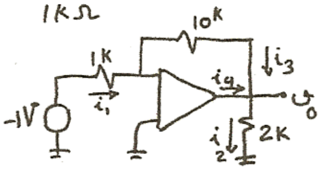
2.16

$\frac{v_o}{v_i} = \frac{-R_2}{R_1} \Rightarrow v_o = -1 \times \frac{-10k\Omega}{1k\Omega} = 10V$



$i_2 = \frac{v_o}{2k\Omega} = 5mA$

$i_1 = i_3 = \frac{v_o}{10k\Omega} = 1mA$

$i_4 = i_2 - i_3 = 4mA$ This additional current comes from the output of the op amp.

2.17

$|Gain| = \frac{R_2}{R_1} = \frac{R_2(1+x/100)}{R_1(1+x/100)} \simeq \frac{R_2}{R_1}\left(1 \pm \frac{2x}{100}\right)$ for small x

$\Rightarrow 2x\%$ is the tolerance on the closed loop gain (G).

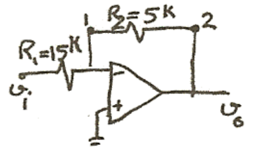
$G = -100 V/V$, $x = 5 \Rightarrow -110 < G < -90$

or more precisely: $-100 \times \frac{105}{95} < G < -100\frac{95}{105}$

$-110.5 < G < -90.5$

2.18

$G = \frac{v_o}{v_i} = \frac{-R_2}{R_1} \Rightarrow \frac{R_2}{R_1} = \frac{5}{15}$



$v_1 = 0V$, $v_2 = v_o = 5V$

For $\pm 1\%$ on R_1, R_2: $R_1 = 15 \pm 0.15\ k\Omega$

$R_2 = 5 \pm 0.05\ k\Omega$

$v_o = v_i \frac{-R_2}{R_1} = 15\frac{R_2}{R_1} \Rightarrow 15 \times \frac{4.95}{15.15} \leq v_o \leq 15 \times \frac{5.05}{14.85}$

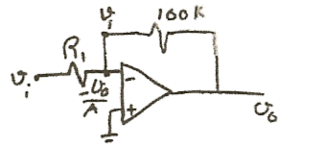
$\Rightarrow 4.9V \leq v_o \leq 5.1V$

For $v_i = -15 \pm 0.15\ V$ $14.85 \times \frac{4.95}{15.15} \leq v_o \leq 15.15 \times \frac{5.05}{14.85}$

$\Rightarrow 4.85V \leq v_o \leq 5.15V$

2.19

$v_1 = \frac{-v_o}{A} = -\frac{v_o}{200}$



$\frac{v_o}{v_i} = -50 V/V$

$\frac{v_i - \left(\frac{-v_o}{A}\right)}{R_1} = \frac{\left(\frac{-v_o}{A} - v_o\right)}{100k\Omega} \Rightarrow R_1 = 100K \times \frac{\frac{v_o}{200} - \frac{v_o}{50}}{\frac{-v_o}{200} - v_o}$

$\Rightarrow R_1 = 100K \times \frac{3}{201} = 1.49k\Omega$

Shunt Resistor R_a : $R_a \parallel 2k\Omega = 1.49K$

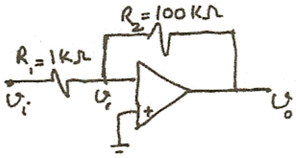
$\frac{R_a \times 2}{R_a + 2} = 1.49 \Rightarrow R_a = 5.84k\Omega$

2.20

ⓐ $\frac{v_o}{v_i} = -\frac{R_2}{R} \Rightarrow -100 V/V = \frac{-R_2}{1K\Omega} \Rightarrow R_2 = 100K\Omega$

ⓑ $A = 1000 V/V$

$v_1 = \frac{-v_o}{A}$



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

$\frac{v_o}{v_i} = \frac{-R_2/R_1}{1 + (1+\frac{R_2}{R_1})/A} = \frac{-100}{1 + \frac{101}{1000}} = -90.8 V/V$

$\Rightarrow \frac{v_o}{v_i} = 90.8\ V/V$

ⓒ Assume $R_1' = R_x \parallel R_1$ when $R_1 = 1K\Omega$

$\frac{v_o}{v_i} = -100\ V/V$

$\frac{v_i - v_1}{R_1'} = \frac{v_1 - v_o}{R_2} \Rightarrow R_1' = R_2 \times \left(\frac{-v_o}{100} - \frac{-v_o}{1000}\right) / \left(\frac{-v_o}{1000} - v_o\right)$

$R_1' = \frac{1 - 0.1}{1.001} = 0.899\ K\Omega = \frac{R_1 R_x}{R_1 + R_x} = \frac{R_x}{1 + R_x}$

$\Rightarrow R_x = 8.9\ K\Omega \simeq 8.87 K\Omega \pm 1\%$

2.21

Voltage of the inverting input terminal

Cont.

2.27

$$|G| = \frac{R_2/R_1}{1 + \frac{1+R_2/R_1}{A}} \qquad A \longrightarrow A\left(1-\frac{x}{100}\right)$$
$$G \longrightarrow G'$$

$$|G'| = \frac{R_2/R_1}{1 + \frac{1+R_2/R_1}{A\left(1-\frac{x}{100}\right)}}$$

For $|G'| = |G|\left(1-\frac{x}{100K}\right)$

$$\frac{R_2/R_1}{1+\frac{1+R_2/R_1}{A\left(1-x/100\right)}} = \frac{R_2/R_1}{1+\frac{1+R_2/R_1}{A}}\left(1-\frac{x}{100K}\right)$$

$$1+\frac{1+R_2/R_1}{A\left(1-\frac{x}{100}\right)} = \left(1+\frac{1+R_2/R_1}{A}\right)\Big/\left(1-\frac{x}{100K}\right)$$

$$1-\frac{x}{100K} + \frac{1+R_2/R_1}{A}\,\frac{1-x/100K}{1-x/100} = 1+\frac{1+R_2/R_1}{A}$$

$$\frac{1+R_2/R_1}{A}\,\frac{1-x/100K-1+x/100}{1-x/100} = \frac{x}{100K}$$

$$A = \frac{-1+K}{1-\frac{x}{100}}\left(1+R_2/R_1\right) = \left(\frac{K-1}{1-\frac{x}{100}}\right)\left(1+\frac{R_2}{R_1}\right)$$

For $\frac{R_2}{R_1}=100$ $\quad x=50 \quad K=100$: $A = \frac{99}{0.5}\times 101 = 19998$

$A \simeq 2\times10^4\ V/V$

Thus for $A = 2\times10^4\ V/V$, a reduction of 50% results in only 0.5% reduction of the closed loop gain whose nominal value is $\frac{R_2}{R_1}$ (100).

2.28

From the results of example 2.2, the gain of the circuit in fig. 2.8 is given by:

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

For $R_1 = R_2 = R_4 = 1M\Omega \longrightarrow \frac{v_o}{v_i} = -\left(1+1+\frac{1}{R_3}\right)$

a) $\frac{v_o}{v_i} = -10\ V/V \Rightarrow 10 = 2+\frac{1}{R_3} \Rightarrow R_3 = \frac{1}{8}M\Omega = 125\,k\Omega$

b) $\frac{v_o}{v_i} = -100\ V/V \Rightarrow 100 = 2+\frac{1}{R_3} \Rightarrow R_3 = \frac{1}{98}M\Omega = 10.2\,k\Omega$

c) $\frac{v_o}{v_i} = -2\ V/V \Rightarrow 2 = 2+\frac{1}{R_3} \Rightarrow R_3 = \infty$: eliminate R_3.

2.29

$R_2/R_1 = 1000$, $R_2 = 100k\Omega \Rightarrow R_1 = 100\Omega$

a) $R_{in} = R_1 = 100\Omega$

b) $\frac{v_o}{v_i} = \frac{-R_2}{R_1}\left(1+\frac{R_4}{R_2}+\frac{R_4}{R_3}\right) = -1000$

IF $R_2 = R_1 = R_4 = 100K \Rightarrow R_3 = \frac{100K}{1000-2} \simeq 100\,\Omega$

$R_{in} = R_1 = 100k\Omega$

2.30

$v_x = 0 - i_1 R_2$, $i_1 = \frac{v_I}{R_1} \Rightarrow v_x = -v_I\frac{R_2}{R_1}$

$$\frac{v_x}{v_I} = -\frac{R_2}{R_1}$$

$$v_x = v_o\,\frac{R_2\|R_3}{R_2\|R_3+R_4} = v_o\,\frac{R_2R_3}{R_2R_3+R_4R_2+R_4R_3}$$

$$\frac{v_o}{v_x} = \frac{R_2R_3+R_2R_4+R_3R_4}{R_2R_3} = 1+\frac{R_4}{R_3}+\frac{R_4}{R_2}$$

$$\frac{v_o/v_x}{v_I/v_x} = \frac{v_o}{v_i} = \frac{\left(1+R_4/R_3+R_4/R_2\right)}{-R_1/R_2} \Rightarrow$$

