ECE210 Laboratory
Lab report #2

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Lab section: ABH

# 2 Laboratory exercise

## 2.1 Using the 741 op-amp

The 741 op-amp contains a complex circuit, composed of 17 bipolar-junction transistors, 5 diodes, 11 resistors, and a capacitor that provides internal compensation to prevent oscillation. When wiring your circuits, however, you only have to make the usual connections: the inverting and non-inverting inputs, the output, and the positive and negative DC supplies. Figure 4 labels and describes the pins.

- The DC supplies must be set carefully to power the op-amp without destroying it:
- The DC sources should be set to +5 V for $V_{CC+}$ supply and -5 V for $V_{CC-}$ supply. 741 op-amp can be powered from 5~15V, since we are using M2K to generate DC supplies, the maximum output voltage is 5 V. However, in general circuit design, 741 op-amp is often set with higher voltage
- The $V_{CC}+$ and $V_{CC}-$ supplies always stay at the same pins throughout the experiment. Do not switch them!
- When you are ready to turn the power on, always *turn on the DC supplies first*, then the AC supply.
- When you turn the circuit off, always *turn off (or disconnect) the AC first* and then the DC.

## 2.2 An op-amp amplifier

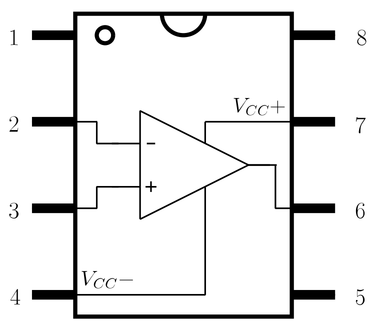



Figure 5: Pin-out diagram for the 741 op-amp.

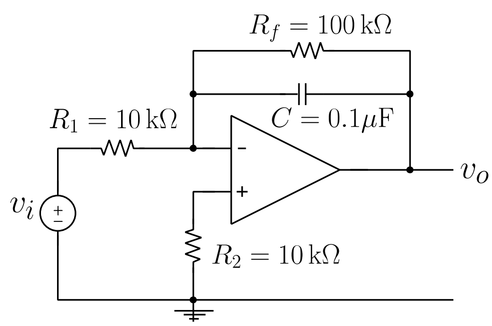
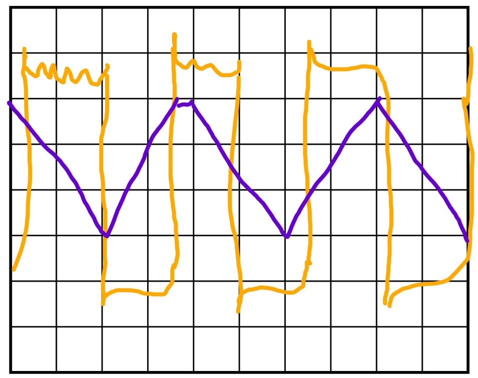



Figure 6: Integrating amplifier.

1. Configure the op-amp amplifier circuit shown in Figure 6 on your protoboard using component values of $R_1 = 10$ k$\Omega$, $R_2 = 10$ k$\Omega$, $R_f = 100$ k$\Omega$, and $C = 0.1\,\mu$F. *In this and all future circuits using op-amps, connect the circuit ground to supply ground*. We recognize this circuit as an op-amp integrator in $R_f \to \infty$ limit, so we will call the circuit with $R_f = 100$ k$\Omega$ an integrating amplifier.

2. Apply a 500 Hz, 2 V amplitude square wave to the input (with 50% duty cycle). Connect both the input and output to the M2K through pin "1+", pin "1-", pin "2+" and pin "2-", and show both signals in the Oscilloscope module in Scopy. Sketch both the waveforms and label each signal to identify them. Describe the shape of the output waveform, and explain how it confirms that the circuit acts as an effective integrator.

