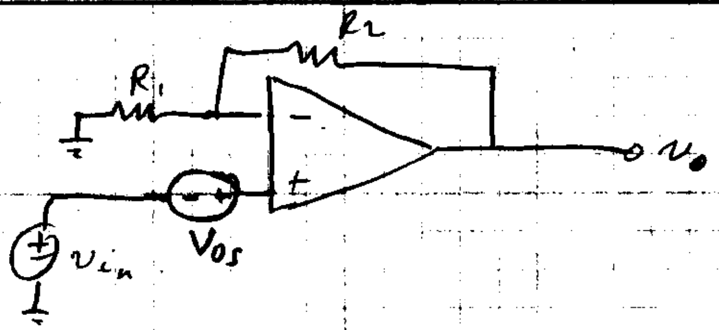
EE 321

Fall 2002

Homework #4

Solutions

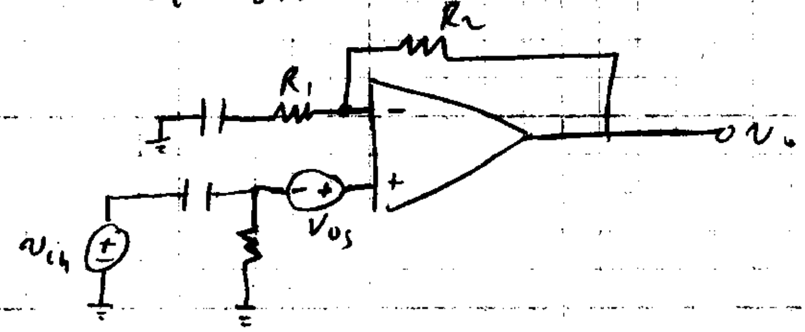
2.87



$$v_0 = \left(1 + \frac{R_2}{R_1}\right)(V_{os} + v_{in}) = 1000(4mV + V_i \sin \omega t)$$

$$v_{o_{max}} = 1000(4mV + V_i) = 12V$$

$$V_i = 8mV$$



Use superposition

With $v_{in} = 0$, $v_+ = V_{os}$ so $v_- = v_+ = V_{os}$

No current flows through R_1, so no current flows through R_2, and $v_0 = v_- = V_{os} = 4mV$

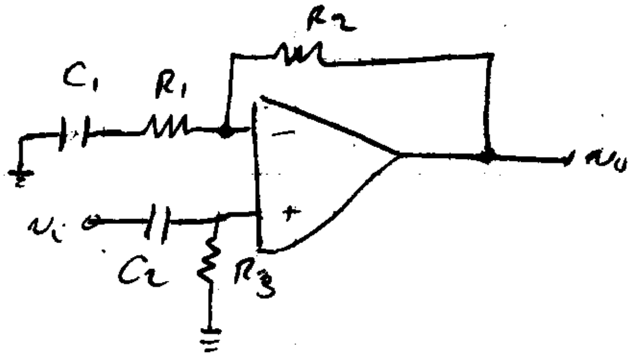
With V_{os} off and v_{in} on, capacitors act like shorts at AC, so $v_0 = 1000\, v_{in} = 1000\, V_i \sin \omega t$

Add the two: $v_o = 4mV + 1000\, V_i \sin \omega t$

$$v_{o_{max}} = 4mV + 1000\, V_i = 12V$$

$$V_i = \frac{12V - 4mV}{1000} \approx \frac{12V}{1000} = 12mV$$

2.91



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

Let $R_2 = 99\,k\Omega$, $R_1 = 1\,k\Omega$

Want $R_3 = R_2 = 99\,k\Omega$ (Want $R_3 = R_2 \parallel (R_1 + \frac{1}{Cs})$ at DC. At DC, $1/Cs = \infty$, so $R_3 = R_2$)

