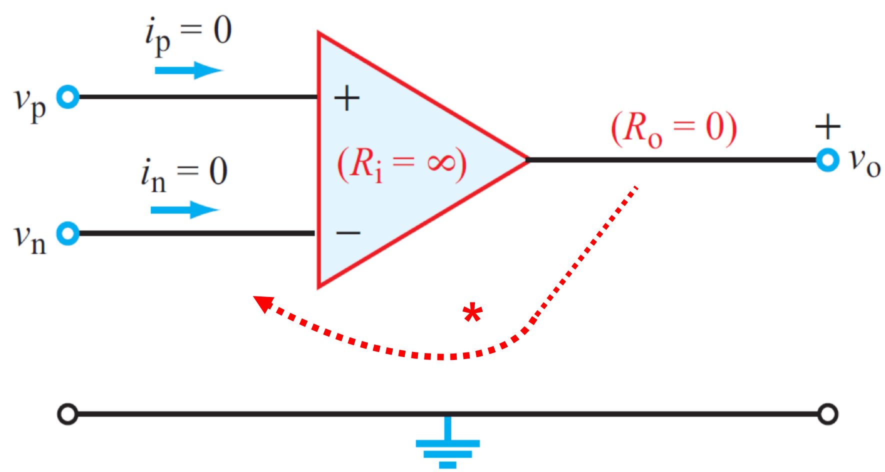
E40M

Op Amps

Ideal Op Amps in Negative Feedback Circuits



Ideal Op Amp

- Current constraint $i_p = i_n = 0$
- Voltage constraint $v_p = v_n$
- $A = \infty$ $R_i = \infty$ $R_o = 0$

The Two Golden Rules **for circuits with ideal op-amps***

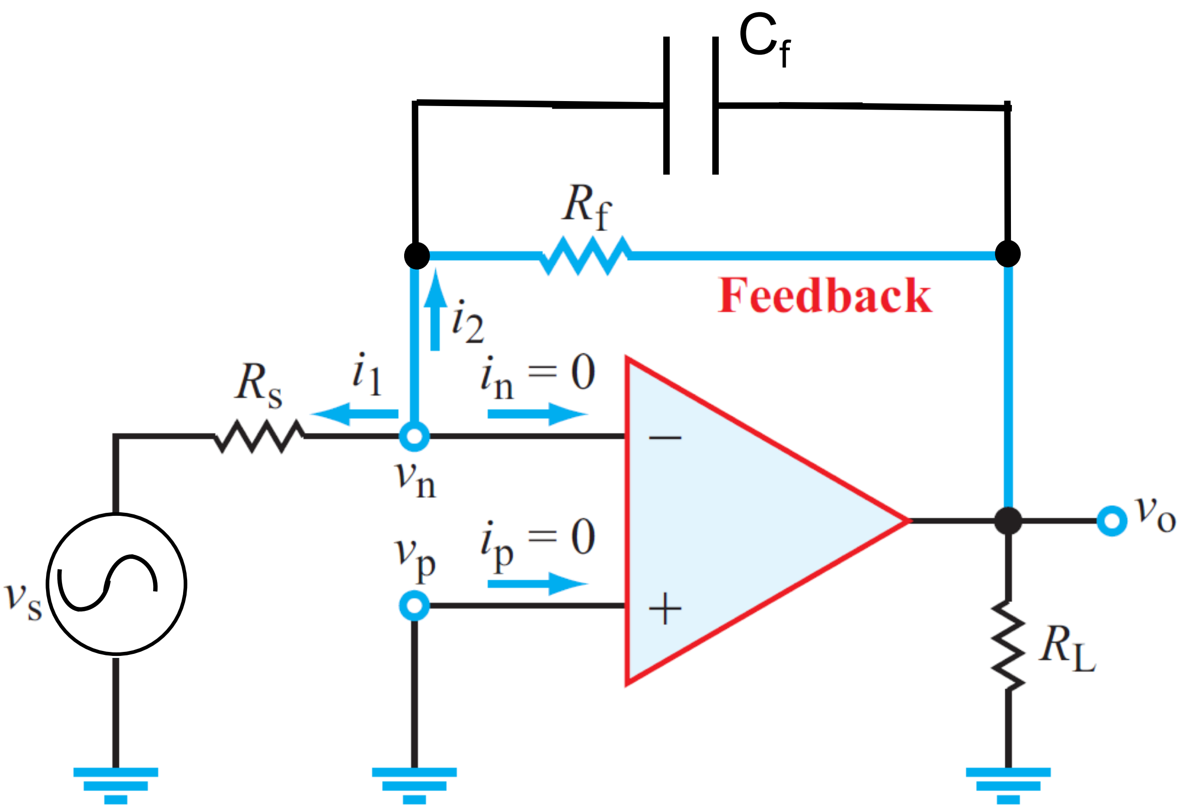
1. $v_p = v_n$ (Ideal op-amp model). **No voltage difference between op-amp input terminals**

