Chapter 7

Exercise Solutions

E7.1

a. $R_S = R_P = 4\ \text{k}\Omega$

$$\omega = \frac{1}{\tau_S} = \frac{1}{(R_S + R_P)C_S}$$
$$C_S = \frac{1}{2\pi f(R_S + R_P)} = \frac{1}{2\pi(20)(4+4)\times 10^3}$$
$$\underline{C_S = 0.995\ \mu\text{F}}$$

b. $$|T(j\omega)| = \left(\frac{R_P}{R_S + R_P}\right)\frac{\omega\tau_S}{\sqrt{1+\omega^2\tau_S^2}}$$

$$\tau_S = (R_S + R_P)C_S = 7.96\times 10^{-3}$$
$$\frac{R_P}{R_S + R_P} = \frac{4}{4+4} = 0.5$$

$f = 40$ Hz
$$|T(j\omega)| = \frac{(0.5)(2\pi)(40)(7.96\times 10^{-3})}{\sqrt{1+[2\pi(40)(7.96\times 10^{-3})]^2}}$$
$$\underline{|T(j\omega)| = 0.447}$$

$f = 80$ Hz
$$|T(j\omega)| = \frac{(0.5)(2\pi)(80)(7.96\times 10^{-3})}{\sqrt{1+[2\pi(80)(7.96\times 10^{-3})]^2}}$$
$$\underline{|T(j\omega)| = 0.485}$$

$f = 200$ Hz
$$|T(j\omega)| = \frac{(0.5)(2\pi)(200)(7.96\times 10^{-3})}{\sqrt{1+[2\pi(200)(7.96\times 10^{-3})]^2}}$$
$$\underline{|T(j\omega)| = 0.498}$$

E7.2

$$\omega = \frac{1}{\tau_P} = \frac{1}{(R_S \| R_P)C_P}$$
$$C_P = \frac{1}{2\pi f(R_S \| R_P)}$$
$$= \frac{1}{2\pi(500\times 10^3)(10\|10)\times 10^3}$$
$$\underline{C_P = 63.7\ \text{pF}}$$

E7.3

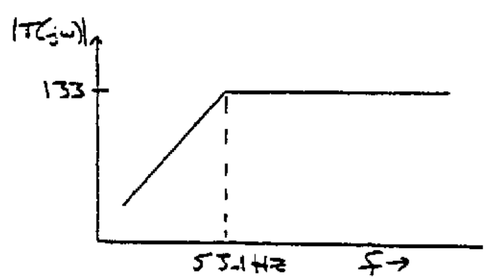
a. $V_0 = -(g_m V_\pi)R_L$

$$V_\pi = \frac{r_\pi}{r_\pi + \dfrac{1}{sC_C} + R_S}\times V_i$$
$$T(s) = \frac{V_0(s)}{V_i(s)} = \frac{-g_m r_\pi R_L}{r_\pi + R_S + (1/sC_C)}$$
$$= \frac{-g_m r_\pi R_L(sC_C)}{1 + s(r_\pi + R_S)C_C}$$
$$g_m r_\pi = \beta$$
$$\underline{T(s) = \frac{-\beta R_L}{r_\pi + R_S}\times\left(\frac{s(r_\pi + R_S)C_C}{1 + s(r_\pi + R_S)C_C}\right)}$$

b. $$\underline{f_{3-dB} = \frac{1}{2\pi(r_\pi + R_S)C_C}}$$

$$f_{3-dB} = \frac{1}{2\pi[2\times 10^3 + 1\times 10^3][10^{-6}]}$$
$$\Rightarrow \underline{f_{3dB} = 53.1\ \text{Hz}}$$
$$|T(j\omega)|_{max} = \frac{r_\pi g_m R_L}{r_\pi + R_S} = \frac{(2)(50)(4)}{2+1}$$
$$\underline{|T(j\omega)|_{max} = 133}$$

c.



E7.4

a. $$V_0 = -g_m V_\pi\left(R_L \| \frac{1}{sC_L}\right)$$
$$V_\pi = \left(\frac{r_\pi}{r_\pi + R_S}\right)\times V_i$$
$$T(s) = \frac{V_0(s)}{V_i(s)} = -g_m\frac{r_\pi}{r_\pi + R_S}\left(\frac{R_L\times\dfrac{1}{sC_L}}{R_L + \dfrac{1}{sC_L}}\right)$$
$$\underline{T(s) = \frac{-\beta R_L}{r_\pi + R_S}\times\left(\frac{1}{1 + sR_LC_L}\right)}$$

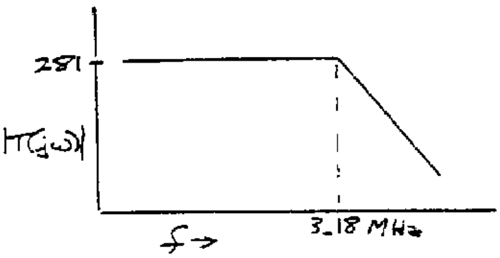
b. $$f_{3-dB} = \frac{1}{2\pi R_L C_L} = \frac{1}{2\pi(5\times 10^3)(10\times 10^{-12})}$$

$\Rightarrow \underline{f_{3dB} = 3.18 \text{ MHz}}$

$$|T(j\omega)| = \frac{g_m r_\pi R_L}{r_\pi + R_S} = \frac{(75)(1.5)(5)}{1.5 + 0.5}$$

$\underline{|T(j\omega)|_{max} = 281}$

c.



E7.5

a. $$20\log_{10}\left(\frac{R_P}{R_P + R_S}\right) = -1$$

$$\Rightarrow \frac{R_P}{R_P + R_S} = 0.891 = \frac{R_P}{R_P + 1}$$

$\Rightarrow (1 - 0.891)R_P = 0.891 \Rightarrow \underline{R_P = 8.17 \text{ k}\Omega}$

$$f_L = \frac{1}{2\pi(R_S + R_P)C_S}$$

$$\Rightarrow C_S = \frac{1}{2\pi(100)(1 + 8.17)\times 10^3}$$

$\underline{C_S = 0.174\ \mu\text{F}}$

$$f_H = \frac{1}{2\pi(R_S \| R_P)C_P}$$

$$\Rightarrow C_P = \frac{1}{2\pi(10^6)(1\|8.17)\times 10^3}$$

$\underline{C_P = 179 \text{ pF}}$

b. $\tau_S = (R_S + R_P)C_S$

$\tau_S = (1\times 10^3 + 8.17\times 10^3)(0.174\times 10^{-6})$

$\underline{\tau_S = 1.60 \text{ ms}}$ open-circuit time-constant

$\tau_P = (R_S \| R_P)C_P$

$\tau_P = (1\|8.17)\times 10^3 (179\times 10^{-12})$

$\underline{\tau_P = 0.160\ \mu s}$ short-circuit time-constant

E7.6

a. Open-circuit time constant ($C_L \to$ open)

$\tau_S = (R_S + r_\pi)C_C$

$= (0.25 + 2)\times 10^3 (2\times 10^{-6}) = 4.5 \text{ ms}$

Short-circuit time constant ($C_C \to$ short)

$\tau_P = R_L C_L = (4\times 10^3)(50\times 10^{-12})$

$\underline{\tau_P = 0.2\ \mu s}$

b. Midband gain

$$V_0 = -g_m V_\pi R_L, \quad V_\pi = \left(\frac{r_\pi}{r_\pi + R_S}\right)V_i$$

$$A_v = \frac{V_0}{V_i} = \frac{-g_m r_\pi R_L}{r_\pi + R_S} = \frac{-(65)(2)(4)}{2 + 0.25}$$

$\underline{A_v = -231}$

c. $$f_L = \frac{1}{2\pi\tau_S} = \frac{1}{2\pi(4.5\times 10^{-3})} \Rightarrow \underline{f_L = 35.4 \text{ Hz}}$$

$$f_H = \frac{1}{2\pi\tau_P} = \frac{1}{2\pi(0.2\times 10^{-6})} \Rightarrow \underline{f_H = 0.796 \text{ MHz}}$$

E7.7

a. $\tau_S = (R_i + R_S)C_C$

b. $f = \dfrac{1}{2\pi\tau_S}$

$R_{TH} = R_1 \| R_2 = 2.2\|20 = 1.98 \text{ k}\Omega$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{2.2}{2.2 + 20}\right)(10) = 0.991 \text{ V}$$

$$I_{BQ} = \frac{V_{TH} - V_{BE}(\text{on})}{R_{TH} + (1+\beta)R_E} = \frac{0.991 - 0.7}{1.98 + (201)(0.1)} = 0.0132 \text{ mA}$$

$I_{CQ} = 2.64 \text{ mA}$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(200)(0.026)}{2.64} = 1.97 \text{ k}\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.64}{0.026} = 102 \text{ mA/V}$$

$R_{ib} = r_\pi + (1+\beta)R_E = 1.97 + (201)(0.1) = 22.1 \text{ k}\Omega$

$R_B = R_1 \| R_2 = 1.98 \text{ k}\Omega$

$R_i = R_B \| R_{ib} = 1.98\|22.1 = 1.82 \text{ k}\Omega$

$\tau_S = (R_i + R_S)C_C$

$= (1.82 + 0.1)(\times 10^3)(47\times 10^{-6})$

$= 90.24 \text{ ms}$

$$f = \frac{1}{2\pi(90.24\times 10^{-3})} \Rightarrow \underline{f = 1.76 \text{ Hz}}$$

Midband Gain

$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E}\cdot\frac{R_i}{R_i + R_S} = \frac{-(200)(2)}{1.97 + (201)(0.1)}\cdot\frac{1.82}{1.82 + 0.1}$$

$\underline{A_v = -17.2}$

E7.8

$$I_{DQ} = K_n(V_{GS} - V_{TN})^2$$

a. $\sqrt{\dfrac{0.8}{0.5}} + 2 = V_{GS} \Rightarrow V_{GS} = 3.26\text{ V}$

$V_S = -3.26 \Rightarrow I_{DQ} = \dfrac{V_S - (-5)}{R_S}$

$R_S = \dfrac{-3.26 + 5}{0.8} \Rightarrow \underline{R_S = 2.18\text{ k}\Omega}$

$V_D = 0 \Rightarrow R_D = \dfrac{5}{0.8} \Rightarrow \underline{R_D = 6.25\text{ k}\Omega}$

b. $\tau_S = (R_D + R_L)C_C = (10 + 6.25) \times 10^3 \times C_C$

$f = \dfrac{1}{2\pi\tau_S} \Rightarrow C_C = \dfrac{1}{2\pi f(16.25 \times 10^3)}$

$C_C = \dfrac{1}{2\pi(20)(16.25 \times 10^3)}$

$\Rightarrow \underline{C_C = 0.49\ \mu\text{F}}$

E7.9

$\tau_S = (R_L + R_E \| R_0)C_{C2}$

$f = \dfrac{1}{2\pi\tau_S} \Rightarrow C_{C2} = \dfrac{1}{2\pi f(R_L + R_E \| R_0)}$

$R_0 = r_0 \,\|\, \left\{\dfrac{r_\pi + (R_S \| R_B)}{1+\beta}\right\}$

From Example 7-5, $R_0 = 35.6\ \Omega$

$R_0 \| R_E = 0.0356 \| 10 \approx 0.0356\text{ k}\Omega$

$C_{C2} = \dfrac{1}{2\pi(10)[10 \times 10^3 + 35.6]}$

$\underline{C_{C2} = 1.59\ \mu\text{F}}$

E7.10

a. $I_{DQ} = K_p(V_{SG} + V_{TP})^2$

$\sqrt{\dfrac{1}{0.5}} - (-2) = V_{SG} \Rightarrow V_{SG} = 3.41\text{ V}$

$V_S = 3.41$

$R_S = \dfrac{5 - 3.41}{1} \Rightarrow \underline{R_S = 1.59\text{ k}\Omega}$

For $V_{SDQ} = V_{SGQ} \Rightarrow V_D = 0$

$\Rightarrow R_D = \dfrac{5}{1} \Rightarrow \underline{R_D = 5\text{ k}\Omega}$

b. $\tau_P = (R_D \| R_L)C_L$

$f = \dfrac{1}{2\pi\tau_P} \Rightarrow C_L = \dfrac{1}{2\pi f(R_D \| R_L)}$

$C_L = \dfrac{1}{2\pi(10^6)(5 \| 10) \times 10^3}$

$\Rightarrow \underline{C_L = 47.7\text{ pF}}$

E7.11

a. $I_{BQ} = \dfrac{0 - 0.7 - (-10)}{0.5 + (101)(4)} = 0.0230\text{ mA}$

$I_{CQ} = 2.30\text{ mA}$

$r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{(100)(0.026)}{2.30} = 1.13\text{ k}\Omega$

$g_m = \dfrac{I_{CQ}}{V_T} = \dfrac{2.30}{0.026} = 88.5\text{ mA/V}$

$\tau_B = \dfrac{R_E(R_S + r_\pi)C_E}{R_S + r_\pi + (1+\beta)R_E}$

$= \dfrac{(4 \times 10^3)(0.5 + 1.13)C_E}{0.5 + 1.13 + (101)(4)}$

$\tau_B = \dfrac{1}{2\pi f_B} = \dfrac{1}{2\pi(200)} = 0.796\text{ ms}$

$\tau_B = 16.07 C_E \Rightarrow C_E = \dfrac{0.796 \times 10^{-3}}{16.07}$

$\Rightarrow \underline{C_E = 49.5\ \mu\text{F}}$

b. $\tau_A = R_E C_E = (4 \times 10^3)(49.5 \times 10^{-6})$

$\Rightarrow \tau_A = 0.198\text{ s}$

$f_A = \dfrac{1}{2\pi\tau_A} = \dfrac{1}{2\pi(0.198)} \Rightarrow \underline{f_A = 0.80\text{ Hz}}$

E7.14

$r_\pi = \dfrac{\beta_0 V_T}{I_{CQ}} = \dfrac{(150)(0.026)}{0.5} = 7.8\text{ k}\Omega$

$f_\beta = \dfrac{1}{2\pi r_\pi(C_\pi + C_\mu)}$

$= \dfrac{1}{2\pi(7.8 \times 10^3)(2 + 0.3) \times 10^{-12}}$

$\Rightarrow \underline{f_\beta = 8.87\text{ MHz}}$

E7.15

$r_\pi = \dfrac{\beta_0 V_T}{I_{CQ}} = \dfrac{(100)(0.026)}{0.25} = 10.4\text{ k}\Omega$

$f_\beta = \dfrac{1}{2\pi r_\pi(C_\pi + C_\mu)}$

$C_\pi + C_\mu = \dfrac{1}{2\pi f_\beta r_\pi} = \dfrac{1}{2\pi(11.5 \times 10^6)(10.4 \times 10^3)}$

