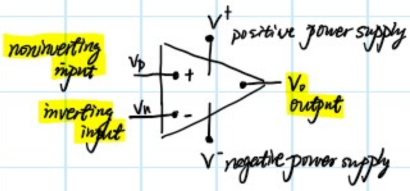
5.1-4

Friday, February 22, 2019 2:31 PM

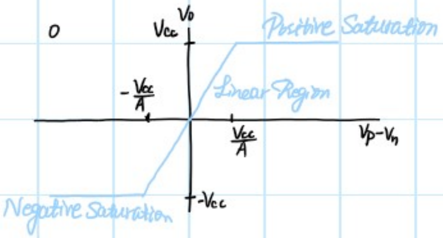
- Op-amp (operational amplifier)
  - o op-amp is a voltage amplifier with high gain
  - o op-amp $\begin{cases} \text{Saturation} & \text{A/D converters, Comparator} \\ \text{Linear} \end{cases}$
  - o



■ The output voltage of an op-amp can't be arbitrarily high

Limit: Power supply. (Energy Conservation)

o



$$V_o = \begin{cases} -V_{cc} & A(V_p - V_n) < -V_{cc} \\ A(V_p - V_n) & -V_{cc} \le A(V_p - V_n) \le V_{cc} \\ V_{cc} & A(V_p - V_n) > +V_{cc} \end{cases}$$

o In a ideal op amp, the gain A is infinite, in a pratical op amp

$A \geq 10000$

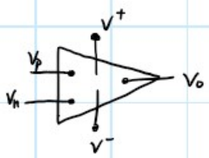
$\therefore$ o $\boxed{V_p = V_n}$ Voltage constrain

e.g. Consider an op amp with $V^+ = 12V$, $V^- = -12V$, $A = 2\times10^6$

(a) If $V_p = 0.1$, $V_n = 0V$, calculate V_o.

(b) What's the max V_p in linear region?

(a) $A \cdot (V_p - V_n) = 2\times10^5 > 12V$



$\therefore$ 12V

(b) $AV_p < 12V$

$V_p < 60mV$

$V_p < 60\,mV$

- Use negative feedback to achieve linear operation.
  - first assume linear, then check if it stands.

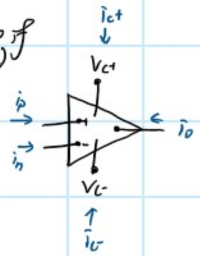
If $v_p - v_n$ is too positive, $v_o \uparrow$, $v_n \uparrow$, $(v_p - v_n) \downarrow$

If $v_p - v_n$ too negative, $v_o \downarrow$, $v_n \downarrow$, $(v_p - v_n) \uparrow$

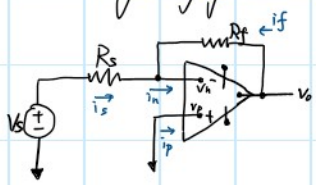
- $\boxed{i_p = i_n = 0}$ (Input $R \to \infty$ if ideal)

$i_o = -(i_{c+} + i_{c-})$

$i_p + i_n + i_{c+} + i_{c-} + i_o = 0$



- **The inverting-Amplifier Circuit**



$\because V_p = 0 \quad \therefore V_n = 0$

$i_n = i_f + i_s = 0, \quad i_s = \frac{V_s}{R_s}, \quad i_f = \frac{V_o}{R_f} \quad A = \frac{V_o}{V_p - V_n}$

$\Rightarrow V_o = -\frac{R_f}{R_s} \cdot V_s \qquad A = \frac{V_o}{V_s} = -\frac{R_f}{R_s}$

$= A(V_p - V_n)$

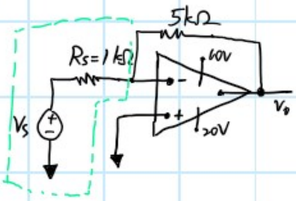
➡ The sign of the output voltage is inverted, and the magnitude is scale by $\frac{R_f}{R_s}$

e.g. find the range of V_s without saturating the inverting amp

$-20 \le -\frac{R_f}{R_s} \cdot V_s \le 10$

$-20 \le -5V_s \le 10$

$-2 \le V_s \le 4$



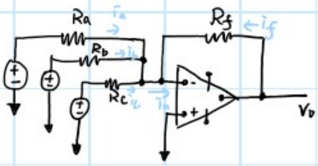
Sometimes need to do source transformation to do this.

- The summing-amplifier circuit

$i_a + i_b + i_c + i_f - i_n = 0$

- The summing-amplifier circuit

$i_a + i_b + i_c + i_f = i_n = 0$



$V_n = V_p = 0$

$\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} + \frac{V_o}{R_f} = 0$

$\Rightarrow$ $V_o = -R_f\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c}\right)$ $\Rightarrow$ Inverting summing-amplifier equation

o if $R_a = R_b = R_c = R_s \Rightarrow$

$V_o = -\frac{R_f}{R_s}(V_a + V_b + V_c)$

e.g. design an opamp that Va, Vb, Vc, Vd are the 1, 2, 3, 4 th digit below decimal pts of Vo. e.g. $V_a = 1$, $V_b = 2$, $V_c = 3$, $V_d = 4$. $V_o = 0.1234$.

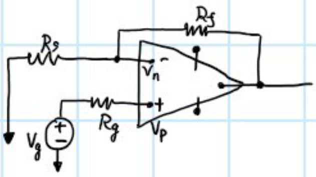
$V_o = -R_f\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} + \frac{V_d}{R_d}\right)$

$R_f : R_a : R_b : R_c : R_d$

$= 1 : 10 : 100 : 1000 : 10000$

To invert the sign, cascade with an inverted amplifier with $R_s = R_f$.

