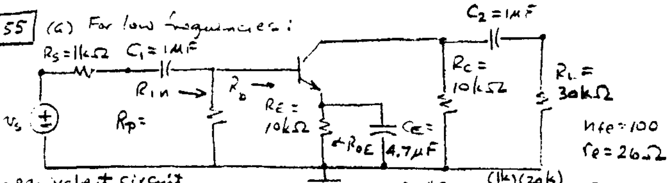
9.55 (a) For low frequencies:



ac-equivalent circuit

$R_p = 60k \| 30k = \dfrac{(60k)(30k)}{60k+30k} = 20k\Omega$ $\qquad R = R_S \| R_p = \dfrac{(1k)(20k)}{1k+20k} = 952\Omega$

$R_b = (1+h_{fe})r_e = 101(26) = 2.63k\Omega$

$R_{in} = R_p \| R_b = \dfrac{(20k)(2.63k)}{20k+2.63k} = 2.32k\Omega$

For input lead network, $\omega_1 = \dfrac{1}{(R_s+R_{in})C_1} = \dfrac{1}{(1k+2.32k)1\mu} = \underline{301 \text{ rad/s}}$

For output lead network, $\omega_2 = \dfrac{1}{(R_C+R_L)C_2} = \dfrac{1}{(10k+30k)1\mu} = \underline{25 \text{ rad/s}}$

$R_{oE} = R_E \| (r_e + \dfrac{R}{1+h_{fe}}) = 10k \| (26 + \dfrac{952}{101}) = 10k \| 35.4 = \dfrac{(10k)(35.4)}{10k+35.4} = 35.3\Omega$

For bypass capacitor, $\omega_3 = \dfrac{1}{R_{oE} C_E} = \dfrac{1}{(35.3)(4.7\mu)} = \underline{6.03 \text{ krad/s}}$

Thus, $\omega_L = \underline{\underline{6.03k \text{ rad/s}}}$ ($f_L = 960$ Hz)

(b) $A = g_m R_T = \dfrac{R_T}{r_e} = \dfrac{R_C \| R_L}{r_e} = \dfrac{10k \| 30k}{26} = \dfrac{7.5k}{26} = 288$ $\qquad C_c = 5pF$

$C_c + C_e = \dfrac{1}{2\pi r_e f_T} = \dfrac{1}{2\pi(26)([illegible])} = [illegible]pF \Rightarrow C_e = 51p - 5p = 46pF$

$r_\pi = (1+h_{fe})r_e = 101(26) = 2.63k\Omega$

$R_g = (R_s \| R_p) \| r_\pi = 952 \| 2.63k = \dfrac{(952)(2.63k)}{952+2.63k} = 699\Omega$

$C_g = C_e + (1+A)C_c = 46p + [illegible] = 1491 pF$

$\omega_g = \dfrac{1}{R_g C_g} = \dfrac{1}{(699)([illegible])} = \underline{[illegible] \text{ rad/s}}$ for input lag network

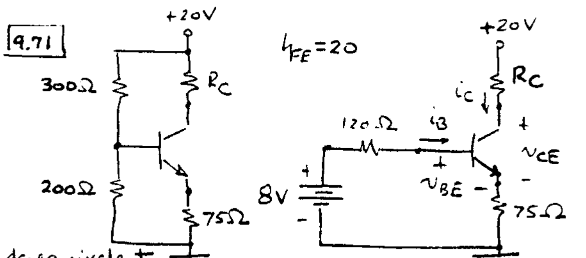
$C_T = \dfrac{1+A}{A} C_c = \dfrac{289}{288} 5p = [illegible] pF$ $\qquad R_T = 10k \| 30k = 7.5k\Omega$

$\omega_T = \dfrac{1}{R_T C_T} = \dfrac{1}{(7.5k)([illegible])} = \underline{[illegible] \text{ rad/s}}$ for output lag network

Thus, $\omega_H = \underline{\underline{960k \text{ rad/s}}}$ ([illegible])

(c) $BW = \omega_H - \omega_L = [illegible] = \underline{\underline{[illegible] k \text{ rad/s}}}$ (152 kHz)

9.71



(a) $v_{oc} = \dfrac{200}{300+200}(20) = 8V$ $\qquad R_o = 200\Omega \| 300\Omega = \dfrac{(200)(300)}{200+300} = 120\Omega$

