EE285
BASIC APPLICATIONS OF OPERATIONAL AMPLIFIERS

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GROUP CO 07
SEMESTER 4
17/01/2018

DATE : 08/11/2018

TITLE : BASIC APPLICATIONS OF OPERATIONAL AMPLIFIERS

APPARATUS

Power Supply
Oscilloscope
Signal Generator
Breadboard + Jumper Wires
LM324
Resistors 1kΩ, 10kΩ

PROCEDURE

A. INVERTING AMPLIFIER

1. Analyze the inverting amplifier circuit shown in Figure 1 and prove that,

$$V out / V in = - R2 / R1$$

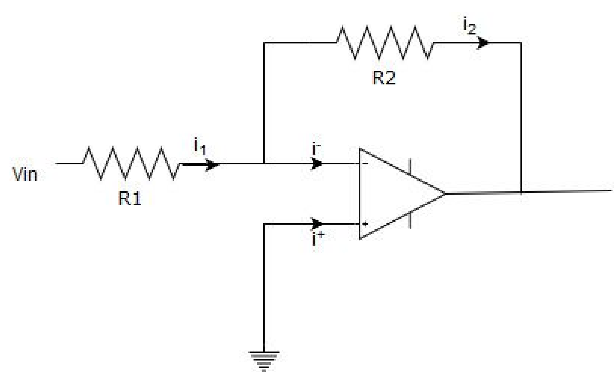

Figure 1: Inverting amplifier circuit

By applying the golden rules,

$$v^- = v^+ = 0$$

$$i^- = i^+ = 0$$

$$i_1 = \frac{v_{in} - v^-}{R_1} = \frac{v_{in}}{R_1}$$

By applying KCL,

$$\begin{aligned} i_1 &= i_2 \\ \frac{v_{in}}{R_1} &= -\frac{v_{out}}{R_2} \\ v_{out} &= -\frac{R_2}{R_1} v_{in} \end{aligned}$$

2. Connect the circuit in the breadboard and apply a 1V_{pp} sinusoidal signal (V_{in}) for frequencies; 50Hz, 100Hz, 500Hz, 1kHz, 10kHz, 50kHz, 100kHz and 500kHz and observe the output waveform (Take R_2=10kΩ and R_1=1kΩ)

3. Then tabulate the following parameters at each of the above frequencies.

- ***V_{in} (peak to peak)***
- ***V_{out} (peak to peak)***
- ***Voltage Gain***

Frequency	***V_{in} (peak to peak)/v***	***V_{out} (peak to peak)/v***	***Voltage Gain***
50Hz	1.00	10.0	10.0
100Hz	1.00	8.80	8.80
500Hz	1.00	8.80	8.80
1kHz	1.00	8.80	8.80
10kHz	1.00	8.80	8.80
50kHz	1.00	2.40	2.40
100kHz	1.00	1.48	1.48
500kHz	1.00	0.26	0.26

Plot the input and output waveforms of the 1kHz signal.