- Non-inverting Amplifier Circuit



$i_p = i_n = 0$ (consider as open circuit)

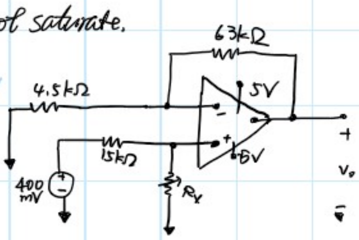
$V_n = V_p = V_g$

$\boxed{V_o = \frac{R_s + R_f}{R_s} V_g}$ $V_n = V_o \cdot \frac{R_s}{R_s + R_f}$

e.g. assume the op-amp ideal

(a) find output voltage when $R_x = 60k\Omega$

(b) Find max of R_x if not saturate.



(a) $V_p = \frac{R_x}{R_x + 15k} \cdot 0.4V = 0.32V$

$V_o = \frac{63k + 4.5k}{4.5k} \cdot 0.32V$

$= 4.8V$

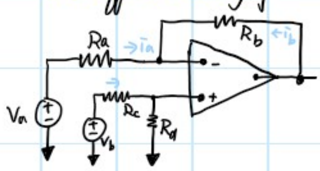
(b) $V_p = \frac{R_x}{R_x + 15k} \cdot 0.4V$

$V_0 = \frac{63k+4.5k}{4.5k} \cdot 0.4V \cdot \frac{R_x}{R_x+15k} \le 5$

$R_x \le 0.83(R_x+15k)$

$R_{x\,(max)} \le 75\,k\Omega$

- The Difference-Amplifier Circuit



$i_n = i_a + i_b = 0$

$\frac{V_a - V_n}{R_a} + \frac{V_0 - V_n}{R_b} = 0 \quad \cdots ①$

$V_p = \frac{R_d}{R_c + R_d} V_b = V_n \quad \cdots ②$

$① \quad \frac{V_0}{R_b} = V_n\left(\frac{1}{R_a} + \frac{1}{R_b}\right) - \frac{V_a}{R_a}$

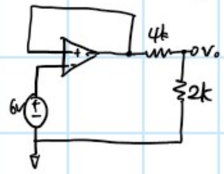
Difference amplifier equation ①② $\boxed{V_0 = \frac{R_d(R_a+R_b)}{R_a(R_c+R_d)} \cdot V_b - \frac{R_b}{R_a} V_a}$

∘ If we want $\frac{R_d}{R_a} \cdot \frac{(R_a+R_b)}{(R_c+R_d)} = \frac{R_b}{R_a}$

$V_0 = \frac{R_b}{R_a} \cdot \left(1+\frac{R_a}{R_b}\right) \frac{1}{1+\frac{R_c}{R_d}} V_b - \frac{R_b}{R_a} \cdot V_a$

⇒ Set $\frac{R_a}{R_b} = \frac{R_c}{R_d}$, then $V_0 = \frac{R_b}{R_a}(V_b - V_a)$

e.g. Power absorbed by the 4 kΩ?



$V_p = V_n = 6V$

∴ 6V, 4k, 2k form a circuit.

$\frac{6 - V_0}{4k} = \frac{V_0}{2k}$

$\therefore V_0 = 2V$

$P = V^2/R = \frac{4^2}{4\Omega} = 4mW.$

Prob

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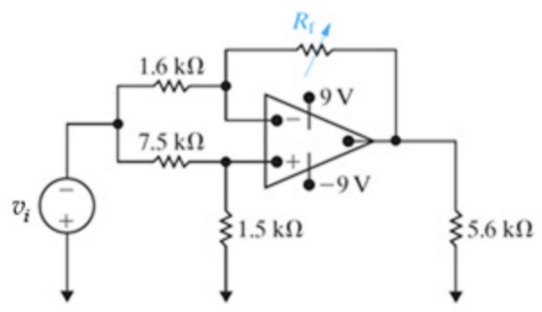
Review | Constants

The resistor R_f in the circuit in the figure is adjusted until the ideal op amp saturates. (Figure 1)



Specify R_f, given that v_i = 15 V .

Express your answer with the appropriate units.

R_f = 1.47 kΩ

Submit Previous Answers

✔ **Correct**

$V_o = 9V.$ $\quad V_p = V_n$

$$\frac{V_p}{1.5k} + \frac{V_p-(-15V)}{7.5k} = 0$$

$$5V_p + V_p + 15 = 0$$
$$V_p = -2.5V$$

$\therefore V_n = -2.5V$

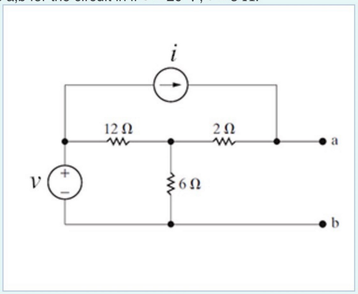
$$\therefore \frac{V_n-(-15V)}{1.6k} + \frac{V_n - V_o}{R_f} = 0$$

$$\frac{-2.5+15}{1.6} = \frac{9+2.5}{R_f}$$

$R_f = 1.472\ k\Omega$

Constants

Find the Norton equivalent with respect to the terminals a,b for the circuit in if $v = 20\ \mathrm{V}$, $i = 5\ \mathrm{A}$.



Approach I.

Mesh Current ⇒ i_{sc}

Deactivate all independent sources ⇒ R_{th}

$i_{sc} \cdot R_{th} = V_{oc}$

Approach II.

$Y \to \pi$

⇒

Use $\frac{V+Ri}{R} = I_{sc}$