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

2.31

a) $R_1 = R$

$R_2 = R\|R + \frac{R}{2} = \frac{R}{2}+\frac{R}{2} = R$

$R_3 = R_2\|R + \frac{R}{2} = R\|R+\frac{R}{2} = R$

$R_4 = R_3\|R + \frac{R}{2} = R\|R+\frac{R}{2} = R$

b) $v_1 = RI = RI_1 \Rightarrow I_1 = I$

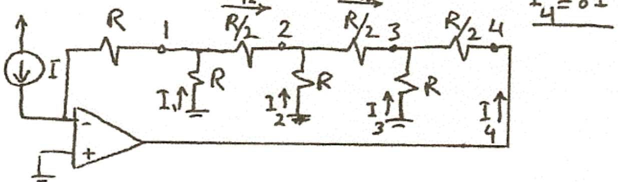
$I_{12} = I+I = 2I \Rightarrow v_1 + 2I\times\frac{R}{2} = RI_2$

$RI + RI = RI_2 \Rightarrow I_2 = 2I$

$I_{13} = I_2 + I_{12} = 4I \Rightarrow v_2 + 4I\times\frac{R}{2} = RI_3$

$R\times2I + 4I\times\frac{R}{2} = RI_3 \Rightarrow I_3 = 4I$, $I_4 = (4I+4I)$

$I_4 = 8I$



Cont.

c) $v_1 = I_1 R = -IR$

$v_2 = -I_2 R = -2IR$

$v_3 = -I_3 R = -4IR$

$v_4 = -I_3 R + I_4 \frac{R}{2} = -4IR - 8I\frac{R}{2} = -8IR$

2.32

a) $I_1 = \frac{1V}{10k\Omega} = 0.1mA$

$I_2 = I_1 = 0.1\,mA$, $I_2 \times 10k\Omega = I_3 \times 100\Omega \Rightarrow I_3 = 10^{mA}$

$v_x = 10mA \times 100\Omega = 1V$

b) $v_x = R_L I_L + v_o$, $I_L = I_2 + I_3 = 10.1mA$

$1V = R_L \times 10.1mA + v_o$

$R_L = \frac{1 - v_o}{10.1} \Rightarrow R_{Lmax} = \frac{1 - v_{o\,min}}{10.1} = \frac{14}{10.1}$

$R_{Lmax} =$

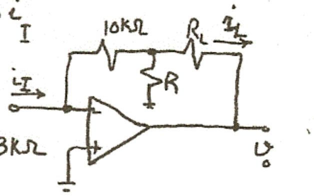
c) $100\Omega \le R_L \le 1k\Omega$

I_L stays fixed at 10.1mA

$v_o = v_x - R_L I_L = 1 - R_L \times 10.1 \Rightarrow -9.1^V \le v_o \le -0.01^V$

2.33

a) $\frac{i_L}{i_i} = 20 \Rightarrow i_L = 20 i_I$



$-10k\Omega \times i_I = R(i_I - i_L)$

$R = \frac{10k\Omega \times i_I}{20 i_I - i_I} = 0.53k\Omega$

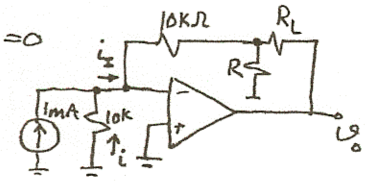
b) $R_L = 1k\Omega$ $\quad -12^V \le v_o \le 12^V$

$v_o = R_L i_L + 10k\Omega \times i_I = i_I (1k\Omega \times \frac{i_L}{i_I} + 10^{k\Omega})$

$v_o = i_I (1 \times 20 + 10) = 30 i_I$

$i_I = \frac{v_o}{30} \Rightarrow \frac{-12}{30} \le i_I \le \frac{12}{30} \Rightarrow -0.4_{mA} \le i_I \le 0.4_{mA}$

c) $R_I = \frac{v_I}{i_I} = \frac{0}{i_I} = 0$



$v_- = 0 \Rightarrow i = 0$

$\Rightarrow i_I = 1mA$

From part a: $i_L = 20 \times i_I = 20\,mA$

2.34

$R_2 \gg R_3$, if we ignore the current accross R_2 : $v_A = \frac{v_o R_3}{R_3 + R_4}$

$\frac{v_I}{R_1} = \frac{0 - v_A}{R_2} \Rightarrow v_A = -\frac{R_2 v_I}{R_1}$

$v_o \frac{R_3}{R_3 + R_4} = -\frac{R_2}{R_1} \times v_I \Rightarrow \frac{v_o}{v_I} = \frac{-R_2}{R_1}\left(1 + \frac{R_4}{R_3}\right)$

Now if we recalculate v_A considering that there is a voltage divider between R_4 and $R_3 || R_2$:

$$v_A = v_o \frac{R_3 || R_2}{R_4 + R_3 || R_2} = v_o \frac{R_3 R_2}{R_4(R_3 + R_2) + R_2 R_3}$$

$$v_A = v_o \frac{R_2 R_3}{R_3 R_4 + R_2 R_4 + R_2 R_3}$$

$$v_A = v_o \frac{1}{R_4/R_2 + \frac{R_4}{R_3} + 1}$$

$v_A = -\frac{R_2}{R_1} \cdot v_I \Rightarrow \frac{v_o}{v_I} = \frac{-R_2}{R_1}\left(\frac{R_4}{R_2} + \frac{R_4}{R_3} + 1\right)$

Same as example 2.2.

2.35

$R_I = 100k\Omega$ $\quad -10 \le \frac{v_o}{v_i} \le -1\, V/V$

$R_I = R_1 = 100k\Omega$

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

$R_4 = 0 \Rightarrow \frac{v_o}{v_i} = \frac{-R_2}{R_1} = -1 \Rightarrow R_2 = 100k\Omega$

$R_4 = 10k\Omega \Rightarrow \frac{v_o}{v_i} = -10 = -1 \times \left(\frac{10k\Omega}{R_3} + \frac{10k\Omega}{100k\Omega} + 1\right)$

$+10 = \left(\frac{10}{R_3} + 1.1\right) \Rightarrow R_3 = 1.12k\Omega$

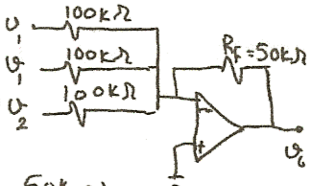
Potentiometer in the middle: $\frac{v_o}{v_i} = -1\left(\frac{5}{5 + R_3} + \frac{5}{100} + 1\right)$

$\frac{v_o}{v_i} = -1.87\, V/V$

2.36

According to eq. 2.7:

$$v_o = -\left(\frac{R_F}{R_1}v_1 + \frac{R_F}{R_2}v_2 + \dots \frac{R_F}{R_n}v_n\right)$$



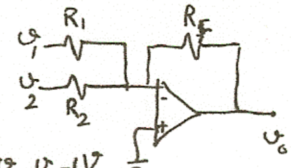
$$v_o = -\left(\frac{50k}{100k}v_1 + \frac{50k}{100k}v_1 + \frac{50k}{100k}v_2\right)$$

$$v_o = -\left(v_1 + \frac{v_2}{2}\right) \qquad v_1 = 3,\ v_2 = -3 \Rightarrow v_o = -1.5v$$

2.37

we choose the weighted summer configuration

$$v_o = -\left[4v_1 + \frac{v_2}{3}\right]$$



$i_1 = \frac{v_1}{R_1}$ $\quad i_2 = \frac{v_2}{R_2}$

$i_1, i_2 \leq 0.1\ mA$ for $v_1, v_2 = 1V$

$R_1, R_2 \geq 10k\Omega$

$\frac{R_F}{R_1} = 4$, if $R_1 = 10k\Omega \Rightarrow R_F = 40k\Omega$

$\frac{R_F}{R_2} = \frac{1}{3} \Rightarrow R_2 = 120k\Omega$

2.38

$$v_o = -(2v_1 + 4v_2 + 8v_3)$$

$R_1, R_2, R_3 \geq 10k\Omega$

$\frac{R_F}{R_1} = 2$, $\frac{R_F}{R_2} = 4$ $\quad \frac{R_F}{R_3} = 8$

$R_3 = 10k\Omega \Rightarrow R_F = 80k\Omega$

$R_2 = 20k\Omega$

$R_1 = 40k\Omega$

2.39

a) $v_o = -(v_1 + 2v_2 + 3v_3)$

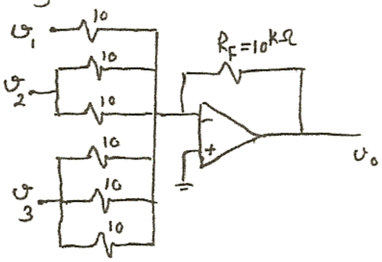
$\frac{R_F}{R_1} = 1 \Rightarrow R_1 = 10k\Omega$, $\frac{R_F}{R_2} = 2 \Rightarrow R_2 = 5k\Omega$

$\frac{R_F}{R_3} = 3 \Rightarrow R_3 = \frac{10}{3}k\Omega$

$R_{I1} = 10k\Omega$

$R_{I2} = 5k\Omega$

$R_{I3} = 3.3K$



b) $v_o = -(v_1 + v_2 + 2v_3 + 2v_4)$

$\frac{R_F}{R_1} = 1 \Rightarrow R_1 = 10k\Omega$

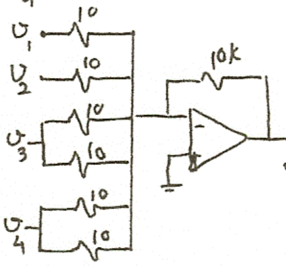
$\frac{R_F}{R_2} = 1 \Rightarrow R_2 = 10k\Omega$