2. $i_p = i_n = 0$ (Ideal op-amp model). **No current into op-amp inputs**

**** when used in negative feedback amplifiers***

OP AMP FILTERS

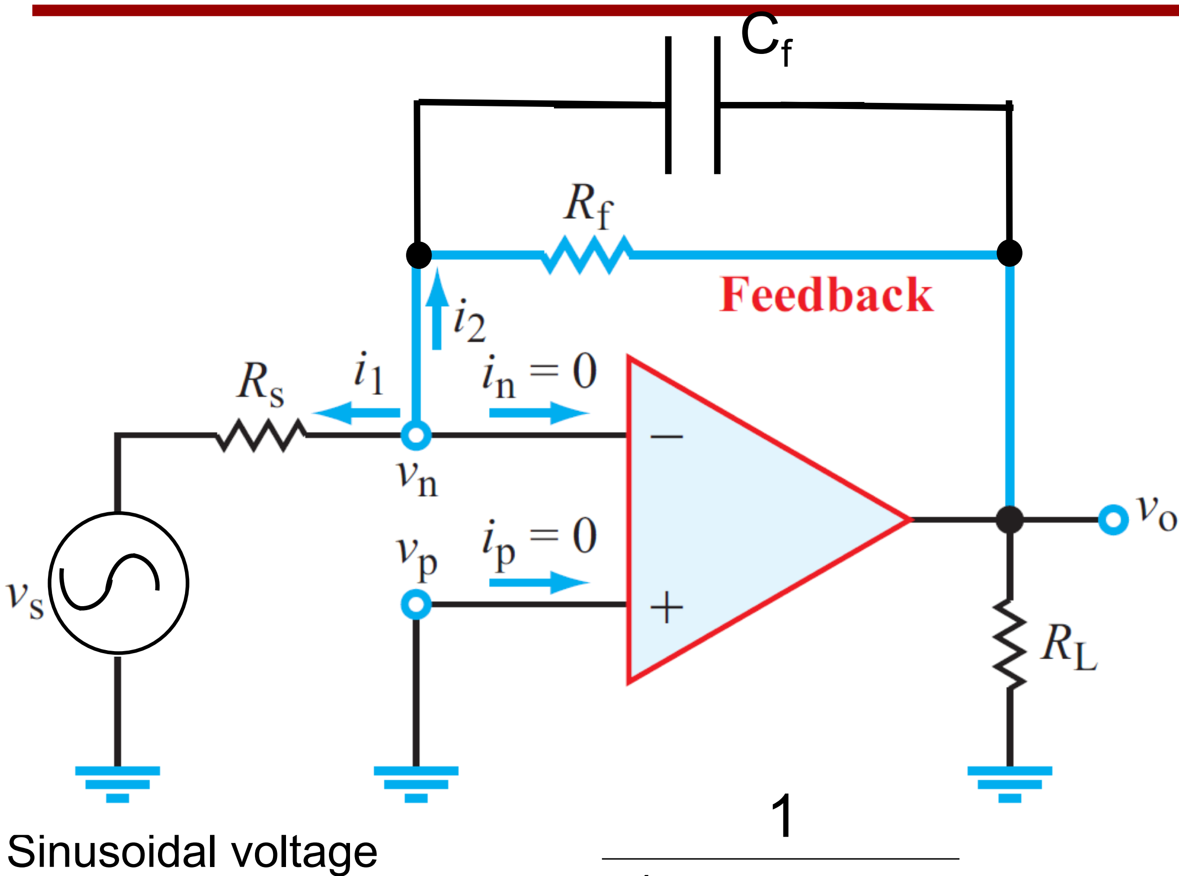
Adding Capacitors



Sinusoidal voltage

- Suppose we add a capacitor in the feedback path of an inverting amp?
- What happens at low frequency?
- What happens at high frequency?

Adding Capacitors



- Suppose we add a capacitor in the feedback
- We can treat this exactly as we did the earlier circuits by using impedances.
- Our earlier analysis showed

