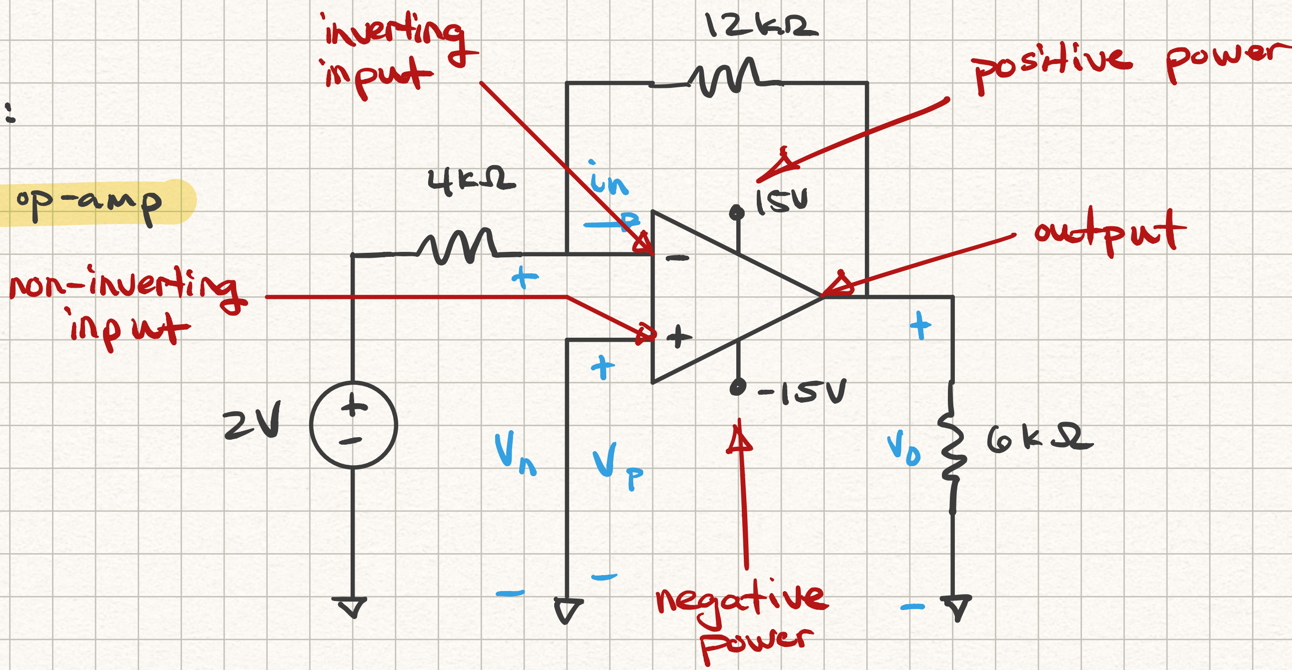
ENGR 221 HW 5, Due: 6/2/20, Sean Lai

CH 5: 1, 6, 14, 15, 42, 48

5.1:

Given:

Ideal op-amp



Find: a) Label 5 op amp terminals
b) what op amp constraint determines i_n? what value?
c) " " " " " $V_p - V_n$? what value?
d) Calculate V_o

Solution:

a) See diagram

b) High input impedance, $i_n = 0$

c) Virtual short, $V_p - V_n = 0$

d) inverting amplifier

$$\rightarrow \quad V_o = -V_{in}\left(\frac{R_f}{R_1}\right), \quad R_f = 12k\Omega, \; R_1 = 4k\Omega$$