$\frac{R_F}{R_3} = 2 \Rightarrow R_3 = \frac{10}{2}k\Omega$

$\frac{R_F}{R_4} = 2 \Rightarrow R_4 = \frac{10}{2}k\Omega$

$R_{I1} = R_{I2} = 10k\Omega$

$R_{I3} = R_{I4} = 5k\Omega$



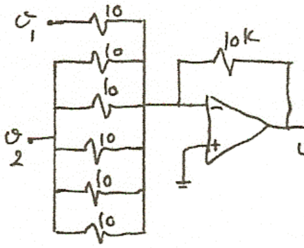
c) $v_o = -(v_1 + 5v_2)$

$R_1 = 10k$

$R_2 = \frac{10k}{5}$

$R_{I1} = 10k\Omega$

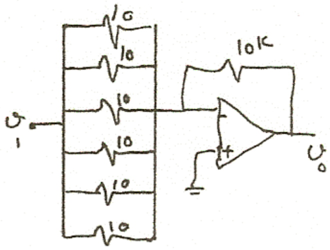
$R_{I2} = 2k\Omega$



d) $v_o = -6v_1$

$R_1 = \frac{10k}{6}$

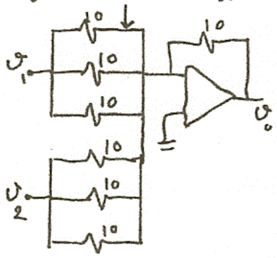
$R_{I1} = 1.67k\Omega$

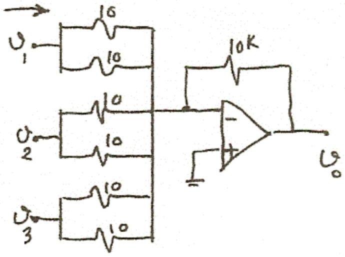


Suggested configurations:

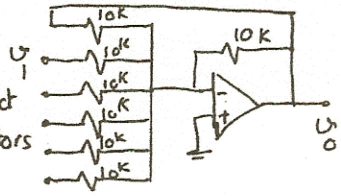
$v_o = -(2v_1 + 2v_2 + 2v_3)$

$v_o = -(3v_1 + 3v_2)$





In order to have coefficient = 0.5, connect one of the input resistors to v_1. $\frac{v_o}{v_1} = -0.5$



2.40

The output signal should be:

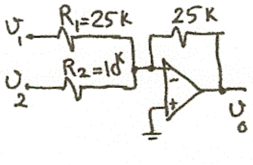
$v_o = -5\sin\omega t - 5$

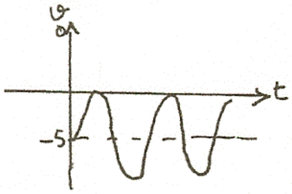
if we assume: $v_1 = 5\sin\omega t$, $v_2 = 2V$ $\Big\}\ v_o = -(v_1 + 2.5v_2)$

In a weighted summer configuration:

$\frac{R_F}{R_1} = +1 \qquad \frac{R_F}{R_2} = 2.5$

$R_2 = 10K\Omega \Rightarrow R_F = 25K = R_1$





2.41

$v_o = v_1 + 2v_2 - 3v_3 - 4v_4$: Consider Fig. 2.11.

According to eq. 2.8 for a weighted summer circuit:

$v_o = v_1 \frac{R_a}{R_1}\frac{R_c}{R_b} + v_2 \frac{R_a}{R_2}\frac{R_c}{R_b} - v_3\frac{R_c}{R_3} - v_4\frac{R_c}{R_4}$

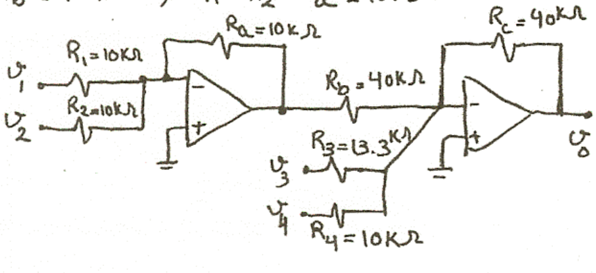
$\frac{R_a}{R_1}\frac{R_c}{R_b} = 1 \ , \quad \frac{R_a}{R_2}\frac{R_c}{R_b} = 1 \ , \quad \frac{R_c}{R_3} = 3 \ , \ \frac{R_c}{R_4} = 4$

assume:

$R_4 = 10K\Omega \Rightarrow R_c = 40^{K\Omega} \Rightarrow R_3 = \frac{40}{3} = 13.3^{K\Omega}$

$\frac{R_a}{R_1} \times \frac{40}{R_b} = 1 \qquad \frac{R_a}{R_2} \times \frac{40}{R_b} = 1$

$R_b = 40K\Omega \ , \quad R_1 = R_2 = R_a = 10K\Omega$



2.42

$v_1 = 3\sin(2\pi \times 60t) + 0.01\sin(2\pi \times 1000t)$

$v_2 = 3\sin(2\pi \times 60t) - 0.01\sin(2\pi \times 1000t)$

we want to have: $v_o = 10v_1 - 10v_2$

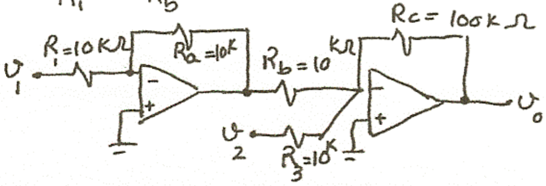
we use the circuit in Fig. 2.11.

According to Eq. 2.8:

$v_o = v_1 \frac{R_a}{R_1}\frac{R_c}{R_b} - v_3\frac{R_c}{R_3}$

$\frac{R_a}{R_1}\frac{R_c}{R_b} = 10 \ , \quad \frac{R_c}{R_3} = 10$, if $R_3 = 10^{K\Omega} \Rightarrow R_c = 100^{K\Omega}$

$\Rightarrow \frac{R_a}{R_1} \times \frac{100^{K\Omega}}{R_b} = 10 \Rightarrow R_a = R_1 = R_b = 10K\Omega$



$v_o = 10v_1 - 10v_2 = 10 \times 0.02\sin 2\pi \times 1000t$

$v_o = 0.2\sin(2\pi \times 1000t) \qquad -0.2^v \leq v_o \leq 0.2^v$

2.43

This is a weighted summer circuit:

$v_o = -\left(\frac{R_F}{R_0}v_0 + \frac{R_F}{R_1}v_1 + \frac{R_F}{R_2}v_2 + \frac{R_F}{R_3}v_3\right)$

we may write: $v_0 = 5^v \times a_0 \qquad v_2 = 5^v \times a_2$

$v_1 = 5^v \times a_1 \ , \quad v_3 = 5^v \times a_3$

$v_o = -R_F\left(\frac{5a_0}{80K} + \frac{5}{40K}a_1 + \frac{5}{20K}a_2 + \frac{5}{10K}a_3\right)$

$v_o = -R_F\left(\frac{a_0}{16} + \frac{a_1}{8} + \frac{a_2}{4} + \frac{a_3}{2}\right)$

$v_o = -\frac{R_F}{16}\left(2^0 a_0 + 2^1 a_1 + 2^2 a_2 + 2^3 a_3\right)$

$-12^v \leq v_o \leq 0 \Rightarrow \frac{R_F}{16}\left(2^0 \times 1 + 2 \times 1 + 2^2 \times 1 + 2^3 \times 1\right) =$

$= \frac{15R_F}{16} = 12$ when $a_0 = a_1 = a_2 = a_3 = 1$ we have the peak value at v_o.

$\Rightarrow R_F = 12.8K\Omega$

2.44

a) $\frac{v_o}{v_i} = 1 = 1 + \frac{R_2}{R_1} \Rightarrow R_2 = 0, R_1 = 10K\Omega$

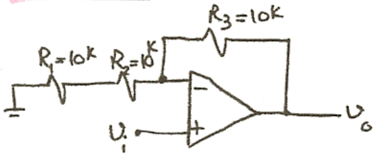
b) $\frac{v_o'}{v_i} = 2 = 1 + \frac{R_2}{R_1} \Rightarrow R_1 = R_2 = 10K\Omega$

Cont.

c) $\frac{v_o}{v_i} = 101\ V/V = 1 + \frac{R_2}{R_1} \Rightarrow$ if $R_1 = 10^{k\Omega} \Rightarrow R_2 = 1^{M\Omega}$

d) $\frac{v_o}{v_i} = 100\ V/V = 1 + \frac{R_2'}{R_1} \Rightarrow$ if $R_1 = 10^{k\Omega} \Rightarrow R_2 = 990\ k\Omega$

2.45

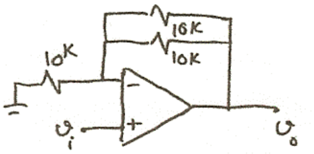


Short-circuit R_2:

$\frac{v_o}{v_i} = 2$

Short circuit R_3:

$\frac{v_o}{v_i} = 1$



2.46

$v_+ = v_- = V = R \times i$, $i = 100\mu A$ when $V = 10^v$

$\Rightarrow R = \frac{10}{0.1mA} = 100k\Omega$

As indicated, i only depends on R and V and the meter resistance does not affect i.

