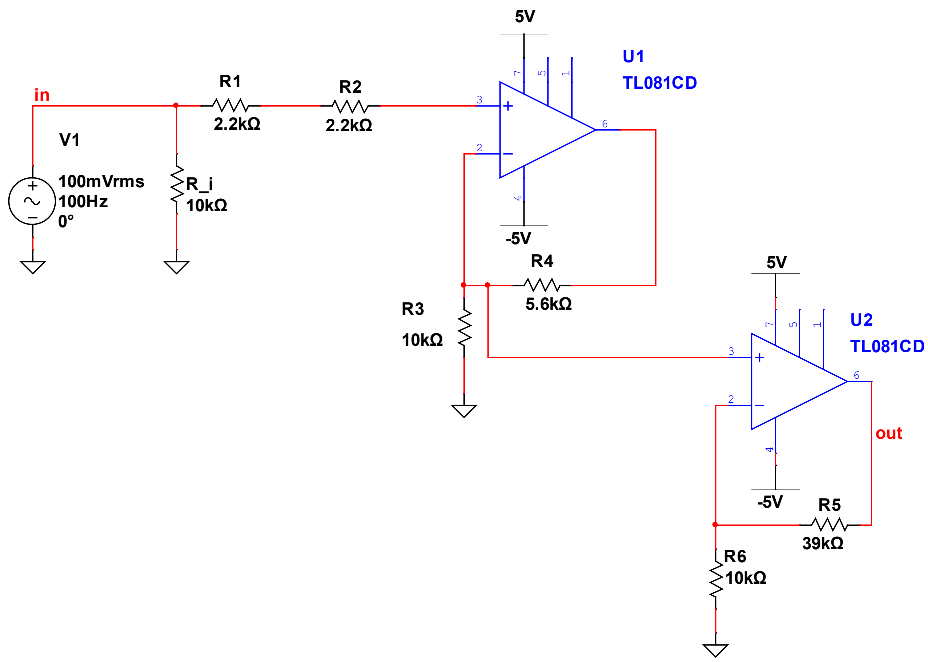


Figure 3 Noninverting amplifiers with filtering resistors

1. Build the circuit shown in Figure 3. Set R1 = R2 = 2.2 kΩ.

2. Turn the power supplies *on*.

3. Connect the sine wave to the input of U1.

4. With the multimeter, measure the V_{DC} at the output of U1. Continue when that V_{DC} is < $\pm$0.1 V.

5. With the multimeter, measure the V_{RMS} at the output of U1. It should be 156 mV_{RMS}. Continue when the $V_{U1\ out}$ is correct within 10 %.

6. With the multimeter, measure the V_{DC} at the output of U2. Continue when that V_{DC} is < $\pm$0.1 V.

7. With the multimeter, measure the V_{RMS} at the output of U2. It should be 500 mV_{RMS}. Continue when the $V_{U2\ out}$ is correct within 5 %.

Demonstrate the noninverting amplifiers' performances to your lab instructor.

8. Disable the generator's output, then turn the power supplies off.

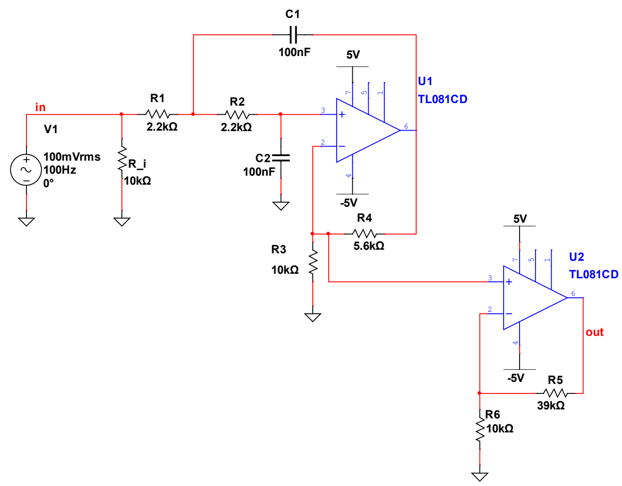


Figure 4 Complete Sallen Key Filter

B. Quick Look

1. Build the circuit shown in Figure 4. Set C1 = C2 = 100 nF.

Photograph this circuit layout from the video to earn prelab points.

