CHAPTER 17

17.1

$$A_v(s) = 25\frac{s^2}{(s+1)(s+20)} \quad | \quad A_{mid} = 25 \quad | \quad F_L(s) = \frac{s^2}{(s+1)(s+20)} \quad | \quad \text{Poles: } -1, -20 \quad | \quad \text{Zeros: } 0, 0$$

$$\text{yes, } s = -20 \quad | \quad A_v(s) \approx 25\frac{s}{(s+20)} \quad | \quad w_L = 20\frac{rad}{s} \quad | \quad f_L = \frac{w_L}{2p} \cong \frac{20}{2p} = 3.18Hz$$

$$f_L = \frac{1}{2p}\sqrt{20^2 + 1^2 - 2(0)^2 - 2(0)^2} = 3.19Hz$$

$$|A_v(jw)| = \frac{25w^2}{\sqrt{w^2+1^2}\sqrt{w^2+20^2}} \quad | \text{ MATLAB: } -3.19\ Hz$$

17.2

$$A_v(s) = 250\frac{s^2}{(s+100)(s+500)} \quad | \quad A_{mid} = 250 \quad | \quad F_L(s) = \frac{s^2}{(s+100)(s+500)}$$

$$\text{Poles: } -100, -500\ \frac{rad}{\mathrm{s}} \quad | \quad \text{Zeros: } 0,\ 0 \quad | \quad \text{Yes, a 5:1 split is sufficient} \quad | \quad s = -500$$

$$A_v(s) \approx 250\frac{s}{(s+500)} \quad | \quad w_L \cong 500\frac{rad}{s} \quad | \quad f_L \cong \frac{500}{2p} = 79.6\ Hz$$

$$f_L \cong \frac{1}{2p}\sqrt{100^2 + 500^2 - 2(0)^2 - 2(0)^2} = 81.2\ Hz$$

$$|A_v(jw)| = \frac{250w^2}{\sqrt{w^2+100^2}\sqrt{w^2+500^2}} \quad | \text{ MATLAB: } 82.6\ Hz$$

17.3

$$A_v(s) = -150\frac{s(s+15)}{(s+12)(s+20)} \quad | \quad A_{mid} = -150 \quad | \quad F_L(s) = \frac{s(s+15)}{(s+12)(s+20)}$$

$$\text{Poles: } -12,\ -20\ \frac{\mathrm{rad}}{\mathrm{s}} \quad | \quad \text{Zeros: } 0,\ -15\ \frac{\mathrm{rad}}{\mathrm{s}} \quad | \quad \text{No, the poles and zeros are closely spaced.}$$

$$f_L \cong \frac{1}{2p}\sqrt{12^2 + 20^2 - 2(0)^2 - 2(15)^2} = 1.54\ Hz$$

$$|A_v(jw)| = \frac{150w\sqrt{w^2+15^2}}{\sqrt{w^2+12^2}\sqrt{w^2+20^2}} \quad | \text{ MATLAB: } \mathrm{f_L} = 2.72\ Hz \quad | \quad w_{\mathrm{L}} = 17.1\frac{\mathrm{rad}}{\mathrm{s}}$$

Note that ω_L =17.1 rad/s does not satisfy the assumption used to obtain Eq. (17.15), and the estimate using Eq. (17.15) is rather poor.

17.4

$$A_v(s)=\frac{(2x10^{11})(10^{-4})(10^{-5})}{\left(\frac{s}{10^4}+1\right)\left(\frac{s}{10^5}+1\right)}=\frac{200}{\left(\frac{s}{10^4}+1\right)\left(\frac{s}{10^5}+1\right)}\quad|\quad A_{mid}=200\quad|\quad F_H(s)=\frac{1}{\left(\frac{s}{10^4}+1\right)\left(\frac{s}{10^5}+1\right)}$$

$$\text{Poles: }\ -10^4,-10^5\ \frac{rad}{s}\quad|\quad\text{Yes: }A_v(s)\approx\frac{200}{\frac{s}{10^4}+1}\quad|\quad\omega_H\cong 10^4\frac{rad}{s}\quad|\quad f_H\cong\frac{10^4}{2\pi}=1.59kHz$$

$$f_H\cong\frac{1}{2\pi}\left(\sqrt{\left(\frac{1}{10^4}\right)^2+\left(\frac{1}{10^5}\right)^2-2\left(\frac{1}{\infty}\right)^2-2\left(\frac{1}{\infty}\right)^2}\right)^{-1}=1.58\ kHz$$

$$|A_v(j\omega)|=\frac{2x10^{11}}{\sqrt{\omega^2+(10^4)^2}\sqrt{\omega^2+(10^5)^2}}\quad|\quad\text{MATLAB: }f_H=1.58\text{ k}Hz$$

17.5

$$A_v(s)=\frac{(2x10^9)\left(1+\frac{s}{2x10^9}\right)}{10^7\left(1+\frac{s}{10^7}\right)\left(1+\frac{s}{10^9}\right)}=200\frac{\left(1+\frac{s}{2x10^9}\right)}{\left(1+\frac{s}{10^7}\right)\left(1+\frac{s}{10^9}\right)}$$

$$A_{mid}=200\quad|\quad F_H(s)=\frac{\left(1+\frac{s}{2x10^9}\right)}{\left(1+\frac{s}{10^7}\right)\left(1+\frac{s}{10^9}\right)}\quad|\quad\text{Poles: }\ -10^7,\ -10^9\ \ \text{Zeros: }\ -2x10^9,\ \infty$$

$$\text{Yes: }A_v(s)\approx\frac{200}{\left(1+\frac{s}{10^7}\right)}\quad|\quad\omega_H\cong 10^7\frac{rad}{s}\quad|\quad f_H\cong\frac{10^4}{2\pi}=1.59\ MHz$$

$$f_H=\frac{1}{2\pi}\left(\sqrt{\left(\frac{1}{10^7}\right)^2+\left(\frac{1}{10^9}\right)^2-2\left(\frac{1}{2x10^9}\right)^2-2\left(\frac{1}{\infty}\right)^2}\right)^{-1}=1.59\ MHz$$

$$|A_v(j\omega)|=\frac{2x10^9\sqrt{\omega^2+(2x10^9)^2}}{\sqrt{\omega^2+(10^7)^2}\sqrt{\omega^2+(10^9)^2}}\quad|\quad\text{MATLAB: }f_H=1.59\text{ M}Hz$$