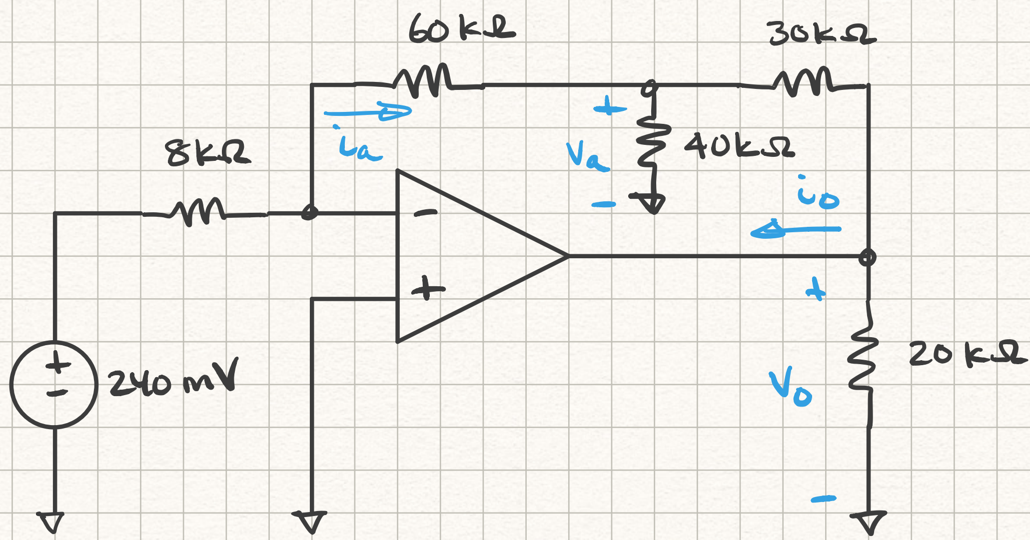
$$\therefore \boxed{V_o = 6V}$$

5.6:

Given:

Ideal op amp:

15V rails



Find: a) i_a
b) v_a
c) v_o
d) i_o

Solution:

a) $i_n = 0 \rightarrow i_a = \frac{0.240}{8000} = 3 \cdot 10^{-5}$ A

$\therefore$ $\boxed{i_a = 30\mu A}$

b) $v_n = v_p = 0 \rightarrow v_a - 0 = -i_a(60k)$

$\boxed{v_a = -1.8V}$

c) $\frac{v_a - v_o}{30k} = i_a - \frac{v_a}{40k}$

$v_o = -30k\left(i_a - \frac{v_a}{40k}\right) + v_a$

$\boxed{v_o = -4.05V}$

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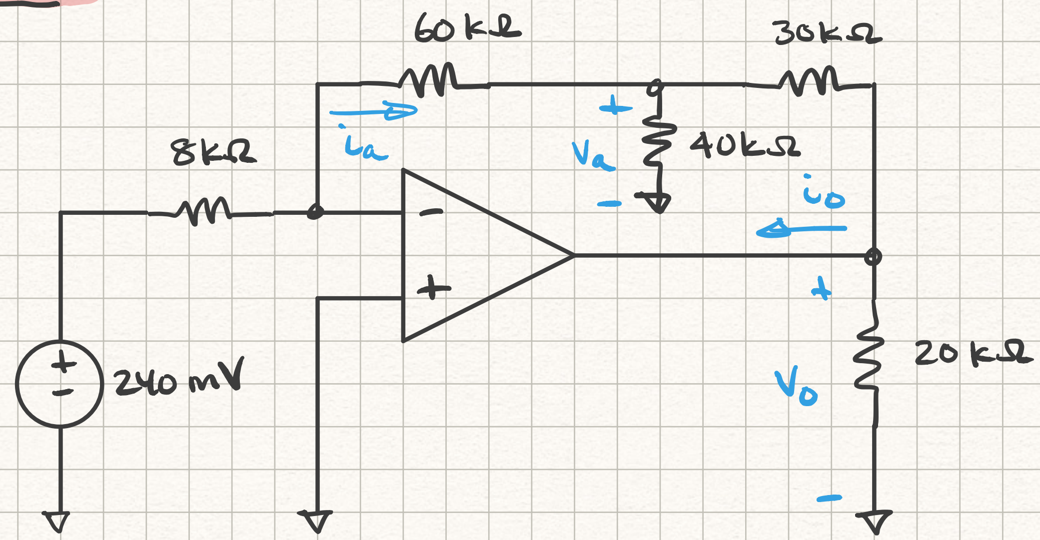
5.6 CONTINUED

d)



