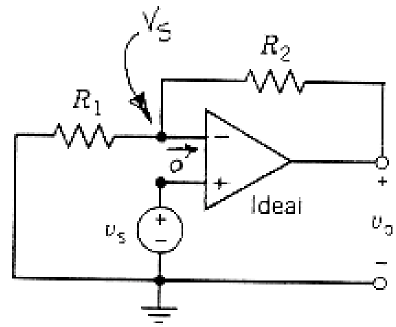
Chapter 6: The Operational Amplifier

Exercises

Ex. 6.4–1

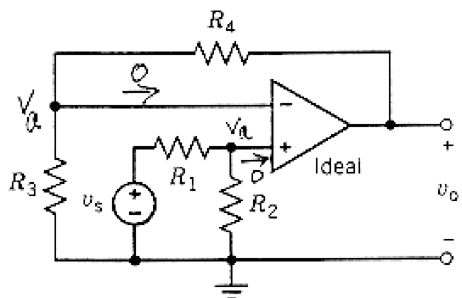
$$\frac{v_s}{R_1}+\frac{v_s-v_0}{R_2}+0 = 0$$

$$\frac{v_0}{v_s} = 1+\frac{R_2}{R_1}$$



Ex. 6.4-2

a)



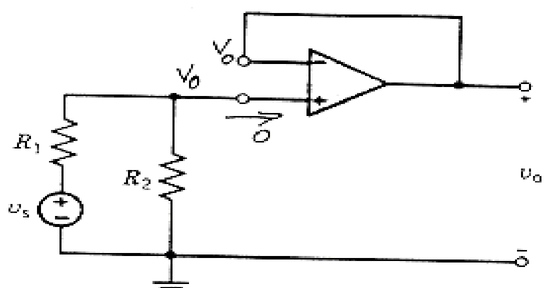
$$v_a = \frac{R_2}{R_1+R_2}v_s$$

$$\frac{v_a}{R_3}+\frac{v_a-v_0}{R_4}+0 = 0$$

$$\frac{v_0}{v_a} = 1+\frac{R_4}{R_3} \Rightarrow \frac{v_0}{v_s} = \left(\frac{R_2}{R_1+R_2}\right)\left(1+\frac{R_4}{R_3}\right)$$

b) When $R_2 >> R_1$ then $\frac{R_2}{R_1+R_2} \simeq \frac{R_2}{R_2} = 1$ and $\frac{v_0}{v_s} \simeq 1+\frac{R_4}{R_3}$

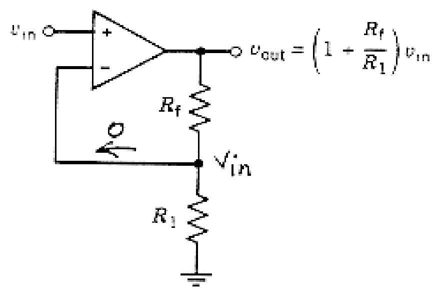
Ex. 6.5-1



$$\frac{v_0}{R_2}+\frac{v_0-v_s}{R_1}+0 = 0$$

$$\frac{v_0}{v_s} = \frac{R_2}{R_1+R_2}$$

Ex. 6.6–1



(b) Noninverting amplifier

$$\frac{v_{in}-v_{out}}{R_f}+\frac{v_{in}}{R_1}+0=0 \Rightarrow v_{out} = \left(1+\frac{R_f}{R_1}\right)v_{in}$$

when $R_f = 100k\Omega$ and $R_1 = 25k\Omega$ then

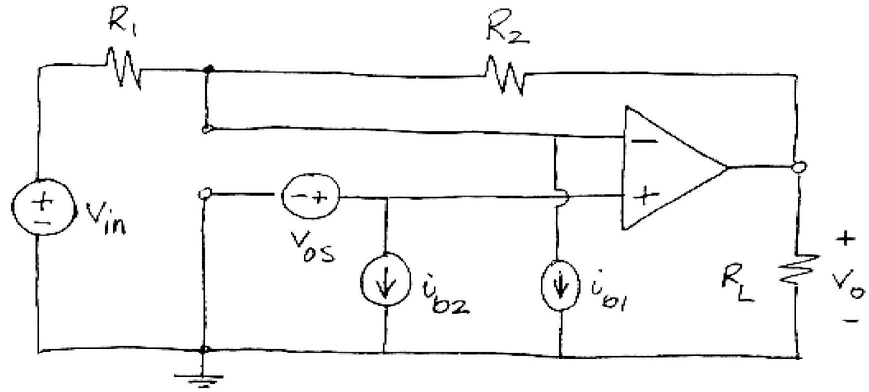
$$\frac{v_{out}}{v_{in}} = \left(1+\frac{100 \cdot 10^3}{25 \cdot 10^3}\right) = 5$$

Ex. 6.7-1 Analysis of the circuit in Section 6.7 showed that output offset voltage = 6 v_{os} + $(50.10^3)i_{b1}$

For a μA741 opamp, $|v_{os}| \leq$ 1mV and $|i_{b1}| \leq$ 80nA so

$|\text{output offset voltage}| = |6\ v_{os} + (50.10^3)i_{b1}| \leq 6\ (10^{-3})+(50.10^3)(80.10^{-9}) = 10\text{mV}$

Ex. 6.7-2



$$v_0 = -\frac{R_2}{R_1} v_{in} + \left(1+\frac{R_2}{R_1}\right) v_{os} + R_2 i_{b1}$$

When $R_2 = 10k\Omega$, $R_1 = 2k\Omega$, $|v_{os}| \le 5mV$ and $|i_{bl}| \le 500nA$ then

output offset voltage $\le 6\left(5.10^{-3}\right) + \left(10.10^{3}\right)\left(500.10^{-9}\right) \le 35.10^{-3} = 35mV$

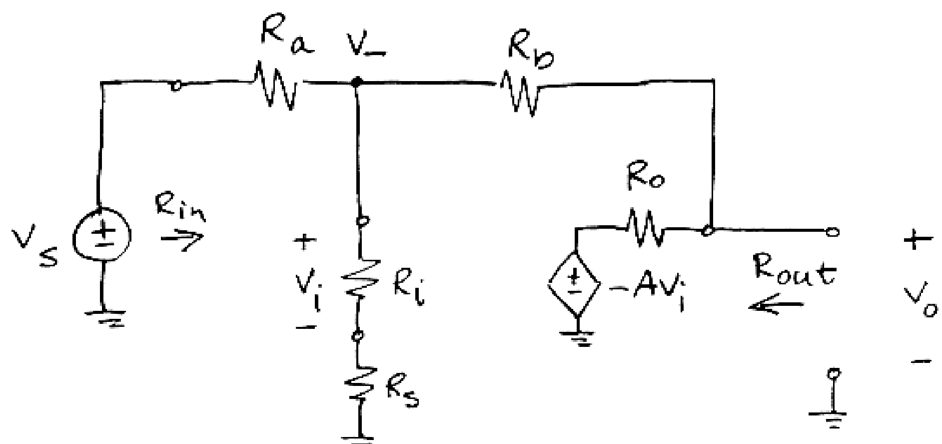
Ex. 6.7-3

Analysis of this circuit in Section 6.7 showed that output offset voltage = $6v_{os} + \left(50\times10^{3}\right) i_{b1}$

