Basics of Electrical and Electronic Circuits

Experiment 7 **Voltage amplifiers using Op-Amp** **Spring 2025**

An ideal voltage amplifier is a VCVS, generating an output voltage with a waveform which is a magnified replica of the input voltage waveform, irrespective of the current that the amplifier has to supply to any load connected to its output. All amplifiers are necessarily linear and time-invariant, and are studied in terms of their sinusoidal steady state behavior using phasor equivalents. Let the input and output voltages of an amplifier be denoted by

$V_1 = V_{1m} \sin(\omega t)$ and $V_2 = V_{2m} \sin(\omega t + \theta)$. Then the phasors are given by $V_1 = V_{1m}$ and $V_2 = V_{2m} \angle\theta$ and the voltage gain is given by $A_v = V_2 / V_1 = A_{vm} \angle\theta$, where $A_{vm} = V_{2m} / V_{1m}$ denotes the magnitude of the voltage gain.

The most important property that characterizes a voltage amplifier is its frequency response, given by the graph of G_v vs **frequency** on a logarithmic scale, where $G_v = 20 \log_{10} A_{vm}$.

Any practical voltage amplifier will behave like an ideal one only as long as the voltage and current at the output and the frequency are within prescribed limits. We will examine these limits for two amplifier circuits using an Operational amplifier (OPAMP): The Inverting Amplifier for the **limits on the output voltage and current**, and the Non-inverting Amplifier for the **limit on frequency**.

An OPAMP is an integrated circuit (IC) consisting of number of transistors and resistors inside the chip. The opamp we will use in this course is the extremely popular 741, which has the pin connection given in **Fig. 1**. (– In) and (+In) are two input terminals, (Out) is the output terminal and **(+VCC)** and **(– VCC)** indicate two power supply terminals where **equal and opposite d-c** voltages have to be connected to the opamp for its normal operation. The exact values of these voltages are flexible, but they must be equal in magnitude (range 6-15V) and opposite in sign.

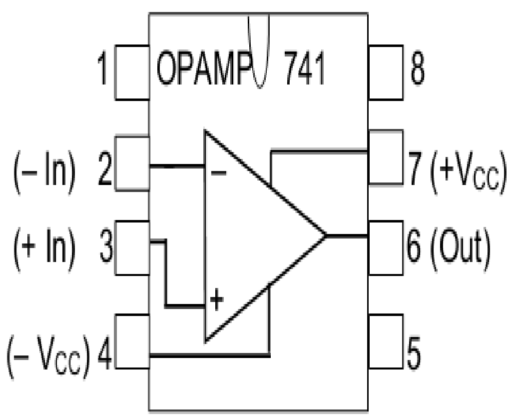


Fig. 1 Pin Connection of OPAMP 741

A. Inverting Amplifier

The circuit of an Inverting Amplifier is shown in **Fig. 2**. If the opamp can be considered to be ideal, i.e. it has no limitations with regard to voltage, current or frequency, the voltage gain of this amplifier is given by

$$A_v = - R_2 / R_1.$$

We will study in this experiment the limitations imposed on the output voltage by the d-c power supply voltages used by the opamp as well as the limitations imposed on the output current by virtue of the protection feature incorporated in the opamp by design.

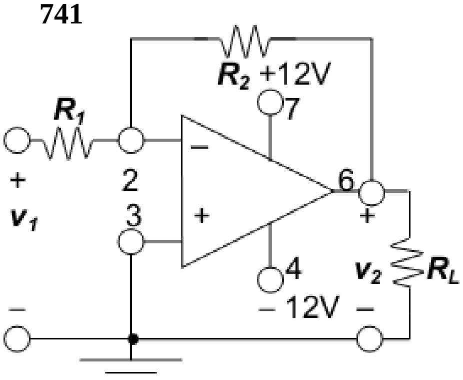


Fig. 2 Inverting Amplifier

1. Build the circuit of Fig. 2 on bread board. Use general purpose OPAMP IC-741.

2. Set up the Inverting Amplifier with R_1 = 1.00kΩ, $R2$ = 10.0kΩ and R_L = 1.80 kΩ. Apply the input voltage v_1 from the voltage source and set it at 1kHz sinusoidal voltage with peak-to-peak value 0.2V. Display the input and output voltage waveforms on the DSO and measure the **peak-to-peak** voltages. Measure the output voltage v_2 for R_2. Note that v_2 is opposite in phase with respect to input v_1

3. Repeat step 2 for R_2 = 82.0kΩ. Justify the use of direct measurement based on your observations. Tabulate the magnitude of the voltage gain against the theoretically expected value of Av for the given values of R_2. This establishes that the Inverting Amplifier behaves like a VCVS with a constant voltage gain for a fairly wide range of load resistances.