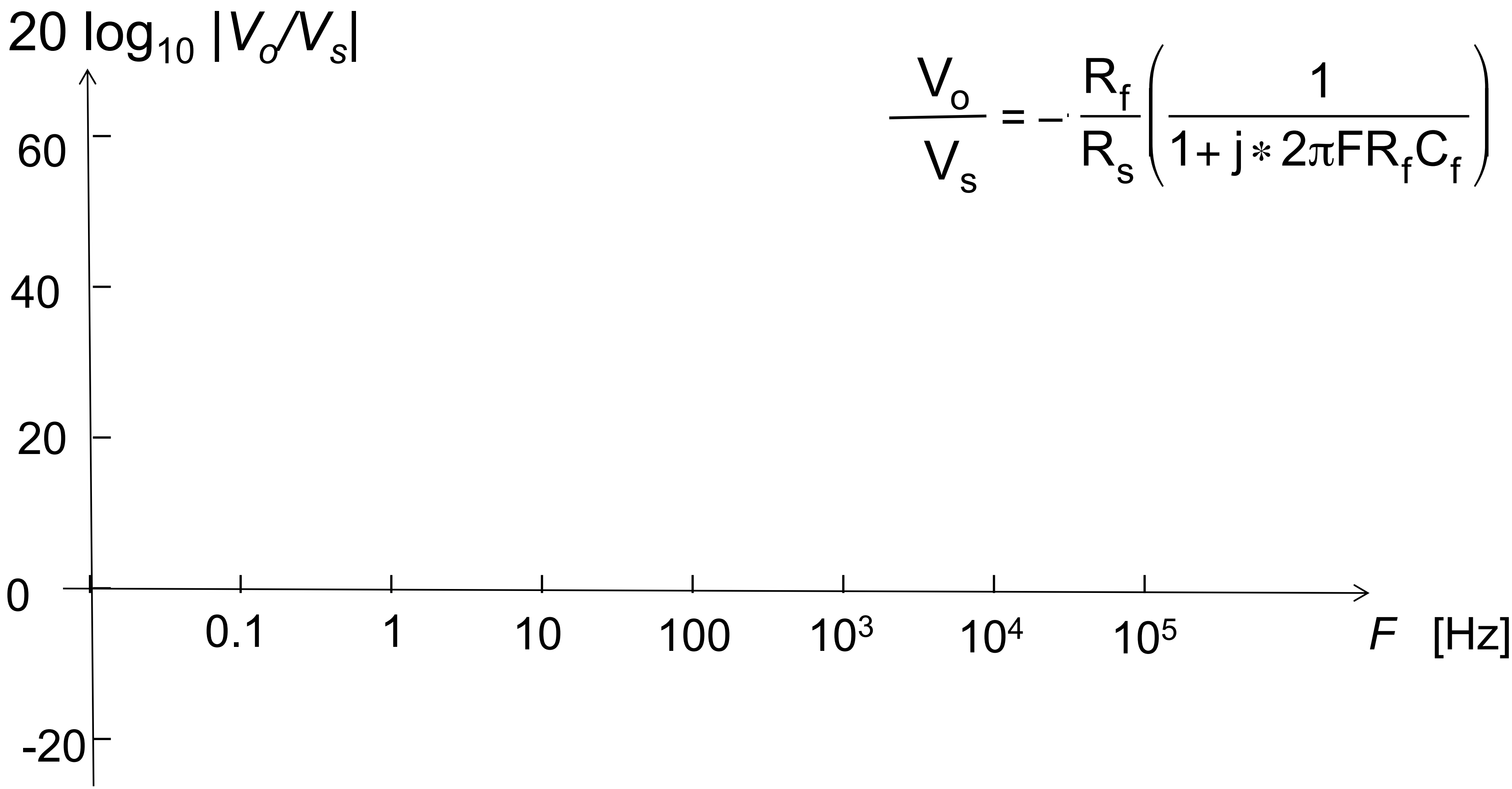
$$v_o = -v_s \frac{R_f}{R_s}$$

$$Z_s = R_s \qquad Z_f = \frac{1}{\frac{1}{R_f} + j * 2\pi F C_f}$$

$$\therefore v_o = -v_s \frac{Z_f}{Z_s} = -\frac{\frac{1}{\frac{1}{R_f} + j * 2\pi F C_f}}{R_s} = -v_s \frac{R_f}{R_s}\left(\frac{1}{1 + j * 2\pi F R_f C_f}\right)$$

Sketching the Bode Plot: low frequency asymptote

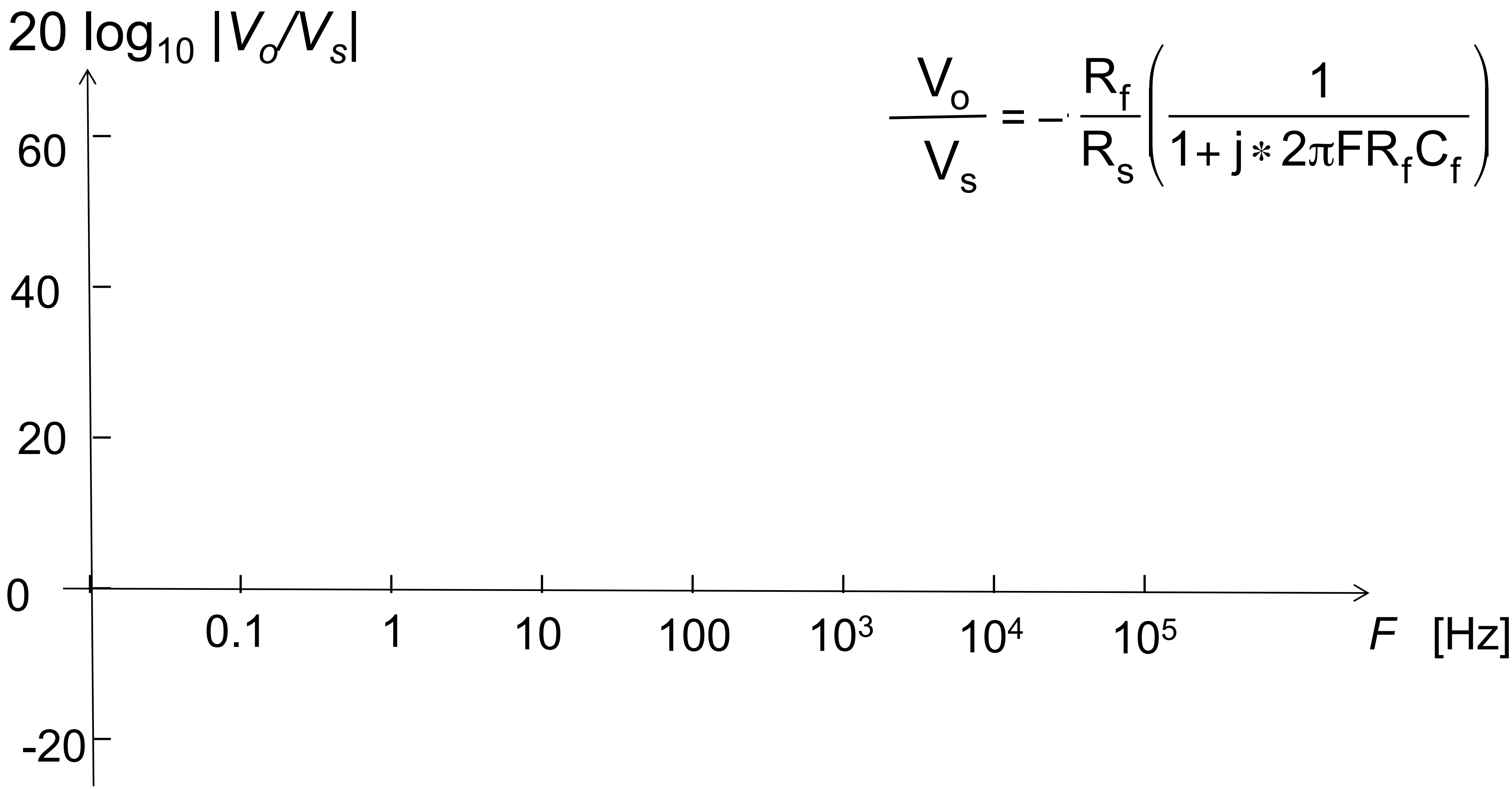
$$\frac{V_o}{V_s} = -\frac{R_f}{R_s}\left(\frac{1}{1 + j * 2\pi F R_f C_f}\right)$$