17.6

$$A_v(s)=\frac{(4x10^9)(5x10^5)\left(1+\frac{s}{5x10^5}\right)}{(1.3x10^5)(2x10^6)\left(1+\frac{s}{1.3x10^5}\right)\left(1+\frac{s}{2x10^6}\right)}=7692\frac{\left(1+\frac{s}{5x10^5}\right)}{\left(1+\frac{s}{1.3x10^5}\right)\left(1+\frac{s}{2x10^6}\right)}$$

$$A_{mid} = 7692 \quad | \quad F_H(s) = \frac{\left(1+\frac{s}{5x10^5}\right)}{\left(1+\frac{s}{1.3x10^5}\right)\left(1+\frac{s}{2x10^6}\right)} \quad | \quad \text{Poles: } -1.3\text{x}10^5,\ -2\text{x}10^6\ \frac{rad}{\text{s}}$$

$$\text{Zeros: } -5x10^5\ \frac{rad}{\text{s}},\ \infty \quad | \quad \text{No, the poles and zeros are closely spaced and will interact.}$$

$$f_H \cong \frac{1}{2p}\left(\sqrt{\left(\frac{1}{1.310^5}\right)^2 + \left(\frac{1}{2x10^6}\right)^2 - 2\left(\frac{1}{5x10^5}\right)^2 - 2\left(\frac{1}{\infty}\right)^2}\right)^{-1} = 22.2\ kHz$$

$$\left|A_v(jw)\right| = \frac{4x10^9\sqrt{w^2+\left(5x10^5\right)^2}}{\sqrt{w^2+\left(1.3x10^5\right)^2}\sqrt{w^2+\left(2x10^6\right)^2}} \quad | \quad \text{MATLAB: } 22.1\ kHz$$

17.7

$$A_v(s) = \frac{10^8}{500(1000)}\frac{s^2}{(s+1)(s+2)}\frac{1}{\left(1+\frac{s}{500}\right)\left(1+\frac{s}{1000}\right)}$$

$$A_v(s) = 200\left[\frac{s^2}{(s+1)(s+2)}\right]\left[\frac{1}{\left(1+\frac{s}{500}\right)\left(1+\frac{s}{1000}\right)}\right] = 200F_L(s)F_H(s)$$

$$\text{Poles; } -1,\ -2,\ -500,\ -1000\ \frac{\text{rad}}{\text{s}} \quad | \quad \text{Zeros: } 0,\ 0,\ \infty,\ \infty \quad | \quad \text{No.} \quad | \quad \text{No.}$$

$$\left|A_v(jw)\right| = \frac{10^8 w^2}{\sqrt{1^2+w^2}\sqrt{2^2+w^2}\sqrt{500^2+w^2}\sqrt{1000^2+w^2}}$$

$$f_L = \frac{1}{2p}\sqrt{(1)^2+(2)^2-2(0)^2-2(0)^2} = 0.356\ Hz \quad | \quad \text{MATLAB : } 0.380\ \text{Hz}$$

$$f_H = \frac{1}{2p}\sqrt{\left(\frac{1}{500}\right)^2+\left(\frac{1}{1000}\right)^2-2\left(\frac{1}{\infty}\right)^2-2\left(\frac{1}{\infty}\right)^2} = 71.2\ kHz \quad | \quad \text{MATLAB: } 66.7\ \text{Hz}$$

17.8

$$A_v(s) = \frac{10^{10}(200)}{(100)^2(300)}\frac{s^2(s+1)}{(s+3)(s+5)(s+7)}\frac{\left(1+\frac{s}{200}\right)}{\left(1+\frac{s}{100}\right)^2\left(1+\frac{s}{300}\right)}$$

$$A_v(s) = 6.67x10^5\left[\frac{s^2(s+1)}{(s+3)(s+5)(s+7)}\right]\left[\frac{\left(1+\frac{s}{200}\right)}{\left(1+\frac{s}{100}\right)^2\left(1+\frac{s}{300}\right)}\right] = 6.67x10^5 F_L(s)F_H(s)$$

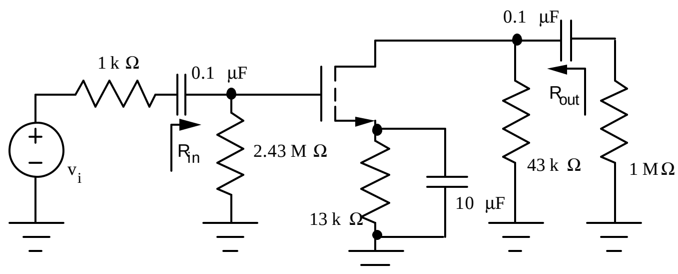
No dominant pole at either low or high frequencies.

$$\left|A_v(jw)\right| = \frac{10^{10} w^2 \sqrt{w^2+1^2}\sqrt{w^2+200^2}}{\sqrt{w^2+3^2}\sqrt{w^2+5^2}\sqrt{w^2+7^2}\left(w^2+100^2\right)\sqrt{w^2+300^2}}$$