2.47

Refer to the circuit in P2.47:

a) using superposition, we first set $v_{P_1} = v_{P_2} = \dots = 0$

The output voltage that results in response to $v_{N_1}, v_{N_2}, \dots v_{N_n}$ is:

$$v_{ON} = -\left[\frac{R_F}{R_{N1}} v_{N_1} + \frac{R_F}{R_{N2}} v_{N2} + \dots + \frac{R_F}{R_{N_n}} v_{N_n}\right]$$

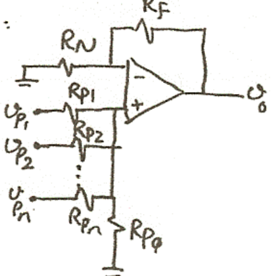
Then we set $v_{N_1} = v_{N_2} = \dots = 0$, then:

$R_N = R_{N1} // R_{N2} \| R_{N3} \| \dots \| R_{Nn}$

The circuit simplifies to:

$$v_{op} = \left(1 + \frac{R_F}{R_N}\right) \times$$

$$\left(v_{P_1} \frac{1/R_{P1}}{\frac{1}{R_{P1}} + \frac{1}{R_{P2}} + \dots + \frac{1}{R_{Pn}}} + v_{P_2} \frac{1/R_{P2}}{\frac{1}{R_{P1}} + \dots + \frac{1}{R_{Pn}}} + \dots v_{P_n} \frac{1/R_{Pn}}{1/R_{P_1} + \dots + \frac{1}{R_{Pn}}}\right)$$



$$v_{op} = \left(1 + \frac{R_F}{R_N}\right)\left(v_{P_1} \frac{R_P}{R_{P_1}} + v_{P_2} \frac{R_P}{R_{P_2}} + \dots + \frac{R_P}{R_{P_n}} v_{P_n}\right)$$

where:

$$R_P = R_{P_1} \| R_{P_2} \| \dots \| R_{P_n}$$

when all inputs are present:

$$v_o = v_{ON} + v_{op} = -\left(\frac{R_F}{R_{N_1}} v_{N_1} + \frac{R_F}{R_{N_2}} v_{N_2} + \dots\right) +$$

$$\left(1 + \frac{R_F}{R_N}\right)\left(\frac{R_P}{R_{P_1}} v_{N_1} + \frac{R_P}{R_{P_2}} v_{N_2} + \dots\right)$$

b) $v_o = -2v_{N_1} + v_{P_1} + 2v_{P_2}$

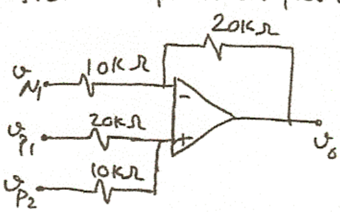
$\frac{R_F}{R_{N_1}} = 2 \qquad R_{N_1} = 10K\Omega \Rightarrow R_F = 20K\Omega$

$\left(1 + \frac{R_F}{R_N}\right)\left(\frac{R_P}{R_{P_1}}\right) = 1 \Rightarrow 3\frac{R_P}{R_{P_1}} = 1 \Rightarrow R_{P_2} = \frac{R_{P_1}}{2}$

$\left(1 + \frac{R_F}{R_N}\right)\left(\frac{R_P}{R_{P_2}}\right) = 2 \Rightarrow 3\frac{R_P}{R_{P_2}} = 2 \Rightarrow R_{P_2} = \frac{R_{P_1}}{2}$

where $R_P = \frac{R_{P_1} \times R_{P2}}{R_{P_1} + R_{P2}}$ (ignoring $R_{P\phi}$)

Note that if the results from the last 2 constraints differ, we would use an additional resistor connected from the positive input to ground. ($R_{P\phi}$)



2.48

$v_o = v_{I1} + 3v_{I2} - 2(v_{I3} + 3v_{I4})$

Refer to P2.47.

$\frac{R_F}{R_{N3}} = 2$ if $R_{N3} = 10k\Omega \Rightarrow R_F = 20k\Omega$

$\frac{R_F}{R_{N4}} = 6 \Rightarrow R_{N4} = \frac{20}{6} = 3.3^{k\Omega}$

$R_N = R_{N3} // R_{N4} = 10K // 3.3^K = 2.48^{k\Omega}$

$\left(1 + \frac{R_F}{R_N}\right)\frac{R_P}{R_{P_1}} = 1 \Rightarrow \left(1 + \frac{20}{2.48}\right)\frac{R_P}{R_{P_1}} = 1 \Rightarrow 9.06R_P = R_{P_1}$

$R_P = R_{P_1} \| R_{P_2} \| R_{P\phi} \Rightarrow R_P = \frac{1}{\frac{1}{R_{P1}} + \frac{1}{R_{P2}} + \frac{1}{R_{P\phi}}}$

$\left(1 + \frac{R_F}{R_N}\right)\frac{R_P}{R_{P_2}} = 3 \Rightarrow 9.06\frac{R_P}{R_{P2}} = 3 \Rightarrow R_{P_2} \simeq 3R_P$

$R_{P1} // R_{P2} = \frac{9 \times 3R_P}{9+3} = 2.25R_P$, $R_P = 2.25R_P // R_{P\phi}$

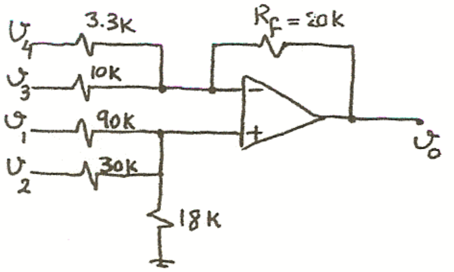
Cont.

$$2.25 R_p + R_{P_0} = 2.25 R_{P_0} \Rightarrow R_{P_0} = 1.8 R_p$$

if $R_p = 10\,K\Omega \Rightarrow R_{P_0} = 18\,K\Omega$

$$R_{P_1} = 9 \times 10K = 90\,K\Omega$$

$$R_{P_2} = 3 \times 10K = 30\,K\Omega$$



2.49

$$V_+ = v_I \frac{R_4}{R_3 + R_4} = v_-$$

$$\frac{v_-}{R_1} = \frac{v_o - v_-}{R_2} \Rightarrow v_o = v_-\left(1 + \frac{R_2}{R_1}\right)$$

from the two above equations :

$$\frac{v_o}{v_I} = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right) = \frac{1 + R_2/R_1}{1 + R_3/R_4}$$

2.50

Refer to Fig. 2.50. Setting $v_2 = 0$, we obtain the output component due to v_1 as:

$$v_{o1} = -20v$$

Setting $v_1 = 0$, we obtain the output component due to v_2 as:

$$v_{o2} = v_2\left(1 + \frac{20R}{R}\right)\left(\frac{20R}{20R + R}\right) = 20 v_2$$

The total output voltage is :

$$v_o = v_{o1} + v_{o2} = 20(v_2 - v_1)$$

For $v_1 = 10 \sin 2\pi \times 60t - 0.1 \sin(2\pi \times 1000t)$

$v_2 = 10 \sin 2\pi \times 60t + 0.1 \sin(2\pi \times 1000t)$

$$v_o = 4 \sin(2\pi \times 1000t)$$

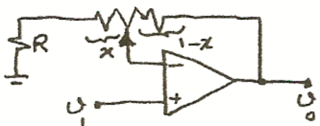
2.51

$$\frac{v_o}{v_i} = 1 + \frac{R_2}{R_1} = 1 + \frac{(1-x)}{x} = 1 + \frac{1}{x} - 1 = \frac{1}{x}$$

$$0 \leq x \leq 1 \Rightarrow 1 \leq \frac{v_o}{v_i} \leq \infty$$

if we add a resistor on the ground path :

$$\frac{v_o}{v_i} = 1 + \frac{(1-x) \times 10K}{x \times 10K + R}$$

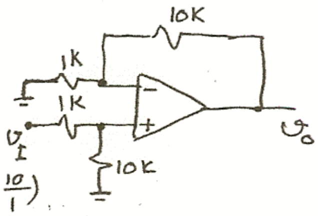


$\text{Gain}_{max} = 21$ when

$$x = 0 \Rightarrow 21 = 1 + \frac{10K}{R}$$

$$\Rightarrow R = \frac{10K}{20} = 0.5\,K\Omega$$

2.52



$$v_o = v_I \frac{10}{1+10}\left(1 + \frac{10}{1}\right)$$

$$v_o = 10 v_I$$

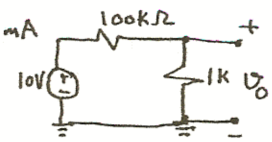
2.53

a) Source is connected directly.

$$v_o = 10 \times \frac{1}{101} = 0.099V$$

$$i_L = \frac{v_o}{1K} = \frac{0.099}{1} = 0.099\,mA$$

current supplied by the source is 0.099 mA.

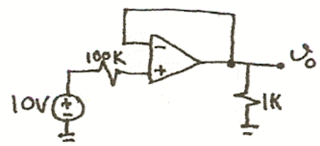


b) inserting a buffer

$$v_o = 10V$$

$$i_L = \frac{10V}{1K} = 10\,mA$$

current supplied by the source is 0.

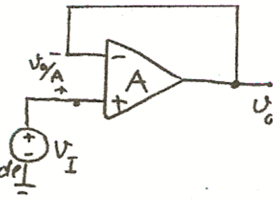


The load current i_L comes from the power supply of the op-amp.

