Name: ______________________________

Hands-on Introduction to Electrical Engineering
Assignment 5: Filters

1 Topics

In this assignment, you will review the following topics:

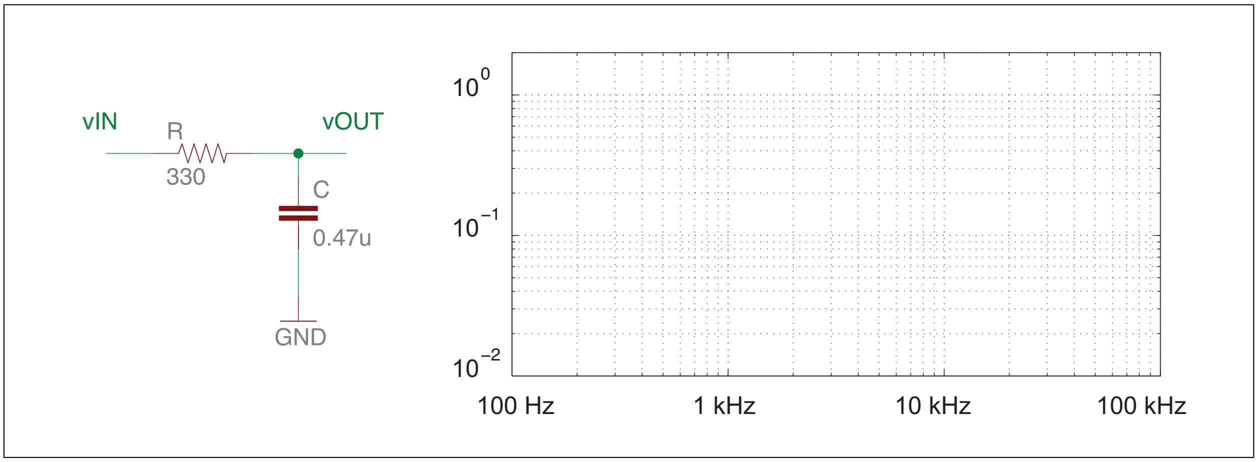
- Sinusoidal inputs to capacitive/inductive circuits,
- Speaker amplifier circuit (from Assignment 3),
- Filtering an audio signal.

Please make sure that you are familiar with these topics prior to the lab session.

2 Sinusoidal response of first-order RC and LR circuits

As a warm-up, you will measure and sketch the gain curve of the various first-order circuits. Using the oscilloscope, measure the gain $|H| = v_{\text{out}}/v_{\text{in}}$ as a function of frequency over 100 Hz to 100 kHz. Sketch the results on the provided **logarithmic** plot.

2.1 RC lowpass

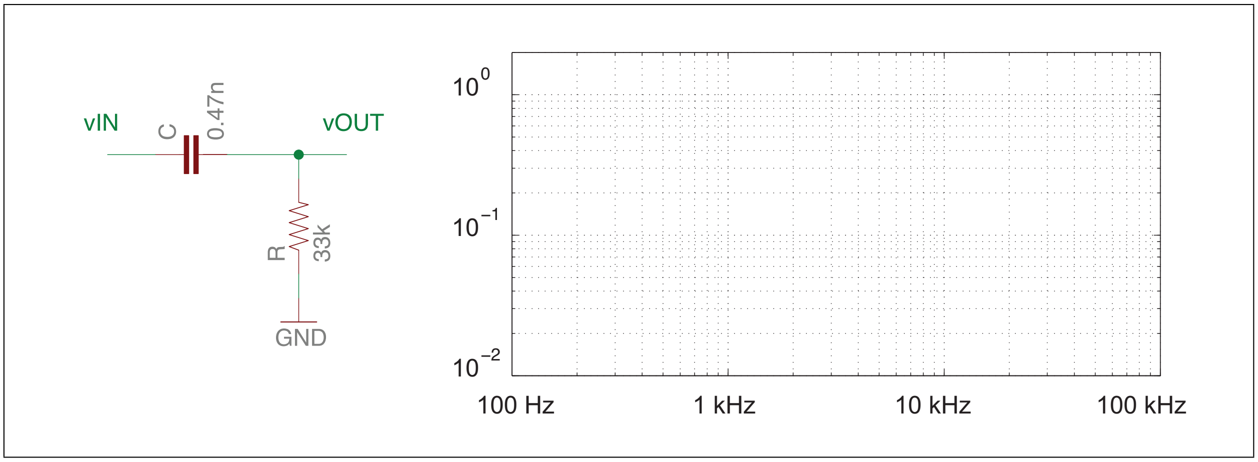


What is the **corner frequency** for the RC-lowpass?