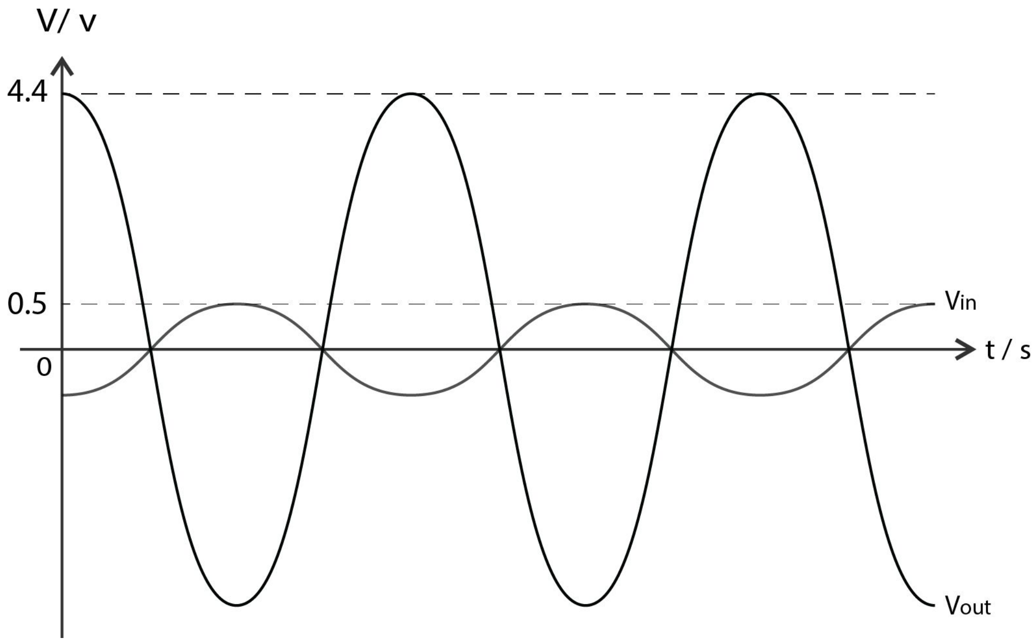

Figure 2: Input and output waveforms of 1kHz signal

B. NON-INVERTING AMPLIFIER

1. Analyze the inverting amplifier circuit shown in Figure 3 and prove that,

$$V\,out\,/\,V\,in\ =\ 1\ +\ (R2\,/\,R1)$$

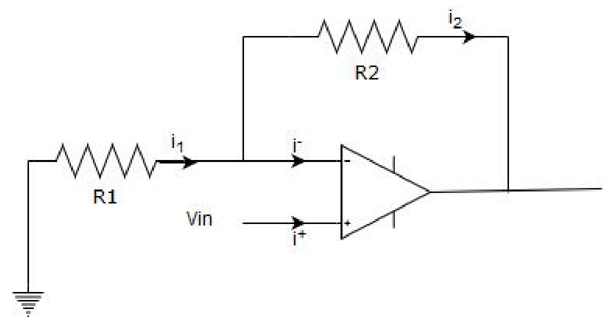

Figure 3: Non-inverting amplifier circuit

By applying the golden rules,

$$v^- = v^+ = v_{in}$$

$$i^- = i^+ = 0$$

By applying KCL,

$$\frac{0 - v^-}{R_1} = \frac{v^- - v_{out}}{R_2}$$

$$\frac{v_{out}}{R_2} = v_{in}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad ;\ v^- = v_{in}$$

$$\frac{v_{out}}{v_{in}} = 1 + \frac{R_2}{R_1}$$

2. Connect the circuit in the breadboard and apply a 1V_{pp} sinusoidal signal (V_{in}) for frequencies; 50Hz, 100Hz, 500Hz, 1kHz, 10kHz, 50kHz, 100kHz and 500kHz and observe the output waveform (Take R_2=10kΩ and R_1=1kΩ)

3. Then tabulate the following parameters at each of the above frequencies.

- ***V_{in} (peak to peak)***
- ***V_{out} (peak to peak)***
- ***Voltage Gain***

Frequency	***V_{in} (peak to peak)/v***	***V_{out} (peak to peak)/v***	***Voltage Gain***
50Hz	1	10.40	10.00
100Hz	1	10.40	10.40
500Hz	1	9.60	9.60
1kHz	1	9.60	9.60
10kHz	1	9.60	9.60
50kHz	1	1.90	1.90
100kHz	1	1.04	1.04
500kHz	1	0.96	0.96

Plot the input and output waveforms of the 1kHz signal.

