EXPERIMENT #3 OP AMP CIRCUITS AND WAVEFORMS ECE212H1F

<u>OBJECTIVES</u>:

- To study the performance and limitations of basic op-amp circuits: the inverting and non-inverting amplifiers, and the inverting integrator.
- To practice using an oscilloscope to measure basic signal parameters such as amplitude and frequency.

<u>GENERAL COMMENTS</u>:

- The op-amps used in the experiment are µA741 models (see Fig. 3).
- To measure the voltage gain of an amplifier use the wave form specified in the instructions for the respective section of the experiment. This is either a square wave or a sine wave.
- Adjust all signals, DC and AC, to required values **before** applying signals to a circuit.
- Set the oscilloscope "probe attenuation settings" to **10X**, at both channels, prior to taking measurements.
  Reference: *Laboratory Equipment Instruction Manual*
- Unless specified otherwise use the DC coupling mode to monitor signals on the oscilloscope.

<u>TABLE OF CONTENTS:</u>

REQUIRED READING:

Alexander and Sadiku, Fundamentals of Electric Circuits (6th Edition), ***Chapter 5 Operational Amplifiers***.

INTRODUCTION & DEFINITIONS:

The purpose of the experiment is to study operational amplifiers and their applications.

An operational amplifier (op-amp) is almost always used in a feedback configuration. In this experiment we will study performance and limitations of inverting and non-inverting amplifiers that use an op-amp as the fundamental building component.

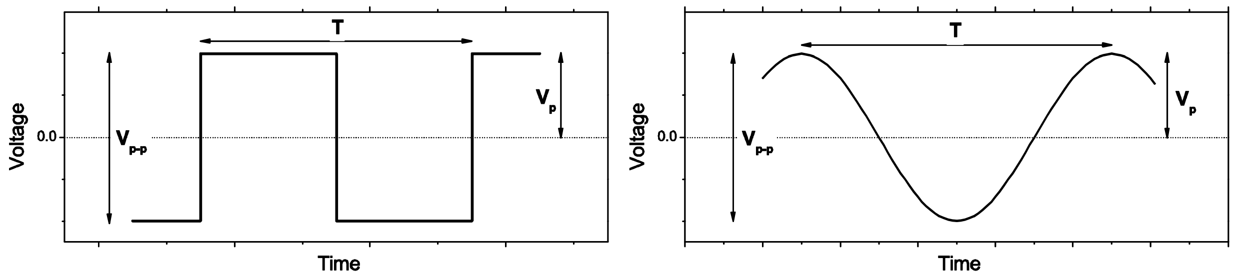

Fig. 1 Square and sinusoidal waveforms.

Test signals used in this experiment are the time-periodic signals shown in Fig. 1, i.e. square and sinusoidal voltage waveforms. Both types of waveforms are characterized by amplitude V_p and frequency f, with $f=1/T$, where T is the period of the waveform. Instead of the amplitude V_p, it is more convenient to use the peak-to-peak voltage $V_{p\text{-}p}$, where $V_{p\text{-}p}=2V_p$. Peak-to-peak voltages and frequencies can be measured using the digital oscilloscope.

When a signal waveform $v_i(t)$ drives an amplifier as in Fig. 2, where *F(t)* is a time-dependent function, the amplifier output $v_o(t)$ is a waveform of the same type and frequency. **The input resistance models the fact that the amplifier draws an input current that is proportional to the input voltage**.

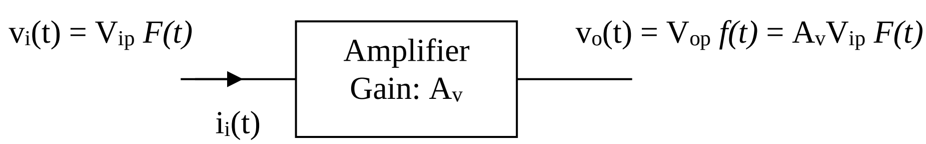

Fig. 2 Block diagram of an amplifier.