$C_\pi + C_\mu = 1.33\text{ pF}$

$C_\mu = 0.1\text{ pF}$

$\Rightarrow \underline{C_\pi = 1.23\text{ pF}}$

E7.16

$h_{fe} = \dfrac{\beta_0}{1 + j(f/f_\beta)}$

$f_\beta = 5\text{ MHz},\quad \beta_0 = 100$

At $f = 50$ MHz

$|h_{fe}| = \dfrac{100}{\sqrt{1 + \left(\dfrac{50}{5}\right)^2}} \Rightarrow \underline{|h_{fe}| = 9.95}$

Phase $= -\tan^{-1}\left(\dfrac{50}{5}\right) \Rightarrow$ $\underline{\text{Phase} = -84.3^\circ}$

E7.17

$$f_\beta = \frac{f_T}{\beta_0} = \frac{500}{120} \Rightarrow \underline{f_\beta = 4.17 \text{ MHz}}$$
$$f_\beta = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)}$$
$$C_\pi + C_\mu = \frac{1}{2\pi f_\beta r_\pi} = \frac{1}{2\pi(4.17 \times 10^6)(5 \times 10^3)}$$
$$C_\pi + C_\mu = 7.63 \text{ pF}$$
$$C_\mu = 0.2 \text{ pF}$$
$$\Rightarrow \underline{C_\pi = 7.43 \text{ pF}}$$

E7.18

$$r_\pi = \frac{\beta_0 V_T}{I_{CQ}} = \frac{(150)(0.026)}{1} \Rightarrow r_\pi = 3.9 \text{ k}\Omega$$
$$f_\beta = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)}$$
$$= \frac{1}{2\pi(3.9 \times 10^3)(4 + 0.5)(10^{-12})}$$
$$\Rightarrow \underline{f_\beta = 9.07 \text{ MHz}}$$
$$f_T = \beta_0 f_\beta = (150)(9.07)$$
$$\Rightarrow \underline{f_T = 1.36 \text{ GHz}}$$

E7.19

$$R_{TH} = R_1 \| R_2 = 200\|220 = 105 \text{ k}\Omega$$
$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{220}{200 + 220}\right)(5)$$
$$= 2.62 \text{ V}$$
$$I_{BQ} = \frac{2.62 - 0.7}{105 + (101)(1)} = 0.00932 \text{ mA}$$
$$I_{CQ} = 0.932 \text{ mA}$$
$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.932}{0.026} \Rightarrow g_m = 35.8 \text{ mA/V}$$
$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.932} \Rightarrow r_\pi = 2.79 \text{ k}\Omega$$

a. $C_M = C_\mu[1 + g_m(R_C \| R_L)]$

$$C_M = (2)[1 + (35.8)(2.2\|4.7)]$$
$$\Rightarrow \underline{C_M = 109 \text{ pF}}$$

b. $R_B = r_S \| R_1 \| R_2 = 100\|200\|220 = 51.2 \text{ k}\Omega$

$$f_{3dB} = \frac{1}{2\pi(R_B \| r_\pi)(C_\pi + C_M)}$$
$$= \frac{1}{2\pi[51.2\|2.79] \times 10^3 \times (10 + 109) \times 10^{-12}}$$
$$\Rightarrow \underline{f_{3dB} = 0.505 \text{ MHz}}$$

E7.20

(a) $g_m = 2K_n(V_{GS} - V_{TN}) = 2(0.4)(3-1)$

$$\Rightarrow g_m = 1.6 \text{ mA/V}$$
$$g'_m = 80\% \text{ of } g_m = 1.28 \text{ mA/V}$$

$$g'_m = \frac{g_m}{1 + g_m r_S}$$
$$1 + g_m r_S = \frac{g_m}{g'_m}$$
$$r_S = \frac{1}{g_m}\left(\frac{g_m}{g'_m} - 1\right) = \frac{1}{1.6}\left(\frac{1.6}{1.28} - 1\right)$$
$$r_S = 0.156 \text{ k}\Omega \Rightarrow \underline{r_S = 156 \text{ ohms}}$$

(b) $g_m = 2K_n(V_{GS} - V_{TN}) = 2(0.4)(5-1)$

$$\Rightarrow g_m = 3.2 \text{ mA/V}$$
$$g'_m = \frac{g_m}{1 + g_m r_S} = \frac{3.2}{1 + (3.2)(0.156)} = 2.13$$
$$\frac{\Delta g_m}{g_m} = \frac{3.2 - 2.13}{3.2} \Rightarrow \text{A } 33.4\% \text{ reduction}$$

E7.21

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$$
$$I_{DQ} = K_n(V_{GS} - V_{TN})^2$$
$$0.4 = 0.2(V_{GS} - 1)^2 \Rightarrow V_{GS} = 2.41 V$$
$$g_m = 2K_n(V_{GS} - V_{TN}) = 2(0.2)(2.41 - 1)$$
$$= 0.564 \, mA/V$$
$$f_T = \frac{0.564 x 10^{-3}}{2\pi(0.25 + 0.02) x 10^{-12}} \Rightarrow$$
$$\underline{f_T = 332 \, MHz}$$

E7.22

$$f_T = \frac{g_m}{2\pi(C_{gsT} + C_{gdT})}$$
$$= \frac{g_m}{2\pi(C_{gs} + C_{gsp} + C_{gdp})}$$
$$C_{gs} = \frac{g_m}{2\pi f_T} - C_{gsp} - C_{gdp}$$
$$= \frac{0.5 \times 10^{-3}}{2\pi(500 \times 10^6)} - (0.01 + 0.01) \times 10^{-12}$$
$$\Rightarrow \underline{C_{gs} = 0.139 \text{ pF}}$$

E7.23

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gsp} + C_{gdp})}$$

$$C_{gsp} = C_{gdp}$$

$$2C_{gsp} = \frac{g_m}{2\pi f_T} - C_{gs} = \frac{1 \times 10^{-3}}{2\pi(350 \times 10^6)} - 0.4 \times 10^{-12}$$

$$2C_{gsp} = 0.0547 \text{ pF}$$

$$\Rightarrow \underline{C_{gsp} = C_{gdp} \cong 0.0274 \text{ pF}}$$

E7.24

dc analysis

$$V_G = \left(\frac{R_2}{R_1 + R_2}\right)V_{DD} = \left(\frac{166}{166 + 234}\right)(10) = 4.15 \text{ V}$$

$$I_D = \frac{V_S}{R_S} \text{ and } V_S = V_G - V_{GS}$$

$$K_n(V_{GS} - V_{TN})^2 = \frac{V_G - V_{GS}}{R_S}$$

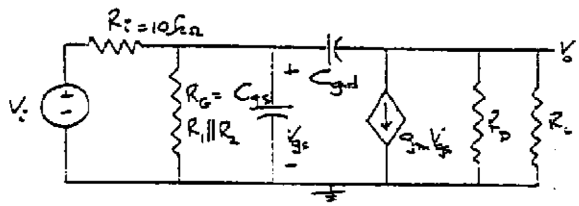
$$(0.5)(0.5)(V_{GS}^2 - 4V_{GS} + 4) = 4.15 - V_{GS}$$

$$0.25V_{GS}^2 - 3.15 = 0 \Rightarrow V_{GS} = 3.55 \text{ V}$$

$$g_m = 2K_n(V_{GS} - V_{TN}) = 2(0.5)(2.55 - 2)$$

$$= 1.55 \text{ mA/V}$$

Small-signal equivalent circuit.



a. $C_M = C_{gd}\left(1 + g_m(R_D \| R_L)\right)$

$$C_M = (0.1)[1 + (1.55)(4\|20)]$$

$$\Rightarrow \underline{C_M = 0.617 \text{ pF}}$$

b. $f_H = \dfrac{1}{2\pi\tau_P}$

$$\tau_P = (R_G \| R_i)(C_{gs} + C_M)$$

$$R_G = R_1 \| R_2 = 234\|166 = 97.1 \text{ k}\Omega$$

$$R_G \| R_i = 97.1\|10 = 9.07 \text{ k}\Omega$$

$$\tau_P = (9.07 \times 10^3)(1 + 0.617) \times 10^{-12} = 14.7 \text{ ns}$$

$$f_H = \frac{1}{2\pi(14.7 \times 10^{-9})} \Rightarrow \underline{f_H = 10.9 \text{ MHz}}$$

E7.25

dc analysis

$$V_{TH} = 0, \quad R_{TH} = 10 \text{ k}\Omega$$

$$I_{BQ} = \frac{0 - 0.7 - (-5)}{10 + (126)(5)} = 0.00672 \text{ mA}$$

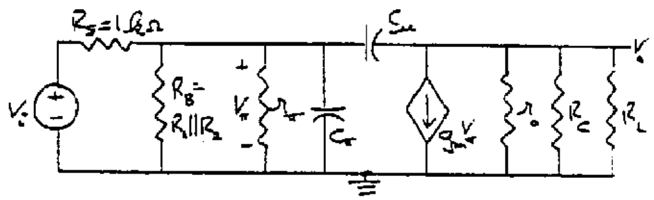
$$I_{CQ} = 0.840 \text{ mA}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(125)(0.026)}{0.840} = 3.87 \text{ k}\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.840}{0.026} = 32.3 \text{ mA/V}$$

$$r_0 = \frac{V_A}{I_{CQ}} = \frac{200}{0.84} = 238 \text{ k}\Omega$$

High-frequency equivalent circuit



a. Miller capacitance

$$C_M = C_\mu(1 + g_m R_L')$$

$$R_L' = r_0 \| R_C \| R_L$$

$$R_L' = 238\|2.3\|5 = 1.57 \text{ k}\Omega$$

$$C_M = (3)[1 + (32.3)(1.57)] \Rightarrow \underline{C_\mu = 155 \text{ pF}}$$

b. $R_{eq} = R_S \| R_B \| r_\pi = R_S \| R_1 \| R_2 \| r_\pi$

$$R_{eq} = 1\|20\|20\|3.87 = 0.736 \text{ k}\Omega$$

$$\tau_P = R_{eq}(C_\pi + C_M)$$

$$= (0.736 \times 10^3)(24 + 155) \times 10^{-12}$$

$$= 1.32 \times 10^{-7}$$

$$f_H = \frac{1}{2\pi(1.32 \times 10^{-7})} \Rightarrow \underline{f_H = 1.21 \text{ MHz}}$$

c. $(A_v)_M = -g_m R_L' \left[\dfrac{R_B \| r_\pi}{R_B \| r_\pi + R_S}\right]$

$$(A_v)_M = -(32.3)(1.57)\left[\frac{10\|3.87}{10\|3.87 + 1}\right]$$

$$\Rightarrow \underline{(A_v)_M = -37.3}$$

E7.26

dc analysis

$$V_G = \left(\frac{50}{50+150}\right)(10) - 5 = -2.5$$

$$V_S = V_G - V_{GS}, \quad I_D = \frac{V_S - (-5)}{R_S}$$

$$K_n(V_{GS} - V_{TN})^2 = \frac{V_G - V_{GS} + 5}{R_S}$$

$$(1)(2)[V_{GS}^2 - 1.6V_{GS} + 0.64] = -2.5 - V_{GS} + 5$$

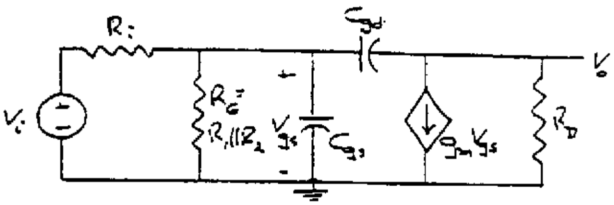
$$2V_{GS}^2 - 2.2V_{GS} - 1.22 = 0$$

$$V_{GS} = \frac{2.2 \pm \sqrt{(2.2)^2 + 4(2)(1.22)}}{2(2)}$$

$$\Rightarrow V_{GS} = 1.51 \text{ V}$$

$$g_m = 2K_n(V_{GS} - V_{TN}) = 2(1)(1.51 - 0.8) = 1.42 \text{ mA/V}$$

Equivalent circuit



(a) $C_M = C_{gd}(1 + g_m R_D) = (0.2)[1 + (1.42)(5)] \Rightarrow$
$\underline{C_M = 1.62\ pF}$

(b) $\tau_P = (R_S \| R_G)(C_{gs} + C_M)$

$$\tau_P = [20\|50\|150] \times 10^3 \times (2 + 1.62) \times 10^{-12}$$

$$= (13 \times 10^3)(3.62 \times 10^{-12}) = 4.71 \times 10^{-8} \text{ s}$$

$$f_H = \frac{1}{2\pi\tau_P} = \frac{1}{2\pi(4.7 \times 10^{-8})}$$

$$\Rightarrow \underline{f_H = 3.38 \text{ MHz}}$$

c. $$(A_v)_M = -g_m R_D \left(\frac{R_G}{R_G + R_S}\right)$$

$$(A_v)_M = -(1.42)(5)\left(\frac{37.5}{37.5 + 20}\right)$$

$$\Rightarrow \underline{(A_v)_M = -4.63}$$

E7.27

The dc analysis

$$I_{BQ} = \frac{10 - 0.7}{100 + (101)(10)} = 0.00838 \text{ mA}$$

$$I_{CQ} = 0.838 \text{ mA}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.838} = 3.10 \text{ k}\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = 32.2 \text{ mA/V}$$

For the input

$$\tau_{P\pi} = \left[\left(\frac{r_\pi}{1+\beta}\right) \| R_E \| R_S\right] C_\pi$$

$$= \left[\frac{3.10}{101} \| 10 \| 1\right] \times 10^3 \times 24 \times 10^{-12}$$

$$= 7.13 \times 10^{-10} \text{ s}$$

$$f_{H\pi} = \frac{1}{2\pi\tau_{P\pi}} = \frac{1}{2\pi(7.13 \times 10^{-10})}$$

$$\Rightarrow \underline{f_{H\pi} = 223 \text{ MHz}}$$

For the output

$$\tau_{P\mu} = [R_C \| R_L] C_\mu = (10\|1) \times 10^3 \times 3 \times 10^{-12}$$

$$= 2.73 \times 10^{-9}$$

$$f_{H\mu} = \frac{1}{2\pi\tau_{P\mu}} = \frac{1}{2\pi(2.73 \times 10^{-9})}$$

$$\Rightarrow \underline{f_{H\mu} = 58.3 \text{ MHz}}$$

$$(A_v)_M = g_m(R_C \| R_L)\left[\frac{R_E \| \left(\frac{r_\pi}{1+\beta}\right)}{R_E \| \left(\frac{r_\pi}{1+\beta}\right) + R_S}\right]$$

$$= (32.2)(10\|1)\left[\frac{10 \| \left(\frac{3.1}{101}\right)}{10 \| \left(\frac{3.1}{101}\right) + 1}\right]$$

$$\Rightarrow \underline{(A_v)_M = 0.869}$$

Chapter 7

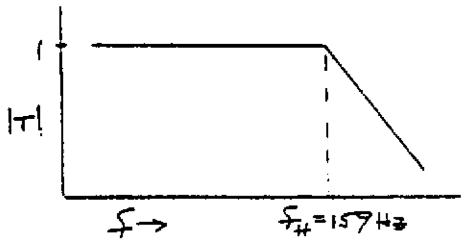
Problem Solutions

7.1

a. $T(s) = \dfrac{V_0(s)}{V_i(s)} = \dfrac{1/(sC_1)}{[1/(sC_1)] + R_1}$

$\underline{T(s) = \dfrac{1}{1 + sR_1C_1}}$

b.



