Chapter 7

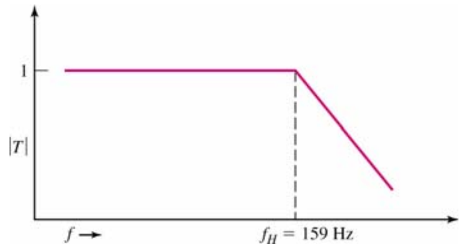
7.1

a.

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

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

b.



$$f_H=\frac{1}{2\pi R_1C_1}=\frac{1}{2\pi(10^3)(10^{-6})}\Rightarrow \underline{f_H=159\text{ Hz}}$$

c.

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

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

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

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

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

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

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

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

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

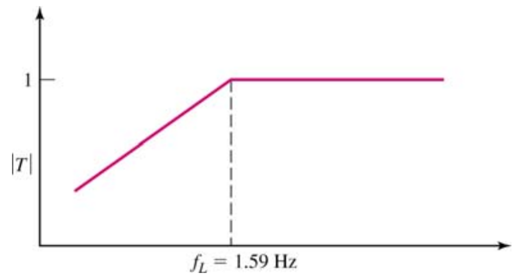
7.2

a.

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

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

b.



$$f_L = \frac{1}{2\pi R_2 C_2} = \frac{1}{2\pi\left(10^4\right)\left(10\times10^{-6}\right)} \Rightarrow \underline{f_L = 1.59 \text{ Hz}}$$

c.

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

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

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

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

7.3

(a) $$T(s) = \frac{V_o}{V_i} = \frac{R_2\left\|\dfrac{1}{sC_2}\right.}{R_2\left\|\dfrac{1}{sC_2}\right. + R_1}$$

Now $$R_2\left\|\frac{1}{sC_2}\right. = \frac{R_2\left(\dfrac{1}{sC_2}\right)}{R_2+\dfrac{1}{sC_2}} = \frac{R_2}{1+sR_2C_2}$$

Then $$T(s) = \frac{\dfrac{R_2}{1+sR_2C_2}}{\dfrac{R_2}{1+sR_2C_2}+R_1} = \frac{R_2}{R_1+R_2+sR_1R_2C_2}$$

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

(b) $\tau = \left(R_1\|R_2\right)C_2 = \left(10\|20\right)\times10^3\times10\times10^{-6} \Rightarrow \tau = 66.7 \text{ ms}$

(c) $$f = \frac{1}{2\pi\tau} = \frac{1}{2\pi\left(66.7\times10^{-3}\right)} = 2.39 \text{ Hz}$$

7.4

a.

$$\tau_S = (R_i + R_P)C_S = (30+10)\times 10^3 \times (10\times 10^{-6}) \Rightarrow \tau_S = 0.40 \text{ s}$$

$$\tau_P = (R_i \| R_P)C_P = (30\|10)\times 10^3 \times (50\times 10^{-12}) \Rightarrow \tau_P = 0.375\ \mu\text{s}$$

b.

$$f_L = \frac{1}{2\pi\tau_S} = \frac{1}{2\pi(0.4)} \Rightarrow f_L = 0.398 \text{ Hz}$$

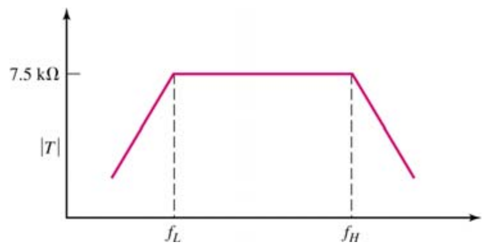
$$f_H = \frac{1}{2\pi\tau_P} = \frac{1}{2\pi(0.375\times 10^{-6})} \Rightarrow f_H = 424 \text{ kHz}$$

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

$$V_o = I_i(R_i \| R_P)$$

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

c.



7.5

(a) $$\frac{V_o}{V_i} = \frac{R_2}{R_2 + R_1} = \frac{20}{20+10} = 0.667$$

(b) $$\frac{V_o}{V_i} = 1$$

(c) $$T(s) = \frac{V_o(s)}{V_i(s)} = \frac{R_2}{R_2 + R_1 \left\| \frac{1}{sC_1}\right.} = \frac{R_2}{R_2 + \frac{R_1}{1+sR_1C_1}}$$

$$T(s) = \frac{R_2(1+sR_1C_1)}{R_1 + R_2 + sR_1R_2C_1} = \left(\frac{R_2}{R_1+R_2}\right)\cdot\frac{(1+sR_1C_1)}{[1+s(R_1\|R_2)C_1]}$$

We have $K = \frac{R_2}{R_1+R_2}$, $\tau_A = R_1C_1$, $\tau_B = (R_1\|R_2)C_1$

7.6

a.

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

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

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.

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

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

$s = j\omega$

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

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

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

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

For

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

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

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

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

c.

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

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

$s = j\omega$

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

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

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

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

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

7.7

(a) $$|T| = \frac{1}{\left[\sqrt{1+\left(\frac{f}{f_T}\right)^2}\right]^3}$$

At $f = f_T$, $|T| = \frac{1}{(\sqrt{2})^3} = 0.35355$

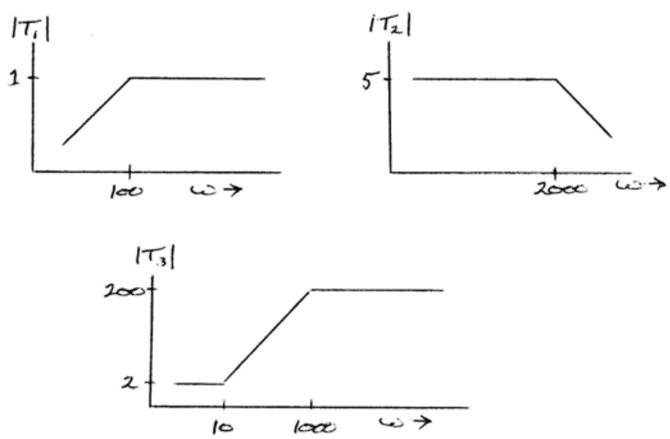
Or $|T|_{dB} = 20\log_{10}(0.35355) = -9.03$ dB

$$\phi = -\tan^{-1}\left(\frac{f}{f_F}\right)^3 = -3\tan^{-1}\left(\frac{f}{f_T}\right) = -3\tan^{-1}(1) = -135°$$

(b) Slope $= 3(-6) = -18$ dB/octave $= -60$ dB/decade

$\phi = 3(-90) = -270°$

7.8



7.9

(a) (ii) $\omega_1 = 1$ rad/s; $\omega_2 = 10$ rad/s; $\omega_3 = 100$ rad/s; $\omega_4 = 1000$ rad/s

(iii) $|T(0)| = 10$

(iv) $|T(\infty)| = 10$

(b) (ii) $\omega = 5$ rad/s

(iii) $|T(0)| = 0$

(iv) $|T(\infty)| = \dfrac{8}{(0.2)^2} = 200$

7.10

(a) $$T(j\omega) = 5\left(\frac{j\dfrac{\omega}{10^2}}{1 + j\dfrac{\omega}{10^2}}\right)\left(\frac{1}{1 + j\dfrac{\omega}{5\times10^4}}\right)$$

or $$T(j\omega) = 2.5\times10^5\left(\frac{j\omega}{10^2 + j\omega}\right)\left(\frac{1}{5\times10^4 + j\omega}\right)$$

(b) $$|T| = \frac{5\left(\frac{\omega}{10^2}\right)}{\sqrt{1+\left(\frac{\omega}{10^2}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{\omega}{5\times 10^4}\right)^2}}$$

(i) At $\omega = 50$ rad/s

$$|T| = \frac{5\left(\frac{50}{100}\right)}{\sqrt{1+\left(\frac{50}{100}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{50}{5\times 10^4}\right)^2}} = 2.236$$

(ii) At $\omega = 150$ rad/s

$$|T| = \frac{5\left(\frac{150}{100}\right)}{\sqrt{1+\left(\frac{150}{100}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{150}{5\times 10^4}\right)^2}} = 4.16$$

(iii) At $\omega = 10^5$

$$|T| = \frac{5\left(\frac{10^5}{10^2}\right)}{\sqrt{1+\left(\frac{10^5}{10^2}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{10^5}{5\times 10^4}\right)^2}} = 2.236$$

7.11

a.

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

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

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

b.

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

$$f_L = \frac{1}{2\pi\tau_S} \Rightarrow \tau_S = \frac{1}{2\pi f_L} = \frac{1}{2\pi(30)} \Rightarrow \tau_S = 5.31\,\text{ms, Open-Circuit}$$

$$\tau_P = \frac{1}{2\pi f_H} = \frac{1}{2\pi(480\times 10^3)} \Rightarrow \tau_P = 0.332\,\mu\text{s, Short-Circuit}$$

c.

$$C_C = \frac{\tau_S}{(R_S + r_\pi)} = \frac{5.31\times 10^{-3}}{(0.5+5.2)\times 10^3} \Rightarrow C_C = 0.932\,\mu\text{F}$$

$$\tau_P = R_L C_L$$

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

7.12

(a) $\dfrac{V_o}{V_i} = \dfrac{R_2 + R_3}{R_1 + R_2 + R_3} = \dfrac{10+40}{10+10=40} = 0.833$

(b) $\dfrac{V_o}{V_i} = \dfrac{R_2}{R_1 + R_2} = \dfrac{10}{10+10} = 0.50$

(c) $R_3 \left\| \dfrac{1}{sC} \right. = \dfrac{R_3\left(\dfrac{1}{sC}\right)}{R_3 + \dfrac{1}{sC}} = \dfrac{R_3}{1+sR_3C}$

$$T(s) = \frac{V_o(s)}{V_i(s)} = \frac{R_2 + \dfrac{R_3}{1+sR_3C}}{R_1 + R_2 + \dfrac{R_3}{1+sR_3C}} = \frac{R_2 + R_3 + sR_2R_3C}{R_1 + R_2 + R_3 + s(R_1+R_2)R_3C}$$

or $T(s) = \left(\dfrac{R_2 + R_3}{R_1 + R_2 + R_3}\right)\cdot \dfrac{[1 + s(R_2 \| R_3)C]}{[1 + s((R_1 + R_2) \| R_3)C]}$

where $K = \dfrac{R_2 + R_3}{R_1 + R_2 + R_3}$, $\tau_A = (R_2 \| R_3)C$, $\tau_B = ((R_1 + R_2) \| R_3)C$

7.13 Computer Analysis

7.14

(a) $|A_\upsilon|_{\max} = g_m R_D$, $g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.4)(0.8)} = 1.131$ mA/V

$|A_\upsilon|_{\max} = (1.131)(1) = 1.13$

(b) $f_H = \dfrac{1}{2\pi R_D C_L} = \dfrac{1}{2\pi(10^3)(10^{-12})}$

$f_H = BW = 159$ MHz

7.15

(a) $f_H = \dfrac{1}{2\pi R_C C_L} \Rightarrow R_C = \dfrac{1}{2\pi f_H C_L} = \dfrac{1}{2\pi(800\times 10^6)(0.08\times 10^{-12})}$

or $R_C = 2.49\ \text{k}\Omega$

(b) $I_{CQ} = \dfrac{V_{CC} - V_{CEQ}}{R_C} = \dfrac{2.5 - 1.25}{2.487} = 0.503\ \text{mA}$

(c) $|A_\upsilon|_{\max} = g_m R_C$, $g_m = \dfrac{0.5026}{0.026} = 19.33$ mA/V

$|A_\upsilon|_{\max} = (19.33)(2.487) = 48.1$

7.16

(a) $T(s)=\dfrac{V_o(s)}{V_i(s)}=-g_m\left(r_o\left\|\dfrac{1}{sC_L}\right.\right)=-g_m\left(\dfrac{r_o\cdot\dfrac{1}{sC_L}}{r_o+\dfrac{1}{sC_L}}\right)=-g_m\,r_o\left(\dfrac{1}{1+sr_oC_L}\right)$

(b) $g_m=2\sqrt{K_nI_{DQ}}=2\sqrt{(0.05)(0.1)}=0.1414\ \text{mA/V}$

$r_o=\dfrac{1}{\lambda I_{DQ}}=\dfrac{1}{(0.01)(0.1)}=1000\ \text{k}\Omega$

$|A_\upsilon|_{\max}=g_mr_o=(0.1414)(1000)=141.4$

(c) $f_H=BW=\dfrac{1}{2\pi r_oC_L}=\dfrac{1}{2\pi(10^6)(0.5\times10^{-12})}\Rightarrow f_H=318\,\text{kHz}$

7.17

a.