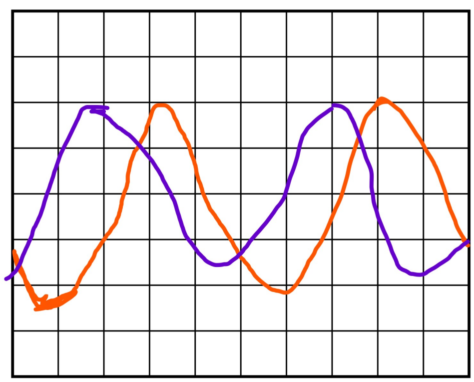


Input : V/div : 0.4 V t/div : 0.5 ms
Output : V/div : 0.2 V (____/2)

Describe $v_0(t)$. Does it looks like the integral of $v_i(t)$? Explain: (____/5)

v0(t) looks like the integral of vi(t). The graph looks flipped because the signal passes through an inverting amplifier component of an Op-Amp.

3. Repeat step 2 for a **sine** wave of 200 Hz, 2 V amplitude. LABEL each signal in your graph to identify input and output.



Input : V/div : 0.5V t/div : 1ms
Output : V/div : 0.5V (____/2)

Describe $v_0(t)$. Does it looks like the integral of $v_i(t)$? Explain: (____/5)

vo is the integral of vi, and we can observe that both waves share the same frequency, but the output is shifted by -/2.
From here we get:
-1 * Integral{sin(x) * dx} = cos(x),

with the negative sign from the inverted amplifier

4. Now change the frequency to 50 Hz and slowly increase the input amplitude from 0.5 V to 2.5 V and describe how the output changes as the input increases. (Hint: Is this a linear or non-linear behavior?) (____/2)

Since the integration is a linear operation, we can expect that the output varies linearly with the input amplitude

Now increase the input amplitude to 4 V and describe the shape of the output: (____/2)

Now the op-amp does not operate in the linear regime, nor can it supply an input voltage large enough to the integrating circuit. The new output looks like a voltage clipper or a sine wave with somewhat flat peaks.

What is the amplitude of the output waveform when the input amplitude is 4 V peak-to-peak? (____/2)

$V_{p-p} =$ 8.05 V

If you were to increase the amplitude of the input further, would that increase the amplitude of the output substantially? No (____/2)

How do you explain what is happening to the output?

(____/4)

The op-amp is operating outside the linear regime so it cannot provide a large enough input voltage to integrate the input signat

## 2.3 Non-Inverting Amplifiers

Now you will build the two amplifiers you designed in the prelab and connect them to your envelope detector. (as shown in Figure 9.)

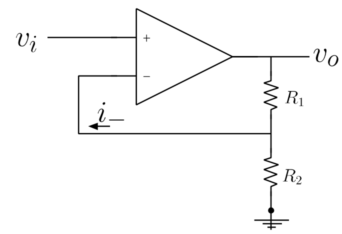



Figure 7: Non-inverting amplifier, showing the signal $i_-$.

1. First, build the non-inverting amplifier with a gain of 21 that you designed in the prelab. Make sure you connect the DC supplies from M2K before you apply any voltage to the op-amp inputs. Also, place the circuit near the center of your protoboard, to allow for other circuits to be built on both sides

2. Apply a 100 Hz sine wave input $v_i$ with 0.2 V amplitude. Measure $v_i$ and $v_o$ with the Oscilloscope module in Scopy. Calculate the voltage gain (you might need to reduce the input if the output saturates):

   $\frac{v_o}{v_i}$ = 4.24/0.2 = 21.2 . (____/2)

   How does this compare with the theoretical value? Even if your measurement is very close to the theoretical value, explain what could be the sources of any difference.

   (____/3)

   We arrive at these theoretical values since we assume that the op-amps are ideal. Realistically, the i- is a non-zero value which would cause the vo to be higher, such as when i- is positive.

   %error = ( |21.2 - 21| /21 ) * 100 = 0.952380952381 %

3. Disconnect the AC input, and then turn off the DC supplies. Without modifying the non-inverting amplifier you just built, build the non-inverting amplifier with a gain of two that you designed in the prelab. Place your new circuit to the right of your protoboard, allowing for some extra space in between the two amplifiers. In addition, leave some space for lab 3 in the leftmost section of the breadboard. You may use the configuration shown in Figure 8.