By KVL,

$8 = 120 i_B + v_{BE} + 75(i_B + i_C)$

For active region, $v_{BE} = 0.7V$, $i_C = h_{FE} i_B = 20 i_B$

$\therefore 8 = 120 i_B + 0.7 + 75(i_B + 20 i_B)$

$7.3 = 120 i_B + 1575 i_B = 1695 i_B \Rightarrow i_B = \dfrac{7.3}{1695} = 4.3mA = I_{BQ}$

$i_C = h_{FE} i_B = 20(4.3m) = 86mA = I_{CQ}$

$v_{CE} = -R_C i_C + 20 - 75(i_B + i_C) = -R_C(86m) + 20 - 75(21)(4.3m)$

$v_{CE} = -86m R_C + 20 - 6.77 = -86m R_C + 13.2 = V_{CEQ}$

$\dfrac{V_{CEQ}}{I_{CQ}} = R_T + R_E \qquad R_T = R_C \qquad R_E = 75\Omega$

$\dfrac{-86m R_C + 13.2}{86m} = R_C + 75$

$-R_C + \dfrac{13.2}{86m} = R_C + 75$

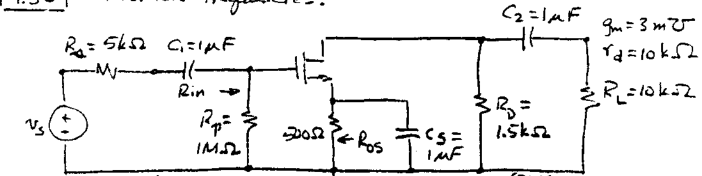
$153 - 75 = 2R_C \Rightarrow R_C = \dfrac{153-75}{2} = \underline{\underline{39\Omega}}$

(b) From above, $V_{CEQ} = 13.2 - 86m R_C = 13.2 - 86m(39) = 9.85V$

$P_o = \frac{1}{2} V_{CEQ} I_{CQ} = \frac{1}{2}(9.85)(86m) = \underline{\underline{424mW}} = \underline{\underline{0.424W}}$

(c) $P_{D(max)} \geq V_{CEQ} I_{CQ} = (9.85)(86m) = \underline{\underline{847mW}} = \underline{\underline{0.847 W}}$

9.56 (a) For low frequencies:



ac-equivalent circuit $\qquad R_g = R_s \| R_p = \dfrac{(5k)(1M)}{5k+1M} = 4.98k\Omega$

$R_p = 2M \| 2M = 1M\Omega \qquad R_{in} = R_p = 1M\Omega \qquad r_d \| R_D = \dfrac{(10k)(1.5k)}{10k+1.5k} = 1.3k\Omega$

For input lead network, $\omega_1 = \dfrac{1}{(R_s+R_p)C_1} = \dfrac{1}{(5k+1M)1\mu} = \underline{0.995 \text{ rad/s}}$

For output lead network, $\omega_2 = \dfrac{1}{(r_d \| R_D + R_L)C_2} = \dfrac{1}{(1.3k+10k)1\mu} = \underline{88.5 \text{ rad/s}}$

$R_{oS} = R_S \| \frac{1}{g_m} \| r_d = 500 \| \frac{1}{3m} \| 10k = 200 \| 10k = 196\Omega$

For the bypass capacitor, $\omega_3 = \dfrac{1}{R_{oS} C_S} = \dfrac{1}{(196)(1\mu)} = \underline{5.1k \text{ rad/s}}$

Thus, $\omega_L = \underline{\underline{5.1 \text{ k rad/s}}}$ ($f_L = 812$ Hz)

(b) $R_T = r_d \| R_D \| R_L = 10k \| 1.5k \| 10k = 5k \| 1.5k = 1.15k\Omega$

$A = g_m R_T = (3m)(1.15k) = 3.45 \qquad R_g = R_s \| R_p = 5k \| 1M = \dfrac{(5k)(1M)}{5k+1M} = 4.95k\Omega$