$R_{TH}=R_1\|R_2=10\|1.5=1.304\ \text{k}\Omega$

$V_{TH}=\left(\dfrac{R_2}{R_1+R_2}\right)V_{CC}=\left(\dfrac{1.5}{1.5+10}\right)(12)=1.565\ \text{V}$

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

$I_{CQ}=7.585\ \text{mA}$

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

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

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

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

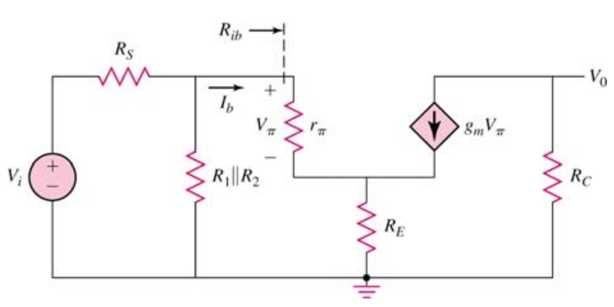
$=1.30\|10.44\Rightarrow R_i=1.159\,\text{k}\Omega$

$\tau=(R_S+R_i)C_C=(0.5+1.16)\times10^3\times(0.1\times10^{-6})$

$\tau=1.659\times10^{-4}\ \text{s}$

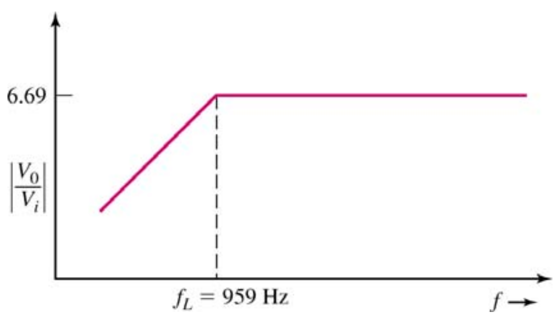
$f_L=\dfrac{1}{2\pi\tau}=\dfrac{1}{2\pi(1.66\times10^{-4})}\Rightarrow f_L=959\ \text{Hz}$

b.



$$V_0 = -(\beta I_b) R_C$$
$$R_{1b} = r_\pi + (1+\beta) R_E$$
$$= 0.343 + (101)(0.1) = 10.44 \text{ k}\Omega$$
$$I_b = \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{ib}} \right) I_i$$
$$= \left(\frac{1.30}{1.30 + 10.4} \right) I_i = (0.111) I_i$$
$$I_i = \frac{V_i}{R_S + R_1 \| R_2 \| R_{ib}}$$
$$= \frac{V_i}{0.5 + (1.3) \| (10.44)}$$
$$I_i = \frac{V_i}{1.659}$$
$$\left| \frac{V_0}{V_i} \right| = \frac{\beta R_C (0.111)}{1.659} \Rightarrow \left| \frac{V_0}{V_i} \right|_{\text{midband}} = \frac{(100)(1)(0.111)}{1.659} \Rightarrow \underline{\left| \frac{V_0}{V_i} \right|_{\text{midband}} = 6.69}$$

c.



7.18

(a) $V_{DSQ} = V_{DD} - I_{DQ}(R_D + R_S)$

$3.2 = 9 - (0.8)(R_D + 0.5) \Rightarrow R_D = 6.75 \text{ k}\Omega$

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

$0.8 = 0.5(V_{GSQ} - 1.2)^2 \Rightarrow V_{GSQ} = 2.465 \text{ V}$

$V_G = (0.8)(0.5) + 2.465 = 2.865 \text{ V}$

$$V_G = \frac{1}{R_1} \cdot R_{in} \cdot V_{DD} \Rightarrow 2.865 = \frac{1}{R_1}(160)(9)$$

which yields $R_1 = 503 \text{ k}\Omega$ and $R_2 = 235 \text{ k}\Omega$

(b) $g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.5)(0.8)} = 1.265 \text{ mA/V}$

$$A_\upsilon = \frac{-g_m R_D}{1 + g_m R_S} = \frac{-(1.265)(6.75)}{1 + (1.265)(0.5)} = -5.23$$

(c) $$f_L = \frac{1}{2\pi R_{in} C_C} \Rightarrow C_C = \frac{1}{2\pi f_L R_{in}} = \frac{1}{2\pi(16)(160 \times 10^3)} \Rightarrow C_C = 0.06217 \ \mu\text{F}$$

$$\tau_S = R_{in} C_C = (160 \times 10^3)(0.06217 \times 10^{-6}) = 9.947 \times 10^{-3} \text{ s}$$

$$|A_\upsilon| = 5.23\left|\frac{s\tau_S}{1+s\tau_S}\right| = (5.23)\left[\frac{\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}}\right]$$

(i) For $f = 5$ Hz,

$$|A_\upsilon| = (5.23)\left[\frac{\frac{5}{16}}{\sqrt{1+\left(\frac{5}{16}\right)^2}}\right] = 1.56$$

(ii) For $f = 14$ Hz,

$$|A_\upsilon| = (5.23)\left[\frac{\frac{14}{16}}{\sqrt{1+\left(\frac{14}{16}\right)^2}}\right] = 3.44$$

(iii) For $f = 25$ Hz,

$$|A_\upsilon| = (5.23)\left[\frac{\frac{25}{16}}{\sqrt{1+\left(\frac{25}{16}\right)^2}}\right] = 4.405$$

7.19

$$I_{DQ} = K_n\left(V_{GS}-V_{TN}\right)^2 \Rightarrow V_{GS} = \sqrt{\frac{I_{DQ}}{K_n}}+V_{TN} = \sqrt{\frac{1}{0.5}}+1 = 2.414\ V$$

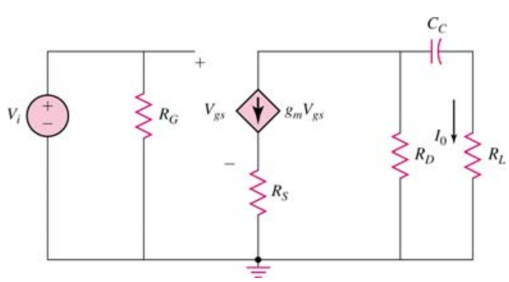
$$V_S = -2.414\ \text{V}$$

$$R_S = \frac{-2.414-(-5)}{1} \Rightarrow \underline{R_S = 2.59\ \text{k}\Omega}$$

$$V_D = V_{DSQ}+V_S = 3-2.414 = 0.586\ \text{V}$$

$$R_D = \frac{5-0.59}{1} \Rightarrow R_D = 4.41\ \text{k}\Omega$$

b.



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

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

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

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

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

c.

$$f_L = \frac{1}{2\pi\tau_L} \Rightarrow \tau_L = \frac{1}{2\pi f_L} = \frac{1}{2\pi(10)} \Rightarrow \tau_L = 15.92 \text{ ms}$$

$$\tau_L = (R_D + R_L)C_C \Rightarrow C_C = \frac{\tau_L}{R_D + R_L} = \frac{15.9 \times 10^{-3}}{(4.41 + 4) \times 10^3} \Rightarrow C_C = 1.89\ \mu\text{F}$$

7.20

a.

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

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

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

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

$$g_m = 2K_P\left(V_{SG} + V_{TP}\right) = 2(0.5)(3 - 2) \Rightarrow g_m = 1 \text{ mA/V}$$

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

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

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

c. $C_C = \dfrac{\tau}{R_o + R_L} = \dfrac{7.96 \times 10^{-3}}{(0.923 + 10) \times 10^3} \Rightarrow C_C = 0.729\ \ \mu\text{F}$

7.21

(a) $R_{TH} = (0.1)(1 + \beta)R_E = (0.1)(121)(4) = 48.4 \text{ k}\Omega$

$$I_{BQ} = \frac{I_{EQ}}{1 + \beta} = \frac{1.5}{121} = 0.012397 \text{ mA}$$

$$V_{TH} = I_{BQ}R_{TH} + V_{BE}(on) + I_{EQ}R_E = \frac{1}{R_1} \cdot R_{TH} \cdot V_{CC}$$

so $\dfrac{1}{R_1}(48.4)(12) = (0.012397)(48.4) + 0.7 + (1.5)(4)$

which yields $R_1 = 79.6\ \text{k}\Omega$ and $R_2 = 124\ \text{k}\Omega$

(b) $I_{CQ} = \left(\dfrac{120}{121}\right)(1.5) = 1.488\ \text{mA}$

$$r_\pi = \frac{(120)(0.026)}{1.488} = 2.097\ \text{k}\Omega\,, \quad r_o = \frac{50}{1.488} = 33.6\ \text{k}\Omega$$

$$A_\upsilon = \frac{(1+\beta)(r_o \| R_E \| R_L)}{r_\pi + (1+\beta)(r_o \| R_E \| R_L)}$$

Now $r_o \| R_E \| R_L = 33.6 \| 4 \| 4 = 1.888\ \text{k}\Omega$

$$A_\upsilon = \frac{(121)(1.888)}{2.097 + (121)(1.888)} = 0.991$$

(c) $R_o = R_E \| r_o \| \dfrac{r_\pi}{1+\beta} = 4 \| 33.6 \| \dfrac{2.097}{121} \Rightarrow R_o = 17.25\,\Omega$

(d) $f_L = \dfrac{1}{2\pi(R_o + R_L)C_{C2}} = \dfrac{1}{2\pi(17.25 + 4000)(2\times10^{-6})}$