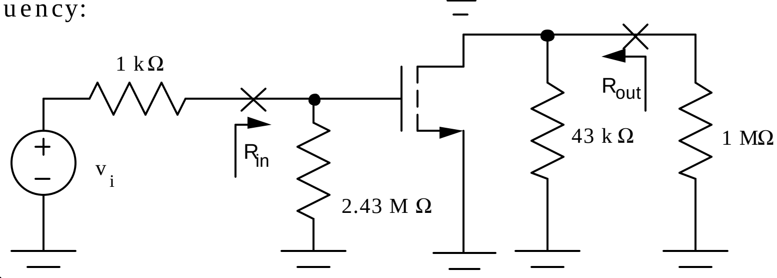
$$f_L = \frac{1}{2p}\sqrt{(3)^2+(5)^2+(7)^2-2(1)^2-2(0)^2} = 1.43\,Hz \quad | \quad \text{MATLAB}: 1.62\text{ Hz}$$

$$f_{\text{H}} = \frac{1}{2p}\left(\sqrt{\left(\frac{1}{100}\right)^2+\left(\frac{1}{100}\right)^2+\left(\frac{1}{300}\right)^2-2\left(\frac{1}{200}\right)^2-2\left(\frac{1}{\infty}\right)^2}\right)^{-1} = 12.5\,Hz \quad | \quad \text{MATLAB}: 10.6\text{ Hz}$$

17.9



Low frequency:



Mid-band:

$$A_{vt} = \frac{v_d}{v_g} = -g_m R_L = -g_m\left(R_{out}\|R_3\right) \quad | \quad A_{mid} = \frac{R_{in}}{R_I + R_{in}} A_{vt} \quad | \quad g_m = \frac{2I_D}{V_{GS}-V_{TN}} = \frac{2(0.2mA)}{1V} = 0.400mS$$

$R_{in} = 2.43M\Omega \quad | \quad R_{out} = R_D\|r_o \cong R_D = 43k\Omega$ assuming $\quad l = 0$ since it is not specified.

$$A_{mid} = -\left(\frac{2.43M\Omega}{1k\Omega + 2.43M\Omega}\right)(0.400mS)\left(43k\Omega\|1M\Omega\right) = -16.5$$

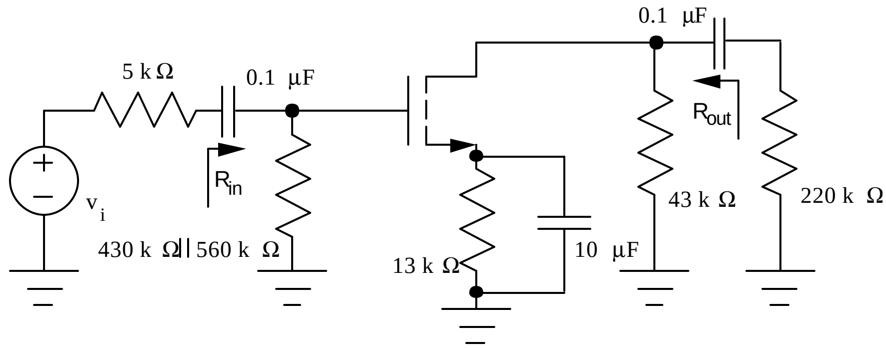
$$w_1 = \frac{1}{\left(10^{-7}F\right)\left(2.43M\Omega + 1k\Omega\right)} = 4.11\frac{rad}{s} \quad | \quad w_2 = \frac{1}{\left(10^{-7}F\right)\left(43k\Omega + 1M\Omega\right)} = 9.59\frac{rad}{s}$$

$$w_3 = \frac{1}{\left(10^{-5}F\right)\left(13k\Omega\left\|\frac{1}{g_m}\right.\right)} = \frac{1}{\left(10^{-5}F\right)\left(13k\Omega\|2.5k\Omega\right)} = 47.7\frac{rad}{s} \quad | \quad w_Z = \frac{1}{\left(10^{-5}F\right)\left(13k\Omega\right)} = 7.69\frac{rad}{s}$$

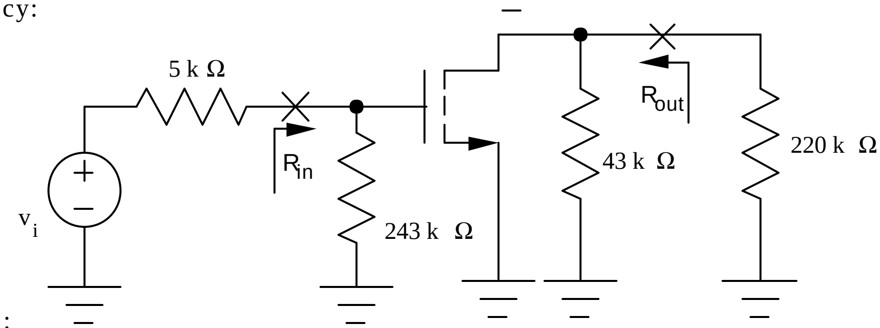
w_3 is dominant : $f_L \cong \frac{w_3}{2p} = 7.59\ Hz$

Using Eq. (17.16) yields : $f_L \cong \frac{1}{2p}\sqrt{(4.11)^2+(9.59)^2+(47.7)^2-2(7.69)^2} = 7.58\,Hz$

17.10



Low frequency:



Mid-band:

$$A_{vt} = \frac{v_d}{v_g} = -g_m R_L = -g_m \left(R_{out} \| R_3\right) \quad | \quad A_{mid} = \frac{R_{in}}{R_I + R_{in}} A_{vt} \quad | \quad g_m = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{2(0.2mA)}{1V} = 0.400mS$$