$$f_c = \frac{1}{2\pi \cdot RC} =$$

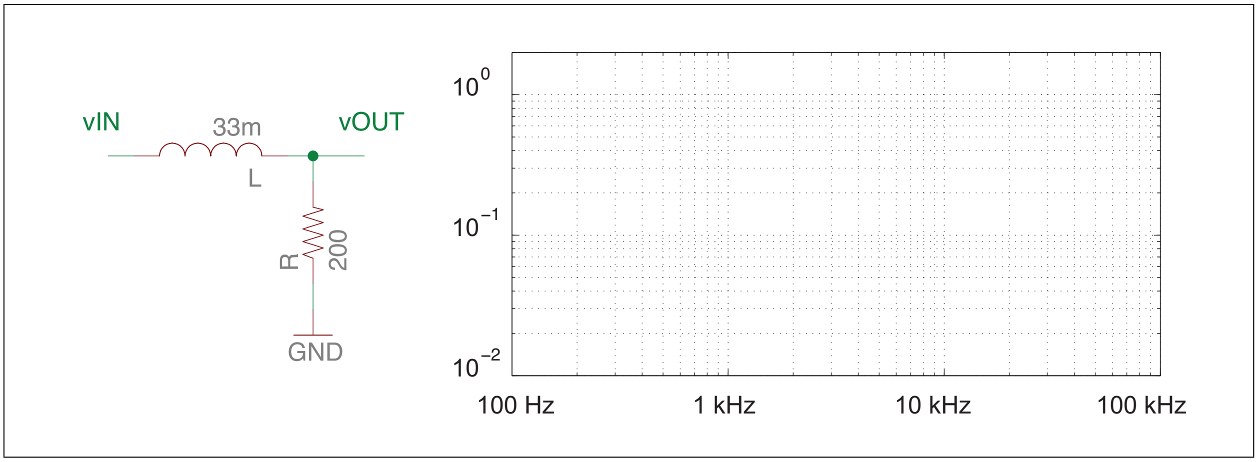
For the RC lowpass circuit, input frequencies lower than f_c are “passed” to the output, while input frequencies above f_c are “cut off.”