$f_L = 19.8\ \text{Hz}$

7.22

(a) $$V_o(s) = -g_m\left(r_o \| R_D \| \frac{1}{sC_L}\right)\cdot V_{gs} = -g_m\left[\frac{(r_o \| R_D)\left(\dfrac{1}{sC_L}\right)}{r_o \| R_D + \dfrac{1}{sC_L}}\right]\cdot V_{gs} = -g_m\left[\frac{r_o \| R_D}{1 + s(r_o \| R_D)C_L}\right]\cdot V_{gs}$$

$$V_{gs} = \frac{\left(\dfrac{1}{sC_i}\right)(V_i(s))}{\dfrac{1}{sC_i} + R_{Si}} = \frac{V_i(s)}{1 + sR_{Si}C_i}$$

$$T(s) = \frac{V_o(s)}{V_i(s)} = -g_m\left(\frac{1}{1 + sR_{Si}C_i}\right)\left(\frac{r_o \| R_D}{1 + s(r_o \| R_D)C_L}\right)$$

(b) $\tau = R_{Si}C_i$

(c) $\tau = (r_o \| R_D)C_L$

7.23

(a) $$\frac{V_{gs}}{V_i} = \frac{-\left(\dfrac{1}{g_m} \Big\| \dfrac{1}{sC_i}\right)}{\left(\dfrac{1}{g_m} \Big\| \dfrac{1}{sC_i}\right) + R_S}$$

Now $\left(\frac{1}{g_m}\Big\|\frac{1}{sC_i}\right)=\frac{\left(\frac{1}{g_m}\right)\left(\frac{1}{sC_i}\right)}{\frac{1}{g_m}+\frac{1}{sC_i}}=\frac{\frac{1}{g_m}}{1+s\left(\frac{1}{g_m}\right)C_i}$

So $\frac{V_{gs}}{V_i}=\frac{-\frac{1}{g_m}}{\frac{1}{g_m}+R_S\left(1+s\left(\frac{1}{g_m}\right)C_i\right)}=\left(\frac{-\frac{1}{g_m}}{\frac{1}{g_m}+R_S}\right)\cdot\frac{1}{\left[1+s\left(\frac{1}{g_m}\|R_S\right)C_i\right]}$

We have

$$V_o=-g_mV_{gs}\left[\frac{R_D}{R_D+R_L+\frac{1}{sC_C}}\right]\cdot R_L=-g_mV_{gs}\left[\frac{R_DR_L(sC_C)}{1+s(R_D+R_L)C_C}\right]$$

$$V_o=-g_mV_{gs}\left(\frac{R_DR_L}{R_D+R_L}\right)\left[\frac{s(R_D+R_L)C_C}{1+s(R_D+R_L)C_C}\right]$$

Then $T(s)=\frac{V_o(s)}{V_i(s)}=\frac{+g_m(R_D\|R_L)}{1+g_mR_S}\cdot\frac{1}{\left[1+s\left(\frac{1}{g_m}\|R_S\right)C_i\right]}\cdot\left[\frac{s(R_D+R_L)C_C}{1+s(R_D+R_L)C_C}\right]$

(b) $\tau=\left(\frac{1}{g_m}\|R_S\right)C_i$

(c) $\tau=(R_D+R_L)C_C$

7.24

(a)

$$I_{EQ}=\frac{5-0.7}{4}=1.075\text{ mA}\quad I_{CQ}=1.064\text{ mA}$$
$$V_{CEQ}=10-(1.064)(2)-(1.075)(4)$$
$$V_{CEQ}=3.57\text{ V}$$
$$g_m=\frac{I_{CQ}}{V_T}=\frac{1.064}{0.026}=40.92\text{ mA/V}$$
$$r_\pi=\frac{\beta V_T}{I_{CQ}}=\frac{(100)(0.026)}{1.064}=2.44\text{ K}$$

(b)

For C_{C1}; $R_{eq1}=R_S+R_E\left\|\frac{r_\pi}{1+\beta}\right.=200+4000\left\|\frac{2440}{101}\right.$

$R_{eq1}=224.0\,\Omega$; $\tau_1=R_{eq1}C_{C1}=1.053\text{ ms}$

For C_{C2}; $R_{eq2}=R_C+R_L=2+47=49\text{ k}\Omega$

$\tau_2=R_{eq2}C_{C2}=49\text{ ms}$

(c)
$$f_1 = \frac{1}{2\pi\tau_1} = \frac{1}{2\pi\left(1.053\times10^{-3}\right)} \Rightarrow \underline{f_1 = 151\text{ Hz}}$$

7.25

(a)
$$\tau_H = \left(R_C \| R_L\right)C_L = \left(2\|47\right)\times10^3\times10\times10^{-12}$$
$$= 1.918\times10^{-8}\text{s}$$
$$f_H = \frac{1}{2\pi\tau_H} = \frac{1}{2\pi\left(1.918\times10^{-8}\right)} \Rightarrow \underline{f_H = 8.30\text{ MHz}}$$

(b)
$$\frac{1}{\sqrt{1+\left(2\pi\tau_H f\right)^2}} = 0.1$$
$$\left(\frac{1}{0.1}\right)^2 = 100 = 1+\left(2\pi\tau_H f\right)^2$$
$$f = \frac{\sqrt{99}}{2\pi\tau_H} = \frac{\sqrt{99}}{2\pi\left(1.918\times10^{-8}\right)}$$
$$f = 82.6\text{ MHz}$$

7.26

(a)
$$\frac{5-V_{SG}}{R_1} = K_P\left(V_{SG}+V_{TP}\right)^2$$
$$5-V_{SG} = (1)(1.2)\left(V_{SG}-1.5\right)^2 = (1.2)\left(V_{SG}^2-3V_{SG}+2.25\right)$$
$$1.2V_{SG}^2-2.6V_{SG}-2.3=0 \Rightarrow \underline{V_{SG}=2.84\,V}$$
$$\underline{I_{DQ} = 1.8\ mA}$$
$$V_{SDQ} = 10-(1.8)(1.2+1.2) \Rightarrow \underline{V_{SDQ} = 5.68\,V}$$
$$g_m = 2\sqrt{K_P I_{DQ}} = 2\sqrt{(1)(1.8)} = 2.683\ mA/V$$
$$r_o = \infty$$

(b)
$$R_{is} = \frac{1}{g_m} = \frac{1}{2.68} = 0.3727\ k\Omega$$
$$R_i = 1.2\|0.373 = 0.284\ k\Omega$$

For $C_{C1},\ \tau_{s1} = (284+200)\left(4.7\times10^{-6}\right) = 2.27\ ms$

For $C_{C2},\ \tau_{s2} = \left(1.2x10^3+50\times10^3\right)\left(10^{-6}\right) = 51.2\ ms$

(c)

C_{C2} dominates,

$$f_{3-dB} = \frac{1}{2\pi\tau_{s2}} = \frac{1}{2\pi\left(51.2\times10^{-3}\right)} = 3.1\ Hz$$

7.27

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

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

$$|A_v| = g_m R_D$$

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

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

We need $g_m = \dfrac{|A_\upsilon|}{R_D} = \dfrac{10}{20} = 0.5$ mA/V and $g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{\left(\dfrac{k_n'}{2}\right)\left(\dfrac{W}{L}\right)I_{DQ}}$

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

Let

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

$$I_{DQ} = 0.2 = \left(\frac{0.080}{2}\right)(7.81)(V_{GS}-1)^2 \Rightarrow V_{GS} = 1.80 = \left(\frac{R_2}{R_1+R_2}\right)(9) = \left(\frac{R_2}{225}\right)(9) \Rightarrow$$

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

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

$$\tau_1 = \frac{1}{2\pi f_1} = \frac{1}{2\pi(200)} = 7.958\times10^{-4}\,s = \left(R_{Si}+R_{TH}\right)C_C \text{ or } C_C = \frac{7.96\times10^{-4}}{\left(200+36\times10^3\right)} \Rightarrow$$

$$C_C = 0.022\ \mu F$$

$$\tau_2 = \frac{1}{2\pi f_2} = \frac{1}{2\pi\left(3x10^3\right)} = 5.305\times10^{-5}\,s = R_D C_L \text{ or } C_L = \frac{5.31\times10^{-5}}{20\times10^3} \Rightarrow \underline{C_L = 2.65\ nF}$$

7.28

$$I_{BQ} = \frac{10-0.7}{430+(201)(2.5)} = 0.00997\ mA$$
$$I_{CQ} = (200)I_{BQ} = 1.995\ mA$$
$$r_\pi = \frac{(200)(0.026)}{1.99} = 2.61\ k\Omega$$
$$R_{ib} = 2.61+(201)(2.5) = 505\ k\Omega$$
$$\tau_s = \frac{1}{2\pi f_L} = \frac{1}{2\pi(15)} = 0.0106\ s$$
$$= R_{eq}C_C = (0.5+505\|430)\times 10^3 C_C = 232.7\times 10^3 C_C$$
Or $\underline{C_C = 4.55\times 10^{-8} F \Rightarrow 45.5\ nF}$

7.29

(a) $V^+ = V_{CEQ} + I_{EQ}R_E$
$$3.3 = 1.8 + (0.25)R_E \Rightarrow R_E = 6\ \text{k}\Omega$$
$$I_{BQ} = \frac{0.25}{121} = 0.002066\ \text{mA}$$
$$V^+ = I_{BQ}R_B + V_{BE}(on) + I_{EQ}R_E$$
$$3.3 = (0.002066)(R_B) + 0.7 + (0.25)(6) \Rightarrow R_B = 532\ \text{k}\Omega$$

(b) $I_{CQ} = \left(\frac{120}{121}\right)(0.25) = 0.2479\ \text{mA},\quad r_\pi = \frac{(120)(0.026)}{0.2479} = 12.59\ \text{k}\Omega$
$$R_{ib} = r_\pi + (1+\beta)R_E = 12.59 + (121)(6) = 738.6\ \text{k}\Omega$$
$$R_i = R_B\|R_{ib} = 532\|738.6 = 309.25\ \text{k}\Omega$$
$$\tau_S = \frac{1}{2\pi f_L} = \frac{1}{2\pi(20)} = 0.007958 = (R_S + R_i)C_C$$
so $C_C = \frac{0.007958}{(0.1+309.25)\times 10^3} \Rightarrow C_C = 0.0257\ \mu\text{F}$

(c) For $R_S << R_B$,
$$A_\upsilon \cong \frac{(1+\beta)R_E}{r_\pi + (1+\beta)R_E} = \frac{(121)(6)}{12.59+(121)(6)} = 0.983$$

7.30

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

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

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

$I_{CQ} = 31.9\ mA$

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

$\tau_{C_{C1}} >> \tau_{C_{C2}}$ and $f = \frac{1}{2\pi\tau}$ 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.