4. Testing the non-inverting amplifier with gain of two: Turn on the DC supplies and connect the AC input (100 Hz sine wave input with 1 V peak-to-peak amplitude) to the new amplifier (gain 2). Observe the voltage gain:

   $\frac{v_o}{v_i}$ = 2.013 . (____/2)

   How does this compare with the theoretical value? ( |2.013-2| / 2 ) * 100 = 0.65% error (____/2)

5. Remove the AC input. Place your envelope detector circuit (from Lab 1) in between the two amplifier circuits as shown in Figure 9. Note that a 33 $\mu$F capacitor is included in the envelope detector circuit to remove DC component from the input signal of the last amplifier (recall that a capacitor acts as an open circuit at DC). A 10 k$\Omega$ resistor is connected between the second op-amp input and ground to allow the input bias currents to flow without charging the "decoupling" 33 $\mu$F capacitor.

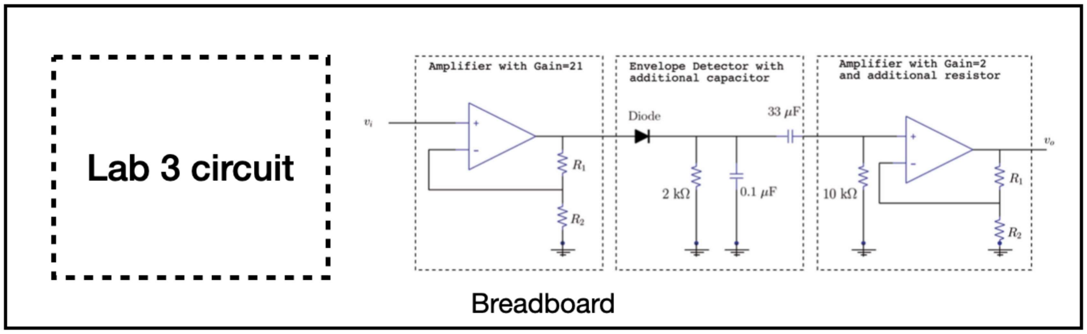



Figure 8: Breadboard layout.

The three-stage circuit that you just built will be part of your radio receiver in Lab 4. As you saw in Lab 1, the envelope detector stage will recover the message from an AM signal. In order for it to work, however, the voltage of input signal must be sufficiently high to turn the diode on and off — hence the first amplifier. The second amplifier, which follows the envelope detector, increases the voltage of the recovered message signal in order to drive a loudspeaker. It also provides a buffer between the envelope detector and the loudspeaker, preventing the loudspeaker from changing the time constant of the tuned envelope detector.

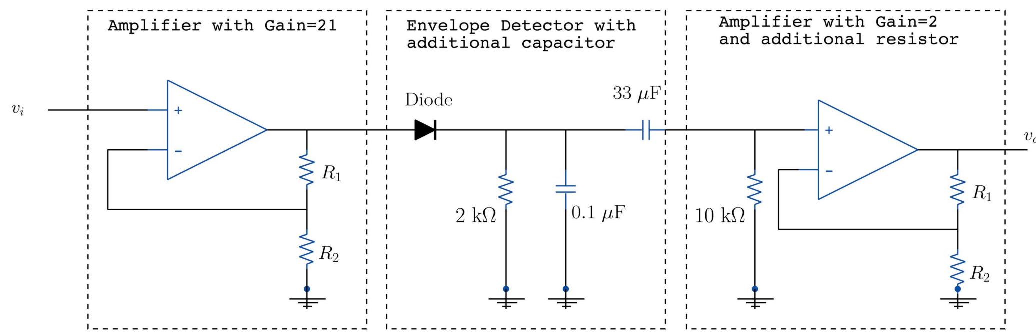
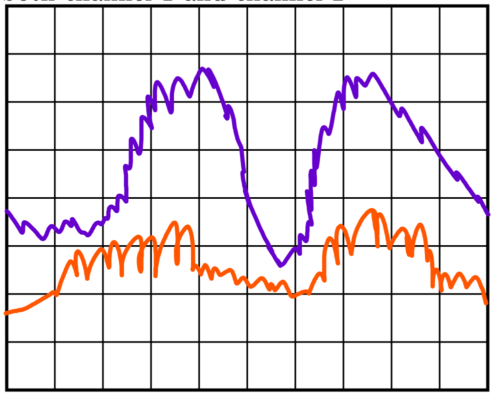