v_o sees R_1, R_2 and C_1 is series, so $\omega_1 = \frac{1}{(R_1+R_2)C_1}$

$$f_1 = \frac{1}{2\pi(R_1+R_2)C_1} \qquad C_1 = \frac{1}{2\pi(R_1+R_2)f_1}$$

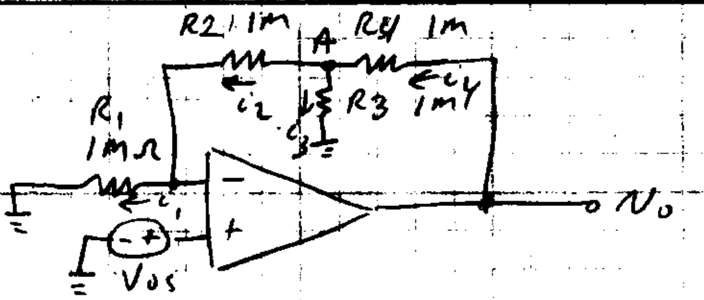
For $f_1 = 100\,Hz$, $C_1 = 16\,nF$

v_i sees C_2 and R_3 in series, so $f_2 = \frac{1}{2\pi R_3 C_2}$

$$C_2 = \frac{1}{2\pi R_3 f_2}$$

For $f_2 = 10\,Hz$, $C_2 = 0.16\,\mu F$

2.93



$$v_- = v_+ = V_{OS} \qquad i_1 = \frac{V_{OS}}{R_1} \qquad i_2 = i_1 = \frac{V_{OS}}{R_1}$$

$$i_2 = \frac{V_A - v_-}{R_2} \Rightarrow V_A = i_2 R_2 + v_- = \frac{V_{OS} R_2}{R_1} + V_{OS}$$

$$i_3 = \frac{V_A}{R_3} = \frac{V_{OS} R_2}{R_1 R_3} + \frac{V_{OS}}{R_3}$$

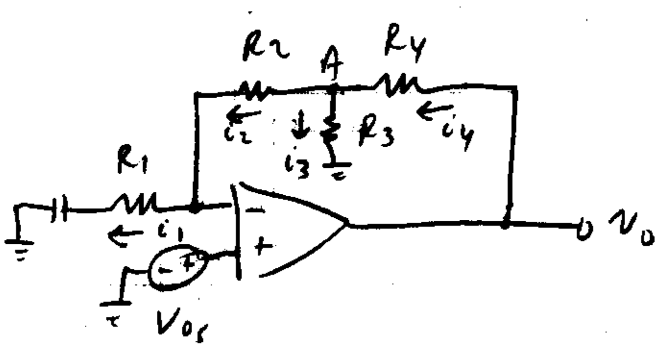
$$i_4 = i_2 + i_3 = \frac{V_{OS}}{R_1} + \frac{V_{OS} R_2}{R_1 R_3} + \frac{V_{OS}}{R_3}$$

$$i_4 = \frac{v_o - V_A}{R_4} \Rightarrow v_o = i_4 R_4 + V_A$$

$$v_o = \frac{V_{OS} R_4}{R_1} + \frac{V_{OS} R_2 R_4}{R_1 R_3} + \frac{V_{OS} R_4}{R_3} + \frac{V_{OS} R_2}{R_1} + V_{OS}$$

$$\approx 2003\, V_{OS}$$

For $V_{OS} = \pm 5\,mV$, $\boxed{v_o = \pm 10\,V}$



$v_- = v_+ = V_{os}$ $\quad i_1 = 0 \quad i_2 = i_1 = 0$

$$i_2 = \frac{V_A - v_-}{R_2} \Rightarrow V_A = i_2 R_2 + v_- = V_{os}$$

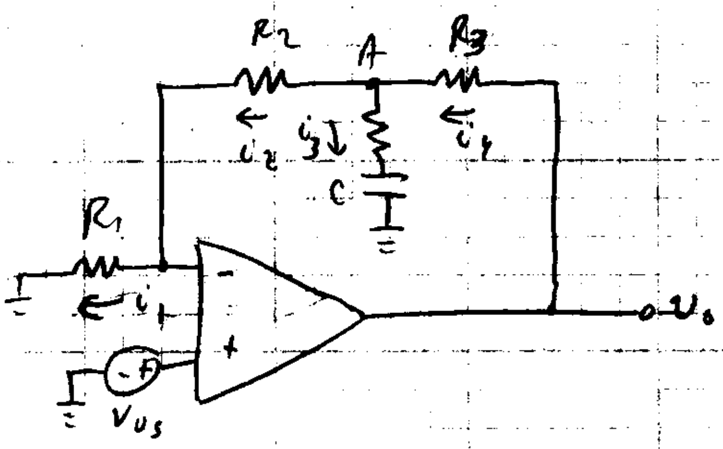
$$i_3 = \frac{V_A}{R_3} = \frac{V_{os}}{R_3}$$

$$i_4 = i_2 + i_3 = \frac{V_{os}}{R_3}$$

$$i_4 = \frac{v_0 - V_A}{R_4} \Rightarrow v_0 = i_4 R_4 + V_A$$

$$v_0 = \frac{V_{os} R_4}{R_3} + V_{os} = 1001\ V_{os}$$

For $V_{os} = \pm 5\,mV$, $\boxed{v_0 = \pm 5\ V}$



$v_+ = v_- = V_{os}$ $\quad i_1 = \frac{V_{os}}{R_1}$ $\quad i_2 = i_1 = \frac{V_{os}}{R_1}$