2.2 RC highpass

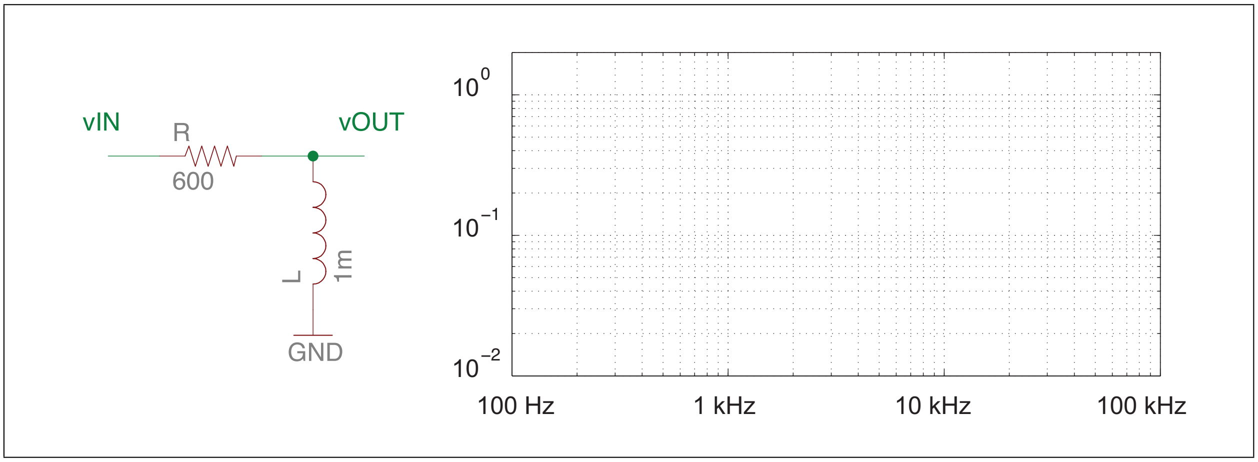


2.3 RL lowpass

We can get filter behavior similar to RC circuits also with inductors.



2.4 RL highpass



3 Audio circuit

The objective of this assignment is to use filters for analog signal processing. In order to *hear* the output, we need to reconstruct the speaker driver circuit from Assignment 3, which is reproduced in Fig. 2.

3.1 Input biasing and AC-coupling

Previously, we used a resistor network to sum an AC source and a DC bias, which comprised the input signal. Now that we know about capacitors, we can use the circuit in Fig. 1 to combine AC and DC.

Let us determine the output v_{OUT} in terms of the circuit parameters. We will use the superposition principle.

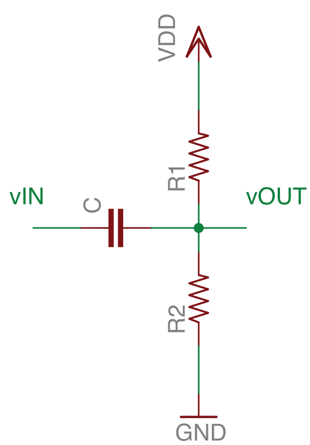


Figure 1: A standard circuit fragment for combining an AC signal v_{IN} with a DC bias.

First, consider the effect of only the DC source V_{DD}. What is its contribution to v_{OUT}?

$v_{OUT,DC} =$

Second, consider the effect of only the AC source. What is the effective f_0 of this circuit fragment?

$f_0 =$

Finally, what is the total output v_{OUT}? Assume that the input signal v_{IN} has high-frequency content (*i.e.* above the effective corner frequency f_0).

$v_{OUT} =$

3.2 Construct the speaker driver circuit

Using the bias circuit of Section 3.1, construct the complete speaker driver circuit. Use a 100 kΩ potentiometer to implement the R_1-R_2 resistive divider. The complete circuit is shown in Fig. 2.

Use an audio source (*e.g.* a computer or iPod) to confirm that the speaker system works as intended.

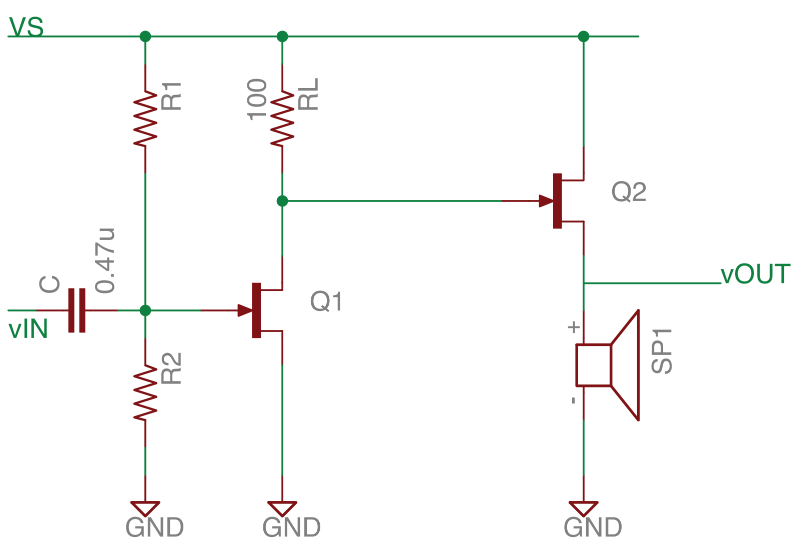


Figure 2: AC-coupled speaker driver. Use a 100 kΩ pot to implement the R_1-R_2 voltage divider.