For a typical OPA1O1AM, $v_{os} = 0.1mV$ and $i_b = 0.012nA$ so

$$|\text{output offset voltage}| \le 6\left[0.1\times10^{-3}\right] + \left(50\times10^{3}\right)\left[0.012\times10^{-9}\right]$$
$$\le 0.6\times10^{-3} + 0.6\times10^{-6} \simeq 0.6\times10^{-3}$$
$$\le 0.6mV$$

Ex. 6.7-4



$$\frac{V_- - V_s}{R_a} + \frac{V_- - V_o}{R_b} + \frac{V_-}{R_i + R_s} = 0$$

$$\frac{V_0 - \left(-A\frac{R_i}{R_i+R_s}V_-\right)}{R_0} + \frac{V_0 - V_-}{R_b} = 0$$

After some algebra

$$A_v = \frac{V_0}{V_s} = \frac{R_0(R_i+R_s)+AR_iR_f}{(R_f+R_0)(R_i+R_s)+R_a(R_f+R_0+R_i+R_s)-AR_iR_a}$$

For the given values, $A_v = -2.00006$

Ex. 6.8-1

```
Spice deck
V1      1 0      200mV
V2      2 0      125mV
V3      3 0      250mV
R1      1 5      50k
R2      2 5      25k
R3      5 4      100k
XOA1    5 0 4    IDEAL_OP_AMP
R4      4 6      25k
R5      3 6      10k
R6      6 7      50k
R7      7 0      100k
XOA2    6 0 7    IDEAL_OP_AMP

.SUBCKT IDEAL_OP_AMP 1 2 3
E 3 0 1 2 -1G
.ENDS IDEAL_OP_AMP
.END

 NODE       VOLTAGE     NODE       VOLTAGE     NODE        VOLTAGE
(    1)        .2000   (    2)        .1250   (    3)         .2500
(    4)       -.9000   (    5)     900.0E-12  (    6)     -550.0E-12
(    7)        .5500
```

Ex. 6.8-2

```
Spice deck
V1    1 0         200mV
V2    2 0         125mV
V3    3 0         250mV
R1    1 5         25k
R2    2 5         50k
R3    5 4         100k
XOA1  5 0 4       TL501_OP_AMP
R4    4 6         25k
R5    3 6         10k
R6    6 7         50k
R7    7 0         100k
XOA2  6 0 7       TL501_OP_AMP


.SUBCKT  TL501_OP_AMP 1 2 5
IB1     1 0     .0175nA
IB2     2 0     .0425nA
VOS     3 2     .59mV
RI      1 3     1MEG
E       4 0 1 3 -105000
RO      4 5     250
.ENDS TL501_OP_AMP
.END

NODE        VOLTAGE     NODE       VOLTAGE     NODE        VOLTAGE
(    1)       .2000    (    2)        .1250   (    3)        .2500
(    4)      -.8958    (    5)     598.6E-06  (    6)     584.8E-06
(    7)       .5463    (XOA1.3)    590.0E-06  (XOA1.4)       -.9070
(XOA2.3)    590.0E-06  (XOA2.4)        .5504
```

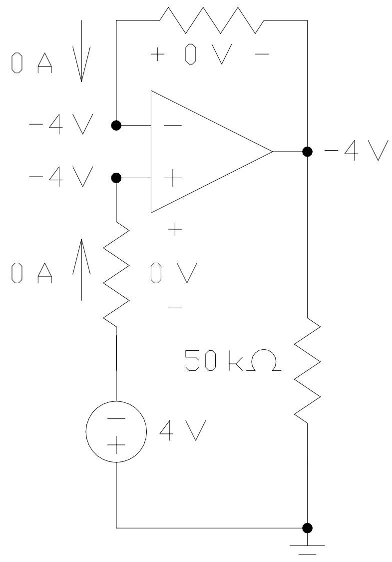
Ex. 6.8-3

```
Spice deck
V1    1 0         200mV
V2    2 0         125mV
V3    3 0         250mV
R1    1 5         5k
R2    2 5         2.5k
R3    5 4         10k
XOA1  5 0 4       UA741_OP_AMP
R4    4 6         2.5k
R5    3 6         1k
R6    6 7         5k
R7    7 0         10k
XOA2  6 0 7       UA741_OP_AMP

SUBCKT UA741_OP_AMP 1 2 5
IB1      1 0      70nA
IB2      2 0      90nA
VOS      3 2      1mV
RI      1 3      2MEG
E      4 0 1 3  -200000
RO       4 5      75
.ENDS  UA741_OP_AMP
.END

NODE        VOLTAGE      NODE       VOLTAGE      NODE       VOLTAGE
(    1)         .2000    (    2)         .1250   (    3)         .2500
(    4)        -.8958    (    5)         .0010   (    6)     997.2E-06
(    7)         .5429    (XOA1.3)         .0010  (XOA1.4)        -.9258
(XOA2.3)         .0010  (XOA2.4)         .5551
```

Problems

Section 6-4: The Ideal Operational Amplifier

P6.4-1



P6.4-2

KVL a1:

$$-12+3000i+0+2000i = 0$$

$$\Rightarrow i = \frac{12}{5000} = 2.4\text{mA}$$

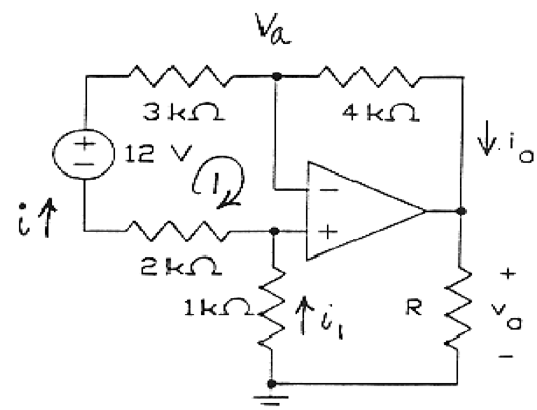
$$i_0 = i = 2.4\text{mA}$$

$$i_1 = i = 2.4\text{mA}$$

$$v_a = -i_1(1000)+0$$

$$= -2.4 \text{ V}$$

$$v_0 = v_a - i_0(4000) = -2.4-\left(2.4\times10^{-3}\right)(4000) = -12 \text{ V}$$