$C_g = C_{gs} + (1+A)C_{gd} = 2p + (1+3.45)3p = 15.4pF$

$C_T = C_{ds} + \dfrac{1+A}{A} C_{gd} = 1p + \dfrac{4.45}{3.45} 3p = 4.87pF$

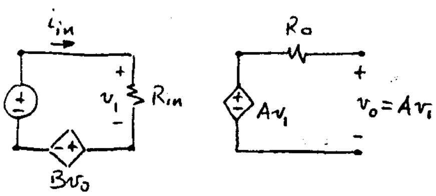
$\omega_g = \dfrac{1}{R_g C_g} = \dfrac{1}{(4.98k)(15.4p)} = \underline{13 \text{ M rad/s}}$ for input lag network

$\omega_T = \dfrac{1}{R_T C_T} = \dfrac{1}{(1.15k)(4.87p)} = \underline{178 \text{ M rad/s}}$ for output lag network

Thus, $\omega_H = \underline{\underline{13 \text{ M rad/s}}}$ (2.07 MHz)

(c) $BW = \omega_H - \omega_L = 13M - 5.1k = \underline{\underline{13 \text{ M rad/s}}}$ (2.07 MHz)

10.35



By KVL, $v_{in} = v_1 + B v_o \Rightarrow v_1 = v_{in} - B v_o \Rightarrow v_o = A(v_{in} - B v_o)$

$v_o = A v_{in} - AB v_o$

$v_o + AB v_o = A v_{in}$

$v_o(1+AB) = A v_{in}$

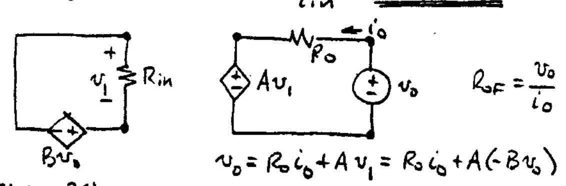
$\therefore \underline{\underline{\dfrac{v_o}{v_{in}} = \dfrac{A}{1+AB}}} = A_F$

By KVL,

$v_{in} = R_{in} i_{in} + B v_o = R_{in} i_{in} + B\left(\dfrac{A}{1+AB} v_{in}\right)$

$v_{in} - \dfrac{AB}{1+AB} v_{in} = R_{in} i_{in}$

$\dfrac{1}{1+AB} v_{in} = R_{in} i_{in} \Rightarrow \dfrac{v_{in}}{i_{in}} = \underline{\underline{(1+AB)R_{in}}} = R_{iF}$



$R_{oF} = \dfrac{v_o}{i_o}$

$v_1 = -B v_o$

$v_o = R_o i_o + A v_1 = R_o i_o + A(-B v_o)$

$v_o + AB v_o = R_o i_o$

$v_o(1+AB) = R_o i_o$

$\underline{\underline{\dfrac{v_o}{i_o} = \dfrac{R_o}{1+AB}}} = R_{oF}$

$\boxed{10.45}$ $A = 200{,}000$ $f_T = 1\,MHz$ $R_1 = 1k\Omega$

$$f_H = \frac{f_T}{A} = \frac{1M}{200{,}000} = \frac{1\times10^6}{2\times10^5} = 5\,Hz$$

$$B = \frac{R_1}{R_1+R_2}$$

(a) $R_2 = 9k\Omega$ $\quad B = \frac{1k}{1k+9k} = \frac{1}{10}$

$$f_{HF} = (1+AB)f_H = (1+200{,}000\cdot\tfrac{1}{10})5$$

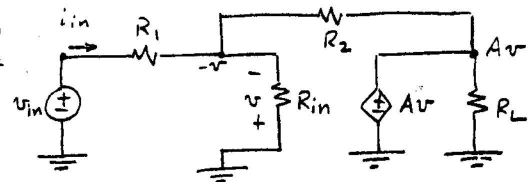
$$f_{HF} = (1+20{,}000)5 = \underline{\underline{100kHz}}$$

