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# OPERATIONAL AMPLIFIERS / PART I

### *Purpose*

The purpose of this experiment is to demonstrate some basic operational amplifier circuits, namely the inverting, summing, and non-inverting amplifiers as well as the voltage follower. All these circuits operate in the closed-loop mode. The inverting amplifier's closed loop voltage gain can be less than, equal to or greater than one. Its output signal is always inverted with respect to its input signal, as the name implies. On the other hand, the non-inverting amplifier's closed loop voltage gain is always greater than one, while its input and output signals are in phase. The summing amplifier, as the name implies, is used to obtain the algebraic sum of multiple inputs. Each input can be weighed by different gain factors. The voltage follower acts as a buffer with high input and low output impedances.

### *Background*

The operational-amplifier is probably the most frequently used linear integrated circuit available. This device exhibits various desirable characteristics. Open-loop characteristics refer to those of an amplifier having no feedback elements between output and input. Closed-loop characteristics are those of an amplifier having an external feedback element or group of elements. When an element (i.e., a resistor, capacitor, inductor, etc) is connected from one of the input terminals to the output terminal, it will provide feedback, whereby a portion of the output voltage is added or subtracted from the input. Ideal operational-amplifiers have open-loop voltage gains of infinity.

This gain is denoted as $A_{VOL}$. Other desirable properties of ideal op-amps are the infinite input resistance and the zero output resistance. A circuit building block that can behave in this fashion finds unlimited applications in electronic circuits as it provides isolation from one stage to another and eliminates loading. The circuit equivalent of an ideal op-amp is shown in Fig. 1.

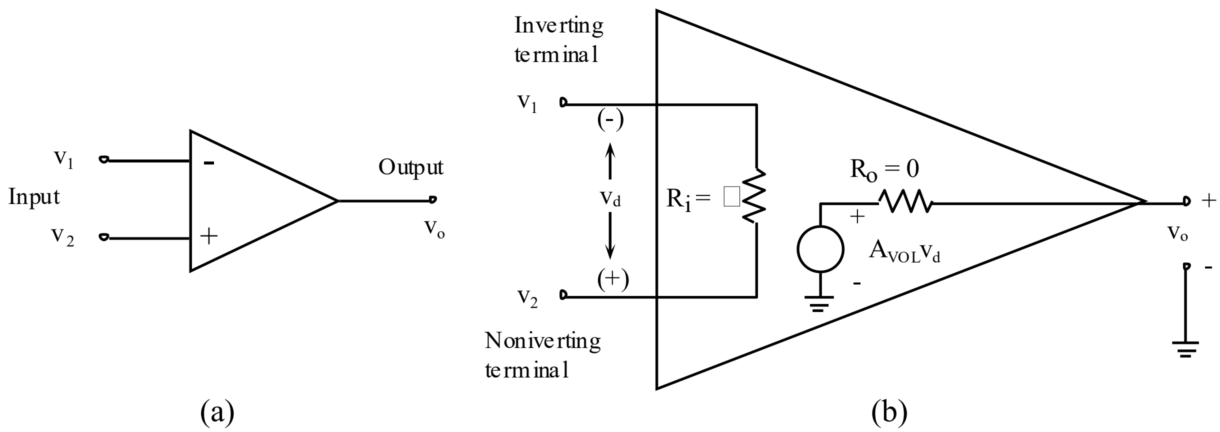



**Figure 1:** (a) Op-amp circuit diagram, (b) Ideal op-amp equivalent circuit.

Practical op-amps, however, do not have infinite input impedance and zero output impedance. Values vary from one manufacturer to another but typical ones are more than 1 MΩ and 75 Ω for the input and output impedance's, respectively.

Most applications require that the operational-amplifier be operated in the closed-loop mode. In this case the gain is no longer infinite but depends on the external circuitry attached to it. Two basic configurations that are commonly used are the *inverting* and the *non-inverting* amplifiers. These configurations will be studied in this experiment.

1. For the op-amp inverting amplifier circuit of Fig. 2, derive the closed loop voltage gain expression

$$A_v = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}$$

and select values for $R_f$ and $R_1$ for gains of

i ) $A_V = -10$, and

ii) $A_V = -1$.