2. Turn the power supplies *on*.

3. Connect the sine wave to the input of U1.

4. With the multimeter, measure the V_{DC} at the output of U1. Continue when that V_{DC} is $< \underline{+}0.1$ V.

5. With the multimeter, measure the V_{RMS} at the output of U1. It should be 156 mV_{RMS}. Continue when the $V_{U1\ out}$ is correct within 10 %.

6. With the multimeter, measure the V_{DC} at the output of U2. Continue when that V_{DC} is $< \underline{+}0.1$ V.

7. With the multimeter, measure the V_{RMS} at the output of U2. It should be 500 mV_{RMS}. Continue when the $V_{U2\ out}$ is correct within 5 %.

   When the circuit is working correctly at 100 Hz, make the following measurements and calculations.

   $V_{out\ 100\ Hz}$ = __________ $A_{o\ ratio\ measured}$ = __________ $A_{o\ ratio\ theory} = 1 + \frac{R5_{actual}}{R6_{actual}}$ = _________

8. Adjust the frequency until $v_{out\ U2} = 0.707 * A_{o\ ratio\ measured} * 100\ mV_{RMS} \sim 350mV_{RMS}$
   This should be close to f_o.

   $f_{-3dB\ measured}$ = _____________ $\sim$ $f_o = \frac{1}{2\pi \times 2.2\ k\Omega \times 100\ nF} = 720Hz$

Photograph the DMM and generator in the video making this measurement in the video for prelab credit.

9. When your circuit is working correctly at f_{-3dB} demonstrate the circuit and data to the instructor.

Demonstrate the derivations and resulting parameter relationships to your lab instructor.

C. Low Pass Frequency and Transient Responses

1. Use the Frequency Response Analysis resource in the oscilloscope to obtain the response of your filter. Set the input amplitude as indicated previously. Sweep the frequency from 100 Hz to 10 kHz in 100 points per decade.

2. Move the cursor to f_{-3dB}. When the circuit is working correctly photograph this display.

3. Change the input to a square wave, 50% duty cycle. Set the frequency at 100 Hz. Change the oscilloscope to display the voltage versus *time* (*not* Frequency Response Analysis).

4. On this display, place tracking cursors at the peak of the transient response, and at its final level. Capture this display to be included in your report.

Photograph the peak overshoot measurement in the video for prelab credit.

Analysis and Conclusions

1. Write a paragraph that discusses errors; their magnitudes, causes, and fixes.

2. Audiophiles complain that a Butterworth filter alters the sound, making it “brighter” than it actually is. Look at the transient response of the low pass filter from step C4.

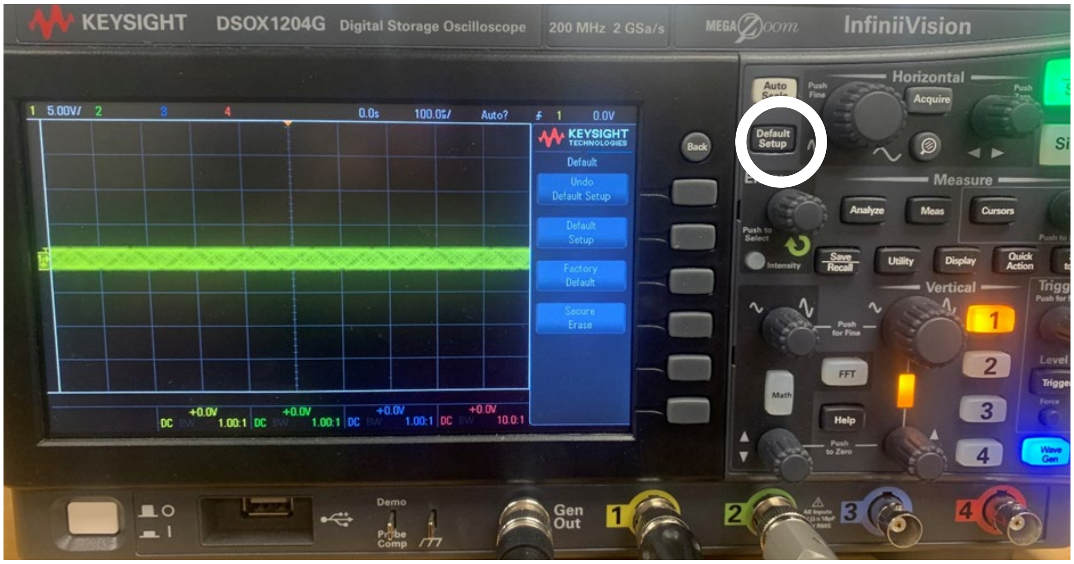
   a. Did the filter *faithfully* pass the step from the input to the output, or did it add (or remove) something to the shape?

   b. Why? Answer using the second order parameters of gain, damping, or critical frequency.

   c. How would you prevent the distortion that the Butterworth filter adds? Be specific, including which component (s) you would change and the new corrected value(s).