$f_H = \dfrac{1}{2\pi R_1C_1} = \dfrac{1}{2\pi(10^3)(10^{-6})}$

$\Rightarrow \underline{f_H = 159 \text{ Hz}}$

c. $V_0(s) = V_i(s) \cdot \dfrac{1}{1 + sR_1C_1}$

For a step function $V_i(s) = \dfrac{1}{s}$

$$V_0(s) = \frac{1}{s} \cdot \frac{1}{1 + sR_1C_1} = \frac{K_1}{s} + \frac{K_2}{1 + sR_1C_1}$$

$$= \frac{K_1(1 + sR_1C_1) + K_2s}{s(1 + sR_1C_1)}$$

$$= \frac{K_1 + s(K_1R_1C_1 + K_2)}{s(1 + sR_1C_1)}$$

$K_2 = -K_1R_1C_1$ and $K_1 = 1$

$$V_0(s) = \frac{1}{s} + \frac{-R_1C_1}{1 + sR_1C_1}$$

$$= \frac{1}{s} - \frac{1}{\frac{1}{R_1C_1} + s}$$

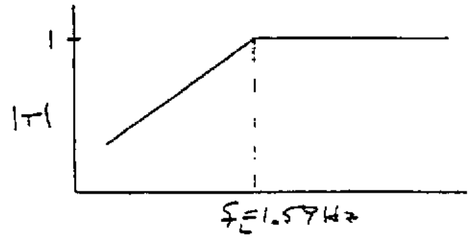
$\underline{v_0(t) = 1 - e^{-t/R_1C_1}}$

7.2

a. $T(s) = \dfrac{V_0(s)}{V_i(s)} = \dfrac{R_2}{R_2 + [1/(sC_2)]}$

$\underline{T(s) = \dfrac{sR_2C_2}{1 + sR_2C_2}}$

b.



$f_L = \dfrac{1}{2\pi R_2C_2} = \dfrac{1}{2\pi(10^4)(10 \times 10^{-6})}$

$\Rightarrow \underline{f_L = 1.59 \text{ Hz}}$

c. $V_0(s) = V_i(s) \cdot \dfrac{sR_2C_2}{1 + sR_2C_2}$

$V_i(s) = \dfrac{1}{s}$

$$V_0(s) = \frac{R_2C_2}{1 + sR_2C_2} = \frac{1}{s + \frac{1}{R_2C_2}}$$

$\underline{v_0(t) = e^{-t/R_2C_2}}$

7.3

a. $T(s) = \dfrac{V_0(s)}{V_i(s)} = \dfrac{R_P \| \frac{1}{sC_P}}{R_P \| \frac{1}{sC_P} + \left(R_S + \frac{1}{sC_S}\right)}$

$$R_P \| \frac{1}{sC_P} = \frac{R_P \cdot \frac{1}{sC_P}}{R_P + \frac{1}{sC_P}} = \frac{R_P}{1 + sR_PC_P}$$

Then

$$T(s) = \frac{R_P}{R_P + \left(R_S + \frac{1}{sC_S}\right)(1 + sR_PC_P)}$$

$$= \frac{R_P}{R_P + R_S + \frac{R_PC_P}{C_S} + \frac{1}{sC_S} + sR_SR_PC_P}$$

$T(s)$

$$= \left(\frac{R_P}{R_P + R_S}\right) \times \left(1/\left[1 + \frac{R_P}{R_P + R_S} \cdot \frac{C_P}{C_S} + \frac{1}{s(R_S + R_P)C_S} + \frac{sR_PR_S}{R_S + R_P} \cdot C_P\right]\right)$$

b.

$$T(s) = \left(\frac{10}{10+10}\right) \times \left(1\Big/\left[1 + \frac{10}{20}\cdot\frac{10^{-11}}{10^{-6}} + \frac{1}{s(2\times10^{4})\cdot10^{-6}} + s(5\times10^{3})\cdot10^{-11}\right]\right)$$

$$= \frac{1}{2}\cdot\frac{1}{1+\frac{1}{s(0.02)}+s(5\times10^{-8})}$$

$s = j\omega$

$$T(j\omega) = \frac{1}{2}\cdot\frac{1}{1+j\left[\omega(5\times10^{-8})-\frac{1}{\omega(0.02)}\right]}$$

For $\omega_L = \frac{1}{(R_S+R_P)C_S} = \frac{1}{(2\times10^{4})(10^{-6})} = 50$

$$T(j\omega) = \frac{1}{2}\cdot\frac{1}{1+j\left[(50)(5\times10^{-8})-\frac{1}{(50)(0.02)}\right]}$$

$$\approx \frac{1}{2}\cdot\frac{1}{1-j} \Rightarrow \underline{|T(j\omega)| = \frac{1}{2}\cdot\frac{1}{\sqrt{2}}}$$

For

$$\omega_H = \frac{1}{(R_S\|R_P)C_P} = \frac{1}{(5\times10^{3})(10^{-11})} = 2\times10^{7}$$

$$T(j\omega) = \frac{1}{2}\cdot\frac{1}{1+j\left[(2\times10^{7})(5\times10^{-8})-\frac{1}{(2\times10^{7})(0.02)}\right]}$$

$$T(j\omega) \approx \frac{1}{2}\cdot\frac{1}{1+j} \Rightarrow \underline{|T(j\omega)| = \frac{1}{2}\cdot\frac{1}{\sqrt{2}}}$$

In each case, $|T(j\omega)| = \frac{1}{\sqrt{2}}\cdot\frac{R_P}{R_P+R_S}$

c. $R_S = R_P = 10\ \text{k}\Omega,\quad C_S = C_P = 0.1\ \mu\text{F}$

$$T(s) = \frac{1}{2}\cdot\left(1\Big/\left[1+\frac{1}{2}\cdot\frac{1}{1}+\frac{1}{s(2\times10^{4}(10^{-7}))} + s(5\times10^{3})(10^{-7})\right]\right)$$

$s = j\omega$

$$T(j\omega) = \frac{1}{2}\cdot\frac{1}{1+\frac{1}{2}+j\left[\omega(5\times10^{-4})-\frac{1}{\omega(2\times10^{-3})}\right]}$$

For $\omega = \frac{1}{(2\times10^{4})(10^{-7})} = 500$

$$T(j\omega) = \frac{1}{2}\cdot\frac{1}{1.5+j\left[(500)(5\times10^{-4})-\frac{1}{(500)(2\times10^{3})}\right]}$$

$$= \frac{1}{2}\cdot\frac{1}{1.5-j(0.75)} \Rightarrow \underline{|T(j\omega)| = 0.298}$$

For $\omega = \frac{1}{(5\times10^{3})(10^{-7})} = 2\times10^{3}$

$$T(j\omega) = \frac{1}{2}\cdot\left\{1\Big/\left(1.5+j\left[(2\times10^{3})(5\times10^{-4}) - \frac{1}{(2\times10^{3})(2\times10^{-3})}\right]\right)\right\}$$

$$= \frac{1}{2}\cdot\frac{1}{1.5+j(0.75)} \Rightarrow \underline{|T(j\omega)| = 0.298}$$

In each case, $|T(j\omega)| < \frac{1}{\sqrt{2}}\cdot\frac{R_P}{R_P+R_S}$

7.4

Circuit (a):

$$T = \frac{V_o}{V_i} = \frac{R_2}{R_2 + R_1\left\|\frac{1}{sC_1}\right.} = \frac{R_2}{R_2+\frac{R_1(1/sC_1)}{R_1+(1/sC_1)}}$$

$$= \frac{R_2}{R_2+\frac{R_1}{1+sR_1C_1}} = \frac{R_2(1+sR_1C_1)}{R_2+sR_1R_2C_1+R_1}$$

or

$$\frac{V_o}{V_i} = \frac{R_2}{R_1+R_2}\cdot\frac{(1+sR_1C_1)}{1+sR_1\|R_2C_1}$$

Low frequency:

$$\left|\frac{V_o}{V_i}\right| = \frac{R_2}{R_1+R_2} = \frac{20}{10+20} = \frac{2}{3}$$

High frequency:

$$\left|\frac{V_o}{V_i}\right| = 1$$

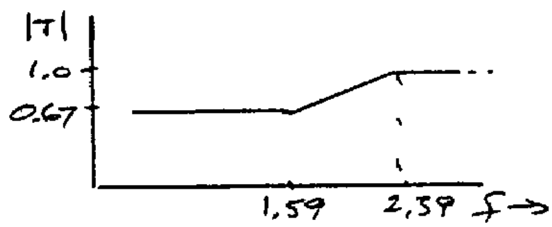
$$\tau_1 = R_1C_1 = (10^{4})(10x10^{-6}) = 0.10 \Rightarrow$$

$$f_1 = \frac{1}{2\pi\tau_1} = 1.59\ Hz$$

$$\tau_2 = (R_1\|R_2)C_1 = (10\|20)x10^{3}x(10x10^{-6}) \Rightarrow$$

$$\tau_2 = 0.0667 \Rightarrow$$

$$f_2 = \frac{1}{2\pi\tau_2} = 2.39\ Hz$$



Circuit (b):

$$T = \frac{V_o}{V_i} = \frac{R_2 \left\| \dfrac{1}{sC_2}\right.}{R_2 \left\| \dfrac{1}{sC_2}\right. + R_1} = \frac{\dfrac{R_2}{1+sR_2C_2}}{\dfrac{R_2}{1+sR_2C_2} + R_1}$$

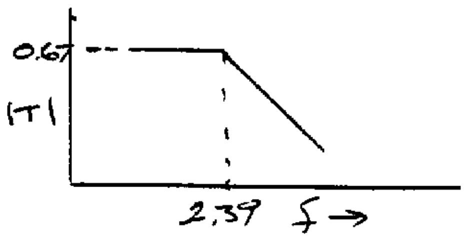
$$= \left(\frac{R_2}{R_1+R_2}\right)\left(\frac{1}{1+s(R_1\|R_2)C_2}\right)$$

Low frequency:

$$\left|\frac{V_o}{V_i}\right| = \frac{R_2}{R_1+R_2} = \frac{20}{20+10} = \frac{2}{3}$$

$$\tau = (R_1\|R_2)C_2 = (10\|20)x10^3x10x10^{-6} = 0.0667$$

$$f = \frac{1}{2\pi\tau} = 2.39\ Hz$$



7.5

a. $\tau_S = (R_i + R_P)C_S = [30 + 10] \times 10^3 \times 10 \times 10^{-6}$

$\Rightarrow \underline{\tau_S = 0.40\ s}$

$\tau_P = (R_i\|R_P)C_P = [30\|10] \times 10^3 \times 50 \times 10^{-12}$

$\Rightarrow \underline{\tau_P = 0.375\ \mu s}$

b. $f_L = \dfrac{1}{2\pi\tau_S} = \dfrac{1}{2\pi(0.4)} \Rightarrow \underline{f_L = 0.398\ \text{Hz}}$

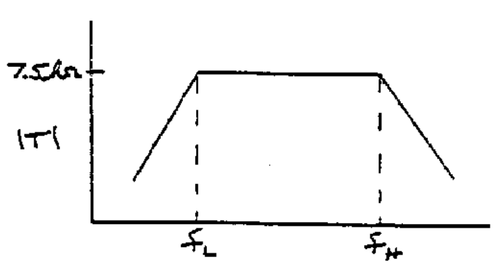
$f_H = \dfrac{1}{2\pi\tau_P} = \dfrac{1}{2\pi(0.375 \times 10^{-6})} \Rightarrow \underline{f_H = 424\ \text{kHz}}$

At midband. $C_S \rightarrow$ short, $C_P \rightarrow$ open

$V_0 = I_i(R_i\|R_P)$

$T(s) = R_i\|R_P = 30\|10 \Rightarrow \underline{T(s) = 7.5\ \text{k}\Omega}$

c.



7.6

(a) $T = \dfrac{1}{(1+j2\pi f\tau)^2} \Rightarrow$

$$|T| = \frac{1}{\left(\sqrt{1+(2\pi f\tau)^2}\right)^2} = \frac{1}{1+(2\pi f\tau)^2}$$

$$|T|_{max} = 1$$

$$\text{At } f = \frac{1}{2\pi\tau} \Rightarrow |T| = \frac{1}{1+(1)^2} = \frac{1}{2}$$

$$|T|_{dB} = 20\log_{10}\left(\frac{1}{2}\right) \Rightarrow \underline{|T|_{dB} \cong -6\ dB}$$

Phase $= 2\tan^{-1}(2\pi f\tau) = -2\tan^{-1}(1) = -2(45°) \Rightarrow$

$\underline{\text{Phase} = -90°}$

(b) Slope

$= -2(6\ dB/oct) =$

$\underline{-12\ dB/oct = -40\ dB/decade}$

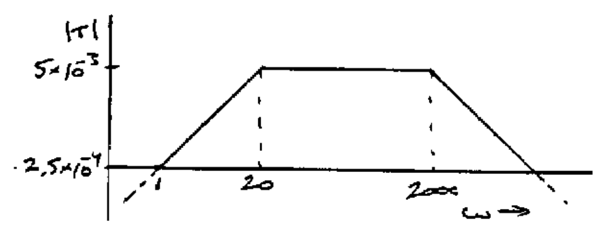
Phase $= -2(90°) \Rightarrow \underline{\text{Phase} = -180°}$

7.7

(a) $T(j\omega) = \dfrac{-10(j\omega)}{20\left(1+\dfrac{j\omega}{20}\right)(2000)\left(1+\dfrac{j\omega}{2000}\right)}$

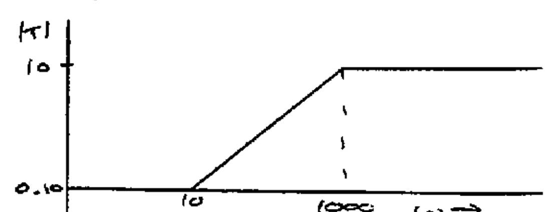
$$= \frac{2.5x10^{-4}(j\omega)}{\left(1+\dfrac{j\omega}{20}\right)\left(1+\dfrac{j\omega}{2000}\right)}$$

$$|T| = \frac{2.5x10^{-4}(\omega)}{\sqrt{1+\left(\dfrac{\omega}{20}\right)^2}\cdot\sqrt{1+\left(\dfrac{\omega}{2000}\right)^2}}$$