R_s = 1 kΩ, R_f = 100 kΩ, C_f = 160 nF

Sketching the Bode Plot: high frequency asymptote

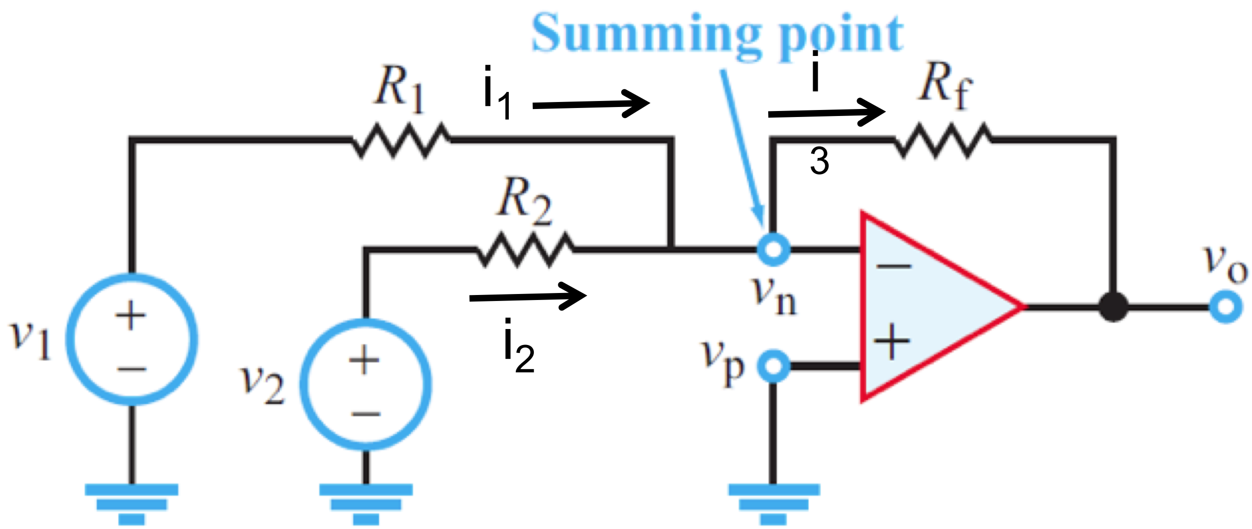
$$\frac{V_o}{V_s} = -\frac{R_f}{R_s}\left(\frac{1}{1 + j * 2\pi F R_f C_f}\right)$$



