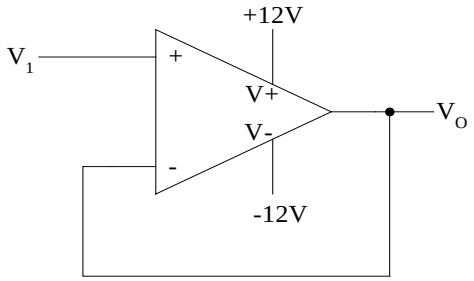
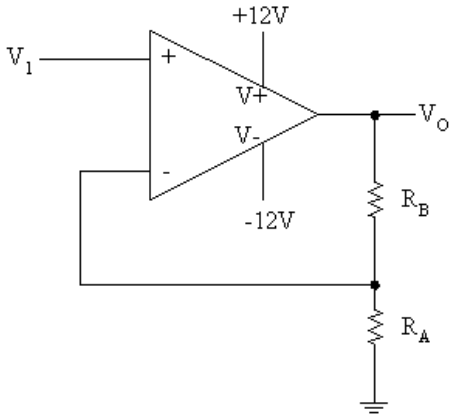
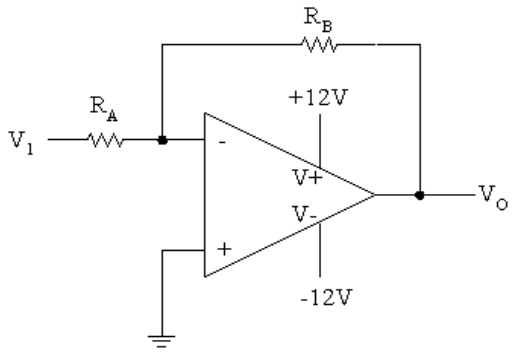
1. Prove the closed-loop gain (V_o / V_i) for the op-amp circuit below equals 1.



2. Derive the closed-loop gain (V_o / V_1) for the op-amp circuit below.
   Also, can this op-amp circuit "attenuate" a signal? Why or why not?



3. The op-amp circuit below is an inverting amplifier. Sketch V_o if $R_A = 1K\Omega$, $R_B = 10K\Omega$ and $V_1 = \cos(628t)$ Volts. Be certain to label, with numerical values, peak voltage and period.



ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

EE 361 | Operational Amplifier (Op-Amp) Circuits Part 1
Voltage Follower, Non-Inverting Amplifier &
Inverting Amplifier | Lab 4

Objective

Examine the characteristics and limitations of op-amps and to observe the operation of common op-amp circuits.

Workbench Equipment

- Digital Oscilloscope, Keysight InfiniiVision MSO-X2022A
- Function Generator, Agilent 33120A or Agilent 33220A
- Digital Multimeter, Agilent 34401A
- DC Power Supply, Agilent E3640A
- Dual-tracking DC Power Supply, TPS-4000

Check-out Equipment, 20-111 window

- Scope Probe (10:1), 2
- Banana to grabber 4 pair, 4red / 4black
- BNC to grabber lead
- Banana to Banana lead, 3

Background

Ideal Op-Amp

An ideal op-amp has the following characteristics:

R_{in} (input resistance) = $\infty\Omega$
A (open-loop gain) = ∞
R_{out} (output resistance) = 0Ω

Since input resistance is equal to infinity (an open) the current at either input of an op-amp is zero. Also, since output resistance is zero (a short) thereby $V_o = AV_{in}$ (refer to Figure 4-1) and since open-loop gain ideally equals infinity; for any finite V_o, $V_{in} = 0V$.

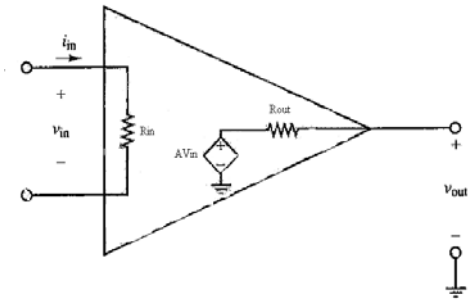


Fig. 4-1 Op-Amp Model

The term “virtual short” refers to both current and voltage equal to zero at the input of an ideal op-amp. A virtual short exists when an op-amp has negative feedback. Negative feedback is an electrical path between the op-amp output and the inverting input (input labeled with a minus sign), see Figure 4-2.