$$i_o + \frac{V_o}{20k} + \frac{V_o - V_a}{30k} = 0$$

$$i_o = -\frac{-4.05}{20k} - \frac{-4.05 - -1.8}{30k}$$

$$i_o = 2.775 \cdot 10^{-4}\ A$$

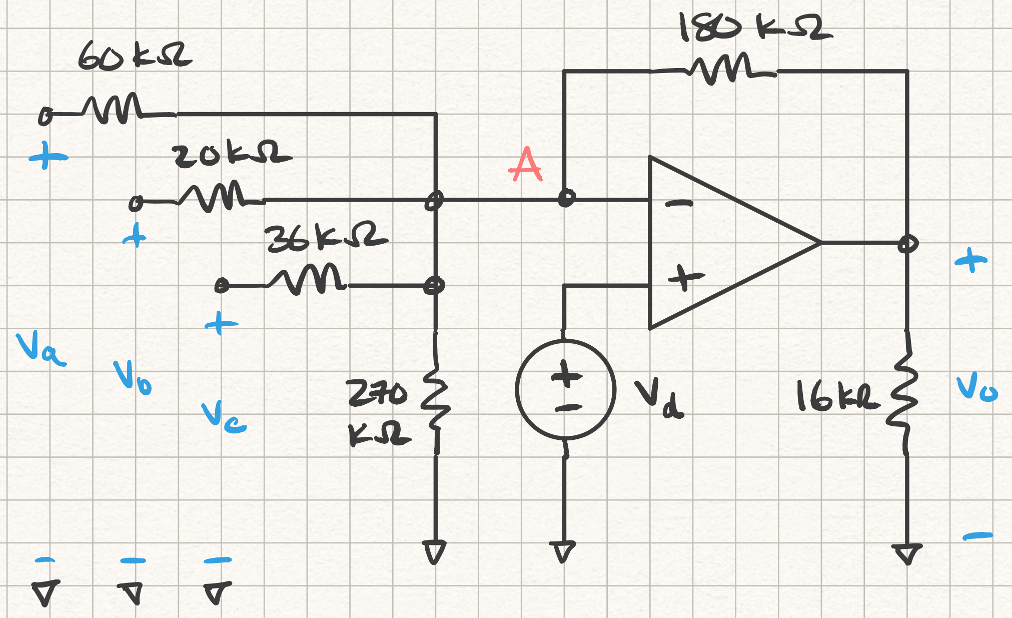
$$\boxed{i_o = 277.5\,\mu A}$$

5.14:

Given:

ideal op amp

±10V rails



Find: a) Find V_o for $V_a = 3V$, $V_b = 9V$, $V_c = 5V$, $V_d = 6V$

b) For $V_a = 3V$, $V_b = 9V$, $V_d = 6V$,
specify range for V_c for linear region (no saturation)

Solution:

a) At A, $v = V_d$.

$$\rightarrow \frac{V_d - V_a}{60k} + \frac{V_d - V_b}{20k} + \frac{V_d - V_c}{36k} + \frac{V_d}{270k} + \frac{V_d - V_o}{180k} = 0$$

$$\rightarrow V_o = 180k\left[\frac{V_d - V_a}{60k} + \frac{V_d - V_b}{20k} + \frac{V_d - V_c}{36k} + \frac{V_d}{270k} + \frac{V_d}{180k}\right]$$

$$\boxed{V_o = -3V}$$

b) $$V_o = 180k\left[\frac{V_d - V_a}{60k} + \frac{V_d - V_b}{20k} + \frac{V_d - V_c}{36k} + \frac{V_d}{270k} + \frac{V_d}{180k}\right]$$

$$V_o = 180k\left[\frac{V_d - V_a}{60k} + \frac{V_d - V_b}{20k} + \frac{V_d}{36k} + \frac{V_d}{270k} + \frac{V_d}{180k}\right] - 5V_c$$

