

## Class Note 20: OP Amp Circuits

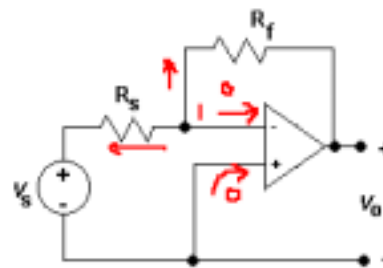
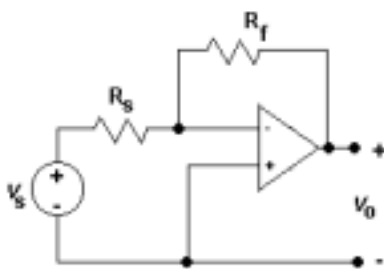
1. Let's consider some useful op amp circuits that often serve as modules for more complex circuits. The op amp circuits we will discuss are:

- Inverting Amplifier
- Noninverting Amplifier and Voltage Follower
- Summing Amplifier
- Difference Amplifier

2. Example problems are included for op amp circuit analysis practices.

### A. Inverting Amplifier

1. An inverting amplifier reverses the polarity of the input signal while amplifying it.
2. A voltage  $V_s$  is connected to the inverting input.
3. The noninverting terminal is grounded.



4. Input-Output relationship (see the figure above right)

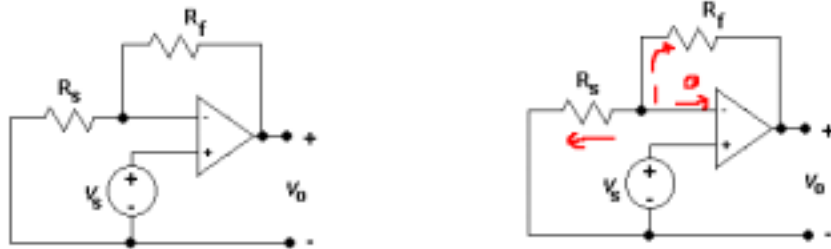
(a) By ideal op amp model:  $V_1=0$  (Why?  $V_p$  is grounded, so  $V_p=0=V_n=V_1$ )

(b) @ node 1:  $\frac{0-V_s}{R_s} + \frac{0-V_o}{R_f} = 0 \rightarrow V_o = -\frac{R_f}{R_s}V_s$

(c) Closed-loop gain:  $A_v = -\frac{R_f}{R_s}$

## B. Noninverting Amplifier and Voltage Follower

1. A noninverting amplifier provides a positive voltage gain.
2. An input voltage  $V_s$  is applied to the noninverting terminal.
3. A resistor  $R_s$  is connected to between the inverting terminal and the ground.



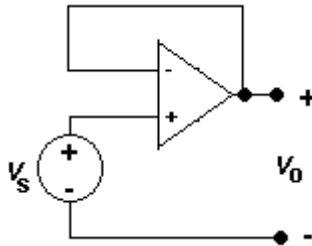
4. Input-Output relationship (see the figure above right)

(a) By ideal op amp model:  $V_i = V_s$  (Why?  $V_p = V_s = V_n$ )

(b) @ node 1:  $\frac{V_s}{R_s} + \frac{V_s - V_o}{R_f} = 0 \rightarrow V_o = \left(1 + \frac{R_f}{R_s}\right)V_s$

(c) Closed-loop gain:  $A_v = 1 + \frac{R_f}{R_s}$

5. If the feedback resistor  $R_f = 0$  (short circuit) and/or input resistor  $R_s = \infty$ , then the closed-loop gain  $A_v = 1$ . This unity gain amplifier is called a **voltage follower** because the output follows the input. Thus, for a voltage follower,  $V_o = V_s$ .

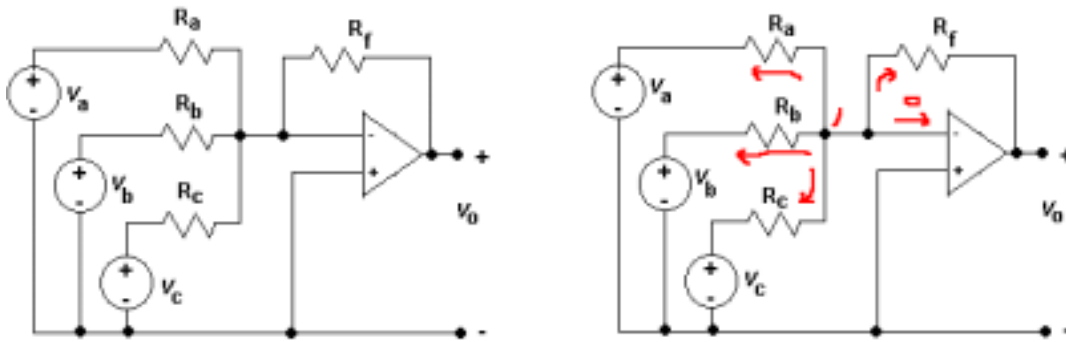


6. A voltage follower is useful as an intermediate stage amplifier (or a buffer amplifier) to isolate one circuit module from another.

7. An example:

### C. Summing Amplifier

1. A summing amplifier combines several inputs and produces an output that is the weighted sum of the inputs.
2. A summing amplifier is also called a summer.
3. A summing amplifier is a variation of the inverting amplifier.