R_s = 1 kΩ, R_f = 100 kΩ, C_f = 160 nF $\qquad F_c = 1/(2\pi R_f C_f)$ = 10 Hz

More Examples

Summing Amplifier



- $i_p = i_n = 0$
- $v_n = v_p = 0$

KCL at the “summing point” (or the “summing node”):

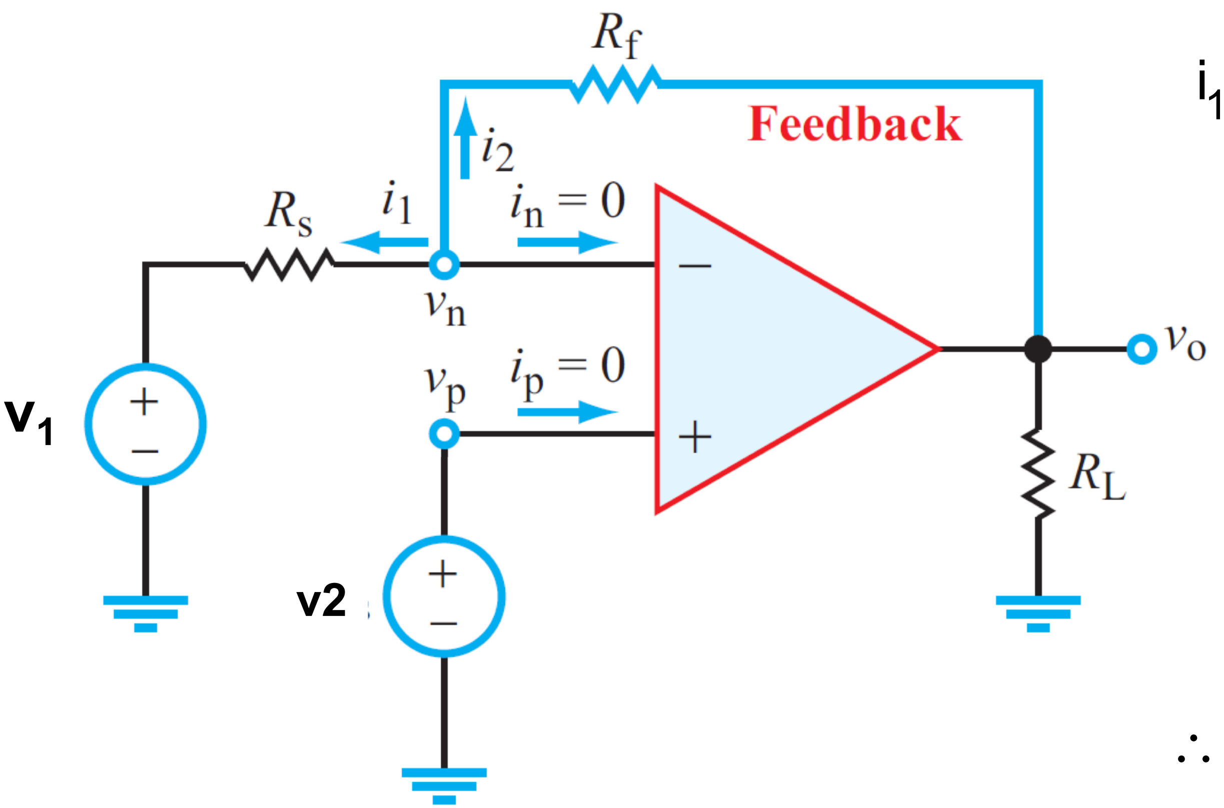
$$i_1 + i_2 = i_3 \quad \text{so} \quad \frac{v_1}{R_1} + \frac{v_2}{R_2} = -\frac{v_o}{R}$$

Output voltage is a scaled sum of the input voltages:

$$v_o = -\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2\right)$$

A Subtracting (Difference) Amplifier?

