LabExp-2. Differential amplifier and Bode diagram

Goals:

1) To obtain experimentally the static transfer function of a differential amplifier based on AO.
2) To obtain experimentally the Bode diagram of an amplifier and estimate the values of the cutoff frequencies and the bandwidth.

Theoretical introduction

The performance features of an OA-based amplifier can be classified into static and dynamic. The static characteristics describe the operation of the amplifier when the input signal is constant or varies very slowly, that is why they are also called continuous or DC features. Among them, the voltage gain (G_u), the input range, and the saturation voltage values at the output ($\pm V_{sat}$) stand out.

On the other hand, the dynamic features describe the operation of the amplifier when the input signal varies significantly in time, that is why they are also called alternating or AC features. These are, for example, the minimum frequencies (lower cutoff frequency, fci) and maximum (upper cutoff frequency, f_{cs}), between which the bandwidth is defined (BW = f_{cs}-f_{ci}). The BW is the frequency range in which the gain of the amplifier remains constant, and usually with a maximum value (G_{max}). The objective of the laboratory experiment is to study how the dynamic characteristics of the OA affect the bandwidth of the amplifier, that is, f_{cs} and f_{ci}. The dynamic characteristics of the OA that will be taken into account are the slew rate (SR) and Gain-Bandwidth product (GBW).

Materials

Units	Reference	Value
1	AO1	741C
2	R4,R5	100 kΩ
2	R6,R7	1 MΩ
1	R1	820 Ω
1	R2	10 kΩ
1	C1	10 μF
1	C2	0.68 nF
1	Connector jack male 3.5 mm	N/A
1	Connector jack female 3.5 mm	N/A
1	Headphones for mobile phone with jack connection 3.5 mm	Each student brings his/her own

Measurement instrumentation, supply sources and signal generators:

- Digital Oscilloscope and 2 probes
- Function Generator
- Digital Multimeter
- Supply Source

IMPORTANT: Part 0 corresponds to the work to be done by the student before attending the laboratory. It does not have an impact on the grade, but it must be carried out so that the teacher can solve the doubts in a coherent way, since the laboratory experiment session is not intended to solve theoretical doubts.

PART 0. Previous work

0.1. Figure 1 shows a voltage amplifier based on OA 741C with differential input and supplied with at ±15 V. Analyze the circuit and obtain the theoretical expression of the voltage gain (G = V_{out}/V_{in}) as a function of the resistors R4, R5, R6 and R7 and its value in V/V. Plot the static transfer function V_{out} versus V_{in} indicating the saturation voltage values at the output and the input range.

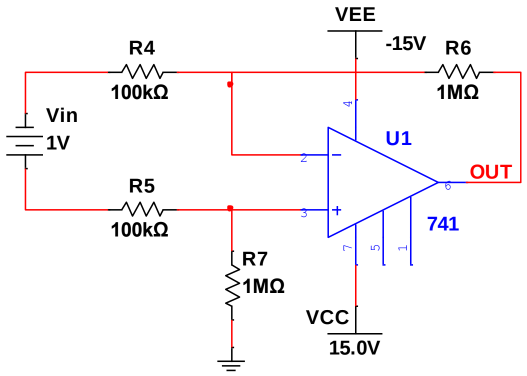

Figure 1. Differential Amplifier based on OA

0.2. To study the effect of the SR and GBP of the OA on the bandwidth (BW) of an OA-based circuit, an inverting amplifier based on an OA741C supplied with ±15 V is shown in Fig. 2. Unlike the circuit in Figure 1, it has a non-differential input. Obtain the theoretical expression of the voltage gain (G = V_{out} / V_{in}) as a function of resistors R1 and R2 and its value in dB.

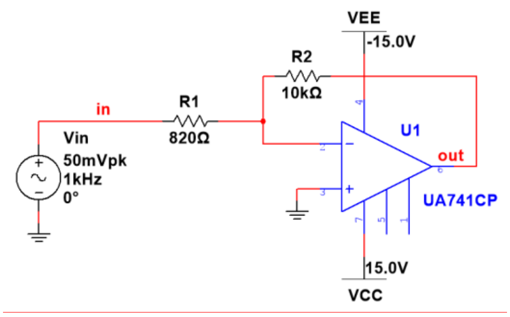

Figure 2. Inverter Amplifier based on OA.

0.3 Using the datasheet features of the OA 741C, estimate theoretically the upper cutoff frequency of the circuit of Fig. 2 in the case that the input voltage is a 50 mV peak sinusoidal wave. Repeat the estimation if the input is a 1 V peak sinusoidal wave.

