The Electron's Path: Fundamental of EEE (ECE1001-Lab.)

Experiment 3 **Voltage amplifiers using Op-Amp** **Monsoon 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.

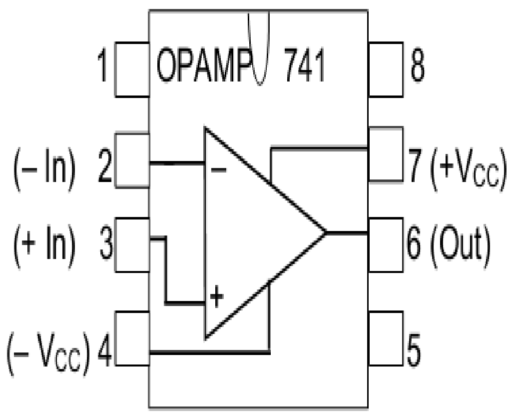


Fig. 1 Pin Connection of OPAMP 741

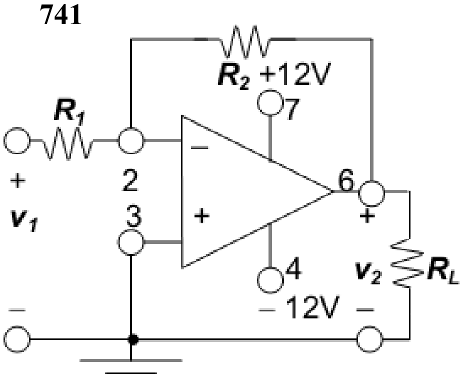


Fig. 2 Inverting Amplifier

A. <u>Inverting Amplifier</u>

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.

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 A_v 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)	v_2	$A_v = V_2 / V_1$	G_v=20log$_{10}$ A_v	*Theoretical* $A_v = -R_2 / R_1$.	Theoretical G_v=20 log$_{10}$ A_{vm}
10.0kΩ	0.2					
82.0kΩ	0.2					

B. Non-inverting Amplifier

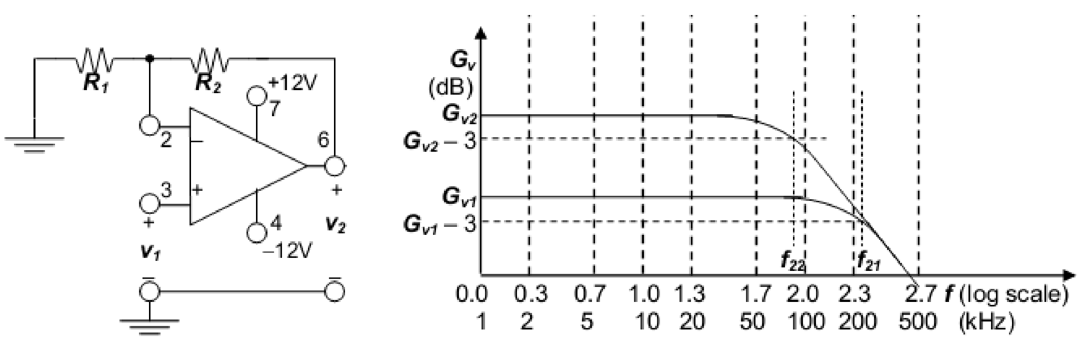
In this experiment, we will study the OpAmp-based circuits of the Non-inverting Amplifier, another popular voltage amplifier using OpAmp.

1. Set up the Non-inverting Amplifier shown in **Fig. 3(a),** with R_1 = 1.00kΩ, $R2$ = 10.0kΩ, R_L = 1.80 kΩ and set the voltage source at 1KHz 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. Measure the output voltage v_2 for R_2.

Observation Table 2

R_2	v_1 (V)	v_2	$A_{vm} = V_2 / V_1$	G_v=20log$_{10}$ A_{vm}	Theoretical $A_{vm} = 1 + R_2 / R_1$.	Theoretical G_v=20 log$_{10}$ A_{vm}
10.0kΩ	0.2					
82.0kΩ	0.2					



(a) Circuit Diagram (b) Frequency Response (for information only)

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.

$$\mathbf{i = v_1/R_1,\ v_2 = -(\int i\,dt)/C = -(\int v_1\,dt)/(CR_1)}$$

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.

$$\mathbf{If\ v_1 = V_{1m} \sin \omega t,\ v_2 = V_{2m} \sin \omega t,\ where\ V_{2m} = V_{1m} / (\omega CR_1)}$$

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

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

Unfortunately, this circuit will never work in practice, because any non-zero average (DC) value of v_1, 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 R_2 in parallel with the capacitor as shown in **figure 4.3**.