$R_{in} = 243k\Omega$ | $R_{out} = R_D \| r_o \cong R_D = 43k\Omega$ assuming $l = 0$ since it is not specified.

$$A_{mid} = -\left(\frac{243k\Omega}{5k\Omega + 243k\Omega}\right)(0.400mS)\left(43k\Omega \| 220k\Omega\right) = -14.1$$

$$w_1 = \frac{1}{\left(10^{-7}F\right)\left(243k\Omega + 5k\Omega\right)} = 40.3\frac{rad}{s} \quad | \quad w_2 = \frac{1}{\left(10^{-7}F\right)\left(43k\Omega + 220k\Omega\right)} = 38.0\frac{rad}{s}$$

$$w_3 = \frac{1}{\left(10^{-5}F\right)\left(13k\Omega \| \frac{1}{g_m}\right)} = \frac{1}{\left(10^{-5}F\right)\left(13k\Omega \| 2.5k\Omega\right)} = 47.7\frac{rad}{s} \quad | \quad w_Z = \frac{1}{\left(10^{-5}F\right)\left(13k\Omega\right)} = 7.69\frac{rad}{s}$$

Using Eq. (17.16) : $f_L \cong \frac{1}{2p}\sqrt{(40.3)^2 + (38.0)^2 + (47.7)^2 - 2(7.69)^2} = 11.5\ Hz$

17.11

(a) Assume that w_3 is dominant : $f_L \cong w_3 = 2p(50) = 314\dfrac{rad}{s}$

$$C_3 = \frac{1}{w_3\left(R_S \left\| \frac{1}{g_m}\right.\right)} = \frac{1}{314\left(13k\Omega \| 2.5k\Omega\right)} = 1.52\ mF \quad \text{where} \quad g_m = \frac{2I_D}{V_{GS}-V_{TN}} = \frac{0.4mA}{1V} = 0.4\,mS$$

(b) Choose $C_3 = 1.5\ mF$ | $w_3 = \dfrac{1}{1.5\ mF\left(13k\Omega \| 2.5k\Omega\right)} = 318\dfrac{rad}{s}$ | $w_Z = \dfrac{1}{(1.5mF)(13k\Omega)} = 51.3\dfrac{rad}{s}$

$w_1 = \dfrac{1}{\left(10^{-7}F\right)\left(2.43M\Omega + 1k\Omega\right)} = 4.11\dfrac{rad}{s}$ | $w_2 = \dfrac{1}{\left(10^{-7}F\right)\left(43k\Omega + 1M\Omega\right)} = 9.59\dfrac{rad}{s}$

Using Eq. (17.16) yields : $f_L \cong \dfrac{1}{2p}\sqrt{(4.11)^2 + (9.59)^2 + (318)^2 - 2(51.3)^2} = 49.3\ Hz$

(c) Assume that w_3 is dominant : $f_L \cong w_3 = 2p(50) = 314\dfrac{rad}{s}$

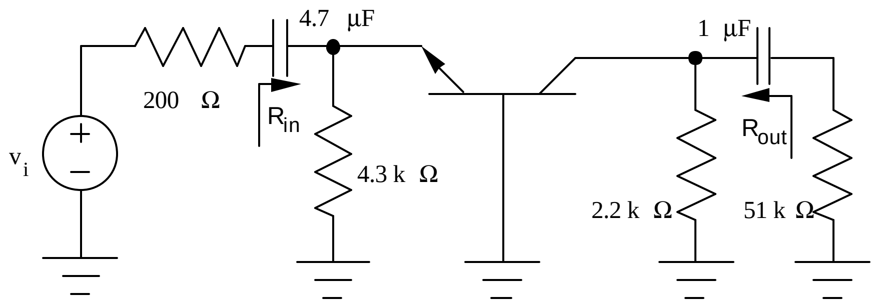
$$C_3 = \frac{1}{w_3\left(R_S \left\| \frac{1}{g_m}\right.\right)} = \frac{1}{314\left(13k\Omega \| 2.5k\Omega\right)} = 1.52\ mF \quad \text{where} \quad g_m = \frac{2I_D}{V_{GS}-V_{TN}} = \frac{0.4mA}{1V} = 0.4\,mS$$

Choose $C_3 = 1.5\ mF$ | $w_3 = \dfrac{1}{1.5\ mF\left(13k\Omega \| 2.5k\Omega\right)} = 318\dfrac{rad}{s}$ | $w_Z = \dfrac{1}{(1.5mF)(13k\Omega)} = 51.3\dfrac{rad}{s}$

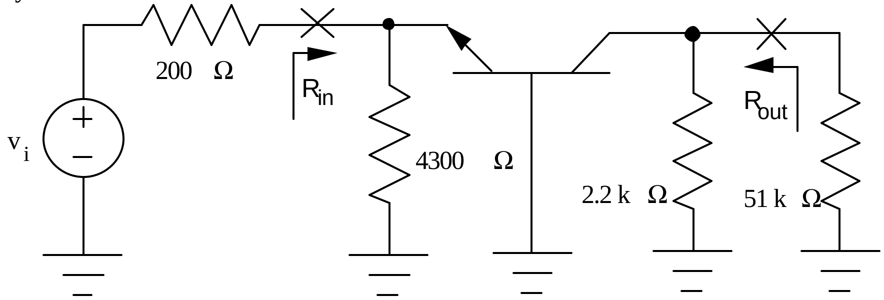
$w_1 = \dfrac{1}{\left(10^{-7}F\right)\left(243k\Omega + 5k\Omega\right)} = 40.3\dfrac{rad}{s}$ | $w_2 = \dfrac{1}{\left(10^{-7}F\right)\left(43k\Omega + 220k\Omega\right)} = 38.0\dfrac{rad}{s}$