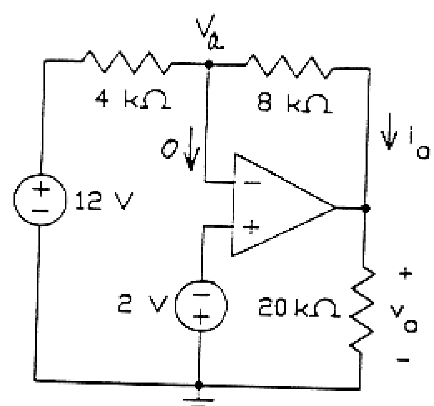
P6.4-3

$$v_a = -2\text{V}$$

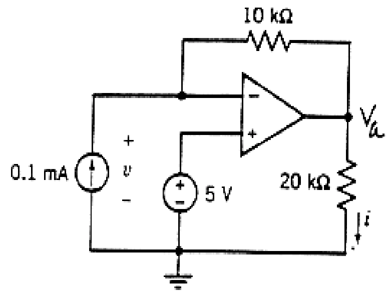
$$\frac{v_0-(-2)}{8000}+\frac{12-(-2)}{4000} = 0$$

$$\Rightarrow v_0 = -30 \text{ V}$$

$$i_0 = \frac{-2-v_0}{8000} = 3.5\text{mA}$$



P6.4-4



$$v = 5\text{ V}$$

$$-\left(\frac{v_a - 5}{10000}\right) - 0.1\times10^{-3} - 0 = 0$$

$$\Rightarrow v_a = 4\text{ V}$$

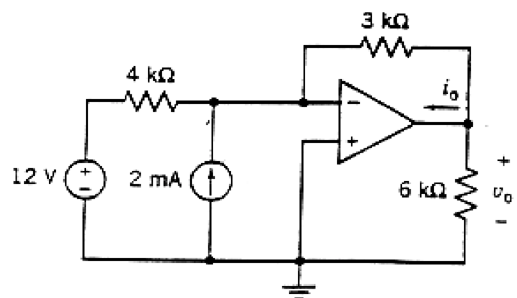
$$i = \frac{v_a}{20000} = \frac{1}{5}\text{mA}$$

P6.4-5

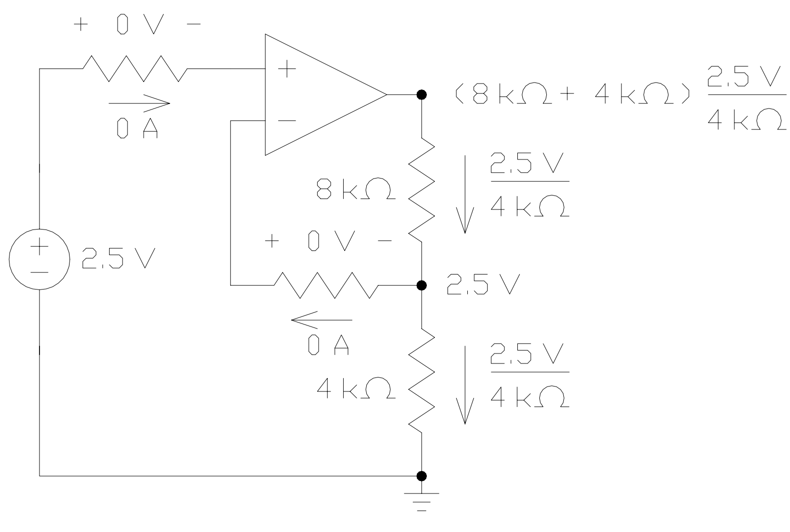
$$-\left(\frac{v_0 - 0}{3000}\right) - \left(\frac{12 - 0}{4000}\right) - 2\cdot10^{-3} = 0$$

$$\Rightarrow v_0 = -15\text{ V}$$

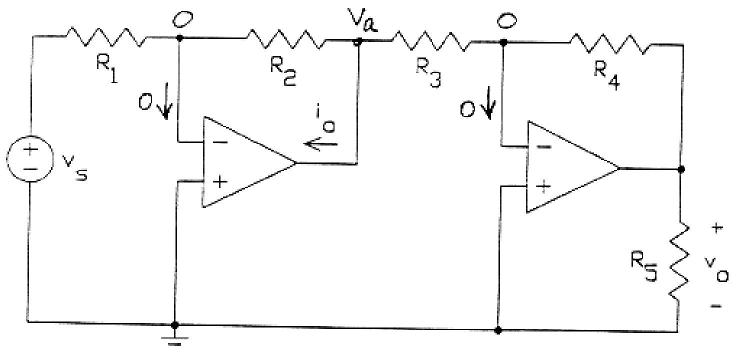
$$i_0 + \frac{v_0}{6000} + \frac{v_0}{3000} = 0 \Rightarrow i_0 = 7.5\text{mA}$$



P6.4-6



P6.4-7

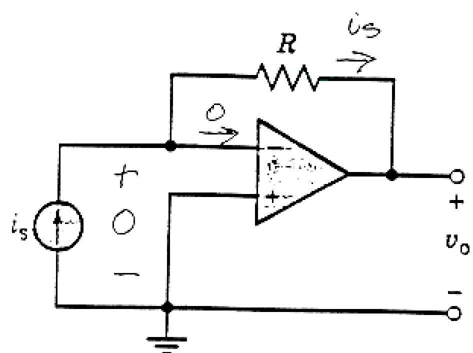


$$-\left(\frac{v_s-0}{R_1}\right)-\left(\frac{v_a-0}{R_2}\right)+0 = 0 \Rightarrow v_a = -\frac{R_2}{R_1}v_s$$

$$i_0 = \frac{0-v_a}{R_2}+\frac{0-v_a}{R_3} = \frac{R_2+R_3}{R_2R_3}v_a = -\left(\frac{R_2+R_3}{R_1R_3}\right)v_s$$

$$-\left(\frac{v_0-0}{R_4}\right)-\left(\frac{v_a-0}{R_3}\right)+0 = 0 \Rightarrow v_0 = -\frac{R_4}{R_3}v_a = \frac{R_2R_4}{R_1R_3}v_s$$