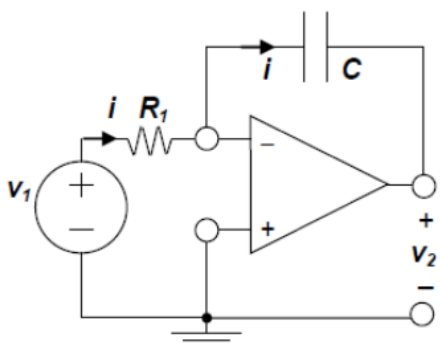


Fig. 4.1 Ideal Integrator

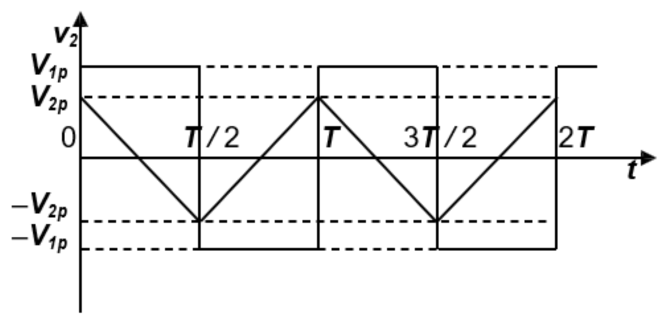


Fig. 4.2 Ideal Integrator Waveforms

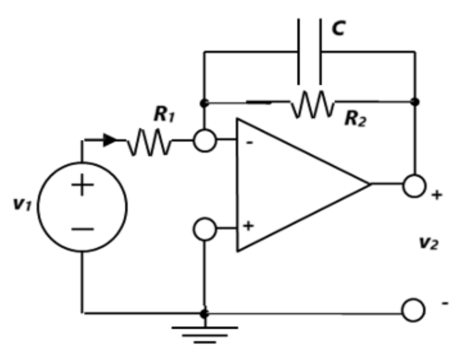


Fig. 4.3 Practical Integrator

Procedure:

1. Set up the practical integrator shown in figure 4.3 with $\mathbf{R_1}$=10 KΩ, $\mathbf{R_2}$=200KΩ and **C** = 0.01 microfarad. Follow the standard opamp pin connection for assembling the circuit including the connections to the DC power supply.

2. Apply to 2KHz square wave input voltage $\mathbf{v_1}$ with peak-to-peak value of 0.8 Volt from the wave Gen. Observe the waveforms of $\mathbf{v_1}$ and $\mathbf{v_2}$ on the DSO, triggering the DSO by Wavegen output. Adjust the vertical scale of CH-1 and CH-2 so that peak to peak swing of V1 and V2 as seen on DSO are exactly equal. Find the value of $\mathbf{v_{2P}/v_{1P}}$ by taking the ratio of scales of CH- 2 and CH-1.
3. Compare the measured value of $\mathbf{v_{2P} / v_{1P}}$ with its theoretical expected value $\mathbf{T/ (4CR_1)}$.
4. Change $\mathbf{v_1}$ to a sine wave with all other settings of Wavegen as before. Note the phase difference between the two waveforms and measure the ratio $\mathbf{v_{2m}/v_{1m}}$ off their peak-to-peak values as done in step A.1 above. Compare the measured value with the theoretically expected value $\mathbf{v_{2m}/v_{1m}} = 1/(\omega CR_1)$ as given above for sinusoidal voltages.

Observation Table 3

i/p Wave shape	v_{1p} *Or* v_{1m}	*O/p wave shape*	v_{2p} *Or* v_{2m}	v_{2p}/v_{1p} *Or* v_{2m}/v_{1m}	*Theoretical* $\mathbf{T/(4CR_1)}$ **or** $\mathbf{1/(\omega CR_1)}$
Square					
Sine					

D. Differentiator Circuit

The ideal circuit of an differentiator is shown in figure 5.1, assuming the opamp to be ideal.

$$\mathbf{i = C\, dv1/dt\ ,\ v_2 = -i\, R_2 = -\, CR_2\, (dv1/dt)}$$

Thus, the output voltage v_2 is proportional to the differential of the input voltage v_1 with a constant of proportionality given by the input voltage v_1 the values of circuit elements.

$$\mathbf{If\ v_1=V_{1m}\sin \omega t,\ v_2=V_{2m}\sin \omega t,\ where\ V_{2m} = V_{1m}\,(\omega CR_2)}$$

implying that a sinusoidal input gives a sinusoidal output with a voltage **Gain=** $\mathbf{(\omega CR_2)}$, and a phase shift of 90 degree.