Using Eq. (17.16) yields : $f_L \cong \dfrac{1}{2p}\sqrt{(40.3)^2 + (38.0)^2 + (318)^2 - 2(51.3)^2} = 50.1\ Hz$

17.12



Low frequency:



Mid-band:

$$(b)\ A_v(s) = A_{mid}\frac{s^2}{(s+w_1)(s+w_2)} \ \mid\ w_1 = \frac{1}{C_1\left(R_S + R_E \left\| \frac{1}{g_m}\right.\right)} \ \mid\ w_2 = \frac{1}{C_2(R_C + R_3)} \ \mid\ 2\ zeros\ at\ w = 0$$

$$(c)\ A_{mid} = \left(\frac{R_{in}}{R_I + R_{in}}\right)A_{vt} = \left(\frac{R_{in}}{R_I + R_{in}}\right)g_m R_L = \left(\frac{R_{in}}{R_I + R_{in}}\right)g_m\left(R_{out}\|R_3\right) \ \mid\ g_m = 40(1mA) = 0.04S$$

$$R_{in} = R_E \left\| \frac{1}{g_m}\right. = 24.9\Omega \ \mid\ R_L = R_{out}\|R_3 \ \mid\ R_{out} = R_C\|r_o = R_C = 2.2k\Omega$$

$$A_{mid} = \left(\frac{24.9\Omega}{200\Omega + 24.9\Omega}\right)(0.04)\left(2.2k\Omega\|51k\Omega\right) = +9.34 \rightarrow 19.4\ dB$$

$$w_1 = \frac{1}{4.7x10^{-6}(200+24.9)} = 946\frac{rad}{s} \ \mid\ w_2 = \frac{1}{10^{-6}(2.2k\Omega + 51k\Omega)} = 18.8\frac{rad}{s}$$

w_1 is dominant : $f_L \cong \frac{w_1}{2p} = 151\ Hz$

$$(d)\ g_m = 40(10mA) = 0.0004S \ \mid\ R_{in} = 2.49k\Omega \ \mid\ R_{out} = R_C\|r_o = R_C = 220k\Omega$$

$$A_{mid} = \left(\frac{2.49k\Omega}{200\Omega + 2.49k\Omega}\right)(0.0004)\left(220k\Omega\|510k\Omega\right) = +56.9 \rightarrow 35.1\ dB$$

$$w_1 = \frac{1}{4.7x10^{-6}(200+2.49k\Omega)} = 79.1\frac{rad}{s} \ \mid\ w_2 = \frac{1}{10^{-6}(220k\Omega + 510k\Omega)} = 1.37\frac{rad}{s}$$

w_1 is dominant : $f_L \cong \frac{w_1}{2p} = 12.6\ Hz$

17.13

(a) Assume w_1 is dominant : $w_L \cong w_1 = 2p(500Hz) = 3140\frac{rad}{s}$

$$C_1 = \frac{1}{w_1(R_I + R_{in})} \ \mid\ R_{in} = R_E\left\|\frac{1}{g_m}\right. \ \mid\ g_m = 40(1mA) = 0.04S \ \mid\ R_{in} = 4300\Omega\|25\Omega = 24.9\Omega$$

$$C_1 = \frac{1}{3.14x10^3(200+24.9)} = 1.42\ mF$$

(b) Choose $C_1 = 1.5\ m\mathrm{F}$ | $w_1 = \frac{1}{1.5x10^{-6}(200+24.9)} = 2960\frac{rad}{s}$

$$w_2 = \frac{1}{10^{-6}(2.2k\Omega + 51k\Omega)} = 18.8\frac{rad}{s} \ \mid\ w_1 \text{ is dominant } : f_L \cong \frac{w_1}{2p} = 472\ Hz$$

(c) Assume w_1 is dominant : $w_L \cong w_1 = 2p\,(500Hz) = 3140\dfrac{rad}{s}$

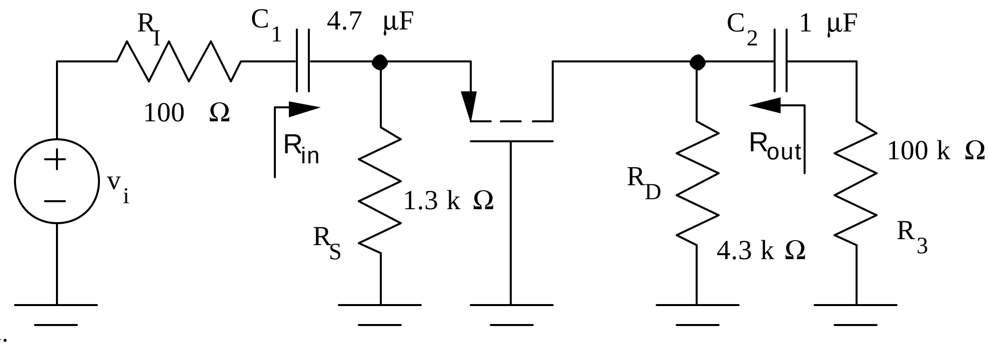
$$C_1 = \frac{1}{w_1(R_I + R_{in})} \quad | \quad R_{in} = R_E \left\| \frac{1}{g_m} \right. \quad | \quad g_m = 40(10mA) = 0.0004S \quad | \quad R_{in} = 430k\Omega \| 2500\Omega = 2.49k\Omega$$

$$C_1 = \frac{1}{3.14x10^3(200+2490)} = 0.118\ mF \quad | \quad \text{Choose } C_1 = 0.12\ m\text{F}$$

$$w_1 = \frac{1}{0.12x10^{-6}(200+2490)} = 2100\frac{rad}{s} \quad | \quad w_2 = \frac{1}{10^{-6}(2.2k\Omega + 51k\Omega)} = 18.8\frac{rad}{s}$$