$$V_o = 22V - 5V_c$$

For $V_o = +10V \rightarrow V_c = 2.4V$
$V_o = -10V \rightarrow V_c = 6.4V$

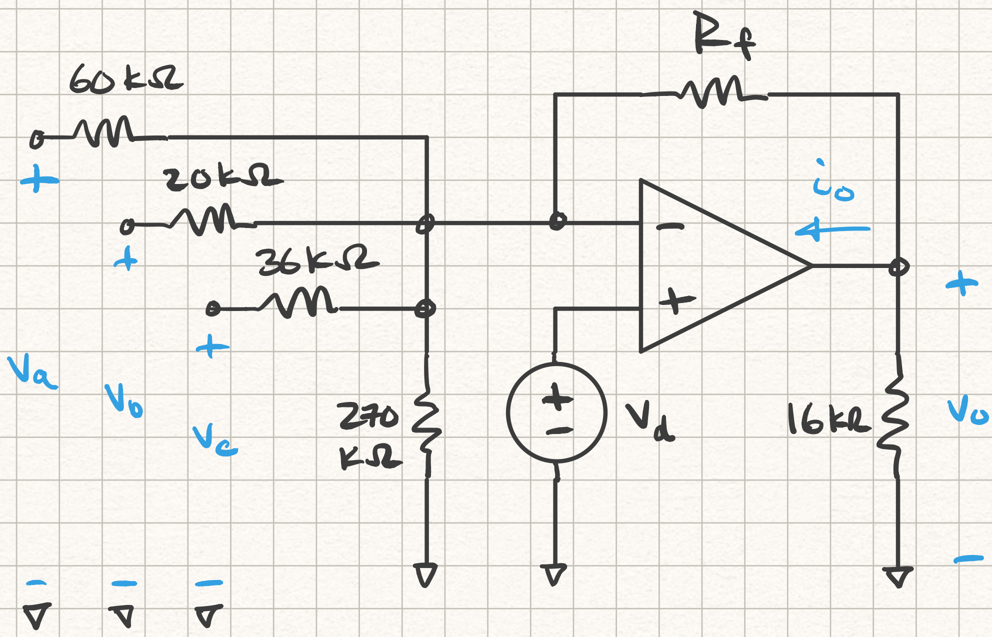
$$\rightarrow \boxed{2.4V \le V_c \le 6.4V}$$

5.15:

Given:

ideal op amp

$\pm 10V$ rails



$$V_a = 3V,\ V_b = 9V,\ V_c = 5V,\ V_d = 6V$$

Find: a) what R_f will cause saturation

b) With R_f value from a), find i_o (μA)

Solution:

$$\frac{V_d - V_a}{60k} + \frac{V_d - V_b}{20k} + \frac{V_d - V_c}{36k} + \frac{V_d}{270k} + \frac{V_d - V_o}{R_f} = 0$$

$$R_f \underbrace{\left[\frac{V_d - V_a}{60k} + \frac{V_d - V_b}{20k} + \frac{V_d - V_c}{36k} + \frac{V_d}{270k} \right]}_{-50\mu A} + V_d = V_o$$

for $V_o = +10V$, $\quad 10V = 6V + R_f(-50\mu A)$

$R_f = -80k \rightarrow$ neg. resistance ✗

for $V_o = -10V$, $\quad -10V = 6V + R_f(-50\mu A)$

a) $\rightarrow$ $\boxed{R_f = 320k\Omega}$

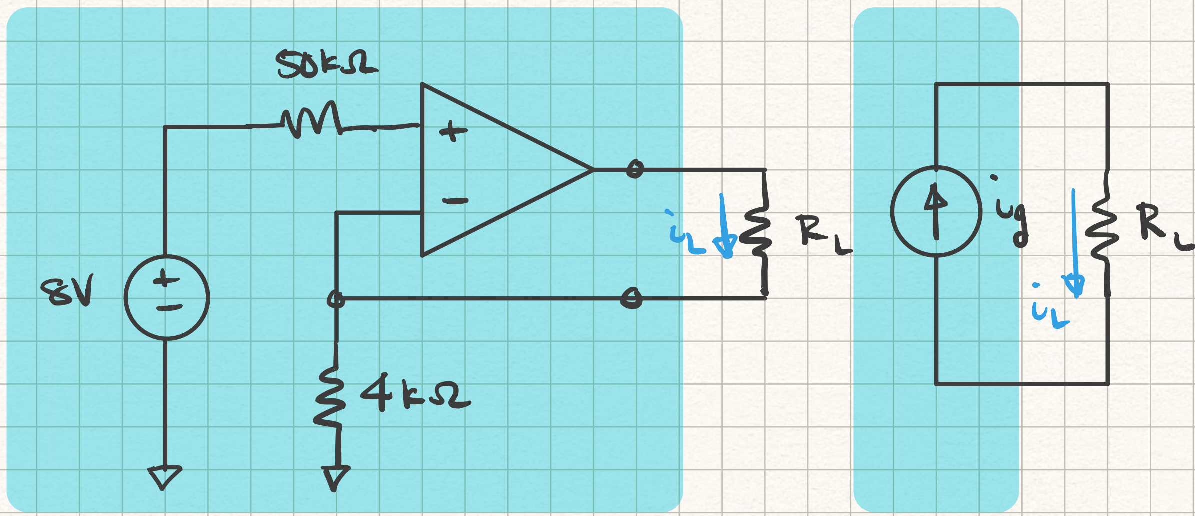
b) $\dfrac{V_o}{16k} + i_o + \dfrac{V_o - V_d}{R_f} = 0$