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

$$\mathbf{V_{2p} = V_{1p}\,(4CR_2)\,/T}$$

For accurate differentiation, the input signal's frequency must be lower than the cutoff frequency, which is determined by both the input and feedback components. Practical differentiator includes a second resistor R_1 in series with the capacitor (ensures a minimum input impedance at high frequencies) and a feedback capacitor C_2 in parallel with the feedback resistor R_2 (to limit the circuit's high-frequency gain) as shown in **figure 5.2(b)**.

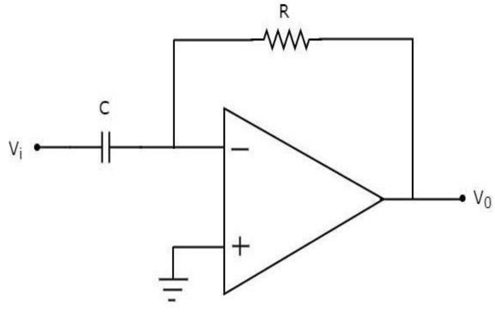


Fig. 5.1 Ideal Differentiator

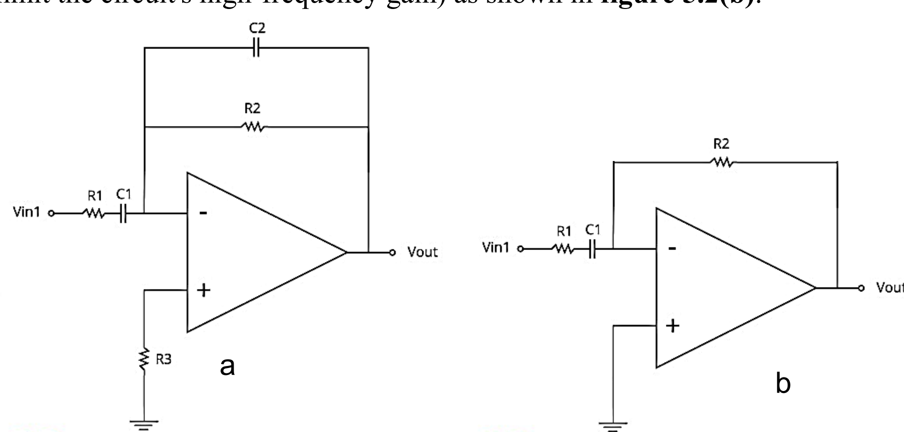


Fig. 5.2 Practical Differentiator

Procedure:

1. Set up the practical differentiator shown in figure 5.1 with **R_1**=10 KΩ, **R_2**=200KΩ and **C** = 1000 pF (1nF) Follow the standard opamp pin connection for assembling the circuit including the connections to the DC power supply.

2. Apply to 2KHz triangular/ ramp wave input voltage **v_1** with peak-to-peak value of 0.8 Volt from the wave Gen. Observe the waveforms of **v_1** and **v_2** on the DSO, triggering the DSO by Wavegen output. Adjust the vertical scale of CH-1 and CH-2 so that peak to peak swing of V1 and V2 as seen on DSO are exactly equal. Find the value of **v_{2P}/v_{1P}** by taking the ratio of scales of CH- 2 and CH-1.

3. Compare the measured value of **v_{2P} / v_{1P}** with its theoretical expected value **$(4R_2C)/T$**.

4. Change **v_1** to a sine wave with all other settings of Wavegen as before. Note the phase difference between the two waveforms and measure the ratio **v_{2m}/v_{1m}** off 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

i/p Wave shape	***v_{1p} Or v_{1m}***	***O/p wave shape***	***v_{2p} Or v_{2m}***	***v_{2p}/v_{1p} Or v_{2m}/v_{1m}***	***Theoretical* $(4CR_2)/T$ or (ωCR_2)**
Triangluar/ Ramp					
Sine					

Results:

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