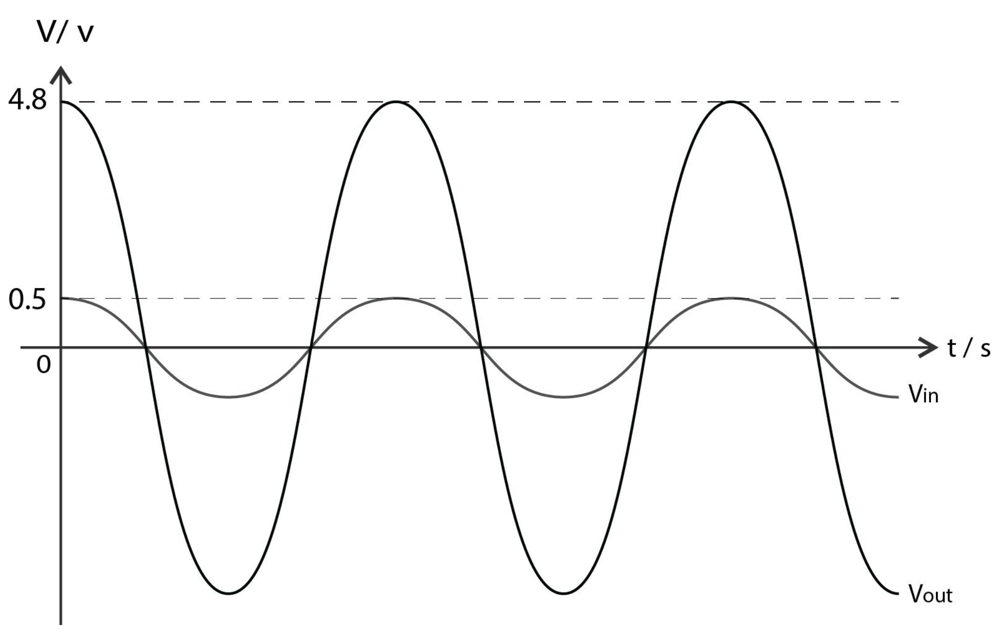

Figure 4: Input and output waveforms of 1kHz signal

C. ADDER (SUMMING AMPLIFIER)

1. Analyze the adder circuit shown in Figure 7 and prove that,

$$V_{out} = -R_2\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{Rc}\right)$$

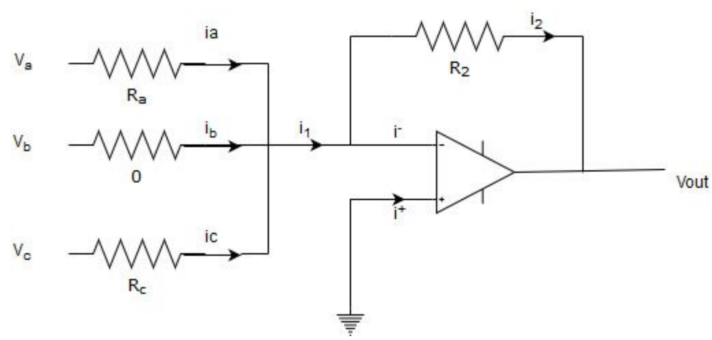

Figure 5: Adder (Summing Amplifier)

By applying KCL,

$$i_a + i_b + i_c = i_2 + i^- \left(i^- = 0,\ Golden\ Rule\right)$$

$$\frac{v_a - v^-}{R_a} + \frac{v_b - v^-}{R_b} + \frac{v_c - v^-}{R_c} = \frac{v^- - v_{out}}{R_2} \left(v^- = 0,\ Golden\ Rule\right)$$

$$\frac{v_a}{R_a} + \frac{v_b}{R_b} + \frac{v_c}{R_c} = -\frac{v_{out}}{R_2}$$

$$v_{out} = -R_2\left(\frac{v_a}{R_a} + \frac{v_b}{R_b} + \frac{v_c}{R_c}\right)$$

2. Connect the circuit in the breadboard without V_c and R_c such that,

$$V_{out} = -R_2\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{Rc}\right)$$

Then take $R_2 = R_a = R_b = 1k\Omega$ such that,

$$V_{out} = -\left(V_a + V_b\right)$$

(a). Take $V_a = V_b = 5V$ and observe the output.