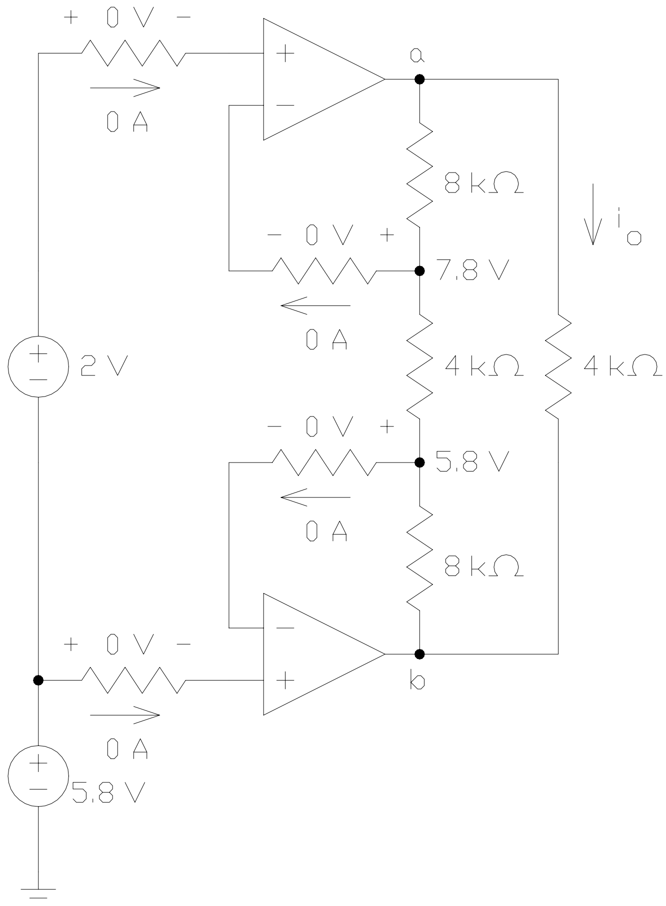
P6.4-8



$$v_0 = 0-Ri_s$$

$$\therefore \frac{v_0}{i_s} = -R$$

P6.4-9



P 6.4-10

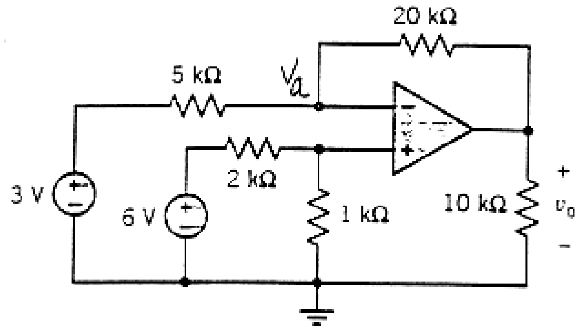
KCL at node a: $\dfrac{v_a-(-18)}{4000}+\dfrac{v_a}{8000}+0=0 \quad \Rightarrow \quad v_a=-12 \text{ V}$

The node voltages at the input nodes of ideal op amps are equal so $v_b = v_a$.

Voltage division: $v_o = \dfrac{8000}{4000+8000} v_b = -8 \text{ V}$

<u>Section 6-5:</u> Nodal Analysis of Circuits Containing Ideal Operational Amplifiers

P6.5-1



$$v_a = \frac{1000}{2000+1000}6 = 2 \text{ V}$$

$$-\left(\frac{v_0-2}{20000}\right)-\left(\frac{3-2}{5000}\right) = 0$$

$$\Rightarrow v_0 = -2 \text{ V}$$

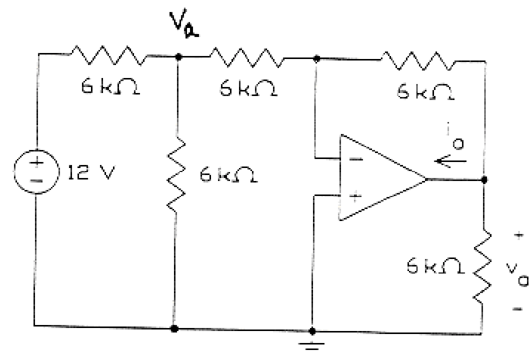
P6.5-2

KCL at node b: $\frac{v_b-2}{20e3}+\frac{v_b}{40e3}+\frac{v_b+5}{40e3}=0 \quad \Rightarrow \quad v_b=-\frac{1}{4}$ V

$v_e = v_b = -\frac{1}{4}$ V because the node voltages at the input nodes of an ideal op amp are equal

KCL at node e: $\frac{v_e}{1000}+\frac{v_d+v_e}{40e3}=0 \quad \Rightarrow \quad v_d = 10\,v_e = -\frac{10}{4}$ V

P6.5-3

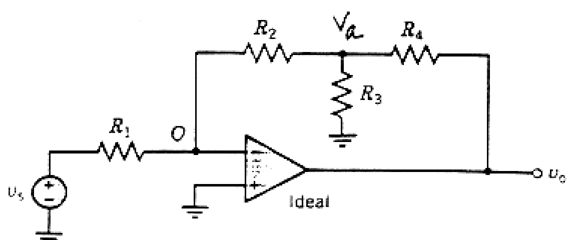


$$0 = \frac{v_a-12}{6000}+\frac{v_a}{6000}+\frac{v_a-0}{6000} \Rightarrow v_a = 4 \text{ V}$$

$$-\left(\frac{v_a-0}{6000}\right)+0+\left(\frac{0-v_0}{6000}\right) = 0 \Rightarrow v_0 = -v_a = -4\text{V}$$

$$i_0 - \left(\frac{0-v_0}{6000}\right)+\frac{v_0}{6000} = 0 \Rightarrow i_0 = -\frac{v_0}{3000} = 1.33\text{mA}$$

P6.5-4



$$-\left(\frac{v_a-0}{R_2}\right)-\left(\frac{v_s-0}{R_1}\right) = 0$$

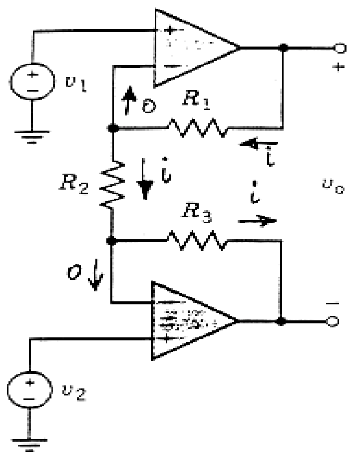
$$\Rightarrow v_a = -\frac{R_2}{R_1}v_s$$

$$\frac{v_a-v_0}{R_4}+\frac{v_a}{R_3}+\frac{v_a-0}{R_2} = 0 \Rightarrow v_0 = R_4\left(\frac{1}{R_4}+\frac{1}{R_3}+\frac{1}{R_2}\right)v_a = \frac{R_2R_3+R_2R_4+R_3R_4}{R_2R_3}v_a$$

$$= -\frac{R_2R_3+R_2R_4+R_3R_4}{R_1R_3}v_s$$

Plug in values $\Rightarrow$ yields $\frac{v_0}{v_s} = -200$

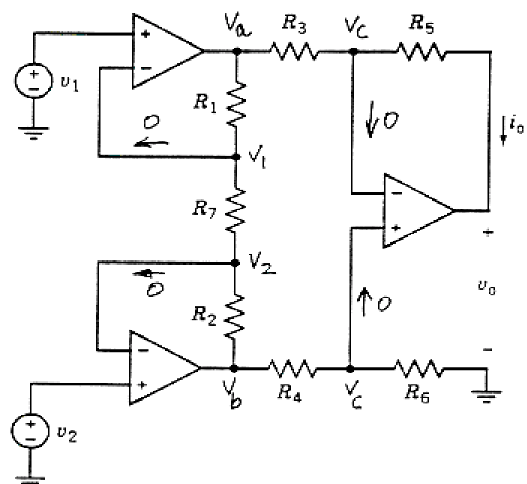
P6.5-5



$$i = \frac{v_1 - v_2}{R_2}$$

$$v_0 = (R_1 + R_2 + R_3)\, i = \frac{R_1 + R_2 + R_3}{R_2}(v_1 - v_2)$$

P6.5-6



$$\frac{v_1 - v_a}{R_1} + \frac{v_1 - v_2}{R_7} + 0 = 0 \;\Rightarrow\; v_a = \left(1 + \frac{R_1}{R_7}\right)v_1 - \frac{R_1}{R_7}v_2$$

$$\frac{v_2 - v_b}{R_2} - \frac{v_1 - v_2}{R_7} + 0 = 0 \;\Rightarrow v_b = \left(1 + \frac{R_2}{R_7}\right)v_2 - \frac{R_2}{R_7}v_1$$

$$-\left(\frac{v_b - v_c}{R_4}\right) + \frac{v_c - 0}{R_6} + 0 = 0 \;\Rightarrow\; v_c = \frac{R_6}{R_4 + R_6}v_b$$

