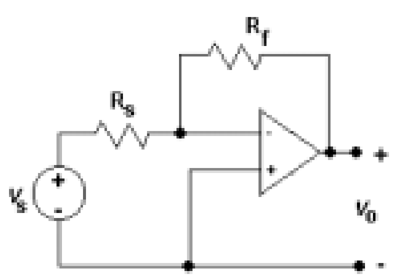
EECE202 NETWORK ANALYSIS I Dr. Charles J. Kim

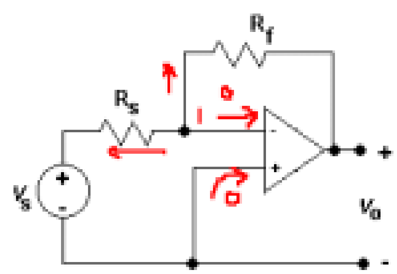
Class Note 20: OP Amp Circuits

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)

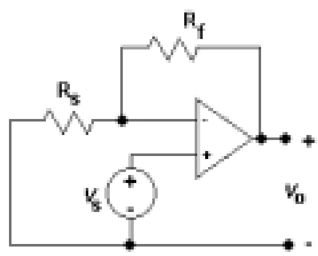
   (a) By ideal op amp model: $V_1=0$ (Why? V_p is grounded, so $V_p=0=V_n=V_1$)

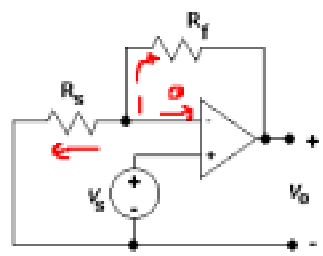
   (b) @ node 1: $\frac{0-V_s}{R_s}+\frac{0-V_o}{R_f}=0$ ---->$V_o=-\frac{R_f}{R_s}V_s$

   (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 Rs is connected to between the inverting terminal and the ground.





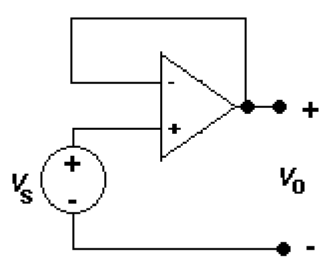
4. Input-Output relationship (see the figure above right)

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

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

   (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, $V_o=V_s$.

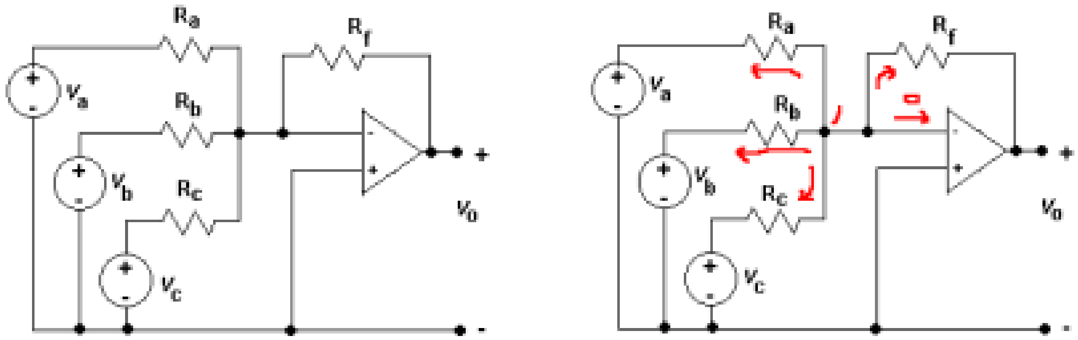


6. A voltage follower is useful as an intermediate stage amplifier (or a buffer amplifier) to isolate once circuit module from another.