2.54

$v_O = v_I - \frac{v_O}{A}$

$\frac{v_O}{v_I} = \frac{1}{1+\frac{1}{A}}$



error of Gain magnitude

$$\frac{\left|\frac{v_O}{v_I}-1\right|}{1} = -\frac{1}{A+1}$$

A (V/V)	1000	100	10
$\frac{v_O}{v_I}$ (V/V)	0.999	0.990	0.909
Gain Error	−0.1%	−1%	−9.1%

2.55

for an inverting amplifier:

$R_i = R_1$, $G = -\frac{R_2}{R_1}$

for a non-inverting amplifier:

$R_i = \infty$ $\quad G = 1+\frac{R_2}{R_1}$

Case	Gain V/V	Rin	R_1	R_2
a	−10	10K	10K	100K
b	−1	100K	100K	100K
c	−2	50K	50K	100K
d	+1	∞	10K	10K
e	+2	∞	10K	10K
f	+11	∞	10K	100K
g	−0.5	10K	10K	5K

2.56

$A = 50\,V/V \qquad 1+\frac{R_2}{R_1} = 10\,V/V$

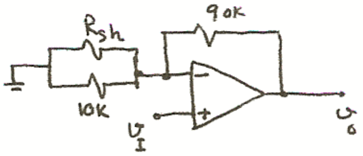
if $R_1 = 10k\Omega \Rightarrow R_2 = 90K$

According to Eq. 2.11: $G = \frac{v_O}{v_I} = \frac{1+\frac{R_2}{R_1}}{1+\frac{1+R_2/R_1}{A}}$

$G = \frac{1+90/10}{1+\frac{1+90/10}{50}} = \frac{10}{1.2} = 8.33\,V/V$

In order to compensate the gain drop, we can shunt a resistor with R_1.

Compensated:



R_{sh}: $\quad 10 = \frac{1+\left(\frac{90}{10}+\frac{90}{R_{sh}}\right)}{1+\frac{1+\frac{90}{10}+\frac{90}{R_{sh}}}{50}} \Rightarrow$

$10\times(510R_{sh}+90R_{sh}+900) = 50\times(10R_{sh}+90R_{sh}+900)$

$100R_{sh} = 3600 \Rightarrow \underline{R_{sh} = 36K\Omega}$

if $A = 100$ then:

$G_{uncompensated} = \frac{1+\frac{90}{10}}{1+\frac{1+90/10}{100}} = \frac{10}{1.1} = 9.09\,V/V$

$G_{compensated} = \frac{1+\frac{90}{10}+\frac{90}{36}}{1+\frac{1+\frac{90}{10}+\frac{90}{36}}{100}} = \frac{12.5}{1.125} = 11.1\,V/V$

2.57

$G = \frac{G_0}{1+\frac{G_0}{A}}$, $\quad \frac{G_0-G}{G_0}\times 100 = \frac{G_0/A\times 100}{1+\frac{G_0}{A}} \leq x$

or $\frac{1+\frac{G_0}{A}}{G_0/A} \geq \frac{100}{x} \Rightarrow \frac{A}{G_0} \geq \underbrace{\left(\frac{100}{x}-1\right)}_{F}$

$\Rightarrow A \geq G_0 F$ where $F = \frac{100}{x} - 1 \simeq \frac{100}{x}$

x	0.01	0.1	1	10
F	10^4	10^3	10^2	10

Thus for:

$x = 0.01$: G_0 (V/V)	1	10	10^2	10^3	10^4
A (V/V)	10^4	10^5	10^6	10^7	10^8

too high to be practical

$x = 0.1$: G_0 (V/V)	1	10	10^2	10^3	10^4
A (V/V)	10^3	10^4	10^5	10^6	10^7

$x = 1$: G_0 (V/V)	1	10	10^2	10^3	10^4
A (V/V)	10^2	10^3	10^4	10^5	10^6

$x = 10$: G_0 (V/V)	1	10	10^2	10^3	10^4
A (V/V)	10	10^2	10^3	10^4	10^5

2.58

for non-inverting amplifier, Eq. 2.11:

$G = \frac{G_0}{1+\frac{G_0}{A}}$, $\varepsilon = \frac{G_0 - G}{G_0}\times 100$

for inverting amplifier, Eq. 2.5:

$G = \frac{G_0}{1+\frac{1-G_0}{A}}$, $\varepsilon = \frac{G_0 - G}{G_0}\times 100$

Case	G_0 (V/V)	A (V/V)	G (V/V)	ε %
a	−1	10	−0.83	16
b	1	10	0.91	9
c	−1	100	−0.98	2
d	10	10	5	50
e	−10	100	−9	10
f	−10	1000	−9.89	1.1
g	+1	2	0.67	33

2.59

Refer to fig. P2.59, when potentiometer is set to the bottom:

$v_0 = v_+ = -15 + \frac{30\times 20}{20+100+20} = -10.714V$

when set to the top: $v_0 = -15 + \frac{30\times 120}{20+100+20} = 10.714V$

$\Rightarrow -10.714 \leq v_0 \leq +10.714$

pot has 20 turn, each turn: $\Delta v_0 = \frac{2\times 10.714}{20} = 1.07V$

2.60

Refer to Fig. 2.16. Notice that similar to eq. 2.15 we have: $\frac{R_4}{R_3} = \frac{R_2}{R_1} = \frac{100}{10}$.

therefore according to 2.16:

$v_0 = \frac{R_2}{R_1} v_{Id} \Rightarrow A = \frac{R_2}{R_1} = 10$ V/V

According to 2.20: $R_{id} = 2R_1 = 20k\Omega$

If $\frac{R_2}{R_1}$, $\frac{R_4}{R_3}$ were different by 1%:

$\frac{R_2}{R_1} = 0.99\frac{R_4}{R_3}$

Refer to eq. 2.19: $A_{cm} = \frac{R_4}{R_4+R_3}\left(1-\frac{R_2}{R_1}\cdot\frac{R_3}{R_4}\right)$

$A_{cm} = \frac{100}{100+10}(1-0.99) = 0.009$

$CMRR = 20\log\frac{|A_d|}{|A_{cm}|}$, so let's calculate A_d

$A_d = \frac{v_o}{v_{id}}$ if we apply superposition:

$v_{01} = -\frac{R_2}{R_1} v_{I_1}$ $\quad v_{02} = v_{I2}\frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)$

$v_0 = v_{02} + v_{01} = v_{I2}\frac{R_4/R_3}{1+\frac{R_4}{R_3}}\left(1+\frac{R_2}{R_1}\right) - \frac{R_2}{R_1}v_{I_1}$

Replace: $\frac{R_2}{R_1} = 0.99\frac{R_4}{R_3} \Rightarrow \frac{R_2}{R_1} = 0.99\times\frac{100}{10} = 9.9$

$v_0 = v_{I2}\frac{10}{1+10}(1+9.9) - v_{I_1}9.9 = 9.9(v_{I2} - v_{I_1})$

$\frac{v_0}{v_{Id}} = 9.9 = A_d \Rightarrow CMRR = 20\log\frac{9.9}{0.009} = 60.8$

$CMRR = 60.8$

2.61

If we assume $R_3 = R_1$, $R_4 = R_2$, then eq. 2.20: $R_{id} = 2R_1 \Rightarrow R_1 = \frac{20}{2} = 10k\Omega$

(Refer to fig. 2.16)

a) $A_d = \frac{R_2}{R_1} = 1$ V/V $\Rightarrow R_2 = 10k\Omega$

$R_1 = R_2 = R_3 = R_4 = 10k\Omega$

b) $A_d = \frac{R_2}{R_1} = 2$ V/V $\Rightarrow R_2 = 20k\Omega = R_4$

$R_1 = R_3 = 10k\Omega$

c) $A_d = \frac{R_2}{R_1} = 100$ V/V $\Rightarrow R_2 = 1M\Omega = R_4$

$R_1 = R_3 = 10k\Omega$

d) $A_d = \frac{R_2}{R_1} = 0.5$ V/V $\Rightarrow R_2 = 5k\Omega = R_4$

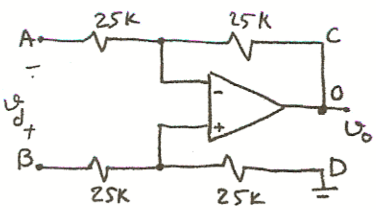
$R_1 = R_3 = 10k\Omega$

2.62

Refer to Fig P2.62:

Cont.