Input and output voltages can be written in terms of peak-to-peak voltages as

$$v_i(t) = \frac{1}{2}V_{ip-p}F(t)\ ,\ v_o(t) = \frac{1}{2}V_{op-p}F(t)\,.$$

The **voltage gain** A_v of an amplifier network is:

$$A_v = \frac{v_o(t)}{v_i(t)} = \frac{V_{op}}{V_{ip}} = \frac{V_{op-p}}{V_{ip-p}}$$

Its **input resistance** is defined as:

$$R_{in} \equiv v_i(t)/i_i(t).$$

EQUIPMENT

- GW Function Generator Model GFG-813
- TEKTRONIX TDS 210 oscilloscope
- 2 DC power supplies
- Digital multimeter (DMN)
- Protoboard
- Components: µA741 Op-amp, 1.2 kΩ, 1.5 kΩ (2), 1.8 kΩ, 2.2 kΩ, 10 kΩ, 12 kΩ, 15 kΩ, 18 kΩ, 22 kΩ.
- Speaker

EXPERIMENT

3.1 Inverting Amplifier

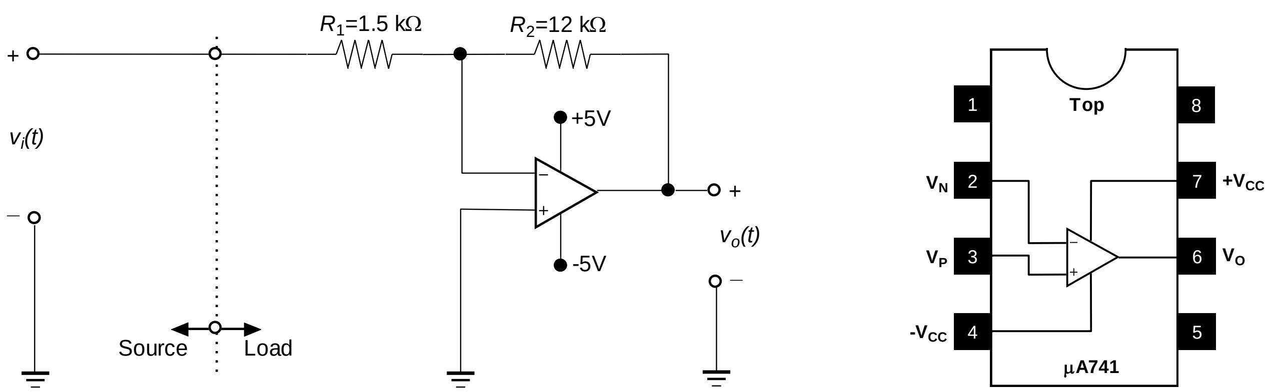

Fig. 3 Inverting amplifier circuit and µA741 OP-AMP pin diagram.

3.1.1 Voltage Gain

Preparation:

- Find an expression for the closed-loop voltage gain $A_v = \frac{V_0(t)}{V_i(t)}$ of the inverting amplifier of Fig. 3 for an ideal op-amp in terms of R_1 and R_2 and give its numerical value for $R_1 = 1.5\ \text{k}\Omega$ and $R_2 = 12\ \text{k}\Omega$ as in Fig. 3.

Experiment:

- Use two DC power supplies, one set to +5 V, the other to –5 V, to power the op-amp as shown in Fig. 3. (Textbook, section 4-1, page 158).

- Connect the output of the function generator (labeled **MAIN**) to one of the BNC connectors on the protoboard. Set the waveform to sine wave and the frequency to 2 kHz.
- Set up the oscilloscope for measurement (see "General Comments").
- Complete the inverting amplifier circuit as shown in Fig. 3.
- Connect one oscilloscope probe to the input of the inverting amplifier, the other one to its output (see pages A-27 and A-28 of the *Laboratory Equipment Instruction Manual* on how to connect the probes) and display simultaneously the input and the output voltage.
- Both waveforms should appear as undistorted sine waves. If that is not the case lower the input voltage level until they do.
- Check if both the input and output waveforms still appear as undistorted sine waves. If that is not the case further lower the input voltage level until they do.
- Set the waveform to square wave, keep the amplitude the same, and keep the frequency at 2 kHz.
- Adjust the amplitude of $v_i(t)$ such that the peak-to-peak value of the **output** voltage, V_{op-p}, is 2 V. Voltage gain is a small-signal parameter, and as a general rule, peak amplitude of the output voltage should not exceed 20% of the supply voltage (±5 V) while measuring A_v.
- Measure the voltage gain, $A_v = V_{op-p} / V_{ip-p}$. Sketch the input voltage, $v_i(t)$, and the output voltage, $v_o(t)$, as seen on the oscilloscope, in your lab-book. Relate the time scales and label all axes.