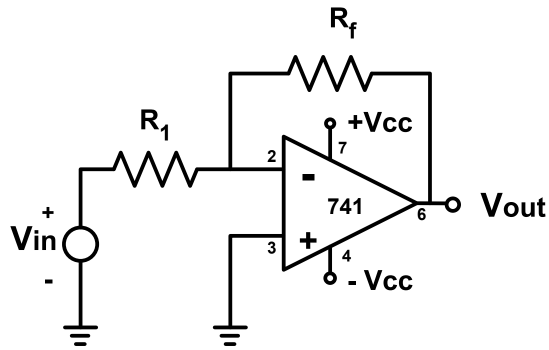



**Figure 2:** Inverting op-amp circuit.

2. For the summing amplifier circuit of Fig. 3, derive the output voltage expression

$$V_{out} = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2\right)$$

Choose values for $R_f$, $R_1$, and $R_2$ to have $V_{out} = -(3V_1 + 5V_2)$.

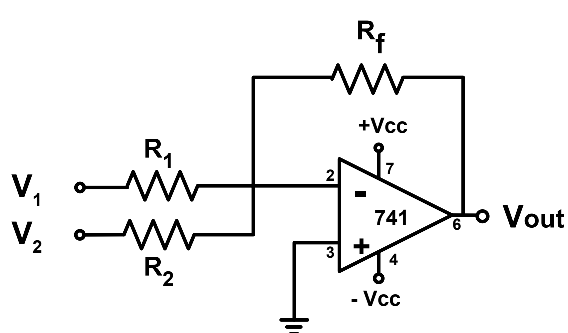



**Figure 3:** Summing op-amp circuit.

3. For the non-inverting amplifier circuit of Fig. 4, derive the closed loop voltage gain expression

$$A_v = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$$

and choose values for $R_f$ and $R_1$ to have a gain of $A_V = 11$.

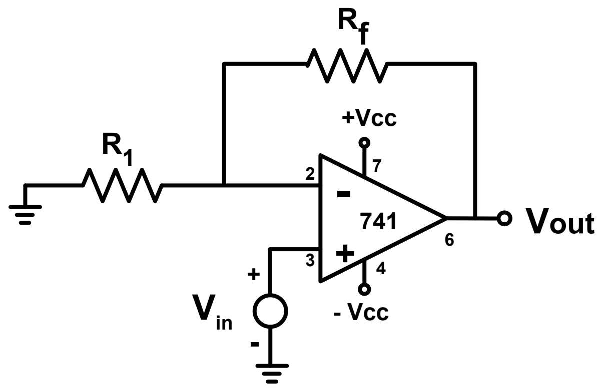
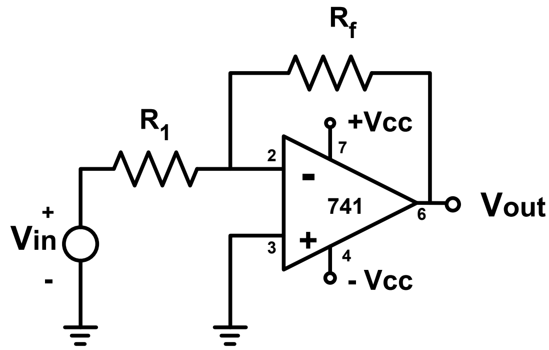



**Figure 4:** Non-inverting op-amp circuit.

***Experimental Procedure***

I. Inverting Amplifier:

Set up the circuit of Fig. 5 for gain of $A_V = -10$, using the resistor values from your preliminary work.




$R_f$ = 10k $R_1$ = 1k

**Figure 5:** Inverting amplifier.

Adjust $\pm V_{CC} = \pm 15$ V. Apply a sinusoidal input signal of frequency f = 1 kHz. Displaying $V_{in}$ and $V_{out}$ on the oscilloscope simultaneously, sketch the waveforms with their phase relation shown clearly. To obtain the phase relationship one has to use the oscilloscope in CHOP viewing mode.

What are the maximum positive and negative swings at the output?

$+V_{(out\ max)}$ = 10.006 V $-V_{(out\ max)}$ = -9.983 V

+Vcc used = 15 -Vcc used= - 15

$$A_V = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}$$

$A_V = -10$

II. Summing Amplifier:

Set up the circuit of Fig. 6 to add **$3V_1 + 5V_2$**. Use the resistor values from your preliminary work.