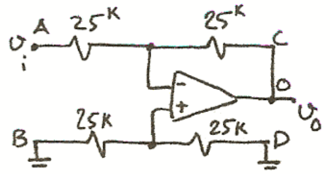
a)



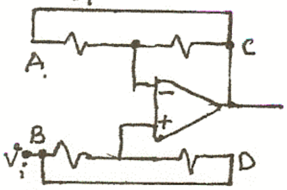
$A_d = 1$

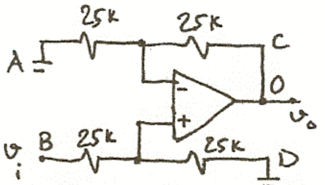
b) $\frac{v_o}{v_i} = -1\ V/V$

i)



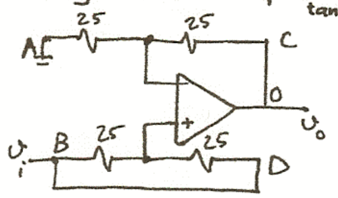
ii) $\frac{v_o}{v_i} = +1\ V/V$





The circuit on the left ideally has infinite input resistance

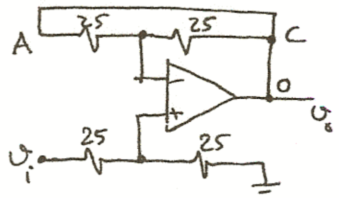
iii) $\frac{v_o}{v_i} = +2\ V/V$



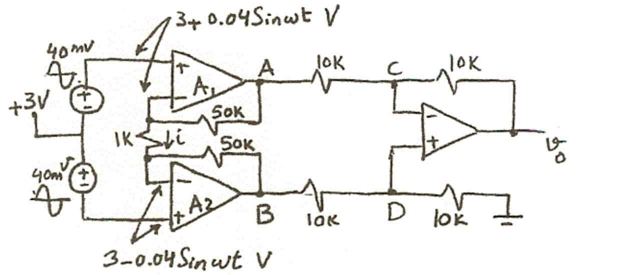
iv) $\frac{v_o}{v_i} = +\frac{1}{2}\ V/V$

$v_+ = \frac{v_i}{2} = v_o$

$\Rightarrow \frac{v_o}{v_i} = \frac{1}{2}$



2.72



$i = \frac{3+0.04\sin\omega t-(3-0.04\sin\omega t)}{1K} = 0.08\sin\omega t,\ mA$

$v_A = 3+0.04\sin\omega t + 50K \times i = 3+4.04\sin\omega t,\ V$

$v_B = 3-0.04\sin\omega t - 50K \times i = 3-4.04\sin\omega t,\ V$

$v_C = v_D = \frac{1}{2} v_B = 1.5 - 2.02\sin\omega t,\ V$

$v_o = v_B - v_A = -8.08\sin\omega t,\ V$

2.73

Refer to Fig. 2.20.a.

The gain of the first stage is: $(1+\frac{R_2}{R}) = 101$

If the opamps of the first stage saturate at ±14 V: $-14 \leq v_I \leq +14V \Rightarrow -14 \leq 101\, v_{ICM} \leq +14$

$\Rightarrow -0.14 \leq v_{ICM} \leq 0.14$

As explained in the text, the disadvantage of circuit in Fig. 2.20.a is that v_{ICM} is amplified by a gain equal to vid, $(1+\frac{R_2}{R})$ in the first stage and therefore a very small v_{icm} range is acceptable to avoid saturation.

b) In Fig. 2.20b, when v_{ICM} is applied, v_- for both A_1 & A_2 is the same and therefore no current flows through $2R_1$. This means voltage at the output of A_1 and A_2 is the same as V_{ICM}.

$-14 \leq v_o \leq 14 \Rightarrow -14 \leq v_{ICM} \leq 14$

This circuit allows for bigger range of V_{icm}.

2.74

$v_{i1} = v_{cm} - v_d/2$

$v_{i2} = v_{cm} + v_d/2$

Refer to fig. 2.20.a.

output of the first stage: $(1+\frac{R_2}{R_1})(v_{cm} - \frac{v_d}{2})$

$v_{o1} = (1+\frac{R_2}{R_1})(v_{cm} - v_d/2)$

$v_{o2} = (1+\frac{R_2}{R_1})(v_{cm} + v_d/2)$

$v_{o2} - v_{o1} = (1+\frac{R_2}{R_1})\, v_d \Rightarrow A_{d(1)} = 1+\frac{R_2}{R_1}$

$\frac{v_{o2}+v_{o1}}{2} = (1+\frac{R_2}{R_1})\, v_{cm} \Rightarrow A_{cm(1)} = 1+\frac{R_2}{R_1}$

$CMRR = 20 \log \left|\frac{A_d}{A_{cm}}\right| = 0$ (First stage)

Now Consider Fig. 2.20.b

$v_{o1} = v_{i1} + R_2 \times \frac{(v_{i1}-v_{i2})}{2R_1}$

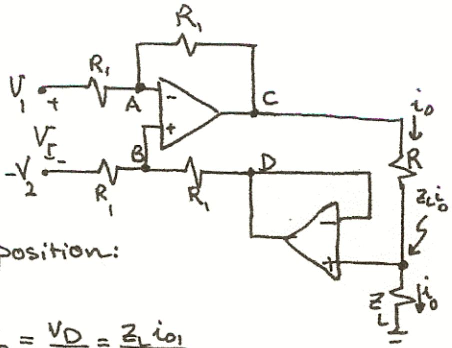
$v_{o1} = v_{cm} - v_d/2 + \frac{R_2}{2R_1}(-v_d)$

Cont.

2.78

Refer to Fig. P.2.78.a:
Since the inputs of the op-amp donot draw any current, V_I appears across R:
$i_o = \frac{V_I}{R}$

Fig. P2.78.B



$V_D = Z_L i_o$

we use superposition:
$V_I = V_1 - V_2$

V_1 only: $\quad V_B = \frac{V_D}{2} = \frac{Z_L i_{o1}}{2}$

$$\frac{V_1 - \frac{Z_L i_{o1}}{2}}{R_1} = \frac{\frac{Z_L i_{o1}}{2} - i_{o1}(Z_L + R)}{R_1}$$

$\Rightarrow V_1 = i_{o1} R \Rightarrow i_{o1} = \frac{V_1}{R}$

Now if only $(-V_2)$ is applied:
$V_B = \frac{-V_2 + Z_L i_{o2}}{2}$, $\quad V_A = \frac{i_{o2} \times (R + Z_L)}{2}$

$V_A = V_B \Rightarrow -V_2 + Z_L i_{o2} = i_{o2} R + i_{o2} Z_L$
$-V_2 = i_{o2} R \Rightarrow i_{o2} = \frac{-V_2}{R}$

The total current due to both sources is:
$i_o = i_{o1} + i_{o2} = \frac{V_1}{R} - \frac{V_2}{R} = \frac{V_I}{R}$

The circuit in Figure P2.78(a) has ideally infinite input resistance, and it requires that both terminals of Z_L be availabe, while the other circuit has finite input resistance with one side of Z_L grounded.

2.79

A_o	f_b (Hz)	f_t (Hz)
10^5	10^2	10^7
10^6	1	10^6
10^5	10^3	10^8
10^7	10^{-1}	10^6
2×10^5	10	2×10^6

eq. 2.28:
$\omega_t = A_o \omega_b$
$\Rightarrow f_t = A_o f_b$

2.80

Eq. 2.25: $A = \frac{A_o}{1 + j\,\omega/\omega_b} \Rightarrow |A| = \frac{|A_o|}{\sqrt{1 + \left(\frac{f}{f_b}\right)^2}}$

$A_o = 86\text{db}$, $A = 40\text{db}$ @ $f = 100\text{KHZ}$

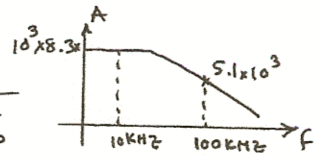
$20\log\sqrt{1 + \left(\frac{f}{f_b}\right)^2} = 20\log\frac{|A_o|}{|A|} = 20\log A_o - 20\log A$
$= 86 - 40 = 46\text{db}$

$1 + \left(\frac{100\text{KHZ}}{f_b}\right)^2 = (199.5)^2 \Rightarrow f_b = 0.501\text{KHZ}$
$f_b = 501\text{ HZ}$

$f_t = A_o f_b = \underbrace{1.995\times10^4}_{86\text{db}} \times 501 = 9.998\text{ MHZ} \cong 10\text{MHZ}$

2.81

$A_o = 8.3\times10^3\ V/V$



Eq. 2.25: $A = \frac{A_o}{1 + j\frac{f}{f_b}}$

$f_t = A_o f_b$

$5.1\times10^3 = \frac{8.3\times10^3}{\sqrt{1 + \left(\frac{100\text{KH}}{f_b}\right)^2}} \Rightarrow 1 + \left(\frac{100\text{KHZ}}{f_b}\right)^2 = 2.65$

$f_b = 60.7\text{ KHZ}$
$f_t = A_o f_b = 8.3\times10^3 \times 60.7\text{K} = 503\text{ MHZ}$

2.82

we have:
$A_{o(db)} = 20\text{db} + A_{(db)}$ $\quad 20\text{db} = 20\log10 \Rightarrow A_o = 10\times A$

a) $A_o = 10\times3\times10^5 = 3\times10^6\ \text{HZ}\ V/V$
$A = \frac{A_o}{1 + jf/f_b} \Rightarrow \left|1 + j\frac{f}{f_b}\right| = \frac{A_o}{A} = 10 \Rightarrow \frac{6\times10^2}{f_b} = \sqrt{99}$

$\Rightarrow f_b = 60.3\text{ HZ}$
$f_t = A_o f_b = 3\times10^6 \times 60.3 = 180.9\text{ MHZ}$

b) $A = 50\times10^5\ V/V \Rightarrow A_o = 10\times50\times10^5 = 50\times10^6\ V/V$
$\left|1 + \frac{jf}{f_b}\right| = \frac{A_o}{A} = 10 \Rightarrow \frac{10\ \text{HZ}}{f_b} = \sqrt{99} \Rightarrow f_b = 1\text{ HZ}$
$f_t = A_o f_b = 50\text{ MHZ}$

c) $A = 1500\ V/V \Rightarrow A_o = 15000\ V/V$

Cont.