$i_2 = \frac{V_A - v_-}{R_2} \Rightarrow V_A = i_2 R_2 + v_- = \frac{V_{os} R_2}{R_1} + V_{os}$

$i_3 = 0$ $\quad i_4 = i_2 + i_3 = \frac{V_{os}}{R_1}$

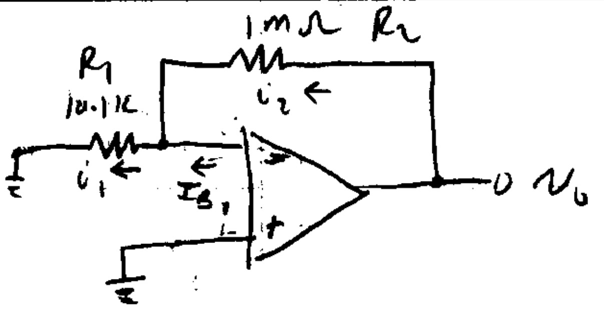
$i_4 = \frac{v_o - V_A}{R_4} \Rightarrow v_o = i_4 R_4 + V_A$

$v_o = \frac{V_{os} R_4}{R_1} + \frac{V_{os} R_2}{R_1} + V_{os}$

$v_o = 3 V_{os}$

For $V_{os} = \pm 5 mV$, $\boxed{v_o = \pm 15 mV}$

2.95



(a) $v_- = v_+ = 0 \Rightarrow i_1 = 0$

$i_1 = i_2 + i_{B_1} \Rightarrow i_2 = -i_{B_1}$ $\qquad v_o = i_2 R_2 = -i_{B_1} R_2$

$v_o = \pm 0.10V$ Due to input bias current, $i_{B_1} = \pm 100nA$

(b) $v_- = v_+ = V_{OS}$ $\qquad i_1 = \frac{v_-}{R_1} = \frac{V_{OS}}{R_1}$

$v_o = i_1 (R_1 + R_2) = V_{OS}\left(1 + \frac{R_1}{R_2}\right) = 100\, V_{OS} = \pm 0.10V$

Largest v_o will be sum of absolute values of above.

$v_o = 0.2V$

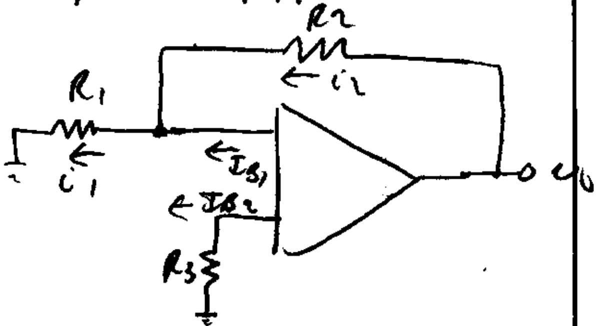
(c) $R_3 = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2} = 10K\Omega$

Assume $I_{B_1} = 100nA$ $I_{B_2} = 90nA$, for 10nA offset current

$v_+ = I_{B_2} R_3 = 0.9mV$ $\qquad v_- = v_+ = 0.9mV$

$i_1 = \frac{v_-}{R_1} = 90nA$

$i_1 = i_2 + i_{B_1} \Rightarrow i_2 = i_1 - i_{B_1} = -10nA$

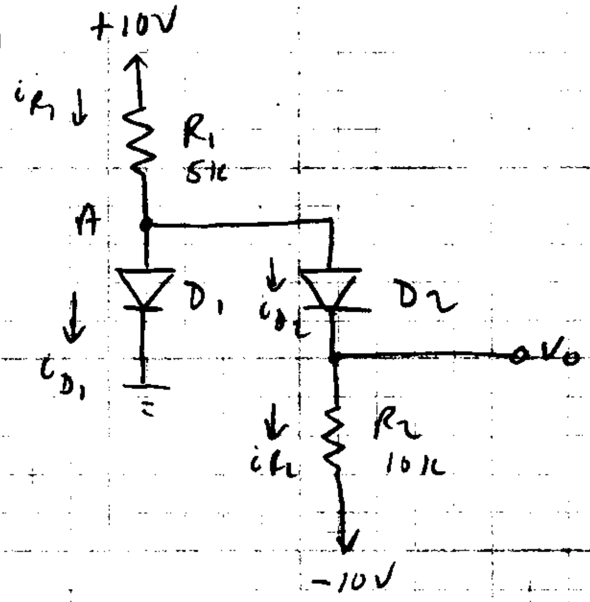


$v_o = i_2 R_2 + v_- = -9.1mV$

$v_o = \pm 9mV \simeq \pm 10mV$

(d) Offset voltage is still 0.1V, so total is 110mV

3.9 (a)