$f_{3-dB}(C_{C2}) = 25\ Hz = \frac{1}{2\pi\tau_2}$, so that $\tau_2 = \frac{1}{2\pi(25)} = 0.006366\ s = R_{eq}C_{C2}$

where

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

$$= 10 + 50 \left\| \left(\frac{81.5 + 600 \| 300}{101}\right)\right. = 10 + 50 \| 2.787 \Rightarrow$$

$R_{eq} = 12.64\ \Omega \Rightarrow C_{C2} = \frac{0.00637}{12.6} \Rightarrow \underline{C_{C2} = 504\ \mu F}$

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

$R_{ib} = 81.5 + (101)(50) = 5132\ \Omega$

$\tau_1 = (100)\tau_2 = (100)(0.006366) = 0.6366\ s = R_{eq1}C_{C1}$

$R_{eq1} = R_S + R_{TH} \| R_{ib} = 300 + 600 \| 5132 = 837.2\ \Omega$

So $C_{C1} = \frac{0.6366}{837.2} \Rightarrow \underline{C_{C1} = 760\ \mu F}$

7.31

From Problem 7.30 $R_{TH} = 0.6$ K, $I_{CQ} = 31.9$ mA, $r_\pi = 81.5\ \Omega$

$\tau_{C2} >> \tau_{C1}$ and $f = \frac{1}{2\pi\tau}$ so $f_{3-dB}(C_{C2}) << f_{3-dB}(C_{C1})$

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

$$f_{3-dB}\left(C_{C1}\right) = 20 \text{ Hz} = \frac{1}{2\pi\tau_{C1}} \Rightarrow \tau_{C1} = 0.007958 \text{ s}$$

$$R_{ib} = r_\pi + (1+\beta)\left(R_E \| R_L\right) = 81.5 + (101)(50\|10) = 923.2\ \Omega$$

$$\tau_{C1} \Rightarrow R_{eq1} = R_S + R_{TH} \| R_{ib} = 300 + 600\|923.2 = 663.7\ \Omega$$

$$C_{C1} = \frac{0.007958}{663.7} \Rightarrow C_{C1} = 12\ \mu\text{F}$$

$$\tau_{C2} = 100\tau_{C1} = 0.7958 \text{ s}$$

$$R_{eq2} = R_L + R_E \left\| \left(\frac{r_\pi + R_{TH}}{1+\beta}\right) = 10 + 50 \right\| \left(\frac{81.5+600}{101}\right)$$

$$R_{eq2} = 10 + 50\|6.748 = 15.95\ \Omega$$

$$C_{C2} = \frac{0.7958}{15.95} \Rightarrow \underline{C_{C2} = 0.050 \text{ F}}$$

7.32

(a) $I_{EQ} = 0.2 \text{ mA},\ I_{BQ} = \dfrac{0.2}{121} = 0.001653 \text{ mA},\ \ I_{CQ} = \left(\dfrac{120}{121}\right)(0.2) = 0.1983 \text{ mA}$

$$V_E = -\left(I_{BQ}R_i + V_{BE}(on)\right) = -\left[(0.001653)(10) + 0.7\right] = -0.7165 \text{ V}$$

$$V_C = V_E + V_{CEQ} = -0.7165 + 2.2 = 1.483 \text{ V}$$

$$R_C = \frac{3 - 1.483}{0.1983} = 7.65 \text{ k}\Omega$$

(b) $r_\pi = \dfrac{(120)(0.026)}{0.1983} = 15.73 \text{ k}\Omega,\ \ g_m = \dfrac{0.1983}{0.026} = 7.627 \text{ mA/V}$

$$A_\upsilon = -g_m\left(R_C \| R_L\right)\left(\frac{r_\pi}{r_\pi + R_i}\right) = -(7.627)(7.65\|20)\left(\frac{15.73}{15.73+10}\right) = -25.8$$

(c) For C_C: $\tau_C = \left(R_C + R_L\right)C_C$

$$f_C = \frac{1}{2\pi\tau_C} = \frac{1}{2\pi\left(R_C + R_L\right)C_C}$$

For C_E: $\tau_E = \left(\dfrac{r_\pi + R_i}{1+\beta}\right)C_E \Rightarrow f_E = \dfrac{1}{2\pi\tau_E}$

(d) $f_E = 10 = \dfrac{1}{2\pi\tau_E} \Rightarrow \tau_E = 0.015915 \text{ s}$

$$0.015915 = \left(\frac{15.73+10}{121}\right)\times 10^3 \times C_E \Rightarrow C_E = 74.8\ \mu\text{F}$$

$$f_C = 50 = \frac{1}{2\pi\tau_C} \Rightarrow \tau_C = 0.003183 \text{ s}$$

$$0.003183 = (7.65 + 20)\times 10^3 \times C_C \Rightarrow C_C = 0.115\ \mu\text{F}$$

7.33

a.

$$I_D = K_n\left(V_{GS} - V_{TN}\right)^2$$

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

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

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

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

(b)

$$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.5)(0.5)} = 1\ \text{mA/V}$$

$$\tau_A = R_S C_S = \left(6.4\times10^3\right)\left(5\times10^{-6}\right)$$

$$= 3.2\times10^{-2}\ \text{s}$$

$$f_A = \frac{1}{2\pi\tau_A} = \frac{1}{2\pi\left(3.2\times10^{-2}\right)} \Rightarrow f_A = 4.97\ \text{Hz}$$

$$\tau_B = \left(\frac{R_S}{1 + g_m R_S}\right)C_S = \left[\frac{6.4\times10^3}{1 + (1)(6.4)}\right]\left(5\times10^{-6}\right)$$

$$= 4.32\times10^{-3}\ \text{s}$$

$$f_B = \frac{1}{2\pi\tau_B} = \frac{1}{2\pi\left(4.32\times10^{-3}\right)} \Rightarrow f_B = 36.8\ \text{Hz}$$

c.

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

As R_S becomes large

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

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

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

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

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

7.34

(a) (i) $T_1(s)=\dfrac{V_{o1}}{V_i}=-g_{m1}\left(r_o\left\|R_D\right\|\dfrac{1}{sC_L}\right)=-g_{m1}\left[\dfrac{(r_o\|R_D)\left(\dfrac{1}{sC_L}\right)}{(r_o\|R_D)+\left(\dfrac{1}{sC_L}\right)}\right]$

$$T_1(s)=-g_{m1}(r_o\|R_D)\cdot\frac{1}{[1+s(r_o\|R_D)C_L]}$$

(ii) $T_2(s)=\dfrac{V_o}{V_{o1}}=-g_{m2}(r_o\|R_D)\cdot\dfrac{1}{[1+s(r_o\|R_D)C_L]}$

(iii) $T(s)=\dfrac{V_o}{V_i}=g_{m1}g_{m2}(r_o\|R_D)^2\cdot\dfrac{1}{[1+s(r_o\|R_D)C_L]^2}$

(b) (i) $f_{3-dB}=\dfrac{1}{2\pi(r_o\|R_D)C_L}$

Now $r_o=\dfrac{1}{(0.02)(0.5)}=100\text{ k}\Omega$, $r_o\|R_D=100\|5=4.762\text{ k}\Omega$

$$f_{3-dB}=\frac{1}{2\pi(4.762\times10^3)(12\times10^{-12})}\Rightarrow f_{3-dB}=2.785\text{ MHz}$$

(ii) $f_{3-dB}=2.785\text{ MHz}$

(iii) Want $\left\{\dfrac{1}{\sqrt{1+[(2\pi f)(r_o\|R_D)C_L]^2}}\right\}^2=\dfrac{1}{\sqrt{2}}$

So $\dfrac{1}{1+\left(\dfrac{f}{2.785\times10^6}\right)^2}=\dfrac{1}{\sqrt{2}}=0.7071$

$$\left(\frac{f}{2.785\times10^6}\right)^2=\frac{1}{0.7071}-1=0.4142$$

which yields $f=1.792\text{ MHz}$

7.35

a. Expression for the voltage gain is the same as Equation (7.59) with $R_S=0$.

b.

$$\tau_A=R_EC_E$$

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

7.36

(a) $I_{EQ} = \left(\frac{91}{90}\right)(0.15) = 0.1517 \text{ mA}$

$$R_E = \frac{3-0.7}{0.1517} = 15.16 \text{ k}\Omega$$

$$V_C = 0.7 - V_{ECQ} = 0.7 - 2.2 = -1.5 \text{ V}$$

$$R_C = \frac{-1.5-(-3)}{0.15} = 10 \text{ k}\Omega$$

(b) $g_m = \frac{0.15}{0.026} = 5.769 \text{ mA/V}$

$$A_\upsilon = -g_m R_C = -(5.769)(10) = -57.7$$

(c) $\tau_A = R_E C_E = (15.16\times10^3)(3\times10^{-6}) = 4.548\times10^{-2} \text{ s}$

$$f_A = \frac{1}{2\pi\tau_A} = \frac{1}{2\pi(4.548\times10^{-2})} = 3.5 \text{ Hz}$$

$$\tau_B = \frac{R_E r_\pi C_E}{r_\pi + (1+\beta)R_E}, \quad \text{where} \quad r_\pi = \frac{(90)(0.026)}{0.15} = 15.6 \text{ k}\Omega$$

$$\tau_B = \frac{(15.16\times10^3)(15.6\times10^3)(3\times10^{-6})}{15.6\times10^3 + (91)(15.16\times10^3)} = 5.085\times10^{-4} \text{ s}$$

$$f_B = \frac{1}{2\pi\tau_B} = \frac{1}{2\pi(5.085\times10^{-4})} = 313 \text{ Hz}$$

7.37

(a) $I_{EQ} = \frac{10-0.7}{10} = 0.93 \text{ mA}, \quad I_{CQ} = \left(\frac{90}{91}\right)(0.93) = 0.9198 \text{ mA}$

$$g_m = \frac{0.9198}{0.026} = 35.38 \text{ mA/V}$$

$$A_\upsilon = g_m (R_C \| R_L) = (35.38)(5\|10) = 118$$

(b) $f = \frac{1}{2\pi\tau} = \frac{1}{2\pi(R_C\|R_L)C_L} = \frac{1}{2\pi(5\|10)\times10^3\times(3\times10^{-12})}$

$$f = 15.9 \text{ MHz}$$

7.38

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

$$0.2 = 0.1(V_{SGQ} - 0.6)^2 \Rightarrow V_{SGQ} = 2.014 \text{ V}$$

$$R_S = \frac{3-2.014}{0.2} = 4.93 \text{ k}\Omega$$

$$V_D = V_{SGQ} - V_{SDQ} = 2.014 - 1.9 = 0.114 \text{ V}$$

$$R_D = \frac{0.114-(-3)}{0.2} = 15.6 \text{ k}\Omega$$

(b) $f_H = \dfrac{1}{2\pi(R_D \| R_L)C_L}$

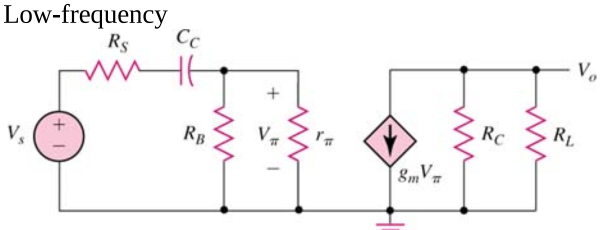
or $C_L = \dfrac{1}{2\pi(15.6\|20)\times10^3 \times 4\times10^6} \Rightarrow C_L = 4.54\text{ pF}$