$$\left|1+\frac{jf}{f_b}\right| = 10 \Rightarrow \frac{0.1\times10^6}{f_b} = \sqrt{99} \Rightarrow f_b = 10\,KHZ$$

$$f_t = 15000 \times 10^K = 150\,MHZ$$

d) $A_o = 10\times100 = 1000\ V/V$

$$\left|1+\frac{jf}{f_b}\right| = 10 \Rightarrow \frac{0.1\times10^9}{f_b} = \sqrt{99} \Rightarrow f_b = 10\ MHZ$$

$$f_t = 1000\times 10^{MHZ} = 10\,GHZ$$

e) $A_o = 25\ V/mV \times 10 = 25\times10^4\ V/V$

$$\left|1+\frac{jf}{f_b}\right| = 10 \Rightarrow \frac{25KHZ}{f_b} = \sqrt{99} \Rightarrow f_b = 2.51^{KHZ}$$

$$f_t = A_o f_b = 25\times10^4\times 2.51\times10^3 = 627.5\,MHZ$$

2.83

$G_{nom} = -\frac{R_2}{R_1} = -20 \qquad A_o = 10^4\ V/V \qquad f_t = 10^6\,HZ$

Eq. 2.35 : $\omega_{3db} = \frac{\omega_t}{1+R_2/R_1} = \frac{2\pi\times10^6}{1+20} = 2\pi\times47.6\ KHZ$

$f_{3db} = 47.6\,KHZ$

Eq. 2.34 : $\frac{V_o}{V_i} \simeq \frac{-R_2/R_1}{1+\frac{s}{\omega_t/(1+\frac{R_2}{R_1})}} = \frac{-20}{1+\frac{21s}{2\pi\times10^6}}$

$f = 0.1\,f_{3db} \Rightarrow \left|\frac{V_o}{V_i}\right| = \frac{-20}{\sqrt{1+(0.1)^2}} = -19.9\ V/V$

$f = 10\,f_{3db} \Rightarrow \left|\frac{V_o}{V_i}\right| = \frac{-20}{\sqrt{1+100}} = 1.99\ V/V$

2.84

$1+\frac{R_2}{R_1} = 100\ V/V \quad , \quad f_t = 20\,MHZ$

$f_{3db} = \frac{f_t}{1+\frac{R_2}{R_1}} = 200\ KHZ$

$G(j\omega) = \frac{100}{1+j\,f/f_{3db}} \Rightarrow \varphi = -\tan^{-1}\frac{f}{f_{3db}} =$

$\varphi = -6^\circ \Rightarrow f = f_{3db}\times\tan 6^\circ = 21\,KHZ$

$\varphi = -84^\circ \Rightarrow f = f_{3db}\times\tan 84^\circ = 1.9\,MHZ$

2.85

a) $-\frac{R_2}{R_1} = -100\ V/V \quad , \quad f_{3db} = 100\,KHZ$

Eq. 2.35 : $\omega_t = \omega_{3db}\left(1+\frac{R_2}{R_1}\right) \Rightarrow f_t = 100^K\times101 = 10.1\ MHZ$

b) $1+\frac{R_2}{R_1} = 100\ V/V \qquad f_{3db} = 100\,KHZ$

$f_t = f_{3db}\left(1+\frac{R_2}{R_1}\right) = 10\ MHZ$

c) $1+\frac{R_2}{R_1} = 2\ V/V \qquad f_{3db} = 10\,MHZ$

$f_t = 10\,MHZ\times2 = 20\ MHZ$

d) $-\frac{R_2}{R_1} = -2\ V/V \qquad f_{3db} = 10\,MHZ$

$f_t = 10\ MHZ\,(1+2) = 30\ MHZ$

e) $-\frac{R_2}{R_1} = -1000\ V/V \qquad f_{3db} = 20\,KHZ$

$f_t = 20K\,(1+1000) = 20.02\,MHZ$

f) $1+\frac{R_2}{R_1} = 1\ V/V \qquad f_{3db} = 1\,MHZ$

$f_t = 1M\times1 = 1\,MHZ$

g) $-\frac{R_2}{R_1} = -1 \qquad f_{3db} = 1\,MHZ$

$f_t = 1M\,(1+1) = 2\,MHZ$

2.86

$1+\frac{R_2}{R_1} = 100\ V/V \qquad f_{3db} = 8\,KHZ$

$f_t = 8\times100 = 800\,KHZ$

for $f_{3db} = 20\,KHZ$: $G_o = \frac{800}{20} = 40\ V/V$

2.87

$f_{3db} = f_t = 1\,MHZ$

$|G| = \frac{1}{\sqrt{1+\left(\frac{f}{f_{3db}}\right)^2}} = \frac{1}{\sqrt{1+f^2}} \qquad f \text{ in } MHZ$

$|G| = 0.99 \Rightarrow f = 0.142\,MHZ$

The follower behaves like a low-pass STC circuit with a time constant $\tau = \frac{1}{\omega_{3db}}$

Thus: $\tau = \frac{1}{2\pi\times10^6} = \frac{1}{2\pi}\ \mu s$

$t_r = 2.2\tau = 0.35\,\mu s \qquad$ (Refer to Appendix F)

Output distortion will be due to slew Rate limitation and will occur at the frequency for which $\left.\frac{dv_o}{dt}\right|_{max} = SR$

$$\omega_{max} \times 5 = \frac{1}{10^{-6}} = 2\times10^{5}\ rad/s \Rightarrow f_{max} = 31.8KHz$$

b) The output will distort at the value of V_i that results in $\left.\frac{dv_o}{dt}\right|_{max} = SR$.

$v_o = 10\,v_i \sin 2\pi\times20\times10^{3}$

$\left.\frac{dv_o}{dt}\right|_{max} = 10\,v_i \times 2\pi\times 20\times10^{3}$

Thus $v_i = \frac{1/10^{-6}}{10\times2\pi\times20\times10^{3}} = 0.795\ V$

c) $v_i = 50mV$ $V_o = 500mV = 0.5V$

Slew rate begins at the frequency for which $w\times0.5 = SR$

which gives $w = \frac{1/10^{-6}}{0.5} = 2\times10^{6}\ rad/s$ or $f = 318.3\ KHz$

However the small signal 3db frequency is

$$f_{3db} = \frac{f_t}{1+\frac{R_2}{R_1}} = \frac{2\times10^{6}}{10} = 200KHz$$

Thus the useful frequency range is limited at 200KHz.

d) for $f = 5KHz$, the slew Rate limitation occurs at the value of v_i given by

$$w\times10\,V_i = SR \Rightarrow V_i = \frac{1/10^{-6}}{2\pi\times5\times10^{3}\times10} = 3.18\ V$$

Such an input voltage, however would ideally result in an output of 31.8V which exceeds V_{omax}. Thus $V_{imax} = \frac{V_{omax}}{10} = 1\ V$ peak.

2.100

$$v_o = v_{os}\left(1+\frac{R_2}{R_1}\right) \Rightarrow -0.3 = V_{os}\left(1+\frac{100}{1}\right) \approx 3mV$$

2.101

$v_{os} = \pm2mV$

$v_o = 0.01 \sin\omega t \times 200 + v_{os}\times200 = 2\sin\omega t \pm 0.4\ V$

2.102

Output DC offset, $v_{os} = 3mV\times1000 = 3V$

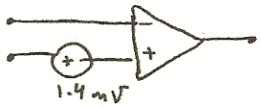
Therefore the maximum amplitude of an input sinusoid is the one that results in an output peak amplitude of $13-3 = 10V \Rightarrow v_i = \frac{10}{1000} = 10\ mV$

If the amplifier is capacity coupled, then:

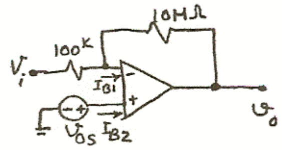
$v_{imax} = \frac{13}{1000} = 13mV$

2.103

$v_{os} = \frac{1.4}{100} = 1.4\ mV$



2.104



a) $I_B = (I_{B1} + I_{B2})/2$

open input:

$v_o = V_+ + R_2 I_{B_1} = v_{os} + R_2 I_{B1}$

$9.31 = v_{os} + 10000\, I_{B1}$ (1)

input connected to ground:

$v_o = V_+ + R_2\left(I_{B1} + \frac{v_{os}}{R_1}\right) = v_{os}\left(1+\frac{R_2}{R_1}\right) + R_2 I_{B1}$

$9.09 = v_{os}\times101 + 10000\, I_{B1}$ (2)

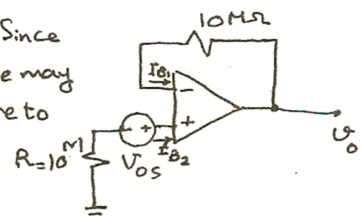
(1), (2) $\Rightarrow 100\,v_{os} = -0.22 \Rightarrow v_{os} = -2.2mV$

$\Rightarrow I_{B_1} = 930nA$

$I_B \simeq I_{B_1} = 930nA$

b) $v_{os} = -2.2\ mV$

c) In this case, Since R is too Large, we may ignore v_{os} compare to the voltage drop across R.