(b) $T(j\omega) = \dfrac{(10)(10)\left(1+\dfrac{j\omega}{10}\right)}{1000\left(1+\dfrac{j\omega}{1000}\right)}$

$$|T| = \frac{(0.10)\sqrt{1+\left(\dfrac{\omega}{10}\right)^2}}{\sqrt{1+\left(\dfrac{\omega}{1000}\right)^2}}$$



7.8

a. $V_0 = -g_m V_\pi R_L \quad V_\pi = \left(\frac{r_\pi}{r_\pi + R_S}\right) V_i$

$|T| = g_m R_L \left(\frac{r_\pi}{r_\pi + R_S}\right) = (29)(6)\left(\frac{5.2}{5.2 + 0.5}\right)$

$\underline{|T_{midband}| = 159}$

b. $\tau_S = (R_S + r_\pi) C_C$

$f_L = \frac{1}{2\pi\tau_S} \Rightarrow \tau_S = \frac{1}{2\pi f_L} = \frac{1}{2\pi(30)}$

$\Rightarrow \underline{\tau_S = 5.31 \text{ ms}}$ Open-circuit

$\tau_P = \frac{1}{2\pi f_H} = \frac{1}{2\pi(480 \times 10^3)}$

$\Rightarrow \underline{\tau_P = 0.332\ \mu s}$ Short-circuit

c. $C_C = \frac{\tau_S}{(R_S + r_\pi)} = \frac{5.31 \times 10^{-3}}{(0.5 + 5.2) \times 10^3}$

$\Rightarrow \underline{C_C = 0.932\ \mu F}$

$\tau_P = R_L C_L$

$C_L = \frac{\tau_P}{R_L} = \frac{0.332 \times 10^{-6}}{6 \times 10^3} \Rightarrow \underline{C_L = 55.3 \text{ pF}}$

7.11

a. $R_{TH} = R_1 \| R_2 = 10 \| 1.5 = 1.30 \text{ k}\Omega$

$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{1.5}{1.5 + 10}\right)(12)$

$= 1.565 \text{ V}$

$I_{BQ} = \frac{1.565 - 0.7}{1.30 + (101)(0.1)} = 0.0759 \text{ mA}$

$I_{CQ} = 7.59 \text{ mA}$

$r_\pi = \frac{(100)(0.026)}{7.59} = 0.343 \text{ k}\Omega$

$g_m = \frac{7.59}{0.026} = 292 \text{ mA/V}$

$R_i = R_1 \| R_2 \| [r_\pi + (1+\beta) R_E]$

$= 10 \| 1.5 \| [0.343 + (101)(0.1)]$

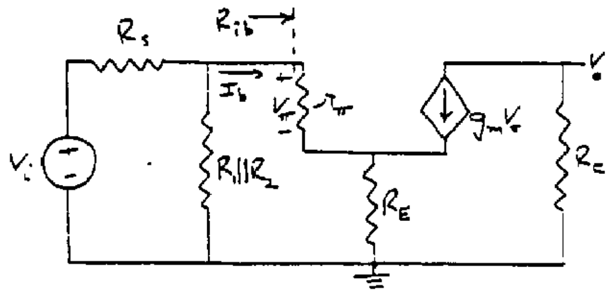
$= 1.30 \| 10.4 \Rightarrow R_i = 1.16 \text{ k}\Omega$

$\tau = (R_S + R_i) C_C = [0.5 + 1.16] \times 10^3 \times 0.1 \times 10^{-6}$

$\tau = 1.66 \times 10^{-4}$

$f_L = \frac{1}{2\pi\tau} = \frac{1}{2\pi(1.66 \times 10^{-4})} \Rightarrow \underline{f_L = 959 \text{ Hz}}$

b.



$V_0 = -(\beta I_b) R_C$

$R_{ib} = r_\pi + (1+\beta) R_E$

$= 0.343 + (101)(0.1) = 10.4 \text{ k}\Omega$

$I_b = \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{ib}}\right) I_i$

$= \left(\frac{1.30}{1.30 + 10.4}\right) I_i = (0.111) I_i$

$I_i = \frac{V_i}{R_S + R_1 \| R_2 \| R_{ib}}$

$= \frac{V_i}{0.5 + (1.3) \| (10.4)}$

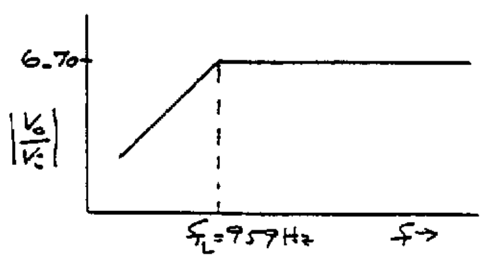
$I_i = \frac{V_i}{1.656}$

$\left|\frac{V_0}{V_i}\right| = \frac{\beta R_C (0.111)}{1.656}$

$\Rightarrow \left|\frac{V_0}{V_i}\right|_{midband} = \frac{(100)(1)(0.111)}{1.656}$

$\Rightarrow \underline{\left|\frac{V_0}{V_i}\right|_{midband} = 6.70}$

c.



7.12

$I_{DQ} = 0.5 \text{ mA} \Rightarrow V_S = (0.5)(0.5) = 0.25 \text{ V}$

$I_{DQ} = K_n (V_{GS} - V_{TN})^2$

$\Rightarrow V_{GS} = \sqrt{\frac{0.5}{0.2}} + 1.5 = 3.08 \text{ V}$

$V_G = V_{GS} + V_S = 3.08 + 0.25 \Rightarrow V_G = 3.33 \text{ V}$

$V_G = \left(\frac{R_2}{R_1 + R_2}\right) V_{DD} \Rightarrow 3.33 = \frac{1}{R_1} \cdot R_{in} \cdot V_{DD}$

$$3.33 = \frac{1}{R_1}(200)(9) \Rightarrow \underline{R_1 = 541\ \text{k}\Omega}$$

$$\frac{541 R_2}{541 + R_2} = 200 \Rightarrow \underline{R_2 = 317\ \text{k}\Omega}$$

$$V_D = V_{DSQ} + V_S = 4.5 + 0.25 = 4.75$$

$$R_D = \frac{9 - 4.75}{0.5} \Rightarrow \underline{R_D = 8.5\ \text{k}\Omega}$$

$$f_L = \frac{1}{2\pi\tau_L} \Rightarrow \tau_L = \frac{1}{2\pi f_L} = \frac{1}{2\pi(20)} = 7.96\ \text{ms}$$

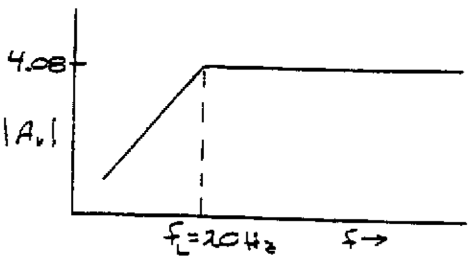
$$\tau_L = R_{in} \cdot C_C \Rightarrow C_C = \frac{\tau_L}{R_{in}} = \frac{7.96 \times 10^{-3}}{200 \times 10^3}$$

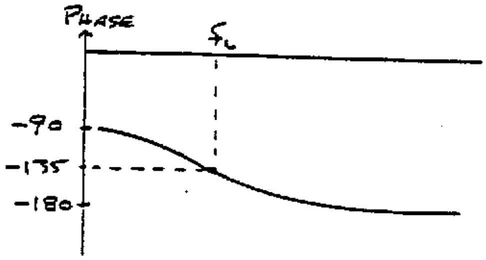
$$\Rightarrow \underline{C_C = 0.0398\ \mu\text{F}}$$

$$g_m = 2(0.2)(3.08 - 1.5) = 0.632\ \text{mA/V}$$

$$|A_v|_{\text{midband}} = \frac{g_m R_D}{1 + g_m R_S} = \frac{(0.632)(8.5)}{1 + (0.632)(0.5)}$$

$$\Rightarrow |A_v| = 4.08$$





7.13

$$I_{DQ} = K_n(V_{GS} - V_{TN})^2$$

$$\Rightarrow V_{GS} = \sqrt{\frac{I_{DQ}}{K_n}} + V_{TN} = \sqrt{\frac{1}{0.5}} + 1 = 2.41\,V$$

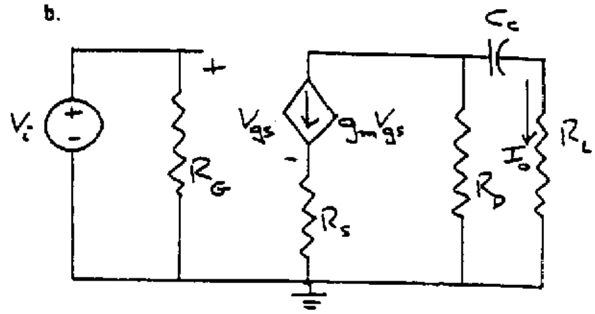
$$V_S = -2.41\ \text{V}$$

$$R_S = \frac{-2.41 - (-5)}{1} \Rightarrow \underline{R_S = 2.59\ \text{k}\Omega}$$

$$V_D = V_{DSQ} + V_S = 3 - 2.41 = 0.59\ \text{V}$$

$$R_D = \frac{5 - 0.59}{1} \Rightarrow \underline{R_D = 4.4\ \text{k}\Omega}$$

b.



$$I_0 = -(g_m V_{gs})\left(\frac{R_D}{R_D + R_L + \frac{1}{sC_C}}\right)$$

$$V_{gs} = \frac{V_i}{1 + g_m R_S}$$

$$\frac{I_0(s)}{V_i(s)} = \frac{-g_m}{1 + g_m R_S} \cdot R_D \left[\frac{sC_C}{1 + s(R_D + R_L)C_C}\right]$$

$$T(s) = \frac{I_0(s)}{V_i(s)}$$

$$= \frac{-g_m R_D}{1 + g_m R_S} \cdot \frac{1}{R_D + R_L} \cdot \frac{s(R_D + R_L)C_C}{1 + s(R_D + R_L)C_C}$$

c. $$f_L = \frac{1}{2\pi\tau_L} \rightarrow \tau_L = \frac{1}{2\pi f_L} = \frac{1}{2\pi(10)} = 15.9\ \text{ms}$$

$$\tau_L = (R_D + R_L)C_C$$

$$\Rightarrow C_C = \frac{\tau_L}{R_D + R_L} = \frac{15.9 \times 10^{-3}}{(4.41 + 4) \times 10^3}$$

$$\Rightarrow \underline{C_C = 1.89\ \mu\text{F}}$$

7.14

a. $$\frac{9 - V_{SG}}{R_S} = I_D = K_p(V_{SG} + V_{TP})^2$$

$$9 - V_{SG} = (0.5)(12)(V_{SG}^2 - 4V_{SG} + 4)$$

$$6V_{SG}^2 - 23V_{SG} + 15 = 0$$

$$V_{SG} = \frac{23 \pm \sqrt{(23)^2 - 4(6)(15)}}{2(6)} \Rightarrow V_{SG} = 3\ \text{V}$$

$$g_m = 2K_p(V_{SG} + V_{TP}) = 2(0.5)(3 - 2)$$

$$\Rightarrow g_m = 1\ \text{mA/V}$$

$$R_o = \frac{1}{g_m} \bigg\| R_S = 1 \| 12 \Rightarrow \underline{R_o = 0.923\ \text{k}\Omega}$$

b. $\underline{\tau = (R_o + R_L)C_C}$

a. $$f_L = \frac{1}{2\pi\tau} \Rightarrow \tau = \frac{1}{2\pi f_L} = \frac{1}{2\pi(20)} = 7.96\ \text{ms}$$

$$C_C = \frac{\tau}{R_o + R_L} = \frac{7.96 \times 10^{-3}}{(0.923 + 10) \times 10^3}$$

$$\Rightarrow \underline{C_C = 0.729\ \mu\text{F}}$$

7.15

a. $I_{CQ} = 1$ mA, $I_{BQ} = \frac{1}{120} = 0.00833$ mA

$R_1 \| R_2 = (0.1)(1+\beta)(R_E)$

$= (0.1)(121)(4) = 48.4$ kΩ

$V_{TH} = I_{BQ}R_{TH} + V_{BE}(\text{on}) + (1+\beta)I_{BQ}R_E$

$\frac{1}{R_1} \cdot R_{TH} \cdot V_{CC}$

$= (0.00833)(48.4) + 0.7 + (121)(0.00833)(4)$

$\frac{1}{R_1}(48.4)(12) = 5.13$

$\underline{R_1 = 113 \text{ k}\Omega}$

$\frac{113R_2}{113+R_2} = 48.4 \Rightarrow \underline{R_2 = 84.7 \text{ k}\Omega}$

b. $R_o = \frac{r_\pi}{1+\beta} \| R_E \| r_o$

$r_\pi = \frac{(120)(0.026)}{1} = 3.12$ kΩ

$r_o = \frac{80}{1} = 80$ kΩ

$R_o = \frac{3.12}{121} \| 4 \| 80 = 0.0258 \| 4 \| 80$

$\Rightarrow \underline{R_o = 25.6\ \Omega}$

c. $\tau = (R_o + R_L)C_{C2}$

$\tau = (0.0256 + 4) \times 10^3 \times 2 \times 10^{-6} = 8.05 \times 10^{-3}$ s

$f = \frac{1}{2\pi\tau} = \frac{1}{2\pi(8.05 \times 10^{-3})} \Rightarrow \underline{f = 19.8 \text{ Hz}}$

7.16

(a) $\frac{5 - V_{SG}}{R_1} = K_p(V_{SG} + V_{TP})^2$

$5 - V_{SG} = (1)(1.2)(V_{SG} - 1.5)^2 = (1.2)(V_{SG}^2 - 3V_{SG} + 2.25)$

$1.2V_{SG}^2 - 2.6V_{SG} - 2.3 = 0 \Rightarrow \underline{V_{SG} = 2.84\ V}$

$\underline{I_{DQ} = 1.8\ mA}$

$V_{SDQ} = 10 - (1.8)(1.2 + 1.2) \Rightarrow \underline{V_{SDQ} = 5.68\ V}$

$g_m = 2\sqrt{K_p I_{DQ}} = 2\sqrt{(1)(1.8)} = 2.68\ mA/V$

$r_o = \infty$

(b) $R_{ic} = \frac{1}{g_m} = \frac{1}{2.68} = 0.373\ k\Omega$

$R_i = 1.2 \| 0.373 = 0.285\ k\Omega$

For C_{C1}, $\tau_{s1} = (285 + 200)(4.7x10^{-6}) = 2.28\ ms$

For C_{C2}, $\tau_{s2} = (1.2x10^3 + 50x10^3)(10^{-6}) = 51.2\ ms$

(c) C_{C2} dominates,

$f_{3-dB} = \frac{1}{2\pi\tau_{s2}} = \frac{1}{2\pi(51.2x10^{-3})} = 3.1\ Hz$

7.17

Assume $V_{TN} = 1V$, $k_n' = 80\ \mu A/V^2$, $\lambda = 0$

Neglecting $R_{Si} = 200\ \Omega$, Midband gain is:

$|A_v| = g_m R_D$

Let $I_{DQ} = 0.2\ mA$, $V_{DSQ} = 5\ V$

Then $R_D \doteq \frac{9-5}{0.2} \Rightarrow \underline{R_D = 20\ k\Omega}$

We need

$g_m = \frac{|A_v|}{R_D} = \frac{10}{20} = 0.5\ mA/V^2$

and

$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)I_{DQ}}$

or

$0.5 = 2\sqrt{\left(\frac{0.080}{2}\right)\left(\frac{W}{L}\right)(0.2)} \Rightarrow \underline{\frac{W}{L} = 7.81}$

Let $R_1 + R_2 = \frac{9}{(0.2)I_{DQ}} = \frac{9}{(0.2)(0.2)} = 225\ k\Omega$

$I_{DQ} = 0.2 = \left(\frac{0.080}{2}\right)(7.81)(V_{GS} - 1)^2$

$\Rightarrow V_{GS} = 1.80 = \left(\frac{R_2}{R_1 + R_2}\right)(9) = \left(\frac{R_2}{225}\right)(9) \Rightarrow$

$\underline{R_2 = 45\ k\Omega,\ \ R_1 = 180\ k\Omega}$

$R_{TH} = R_1 \| R_2 = 180 \| 45 = 36\ k\Omega$

$\tau_1 = \frac{1}{2\pi f_1} = \frac{1}{2\pi(200)} = 7.96x10^{-4}\ s = (R_{Si} + R_{TH})C_C$

or

$C_C = \frac{7.96x10^{-4}}{(200 + 36x10^3)} \Rightarrow \underline{C_C = 220\ \mu F}$

$\tau_2 = \frac{1}{2\pi f_2} = \frac{1}{2\pi(3x10^3)} = 5.31x10^{-5}\ s = R_D C_L$

or

$C_L = \frac{5.31x10^{-5}}{20x10^3} \Rightarrow \underline{C_L = 2.66\ nF}$

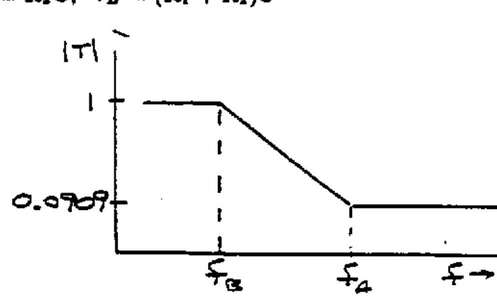
7.18

a. $T(s) = \frac{R_2 + (1/sC)}{R_2 + (1/sC) + R_1}$

$\underline{T(s) = \frac{1 + sR_2C}{1 + s(R_1 + R_2)C}}$

$\tau_A = R_2C$, $\tau_B = (R_1 + R_2)C$

b.



c. $\tau_A = R_2 C = (10^3)(100 \times 10^{-12}) = \underline{10^{-7}\ s = \tau_A}$

$\tau_B = (R_1 + R_2)C = [10 + 1] \times 10^3 \times 100 \times 10^{-12}$

$= \underline{1.1 \times 10^{-6}\ s = \tau_B}$

$f_A \approx \dfrac{1}{2\pi\tau_A} = \dfrac{1}{2\pi(10^{-7})} \Rightarrow \underline{f_A = 1.59\text{ MHz}}$

$f_B \approx \dfrac{1}{2\pi\tau_B} = \dfrac{1}{2\pi(1.1 \times 10^{-6})}$

$\Rightarrow \underline{f_B = 0.145\text{ MHz}}$

7.19

$I_{BQ} = \dfrac{10 - 0.7}{430 + (201)(2.5)} = 0.00997\ mA$

$I_{CQ} = (200) I_{BQ} = 1.99\ mA$

$r_\pi = \dfrac{(200)(0.026)}{1.99} = 2.61\ k\Omega$

$R_{ib} = 2.61 + (201)(2.5) = 505\ k\Omega$

$\tau_s = \dfrac{1}{2\pi f_L} = \dfrac{1}{2\pi(15)} = 0.0106\ s$

$= R_{eq} C_C = (0.5 + 505 \| 430) x 10^3 C_C = 232.7 x 10^3 C_C$

Or

$\underline{C_C = 4.56 x 10^{-8}\ F \Rightarrow 45.6\ nF}$

7.20

$R_{TH} = R_1 \| R_2 = 1.2 \| 1.2 = 0.6\ k\Omega$

$V_{TH} = \left(\dfrac{R_2}{R_1 + R_2}\right)(V_{CC}) = \left(\dfrac{1.2}{1.2 + 1.2}\right)(5) = 2.5\ V$

$I_{BQ} = \dfrac{2.5 - 0.7}{0.6 + (101)(0.05)} = 0.319\ mA$

$I_{CQ} = 31.9\ mA$

$r_\pi = \dfrac{(100)(0.026)}{31.9} = 0.0815\ k\Omega$

$\tau_{C_{C1}} >> \tau_{C_{C2}}$ and $f = \dfrac{1}{2\pi\tau}$ so that

$f_{3-dB}(C_{C1}) << f_{3-dB}(C_{C2})$

Then, for $f_{3-dB}(C_{C1}) \Rightarrow C_{C2}$ acts as an open and for $f_{3-dB}(C_{C2}) \Rightarrow C_{C1}$ acts as a short circuit.

$f_{3-dB}(C_{C2}) = 25\ Hz = \dfrac{1}{2\pi\tau_2}$, so that

$\tau_2 = \dfrac{1}{2\pi(25)} = 0.00637\ s = R_{eq} C_{C2}$

where $R_{eq} = R_L + R_E \left\| \left(\dfrac{r_\pi + R_1 \| R_2 \| R_S}{1 + \beta}\right)\right.$

$= 10 + 50 \left\| \left(\dfrac{81.5 + 600 \| 300}{101}\right) = 10 + 50 \| 2.79 \Rightarrow\right.$

$R_{eq} = 12.6\ \Omega \Rightarrow C_{C2} = \dfrac{0.00637}{12.6} \Rightarrow \underline{C_{C2} = 506\ \mu F}$

$R_{ib} = r_\pi + (1 + \beta) R_E$ Assume C_{C2} an open

$R_{ib} = 815 + (101)(50) = 5132\ \Omega$

$\tau_1 = (100)\tau_2 = (100)(0.00637) = 0.637\ s = R_{eq1} C_{C1}$

$R_{eq1} = R_S + R_{TH} \| R_{ib} = 300 + 600 \| 5132 = 837\ \Omega$

So $C_{C1} = \dfrac{0.637}{837} \Rightarrow \underline{C_{C1} = 761\ \mu F}$

7.21

a. $I_D = K_n (V_{GS} - V_{TN})^2$

$V_{GS} = \sqrt{\dfrac{I_D}{K_n}} + V_{TN} = \sqrt{\dfrac{0.5}{0.5}} + 0.8 = 1.8\ V$

$R_S = \dfrac{-V_{GS} - (-5)}{0.5} = \dfrac{5 - 1.8}{0.5} \Rightarrow \underline{R_S = 6.4\text{ k}\Omega}$

$V_D = V_{DSQ} + V_S = 4 - 1.8 = 2.2\text{ V}$

$R_D = \dfrac{5 - 2.2}{0.5} \Rightarrow \underline{R_D = 5.6\text{ k}\Omega}$

(b) $g_m = 2\sqrt{K_n I_D} = 2\sqrt{(0.5)(0.5)} = 1\ mA/V$

From Problem 7.20,

$\tau_A = R_S C_S = (6.4 \times 10^3)(5 \times 10^{-6})$

$= 3.2 \times 10^{-2}\text{ s}$

$f_A = \dfrac{1}{2\pi\tau_A} = \dfrac{1}{2\pi(3.2 \times 10^{-2})} \Rightarrow \underline{f_A = 4.97\text{ Hz}}$

$\tau_B = \left(\dfrac{R_S}{1 + g_m R_S}\right) C_S = \left[\dfrac{6.4 \times 10^3}{1 + (1)(6.4)}\right](5 \times 10^{-6})$

$= 4.32 \times 10^{-3}\text{ s}$

$f_B = \dfrac{1}{2\pi\tau_B} = \dfrac{1}{2\pi(4.32 \times 10^{-3})} \Rightarrow \underline{f_B = 36.8\text{ Hz}}$

c.

$$|A_v| = \frac{g_m R_D (1 + s R_S C_S)}{(1 + g_m R_S)\left[1 + s\left(\dfrac{R_S}{1 + g_m R_S}\right) C_S\right]}$$

As R_S becomes large

$$|A_v| \to \frac{g_m R_D (s R_S C_S)}{(g_m R_S)\left[1 + s\left(\dfrac{R_S}{g_m R_S}\right) C_S\right]}$$

$$A_v = \frac{(g_m R_D)\left[s\left(\dfrac{1}{g_m}\right) C_S\right]}{1 + s\left(\dfrac{1}{g_m}\right) C_S}$$

The corner frequency $f_B = \dfrac{1}{2\pi(1/g_m)C_S}$ and the corresponding $\underline{f_A \to 0}$

$g_m = 2\sqrt{K_n I_D} = 2\sqrt{(0.5)(0.5)} = 1\,mA/V$

$f_B = \dfrac{1}{2\pi\left(\dfrac{1}{10^{-3}}\right)(5\times10^{-6})} \Rightarrow \underline{f_B = 31.8\text{ Hz}}$

7.22

a. $f_B = \dfrac{1}{2\pi\tau_B}$

and $\tau_B = \dfrac{R_E(R_S + r_\pi)C_E}{R_S + r_\pi + (1+\beta)R_E}$

For $R_S = 0$ $\tau_B = \dfrac{R_E r_\pi C_E}{r_\pi + (1+\beta)R_E}$

$I_{EQ} = \dfrac{-0.7-(-10)}{5} = 1.86\text{ mA}$

$\beta = 75 \Rightarrow I_{CQ} = 1.84\text{ mA}$

$\beta = 125 \Rightarrow I_{CQ} = 1.85\text{ mA}$

For $f_B \le 200$ Hz

$\Rightarrow \tau_B \ge \dfrac{1}{2\pi(200)} = 0.796\text{ ms}$

$r_\pi \alpha \beta$ so smallest τ_B will occur for smallest β.

$\beta = 75;\quad r_\pi = \dfrac{(75)(0.026)}{1.84} = 1.06\text{ k}\Omega$

$0.796\times10^{-3} = \dfrac{(5\times10^3)(1.06)C_E}{1.06+(76)(5)}$

$\Rightarrow \underline{C_E = 57.2\ \mu F}$

b. For $\beta = 125;\ r_\pi = \dfrac{(125)(0.026)}{1.85} = 1.76\text{ k}\Omega$

$\tau_B = \dfrac{(5\times10^3)(1.76)(57.2\times10^{-6})}{1.76+(126)(5)} = 0.797\text{ ms}$

$f_B = \dfrac{1}{2\pi\tau_B} = \dfrac{1}{2\pi(0.797\times10^{-3})}$

$\Rightarrow \underline{f_B = 199.7\text{ Hz}}$ Essentially independent of β.

$\tau_A = R_E C_E = (5\times10^3)(57.2\times10^{-6}) = 0.286\text{ sec}$

$f_A = \dfrac{1}{2\pi\tau_A} = \dfrac{1}{2\pi(0.286)}$

$\Rightarrow \underline{f_A = 0.556\text{ Hz}}$ Independent of β.

7.23

a. Expression for the voltage gain is the same as Equation (7.58) with $R_S = 0$.

b. $\tau_A = R_E C_E$

$\tau_B = \dfrac{R_E r_\pi C_E}{r_\pi + (1+\beta)R_E}$

7.24

$\tau_H = (R_L \| R_C)C_L = (10\|5)\times10^3\times15\times10^{-12}$

$\tau_H = 5\times10^{-8}$ s

$f_H = \dfrac{1}{2\pi\tau_H} = \dfrac{1}{2\pi(5\times10^{-8})} \Rightarrow \underline{f_H = 3.18\text{ MHz}}$

$I_{EQ} = \dfrac{10-0.7}{10} = 0.93\text{ mA},\ I_{CQ} = 0.921\text{ mA}$

$g_m = \dfrac{0.921}{0.026} = 35.4\text{ mA/V}$

$A_v = g_m(R_C\|R_L) = 35.4(5\|10) \Rightarrow \underline{A_v = 118}$

7.25

$V_G = \left(\dfrac{R_2}{R_1+R_2}\right)V_{DD} = \left(\dfrac{166}{166+234}\right)(10)$

$= 4.15$ V

$I_D = \dfrac{V_G - V_{GS}}{R_S} = K_n(V_{GS} - V_{TN})^2$

$4.15 - V_{GS} = (0.5)(0.5)(V_{GS}^2 - 4V_{GS} + 4)$

$0.25V_{GS}^2 - 3.15 = 0 \Rightarrow V_{GS} = 3.55$ V

$g_m = 2K_n(V_{GS} - V_{TN}) = 2(0.5)(3.55-2)$

$g_m = 1.55\,mA/V$

$R_0 = R_S \,\Big\|\, \dfrac{1}{g_m} = 0.5 \,\Big\|\, \dfrac{1}{1.55} = 0.5\|0.645$

$R_0 = 0.282\text{ k}\Omega$

$\tau = (R_0\|R_L)C_L$ and $f_H = \dfrac{1}{2\pi\tau}$

$B\omega \approx f_H = 5$ MHz

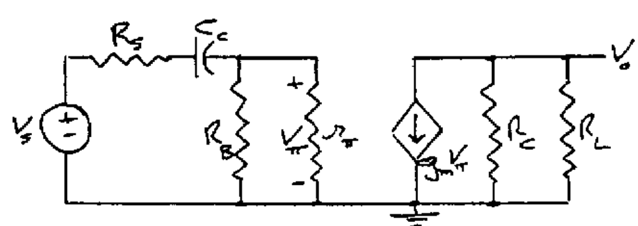
$\Rightarrow \tau = \dfrac{1}{2\pi(5\times10^6)} = 3.18\times10^{-8}$ s