3.1.2 Transfer Characteristics

Preparation:

- Determine the linear region and the saturation regions when the supply voltage is ±5V. Sketch the expected transfer characteristics, i.e. the output voltage v_o as a function of the input voltage v_i, of the inverting amplifier of Fig. 4. Consider input voltages from -2V to +2V.
- Which peak-to-peak voltage of the input waveform will result in an output voltage of 2 V_{p-p}?
- For a sinusoidal input signal of frequency 500 Hz with the peak-to-peak voltage from the previous step, plot the input and output voltage as functions of time.

Experiment:

- Continue using the inverting amplifier circuit as set in part 3.1.1 and set the input signal to a sine wave with the peak-to-peak voltage from your preparation and keep the frequency at 2 kHz.
- Gradually increase the amplitude of the **input** voltage to about 1.8 V_{p-p}. Observe a "clipping" of the output voltage. Sketch the "clipped" output voltage, as seen on the oscilloscope, in your lab-book. Label the axes. Indicate the clipping levels.
- Change the oscilloscope setting to XY display. (To change the display to XY mode, press the **DISPLAY** button and push the third menu box button to change the Format from YT to XY, for details refer to the oscilloscope manual) and display the transfer characteristics of the inverting amplifier. Sketch the transfer characteristics, as seen on the oscilloscope, in your lab-book. Label the axes, and indicate the +saturation region, the –saturation region, and the linear region of operation. (Textbook, section 4-2, pages 157-165).
- How are the saturation (clipping) levels related to the ± DC power supply levels? What is the slope in the linear region of the transfer function equal to?

3.1.3 Loading Effect and Input Resistance

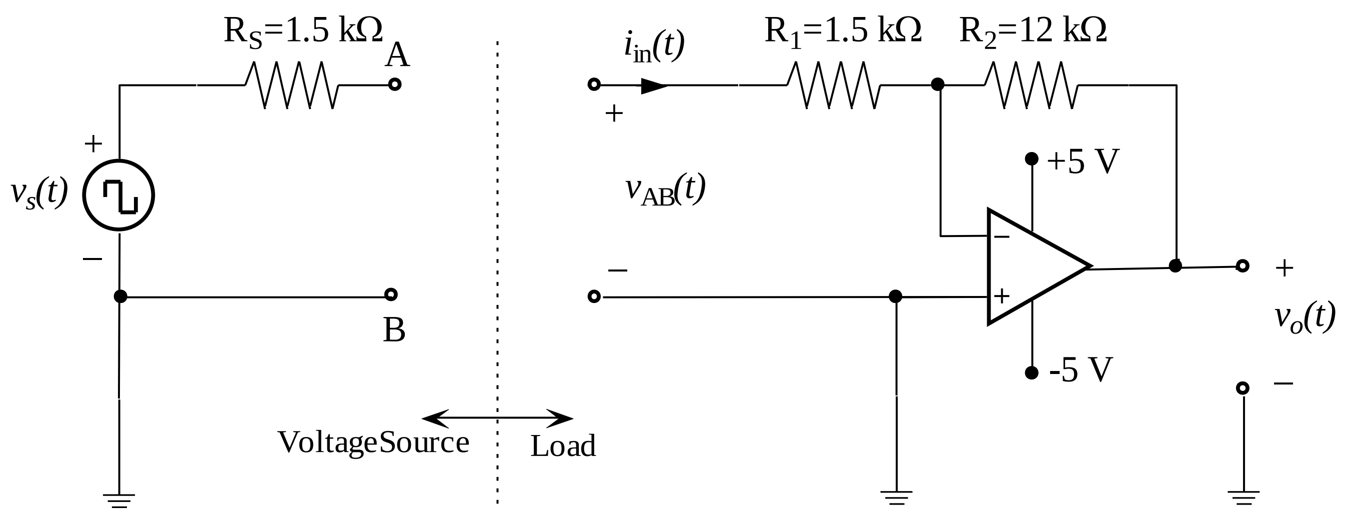

Fig. 4 Inverting amplifier and Thevenin signal source.

Preparation:

- Use the complete circuit of Fig. 4 to calculate the input resistance of the inverting amplifier $R_{in}=v_{AB}/i_{in}$. Consider the op-amp as ideal.