0.4. To study the effect of external capacitors on the bandwidth (BW) of an OA-based circuit, the circuit in Fig. 3 will be used. Obtain the theoretical expression of the voltage gain ($G = V_{out} / V_{in}$) as a function of the frequency of the input signal ($j\omega$) and of the external components R1, R2, C1 and C2. From the values of these components, represent graphically the Bode diagram (modulus and phase), determine the value of the cutoff frequencies (upper and lower), and calculate the bandwidth.

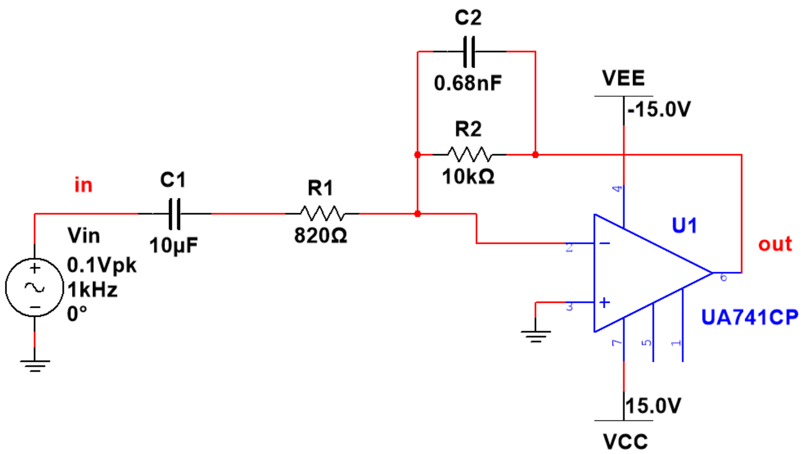

Figure 3. Inverter amplifier base don OA with BW limited by capacitors.

PART 1. Equipment and components setting

1. Use the digital multimeter to measure all resistances. Write down the value next to each component to avoid confusion during assembly.

2. Check the operation of the oscilloscope and voltage probes. To do this, connect each probe to one of the oscilloscope channels (1 and 2). Uses the square auxiliary signal generated by the oscilloscope itself to do the check. Remember that the probes can have fixed attenuation (×10) or adjustable (×1, ×10), and that consequently it is necessary to indicate to the oscilloscope which is the attenuation for each channel.

3. Check the function generator operation. To do this, for example, program a sinusoidal signal with 1 kHz frequency and 1 V amplitude (peak). Extract the signal from the generator using the BNC-crocodile cable. Display the signal on channel 1 of the oscilloscope. DO NOT connect the crocodile directly to the oscilloscope probe, as you can damage the probe tip. Use an intermediate wire.

4. Check the operation of the power supply. To do this, measure with the multimeter the direct voltage generated at the symmetrical output of ±15 V (that is, between +15 and the reference point, and between -15 and the reference point). Measure the adjustable voltage output by varying its value between 0 and 10 V in steps of 2 V.

PART 2. Transfer function of a differential amplifier

5. Using the values measured in step 1, calculate the value of the expected gain (G_u) for the circuit of Fig. 1, and compare it with the value obtained in section 0.1 of the previous calculations.

6. Assemple the circuit in Figure 1 on a prototype board. Remember to connect wires for the symmetrical power supply of the OA. Once the circuit is assembled, and before supplying the OA, check ALL the connections using the multimeter using the "continuity" mode.

7. If everything is correct, supply the AO and check with the multimeter that the voltage reaches the OA own pins: +15 V on pin 7, and -15 V on pin 4.

8. If everything is correct, proceed to experimentally obtain the value of the voltage gain (G_u) and the saturation voltages ($\pm V_{sat}$). To do this, use DC signals obtained from the power supply through the adjustable voltage output. This will be connected to the input of the amplifier (V_e) as shown in Figure 4. In order to have a differential input voltage (that is, not referred to the reference point of the circuit), the terminal must NOT be connected negative terminal of the variable power supply (black terminal) with the reference point of the circuit (blue terminal of the ±15 V supply), but to the negative terminal of the input voltage (V1).
   Negative voltages are obtained by swapping the two output terminals of the adjustable voltage source (ie red to V_1 and black to V_2). For each value of V_e, measure both the input voltage (V_e) and the output voltage (V_s) with the multimeter, thus completing Table 1.