7.39

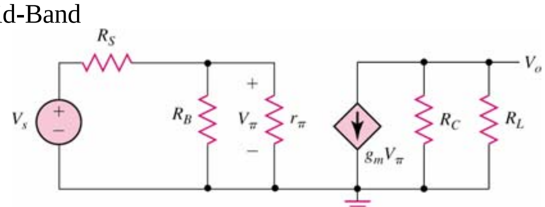
$$V_G = \left(\frac{R_2}{R_1+R_2}\right)V_{DD} = \left(\frac{166}{166+234}\right)(10)$$
$$= 4.15\text{ V}$$
$$I_D = \frac{V_G - V_{GS}}{R_S} = K_n\left(V_{GS}-V_{TN}\right)^2$$
$$4.15 - V_{GS} = (0.5)(0.5)\left(V_{GS}^2 - 4V_{GS} + 4\right)$$
$$0.25V_{GS}^2 - 3.15 = 0 \Rightarrow V_{GS} = 3.55\text{ V}$$
$$g_m = 2K_n\left(V_{GS}-V_{TN}\right) = 2(0.5)(3.55-2)$$
$$g_m = 1.55\ mA/V$$
$$R_0 = R_S \left\| \frac{1}{g_m} = 0.5 \right\| \frac{1}{1.55} = 0.5 \| 0.645$$
$$R_0 = 0.282\text{ k}\Omega$$
$$\tau = (R_o\|R_L)C_L \quad\text{and}\quad f_H = \frac{1}{2\pi\tau}$$
$$\text{BW} \cong f_H = 5\text{ MHz} \Rightarrow \tau = \frac{1}{2\pi\left(5\times10^6\right)} = 3.18\times10^{-8}\text{ s}$$
$$C_L = \frac{\tau}{R_o\|R_L} = \frac{3.18\times10^{-8}}{(0.282\|4)\times10^3} \Rightarrow C_L = 121\text{pF}$$

7.40

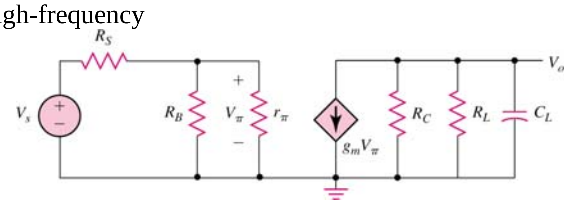
(a) Low-frequency



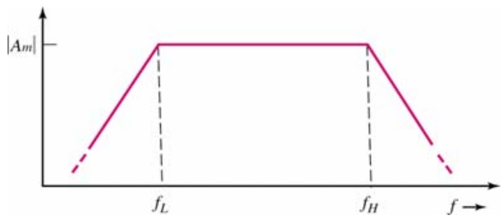
Mid-Band



High-frequency



(b)



(c)

$$I_{BQ} = \frac{12-0.7}{1\,M\Omega} = 11.3\ \mu A$$

$$I_{CQ} = 1.13\ mA$$

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

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

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

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

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

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

$$f_L = \frac{1}{2\pi\tau_L},\quad \tau_L = (R_S + R_B \| r_\pi)C_C = (1+1000\|2.3)\times 10^3 \times (10\times 10^{-6})$$

$$\Rightarrow \tau_L = 3.29\times 10^{-2}\text{ s},\quad f_L = 4.83\text{ Hz}$$

$$f_H = \frac{1}{2\pi\tau_H},\quad \tau_H = (R_C \| R_L)C_L = (5.1\|500)\times 10^3 \times (10\times 10^{-12})$$

$$\Rightarrow \tau_H = 5.05\times 10^{-8}\text{ s},\quad f_H = 3.15\text{ MHz}$$

7.41

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

$$A_\upsilon = -g_m(R_D\|R_L)\left[\frac{1}{1+s(R_D\|R_L)C_L}\right]$$

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

(c) $5 = I_D R_S + V_{SG} = K_p R_S (V_{SG} + V_{TP})^2 + V_{SG}$

$5 = (0.25)(3.2)(V_{SG} - 2)^2 + V_{SG}$

We find $0.8V_{SG}^2 - 2.2V_{SG} - 1.8 = 0 \Rightarrow V_{SG} = 3.41\text{ V}$

$I_{DQ} = (0.25)(3.41 - 2)^2 = 0.497\text{ mA}$

$\tau = (10\|20) \times 10^3 \times 10 \times 10^{-12} = 6.67 \times 10^{-8}\text{ s}$

$$f_H = \frac{1}{2\pi\tau} = \frac{1}{2\pi(6.67 \times 10^{-8})} \Rightarrow f_H = 2.39\text{ MHz}$$

$g_m = 2\sqrt{K_p I_{DQ}} = 2\sqrt{(0.25)(0.497)} = 0.705\text{ mA/V}$

$A_\upsilon = -g_m (R_D \| R_L) = -(0.705)(10\|20) = -4.7$

7.42 Computer Analysis

7.43 Computer Analysis

7.44 Computer Analysis

7.45

$$g_m = \frac{0.25}{0.026} = 9.615\text{ mA/V}$$

$$f_\beta = \frac{f_T}{\beta_o} = \frac{4 \times 10^9}{120} \Rightarrow f_\beta = 33.3\text{ MHz}$$

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} \Rightarrow C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{9.615 \times 10^{-3}}{2\pi(4 \times 10^9)}$$

or $C_\pi + C_\mu = 0.3826\text{ pF}$

Then $C_\pi = 0.3826 - 0.08 = 0.303\text{ pF}$

7.46

(a) $$f_\beta = \frac{f_T}{\beta_o} = \frac{2 \times 10^9}{120} \Rightarrow f_\beta = 16.67\text{ MHz}$$

$$g_m = \frac{0.4}{0.026} = 15.38\text{ mA/V}$$

$$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{15.38 \times 10^{-3}}{2\pi(2 \times 10^9)}$$

$C_\pi + C_\mu = 1.224\text{ pF}$, $C_\pi = 1.224 - 0.075 = 1.15\text{ pF}$

(b) $$|h_{fe}| = \frac{\beta_o}{\sqrt{1 + \left(\dfrac{f}{f_\beta}\right)^2}}$$

(i)At $f = 10$ MHz, $\left|h_{fe}\right| = \dfrac{120}{\sqrt{1+\left(\dfrac{10}{16.67}\right)^2}} = 103$

(ii)At $f = 20$ MHz, $\left|h_{fe}\right| = \dfrac{120}{\sqrt{1+\left(\dfrac{20}{16.67}\right)^2}} = 76.8$

(iii) At $f = 50$ MHz, $\left|h_{fe}\right| = \dfrac{120}{\sqrt{1+\left(\dfrac{50}{16.67}\right)^2}} = 38.0$

7.47

(a) $f_\beta = \dfrac{f_T}{\beta_o} = \dfrac{540\times10^6}{120} \Rightarrow f_\beta = 4.5$ MHz

$g_m = \dfrac{0.2}{0.026} = 7.692$ mA/V

$C_\pi + C_\mu = \dfrac{g_m}{2\pi f_T} = \dfrac{7.692\times10^{-3}}{2\pi\left(540\times10^6\right)} \Rightarrow C_\pi + C_\mu = 2.267$ pF

$C_\pi = 2.267 - 0.4 = 1.87$ pF

(b) $g_m = \dfrac{0.8}{0.026} = 30.77$ mA/V

$f_T = \dfrac{g_m}{2\pi\left(C_\pi + C_\mu\right)} = \dfrac{30.77\times10^{-3}}{2\pi\left(2.267\times10^{-12}\right)} \Rightarrow f_T = 2.16$ GHz

$f_\beta = \dfrac{2.16\times10^9}{120} \Rightarrow f_\beta = 18.0$ MHz

---

7.48

(a)

$V_0 = -g_m V_\pi R_L$ where

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

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

So

$$A_v(s) = \frac{V_0(s)}{V_i(s)} = -g_m R_L \left(\frac{r_\pi}{r_\pi + r_b}\right)\left(\frac{1}{1+s\left(r_b \| r_\pi\right)C_1}\right)$$

(b) Midband gain: $r_\pi = \frac{(100)(0.026)}{1} = 2.6\ k\Omega,\ g_m = \frac{1}{0.026} = 38.46\ mA/V$

For $r_b = 100\ \Omega$

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

For $r_b = 500\ \Omega$

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

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

For $r_b = 100\ \Omega$

(i) $\tau_1 = (0.1\|2.6)\times 10^3 (2.2\times 10^{-12}) = 2.12\times 10^{-10}\ s \Rightarrow \underline{f_{3-db} = 751\ MHz}$

For $r_b = 500\ \Omega$

(ii) $\tau_2 = (0.5\|2.6)\times 10^3 (2.2\times 10^{-12}) = 9.23\times 10^{-10}\ s\ \underline{f_{3-dB} = 173\ MHz}$

7.49

$f = 10\text{ kHz} = 10^4$

$$Z_i = 200 + \frac{2500\left(1 - j(10^4)(1.333\times 10^{-6})\right)}{1 + (10^4)^2 (1.333\times 10^{-6})^2}$$

(b) $= 200 + 2500 - j33.3 = 2700 - j33.3$

$f = 100\text{ kHz} = 10^5$

$$Z_i = 200 + \frac{2500\left(1 - j(10^5)(1.333\times 10^{-6})\right)}{1 + (10^5)^2 (1.333\times 10^{-6})^2}$$

(c) $Z_i = 200 + 2456 - j327 = 2656 - j327$

$f = 1\text{ MHz} = 10^6$

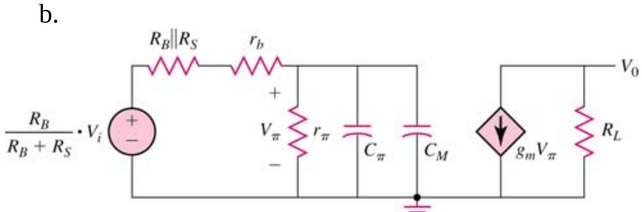
$$Z_i = 200 + \frac{2500\left(1 - j(10^6)(1.333\times 10^{-6})\right)}{1 + (10^6)^2 (1.333\times 10^{-6})^2}$$

(d) $Z_i = 200 + 900 - j1200 = 1100 - j1200$

7.50

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

b.