4 Audio filtering

4.1 Exercise 1: Range of audible frequencies

Use the pure sinusoid from the function generator to determine the range of audible frequencies. (The actual audible range may differ from person to person.) What is the range?

Audible frequency range:

4.2 Exercise 2: Remove high frequency noise

In this exercise, we will use a lowpass RC circuit to filter out high-frequency (audible) noise. We will use the function generator to provide an annoying 15 kHz noise.

4.2.1 Purposely add noise to the audio signal

Suggest a simple circuit to perform

$$v_{\text{SUM}} = \frac{1}{2} \cdot v_{\text{AUDIO}} + \frac{1}{2} \cdot v_{\text{NOISE}},$$

where v_{AUDIO} represents the signal from your audio source, and v_{NOISE} represents the 15 kHz sinusoid from the function generator.

Your “sum” circuit. (Hint: Use only two 100 ohm resistors.)

Listen to the summed signal using the speaker. You should hear an annoying high-frequency noise on top of the original audio signal.

4.2.2 Design an *RC* lowpass filter to remove high-frequency noise

We will now design a simple lowpass filter to remove the 15 kHz noise.

Below, draw the RC topology that corresponds to a lowpass filter.

We desire a corner frequency of $f_c = 1$ kHz. What should be the value of the resistance R, if we use a capacitor $C = 0.47$ μF?

$R =$

Now, construct the RC filter. Use the RC filter to remove the 15 kHz noise from the input signal. You should find that the high-pitch noise is notably reduced.

4.3 Exercise 3: Remove (high-frequency) voice from music

The previous exercise showed how a simple first-order circuit can be used for analog signal processing. The first-order lowpass, however, has relatively weak frequency selectivity and cannot be used to differentiate between nearby frequencies (*e.g.* in the same decade).

You will be shown a very steep (8-th order) lowpass filter based on the MAX294 integrated circuit. The gain curve as a function of frequency for this filter is shown in Fig. 3. Also shown, at the same scale, is the frequency response of a first-order lowpass filter (dashed red curve) like the RC circuit you constructed.

Another convenience of the MAX294 is that the corner frequency f_c can be easily controlled externally without having to replace circuit components. This allows for interesting filter experiments. For instance, I used the MAX294 filter to remove the high-pitch harmony of a Mongolian throat singer, which will be demonstrated. Can you think of other audio processing applications?

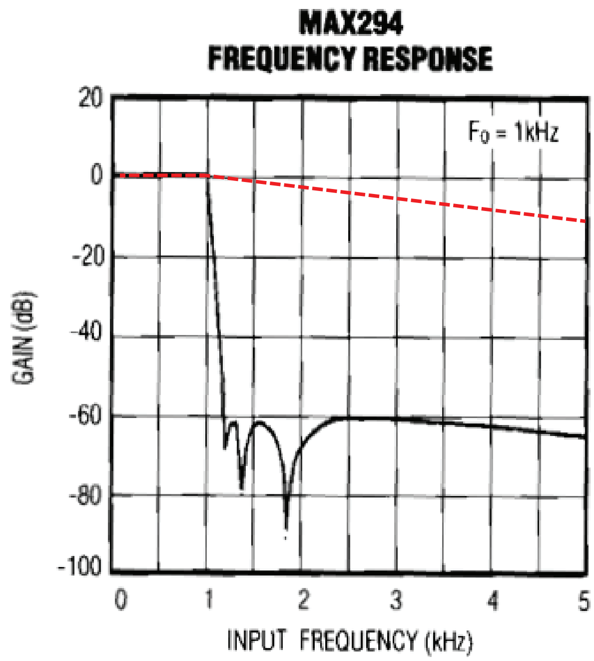


Figure 3: An 8-th order lowpass filter with $f_c = 1$ kHz, based on the MAX294 filter IC. The dotted red curve shows the frequency selectivity of a first-order lowpass filter with the same corner frequency.