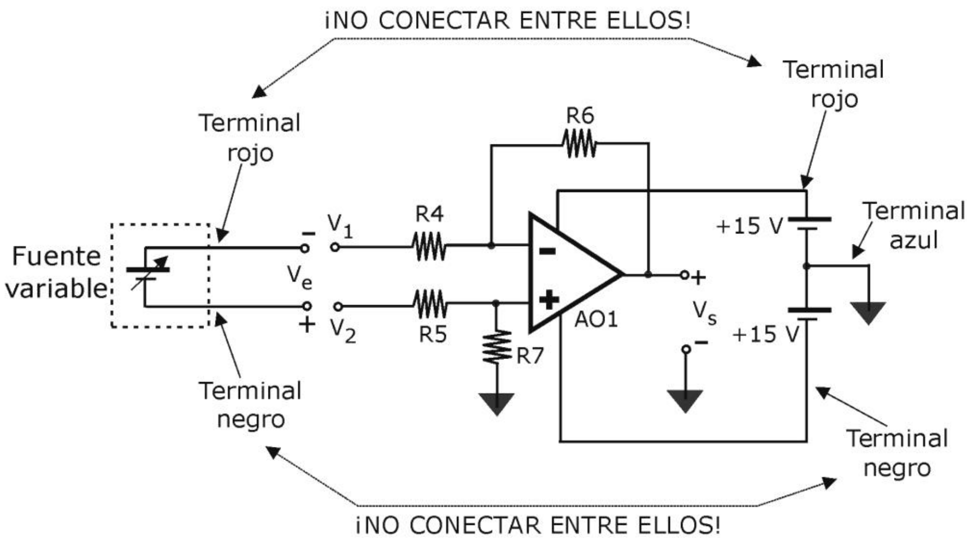

Figure 4. Connectiosn scheme to supply the circuit in Figure 1.

Table 1

V_e (V)	V_e (V)	V_s (V)
– 2.0		

– 1.5		
– 1.0		
– 0.5		
– 0.1		
+ 0.1		
+ 0.5		
+ 1.0		
+ 1.5		
+ 2.0		

9. From the data in Table 1, represent the transfer function of the amplifier in Figure 1. Remember that the transfer function has the input voltage on the abscissa axis and the output voltage on the ordinate axis. If necessary for a correct graphical representation, take other values of Ve apart from those in Table 1.

A1 (assessable). Use an Excel sheet to enter the values and get the fitted curve. Paste here the graph of the transfer function obtained with Excel.
Estimate the gain of the circuit from the fited curve.
Estimate the saturation voltages ($\pm V_{sat}$).
Justify how you have calculated the values.

PART 3. Dynamic characteristics of an inverting amplifier (effect of the GBP and SR of the OA)

10. From the values measured in step 1, calculate the value of the expected gain (G_u) for the circuit of Fig. 2 and compare it with the value obtained in section 0.2 of the previous calculations.

11. Assemble the circuit in Figure 2 on a prototype board. Remember to connect wires for the symmetrical power supply of the AO. Once the circuit is assembled, and before supplying the AO, check ALL the connections using the multimeter using the "continuity" mode.

12. If everything is correct, supply power to the AO and check with the multimeter that the voltage reaches the AO's own pins: +15 V on pin 7, and □15 V on pin 4.

13. If everything is correct, program the function generator to have a sinusoidal input signal (Ve) of 50 mV in amplitude (peak value) and 100 Hz in frequency. Always use channel 1 of the oscilloscope to view the input and channel 2 for the output. Measure the voltage (peak) of the input and output using the oscilloscope, and write down the values in the second and third columns of Table 2. Repeat the measurement for the frequencies specified in the first column of Table 2 (doing a frequency sweep).

Table 2

	Case V_e = 50 mV		**Case V_e = 1 V**	
Frequency	**V_s (V)**	**G_u (V/V)**	**V_s (V)**	**G_u (V/V)**
100 Hz				

500 Hz				
1 kHz				
10 kHz				
50 kHz				
100 kHz				
500 kHz				
1 MHz				
1.5 MHz				
2 MHz				

A2 (assessable). Indicate at what frequency the output signal is attenuated by 30% with respect to its maximum value. Thus, determine the cutoff frequency for the specific case of Ve = 50 mV. fcs = ………… .. (Hz). Compare it with the theoretical value estimated in section 0.3 of the previous calculations. Explain the possible differences.

A3 (assessable). Using an Excel sheet and the data from the first three columns of Table 2, represent the Bode diagram of the circuit. Determine the voltage gain and upper cutoff frequency from the graph.
Remember that in the Bode diagram the ordinate axis is the gain expressed in dB, while the abscissa axis is represented in a logarithmic form.
Paste here the graph of the transfer function obtained with Excel.