$C_L = \dfrac{\tau}{R_0\|R_L} = \dfrac{3.18\times10^{-8}}{(0.282\|4)\times10^3}$

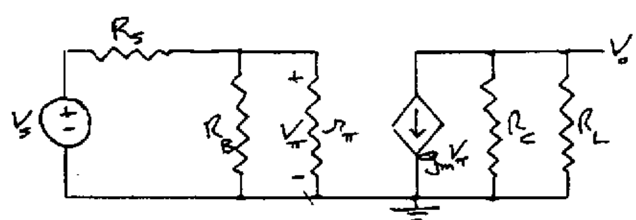
$\Rightarrow \underline{C_L = 121\text{ pF}}$

7.26

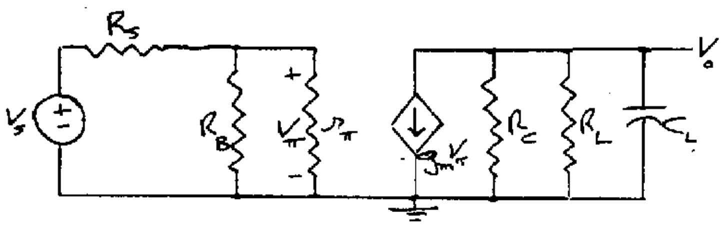
(a) Low-frequency



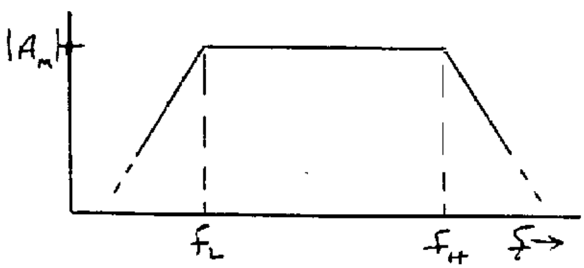
Mid-Band



High-frequency



(b)



(c) $I_{BQ} = \dfrac{12-0.7}{1\ M\Omega} = 11.3\ \mu A$

$I_{CQ} = 1.13\ mA$

$r_\pi = \dfrac{(100)(0.026)}{1.13} = 2.3\ k\Omega$

$g_m = \dfrac{1.13}{0.026} = 43.46\ mA/V$

$A_m = \dfrac{V_o}{V_s}(midband) = -g_m(R_C \| R_L)\left(\dfrac{R_B \| r_\pi}{R_B \| r_\pi + R_S}\right)$

$= -(43.46)(5.1 \| 500)\left(\dfrac{1000 \| 2.3}{1000 \| 2.3 + 1}\right)$

$= -(43.46)(5.05)\left(\dfrac{2.29}{2.29+1}\right) \Rightarrow\ |A_m| = 153$

$\underline{|A_m|_{dB} = 43.7\ dB}$

$f_L = \dfrac{1}{2\pi\tau_L},\quad \tau_L = (R_S + R_B \| r_\pi)C_C$

or

$\tau_L = (1 + 1000 \| 2.3)x10^3(10x10^{-6}) \Rightarrow$

$\tau_L = 3.29x10^{-2}\ s \Rightarrow\ \underline{f_L = 4.84\ Hz}$

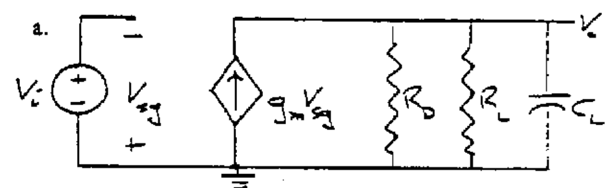
$f_H = \dfrac{1}{2\pi\tau_H},\quad \tau_H = (R_C \| R_L)C_L \Rightarrow$

$\tau_L = (5.1 \| 500)x10^3(10x10^{-12}) = 5.05x10^{-8}\ s$

$\underline{\Rightarrow f_H = 3.15\ MHz}$

7.27

a.



$V_0 = (g_m V_{sg})\left(R_o \parallel R_L \parallel \dfrac{1}{sC_L}\right)$

$V_{sg} = -V_i$

$A_v(s) = \dfrac{V_0(s)}{V_i(s)} = -g_m\left(R_D \parallel R_L \parallel \dfrac{1}{sC_L}\right)$

$= -g_m\left[\dfrac{R_D \| R_L \cdot \frac{1}{sC_L}}{R_D \| R_L + \frac{1}{sC_L}}\right]$

$\underline{A_v(s) = -g_m(R_D \| R_L) \cdot \dfrac{1}{1 + s(R_D \| R_L)C_L}}$

b. $\tau = (R_D \| R_L)C_L$

c. $\tau = (10 \| 20) \times 10^3 \times 10 \times 10^{-12}$

$\Rightarrow \underline{\tau = 6.67 \times 10^{-8}\ s}$

$f_H = \dfrac{1}{2\pi\tau} = \dfrac{1}{2\pi(6.67 \times 10^{-8})}$

$\Rightarrow \underline{f_H = 2.39\ \text{MHz}}$

From Example 7.6, $g_m = 0.705$ mA/V

$|A_v| = g_m(R_D \| R_L) = (0.705)(10 \| 20)$

$\Rightarrow \underline{|A_v| = 4.7}$

7.31

$f_T = \dfrac{g_m}{2\pi(C_\pi + C_\mu)}$

$g_m = \dfrac{I_{CQ}}{V_T} = \dfrac{1}{0.026} = 38.5$ mA/V

$f_T = \dfrac{38.5 \times 10^{-3}}{2\pi(10+2) \times 10^{-12}}$

$\underline{f_T = 511\ \text{MHz}}$

$f_\beta = \dfrac{f_T}{\beta} = \dfrac{511}{120} \Rightarrow \underline{f_\beta = 4.26\ \text{MHz}}$

7.32

$$f_\beta = \frac{f_T}{\beta} = \frac{5000\text{ MHz}}{150} \Rightarrow \underline{f_\beta = 33.3\text{ MHz}}$$

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$$

$$g_m = \frac{0.5}{0.026} = 19.2\text{ mA/V}$$

$$5\times 10^9 = \frac{19.2\times 10^3}{2\pi(C_\pi + 0.15)\times 10^{-12}}$$

$$C_\pi + 0.15 = \frac{19.2\times 10^3}{2\pi(10^{-12})(5\times 10^9)} = 0.611\text{ pF}$$

$$\underline{C_\pi = 0.461\text{ pF}}$$

7.33

a. $$f_\beta = \frac{f_T}{\beta} = \frac{2000\text{ MHz}}{150} = \underline{13.3\text{ MHz} = f_\beta}$$

b. $$h_{fe} = \frac{150}{1 + j(f/f_\beta)}$$

$$|h_{fe}| = \frac{150}{\sqrt{1+(f/f_\beta)^2}} = 10$$

$$1 + \left(\frac{f}{f_\beta}\right)^2 = \left(\frac{150}{10}\right)^2 = 225$$

$$f = f_\beta\cdot\sqrt{224} = (13.3)\sqrt{224}$$

$$\Rightarrow \underline{f = 199\text{ MHz}}$$

7.34

(a) $V_o = -g_m V_\pi R_L$ where

$$V_\pi = \frac{r_\pi \left\| \frac{1}{sC_1}\right.}{r_\pi \left\| \frac{1}{sC_1}\right. + r_b}\cdot V_i = \frac{\frac{r_\pi}{1+sr_\pi C_1}}{\frac{r_\pi}{1+sr_\pi C_1} + r_b}\cdot V_i$$

$$= \frac{r_\pi}{r_\pi + r_b + sr_b r_\pi C_1}\cdot V_i = \left(\frac{r_\pi}{r_\pi + r_b}\right)\left(\frac{1}{1+s(r_b\|r_\pi)C_1}\right)\cdot V_i$$

So

$$A_v(s) = \frac{V_o(s)}{V_i(s)} = -g_m R_L\left(\frac{r_\pi}{r_\pi + r_b}\right)\left(\frac{1}{1+s(r_b\|r_\pi)C_1}\right)$$

(b) Midband gain:

$$r_\pi = \frac{(100)(0.026)}{1} = 2.6\ k\Omega\ ,$$

$$g_m = \frac{1}{0.026} = 38.46\ mA/V$$

(i) For $r_b = 100\,\Omega$

$$A_{v1} = -(38.46)(4)\left(\frac{2.6}{2.6+0.1}\right) \Rightarrow \underline{A_{v1} = -148.1}$$

(ii) For $r_b = 500\,\Omega$

$$A_{v2} = -(38.46)(4)\left(\frac{2.6}{2.6+0.5}\right) \Rightarrow \underline{A_{v2} = -129.0}$$

(c) $f_{3-dB} = \dfrac{1}{2\pi\tau}$, $\tau = (r_b\|r_\pi)C_1$

(i) For $r_b = 100\,\Omega$

$$\tau_1 = (0.1\|2.6)x10^3(2.2x10^{-12}) = 2.12x10^{-10}\ s$$

$$\underline{\Rightarrow f_{3-db} = 751\ MHz}$$

(ii) For $r_b = 500\,\Omega$

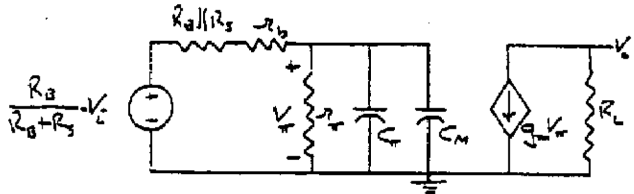
$$\tau_2 = (0.5\|2.3)x10^3(2.2x10^{-12}) = 9.04x10^{-10}\ s$$

$$\underline{f_{3-dB} = 176\ MHz}$$

7.35

a. $\underline{C_M = C_\mu(1 + g_m R_L)}$

b.



$V_0 = -g_m V_\pi R_L$ Let $C_\pi + C_M = C_i$

$$V_\pi = \frac{r_\pi \left\| \frac{1}{sC_i}\right.}{r_\pi \left\| \frac{1}{sC_i}\right. + R_B\|R_S + r_b}\cdot\left(\frac{R_B}{R_B+R_S}\right)V_i$$

$$A_v(s) = \frac{V_0(s)}{V_i(s)}$$

$$= -g_m R_L\left(\frac{R_B}{R_B+R_S}\right)\left[\frac{\frac{r_\pi\cdot\frac{1}{sC_i}}{r_\pi + \frac{1}{sC_i}}}{\frac{r_\pi\cdot\frac{1}{sC_i}}{r_\pi + \frac{1}{sC_i}} + R_B\|R_S + r_b}\right]$$

$$= -g_m R_L\left(\frac{R_B}{R_B+R_S}\right)$$

$$\times\left[\frac{r_\pi}{r_\pi + (1 + sr_\pi C_i)(R_B\|R_S + r_b)}\right]$$

Let $R_{eq} = (R_B\|R_S + r_b)$

$$A_v(s) = -\beta R_L\left(\frac{R_B}{R_B+R_S}\right)$$

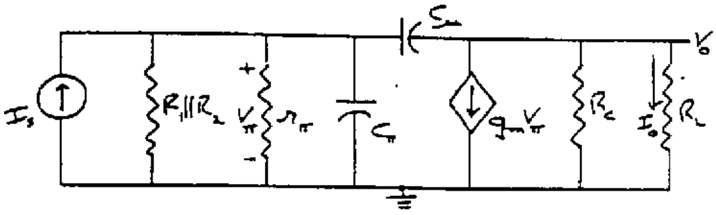
$$\times\left[\frac{1}{(r_\pi + R_{eq})[1 + s(r_\pi\|R_{eq})C_i]}\right]$$

$$\underline{A_v(s) = \frac{-\beta R_L}{r_\pi + R_{eq}}\cdot\left(\frac{R_B}{R_B+R_S}\right)\cdot\frac{1}{1+s(r_\pi\|R_{eq})C_i}}$$

c. $$\underline{f_H = \frac{1}{2\pi(r_\pi\|R_{eq})C_i}}$$

7.36

High Freq. $\Rightarrow C_{C1},\ C_{C2},\ C_E \rightarrow$ short circuits



$$g_m = \frac{I_{CQ}}{V_T} = \frac{5}{0.026} = 192 \text{ mA/V}$$

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} \Rightarrow 250 \times 10^6 = \frac{192 \times 10^{-3}}{2\pi(C_\pi + C_\mu)}$$

$$C_\pi + C_\mu = 122 \text{ pF} \Rightarrow C_\mu = 5 \text{ pF},\ C_\pi = 117 \text{ pF}$$

$$C_M = C_\mu(1 + g_m(R_C \| R_L))$$

$$= 5[1 + (192)(1\|1)] \Rightarrow C_M = 485 \text{ pF}$$

$$C_i = C_\pi + C_M = 117 + 485 = 602 \text{ pF}$$

$$r_\pi = \frac{(200)(0.026)}{5} = 1.04 \text{ k}\Omega$$

$$R_{eq} = R_1 \| R_2 \| r_\pi = 5\|1.04 = 0.861 \text{ k}\Omega$$

$$\tau = R_{eq} \cdot C_i = (0.861 \times 10^3)(602 \times 10^{-12})$$

$$= 5.18 \times 10^{-7} \text{ s}$$

$$f = \frac{1}{2\pi\tau} = \frac{1}{2\pi(5.18 \times 10^{-7})} \Rightarrow \underline{f = 307 \text{ kHz}}$$

7.37

$$R_{TH} = R_1 \| R_2 = 60\|5.5 = 5.04 \text{ k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{5.5}{5.5 + 60}\right)(15) = 1.26 \text{ V}$$

$$I_{BQ} = \frac{1.26 - 0.7}{5.04 + (101)(0.2)} = 0.0222 \text{ mA}$$

$$I_{CQ} = 2.22 \text{ mA}$$

$$r_\pi = \frac{(100)(0.026)}{2.22} = 1.17 \text{ k}\Omega$$

$$g_m = \frac{2.22}{0.026} = 85.4 \text{ mA/V}$$

Lower $3 - dB$ frequency:

$$\tau_L = R_{eq} \cdot C_{C1}$$

$$R_{eq} = R_S + R_1 \| R_2 \| r_\pi$$

$$= 2 + 60\|5.5\|1.17 = 2.95 \text{ k}\Omega$$

$$\tau_L = (2.95 \times 10^3)(0.1 \times 10^{-6}) = 2.95 \times 10^{-4} \text{ s}$$

$$f_L = \frac{1}{2\pi\tau_L} = \frac{1}{2\pi(2.95 \times 10^{-4})} \Rightarrow \underline{f_L = 540 \text{ Hz}}$$

Upper $3 - dB$ frequency:

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} \Rightarrow 400 \times 10^6 = \frac{85.4 \times 10^{-3}}{2\pi(C_\pi + C_\mu)}$$

$$C_\pi + C_\mu = 34 \text{ pF};\ C_\mu = 2 \text{ pF} \Rightarrow C_\pi = 32 \text{ pF}$$

$$C_M = C_\mu(1 + g_m R_C) = 2(1 + (85.4)(4))$$

$$\Rightarrow C_M = 685 \text{ pF}$$

$$C_i = C_\pi + C_M = 32 + 685 = 717 \text{ pF}$$

$$R_{eq} = R_S \| R_1 \| R_2 \| r_\pi = 2\|60\|5.5\|1.17$$

$$= 0.644 \text{ k}\Omega$$

$$\tau = R_{eq} \cdot C_i = (0.644 \times 10^3)(717 \times 10^{-12})$$

$$= 4.62 \times 10^{-7} \text{ s}$$

$$f_H = \frac{1}{2\pi\tau} \Rightarrow \underline{f_H = 344 \text{ kHz}}$$

7.38

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$$

$$g_m = 2\sqrt{K_n I_D}, \quad K_n = (15)\left(\frac{40}{10}\right) = 60\ \mu A/V^2$$

$$g_m = 2\sqrt{(60)(100)} = 155\ \mu A/V^2$$

$$f_T = \frac{155x10^{-6}}{2\pi(0.5 + 0.05)x10^{-12}} \Rightarrow \underline{f_T = 44.9\ MHz}$$

7.39

a. $C_M = C_{gd}\ (1 + g_m(r_0 \| R_D))$

$C_M = 5[1 + (3)(15\|10)] \Rightarrow \underline{C_M = 95 \text{ pF}}$

b. $\tau = (r_i)(C_{gs} + C_M)$

$$\tau = (10 \times 10^3)(50 + 95) \times 10^{-12} = 1.45 \times 10^{-6} \text{ s}$$

$$f = \frac{1}{2\pi\tau} = \frac{1}{2\pi(1.45 \times 10^{-6})}$$

$$\Rightarrow \underline{f = 110 \text{ kHz}}$$

7.40

$$f_T = \frac{g_m}{2\pi(C_{gsT} + C_{gdT})} \quad \text{(Eq. 7.90)}$$

Let $C_{gdT} = 0$ and $C_{gsT} = \left(\frac{2}{3}\right)(WLC_{ox})$

$$g_m = 2\sqrt{K_n I_D} = 2\sqrt{\left(\frac{\mu_n C_{ox}}{2}\right)\left(\frac{W}{L}\right)I_D}$$

$$\text{So } f_T = \frac{2\sqrt{\left(\frac{1}{2}\mu_n C_{ox}\right)\left(\frac{W}{L}\right)I_D}}{2\pi\left(\frac{2}{3}\right)(WLC_{ox})}$$

$$= \frac{3}{2\pi L}\cdot\frac{\sqrt{\left(\frac{1}{2}\mu_n C_{ox}\right)\left(\frac{W}{L}\right)I_D}}{WC_{ox}}$$

$$\underline{f_T = \frac{3}{2\pi L}\cdot\sqrt{\frac{\mu_n I_D}{2WC_{ox}L}}}$$

7.41

(a) $g_m' = \dfrac{g_m}{1+g_m r_S}$

$g_m = 2K_n(V_{GS} - V_{TN})$

$$K_n = \left(\frac{\mu_n C_{ox}}{2}\right)\left(\frac{W}{L}\right) = \left(\frac{(400)(7.25x10^{-8})}{2}\right)(10)$$

$K_n = 1.45x10^{-4}\ mA/V^2$

For $V_{GS} = 5$ V

$g_m = 2(1.45 \times 10^{-4})(5 - 0.65) = 1.26 \times 10^{-3}$

$g_m' = (0.80)g_m = 1.01 \times 10^{-3}$

$$1.01 \times 10^{-3} = \frac{1.26 \times 10^{-3}}{1 + (1.26 \times 10^{-3})r_S}$$

$1 + (1.26 \times 10^{-3})r_S = 1.25$

$\Rightarrow \underline{r_S = 198\ \Omega}$

b. For $V_{GS} = 3$ V

$g_m = 2(1.45 \times 10^{-4})(3 - 0.65) = 0.6815 \times 10^{-3}$

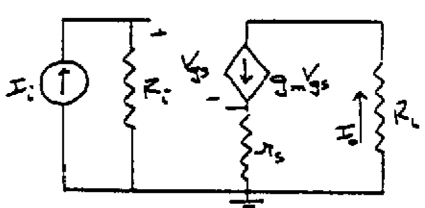
$$g_m' = \frac{0.6815 \times 10^{-3}}{1 + (0.6815 \times 10^{-3})(198)}$$

$\underline{g_m' = 0.60 \times 10^{-3}\ \text{A/V}}$

<u>Reduced by $\approx 12\%$</u>

7.42

a.

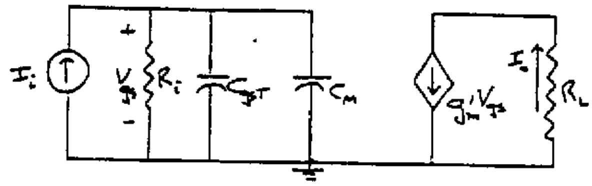


$I_0 = g_m V_{gs}$ and $V_{gs} = I_i R_i - g_m V_{gs} r_S$

so $V_{gs} = \dfrac{I_i R_i}{1 + g_m r_S}$

Then $\underline{A_i = \dfrac{I_0}{I_i} = \dfrac{g_m R_i}{1 + g_m r_S}}$

b. As an approximation, consider



In this case

$$A_i = \frac{I_0}{I_i} = g_m' R_i \cdot \frac{1}{1 + sR_i(C_{gsT} + C_M)}$$

where $C_M = C_{gdT}(1 + g_m' R_L)$ and $g_m' = \dfrac{g_m}{1 + g_m r_s}$

c. As r_S increases, C_M decreases, so the bandwidth increases, but the current gain magnitude decreases.

7.43

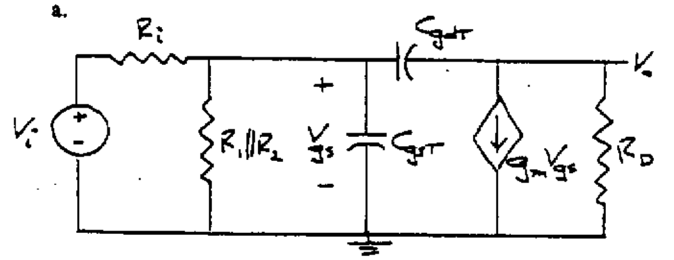
$$V_{GS} = \left(\frac{R_2}{R_1 + R_2}\right)V_{DD} = \left(\frac{225}{225 + 500}\right)(10)$$

$V_{GS} = 3.10$ V

$g_m = 2K_n(V_{GS} - V_{TN}) = 2(1)(3.10 - 2)$

$g_m = 2.2\ mA/V$

a.



b. $C_M = C_{gdT}(1 + g_m R_D) = (1)[1 + (2.2)(5)]$

$\underline{C_M = 12\ \text{pF}}$

c. $\tau = (R_i \| R_1 \| R_2)(C_{gsT} + C_M)$

$R_i \| R_1 \| R_2 = 1\|500\|225 = 1\|155 = 0.994\ \text{k}\Omega$

$\tau = (0.994 \times 10^3)(5 + 12) \times 10^{-12} = 1.69 \times 10^{-8}$ s

$$f_H = \frac{1}{2\pi\tau} = \frac{1}{2\pi(1.69 \times 10^{-8})} \Rightarrow \underline{f_H = 9.42\ \text{MHz}}$$

$A_v = \dfrac{-g_m V_{gs} R_D}{V_i}$ and

$$V_{gs} = \frac{R_1 \| R_2}{R_1 \| R_2 + R_i}\cdot V_i = \frac{155}{155 + 1}\cdot V_i = 0.994 V_i$$

$A_v = -(2.2)(5)(0.994) \Rightarrow \underline{A_v = -10.9}$

7.44

$$R_{TH} = R_1 \| R_2 = 33\|22 = 13.2 \text{ k}\Omega$$
$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)(5) = \left(\frac{22}{22+33}\right)(5) = 2 \text{ V}$$
$$I_{BQ} = \frac{2-0.7}{13.2+(121)(4)} = 0.00261 \text{ mA}$$
$$I_{CQ} = 0.314 \text{ mA}$$

$$r_\pi = \frac{(120)(0.026)}{0.314} = 9.94 \text{ k}\Omega$$
$$g_m = \frac{0.314}{0.026} = 12.1 \text{ mA/V}$$
$$r_0 = \frac{100}{0.314} = 318 \text{ k}\Omega$$

a. $f_T = \dfrac{g_m}{2\pi(C_\pi + C_\mu)}$

$$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{12.1 \times 10^{-3}}{2\pi(600 \times 10^6)}$$
$$C_\pi + C_\mu = 3.21 \text{ pF};\ C_\mu = 1 \text{ pF} \Rightarrow C_\pi = 2.21 \text{ pF}$$
$$C_M = C_\mu[1 + g_m(r_0\|R_C\|R_L)]$$
$$= (1)[1 + (12.1)(318\|4\|5)]$$
$$C_M = 27.7 \text{ pF}$$

b. $\tau = R_{eq}(C_\pi + C_M)$

$$R_{eq} = R_1\|R_2\|R_S\|r_\pi = 33\|22\|2\|r_\pi$$
$$= 1.74\|9.94 \text{ k}\Omega \Rightarrow R_{eq} = 1.48 \text{ k}\Omega$$
$$\tau = (1.48 \times 10^3)(2.21 + 27.7) \times 10^{-12}$$
$$\tau = 4.43 \times 10^{-8} \text{ s}$$
$$f_H = \frac{1}{2\pi\tau} = \frac{1}{2\pi(4.43 \times 10^{-8})}$$
$$\Rightarrow \underline{f_H = 3.59 \text{ MHz}}$$

$$V_0 = -g_m V_\pi(r_0\|R_C\|R_L)$$
$$V_\pi = \left(\frac{R_1\|R_2\|r_\pi}{R_1\|R_2\|r_\pi + R_S}\right)V_i$$
$$R_1\|R_2\|r_\pi = 33\|22\|9.94 = 5.67 \text{ k}\Omega$$
$$V_\pi = \left(\frac{5.67}{5.67+2}\right)V_i = 0.739V_i$$
$$r_0\|R_C\|R_L = 318\|4\|5 = 2.18 \text{ k}\Omega$$
$$A_v = -(12.1)(0.739)(2.18)$$
$$\underline{A_v = -19.5}$$

7.45

$$R_{TH} = R_1\|R_2 = 40\|5 = 4.44 \text{ k}\Omega$$
$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)V_{CC} = \left(\frac{5}{5+40}\right)(10) = 1.11 \text{ V}$$
$$I_{BQ} = \frac{1.11-0.7}{4.44+(121)(0.5)} = 0.00631 \text{ mA}$$
$$I_{CQ} = 0.758 \text{ mA}$$

$$r_\pi = \frac{(120)(0.026)}{0.758} = 4.12 \text{ k}\Omega$$
$$g_m = \frac{0.758}{0.026} = 29.2 \text{ mA/V}$$
$$r_0 = \infty$$

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$$
$$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{29.2 \times 10^{-3}}{2\pi(250 \times 10^6)}$$
$$C_\pi + C_\mu = 18.6 \text{ pF};\ C_\mu = 3 \text{ pF} \Rightarrow C_\pi = 15.6 \text{ pF}$$

a. $C_M = C_\mu[1 + g_m(R_C\|R_L)]$

$$C_M = 3[1 + (29.2)(5\|2.5)] \Rightarrow C_M = 149 \text{ pF}$$

For upper frequency:

$$\tau_H = R_{eq}(C_\pi + C_M)$$
$$R_{eq} = r_\pi\|R_1\|R_2\|R_S = 4.12\|40\|5\|0.5$$
$$R_{eq} = 0.405 \text{ k}\Omega$$

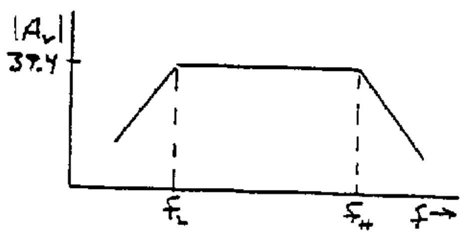
$$\tau_H = (0.405 \times 10^3)(15.6 + 149) \times 10^{-12}$$
$$= 6.67 \times 10^{-8} \text{ s}$$
$$f_H = \frac{1}{2\pi\tau_H} \Rightarrow \underline{f_H = 2.39 \text{ MHz}}$$

For lower frequency:

$$\tau_L = R_{eq}C_{C1}$$
$$R_{eq} = R_S + R_1\|R_2\|r_\pi = 0.5 + 40\|5\|4.12$$
$$R_{eq} = 2.64 \text{ k}\Omega$$

$$\tau_L = (2.64 \times 10^3)(4.7 \times 10^{-6}) = 1.24 \times 10^{-2} \text{ s}$$
$$f_L = \frac{1}{2\pi\tau_L} \Rightarrow \underline{f_L = 12.8 \text{ Hz}}$$

b.



$$V_0 = -g_m V_\pi(R_C\|R_L)$$
$$V_\pi = \left(\frac{R_1\|R_2\|r_\pi}{R_1\|R_2\|r_\pi + R_S}\right)V_i$$
$$V_\pi = \left(\frac{2.14}{2.14+0.5}\right)V_i = 0.8106V_i$$

$$|A_v| = (29.2)(0.8106)(5\|2.5)$$
$$\underline{|A_v| = 39.4}$$

7.46

$$I_D = K_p(V_{SG}+V_{TP})^2 = \frac{9-V_{SG}}{R_S}$$

$$(2)(1.2)(V_{SG}^2 - 4V_{SG} + 4) = 9 - V_{SG}$$

$$2.4V_{SG}^2 - 8.6V_{SG} + 0.6 = 0$$

$$V_{SG} = \frac{8.6 \pm \sqrt{(8.6)^2 - 4(2.4)(0.6)}}{2(2.4)}$$

$$V_{SG} = 3.51 \text{ V}$$

$$g_m = 2K_p(V_{SG}+V_{TP}) = 2(2)(3.51-2)$$

$$g_m = 6.04\ mA/V$$

$$I_D = (2)(3.51-2)^2 = 4.56 \text{ mA}$$

$$r_0 = \frac{1}{\lambda I_0} = \frac{1}{(0.01)(4.56)} \Rightarrow r_0 = 21.9 \text{ k}\Omega$$

a. $C_M = C_{gdT}(1 + g_m(r_0 \| R_D))$

$C_M = (1)[1 + (6.04)(21.9\|1)] \Rightarrow \underline{C_M = 6.78 \text{ pF}}$

b. $\tau_H = (R_i \| R_G)(C_{gsT} + C_M)$

$\tau_H = (2\|100) \times 10^3(10 + 6.78) \times 10^{-12}$

$\tau_H = 3.29 \times 10^{-8}$ s

$f_H = \dfrac{1}{2\pi\tau_H} \rightarrow \underline{f_H = 4.84 \text{ MHz}}$

$V_0 = -g_m(r_0\|R_D)\cdot V_{gs}$

$V_{gs} = \left(\dfrac{R_G}{R_G + R_i}\right)V_i = \left(\dfrac{100}{102}\right)V_i$