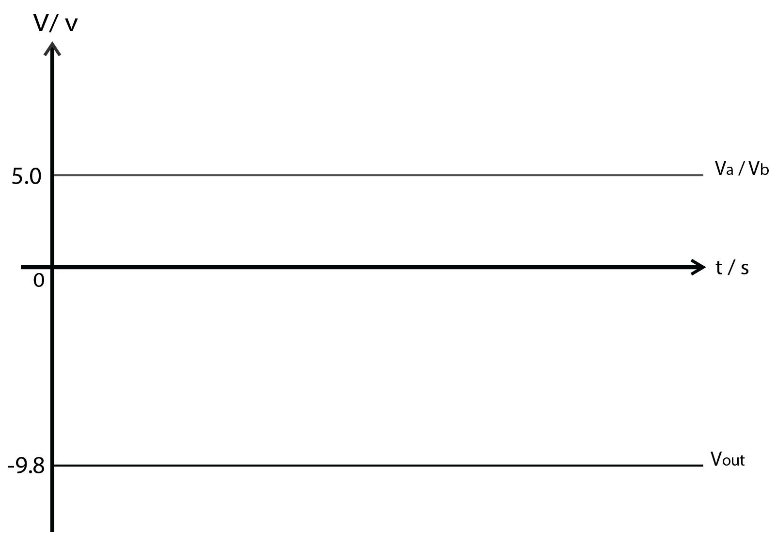

Figure 6: Input and output waveforms of 2(a)

(b). Take $V_a = 5V$ and Vb as $1V_{pp}$ sinusoidal signal of 2kHz and observe the output.

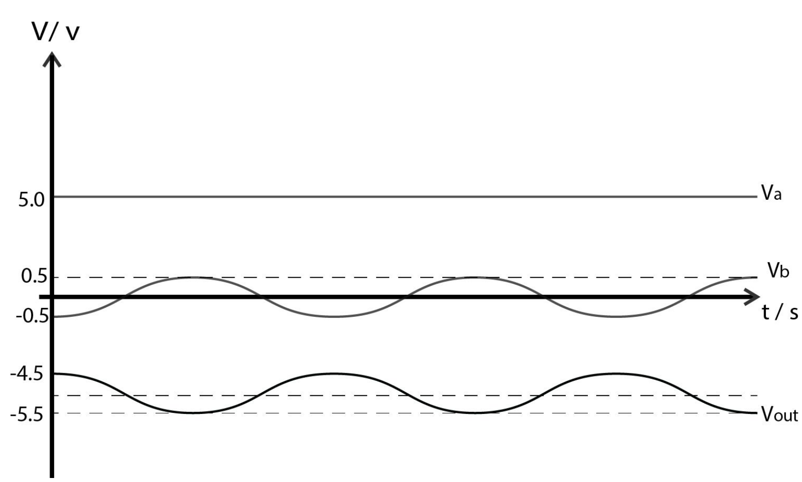

Figure 7: Input and output waveforms of 2(b)

D. COMPARATOR

1. Analyze the comparator circuit shown in Figure 8 and understand its behavior. Can you apply Golder Rules for this circuit for any purpose? Explain why?

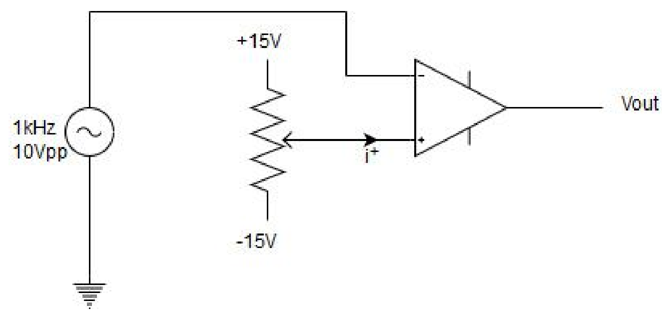

Figure 8: Comparator circuit

Golden rules only can be applied for systems with feedback implemented. (Otherwise, both inputs must have same voltage). In here, input terminals have different voltages. Hence we can't apply *Golden rules* for this circuit.

Comparator circuits are using the saturation mode/region of the op-amp. This kind of circuits have only two outputs, one is positive saturated voltage (+15V for this circuit) and other is negative saturated voltage (-15V for this circuit).

