2.65, 2.69, 2.75
2.123, 3.4, 3.9,
3.15

Engineering 72
Electronic Circuit Applications
Assignment 3 Solutions

LAM
2005

1. (2.65) In difference amplifier, all $R = 100k\Omega \pm x\%$. Find worst case CMRR & evaluate for $x = 0.1, 1, \& 5$.

eq. 2.19 $A_{cm} = \dfrac{1}{1+R_3/R_4}\left(1 - \dfrac{R_2}{R_1}\dfrac{R_3}{R_4}\right)$; $A_{cm}|_{max}$ @ $\dfrac{R_2}{R_1}$ min, $\dfrac{R_3}{R_4}$ min

so let $\dfrac{R_2}{R_1} = \dfrac{R_3}{R_4} = \dfrac{100k(1 - x/100)}{100k(1+x/100)}$ Then $A_{cm}|_{max} = \dfrac{1}{1+\frac{1-x/100}{1+x/100}}\left[1-\left(\dfrac{1-x/100}{1+x/100}\right)^2\right]$

$\boxed{A_{cm}|_{max} = \dfrac{2x}{x+100}}$ so let $R_1 = R_4 = 100(1+\frac{x}{100})k$, $R_2 = R_3 = 100(1-\frac{x}{100})k$

$CMRR = 20\log\left|\dfrac{A_d}{A_{cm}}\right|$

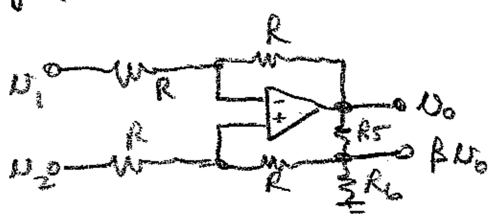
& from eq 2.21, $A_d = \dfrac{R_4}{R_3}\left(1+\dfrac{R_2}{R_1}\right) = \dfrac{1+\frac{x}{100}}{1-\frac{x}{100}}\left(1+\dfrac{1-\frac{x}{100}}{1+\frac{x}{100}}\right)$ (is very close to 1).

Plug into computer/calculator. Check using approx: $A_{cm} \simeq \frac{x}{50}$, $A_d \simeq 1$.

2. (2.69) $R_5, R_6 << R \Rightarrow \beta \simeq \dfrac{R_6}{R_5+R_6}$

Show $A_d = \dfrac{v_O}{v_{Id}} = \dfrac{1}{1-\beta}$.

Obtain values for $A_d = 10\,V/V$, $R_i = 2M\Omega$



Use superposition

w/ $v_2 = 0$, by V ÷, $v_+ = \dfrac{\beta v_{O1}}{2} = v_-$ & $\sum i = 0 = \dfrac{v_1 - v_-}{R} + \dfrac{v_O - v_-}{R} \Rightarrow v_{O1} = \dfrac{v_1}{\beta - 1}$

w/ $v_1 = 0$, by V ÷, $v_- = \dfrac{v_{O2}}{2} = v_+$ & $\sum_+ i = 0 = \dfrac{v_2 - v_+}{R} + \dfrac{\beta v_O - v_+}{R} \Rightarrow v_{O2} = \dfrac{-v_2}{\beta - 1}$

so $v_O = v_{O1} + v_{O2} = \dfrac{1}{1-\beta}(v_2 - v_1) = A_d(v_2 - v_1) \Rightarrow$ for $A_d = 10$, $\beta = 0.9 = \dfrac{R_6}{R_5+R_6}$

$R_{id} = 2R = 2M\Omega \Rightarrow \boxed{R = 1M\Omega}$ $R_5 + R_6 < \dfrac{R}{100} \Rightarrow$ choose $\boxed{R_5+R_6 \simeq 10k\Omega}$

3. (2.75) $2R_1 = 10k\Omega$, $R_2 = R_3 = R_4 = 100k\Omega$. (see Fig 2.20b in text)

For ideal components, find A_d, A_{cm}, & CMRR

$\boxed{A_{cm} = 0}$ (how we chose the relationship between the Rs) & CMRR $= \infty$.

eq 2.22 $\Rightarrow A_d = \dfrac{R_4}{R_3}\left(1+\dfrac{R_2}{R_1}\right) = 1\left(1+\dfrac{100}{5}\right) = \boxed{21\,V/V = A_d}$

For $\pm 1\%$ resistors, use results of 2.65 $\Rightarrow A_{cm} = \dfrac{2x}{x+100}$ & $A_d = \dfrac{1+0.01}{1-0.01}\left(1+\dfrac{1+0.01}{1-0.01}\right)$

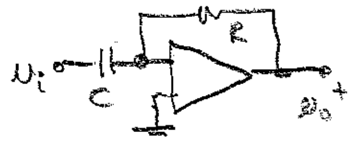
use calculator; result should be close to estimate of $A_{cm} \simeq \frac{1}{50}$, $A_d \simeq 21$

so $CMRR \simeq 20\log_{10}\left(\dfrac{21}{1/50}\right) \simeq 60dB$

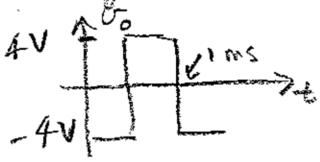
If $2R_1 = 1k$, $A_d = \dfrac{R_4}{R_3}\left(1+\dfrac{R_2}{R_1}\right) = 201\,V/V$; A_{cm} still $\simeq \frac{1}{50} \Rightarrow \boxed{CMRR \simeq 80db}$

∴ Obtain higher CMRR if we ↑ gain in stage 1 of the amplifier

(4.) (2.123) $R = 10k\Omega$, $C = 0.1\mu F$



For triangle input w/ $\pm 1V$ p-p @ 1 kHz, find v_o.