$$-\left(\frac{v_a - v_c}{R_3}\right) + \left(\frac{v_c - v_0}{R_5}\right) + 0 = 0 \Rightarrow v_0 = -\frac{R_5}{R_3}v_a + \left(1 + \frac{R_5}{R_3}\right)v_c$$

$$v_0 = \left[\frac{R_5 R_1}{R_3 R_7} + \frac{R_6(R_3 + R_5)}{R_3(R_4 + R_6)}\left(1 + \frac{R_2}{R_7}\right)\right]v_2 - \left[\frac{R_5}{R_3}\left(1 + \frac{R_1}{R_7}\right) + \frac{R_6(R_3 + R_5)\,R_2}{R_3\,(R_4 + R_6)\,R_7}\right]v_1$$

$$i_0 = \frac{v_c - v_0}{R_5} = \cdots$$

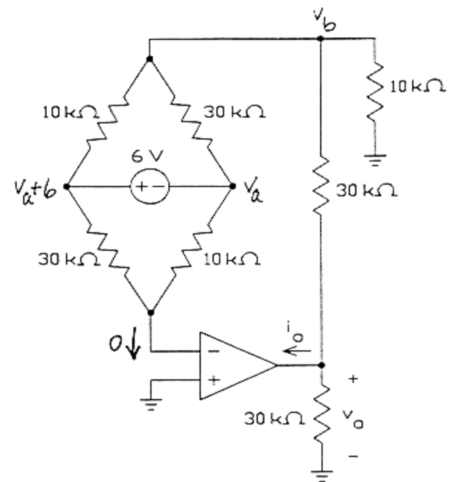
P6.5-7

KCL at node b: $\dfrac{v_a}{20e3} + \dfrac{v_c}{25e3} = 0 \quad \Rightarrow \quad v_c = -\dfrac{5}{4}v_a$

KCL at node a: $\dfrac{v_a - (-12)}{40e3} + \dfrac{v_a}{10e3} + \dfrac{v_a + 0}{20e3} + \dfrac{v_a - \left(-\frac{5}{4}v_a\right)}{10e3} = 0 \quad \Rightarrow \quad v_a = -\dfrac{3}{4}$ V

so $v_c = -\dfrac{5}{4}v_a = -\dfrac{15}{16}$.

P6.5-8



$$-\left(\frac{v_a-0}{10000}\right)+0-\left(\frac{(v_a+6)-0}{30000}\right) = 0$$

$$\Rightarrow v_a = -1.5\text{ V}$$

$$\frac{v_a-0}{10000}+\frac{v_a+6-0}{30000}+\frac{v_a-v_b}{30000}+\frac{(v_a+6)-0}{10000} = 0$$

$$\Rightarrow \quad 3v_a+v_a+6+v_a-v_b+3\left[(v_a+6)-v_b\right] = 0$$

$$\Rightarrow \quad v_b = 2v_a+6 = 3\text{ V}$$

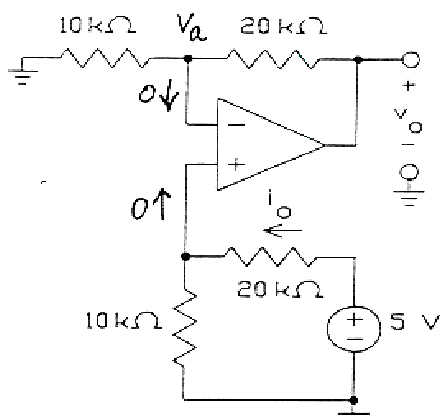
$$\frac{v_b}{10000}+\frac{v_b-v_0}{30000}-\left(\frac{v_a-v_b}{30000}\right)-\left(\frac{(v_a+6)-v_b}{10000}\right)=0$$

$$\Rightarrow \quad 3v_b+(v_b-v_0)-(v_a-v_b)-3\left[(v_a+6)-v_b\right]=0$$

$$\Rightarrow \quad v_0 = 8v_b-4v_a-18 = \underline{12\text{ V}}$$

$$i_0+\frac{v_0}{30000}+\frac{v_0-v_b}{30000} = 0 \Rightarrow i_0 = -0.7\text{mA}$$

P6.5-9



$$-i_0(10000)-i_0(20000)+5 = 0$$

$$i_0 = \frac{1}{6}\text{ mA}$$

$$v_a = 10000\ i_0 = \frac{10}{6}\text{ V}$$

$$\frac{v_a}{10000}+\frac{v_a-v_0}{20000} = 0$$

$$\Rightarrow v_0 = 3v_a = 5\text{ V}$$

P6.5-10

KCL at node b: $\frac{v_b+12}{40e3}+\frac{v_b}{20e3}=0 \quad\Rightarrow\quad v_b=-4\text{ V}$

$v_c=v_b=-4\text{ V}$ because the node voltages at the input nodes of an ideal op amp are equal.

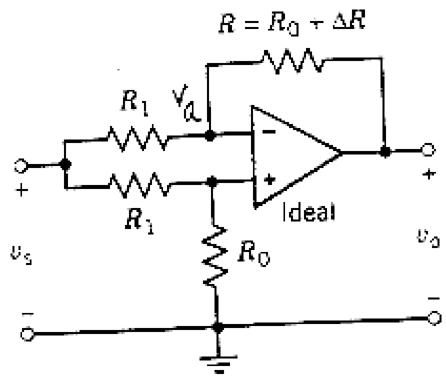
$v_d=v_c+0\cdot 10e3=-4\text{ V}$ because the currents into the inputs of an ideal op amp are zero.

KCL at node g: $-\left(\frac{v_f-v_g}{20e3}\right)+\frac{v_g}{40e3}=0 \quad\Rightarrow\quad v_g=\frac{2}{3}v_f$

KCL at node d: $\frac{v_d-v_f}{20e3}+\frac{v_d-\frac{2}{3}v_f}{20e3}=0 \quad\Rightarrow\quad v_f=\frac{6}{5}v_d=-\frac{24}{5}\text{ V}$ so $v_g=\frac{2}{3}v_f=-\frac{15}{5}\text{ V}$.