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)

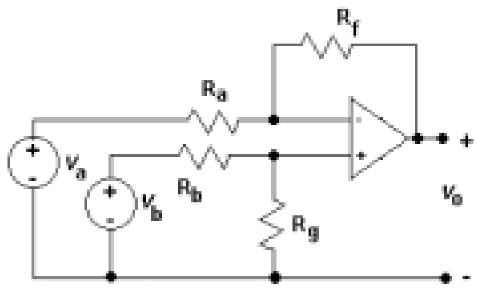
   (a) By ideal op amp model: $V_1=0$ (Why? $V_p=0=V_n=V_1$)

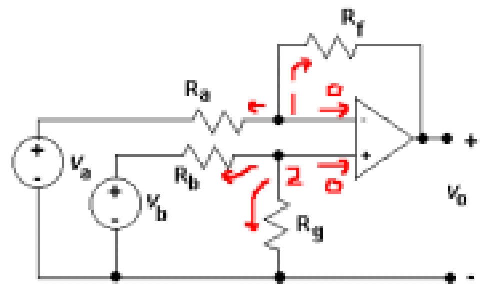
   (b) @ node 1: $\frac{0-V_a}{R_a}+\frac{0-V_b}{R_b}+\frac{0-V_c}{R_c}+\frac{0-V_o}{R_f}=0$ ----> $V_o=-\left(\frac{R_f}{R_a}V_a+\frac{R_f}{R_b}V_b+\frac{R_f}{R_c}V_c\right)$

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 <u>differential amplifier</u>.
3. A difference amplifier is also known as the <u>subtractor</u>.





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: $\dfrac{V_1 - V_a}{R_a} + \dfrac{V_1 - V_0}{R_f} = 0$ ----> $V_o = \left(\dfrac{R_f}{R_a} + 1\right)V_1 - \dfrac{R_f}{R_a}V_a$ -----(1)

(c) @ node 2: $\dfrac{V_1 - V_b}{R_b} + \dfrac{V_1}{R_g} = 0$ -----> $V_1 = \dfrac{R_g V_b}{R_b + R_g}$ ----(2)

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

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

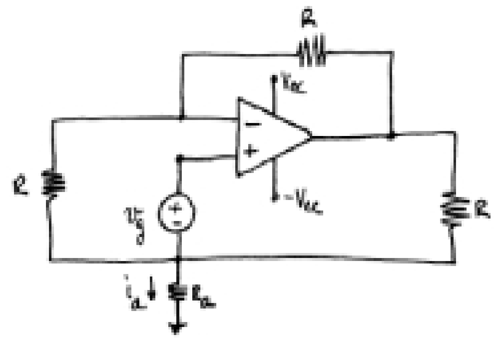
(e) Since a difference amplifier must reject a signal common to the two inputs, it's output must be zero, i.e., V_o=0, when V_a=V_b. Applying this condition to (3) yields: $\dfrac{R_a}{R_f} = \dfrac{R_b}{R_g}$.

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

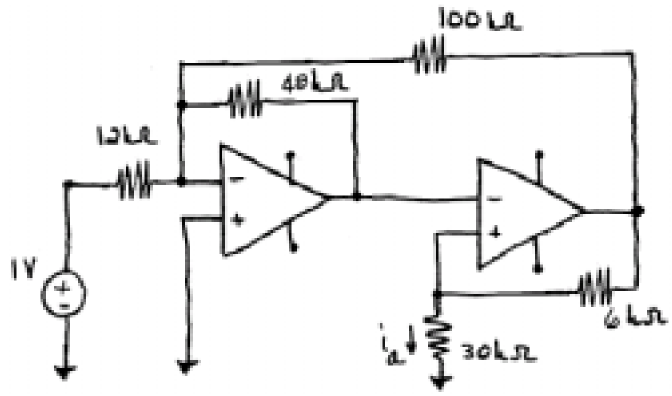
(g) When R_a=R_f and R_b=R_g, the difference amplifier becomes a subtractor with the output $V_o = V_b - V_a$

E. Op Amp Circuit Problems

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



2. Find i_a.



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