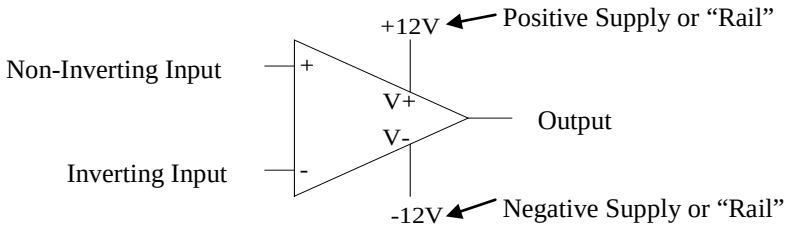


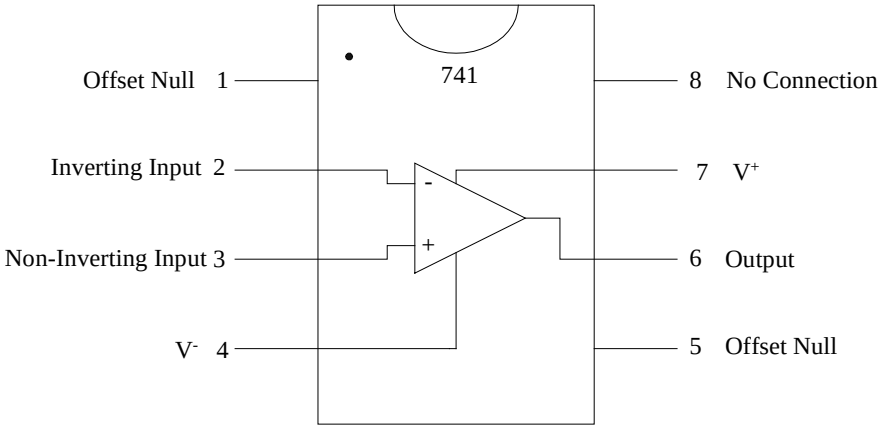
Fig. 4-2 Op-Amp Circuit Symbol

The op-amp output is limited by the voltage supply values (or “rails”) which power the op-amp. The output signal V_{out} can never be more positive than V^+ and V_{out} can never be more negative than V^-. V_{out} will distort if any portion of its waveform contacts either limit.

An op-amp can be connected into a circuit to provide useful operations. Depending on the components connected to the op-amp; op-amp circuits can provide amplification or attenuation with inversion, amplification without inversion, loading prevention and digital to analog conversion, as well as, many other useful applications such as filtering, integration and threshold detection. These half dozen or so op-amp circuits are only a small sample of common op-amp applications. There are many other common and custom applications of op-amps than those demonstrated in this experiment, the usefulness of an op-amp is only limited by one’s imagination.

741 Op-Amp IC Important Information

Pin Diagram: Note: Offset Null will not be used.



Top View

Maximum Ratings:

Supply voltage	± 18 volts
Input voltage	± 15 volts*

*Note: The input voltage must be <u>less</u> than the actual supply voltage.

Operational Notes:

A dc path must exist from each input to ground to allow for the necessary input biasing current to flow.

A resistor or some other feedback element must be provided.

A dual power supply providing + and - voltages must be used. These connections are not often shown on op amp diagrams.

Procedure 1: Voltage Follower

- Build op-amp circuit of prelab #1. Use TPS-4000 Dual Power Supply for +12V and -12V to power op-amp IC.
  - Make certain connect +12V to pin 7 of 741IC and -12V to pin 4. If these supply voltages are reversed, the op-amp will fry!!
  - Measure +12V and -12V with DVM, do not rely on supply analog meters.
- Use function generator (Hi Z mode) to apply a 1Vpp 200Hz sinusoidal signal at V_1.
- Observe both V_1 and V_o on scope, capture scope image.
  - V_1 and V_o should be very close to identical, if not consult instructor.
- Change input signal to a 10Vpp 200Hz <u>square wave</u>.
- Observe V_o on scope and verify output signal matches closely to input signal.
- Increase frequency of square wave to 20,000Hz. Observe output signal on scope, it should be severely distorted (trapezoidal). Capture scope image.
  - Note: There is a postlab question on this observation.

Procedure 2: Non-inverting Amplifier

- Build op-amp circuit of prelab #2.
- Use function generator (Hi Z mode) to apply a 0.5Vpp 200Hz sinusoidal signal at V_1.
- For $R_A = 10K\Omega$, complete Table 4-1.
  - Make certain output and input are approximately in-phase. If not, consult instructor.

R_B (KΩ)	$V_{o\ p\text{-}p}$ (V)	$\frac{V_o}{V_i}_{TH}$	$\frac{V_o}{V_i}_{EXP}$	%Error
1	_____	_____	_____	_____
10	_____	_____	_____	_____
39	_____	_____	_____	_____
100	_____	_____	_____	_____

Table 4-1 Non-Inverting Amplifier Close-Loop Gain

- For $R_B = 100K\Omega$, increase amplitude of V_1 until V_o distorts by hitting both limits.
- Measure with cursors V_{omax} and record below. Capture scope image.

V_{omax} = _____

Procedure 3: Inverting Amplifier

- Build op-amp circuit of prelab #3.
- Use function generator (Hi Z mode) to apply a 1Vpp 200Hz sinusoidal signal at V_1.
- For R_A = 10KΩ, complete Table 4-2.
    - Make certain output and input are approximately out-of-phase by 180°. If not, consult instructor.

R_B (KΩ)	$V_{o\ p\text{-}p}$ (V)	$\frac{V_o}{V_i}_{TH}$	$\frac{V_o}{V_i}_{EXP}$	%Error
1	_____	_____	_____	_____
10	_____	_____	_____	_____
82	_____	_____	_____	_____
100	_____	_____	_____	_____

Table 4-2 Inverting Amplifier Close-Loop Gain

- For R_B = 100KΩ, increase amplitude of V_1 until V_o distorts by hitting both limits.
- Measure with cursors V_{omax} and record below. Capture scope image.

- V_{omax} = _____

Discussion

1. What is the primary application of a voltage follower? Illustrate its importance with a numerical example.
2. Why did the 20,000Hz input square wave produced a trapezoidal distorted output signal in procedure 1?
3. What is the <u>primary</u> reason for any differences between $\frac{V_o}{V_i}_{Th}$ and $\frac{V_o}{V_i}_{EXP}$ in the non-inverting and inverting amplifier procedures?
4. How is the output signal distorted when the input voltage is increased in the last step of procedures 2 and 3?
5. Under what circumstances would a 1 MΩ internal input resistance of an op-amp affect circuit operation?