$v_c=v_g=-\frac{16}{5}\text{ V}$ because the node voltages at the input nodes of an ideal op amp are equal

P6.5-11



$$v_a = \frac{R_0}{R_1+R_0} v_s$$

$$\frac{v_a - v_s}{R_1} + \frac{v_a - v_0}{R_0+\Delta R} = 0$$

$$\frac{R_0+\Delta R}{R_1}(v_a - v_s) + v_a = v_0$$

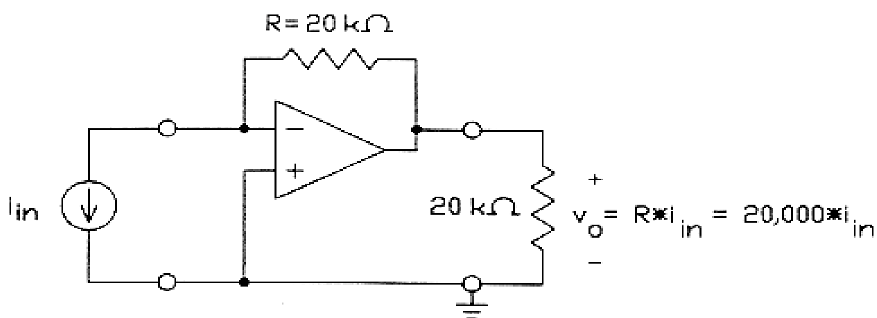
$$v_0 = \left[\left(\frac{R_0+\Delta R}{R_1}+1\right)\frac{R_0}{R_1+R_0} - \frac{R_0+\Delta R}{R_1}\right] v_s$$

$$= -\frac{\Delta R}{R_1+R_0} v_s$$

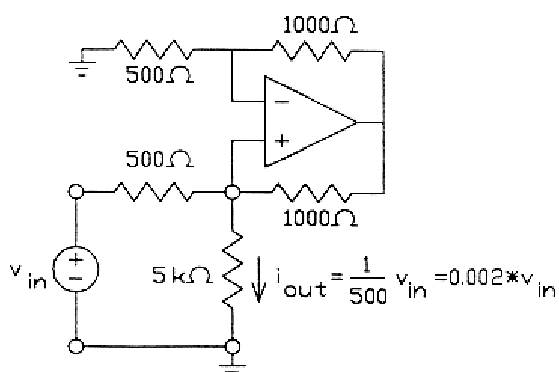
$$= \left(-v_s \frac{R_0}{R_1+R_0}\right)\frac{\Delta R}{R_0}$$

<u>Section 6-6:</u> Design Using Operational Amplifier

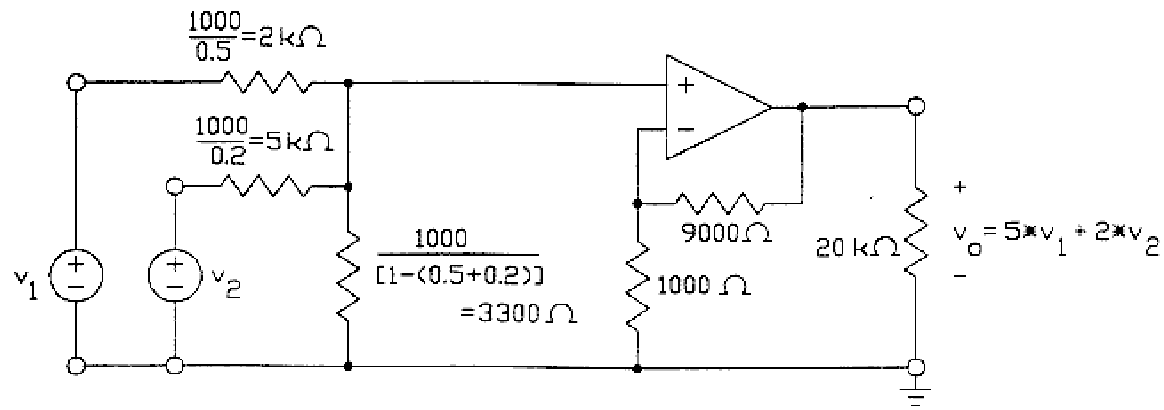
P6.6-1



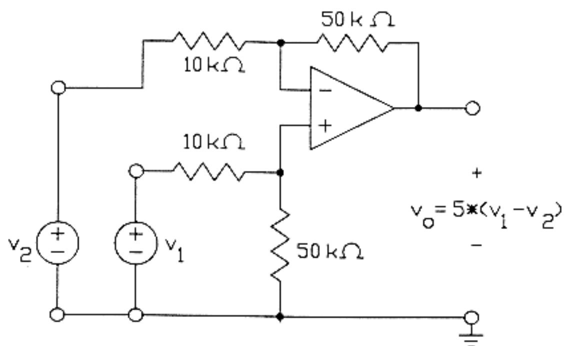
P6.6-2



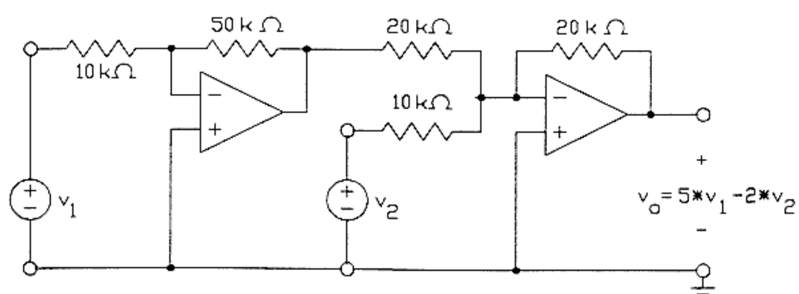
P6.6-3



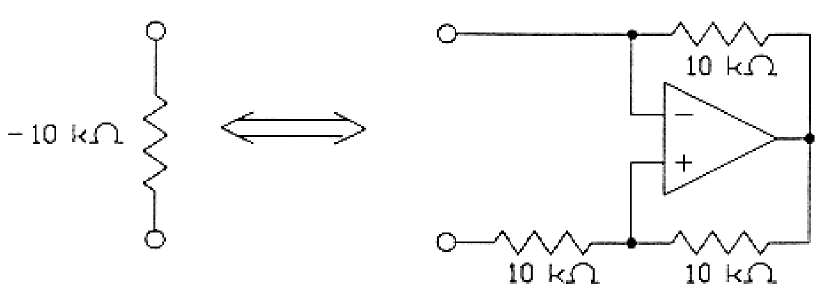
P6.6-4



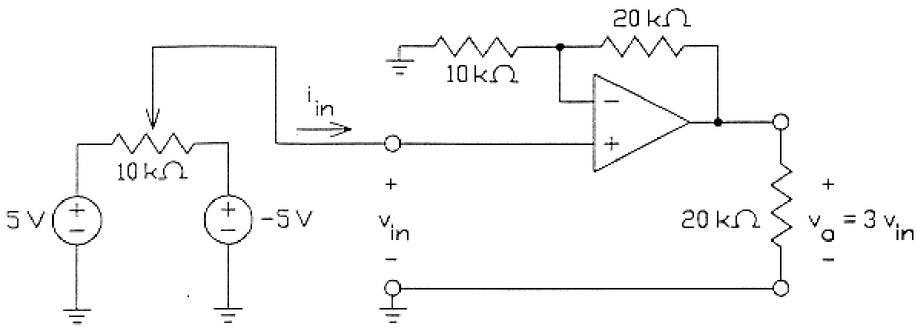
P6.6-5



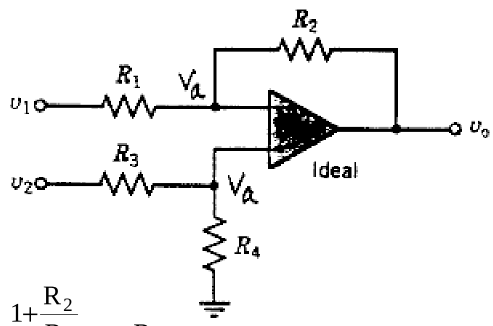
P6.6-6



P6.6-7



P6.6-8



(a) $$v_a = \frac{R_4}{R_3+R_4} v_2$$

$$\frac{v_a - v_1}{R_1} + \frac{v_a - v_0}{R_2} = 0$$

$$\Rightarrow v_0 = \left(\frac{R_2}{R_1}+1\right) v_a - \frac{R_2}{R_1} v_1$$

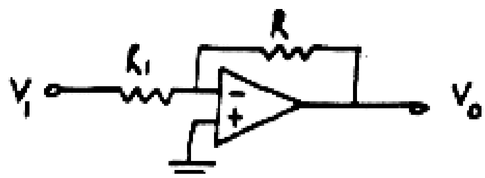
$$= \left(\frac{R_2}{R_1}+1\right)\frac{R_4}{R_3+R_4} v_2 - \frac{R_2}{R_1} v_1 = \frac{1+\frac{R_2}{R_1}}{1+\frac{R_3}{R_4}} v_2 - \frac{R_2}{R_1} v_1$$