$V_0 = -g_m V_\pi R_L \quad \text{Let } C_\pi + C_M = C_i$

$$V_\pi = \frac{r_\pi \left\| \frac{1}{sC_i} \right.}{r_\pi \left\| \frac{1}{sC_1} \right. + R_B \| R_S + r_b} \cdot \left(\frac{R_B}{R_B + R_S} \right) V_i$$

$$A_\upsilon(s) = \frac{V_o(s)}{V_i(s)}$$

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

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

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

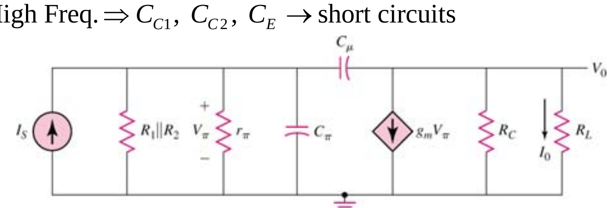
$$A_v(s) = -\beta R_L \left(\frac{R_B}{R_B + R_S} \right) \times \left[\frac{1}{\left(r_\pi + R_{eq} \right) \left[1 + s \left(r_\pi \| R_{eq} \right) C_i \right]} \right]$$

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

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

7.51

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



$$g_m = \frac{I_{CQ}}{V_T} = \frac{5}{0.026} = 192.3 \text{ mA/V}$$

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

$C_\pi + C_\mu = 122.4 \text{ pF} \Rightarrow C_\mu = 5 \text{ pF},\ C_\pi = 117.4 \text{ pF}$

$$C_M = C_\mu \left(1 + g_m \left(R_C \| R_L\right)\right)$$
$$= 5\left[1 + (192.3)(1\|1)\right] \Rightarrow C_M = 485.8 \text{ pF}$$
$$C_i = C_\pi + C_M = 117 + 485 = 603 \text{ pF}$$
$$r_\pi = \frac{(200)(0.026)}{5} = 1.04 \text{ k}\Omega$$
$$R_{eq} = R_1 \| R_2 \| r_\pi = 5 \| 1.04 = 0.861 \text{ k}\Omega$$
$$\tau = R_{eq} \cdot C_i = \left(0.861 \times 10^3\right)\left(603 \times 10^{-12}\right)$$
$$= 5.19 \times 10^{-7} \text{ s}$$
$$f = \frac{1}{2\pi\tau} = \frac{1}{2\pi\left(5.19 \times 10^{-7}\right)} \Rightarrow f = 307 \text{ kHz}$$

7.52

$$R_{TH} = R_1 \| R_2 = 60 \| 5.5 = 5.04 \text{ k}\Omega$$
$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{5.5}{5.5 + 60}\right)(15) = 1.26 \text{ V}$$
$$I_{BQ} = \frac{1.26 - 0.7}{5.04 + (101)(0.2)} = 0.0222 \text{ mA}$$
$$I_{CQ} = 2.22 \text{ mA}$$
$$r_\pi = \frac{(100)(0.026)}{2.22} = 1.17 \text{ k}\Omega$$
$$g_m = \frac{2.22}{0.026} = 85.4 \text{ mA/V}$$

Lower 3 – *dB* frequency:

$$\tau_L = R_{eq} \cdot C_{C1}$$
$$R_{eq} = R_S + R_1 \| R_2 \| r_\pi$$
$$= 2 + 60 \| 5.5 \| 1.17 = 2.95 \text{ k}\Omega$$
$$\tau_L = \left(2.95 \times 10^3\right)\left(0.1 \times 10^{-6}\right) = 2.95 \times 10^{-4} \text{ s}$$
$$f_L = \frac{1}{2\pi\tau_L} = \frac{1}{2\pi\left(2.95 \times 10^{-4}\right)} \Rightarrow f_L = 540 \text{ Hz}$$

Upper 3 – *dB* frequency:

$$f_T = \frac{g_m}{2\pi\left(C_\pi + C_\mu\right)} \Rightarrow 400 \times 10^6 = \frac{85.4 \times 10^{-3}}{2\pi\left(C_\pi + C_\mu\right)}$$
$$C_\pi + C_\mu = 34 \text{ pF}; \quad C_\mu = 2 \text{ pF}; \quad C_\pi = 32 \text{ pF}$$
$$C_M = C_\mu\left(1 + g_m R_C\right) = 2\left[1 + (85.4)(4)\right] \Rightarrow C_M = 685 \text{ pF}$$
$$C_i = C_\pi + C_M = 32 + 685 = 717 \text{ pF}$$
$$R_{eq} = R_S \| R_1 \| R_2 \| r_\pi = 2 \| 60 \| 5.5 \| 1.17 \Rightarrow R_{eq} = 0.644 \text{ k}\Omega$$
$$\tau = R_{eq} \cdot C_i = \left(0.644 \times 10^3\right)\left(717 \times 10^{-12}\right)$$
$$= 4.62 \times 10^{-7} \text{ s}$$
$$f_H = \frac{1}{2\pi\tau} \Rightarrow f_H = 344 \text{ kHz}$$

7.53

$$R_{TH} = R_1 \| R_2 = 600 \| 55 = 50.38 \text{ K}$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)(15) = \left(\frac{55}{600+55}\right)(15) = 1.2595 \text{ V}$$

$$I_{BQ} = \frac{1.26 - 0.7}{50.4 + (101)(2)} = 0.00222 \text{ mA}$$

$$I_{CQ} = 0.2217 \text{ mA}$$

$$r_\pi = \frac{(100)(0.026)}{0.222} = 11.73 \text{ K}$$

$$g_m = \frac{0.2217}{0.026} = 8.527 \text{ mA/V}$$

Lower – 3dB Freq

$$\tau_L = \mathrm{R}_{eq1} C_{c1};\ R_{eq1} = R_S + R_{TH} \| r_\pi$$

$$= 0.50 + 50.38 \| 11.73 = 10.0 \text{ K}$$

$$\tau_L = \left(10\times10^3\right)\left(0.1\times10^{-6}\right) = 10^{-3} \text{ s}$$

$$f_L = \frac{1}{2\pi\tau_L} = \frac{1}{2\pi\left(10^{-3}\right)} \Rightarrow f_L = 159 \text{ Hz}$$

Upper – 3dB Freq

$$f_T = \frac{g_m}{2\pi\left(C_\pi + C_\mu\right)} = \frac{8.527\times10^{-3}}{2\pi\left(C_\pi + 2\right)\times10^{-12}} = 400\times10^6$$

$$C_\pi + C_\mu = 3.393 \text{ pF} \Rightarrow C_\pi = 1.393 \text{ pF}$$

$$C_M = C_\mu\left(1 + g_m R_C\right) = 2\left[1 + (8.527)(40)\right] = 684 \text{ pF}$$

$$C_T = C_\pi + C_M = 1.393 + 684 = 685.4 \text{ pF}$$

$$R_{eq2} = R_S \| R_{TH} \| r_\pi = 0.5 \| 50.38 \| 11.73$$

$$= 50.38 \| 0.480 = 0.4750 \text{ K}$$

$$\tau_H = \mathrm{R}_{eq2} . C_T = \left(0.4750\times10^3\right)\left(685.4\times10^{-12}\right)$$

$$= 3.256\times10^{-7} \text{ s}$$

$$f_H = \frac{1}{2\pi\tau_H} = \frac{1}{2\pi\left(3.256\times10^{-7}\right)} \Rightarrow f_H = 489 \text{ KHz}$$

7.54

(a) $R_{TH} = R_1 \| R_2 = 33 \| 22 = 13.2 \text{ k}\Omega$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) \cdot V_{CC} = \left(\frac{22}{22+33}\right)(5) = 2 \text{ V}$$

$$I_{BQ} = \frac{V_{TH} - V_{BE}(on)}{R_{TH} + (1+\beta)R_E} = \frac{2 - 0.7}{13.2 + (151)(4)} = 0.002106 \text{ mA}$$

$I_{CQ} = 0.3159$ mA, $I_{EQ} = 0.3180$ mA

$V_{CEQ} = 5 - (0.3159)(5) - (0.3180)(4) = 2.15 \text{ V}$

(b) $$f_\beta = \frac{f_T}{\beta_o} = \frac{800 \times 10^6}{150} \Rightarrow f_\beta = 5.33 \text{ MHz}$$

$$g_m = \frac{0.3159}{0.026} = 12.15 \text{ mA/V}$$

$$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{12.15 \times 10^{-3}}{2\pi(800 \times 10^6)} \Rightarrow C_\pi + C_\mu = 2.417 \text{ pF}$$

$C_\pi = 2.417 - 0.45 = 1.97$ pF

$C_M = C_\mu [1 + g_m R_C] = (0.45)[1 + (12.15)(5)] = 27.79$ pF

(c) $$r_\pi = \frac{(150)(0.026)}{0.3159} = 12.35 \text{ k}\Omega, \quad R_{TH} \| r_\pi = 13.2 \| 12.35 = 6.38 \text{ k}\Omega$$

$$f_{3-dB} = \frac{1}{2\pi(R_{TH} \| r_\pi)(C_\pi + C_M)} = \frac{1}{2\pi(6.38 \times 10^3)(1.97 + 27.79) \times 10^{-12}}$$

$f_{3-dB} = 838$ kHz

7.55

$$g_{m1} = 2\sqrt{\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right) I_{DQ}} = 2\sqrt{\left(\frac{0.08}{2}\right)\left(\frac{4}{0.8}\right)(0.6)} = 0.6928 \text{ mA/V}$$

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})} = \frac{0.6928 \times 10^{-3}}{2\pi(50+10) \times 10^{-15}} \Rightarrow f_T = 1.84 \text{ GHz}$$

7.56

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

$0.12 = K_n (0.2)^2 \Rightarrow K_n = 3 \text{ mA/V}^2$

$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(3)(0.12)} = 1.2 \text{ mA/V}$

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})} = \frac{1.2 \times 10^{-3}}{2\pi(40+10) \times 10^{-15}} \Rightarrow f_T = 3.82 \text{ GHz}$$

7.57

(a) $g_m = 2\sqrt{(1.5)(0.05)} = 0.5477 \text{ mA/V}$

$$f_T = \frac{0.5477 \times 10^{-3}}{2\pi(60+10) \times 10^{-15}} \Rightarrow f_T = 1.25 \text{ GHz}$$

(b) $g_m = 2\sqrt{(1.5)(0.3)} = 1.342\text{ mA/V}$

$$f_T = \frac{1.342\times10^{-3}}{2\pi(60+10)\times10^{-15}} \Rightarrow f_T = 3.05\text{ GHz}$$

(c) $3\times10^9 = \dfrac{g_m}{2\pi(60+10)\times10^{-15}} \Rightarrow g_m = 1.319\text{ mA/V}$

$$g_m = 2\sqrt{K_n I_{DQ}} \Rightarrow I_{DQ} = \frac{1}{K_n}\left(\frac{g_m}{2}\right)^2 = \frac{1}{1.5}\left(\frac{1.319}{2}\right)^2 = 0.29\text{ mA}$$

(d) $g_m = 2\sqrt{(1.5)(0.25)} = 1.225\text{ mA/V}$

$$2.5\times10^9 = \frac{1.225\times10^{-3}}{2\pi(C_{gs}+8)\times10^{-15}} \Rightarrow C_{gs} = 70\text{ fF}$$

7.58

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

$$C_{gs}+C_{gd} = WLC_{ox}$$

$$g_m = 2K_n(V_{GS}-V_{TN}) = 2\left(\frac{W}{L}\right)\left(\frac{\mu_n C_{ox}}{2}\right)(V_{GS}-V_{TN})$$