14. Repeat step 13 for the case of a sinusoidal input voltage of 1 V peak, and fill in the last two columns of Table 1.

A4 (assessable). Using an Excel sheet and new data for Ve = 1 V, represent the Bode diagram of the circuit. Determine the voltage gain and upper cutoff frequency from the graph.
Compare it with the theoretical value estimated in section 0.3 of the previous calculations. Explain the possible differences.
Why is the upper cutoff frequency dependent on the amplitude of the input signal? Justify the answer

PART 4. Effect of external capacitors on the BW of the circuit

15. From the values measured in step 1, calculate the expected values of the gain (G_u) and the cutoff frequencies for the circuit in Fig. 3. Compare them with those obtained in section 0.4 of the previous calculations.

16. Assemble the circuit in Figure 3 on a prototype board. Remember to connect wires for the symmetrical power supply of the OA. Once the circuit is assembled, and before supplying the AO, check ALL the connections using the multimeter using the "continuity" mode.

17. If everything is correct, supply the OA and check with the multimeter that the voltage reaches the AO's own pins: +15 V on pin 7, and -15 V on pin 4.

18. If everything is correct, program in the function generator to provide a sinusoidal input signal Ve of 500 mV peak in amplitude (without DC level). Display the input in channel 1 of the oscilloscope and the output in channel 2. Perform a frequency sweep between 5 Hz and 30 kHz. Tip: Choose the frequency values so that they are less separated from each other in those margins where the output voltage changes more abruptly with the change of frequency. Fill in Table 3.

Table 3

Frequency (Hz)	**V_e (V) peak**	**V_s (V) peak**	**Gain (V_s/V_e)**	**G (dB)**

A5 (assessable). Using an Excel sheet and the data in Table 3, represent the Bode diagram of the circuit. Determine the voltage gain and cutoff frequencies from the graph. Paste here the graph of the transfer function obtained with Excel. Compare the results with the estimated values in step 15.

PART 5. Practical application

19. To illustrate an application of the amplifier in Fig. 3 and to analyze its frequency response, we are going to use it as an intermediate stage in an audio processing system. To do this, first connect the speaker directly to the output of the circuit in Figure 3. The speaker is actually a pair of headphones. Once this is done, introduce a sinusoidal signal with an amplitude of 200 mV (peak value) into the circuit (using the function generator) and vary its frequency. Display on the oscilloscope the output (that is, at the headphone connector terminals) obtained at the same time as the audio signal is heard.

20. This system could be used, for example, to perform audiometry, that is, to assess the ability that each individual has to detect sounds at certain frequencies. In practice, it only evaluates (for each member of the group) the audible frequency ranges, that is, the upper and lower frequencies beyond which the signal is no longer heard. Fill in Table 4.

Table 4

	#1	#2	#3
Low cutoff frequency (Hz)			
High cutoff frequency (kHz)			
Gender (M/F)*			

* Theoretically, the audible frequency range is a parameter dependent on sex and age.

21. Once you have checked the correct operation of the headphones and their connection to the amplifier, connect the audio output of your mobile phone via a 3.5 mm jack plug to the input of the AO-based amplifier (Stage 2 of Figure 5). Connect the headphones to the output of the amplifier and listen to music that you have recorded or download it from the web. It is recommended to lower the volume of the telephone itself to a minimum since the amplifier already provides gain.

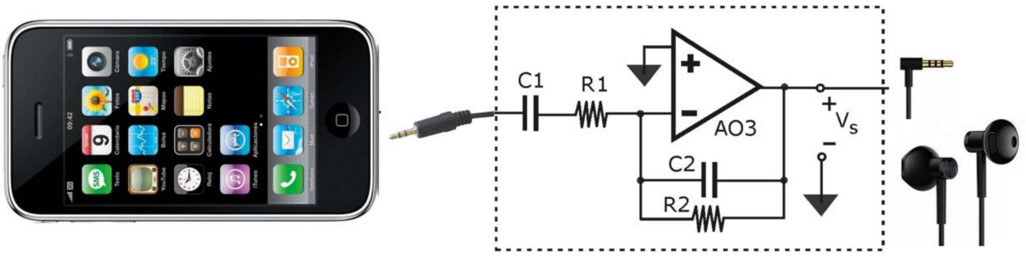

Figure 5. Connection of the mobile phone to the amplifier based on OA.

22. Redesign the component values to process only the mid and high frequency components, specifically those above 700 Hz. Listen to the music to see the differences.

23. Redesign again the value of the components to process only the low and medium frequency components, specifically those that are below 5 kHz. Listen to the music to appreciate the differences.

A6 (assessable). Write here and justify how you have calculated the new values of the components designed for sections 22 and 23.

TASK DELIVERY: Once all the sections have been completed, generate a unique PDF aper group and upload it in the corresponding PoliformaT task. The complete names and surnames of all the components of the group must be indicated in the document. The name of the file will be:
LabExp1_LastName1_LastName2_LastName3.pdf