(b) $R_2 = 1M\Omega$ $\quad B = \frac{1k}{1k+1M} = 9.99\times10^{-4}$

$$f_{HF} = (1+AB)f_H = (1+200{,}000[9.99\times10^{-4}])5$$

$$f_{HF} = \underline{\underline{1.00k\,Hz}}$$

$\boxed{10.49}$



By KCL at node $-v$,

$$\frac{v_{in}+v}{R_1} + \frac{v}{R_{in}} + \frac{Av+v}{R_2} = 0$$

$$\frac{1}{R_1}v_{in} + \frac{v}{R_1} + \frac{v}{R_{in}} + \frac{Av+v}{R_2} = 0$$

$$\frac{1}{R_1}v_{in} = -\left(\frac{1}{R_1}+\frac{1}{R_{in}}+\frac{1+A}{R_2}\right)v$$

$$\therefore v = \frac{-\frac{1}{R_1}v_{in}}{\frac{1}{R_1}+\frac{1}{R_{in}}+\frac{1+A}{R_2}}$$

$$i_{in} = \frac{v_{in}+v}{R_1} \Rightarrow R_1 i_{in} = v_{in}+v = v_{in} - \frac{\frac{1}{R_1}v_{in}}{\frac{1}{R_1}+\frac{1}{R_{in}}+\frac{1+A}{R_2}}$$

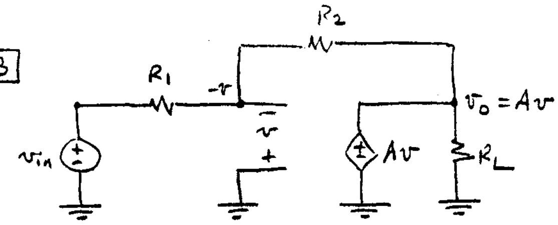
$$R_1 i_{in} = \frac{\left(\cancel{\frac{1}{R_1}}+\frac{1}{R_{in}}+\frac{1+A}{R_2}-\cancel{\frac{1}{R_1}}\right)v_{in}}{\frac{1}{R_1}+\frac{1}{R_{in}}+\frac{1+A}{R_2}}$$

$$\therefore \frac{v_{in}}{i_{in}} = \frac{R_1\left(\frac{1}{R_1}+\frac{1}{R_{in}}+\frac{1+A}{R_2}\right)}{\frac{1}{R_{in}}+\frac{1+A}{R_2}} = \frac{1+\frac{R_1}{R_{in}}+\frac{(1+A)R_1}{R_2}}{\frac{1}{R_{in}}+\frac{1+A}{R_2}}$$

$$R_{iF} = \frac{v_{in}}{i_{in}} = \frac{1+\frac{R_1R_2+(1+A)R_1R_{in}}{R_{in}R_2}}{\frac{R_2+(1+A)R_{in}}{R_{in}R_2}} = \frac{R_{in}R_2+R_1R_2+(1+A)R_1R_{in}}{R_2+(1+A)R_{in}}$$

$$R_{iF} = \frac{R_{in}R_2}{R_2+(1+A)R_{in}} + R_1 = R_1 + \frac{R_{in}\frac{R_2}{1+A}}{R_{in}+\frac{R_2}{1+A}} = \underline{\underline{R_1 + R_{in}\,//\,\frac{R_2}{1+A}}}$$

$\boxed{10.48}$



By KCL at node $-v$,

$$\frac{-v-v_{in}}{R_1} + \frac{-v-Av}{R_2} = 0$$

$$R_2v + R_2v_{in} + R_1v + AR_1v = 0$$

$$R_2v_{in} = (-R_1 - AR_1 - R_2)v$$

$$v = \frac{-R_2}{R_1+AR_1+R_2}v_{in}$$

$$\therefore v_o = Av = \frac{-AR_2}{R_1+AR_1+R_2}v_{in}$$

Hence, $$A_F = \frac{v_o}{v_{in}} = \frac{-AR_2}{AR_1+R_1+R_2} = \underline{\underline{\frac{-R_2}{R_1+\frac{R_1+R_2}{A}}}}$$

$\boxed{10.54}$ (a) $g_m = 5\,m℧$, $R = 100k\Omega$, $f_o = 1kHz$

$$g_m \geq \frac{29}{R_D} \Rightarrow R_D \geq \frac{29}{g_m} = \frac{29}{5m} = \underline{\underline{5.8k\Omega}}$$

$$\omega_o = \frac{1}{\sqrt{6}RC} \Rightarrow C = \frac{1}{\sqrt{6}\,\omega_o R} = \frac{1}{\sqrt{6}(2\pi)(1k)(100k)} = \underline{\underline{650\,pF}}$$