w_1 is dominant : $f_L \cong \dfrac{w_1}{2p} = 493\ Hz$

17.14



Low Frequency:

$$(b)\ A_v(s) = A_{mid}\frac{s^2}{(s+w_1)(s+w_2)} \quad | \quad w_1 = \frac{1}{C_1\left(R_I + R_S \left\| \dfrac{1}{g_m}\right.\right)} \quad | \quad w_2 = \frac{1}{C_2(R_D + R_3)} \quad | \text{ 2 zeros at } w = 0$$

$$(c) A_{mid} = \left(\frac{R_{in}}{R_I + R_{in}}\right)A_{vt} = \left(\frac{R_{in}}{R_I + R_{in}}\right)g_m R_L = \left(\frac{R_{in}}{R_I + R_{in}}\right)g_m\left(R_{out}\|R_3\right) \quad | \quad g_m = 5mS$$

$$R_{in} = R_S \left\| \frac{1}{g_m} \right. = 173\Omega \quad | \quad R_L = R_{out}\|R_3 \quad | \quad R_{out} = R_D\|r_o = R_D = 4.3k\Omega \quad (\text{assuming } r_o = \infty)$$

$$A_{mid} = \left(\frac{173\Omega}{100\Omega + 173\Omega}\right)(0.005)(4.3k\Omega\|100k\Omega) = +13.1 \rightarrow 22.3\ dB$$

$$w_1 = \frac{1}{4.7x10^{-6}(100+173)} = 779\frac{rad}{s} \quad | \quad w_2 = \frac{1}{10^{-6}(4.3k\Omega + 100k\Omega)} = 9.59\frac{rad}{s}$$

w_1 is dominant : $f_L \cong \dfrac{w_1}{2p} = 124\ Hz$

17.15

$$(a)\ \text{Assume}\ \ w_1\ \ \text{is dominant}\ \ :\ w_L \cong w_1 = 2p(1000Hz) = 6280\frac{rad}{s}\quad |\quad C_1 = \frac{1}{w_1(R_I + R_{in})}$$

$$R_{in} = R_S \left\| \frac{1}{g_m} \right. = 1300\Omega \| 200\Omega = 173\Omega \quad | \quad C_1 = \frac{1}{6.28x10^3(100+173)} = 0.583\ mF$$

$$(b)\ \text{Choose}\ \ C_1 = 0.56\ m\text{F}\quad |\quad w_1 = \frac{1}{0.56x10^{-6}(100+173)} = 6540\frac{rad}{s}$$

$$w_2 = \frac{1}{10^{-6}(22k\Omega + 75k\Omega)} = 10.3\frac{rad}{s}\quad |\quad w_1\ \ \text{is dominant}\ \ :\ f_L \cong \frac{w_1}{2p} = 1040\ Hz$$

17.16

$$(a)\ g_m = 40I_C = 40(0.175mA) = 7.00mS\ |\ \text{r}_p = \frac{b_o}{g_m} = \frac{100}{7.00mS} = 14.3k\Omega\ |\ \text{r}_o = \infty\ (\text{V}_A\ \text{not given})$$

$$R_{in} = R_1 \| R_2 \| r_p = 100k\Omega \| 300k\Omega \| 14.3k\Omega = 12.0k\Omega \quad | \quad R_L = R_C \| R_3 = 43k\Omega \| 100k\Omega = 30.1k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} g_m R_L = \frac{12.0k\Omega}{1k\Omega + 12.0k\Omega}(7.00mS)(30.1k\Omega) = -194$$

$$\text{SCTC}:\ R_{1S} = R_I + R_{in} = 1k\Omega + 12.0k\Omega = 13.0k\Omega \quad | \quad R_{th} = R_1 \| R_2 \| R_I = 100k\Omega \| 300k\Omega \| 1k\Omega = 987\Omega$$

$$R_{2S} = R_E \left\| \frac{R_{th} + r_p}{b_o + 1} \right. = 15k\Omega \left\| \frac{987\Omega + 14.3k\Omega}{101} \right. = 150\Omega \quad | \quad R_{3S} = R_C + R_3 = 43k\Omega + 100k\Omega = 143k\Omega$$

$$f_L \cong \frac{1}{2p}\left[\frac{1}{2x10^{-6}(13.0k\Omega)} + \frac{1}{10x10^{-6}(150\Omega)} + \frac{1}{1x10^{-7}(143k\Omega)}\right] = \frac{(38.5 + 667 + 69.9)}{2p} = 123\ Hz$$

(b) Note that the Q-point assumed in part (a) is not quite correct.

SPICE yields: (144 μA, 3.67 V), A_{mid} = 43.9 dB, f_L = 91 Hz

$$(c)\ V_{EQ} = V_{CC}\frac{R_1}{R_1 + R_2} = 12\frac{100k\Omega}{100k\Omega + 300k\Omega} = 3V \quad | \quad R_{EQ} = R_1 \| R_2 = 100k\Omega \| 300k\Omega = 75.0k\Omega$$

$$I_C = b_F \frac{V_{EQ} - V_{BE}}{R_{EQ} + (b_F + 1)R_E} = 100\frac{3 - 0.7}{75k\Omega + (101)15k\Omega} = 145mA$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E = 12 - (0.145mA)(43k\Omega) - \frac{101}{100}(0.145mA)(15k\Omega) = 3.57\ V$$

These values agree with the SPICE results listed above in part (b).