(b) $$11 = \frac{R_2}{R_1} \text{ and } 4 = \frac{1+\frac{R_2}{R_1}}{1+\frac{R_3}{R_4}} = \frac{12}{1+\frac{R_3}{R_4}} \Rightarrow \frac{R_3}{R_4} = 2$$

For example:

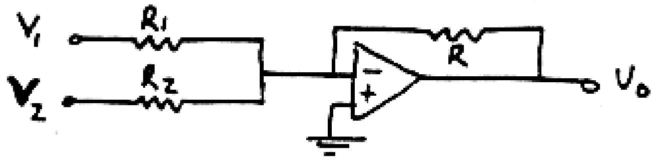
$R_1 = 10\text{k}\Omega, \quad R_2 = 110\text{k}\Omega, \quad R_3 = 20\text{k}\Omega \ \& \ R_4 = 10\text{k}\Omega$

P6.6-9



We know this ckt yields $v_0 = -\frac{R}{R_1}v_1$

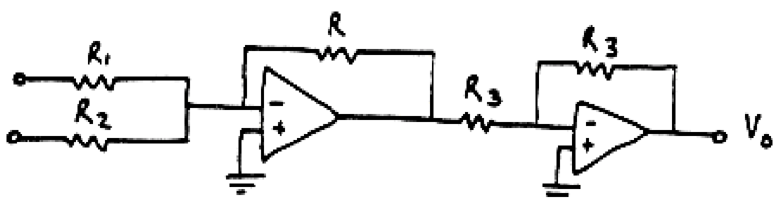
so consider adding another input lead into the negative terminal



with $v_i \simeq 0$, KCL at negative input yields

$$-v_1/R_1 - v_2/R_2 = v_0/R \Rightarrow v_0 = -\frac{R}{R_1}v_1 - \frac{R}{R_2}v_2$$

Since need to invert the answer, add an inverter to the output,

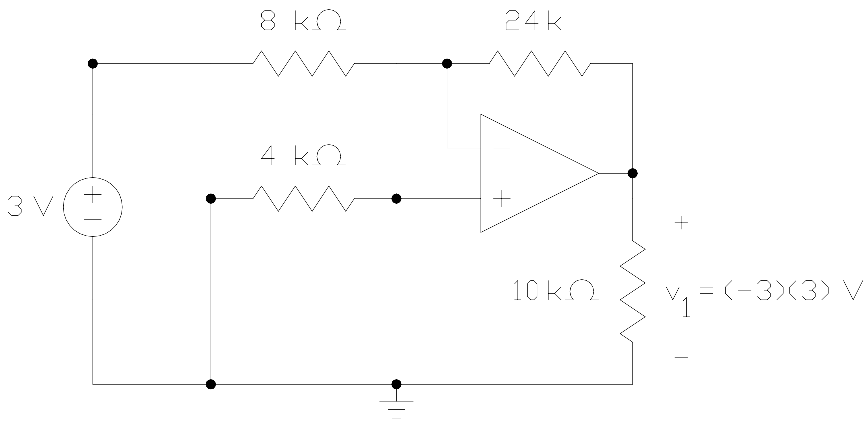


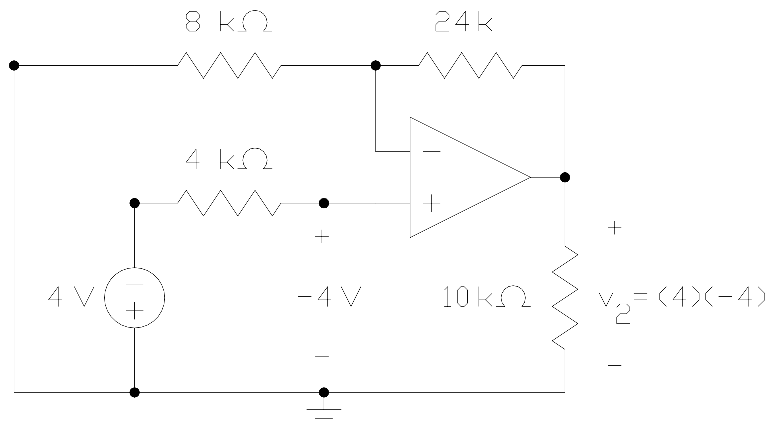
Let $\underline{R_3 = 10\text{k}\Omega}$

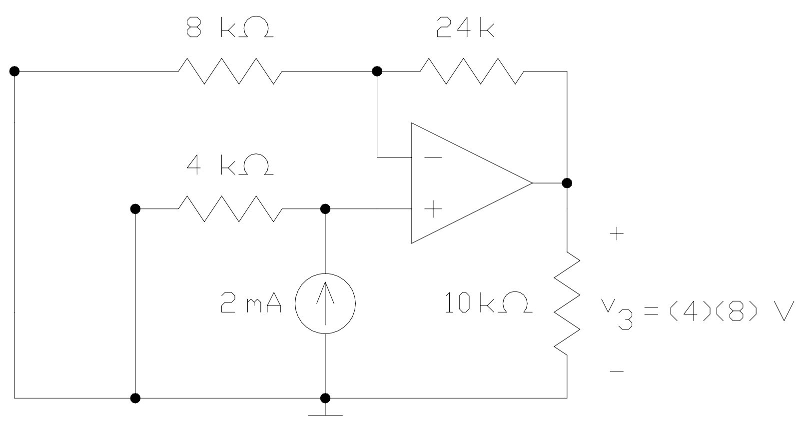
Now $\frac{R}{R_1} = 6$ and $\frac{R}{R_2} = 2$ $\therefore$ let R = 60 kΩ