$f = 1\,kHz$, $v_p = 4V$, $v_{avg} = 0$

For $v_p = 10\,V$, need to $\uparrow R$ by factor of 2.5 $\Rightarrow R = 25k\Omega$

$C\frac{dv_i}{dt} + \frac{v_o}{R} = 0 \Rightarrow$

$v_o = -RC\frac{dv_i}{dt}$

For 1 V, sin wave input, output is also a sin wave (shifted)

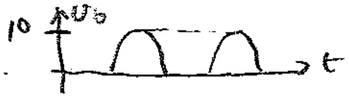
Using 2.44a, 2nd formula, $v_o = -RC\frac{dv_i}{dt} = -10^{-3}(2\pi \cdot 10^3)\cos(2\pi \cdot 10^3)t \Rightarrow$ peak $= 2\pi$ & shifted by π (neg sign) $+ \frac{\pi}{2}$ or $\frac{3\pi}{2} = -\pi/2$

Using 2.44a 3rd formula, $\frac{V_o}{V_i} = -j\omega RC \Rightarrow$ again, $-\pi/2$ phase shift & peak of $2\pi fRC = 2\pi$

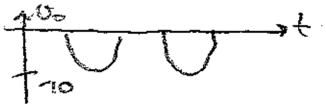
Third way seems redundant -- like the 1st.

(5.) (3.4)

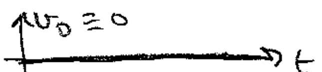
f = 1 kHz for all non-zero waveforms

a. 

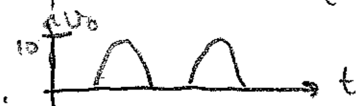
$V_{p+} = 10\,V$
$V_{p-} = 0\,V$

b. 

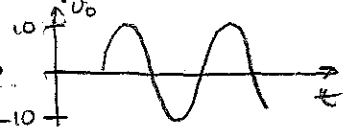
$V_{p+} = 0\,V$
$V_{p-} = -10\,V$

c. 

D_1 & D_2 off

d. 

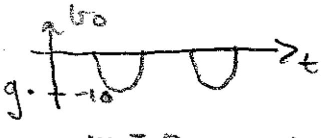
$V_{p+} = 10\,V$
$V_{p-} = 0\,V$
D_1 & D_2 on for $v_I > 0$

e. 

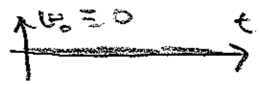
$V_{p+} = -V_{p-} = 10\,V$
D_1 on for $v_I > 0$
D_2 on for $v_I < 0$

f. 

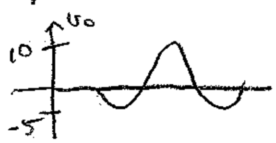
$V_{p+} = 10\,V$
$V_{p-} = 0\,V$
D_1 off for $v_I < 0$

g. 

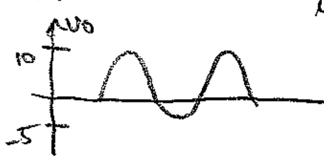
$V_{p+} = 0$
$V_{p-} = -10$
D_1 off when $v_I < 0$
output grounded when D_1 on

h. 

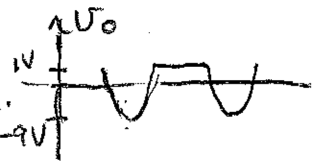
D_1 connects output to 0 when $v_I \geq 0$
D_2 " when $v_I < 0$

i. 

D_1 off when $v_I > 0$
D_1 on when $v_I < 0 \Rightarrow V\div$:
$v_{p+} = 10$, $v_{p-} = -5$

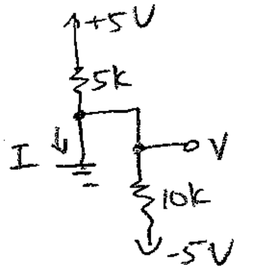
j. 

D_1 on when $v_I > 0$
D_1 off when $v_I < 0$ $\Rightarrow V\div$:
$v_p^+ = 10$, $v_p^- = -5$

k. 

D_1 off, D_2 on for $v_I > 0$
D_1 on, D_2 off for $v_I < 0$
$v_{p+} = 1\,V$, $v_{p-} = -9V$

(6.) (3.9) a. D_1 & D_2 on.

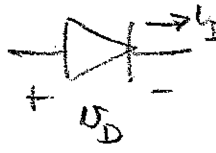


$V = 0$

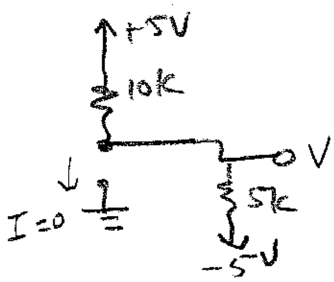
$I = \frac{5-0}{5k} - \frac{0-(-5)}{10k}$

$= 0.5\,mA$.

Ck that "ON" diodes have $v_D = 0$ & $i_D > 0$ ✓



b. D_1 off; D_2 on



By $V\div$,

$V = -5 + \frac{5}{10+5}(5-(-5))$

$= -5 + \frac{5}{15}(10)$

$= -\frac{5}{3}\,V$.

Ck for D_2 on as in part a & D_1 off ($i_D = 0$, $v_D < 0$)

7. 3.15 done in class