Assume D_1, D_2 both on:

$V_A = 0$, $V_o = 0$ $\Rightarrow$ $V_{D_1} = 0$ $\quad V_{D_2} = 0$

$i_{R_1} = \dfrac{10\,V}{5k\Omega} = 2\,mA \qquad i_{R_2} = \dfrac{10\,V}{10k\Omega} = 1\,mA$

$i_{D_2} = i_{R_2} = 1\,mA$

$i_{R_1} = i_{D_1} + i_{D_2} \Rightarrow i_{D_1} = i_{R_1} - i_{D_2} = 1\,mA$

We have $V_{D_1} = 0 \quad i_{D_1} = 1\,mA$ ok

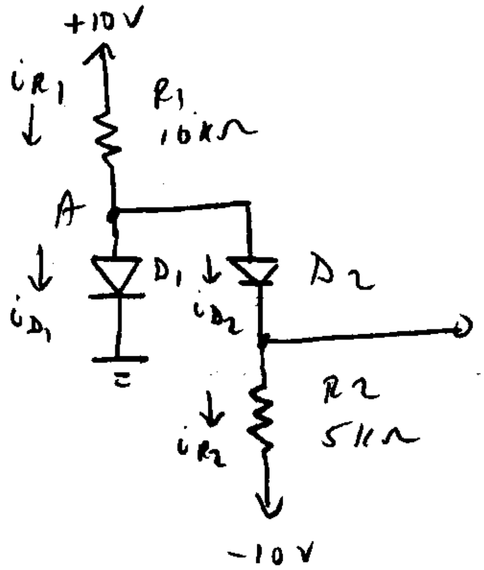
$V_{D_2} = 0 \quad i_{D_2} = 2\,mA$ ok

$\therefore$ Both diodes on,

$V_o = 0V$

$I = i_{D_1} = 1\,mA$

(b)



Assume both diodes on: $V_A = 0$, $V_0 = 0$

$i_{R_1} = \frac{10V}{10k\Omega} = 1mA$ $\quad i_{D_2} = i_{R_2} = \frac{10V}{5k\Omega} = 2mA$

$i_{D_1} = i_{R_1} - i_{D_2} = -1mA$ ← Impossible

Assume D_1 off, D_2 on

$i_{D_1} = 0 \Rightarrow i_{R_1} = i_{D_2} = i_{R_2} = \frac{20V}{15k\Omega} = \frac{4}{3} mA$

$i_{R_2} = \frac{V_0 - (-10V)}{R_2} \Rightarrow V_0 = i_{R_2} R_2 - 10V = -\frac{10}{3} V$

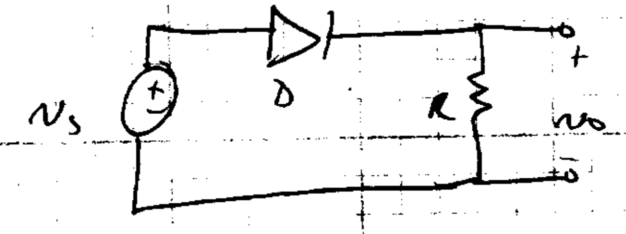
$V_A = V_0 = -\frac{10}{3} V$

$V_{D_1} = V_A = -\frac{10}{3} V$ $\quad i_{D_1} = 0$ $\quad$ ok

$V_{D_2} = V_A - V_0 = 0$ $\quad i_{D_2} = \frac{4}{3} mA$ $\quad$ ok

$\therefore$ $V_0 = -\frac{10}{3} V$ $\quad I = i_{D_1} = 0$

3.11



$v_s = \sqrt{2}\, V_{Rms} \cos(\omega t) = 170 \cos(\omega t)$ V

Max i_R will be when $v_s = 170$ V

$R = \frac{v}{i} = \frac{170\text{V}}{0.1\text{A}} = 1.7\ k\Omega$

When $v_s = -170$V, diode is off, no voltage across R,

so $v_D = -170$ V