4. Input-Output relationship (see the figure above right for a 3-input summer)

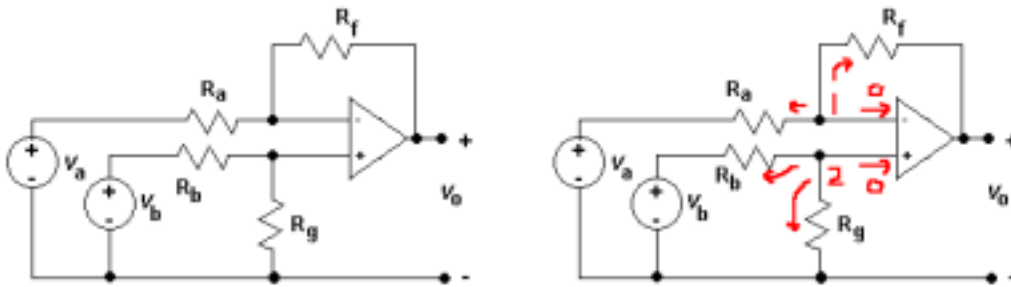
(a) By ideal op amp model:  $V_1=0$  (Why?  $V_p=0=V_n=V_1$ )

(b) @ node 1: 
$$\frac{0-V_a}{R_a} + \frac{0-V_b}{R_b} + \frac{0-V_c}{R_c} + \frac{0-V_o}{R_f} = 0 \rightarrow V_o = -\left(\frac{R_f}{R_a}V_a + \frac{R_f}{R_b}V_b + \frac{R_f}{R_c}V_c\right)$$

5. Can we design a DAC (Digital-to-Analog) by applying the summing amplifier?

## D. Difference Amplifier

1. A difference amplifier amplifies the difference between two inputs but rejects any signals common to the two inputs.
2. A difference amplifier is also called a differential amplifier.
3. A difference amplifier is also known as the subtractor.



4. Input-Output relationship (see the figure above right for a 3-input summer)

(a) By ideal op amp model:  $V_1=V_2$  (Why?  $V_p=V_n$ )

(b) @ node 1:  $\frac{V_1 - V_a}{R_a} + \frac{V_1 - V_o}{R_f} = 0 \rightarrow V_o = \left( \frac{R_f}{R_a} + 1 \right) V_1 - \frac{R_f}{R_a} V_a \quad \text{-----(1)}$

(c) @ node 2:  $\frac{V_1 - V_b}{R_b} + \frac{V_1}{R_g} = 0 \rightarrow V_1 = \frac{R_g V_b}{R_b + R_g} \quad \text{-----(2)}$

(d) Substituting (2) into (1) yields:

$$V_o = \left( \frac{R_f}{R_a} + 1 \right) \cdot \frac{R_g}{R_b + R_g} V_b - \frac{R_f}{R_a} V_a = \frac{R_f}{R_a} \left( \frac{1 + \frac{R_a}{R_f}}{1 + \frac{R_b}{R_g}} \cdot V_b - V_a \right) \quad \text{-----(3)}$$

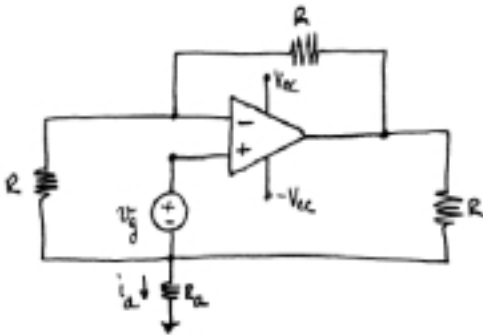
(e) Since a difference amplifier must reject a signal common to the two inputs, it's output must be zero, i.e.,  $V_o=0$ , when  $V_a=V_b$ . Applying this condition to (3) yields:  $\frac{R_a}{R_f} = \frac{R_b}{R_g}$ .

(f) Therefore, when  $\frac{R_a}{R_f} = \frac{R_b}{R_g}$ , the output is:  $V_o = \frac{R_f}{R_a} (V_b - V_a)$

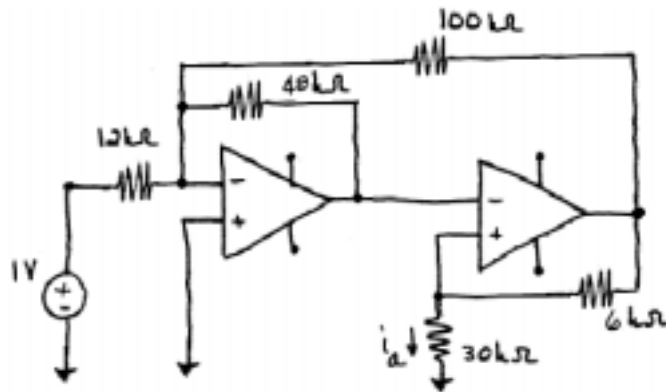
(g) When  $R_a=R_f$  and  $R_b=R_g$ , the difference amplifier becomes a subtractor with the output  $V_o = V_b - V_a$

### E. Op Amp Circuit Problems

1. Show that  $i_a = \frac{3v_g}{R}$ .



2. Find  $i_a$ .



3. The op amp has an input resistance of  $400\text{ k}\Omega$ , and output resistance of  $2\text{ k}\Omega$ , and an open-loop gain of  $500,000$ . Calculate the closed-loop voltage gain  $A_v = \frac{v_o}{v_g}$  when  $R_g = 8\text{ k}\Omega$  and  $R_f = 320\text{ k}\Omega$ .