Then $f_T = \dfrac{\left(\frac{W}{L}\right)(\mu_n C_{ox})(V_{GS}-V_{TN})}{2\pi WLC_{ox}}$

$$f_T = \frac{\mu_n(V_{GS}-V_{TN})}{2\pi L^2}$$

(a) $f_T = \dfrac{450(0.5)}{2\pi\left(1.2\times10^{-4}\right)^2} \Rightarrow f_T = 2.49\text{ GHz}$

(b) $f_T = \dfrac{450(0.5)}{2\pi\left(0.18\times10^{-4}\right)} \Rightarrow f_T = 111\text{ GHz}$

7.59

(a) $C_M = C_{gd}\left[1+g_m(r_o\|R_D)\right] = (12)\left[1+(3)(120\|10)\right] = 344.3\text{ fF}$

(b) $f_{3-dB} = \dfrac{1}{2\pi\tau}$

$$\tau = r_i(C_{gs}+C_M) = (10^4)(80+344.3)\times10^{-15} = 4.243\times10^{-9}\text{ s}$$

$$f_{3-dB} = \frac{1}{2\pi(4.243\times10^{-9})} \Rightarrow f_{3-dB} = 37.5\text{ MHz}$$

7.60

$$f_T = \frac{g_m}{2\pi\left(C_{gsT} + C_{gdT}\right)} \quad \text{(Eq. (7.97))}$$

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

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

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

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

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

7.61

(a) $K_n = \left(\frac{\mu_n C_{ox}}{2}\right)\left(\frac{W}{L}\right) = \frac{(400)\left(6.9\times10^{-9}\right)}{2}(8) \Rightarrow K_n = 1.104 \text{ mA/V}^2$

$$I_D = K_n\left(V_{GS} - V_{TN}\right)^2 = (1.104)(3-0.4)^2 = 7.463 \text{ mA}$$

$$g_m = 2\sqrt{K_n I_D} = 2\sqrt{(1.104)(7.463)} = 5.741 \text{ mA/V}$$

$$g'_m = \frac{g_m}{1+g_m r_s}$$

$$(0.8)g_m = \frac{g_m}{1+g_m r_s} \Rightarrow g_m r_s = \frac{1}{0.8} - 1 = 0.25$$

$$r_s = \frac{0.25}{5.741} \Rightarrow r_s = 43.5\,\Omega$$

(b) $I_D = (1.104)(1-0.4)^2 = 0.3974 \text{ mA}$

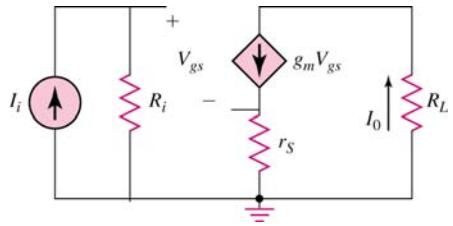
$$g_m = 2\sqrt{(1.104)(0.3974)} = 1.325 \text{ mA/V}$$

$$g'_m = \frac{1.325}{1+(1.325)(0.04355)} = 1.253 \text{ mA/V}$$

$$\frac{g'_m}{g_m} \Rightarrow 94.5\%$$

7.62

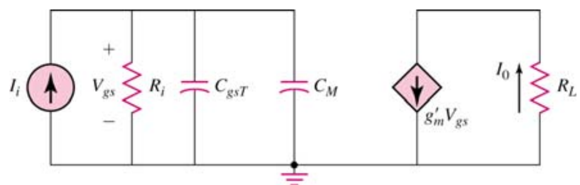
a.



$I_0 = g_m V_{gs}$ 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 $A_i = \dfrac{I_0}{I_i} = \dfrac{g_m R_i}{1 + g_m r_S}$

b. As an approximation, consider



In this case

$A_i = \dfrac{I_0}{I_i} = g'_m R_i \cdot \dfrac{1}{1 + sR_i\left(C_{gsT} + C_M\right)}$ where $C_M = C_{gdT}\left(1 + g'_m R_L\right)$ 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.

7.63

(b) $V_{GS} = \left(\dfrac{225}{225 + 500}\right)(10) = 3.103\ \text{V}$

$I_{DQ} = (1)(3.103 - 2)^2 = 1.218\ \text{mA}$

$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(1)(1.218)} = 2.207\ \text{mA/V}$

$C_M = C_{gd}\left(1 + g_m R_D\right) = (8)\left[1 + (2.207)(5)\right] = 96.28\ \text{fF}$

(c) $f_{3-dB} = \dfrac{1}{2\pi\tau}$, $\tau = \left(R_i \| R_1 \| R_2\right)\left(C_{gs} + C_M\right)$

Now $R_i \| R_1 \| R_2 = 1 \| 500 \| 225 = 0.9936\ \text{k}\Omega$

$\tau = \left(0.9936 \times 10^3\right)(50 + 96.28) \times 10^{-15} = 1.453 \times 10^{-10}\ \text{s}$

$f_{3-dB} = \dfrac{1}{2\pi\left(1.453 \times 10^{-10}\right)} \Rightarrow f_{3-dB} = 1.095\ \text{GHz}$

$A_\upsilon = -g_m R_D \left(\dfrac{R_1 \| R_2}{R_1 \| R_2 + R_i}\right) = -(2.207)(5)\left(\dfrac{155.2}{155.2 + 1}\right) = -10.96$

7.64

(a) $C_M = C_{gd}\left(1+|A_\upsilon|\right) = (0.04)(1+15) = 0.64 \text{ pF}$

(b) $f_H = \dfrac{1}{2\pi\tau}$, $\Rightarrow \tau = \dfrac{1}{2\pi f} = \dfrac{1}{2\pi\left(5\times10^6\right)} = 3.183\times10^{-8} \text{ s}$

$\tau = R_{eq}\left(C_{gs}+C_M\right)$

or $R_{eq} = \dfrac{\tau}{\left(C_{gs}+C_M\right)} = \dfrac{3.183\times10^{-8}}{(0.2+0.64)\times10^{-12}} \Rightarrow R_{eq} = 37.9 \text{ k}\Omega$

7.65

$$R_{TH} = R_1\|R_2 = 33\|22 = 13.2 \text{ k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1+R_2}\right)(5) = \left(\frac{22}{22+33}\right)(5) = 2 \text{ V}$$

$$I_{BQ} = \frac{2-0.7}{13.2+(121)(4)} = 0.00261 \text{ mA}$$

$$I_{CQ} = 0.3138$$

$$r_\pi = \frac{(120)(0.026)}{0.3138} = 9.94 \text{ k}\Omega$$

$$g_m = \frac{0.3138}{0.026} = 12.07 \text{ mA/V}$$

$$r_0 = \frac{100}{0.3138} = 318 \text{ k}\Omega$$

a.

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

$$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{12.07\times10^{-3}}{2\pi\left(600\times10^6\right)}$$

$$C_\pi + C_\mu = 3.20 \text{ pF};\ C_\mu = 1 \text{ pF} \Rightarrow C_\pi = 2.20 \text{ pF}$$

$$C_M = C_\mu\left[1+g_m\left(r_o\|R_C\|R_L\right)\right]$$

$$= (1)\left[1+(12.07)\left(318\|4\|5\right)\right]$$

$$C_M = 27.6 \text{ pF}$$

b.

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

$$R_{eq} = R_1 \| R_2 \| R_S \| r_\pi = 33 \| 22 \| 2 \| r_\pi$$

$$= 1.74 \| 9.94 \Rightarrow R_{eq} = 1.48 \text{ k}\Omega$$

$$\tau = (1.48 \times 10^3)(2.20 + 27.6) \times 10^{-12}$$

$$\tau = 4.41 \times 10^{-8} \text{ s}$$

$$f_H = \frac{1}{2\pi\tau} = \frac{1}{2\pi(4.41 \times 10^{-8})} \Rightarrow f_H = 3.61 \text{ MHz}$$

$$V_o = -g_m V_\pi (r_o \| R_C \| R_L)$$

$$V_\pi = \frac{R_1 \| R_2 \| r_\pi}{R_1 \| R_2 \| r_\pi + R_S} \cdot V_i$$

$$R_1 \| R_2 \| r_\pi = 33 \| 22 \| 9.94 = 5.67 \text{ k}\Omega$$

$$V_\pi = \frac{5.67}{5.67 + 2} \cdot V_i = (0.739) V_i$$

$$r_o \| R_C \| R_L = 318 \| 4 \| 5 = 2.18 \text{ k}\Omega$$

$$A_\upsilon = -(12.07)(0.739)(2.18)$$

$$A_\upsilon = -19.7$$

7.66

$$R_{TH} = R_1 \| R_2 = 40 \| 5 = 4.44 \text{ k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{5}{5 + 40}\right)(10) = 1.111 \text{ V}$$

$$I_{BQ} = \frac{1.111 - 0.7}{4.44 + (121)(0.5)} = 0.00633 \text{ mA}$$

$$I_{CQ} = 0.760 \text{ mA}$$

$$r_\pi = \frac{(120)(0.026)}{0.760} = 4.11 \text{ k}\Omega$$

$$g_m = \frac{0.760}{0.026} = 29.23 \text{ mA/V}$$

$$r_0 = \infty$$

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

$$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{29.23 \times 10^{-3}}{2\pi(250 \times 10^6)}$$

$$C_\pi + C_\mu = 18.6 \text{ pF; } C_\mu = 3 \text{ pF} \Rightarrow C_\pi = 15.6 \text{ pF}$$

a.

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

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

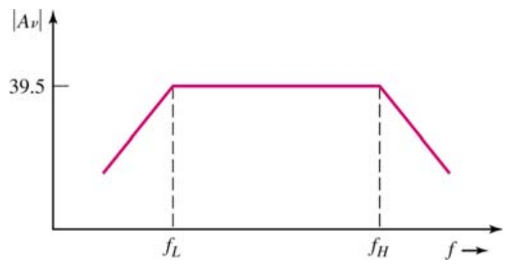
For upper frequency:

$$\tau_H = R_{eq}\left(C_\pi + C_M\right)$$
$$R_{eq} = r_\pi \| R_1 \| R_2 \| R_S = 4.11 \| 40 \| 5 \| 0.5$$
$$R_{eq} = 0.405 \text{ k}\Omega$$
$$\tau_H = \left(0.405\times 10^3\right)\left(15.6+149\right)\times 10^{-12}$$
$$= 6.67\times 10^{-8} \text{ s}$$
$$f_H = \frac{1}{2\pi\tau_H} \Rightarrow f_H = 2.39 \text{ MHz}$$

For lower frequency:

$$\tau_L = R_{eq}C_{C1}$$
$$R_{eq} = R_S + R_1 \| R_2 \| r_\pi = 0.5 + 40 \| 5 \| 4.11$$
$$R_{eq} = 2.64 \text{ k}\Omega$$
$$\tau_L = \left(2.64\times 10^3\right)\left(4.7\times 10^{-6}\right) = 1.24\times 10^{-2} \text{ s}$$
$$f_L = \frac{1}{2\pi\tau_L} \Rightarrow f_L = 12.8 \text{ Hz}$$

b.