- Take an inverting amplifier and put a 2nd voltage on the other input?



$$i_1 + i_2 = 0 \quad \text{so} \quad \frac{v_n - v_1}{R_s} + \frac{v_n - v_o}{R_f} = 0$$

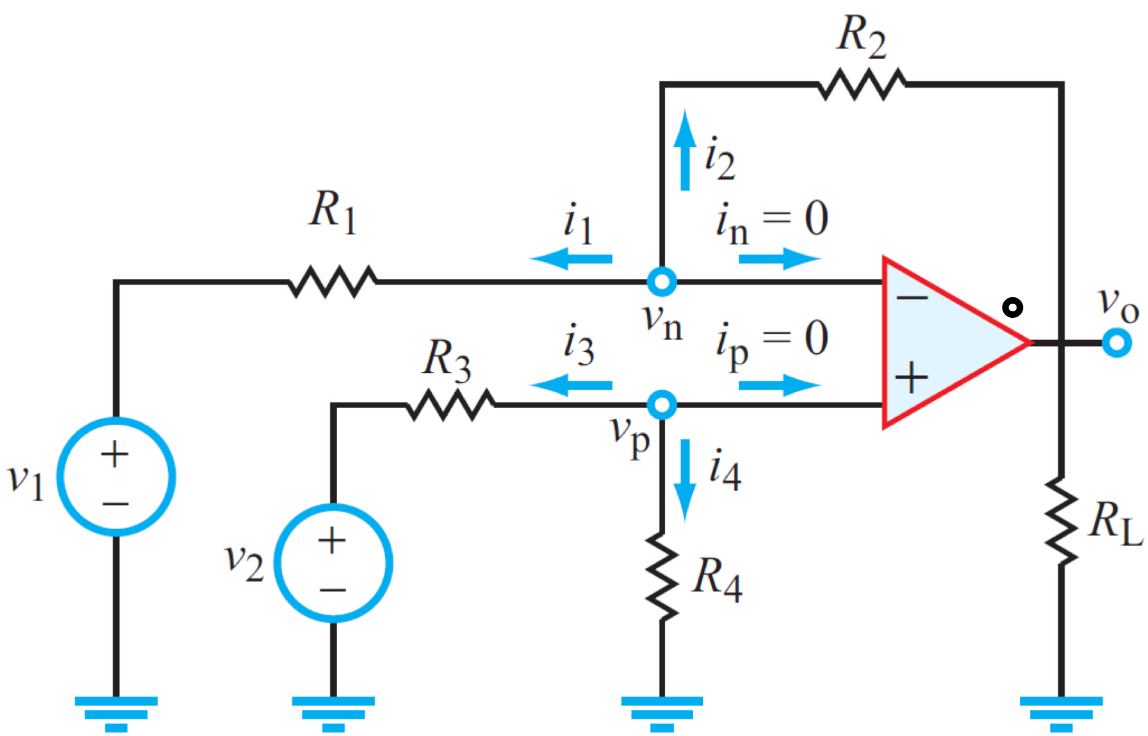
$$v_n = v_2 \quad \text{so} \quad \frac{v_2 - v_1}{R_s} = \frac{v_o - v_2}{R_f}$$

$$\therefore \frac{v_o}{R_f} = \frac{v_2 - v_1}{R_s} + \frac{v_2}{R_f}$$

$$\therefore v_o = -v_1 \frac{R_f}{R_s} + v_2 \frac{R_f + R_s}{R_s}$$

- Not quite what we wanted. We'd like $v_o \propto (v_1 - v_2)$.

Differential Amplifier 1.0



$$\frac{v_1 - v_n}{R_1} = \frac{v_n - v_o}{R_2}$$

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

$$\therefore \frac{v_o}{R_2} = -\frac{v_1}{R_1} + \frac{v_2}{R_1}\left(\frac{R_4}{R_3 + R_4} + \frac{R_1}{R_2}\frac{R_4}{R_3 + R_4}\right)$$

But if $R_3 = R_1$ and $R_4 = R_2$

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