Experiment:

- Keep the inverting amplifier on the protoboard.
- Build a Thevenin source as shown on the left-hand side of Fig. 4 ("Voltage Source"). Do not attach it to the amplifier circuit ("Load") yet.
- Set the source voltage $v_s(t)$ back to a square wave at 2 kHz and measure its peak-to-peak open-circuit voltage (between terminals A and B). Make sure it does not exceed the peak-to-peak input voltage you used in part 3.1.1.
- Connect the Thevenin source to the input of the inverting amplifier and re-measure the voltage between A and B. How much of the source voltage has been transferred across the input of the amplifier?
- Use the voltage drop across R_S to find the input resistance of the inverting amplifier. How is the value of the input resistance related to the value of the resistor R_1?
- Confirm the amplifier voltage gain, $A_v = V_{op\text{-}p} / V_{ABp\text{-}p}$, by measurement.

3.2 Non-Inverting Amplifier

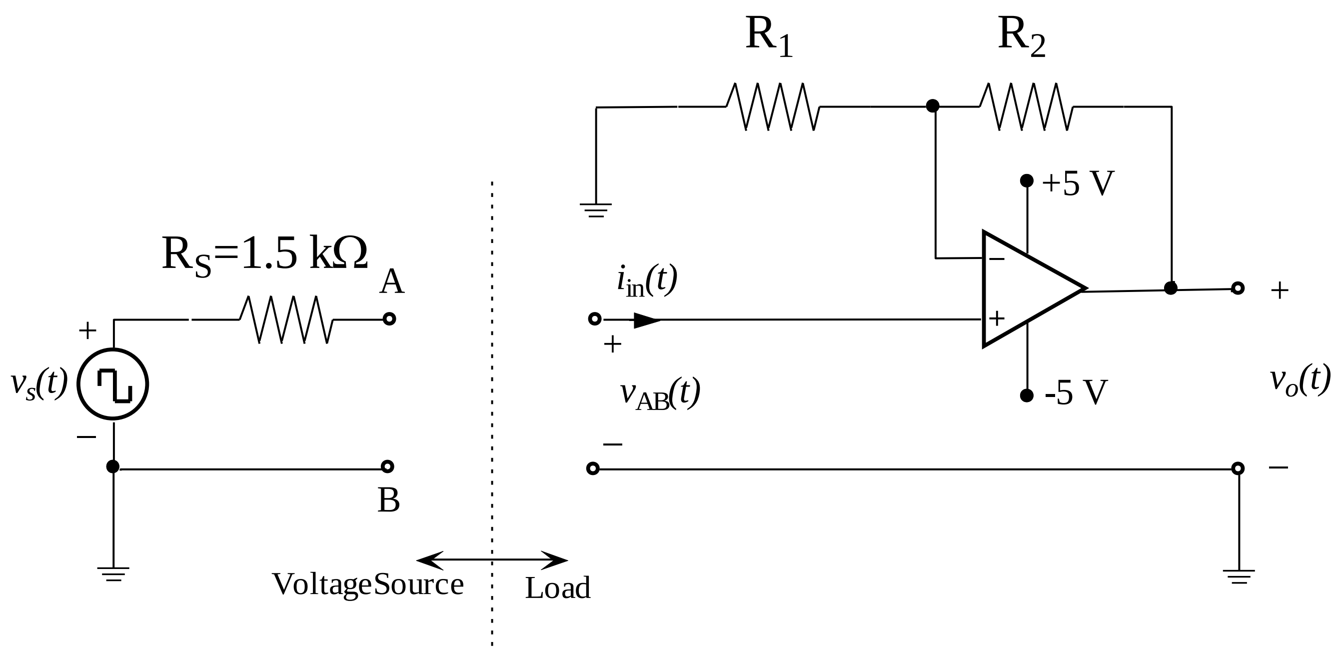

Fig. 5 Non-inverting amplifier circuit.

2.3.1 Voltage Gain and Input Resistance

Preparation:

- Find an expression for the closed-loop voltage gain $A_v = v_o(t)/v_i(t)$ of the non-inverting amplifier of Fig. 5 using the ideal op-amp model.
- What is the input resistance of the non-inverting amplifier?
- Pick two of the resistors provided (see under "Equipment" on Page Exp. 2-3) for R_1 and R_2 to obtain a voltage gain of A_v=2.5.