Figure 9: Three-stage circuit for radio.

7. To test your three-stage circuit, create an AM signal with the Signal Generator module using math function :
   - In "Signal Generator" module, select "math"
   - Set Record Length to be 25 ms and SampleRate to be 5 Msps
   - Set $f(t) = 0.05 * \cos(13000 * 2 * pi * t) * (\cos(880 * 2 * pi * t) + 2)$
   - Click "Run"
   - Listen to the AM signal on the loudspeaker.
8. Turn on DC supplies, and connect the "W" pin to the input of your three-stage circuit. Connect the "1+" pin (channel 1) to the input and connect the "2+" to the output of your three-stage circuit. Both "1-" and "2-" should be connected to ground. In "Oscilloscope" module, use "Single" to generate output. You might have to use multiple times to capture a good one. Adjust the Time Base and Volts/Div if needed.
9. Now let's observe how the output changes according to the message-signal frequency. In Signal Generator module, sweep the message-signal frequency from 880 Hz to 2000 Hz **(Demo required part1)** :
   - Change the function in $f(t)$ from $f(t) = 0.05 * \cos(13000 * 2 * pi * t) * (\cos(880 * 2 * pi * t) + 2)$ to $f(t) = 0.05 * \cos(13000 * 2 * pi * t) * (\cos(W * 2 * pi * t) + 2)$, where $W$ is 100
   - Click "Apply"
   - Go to Oscilloscope module and click "Single" to see the updates
   - Repeat from the first step but increase $W$ from 10 to 200

- Repeat from the first step with more different choices of $W$ until you try $W = 2000$

Sketch the display of oscilloscope for both channel 1 and channel 2



Input : V/div : 200mV t/div : 200s

Output : V/div : 2V

(____/2)

Describe how the output signal changes while sweeping the message-signal frequency from 100 Hz and 2000 Hz.

As the input wave's frequency increases, the output wave's frequency approaches the input envelope

(____/3)

10. Until now we have been displaying signals on our oscilloscopes. However, signals in audio frequency range can also be "displayed" acoustically using loudspeakers. **We will next use a corner of our protoboard, an audio jack, and a pair of speakers to *listen* to a number of signal waveforms**: (Note: For this part you don't need your circuit.)

    - Connect the "Ground" pin to the top pin of the audio jack through your breadboard
    - Connect the "W" pin to either the leftmost or the rightmost pin of the audio jack through breadboard
    - Plug the 3.5 mm AUX cable of your speaker into the audio jack
    - In Signal Generator module, generate a 880 Hz 1 V sine wave
    - Repeat for a 13 kHz sine wave
    - Describe what you hear in each case — in what ways 880 Hz and 13 kHz audio signals sound different to your ear?

Both tones are steady but vary in pitch. The 800Hz frequency has a lower pitch, but it much less irritating than the 13kHz signal

(____/3)

11. Now connect the "W" pin back to the input of the circuit and generate the modulated signal as described in part 7. Connect a loudspeaker to the output. Describe what do you hear, and explain what the circuit acomplished.

(____/4)

The sound gets closer to the low frequency previously tested, but has some minor resemblance to the higher frequency

12. Sweep the message signal frequency from 100 Hz to 2000 Hz again. (Similar operations as part 9) **(Demo required part2)** This time describe how the sound changes as the frequency is swept.

(____/3)

The pitch increases as the wave's frequency increases