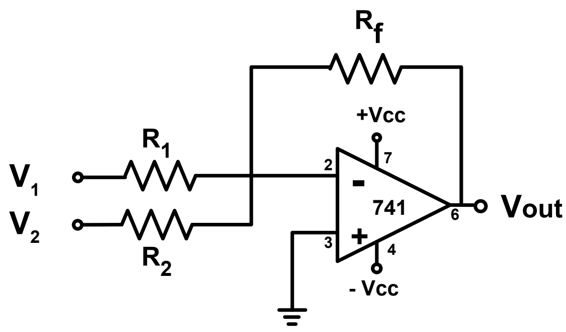
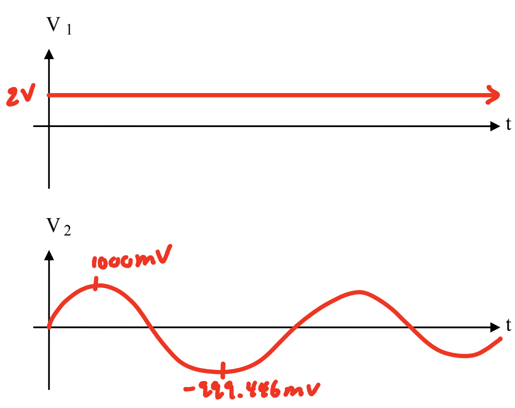


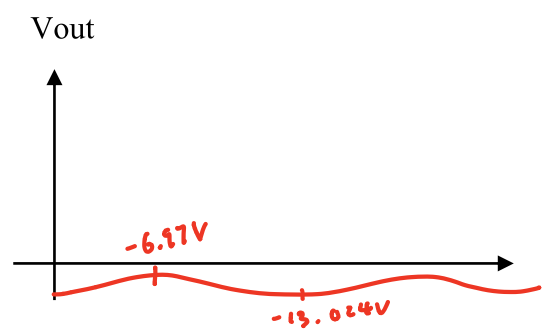

**Figure 6:** Summing amplifier circuit.

$R_1$ = 2k    $R_2$ = 3.3k    $R_f$ = 10k

Adjust $\pm V_{CC} = \pm 15$ V. Apply a sinusoidal input $V_1$ of frequency $f$ = 1kHz and a DC input $V_2$ to the inputs of Fig. 6. Sketch $V_1$, $V_2$, and $V_{out}$.

**Make sure that the output voltage will not exceed the values from the last part (no clippings!).**

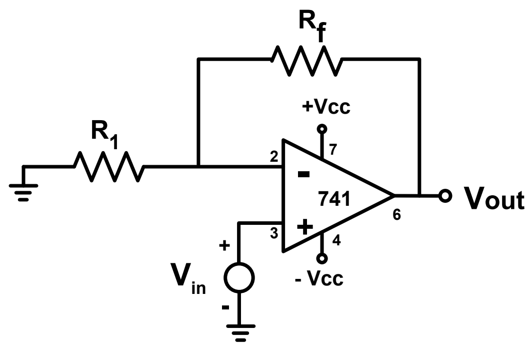



$V_{1(p\text{-}p)}$ = 2V    $V_2$ = 2V    $V_{out}$ = -13.94 V

III. Non-Inverting Amplifier:

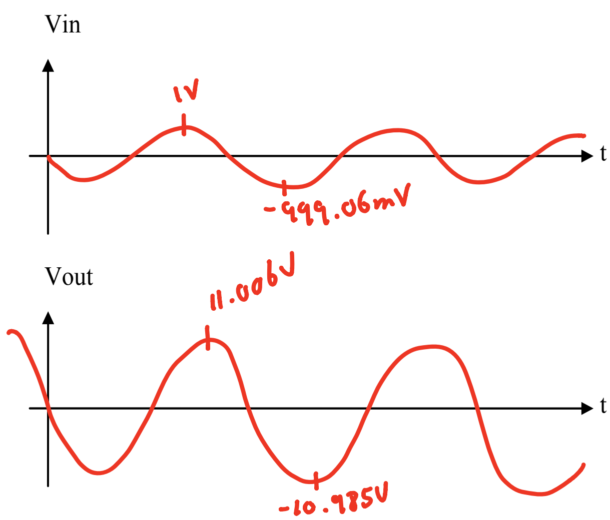
Set up the circuit of Fig. 7, for a gain of $A_V = 11$. Use the resistor values from your preliminary work.