Experiment:

- Modify the inverting amplifier to the non-inverting amplifier shown in Fig. 5.
- Set the function generator to a square wave of 0.8 V peak-to-peak and frequency 2 kHz.
- Display both $v_{AB}(t)$ and $v_o(t)$ on the oscilloscope and determine the voltage gain.
- Investigate the loading effect of the non-inverting amplifier by repeating the procedure described in section 3.1.3, i.e. measure the voltage v_{AB} between A and B with and without the amplifier.
- How much of the source voltage has been transferred across the input of the non-inverting amplifier?
- Determine the input resistance of the non-inverting amplifier using your measured results.

3.2.2 Audio Experiment and Maximum Instantaneous Power

When the voltage applied to a resistor is a sinusoidal function of time, $v(t)=v_0\sin(\omega t)$, the resistor current is a sinusoidal function of time too, $i(t)=i_0\sin(\omega t)$. The power delivered to the load at any given time is $p(t)=(v(t))^2/R$, a function of time as well. This is the ***instantaneous power***. The maximum instantaneous power delivered to the load is therefore $v_0^2/R= V_{p\text{-}p}^2/4R$ where V_{pp} is the peak-to-peak voltage.

Experiment:

- Modify your non-inverting amplifier circuit such that it resembles that in Fig. 6 (with no speaker attached). Adjust the input voltage $v_i(t)$ to a 200 mV peak-to-peak sine wave at 2 kHz. Confirm the closed-loop voltage gain, A_v, by measurement.
- Apply a load to the output of the amplifier, i.e. connect the 8 Ω speaker provided. Monitor the input and the output signals and check the output waveform for a distortion. If the output voltage shows any distortion, lower the amplitude of the input voltage until the output signal becomes an undistorted sine wave (at $V_{op\text{-}p}$ equal to approximately 100–120 mV peak-to-peak).
- Use either the peak-to-peak value or the amplitude of the output voltage (with the speaker attached) to calculate the maximum instantaneous power that can be delivered by the non-inverting amplifier into a load (in our case the 8 Ω speaker).
- Use the value of the maximum instantaneous output power to determine the **maximum current** that can be supplied by the amplifier. It is the maximum output current of the op-amp used that limits the maximum instantaneous output power and the maximum current into the load. (A typical value of the maximum output current specified for a μA741 op-amp is between 10–20 mA.)
- Test your hearing frequency range. Keep the output amplitude constant (and undistorted) and vary the frequency. Listen. Typically, the human ear is responsive to frequencies between 40 Hz to 16 kHz. Record your hearing range.

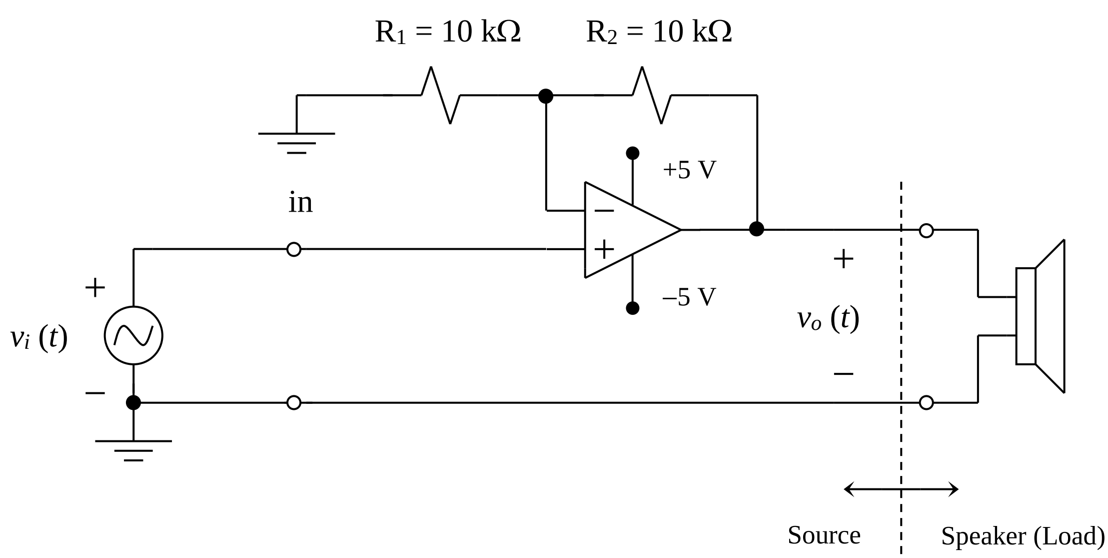

Fig. 6 Noninverting amplifier driving a speaker.