$A_v = -(6.04)\left(\dfrac{100}{102}\right)(21.9\|1)$

$\underline{A_v = -5.66}$

7.47

$$V_G = \left(\frac{R_2}{R_1 + R_2}\right)(20) - 10 = \left(\frac{22}{22+8}\right)(20) - 10$$

$$V_G = 4.67 \text{ V}$$

$$I_D = \frac{10 - V_{SG} - 4.67}{R_S} = K_p(V_{SG}+V_{TP})^2$$

$$5.33 - V_{SG} = (1)(0.5)(V_{SG}^2 - 4V_{SG} + 4)$$

$$0.5V_{SG}^2 - V_{SG} - 3.33 = 0$$

$$V_{SG} = \frac{1 \pm \sqrt{1 + 4(0.5)(3.33)}}{2(0.5)} \Rightarrow V_{SG} = 3.77 \text{ V}$$

$$g_m = 2K_p(V_{SG}+V_{TP}) = 2(1)(3.77-2)$$

$$g_m = 3.54\ mA/V$$

b. $C_M = C_{gdT}(1 + g_m(R_D\|R_L))$

$C_M = (3)[1 + (3.54)(2\|5)] \Rightarrow \underline{C_M = 18.2 \text{ pF}}$

a. $\tau = R_{eq}(C_{gsT} + C_M)$

$R_{eq} = R_i\|R_1\|R_2 = 0.5\|8\|22 = 0.461 \text{ k}\Omega$

$\tau = (0.461 \times 10^3)(15 + 18.2) \times 10^{-12}$

$= 1.53 \times 10^{-8}$ s

$f_H = \dfrac{1}{2\pi\tau} \Rightarrow \underline{f_H = 10.4 \text{ MHz}}$

c. $V_0 = -g_m V_{gs}(R_D\|R_L)$

$V_{gs} = \left(\dfrac{R_1\|R_2}{R_1\|R_2 + R_i}\right)V_i = \left(\dfrac{5.87}{5.87 + 0.5}\right)V_i$

$\Rightarrow V_{gs} = (0.9215)V_i$

$A_v = -(3.54)(0.9215)(2\|5)$

$\Rightarrow \underline{A_v = -4.66}$

7.48

$I_E = 0.5 \text{ mA} \Rightarrow I_{CQ} = \left(\dfrac{100}{101}\right)(0.5) = 0.495 \text{ mA}$

$g_m = \dfrac{0.495}{0.026} = 19.0 \text{ mA/V}$

$r_\pi = \dfrac{(100)(0.026)}{0.495} = 5.25 \text{ k}\Omega$

a. Input: From Eq. 7.107b

$\tau_{P\pi} = \left[\dfrac{r_\pi}{1+\beta} \,\Big\|\, R_E \,\Big\|\, R_S\right]C_\pi$

$= \left[\dfrac{5.25}{101} \,\Big\|\, 0.5 \,\Big\|\, 0.05\right] \times 10^3 \times 10 \times 10^{-12}$

$= 2.43 \times 10^{-10}$ s

$f_{H\pi} = \dfrac{1}{2\pi\tau_{P\pi}} \Rightarrow \underline{f_{H\pi} = 656 \text{ MHz}}$

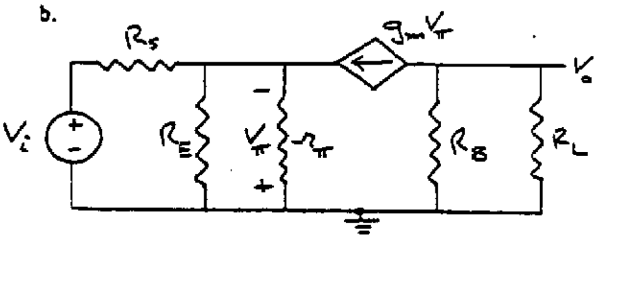
Output: From Eq. 7.108b

$\tau_{P\mu} = (R_B\|R_L)C_\mu = (100\|1) \times 10^3 \times 10^{-12}$

$= 9.90 \times 10^{-10}$ s

$f_{H\mu} = \dfrac{1}{2\pi\tau_{P\mu}} \Rightarrow \underline{f_{H\mu} = 161 \text{ MHz}}$

b.



$$V_0 = -g_m V_\pi (R_B \| R_L)$$
$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_i - (-V_\pi)}{R_S} = 0$$
$$V_\pi \left[g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S} \right] = \frac{-V_i}{R_S}$$
$$V_\pi \left[19 + \frac{1}{5.25} + \frac{1}{0.5} + \frac{1}{0.05} \right] = \frac{-V_i}{0.05}$$
$$V_\pi (41.19) = -V_i(20)$$
$$V_\pi = -(0.4856)V_i$$
$$\frac{V_0}{V_i} = -(19)(-0.4856)(100\|1)$$
$$\underline{A_v = 9.14}$$

c. $\tau = C_L(R_L \| R_B) = (15 \times 10^{-12})(1\|100) \times 10^3$

$$\tau = 1.485 \times 10^{-8} \text{ s}$$
$$f = \frac{1}{2\pi\tau} \to f = 10.7 \text{ MHz}$$
Since $f < f_{H\mu} \Rightarrow 3dB$ freq. dominated by C_L.

7.49

$$I_{EQ} = \frac{20 - 0.7}{10} = 1.93 \text{ mA}$$
$$I_{CQ} = \left(\frac{100}{101}\right)(1.93) = 1.91 \text{ mA}$$
$$g_m = \frac{1.91}{0.026} = 73.5 \text{ mA/V}$$
$$r_\pi = \frac{(100)(0.026)}{1.91} = 1.36 \text{ k}\Omega$$

a. Input:

$$\tau_{P\pi} = \left[\frac{r_\pi}{1+\beta} \middle\| R_E \middle\| R_S \right] \cdot C_\pi$$
$$= \left[\frac{1.36}{101} \middle\| 10 \middle\| 1 \right] \times 10^3 \times 10 \times 10^{-12}$$
$$\tau_{P\pi} = 1.327 \times 10^{-10} \text{ s}$$
$$f_{P\pi} = \frac{1}{2\pi\tau_{P\pi}} \Rightarrow \underline{f_{P\pi} = 1.20 \text{ GHz}}$$

output:

$$\tau_{P\mu} = (R_C \| R_L)C_\mu = (6.5\|5) \times 10^3 \times 10^{-12}$$
$$\tau_{P\mu} = 2.826 \times 10^{-9} \text{ s}$$
$$f_{P\mu} = \frac{1}{2\pi\tau_{P\mu}} \to \underline{f_{P\mu} = 56.3 \text{ MHz}}$$

b. $V_0 = -g_m V_\pi (R_C \| R_L)$

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_i - (-V_\pi)}{R_S} = 0$$
$$V_\pi \left(g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S} \right) = -\frac{V_i}{R_S}$$
$$V_\pi \left[73.5 + \frac{1}{1.36} + \frac{1}{10} + \frac{1}{1} \right] = \frac{-V_i}{(1)}$$
$$V_\pi(75.34) = -V_i \Rightarrow V_\pi = -(0.01327)V_i$$
$$V_0 = -(73.5)(-0.01327)(6.5\|5)V_i$$
$$\underline{A_v = 2.76}$$

c. $\tau = C_L(R_L \| R_C) = (15 \times 10^{-12})(6.5\|5) \times 10^3$

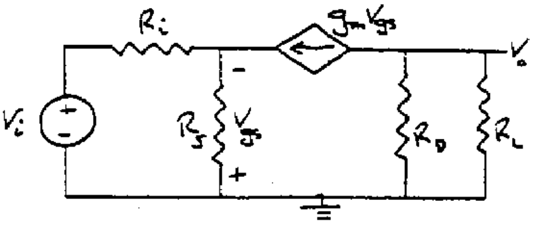
$$\tau = 4.24 \times 10^{-8} \text{ s}$$
$$f = \frac{1}{2\pi\tau} \to f = 3.75 \text{ MHz}$$
Since $f < f_{P\mu}$, $3dB$ frequency is dominated by C_L.

7.50

$$V_{GS} + I_D R_S = 5$$
$$I_D = \frac{5 - V_{GS}}{R_S} = K_n(V_{GS} - V_{TN})^2$$
$$5 - V_{GS} = (3)(10)(V_{GS}^2 - 2V_{GS} + 1)$$
$$30V_{GS}^2 - 59V_{GS} + 25 = 0$$
$$V_{GS} = \frac{59 \pm \sqrt{(59)^2 - 4(30)(25)}}{2(30)} \Rightarrow V_{GS} = 1.35 \text{ V}$$
$$g_m = 2K_n(V_{GS} - V_{TN}) = 2(3)(1.35 - 1)$$
$$g_m = 2.1 \, mA/V$$

On the output:

$$\tau_{P\mu} = (R_D \| R_L)C_{gdT} = (5\|4) \times 10^3 \times 4 \times 10^{-12}$$
$$\tau_{P\mu} = 8.89 \times 10^{-9} \text{ s}$$
$$f_{P\mu} = \frac{1}{2\pi\tau_{P\mu}} \to \underline{f_{P\mu} = 17.9 \text{ MHz}}$$



$$V_0 = -g_m V_{gs}(R_D \| R_L)$$
$$g_m V_{gs} + \frac{V_{gs}}{R_S} + \frac{V_i - (-V_{gs})}{R_i} = 0$$
$$V_{gs}\left(g_m + \frac{1}{R_S} + \frac{1}{R_i} \right) = -\frac{V_i}{R_i}$$
$$V_{gs}\left(2.1 + \frac{1}{10} + \frac{1}{2} \right) = -\frac{V_i}{2}$$
$$V_{gs} = -(0.185)V_i$$
$$A_v = \frac{V_0}{V_i} = (2.1)(0.185)(5\|4)$$
$$\underline{A_v = 0.863}$$

7.51

dc analysis

$$I_D = \frac{V^+ - V_{SG}}{R_S} = K_p(V_{SG} + V_{TP})^2$$

$$5 - V_{SG} = (1)(4)(V_{SG} - 0.8)^2$$

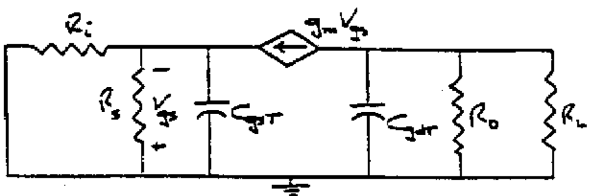
$$= 4(V_{SG}^2 - 1.6V_{SG} + 0.64)$$

$$4V_{SG}^2 - 5.4V_{SG} - 2.44 = 0$$

$$V_{SG} = \frac{5.4 \pm \sqrt{(5.4)^2 + 4(4)(2.44)}}{2(4)} = 1.707$$

$$g_m = 2K_p(V_{SG} + V_{TP}) = 2(1)(1.707 - 0.8)$$

$$g_m = 1.81\ mA/V$$



$3 \cdot dB$ frequency due to C_{gsT} : $R_{eq} = \frac{1}{g_m} \Big\| R_S \Big\| R_i$

$$f_A = \frac{1}{2\pi R_{eq} \cdot C_{gsT}}$$

$$R_{eq} = \frac{1}{1.81} \Big\| 4 \Big\| 0.5 = 0.246\ \text{k}\Omega$$

$$f_A = \frac{1}{2\pi(246)(4 \times 10^{-12})} = 162\ \text{MHz}$$

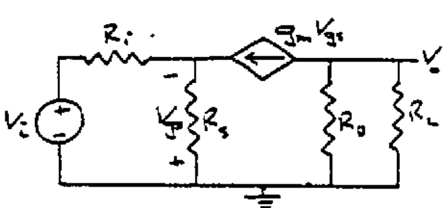
$3 - dB$ frequency due to C_{gdT}

$$f_B = \frac{1}{2\pi(R_D \| R_L)C_{gdT}}$$

$$= \frac{1}{2\pi(2\|4) \times 10^3 \times 10^{-12}}$$

$\underline{f = 119\ \text{MHz}}$

Midband gain



$$V_{gs} = \frac{-\frac{1}{g_m} \Big\| R_S}{\frac{1}{g_m} \Big\| R_S + R_i} \cdot V_i = \frac{-\frac{1}{1.81} \Big\| 4}{\frac{1}{1.81} \Big\| 4 + 0.5} \cdot V_i$$

$$= -0.492V_i$$

$$V_0 = -g_m V_{gs}(R_D \| R_L)$$

$$A_v = (0.492)(1.81)(4\|2) \Rightarrow \underline{A_v = 1.19}$$

7.52

$$r_\pi = \frac{(120)(0.026)}{1.02} = 3.06\ \text{k}\Omega$$

$$g_m = 39.2\ \text{mA/V}$$

a. Input: $f_{H\pi} = \frac{1}{2\pi\tau_\pi}$

$$\tau_\pi = [R_S \| R_2 \| R_3 \| r_\pi](C_\pi + 2C_\mu)$$

$$= 0.1\|20.5\|28.3\|3.06 = 0.096\ \text{k}\Omega$$

$$\tau_\pi = (96)(12 + 2(2)) \times 10^{-12} = 1.536 \times 10^{-9}\ \text{s}$$

$$f_{H\pi} = \frac{1}{2\pi(1.536 \times 10^{-9})} = \underline{103.6\ \text{MHz}}$$

Output: $f_{H\mu} = \frac{1}{2\pi\tau_\mu}$

$$\tau_\mu = (R_C \| R_L)C_\mu$$

$$= (5\|10) \times 10^3 \times 2 \times 10^{-12}$$

$$= 6.67 \times 10^{-9}$$

$$f_{H\mu} = \frac{1}{2\pi(6.67 \times 10^{-9})} = \underline{23.9\ \text{MHz}}$$

b. $A = g_m(R_C \| R_L)\left[\frac{R_2 \| R_3 \| r_\pi}{R_2 \| R_3 \| r_\pi + R_S}\right]$

$$R_2 \| R_3 \| r_\pi = 20.5\|28.3\|3.06 = 2.43\ \text{k}\Omega$$

$$A = (39.2)(5\|10)\left[\frac{2.43}{2.43 + 0.1}\right] \Rightarrow \underline{A = 125.5}$$

c. $C_L = 15\ \text{pF} > C_\mu \Rightarrow C_L$ dominates frequency response.