17.17

(a) Use the values from Section 17.3.1, and assume w_3 is dominant.

$$w_L = 2p(1000Hz) = 6280\frac{rad}{s} \quad | \quad w_3 = w_L - w_1 - w_2 = 6280 - 225 + 96.1 = 5960\frac{rad}{s}$$

$$C_3 = \frac{1}{w_3 R_{3S}} = \frac{1}{5960(22.7\Omega)} = 7.39\ mF$$

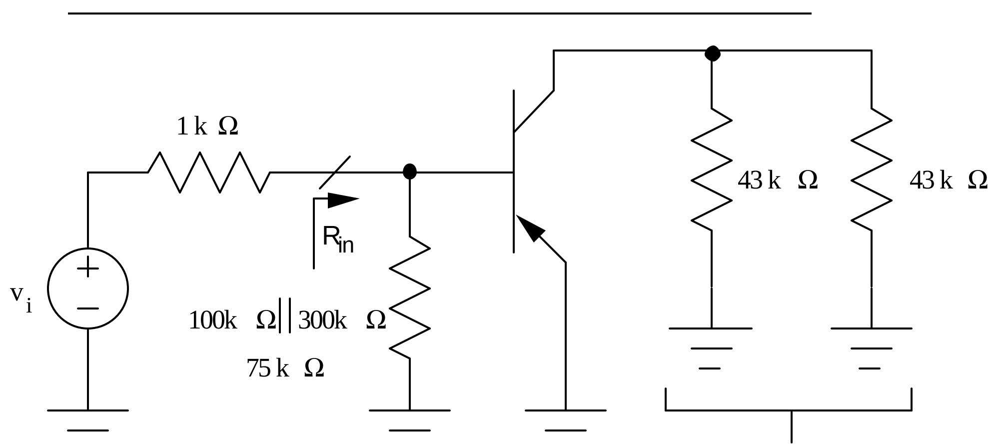
$$(b)\text{ Choose } C_3 = 6.8\ m\text{F} \quad | \quad w_3 = \frac{1}{6.8x10^{-6}(22.7\Omega)} = 6480\frac{rad}{s}$$

$$w_2 = 96.1\frac{rad}{s} \quad | \quad w_1 = 225\frac{rad}{s} \quad | \quad f_L \cong \frac{225 + 96.1 + 6480}{2p} = 1080\ Hz$$

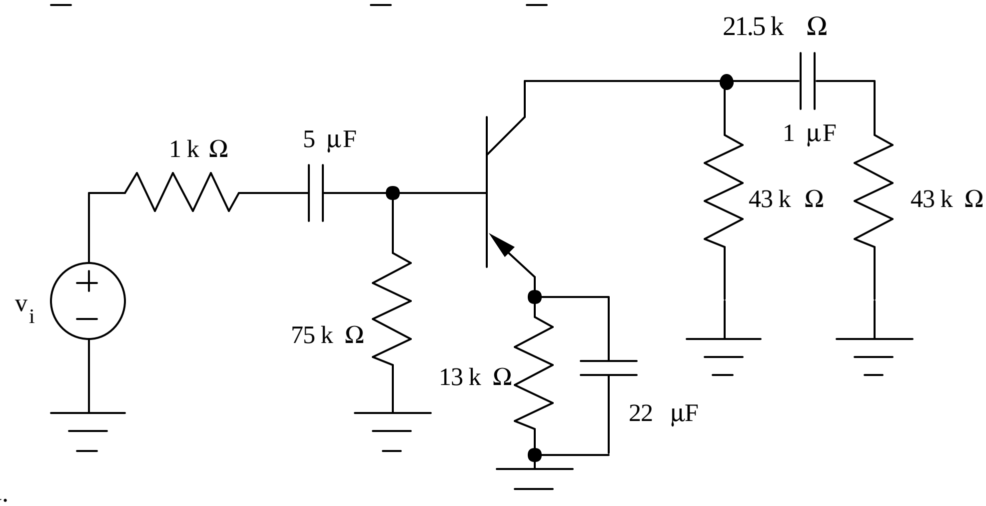
or if w_L must be no more than 1000 Hz, choose $C_3 = 8.2\ m\text{F}$

$$w_3 = \frac{1}{8.2x10^{-6}(22.7\Omega)} = 5370\frac{rad}{s} \quad | \quad f_L \cong \frac{225 + 96.1 + 5370}{2p} = 906\ Hz$$

17.18



Mid-band:



Low frequency:

$$(b)\ g_m = 40I_C = 40(0.164mA) = 6.56mS\ \mid\ r_p = \frac{b_o}{g_m} = \frac{100}{6.56mS} = 15.2k\Omega\ \mid\ r_o = \infty\ (V_A \text{ not given })$$

$$R_{in} = R_1 \| R_2 \| r_p = 100k\Omega \| 300k\Omega \| 15.2k\Omega = 12.6k\Omega\ \mid\ R_L = R_C \| R_3 = 43k\Omega \| 43k\Omega = 21.5k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} g_m R_L = \frac{12.6k\Omega}{1k\Omega + 12.6k\Omega}(6.56mS)(21.5k\Omega) = -131$$

$$\text{SCTC}:\ R_{1S} = R_I + R_{in} = 1k\Omega + 12.6k\Omega = 13.6k\Omega\ \mid\ R_{th} = R_1 \| R_2 \| R_I = 100k\Omega \| 300k\Omega \| 1k\Omega = 987\Omega$$

$$R_{2S} = R_E \left\| \frac{R_{th} + r_p}{b_o + 1} = 13k\Omega \right\| \frac{987\Omega + 15.2k\Omega}{101} = 158\Omega\ \mid\ R_{3S} = R_C + R_3 = 43k\Omega + 43k\Omega = 86k\Omega$$

$$f_L \cong \frac{1}{2p}\left[\frac{1}{5x10^{-6}(13.6k\Omega)} + \frac{1}{22x10^{-6}(158\Omega)} + \frac{1}{1x10^{-6}(86k\Omega)}\right] = \frac{(14.7 + 288 + 11.6)}{2p} = 50.0\ Hz$$