Observation Table 1

R_2	v_1	v_2	Av	Theoretical $A_v = -R_2 / R_1$.
10.0kΩ				
82.0kΩ				

4. Keeping R_2 = 82.0kΩ, increase amplitude of v_1 until the waveform of v becomes flat both at the top and at the bottom. These flat levels correspond to the output **voltage saturation levels** V_{O+} and V_{O-} of the OpAmp for the d-c power supply voltages used. Find V_{O+} and V_{O-} by using direct measurement of the **Max** and **Min** levels and verify that increase in v_1 widens the flat levels, but not their values.

5. Set v_1 back to 0.2V peak to peak, keeping R_2 = 82.0kΩ, and observe the waveform of v_2 with R_L = 330Ω, 220Ω and 100Ω. Note the flattening of the waveform both at the top and at the bottom, and measure the values of these two levels for each R_L, using direct measurement of the **Max** and **Min** levels. Note that these levels are NOT the same as the voltage saturation levels V_{O+} and V_{O-}, but are given by $R_L I_{O+}$ and $R_L I_{O-}$, where I_{O+} and I_{O-} are the **current limits imposed by design** for positive and negative values of v_O respectively. Calculate the values of I_{O+} and I_{O-} for each value of R_L.

B. Non-inverting Amplifier

In this experiment, we will study the **frequency limitation** on OpAmp-based circuits by measuring the Frequency Response of the Non-inverting Amplifier, another popular voltage amplifier using OpAmp.

1. Set up the Non-inverting Amplifier shown in **Fig. 3(a),** with R_1 = 2.00kΩ and set the voltage source at 100 Hz sinusoidal voltage with peak-to-peak value 0.2V. Display the input and output voltage waveforms on the waveform viewer and measure the **peak-to-peak** voltages.

2. With R_2 = 18.0kΩ, measure v_2 for frequencies in the 1-2-5 sequence: f = 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200 and 500 kHz, maintaining the peak-to-peak value of v_1 at 0.2V.

Observation Table 2

Frequency	v_1	v_2	$A_{vm} = V_{2m} / V_{1m}$	$G_v = 20 \log_{10} A_{vm}$	Theoretical $A_{vm} = 1 + R_2 / R_1$.
	0.2				
	0.2				

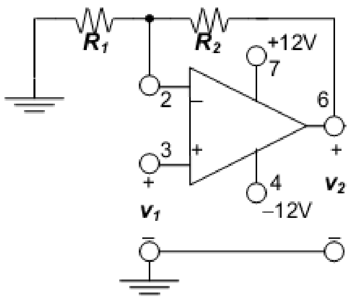
3. Repeat step **B.2** with $R_2 = 56.0k\Omega$

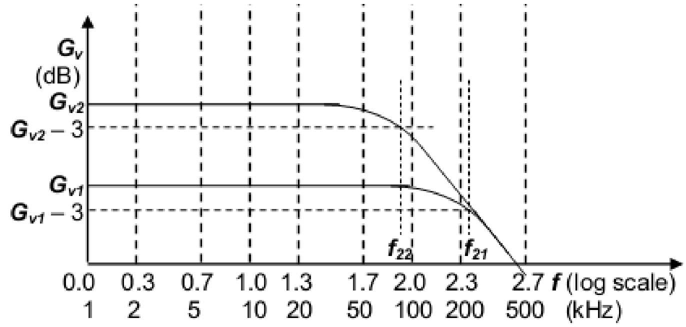
Observation Table 3

Frequency	v_1	v_2	$A_{vm} = V_{2m} / V_{1m}$	$G_v = 20 \log_{10} A_{vm}$	Theoretical $A_{vm} = 1 + R_2 / R_1$.
	0.2				
	0.2				

4. Calculate and plot the ***dB*** gain G_V against f for all values of R_2 on the **same scale** by choosing the log scale.

5. Note the low-pass nature of the frequency response and determine the values of G_{v1} and G_{v2} from the flat regions of the graphs corresponding to $R_2 = 18.0k\Omega$, and $56.0k\Omega$ respectively. Compare these values with the values expected from the theoretical expression $A_{vm} = 1 + R_2 / R_1$.