$R_1 =$ 1k $R_f =$ 10k

**Figure 7:** Non-inverting amplifier circuit.

Adjust $\pm V_{CC} = \pm 15$ V. Apply a sinusoidal input signal $V_{in}$ of frequency $f = 1$kHz. Displaying $V_{in}$ and $V_{out}$ on the oscilloscope simultaneously, sketch the waveforms showing their phase relation clearly. Measure $V_{in}$, $V_{out}$, and calculate the gain $A_V$.




$V_{in}$ (p-p) = 2V $V_{out}$ (p-p) = 22.012V $A_V = \frac{V_{out}}{V_{in}} =$ 11.006V

IV. The Voltage Follower:

Connect the circuit of Fig. 8. With $V_{in}$ = 5 $V_{peak}$ at 1 kHz, measure the output voltage $V_{out}$. Note the phase angle of the output $V_o$ with respect to the input $V_{in}$. Repeat this procedure with $V_{in}$ = 10 Vdc and again with $V_{in}$ = 2 $V_{peak}$ square wave. Plot your findings in the graphs provided.

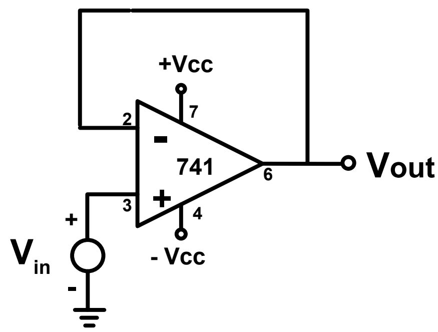
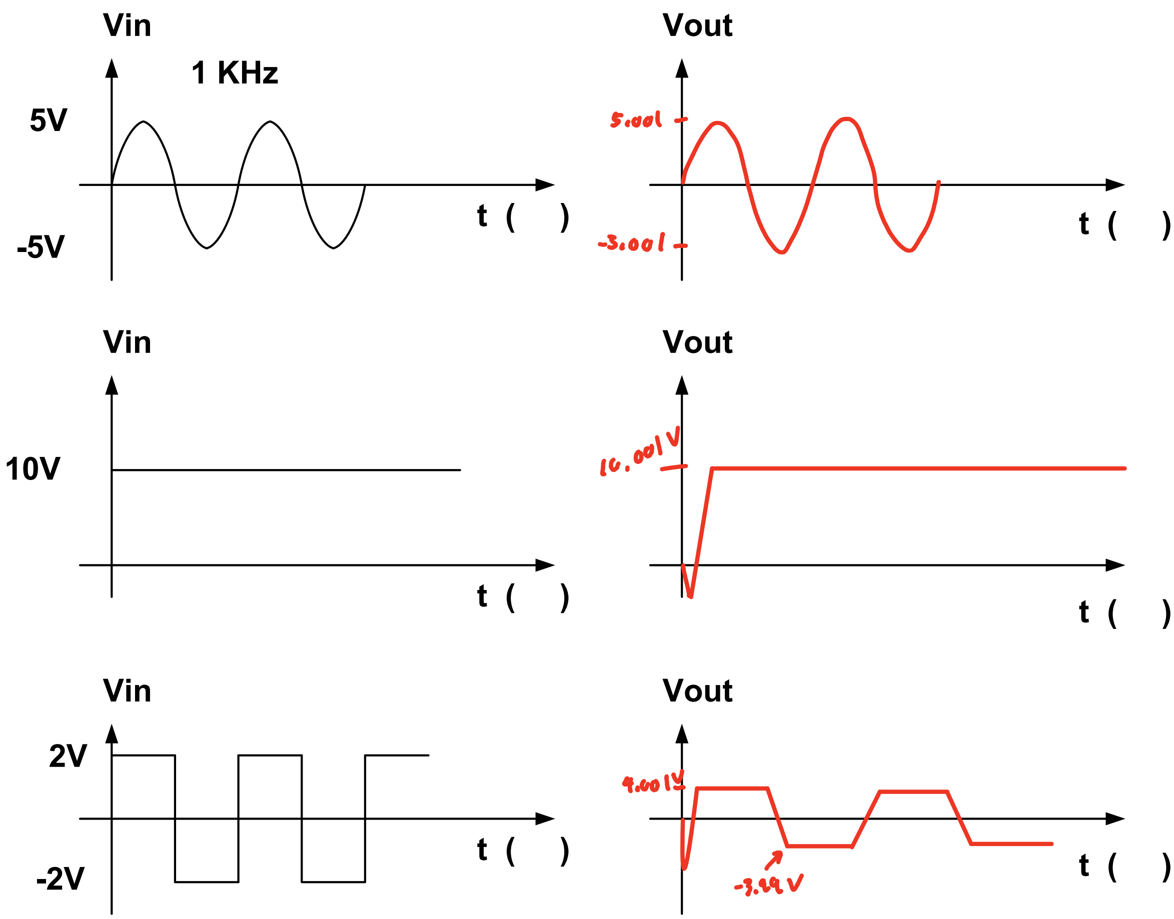
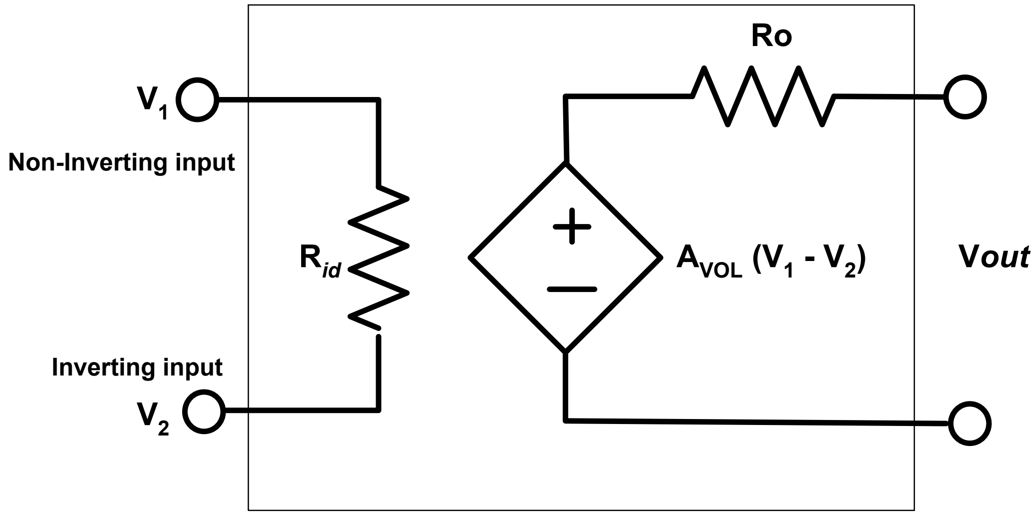