$\rightarrow$ $\boxed{i_o = 675\ \mu A}$

5.42:

Given:

±20V rails



Find:
a) Find i_L for $R_L = 4k\Omega$
b) Find max R_L for which i_L has value from a)
c) For $R_L = 16k\Omega$, $i_n = i_p \approx 0$, explain circuit operation
d) sketch i_L vs. R_L for $0 \le R_L \le 16k\Omega$

Solution:

a) for $i_p = 0$, $V_p = 8V = V_n$

$$\rightarrow \frac{V_n}{4000} + -i_L = 0$$

$$\therefore \boxed{i_L = 2mA}$$

b) For $V_o \pm 20V$, $V_o = i_L (R_L + 4k\Omega)$

$R_L = \frac{V_o}{i_L} - 4k\Omega$, let $V_o = +20V$

$$\therefore \boxed{R_{L\,max} = 6k\Omega}$$

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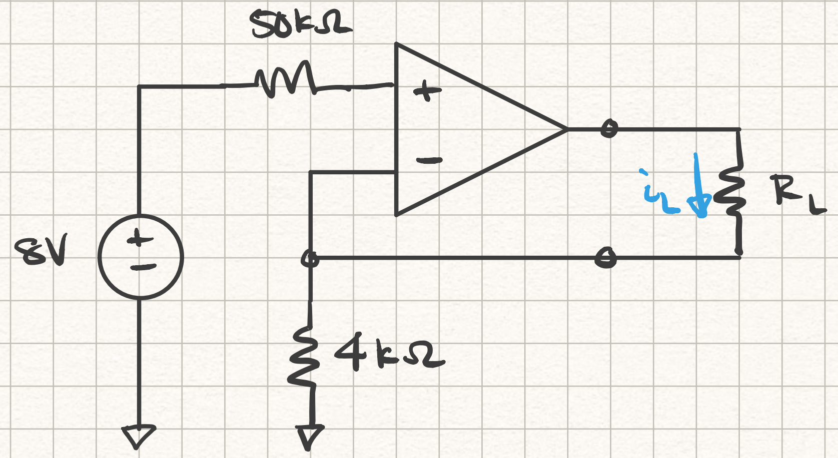
5.42 CONTINUED

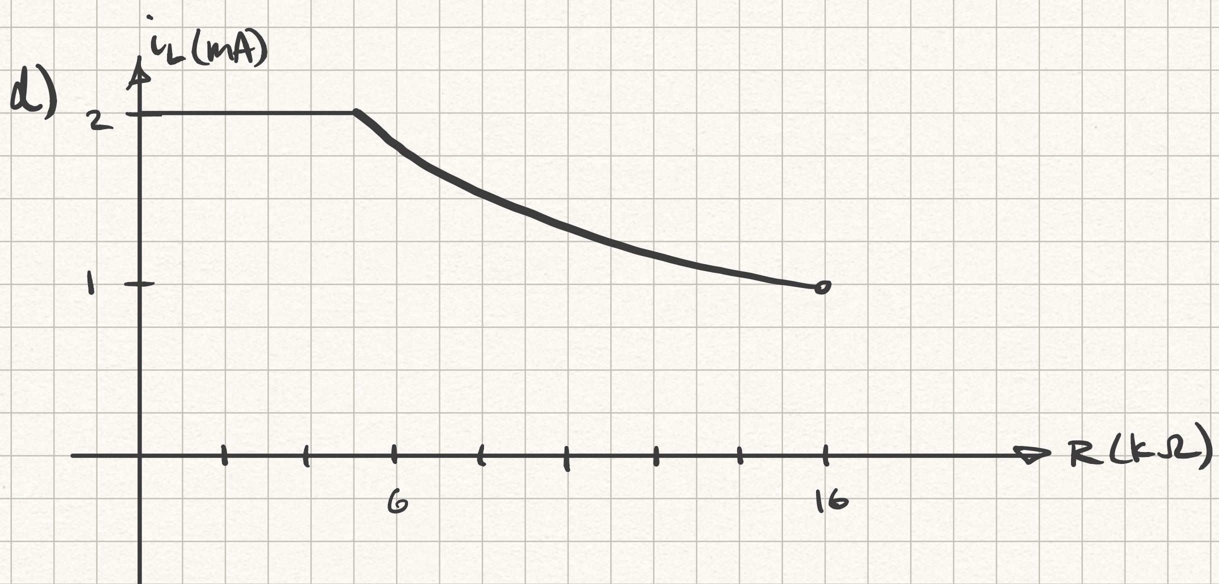
c) $R_L = 16\,k\Omega$, $i_p = i_n \approx 0$