(b) $g_m = 10m℧$, $C = 0.001\mu F$, $f_o = 1kHz$

$$g_m \geq \frac{29}{R_D} \Rightarrow R_D \geq \frac{29}{g_m} = \frac{29}{10m} = \underline{\underline{2.9k\Omega}}$$

$$\omega_o = \frac{1}{\sqrt{6}RC} \Rightarrow R = \frac{1}{\sqrt{6}\,\omega_o C} = \frac{1}{\sqrt{6}(2\pi)(1k)(0.001\mu)} = \underline{\underline{65k\Omega}}$$

(c) $R_D = 5k\Omega$, $R = 100k\Omega$, $C = 0.001\mu F$

$$g_m \geq \frac{29}{R_D} = \frac{29}{5k} = \underline{\underline{5.8m℧}}$$

$$\omega_o = \frac{1}{\sqrt{6}RC} = 2\pi f_o \Rightarrow f_o = \frac{1}{2\pi\sqrt{6}RC} = \frac{1}{2\pi\sqrt{6}(100k)(0.001\mu)}$$

$$f_o = \underline{\underline{650\,Hz}}$$

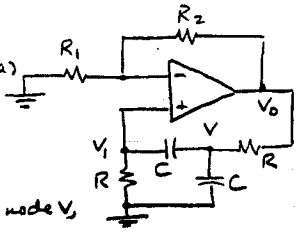
(d) $R_D = 5k\Omega$, $R = 100k\Omega$, $f_o = 2kHz$

$$g_m \geq \frac{29}{R_D} = \frac{29}{5k} = \underline{\underline{5.8\,m℧}}$$

$$\omega_o = \frac{1}{\sqrt{6}RC} \Rightarrow C = \frac{1}{\sqrt{6}\,\omega_o R} = \frac{1}{\sqrt{6}(2\pi)(2k)(100k)}$$

$$C = \underline{\underline{325\,pF}}$$

10.58 (a)



By KCL at node V_1,

$$\frac{V_1}{R} + \frac{V_1 - V}{1/j\omega C} = 0$$

$$V_1 + j\omega RCV_1 - j\omega RCV = 0$$

$$(1 + j\omega RC)V_1 = j\omega RCV$$

$$V = \frac{1 + j\omega RC}{j\omega RC} V_1$$

By KCL at node V,

$$\frac{V - V_1}{1/j\omega C} + \frac{V}{1/j\omega C} + \frac{V - V_o}{R} = 0$$

$$j\omega RCV - j\omega RCV_1 + j\omega RCV + V - V_o = 0$$

$$(1 + j\omega 2RC)V - j\omega RCV_1 = V_o$$

$$(1 + j\omega 2RC)\frac{(1 + j\omega RC)}{j\omega RC} V_1 - j\omega RCV_1 = V_o$$

$$\left[(1 + j\omega 2RC)(1 + j\omega RC) - (j\omega RC)^2\right] V_1 = j\omega RCV_o$$

$$\left[1 + j\omega 2RC + j\omega RC + 2(j\omega RC)^2 - (j\omega RC)^2\right]V_1 = j\omega RCV_o$$

$$\frac{V_1}{V_o} = \frac{j\omega RC}{1 + j\omega 3RC + (j\omega RC)^2} = \frac{1}{\frac{1}{j\omega RC} + 3 + j\omega RC}$$

$$\frac{V_1}{V_o} = \frac{1}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)} = B$$

(b) Oscillation occurs when $\omega RC = \frac{1}{\omega RC} \Rightarrow \omega^2 = \frac{1}{(RC)^2} \Rightarrow \omega_o = \frac{1}{RC}$

(c) By KCL at the inverting input of the op amp,

$$\frac{V_1}{R_1} + \frac{V_1 - V_o}{R_2} = 0 \Rightarrow R_2 V_1 + R_1 V_1 - R_1 V_o = 0$$

$$(R_1 + R_2)V_1 = R_1 V_o \Rightarrow \frac{V_o}{V_1} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1} = A$$

When $\omega = \frac{1}{RC}$, then $B = \frac{V_1}{V_o} = \frac{1}{3}$

For oscillation, $AB = 1$ (minimum)

$$\left(1 + \frac{R_2}{R_1}\right)\frac{1}{3} = 1 \Rightarrow 1 + \frac{R_2}{R_1} = 3 \Rightarrow \frac{R_2}{R_1} = 2$$

$$\therefore R_2 = 2R_1$$