The output value is given by the following equation. ***A*** is the gain of the amplifier.

$$v_{out} = A\left(v_{+} - v_{-}\right)$$

In practical situations, there is a little voltage drop in the output voltage of the op-amp, due to gate voltages of semiconductors. So output voltage is little below than V_{cc} in positive saturated status and little higher than V_{ee} in negative saturated status.

2. Connect the circuit in the breadboard and apply an input signal as shown in Figure 8.

3. Adjust the rheostat such that V_+ = -15V. Then gradually increase V_+ towards +15V using the rheostat. Observe how the output waveform changes when you change V_+ Plot the output waveforms for V_+ = -12V, -5V, 0V, +5V, +12V

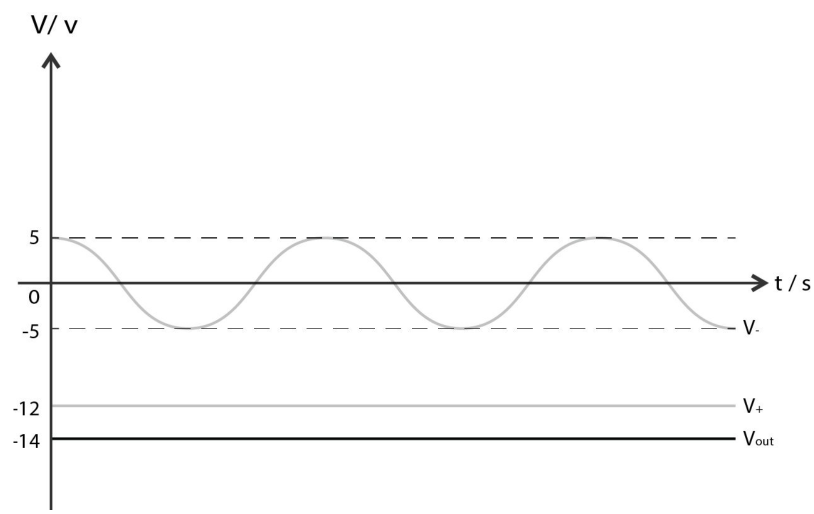

Figure 9: Input and Output waveforms when $V_{\pm}$ = -12V

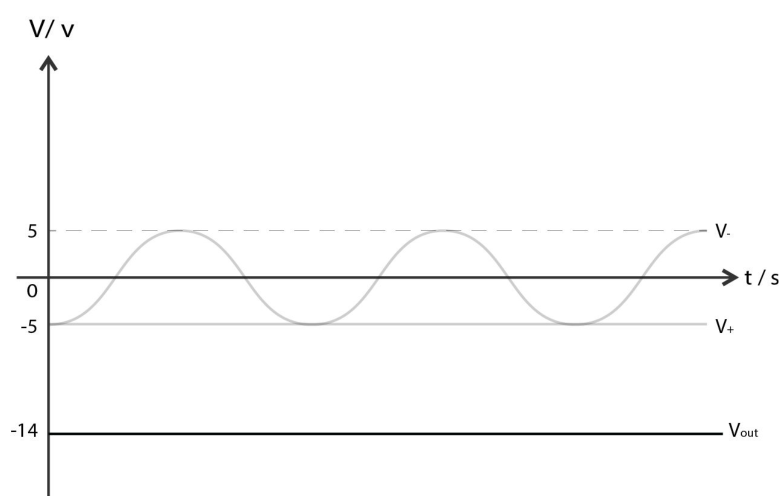

Figure 10: Input and Output waveforms when $V_{\pm}$ = -5V

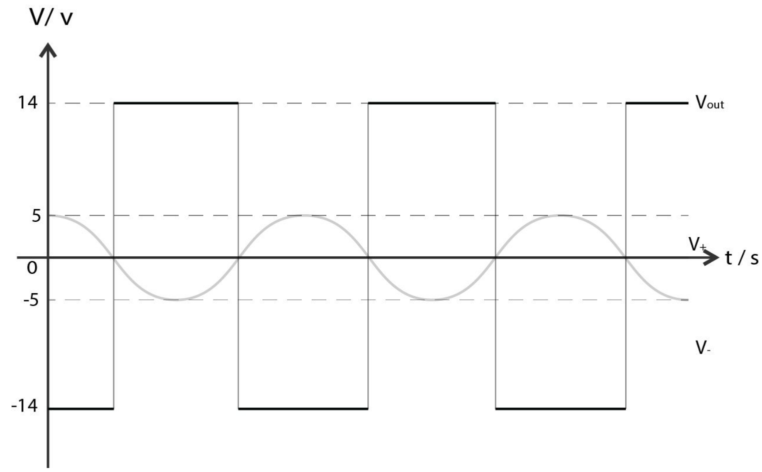

Figure 11: Input and Output waveforms when $V_{\pm}$ = 0V

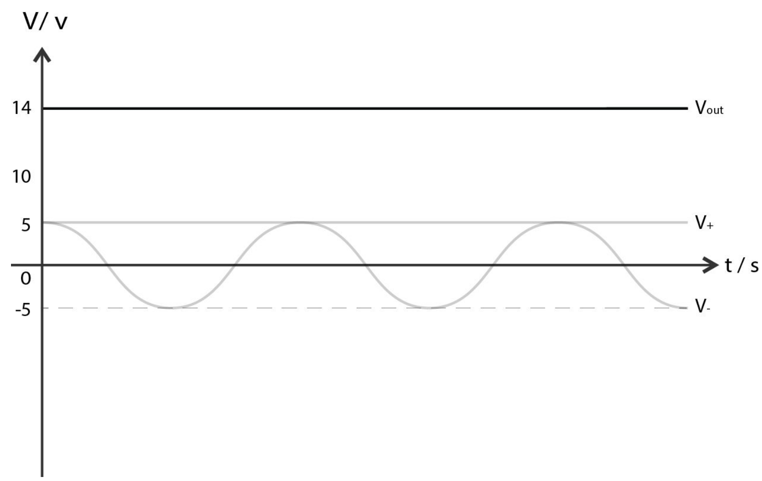

Figure 12: Input and Output waveforms when $V_{\pm}$ = +5V

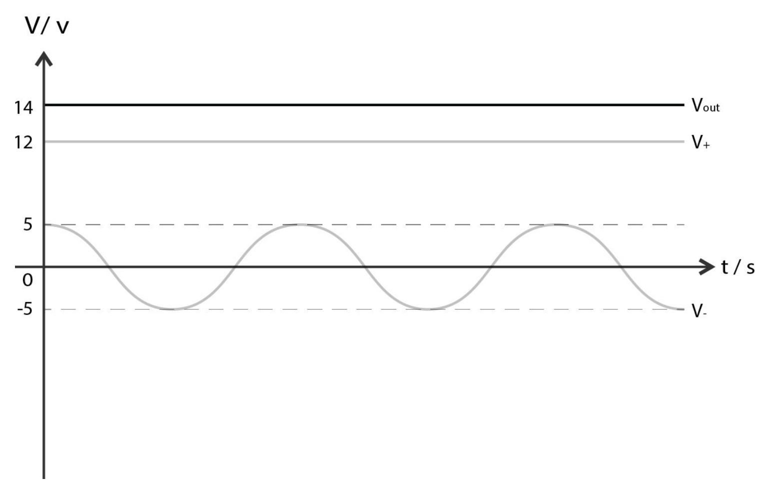

Figure 13: Input and Output waveforms when $V_{\pm}$ = +12V

DISCUSSION

1. Draw the equivalent circuit (model) for an OP-Amp. It should include the terms Z_{in} , Z_{out} , A_v , V^+ and V_{out} . State the ideal values for Z_{in} , Z_{out} , A_v