(a) Circuit Diagram (b) Frequency Response (for two cases)

Fig.3 Non-inverting Amplifier

C. Integrator Circuit

The ideal circuit of an integrator is shown in figure 4.1, assuming the opamp to be ideal.

$$i = v_1/R_1,\ v_2 = -\left(\int i\,dt\right)/C = -\left(\int v_1\,dt\right)/(CR_1)$$

Thus, the output voltage v2 is proportional to the integral of the input voltage v1 with a constant of proportionality given by the input voltage v1 with a constant of proportionality given by the values of circuit elements.

$$\text{If } v_1 = V_{1m} \sin \omega t,\ v_2 = V_{2m} \sin \omega t, \text{ where } V_{2m} = V_{1m} / (\omega C R_1)$$

implying that a sinusoidal input gives a sinusoidal output with a voltage **Gain= 1/ (ωCR₁)**, and a phase shift of 90 degree.

A more interesting way of checking the operation of an integrator is to use a symmetrical square wave input, which results in an output voltage having a triangular waveform, as shown in **figure 4.2**. This is easy to show by taking the areas under the different segments of the square wave that

$$V_{2p} = V_{1p}\, T / (4CR_1)$$

Unfortunately, this circuit will never work in practice, because any non-zero average (DC) value of v1, as well as the very small but nonzero current flowing into the opamp input terminals will lead to a continuous change in the output voltage, eventually forcing the opamp to go into voltage saturation. So practical integrators include a second resistor in parallel with the capacitor s shown in **figure 4.3**.

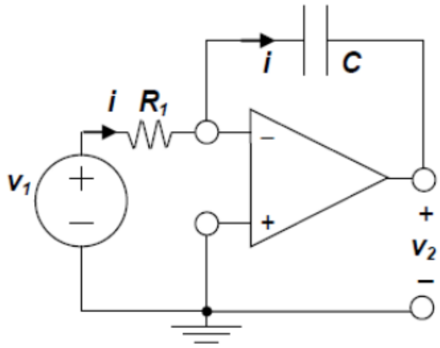


Fig. 4.1 Ideal Integrator

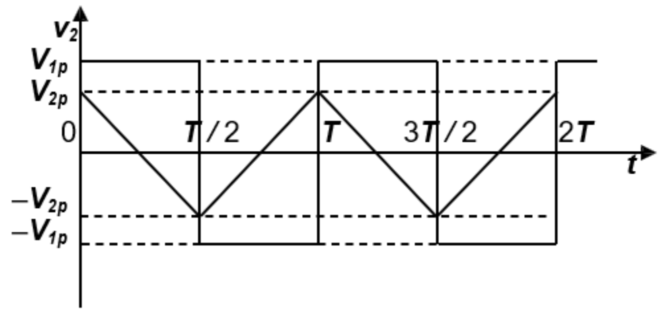


Fig. 4.2 Ideal Integrator Waveforms

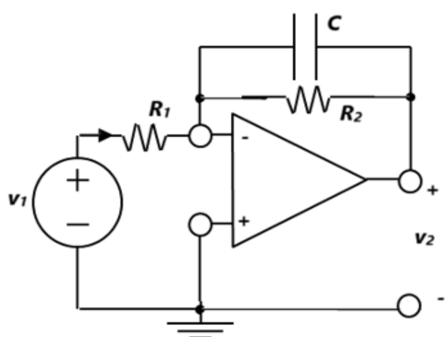


Fig. 4.3 Practical Integrator

1. Set up the practical integrator shown in **Fig. 4.3**,with R_1 = 2.00kΩ, R_2 = 200kΩ and C = 0.01μF. Follow the standard opamp pin connection for assembling the circuit, including the connections to the d-c power supply (not shown here).
2. Apply a 2kHz square wave input voltage v_1 with peak-to-peak value 0.8V from the Wavegen. Observe the waveforms of v_1 and v_2 on the DSO, triggering the DSO by the Wavegen output. Adjust the vertical scales of CH-1 and CH-2 so that the peak-to-peak swings of v_1 and v_2 as seen on the DSO are exactly equal. Find the value of V_{2p} / V_{1p} by taking the ratio of the scales of CH-2 and CH-1.
3. Compare the measured value of V_{2p} / V_{1p} with its theoretically expected value $T/(4R_1C)$.
4. Change v_1 to a sine wave with all other settings of the Wavegen as before. Note the phase difference between the two waveforms and measure the ratio V_{2m} / V_{1m} of their peak-to-peak values as done in step **A.1** above. Compare the measured value with the theoretically expected value $V_{2m} / V_{1m} = 1/(\omega CR_1)$ as given above for sinusoidal voltages.

Observation Table 4

Wave shape	v_{1p} ***Or*** v_{1m}	v_{2p} ***Or*** v_{2m}	v_{2p}/v_{1p} ***Or*** v_{2m}/v_{1m}	***Theoretical*** **T/ (4CR₁) or 1/ (ωCR₁)**
Square				
Sine				

Results:

Conclusion: It must be in your words and be based on your understanding/ learning in the experiment.