$R_1 = 10\text{k}\Omega$ and $\underline{R_2 = 30\text{k}\Omega}$

P6.6-10





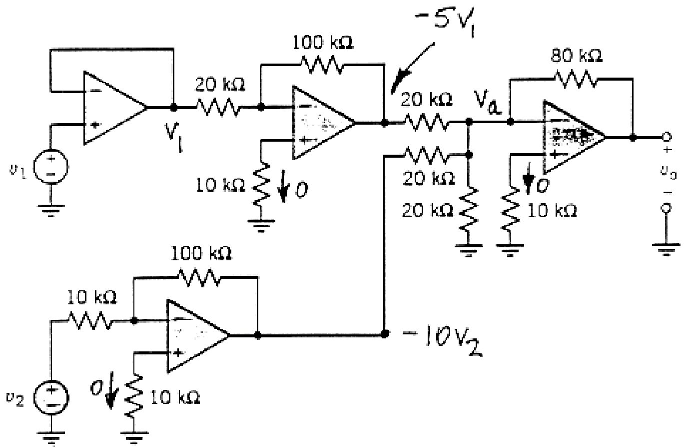


Using superposition, $v_o = v_1 + v_2 + v_3 = -9 - 16 + 32 = 7$ V

P6.6-11

R_1	6	12	24	6‖12	6‖24	12‖12	12‖24	6‖12‖12	6‖12‖24	12‖12‖24
R_2	12‖12‖24	6‖12‖24	6‖12‖12	12‖24	12‖12	6‖24	6‖12	24	12	6
$-v_o/v_s$	0.8	0.286	0.125	2	1.25	0.8	0.5	8	3.5	1.25

P6.6-12



$$\frac{v_a-(-5v_1)}{20k\Omega}+\frac{v_a-(-10v_2)}{20k\Omega}+\frac{v_a}{20k\Omega}+\frac{v_a-v_0}{80k\Omega} = 0$$

$$4(v_a+5v_1)+4\,(v_a+10v_2)+4v_a+v_a-v_0 = 0$$

$$v_a = 0(10k\Omega) = 0$$

$$v_0 = 20v_1+40v_2$$

P 6.6-13

$$v_c = -\left(3\,v_a+1\right)$$

$$v_o = -\left(3\,v_b+2\,v_c+2\right) = -\left(3\,v_b-2\left(3\,v_a+1\right)+2\right) = -3\,v_b+6\,v_a$$

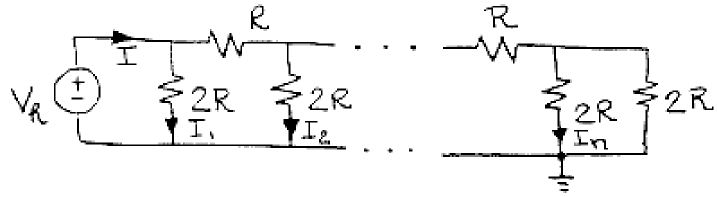
P6.6-14

(a) $2R||2R \;=\; R$

R in series with $R \;=\; 2R$

$\vdots$

$R_{eq} \;=\; R$



$\underline{I = \frac{v_R}{R}}$, $\qquad I_1 = \frac{v_R}{R}\left(\frac{2R}{4R}\right) = \frac{v_R}{2R}$

$$I_2 = \frac{v_R}{2R}\left(\frac{2R}{4R}\right) = \frac{v_R}{2^2 R}$$

$\vdots$

$$I_n = \frac{v_R}{2^n R}$$

(b) $$\frac{V_0}{R_f} = b_1 I_1 + b_2 I_2 + ...+ b_n I_n$$

$$V_0 = R_f\left[b_1\frac{V_R}{2R}+b_2\frac{V_R}{2^2R}+.....+b_n\frac{V_R}{2^nR}\right] = \underline{\frac{R_f V_R}{R}\left[b_1 2^{-1}+b_2 2^{-2}+...+b_n 2^{-n}\right]}$$

(c) $$I^+ + I^- = \frac{V_R}{2R}+\frac{V_R}{2^2R}+.....+\frac{V_R}{2^nR}$$

$$= \frac{V_R}{R}\left[2^{-1}+2^{-2}+.....+2^{-n}\right]$$

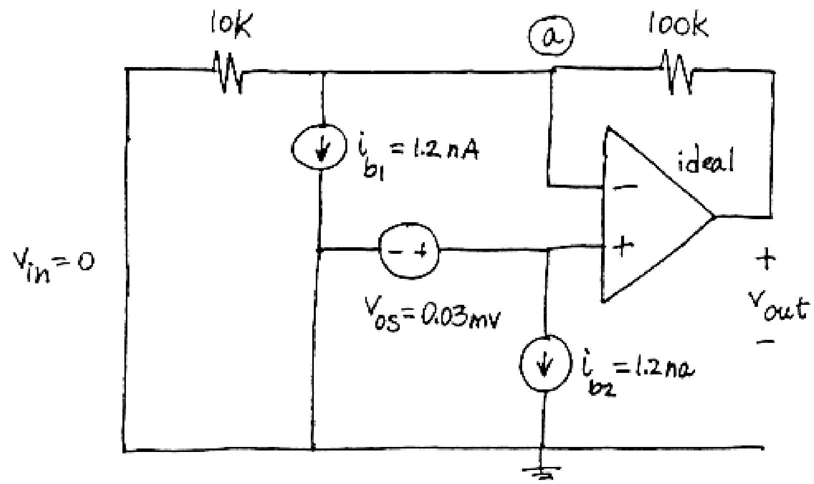
$$= \underline{\frac{V_R}{R}\left[1-2^{-n}\right]}$$

(d)

$-V_0$	b1	b2	b3	b4
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	0	0	0	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
13	1	1	0	1
14	1	1	1	0
15	1	1	1	1

Section 6-7: Characteristics of the Practical Operational Amplifier

P6.7-1



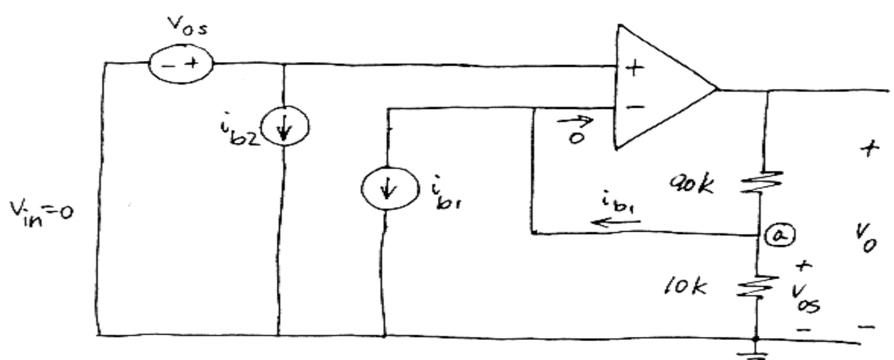
The node equation at node a is $\frac{v_{out} - v_{os}}{100k} = \frac{v_{os}}{10k} + i_{b1}$

so $v_{out} = \left(1 + \frac{100k\Omega}{10k\Omega}\right) v_{os} + 100k\Omega \cdot i_{b1} = 11 v_{os} + 100k\Omega \cdot i_{b1}$

$= 11(0.03mV) + 100k\Omega(1.2nA)$

$= 0.45mV$

P6.7-2



The node equation at node a is

$$\frac{v_{os}}{10k} + i_{b1} = \frac{v_0 - v_{os}}{90k\Omega}$$

so $v_0 = \left(1 + \frac{90k\Omega}{10k\Omega}\right) v_{os} + 90k\Omega\, i_{b1} = 10 v_{os} + 90k\Omega\, i_{b1}$

$= 10(5mV) + 90k\Omega(.05nA)$

$= 50.0045mV \simeq 50mV$