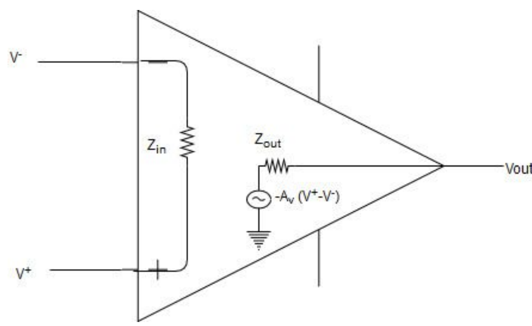

Figure 14: Equivalent circuit (model) for an op-amp

Z_{in} and A_v are equal to infinity
Z_{out} equal to zero

2. What is meant by the term *Virtual Earth* when an inverting amplifier is considered?

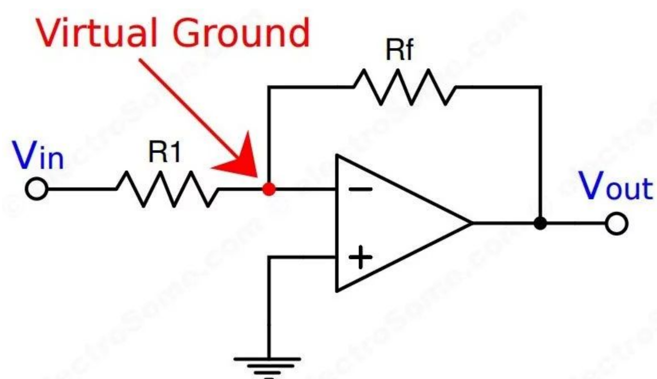

Figure 15: Inverted Amplifier

In an inverting amplifier, we can introduce the term, virtual earth / virtual ground for easy to do the calculations. This terminal is not actually connected to the ground, but almost equal to the ground voltage.

An ideal Op-Amp gives infinity gain. So V_1 - V_2 should equal to zero when a feedback network is implemented. V_+ is grounded, so V_- is also should be equal to the 0V according to the *Golden Rule*. But it isn't directly wired to ground and then it is considered as virtually grounded.

3. What is Unity Gain Buffer (Voltage Follower)?

Explain its operation using your own words (also analyze the circuit and derive an expression for the output in terms of the input). What are the practical applications of the unity gain buffer?

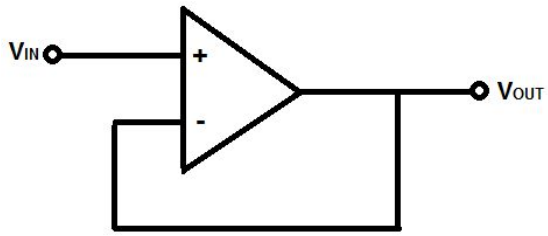

Figure 16: Unity Gain Buffer Circuit

Unity Gain Buffer (Unity Gain Amplifier / Voltage Follower) is an op-amp circuit that has a unit voltage gain (x1). Therefore the output voltage signal is the same as the input voltage signal.

But op-amp circuit has a very high input impedance and a very low output impedance (Zero for idea op-amp). So it can operate with very small input current and provide a significant output current. (Technically we can say this is a current amplifier)

$$V_+ = V_{in}$$
$$V_- = V_{out}$$

By applying the Golden Rules,

$$i+ = i- = 0$$

Then,

$$V_{in} = V_{out}$$

Few practical applications of unity gain amplifier are,

1. Voltage Divider

    We can use *Unity Gain Buffer* to get a voltage from a voltage divider. Due to the high impedance of the *Unity Gain Buffer,* no current flows out from the divider source and we can take a significant current from V_{out} with the same voltage that voltage divider has.

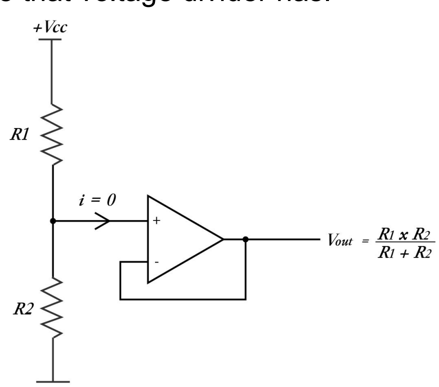

Figure 17: Application of unity gain buffer in voltage divider

2. Filter Isolators

Unity gain buffers are used to isolate filter output stages when building multistage filters. It helps to prevent excessive loading on the filters outputs.