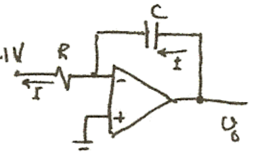
$v_{os} \ll R I_B$, Also Eq. 2.46 holds: $R_3 = R_1 \| R_2$

therefore from Eq. 2.47: $v_o = I_{os}\times R_2 \Rightarrow I_{os} = \frac{-0.8}{10^{M}}$

$I_{os} = -80\ nA$

d) The phase doesnot change and the output still leads the input by 90°

2.113



$R_{in} = R = 100K\Omega$

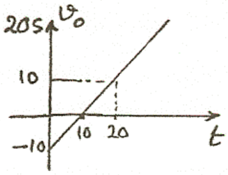
$CR = 1S \Rightarrow C = \frac{1}{100\times10^3} = 10\mu F$

with a $-1V$ dc input applied, the capacitor charges with a constant current:

$I = \frac{1V}{R} = 0.01\ mA$ and its voltage rises linearly:

$v_o(t) = -10 + \frac{1}{C}\int_0^t I dt = -10 + \frac{I}{C}t = -10 + \frac{t}{RC}$

the voltage reaches $0V$ at $t = 10RC = 10s$ and it reaches $10V$ at $t = 20s$



2.114

$|T| = \frac{1}{\omega RC}$ If $|T| = 100V/_V$ for $f = 1^{KHZ}$, then for $|T| = 1V/_V$, f has to be $1^K \times 100 = 100\ KHZ$.

Also $RC = \frac{1}{\omega\cdot T} = \frac{1}{2\pi\times1^K\times100} = 1.59\ \mu s$

2.115

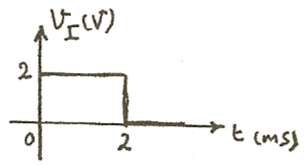
$R_{in} = R$, Thus $R = 100k\Omega$.

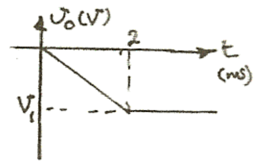
$|T| = \frac{1}{WRC} = 1$ at $\omega = \frac{1}{RC}$.

$\omega = 1000 = \frac{1}{RC} \Rightarrow C = \frac{1}{1000\times100^k} = 10^{nF}$

with a $2V$-$2ms$ pulse at the input, the output falls linearly until $t = 2ms$ at which $v_o = V_1$, $v_o = \frac{-I}{C}t = \frac{-2}{RC}t = -2t$ Volts where t in ms

Thus $V_1 = -4V$





with $V_I = 2 Sin\ 1000t$ applied at the input,

$v_o(t) = 2\times\frac{1}{1000\times10^{-3}} Sin(1000t + 90^\circ)$

$v_o(t) = 2\ Sin(1000t + 90^\circ)$

2.116

$R_{in} = R = 20k\Omega$

$|T| = \frac{1}{WRC} = 1$ at $\omega = 2\pi\times10^{KHZ} \Rightarrow C = \frac{1}{2\pi\times10^k\times20^K}$

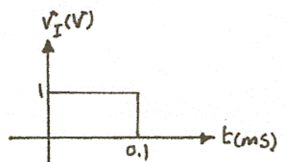
$C = 0.796\ nF$

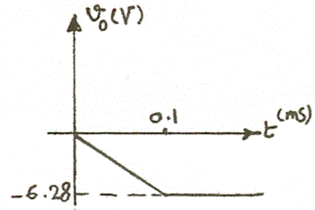
Refer to discussion in page 110:

$\frac{V_o}{V_i} = \frac{R_F/R}{1+s\ CR_F}$ and the finite dc gain is $-\frac{R_F}{R}$. There fore for 40db gain or equivalently $100V/_V$ we have: $\frac{-R_F}{R} = -100\ V/_V$

$\Rightarrow R_F = 100\times20K = 2M\Omega$

The corner frequency $\frac{1}{C\ R_F}$ is: $\frac{1}{0.796^n\times2^M} = 628^{HZ}$





a) when no R_F

$v_o(t) = \frac{-1}{RC}\int_0^t 1.dt = -62.8t$ $\quad 0 \leq t \leq 0.1ms$

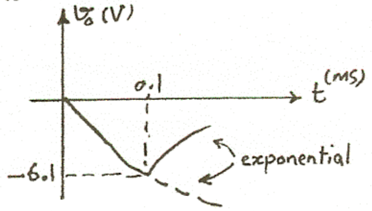
$v_o(0.1) = -6.28V$

b) with R_F: $v_o(t) = V_o(\infty)(1 - e^{-t/CR_F})$

(Refer to pg. 112)

$v_o(\infty) = -I\times R_F = -\frac{1V}{20k}\times2^M = -100V$

$v_o(t) = -100(1 - e^{-t/1.6})$

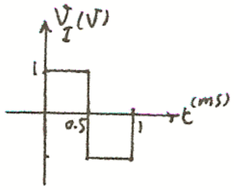


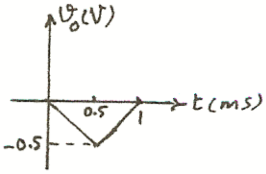
2.117

For $0 \leq t \leq 0.5\,ms$: $v_O(t) = v_O(0) - \frac{1}{RC}\int_0^t v_I\,dt$

$v_O(t) = 0 - \frac{t}{RC} = -\frac{t}{1ms}$

$v_O(0.5) = -0.5V$





for $0.5 \leq t \leq 1\,ms$: $v_O(t) = v_O(0.5) - \frac{1}{RC}\int_{0.5}^t -1\,dt$

$v_O(t) = -0.5 + \frac{1}{RC}(t - 0.5)$

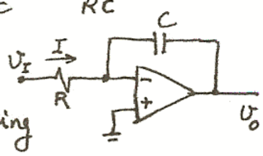
$v_O(1^{ms}) = -0.5 + \frac{0.5}{1} = 0V$

Another way of thinking about this circuit is as follows:

for $0 \leq t \leq 0.5\,ms$ a current $I = \frac{1^V}{R}$ flows through R and C in the direction indicated on the diagram. At time t we write:

$I.t = -C\,v_O(t) \Rightarrow v_O(t) = \frac{-I}{C}t = \frac{-1}{RC}t$

which indicates that the output voltage is linearly decreased, reaching $-0.5V$ at $t = 0.5ms$.



Then for $0.5 \leq t \leq 1^{ms}$, the current flows in the opposite direction and v_O riser linearly reaching 0^V at $t = 1ms$.

For $v_I = \pm 2V$: we obtain the following waveform: (assuming time constant is the same)

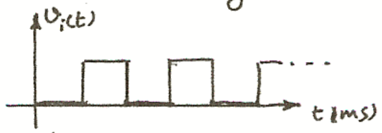
If RC is also doubled, then the waveform becomes the same as the first case where $v_I = \pm 1V$ and $RC = 1^{ms}$.

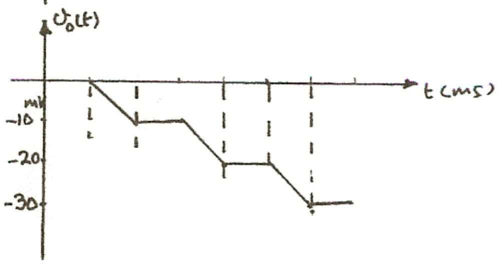
2.118

Each pulse lowers the output voltage by:

$\Delta v_O = \frac{1}{RC}\int_0^{10ms} 1.dt = \frac{10^{\mu s}}{RC} = \frac{10^{\mu s}}{1^{ms}} = 10^{mV}$

Therefore a total of 100 pulses are required to cause a change of $1V$ in $v_O(t)$.





2.119

Refer to Fig. P2.119.

$\frac{V_o}{V_i} = -\frac{Z_2}{Z_1} = -\frac{Y_1}{Y_2} = -\frac{1/R_1}{1/R_2 + SC} = -\frac{R_2/R_1}{1 + SCR_2}$

which is an STC LP circuit with a dc gain of $-\frac{R_2}{R_1}$ and a 3-db frequency $\omega_0 = \frac{1}{CR_2}$.

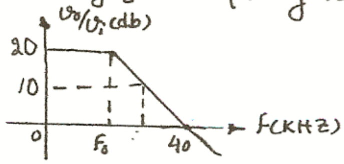
The input resistance equal to R_1. So for:

$R_i = 1K \Rightarrow \underline{R_1 = 1K\Omega}$ and for dc-gain of 20^{db} or 10 : $\frac{R_2}{R_1} = 10 \Rightarrow \underline{R_2 = 10\ K\Omega}$

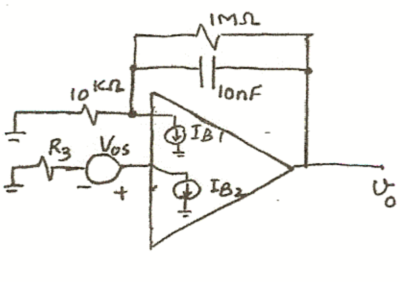
for 3db frequency of 4KHZ: $\omega_0 = 2\pi \times 4 \times 10^3 = \frac{1}{CR_2}$

$\Rightarrow C \cong \underline{4nF}$

the unity gain frequency is (odb) is 40 KHZ



2.120



Cont.