$$V_0 = -g_m V_\pi \left(R_C \| R_L\right)$$
$$V_\pi = \left(\frac{R_1 \| R_2 \| r_\pi}{R_1 \| R_2 \| r_\pi + R_S}\right)V_i$$
$$V_\pi = \left(\frac{2.135}{2.135+0.5}\right)V_i = 0.8102V_i$$
$$\left|A_V\right| = (29.23)(0.8102)\left(5\|2.5\right)$$
$$\underline{\left|A_V\right| = 39.5}$$

7.67

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

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

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

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

$$V_{SG} = 3.512 \text{ V}$$

$$g_m = 2K_P\left(V_{SG} + V_{TP}\right) = 2(2)(3.512 - 2)$$

$$g_m = 6.049\ mA/V$$

$$I_D = (2)(3.512 - 2)^2 = 4.572 \text{ mA}$$

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

$$C_M = C_{gdT}\left(1 + g_m\left(r_o \| R_D\right)\right)$$

a. $$C_M = (1)\left[1 + (6.04)(21.9\|1)\right] \Rightarrow \underline{C_M = 6.785 \text{ pF}}$$

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

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

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

$$f_H = \frac{1}{2\pi\tau_H} \Rightarrow f_H = 4.84\,\text{MHz}$$

$$V_o = -g_m\left(r_o \| R_D\right)\cdot V_{gs}$$

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

$$A_\upsilon = -(6.04)\left(\frac{100}{102}\right)(21.9\|1)$$

$$A_\upsilon = -5.67$$

7.68

(a) $$I_{DQ} = K_p\left(V_{SGQ} + V_{TP}\right)^2$$

$$0.5 = 0.5\left(V_{SGQ} - 0.5\right)^2 \Rightarrow V_{SGQ} = 1.5\text{ V}$$

$$R_S = \frac{3 - 1.5}{0.5} = 3\text{ k}\Omega$$

$$V_D = 1.5 - 2 = -0.5\text{ V}$$

$$R_D = \frac{-0.5 - (-3)}{0.5} = 5\text{ k}\Omega$$

(b) $$g_m = 2\sqrt{K_p I_{DQ}} = 2\sqrt{(0.5)(0.5)} = 1\text{ mA/V}$$

$$A_\upsilon = -g_m R_D\left(\frac{R_G}{R_G + R_i}\right) = -(1)(5)\left(\frac{200}{200 + 4}\right) = -4.90$$

(c) $C_M = C_{gd}(1+g_m R_D) = (0.08)[1+(1)(5)] = 0.48\text{ pF}$

(d) $f_{3-dB} = \dfrac{1}{2\pi\tau}$

where $\tau = R_{eq}\cdot C_{eq} = (R_i \| R_G)(C_{gs}+C_M) = (4\|200)\times 10^3 \times (0.8+0.48)\times 10^{-12}$

which yields $\tau = 5.02\times 10^{-9}$ s

Then $f_{3-dB} = \dfrac{1}{2\pi(5.02\times 10^{-9})} \Rightarrow f_{3-dB} = 31.7\text{ MHz}$

7.69

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

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

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

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

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

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

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

$$g_m = 3.54\ mA/V$$

b.

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

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

a.

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

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

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

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

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

c.

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

$$V_{gs} = \left(\frac{R_1\|R_2}{R_1\|R_2+R_i}\right)\cdot V_i = \left(\frac{5.87}{5.87+0.5}\right)\cdot V_i = (0.9215)V_i$$

$$A_\upsilon = -(3.54)(0.9215)(2\|5) \Rightarrow A_\upsilon = -4.66$$

7.70

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

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

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

a. Input: From Eq. (7.114(b))

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

$$= \left[\frac{5.25}{101}\middle\|0.5\middle\|0.05\right]\times 10^3 \times \left(10\times 10^{-12}\right)$$

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

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

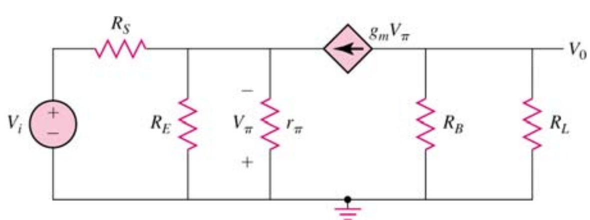
Output: From Eq. (7.115(b))

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

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

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

b.



$$V_o = -g_m V_\pi \left(R_B \| R_L\right)$$

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_i - (-V_\pi)}{R_S} = 0$$

$$V_\pi\left[g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S}\right] = -\frac{V_i}{R_S}$$

$$V_\pi\left[19 + \frac{1}{5.25} + \frac{1}{0.5} + \frac{1}{0.05}\right] = \frac{-V_i}{0.05}$$

$$V_\pi(41.19) = -V_i(20)$$

$$V_\pi = -(0.4856)V_i$$

$$\frac{V_o}{V_i} = -(19)(-0.4856)(100\|1)$$

$$A_\upsilon = 9.14$$

c.

$$\tau = (R_B \| R_L)C_L = (100\|1)\times 10^3 \times (15\times 10^{-12})$$
$$\tau = 1.485\times 10^{-8}\text{ s}$$
$$f = \frac{1}{2\pi\tau} \Rightarrow f = 10.7\text{ MHz}$$

Since $f < f_{H\mu} \Rightarrow 3$ -dB frequency dominated by C_L

7.71

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

a. Input:

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

Output:

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

b.

$$V_o = -g_m V_\pi (R_C\|R_L)$$
$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_i - (-V_\pi)}{R_S} = 0$$
$$V_\pi\left(g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S}\right) = -\frac{V_i}{R_S}$$
$$V_\pi\left(73.5 + \frac{1}{1.36} + \frac{1}{10} + \frac{1}{1}\right) = \frac{-V_i}{1}$$
$$V_\pi(75.34) = -V_i \Rightarrow V_\pi = -(0.01327)V_i$$
$$V_o = -(73.5)(-0.01327)(6.5\|5)V_i$$
$$A_\upsilon = 2.76$$

c.

$$\tau = (R_C \| R_L)C_L = (6.5\|5)\times 10^3 \times (15\times 10^{-12})$$
$$\tau = 4.24\times 10^{-8}\text{ s}$$
$$f = \frac{1}{2\pi\tau} \Rightarrow f = 3.75\text{ MHz}$$

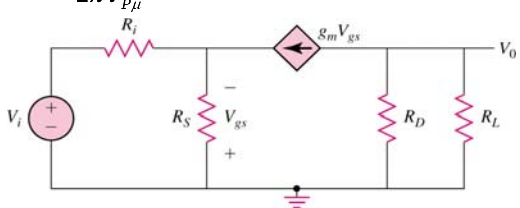
Since $f < f_{P\mu}$, 3-dB frequency is dominated by C_L

7.72

$$V_{GS} + I_D R_S = 5$$
$$I_D = \frac{5 - V_{GS}}{R_S} = K_n (V_{GS} - V_{TN})^2$$
$$5 - V_{GS} = (3)(10)(V^2{}_{GS} - 2V_{GS} + 1)$$
$$30V^2{}_{GS} - 59V_{GS} + 25 = 0$$
$$V_{GS} = \frac{59 \pm \sqrt{(59)^2 - 4(30)(25)}}{2(30)} \Rightarrow V_{GS} = 1.349\text{ V}$$
$$g_m = 2K_n (V_{GS} - V_{TN}) = 2(3)(1.35 - 1)$$
$$g_m = 2.093\ mA/V$$

On the output:

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



$$V_0 = -g_m V_{gs} (R_D \| R_L)$$
$$g_m V_{gs} + \frac{V_{gs}}{R_S} + \frac{V_i - (-V_{gs})}{R_S} = 0$$
$$V_{gs}\left(g_m + \frac{1}{R_S} + \frac{1}{R_i}\right) = -\frac{V_i}{R_i}$$
$$V_{gs}\left(2.093 + \frac{1}{10} + \frac{1}{2}\right) = -\frac{V_i}{2}$$
$$V_{gs} = (0.1857)V_i$$
$$A_v = \frac{V_0}{V_i} = (2.093)(0.1857)(5\|4)$$
$$\underline{A_v = 0.864}$$

7.73

dc analysis

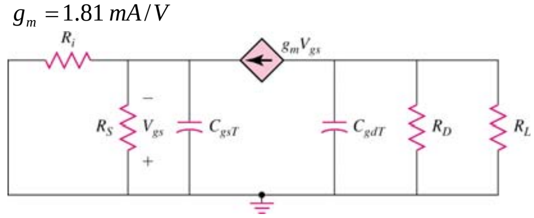
$$I_D = \frac{V^+ - V_{SG}}{R_S} = K_P\left(V_{SG} + V_{TP}\right)^2$$

$$5 - V_{SG} = (1)(4)(V_{SG} - 0.8)^2$$
$$= 4\left(V_{SG}^2 - 1.6V_{SG} + 0.64\right)$$

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

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

$$g_m = 2K_P\left(V_{SG} + V_{TP}\right) = 2(1)(1.707 - 0.8)$$
$$g_m = 1.81\ mA/V$$



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

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

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

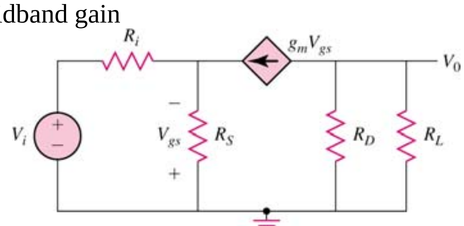
$$f_A = \frac{1}{2\pi(246)\left(4 \times 10^{-12}\right)} = 162\ \text{MHz}$$

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

$$f_B = \frac{1}{2\pi\left(R_D \| R_L\right)C_{gdT}}$$
$$= \frac{1}{2\pi\left(2\|4\right) \times 10^3 \times 10^{-12}}$$

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

Midband gain



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

$$= -0.492 V_i$$

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

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

7.74

$$r_\pi = \frac{(120)(0.026)}{1.02} = 3.059\ \text{k}\Omega$$

$$g_m = 39.23\ \text{mA/V}$$

a.

Input: $f_{H\pi} = \dfrac{1}{2\pi\tau_\pi}$

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

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

$$\tau_\pi = (96)[12 + 2(2)]\times 10^{-12} = 1.537\times 10^{-9}\ \text{s}$$

$$f_{H\pi} = \frac{1}{2\pi\left(1.537\times 10^{-9}\right)} \Rightarrow f_{H\pi} = 103.6\ \text{MHz}$$

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

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

$$= (15\|10)\times 10^3 \times \left(2\times 10^{-12}\right)$$

$$\tau_\mu = 6.67\times 10^{-9}\ \text{s}$$

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

b.

$$A_\upsilon = g_m\left(R_C\|R_L\right)\left(\frac{R_2\|R_3\|r_\pi}{R_2\|R_3\|r_\pi + R_S}\right)$$

$$R_2\|R_3\|r_\pi = 20.5\|28.3\|3.059 = 2.433\ \text{k}\,\Omega$$

$$A_\upsilon = (39.23)(5\|10)\left(\frac{2.433}{2.433 + 0.1}\right) \Rightarrow A_\upsilon = 125.6$$

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