Frequency Response Analysis
using the
Keysight DSOX1204G Oscilloscope

A. Default Setup



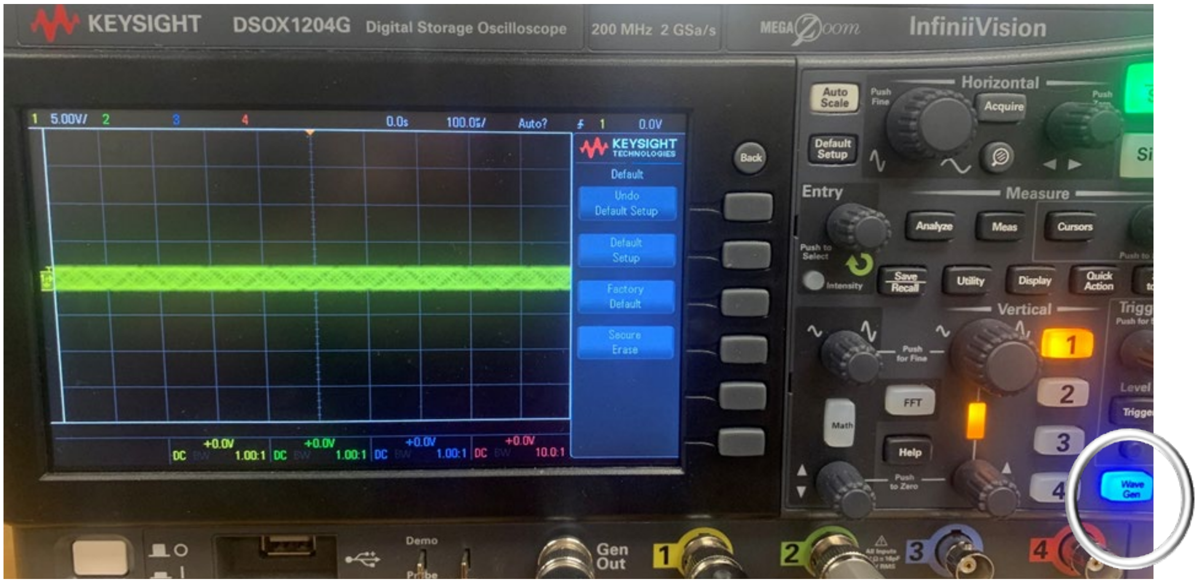
B. Connections

Gen Out connects to the input of the circuit under test.

Channel 1 also connects to the <u>input</u> of the circuit under test. Set the probe attenuation to 1:1 and assure that that channel also has the probe at 1:1.

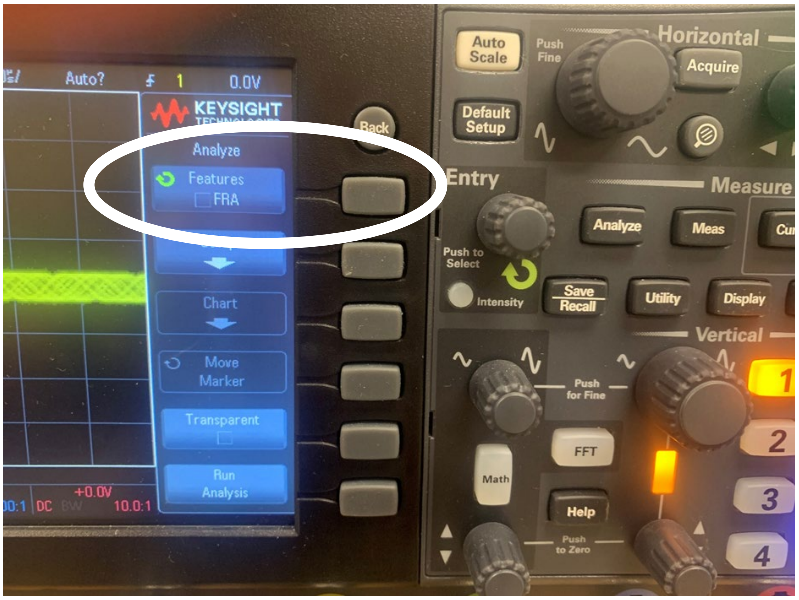
Channel 2 connects to the <u>output</u> of the circuit under test. Set the probe attenuation to 1:1 and assure that that channel also has the probe at 1:1.