from b), for $R_L > 6\,k\Omega$, op amp is saturated, and $V_o = +20\,V$.

So, for $R_L = 16\,k\Omega$, $i_L = \dfrac{20V}{16k + 4k} = 1\,mA$

d)

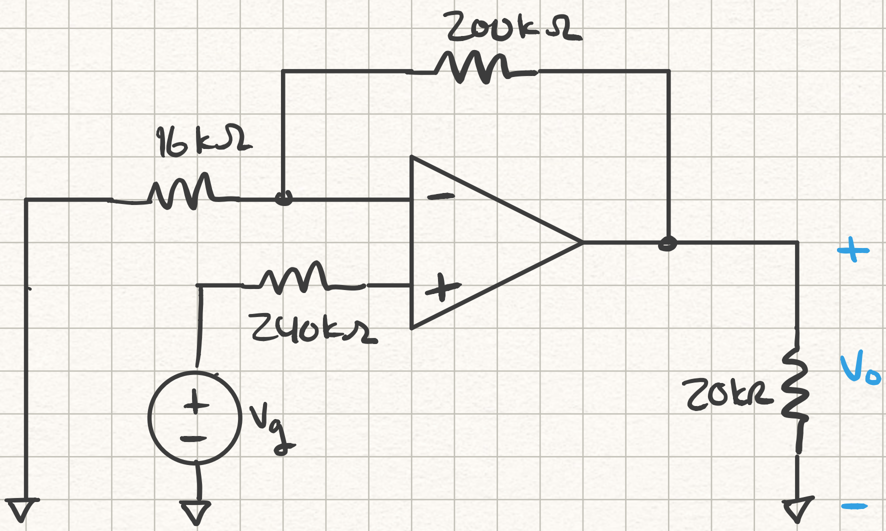


$i_L = \dfrac{V_o}{R_L + 4k}$ in saturation region

$\therefore \boxed{i_L \propto \dfrac{1}{R_L}}$

5.48:

Given:

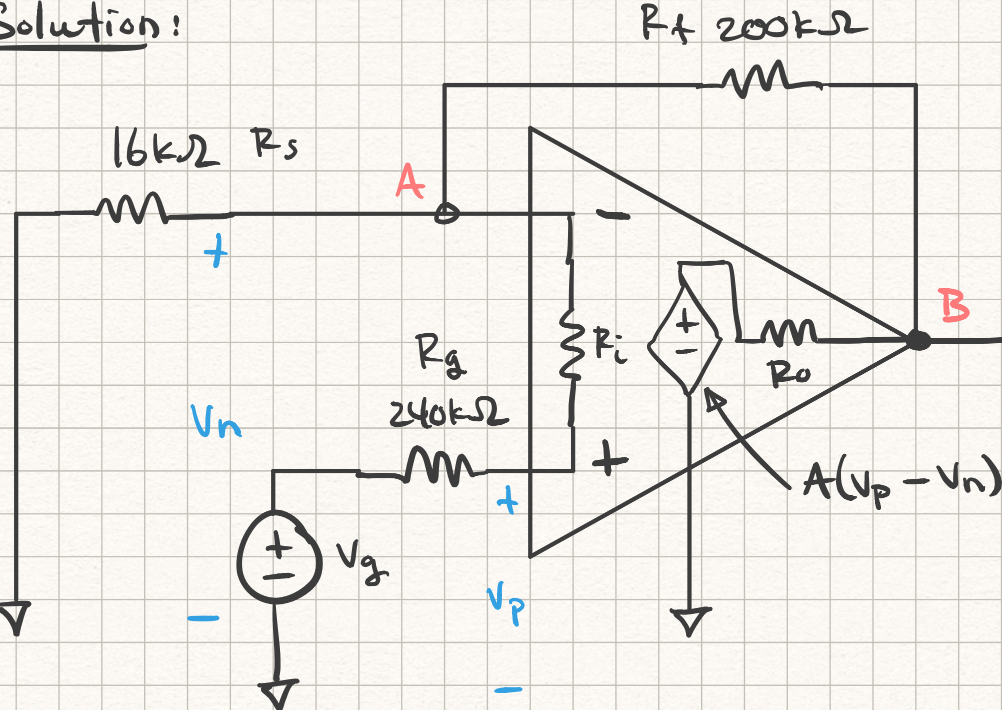


±15V rails
operating in linear region

Find:
a) voltage gain (V_o/V_g)
b) V_n, V_p in mV when $V_g = 1V$
c) $V_p - V_n$ in μV when $V_g = 1V$
d) current drain at V_g when $V_g = 1V$, in pA (10^{-12}A)
e) repeat a) − d) assuming ideal op amp

Solution:

$R_i = 560k\Omega$
$R_o = 8k\Omega$
$A = 50k$
± 15 rails



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5.48 CONTINUED:

a) **A:** $$\frac{V_n}{R_s} + \frac{V_n - V_g}{R_g + R_i} + \frac{V_n - V_o}{R_f} = 0$$

B: $$\frac{V_o}{R_L} + \frac{V_o - V_n}{R_f} + \frac{V_o - A(V_p - V_n)}{R_o}$$

also, $$V_p = \underbrace{(V_n - V_g)\left(\frac{R_g}{R_g + R_i}\right)}_{\text{V divider}} + \underbrace{V_g}_{+\text{offset}}$$

into B: $$V_o\underbrace{\left(\frac{1}{R_L} + \frac{1}{R_f} + \frac{1}{R_o}\right)}_{c} + V_n\underbrace{\left(-\frac{1}{R_f} + \frac{A}{R_o}\right)}_{a} - \frac{A}{R_o} \cdot \left[(V_n - V_g)\underbrace{\left(\frac{R_g}{R_g + R_i}\right)}_{b} + V_g\right] = 0$$

$$\rightarrow cV_o + aV_n - \frac{A}{R_o} \cdot bV_n + \frac{A}{R_o} \cdot bV_g - \frac{A}{R_o}V_g = 0$$

$$V_o(c) + V_n\left(a - \frac{bA}{R_o}\right) + V_g\left(\frac{A}{R_o}(b-1)\right) = 0$$

where
$$a = 6.25$$
$$b = 0.3$$
$$c = 1.8 \cdot 10^{-4}$$

$$\rightarrow V_o(c) + 4.375\,V_n - 4.375\,V_g = 0$$

$$V_n = V_g - \frac{c}{4.375}V_o$$

$$V_n = V_g - 4.114 \cdot 10^{-5}\,V_o$$

into A: $$\frac{V_n}{R_s} + \frac{V_n - V_g}{R_g + R_i} + \frac{V_n - V_o}{R_f} = 0$$

$$V_n\underbrace{\left(\frac{1}{R_s} + \frac{1}{R_g + R_i} + \frac{1}{R_f}\right)}_{d} - V_g\left(\frac{1}{R_g + R_i}\right) - V_o\left(\frac{1}{R_f}\right) = 0$$

$$d = 6.875 \cdot 10^{-5}$$

CONTINUED →

5.48 CONTINUED:

$$d\left(V_g - 4.114\cdot10^{-5}V_o\right) - 1.25\cdot10^{-6}V_g - 5\cdot10^{-6}V_o = 0$$

$$6.75\cdot10^{-5}V_g = 5\cdot10^{-6}V_o$$

$$\rightarrow \boxed{\frac{V_o}{V_g} = 13.49}$$

b) For $V_g = 1V$, $V_o = 13.49V$

$$\rightarrow V_n = 1V - 4.114\cdot10^{-5}(13.49V)$$

$$\boxed{V_n = 999.445\ mV}$$

$$V_p = (V_n - V_g)\left(\frac{R_g}{R_g+R_i}\right) + V_g$$

$$V_p = (999.445 - 1000)(0.3) + 1$$

$$\boxed{V_p = 999.834\ mV}$$

c)

$$\boxed{V_p - V_n = 388.5\ \mu V}$$

d) $i_g = \dfrac{V_g - V_p}{R_g}$

$$\boxed{i_g = 691.67\ pA}$$