**Figure 8:** Voltage follower circuit.



## *PSpice*

A basic sub-circuit to model an Op-Amp is shown below. With $R_{id}$ = 6 MΩ, $R_o$ = 75 Ω and $A_{VOL}$ = 200,000 use PSpice to simulate an inverting amplifier with a gain of -10.
Repeat the simulation with the 741 instead of the sub-circuit and comment on the results.




## *Discussion of the Results*

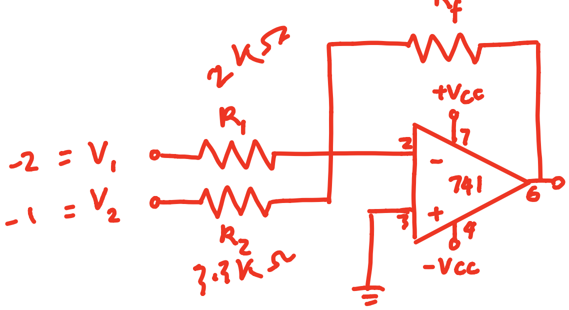
1. Design a summing amplifier to give $V_{out} = +(3V_1 + 5V_2)$. Draw the circuit diagram and label resistor values.

2. Write a conclusion.

Disscussion

1.

$V = IR$




$V_{out} = +(3V_1 + 5V_2) = 13.0303$

$V_{out} = \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2$

2. In this experiment we learned about the different operational amplifiers and the how they work. And leaned how specifically the little changes can affect the amplifier. We also learned about calculating the gain of the amplifier and Vout. And since we used falstad our measurements should be pretty accurate, with little error.