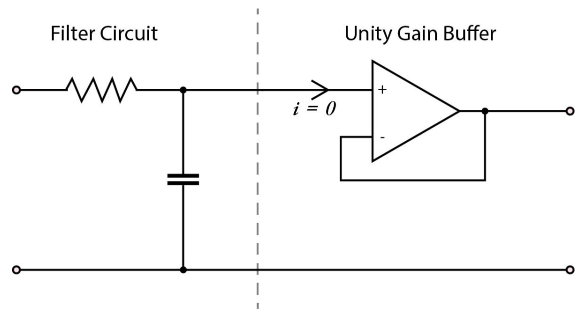

Figure 18: Application of unity gain buffer in filter circuits

3. As an impedance converter

Unity gain buffers can be used to convert voltage signals to high impedance voltage outputs.

4. In ADC units

Unity gain buffers are used in ADC units, before the ADC circuit. Thus, we can use the ADC circuit to measure voltages on circuits without affecting the currents flow through the circuit.

4. How would you build a Difference amplifier (to amplify the difference between two input signals) using an Op-Amp?

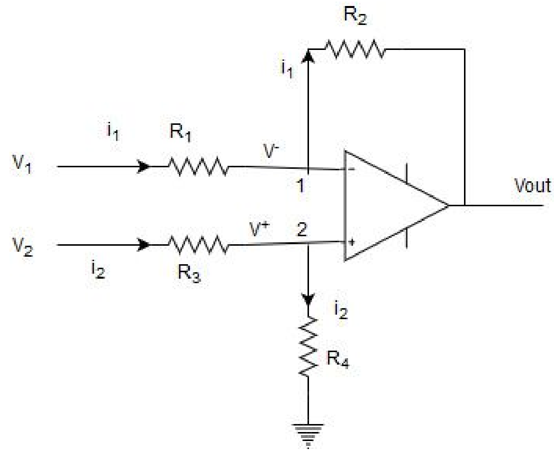

Figure 19: Diffrence Amplifier Circuit

By applying Golden Rules,

$$v^- = v^+ = 0$$
$$i^- = i^+ = 0$$

For Node 1 and 2,

$$i_1 = \frac{v_1 - v^-}{R_1} = \frac{v^- - v_O}{R_2}$$
$$v^- = \frac{v_1 R_2 - v_0 R_1}{R_1 + R_2}$$

$$i_2 = \frac{v_2 - v^+}{R_3} = \frac{v^+ - 0}{R_4}$$
$$v^+ = \frac{v_2 R_4}{R_3 + R_4}$$

Now,

$$\frac{v_1 R_2 - v_0 R_1}{R_1 + R_2} = \frac{v_2 R_4}{R_3 + R_4}$$

$$\frac{v_2 R_4}{R_3 + R_4} - \frac{v_1 R_2}{R_1 + R_2} = \frac{v_0 R_1}{R_1 + R_2}$$

Let's take,

$$\frac{R_4}{R_3} = \frac{R_2}{R_1}$$

Now,

$$\frac{v_0 R_1}{R_1 + R_2} = \frac{v_2 R_2}{R_1 + R_2} - \frac{v_1 R_2}{R_1 + R_2}$$

$$v_0 = \frac{R_2}{R_1}(v_2 - v_1)$$

5. What are the practical limitations of μ741 Op-Amp?

- Input offset current: 20nA (In ideal, this should not exists)
- Input bias current: 80nA (In ideal, this should be 0)

- Input resistance: 2MΩ (In ideal conditions, input impedance should be infinity)
- Input resistance: 70Ω (In ideal conditions, input impedance should be zero)

- Common mode input voltage range ±13V
- Common mode output voltage range ±13V
  (For ideal op-amp, this should be ±15V, when Vcc=+15V and Vee = -15V)

- Open loop gain is 106 dB while driving a 20kΩ load (in an ideal op-amp, it should be infinite)

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