C. Waveform Gen

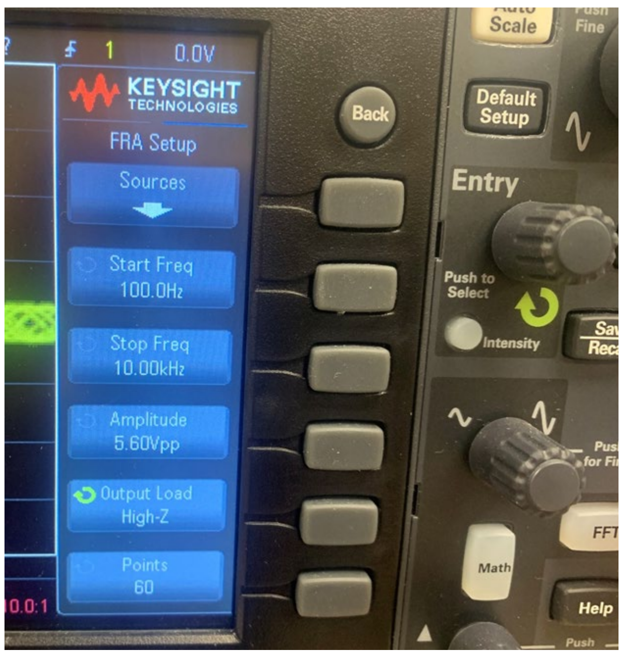


D. Analysis

E. Frequency Response Analysis (FRA)



F. Setup



Adjust the parameters in the **FRA Setup** menu by pressing the button to the right of the parameter, then rotating the **Entry** knob to get the value needed.

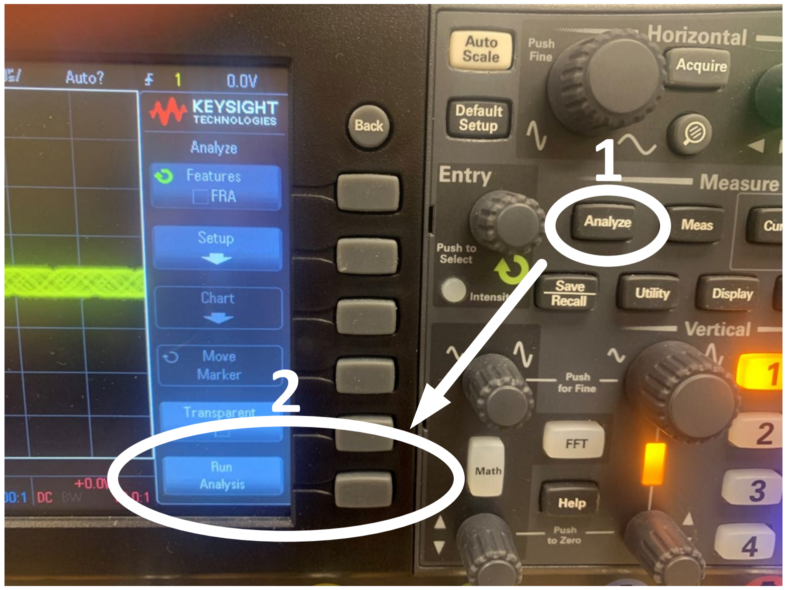
Adjust the **Start Frequency** and the **Stop Frequency** to values that interest you. Too wide of a range will cause the sweep to take a *long* time.

Notice that the **Amplitude** is in V_{pp}. Set this to 2.8 V_{pp} to send 1 V_{RMS} to the circuit.

Increase the **Points** to get finer resolution. But the more points you use, the longer the sweep.

G. Run Analysis

Press the **Analysis** button again to get back to the Analysis menu. Then select **Run Analysis**.



H. Displays

The signals are swept by the oscilloscope and are displayed on the screen with the measured magnitude and phase. In the background you can see the plot growing.

Once the analysis is complete the plot is shown. Use the Entry knob to move cursors to the points of interest. The cursor values are shown below the plot. The example below is for a bandpass filter, *not* a low pass filter.