17.19 $R_S = 6.8\ k\Omega$

$$\text{SCTC}:\ R_{1S} = R_I + R_G = 1k\Omega + 1M\Omega = 1.00\,M\Omega\ \mid\ w_1 = \frac{1}{1.00M\Omega(0.1mF)} = 10.0\frac{rad}{s}$$

$$R_{2S} = R_S \left\| \frac{1}{g_m} = 6.8k\Omega \right\| \frac{1}{1.5mS} = 607\Omega\ \mid\ w_2 = \frac{1}{607\Omega(10mF)} = 165\frac{rad}{s}$$

$$R_{3S} = R_D + R_3 = 22k\Omega + 100k\Omega = 122k\Omega\ \mid\ w_3 = \frac{1}{122k\Omega(0.1mF)} = 82.0\frac{rad}{s}$$

$$f_L \cong \frac{(10.0 + 165 + 82.0)}{2p} = 40.9\ Hz$$

17.20 $R_S = 10\ k\Omega$

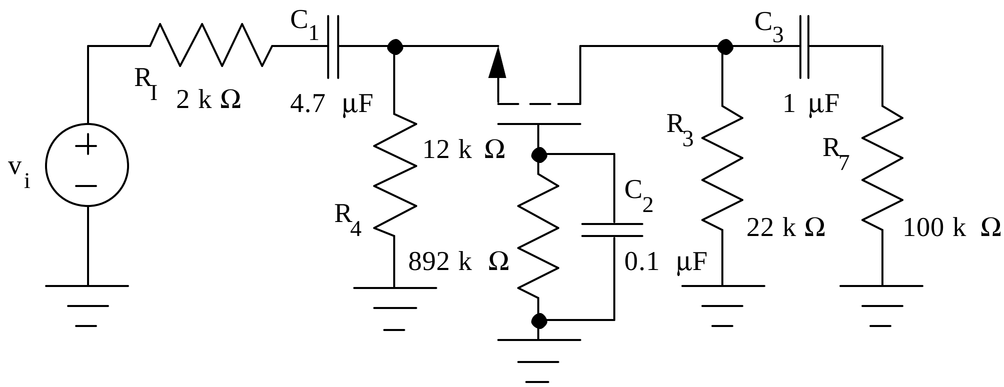
$$\text{SCTC}:\ R_{1S} = R_I + R_G = 1k\Omega + 500k\Omega = 501k\Omega\ \mid\ w_1 = \frac{1}{501k\Omega(0.1mF)} = 20.0\frac{rad}{s}$$

$$R_{2S} = R_S \left\| \frac{1}{g_m} = 10k\Omega \right\| \frac{1}{0.75mS} = 1.18k\Omega\ \mid\ w_2 = \frac{1}{1.18k\Omega(10mF)} = 84.8\frac{rad}{s}$$

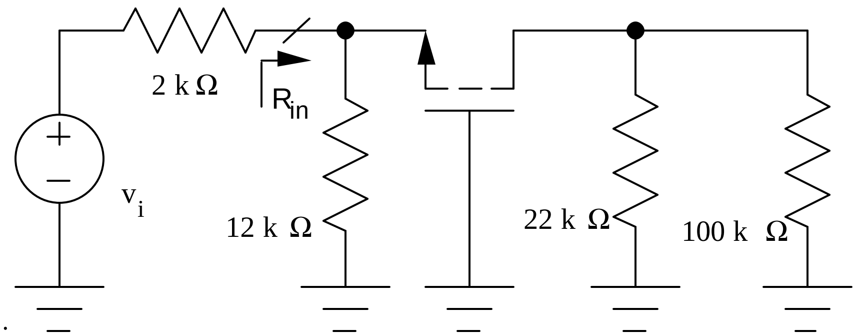
$$R_{3S} = R_D + R_3 = 43k\Omega + 100k\Omega = 143k\Omega\ \mid\ w_3 = \frac{1}{143k\Omega(0.1mF)} = 69.9\frac{rad}{s}$$

$$f_L \cong \frac{(20.0 + 84.8 + 69.9)}{2p} = 27.8\ Hz$$

17.21



Low Frequency:



Mid-band:

$$g_m = \frac{2(0.1mA)}{1V} = 0.200mS \quad | \quad \frac{1}{g_m} = 5000\Omega$$

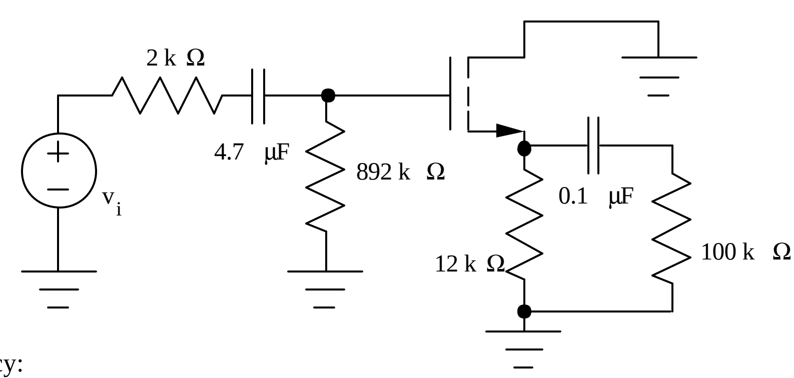
$$R_{in} = R_S \| \frac{1}{g_m} = 12k\Omega \| 5k\Omega = 3.53k\Omega \quad | \quad R_L = 22k\Omega \| 100k\Omega = 18.0k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} g_m R_L = \frac{3.53k\Omega}{2k\Omega + 3.53k\Omega}(0.200mS)(18\text{k}\Omega) = 2.30 \ (7.24\text{dB})$$

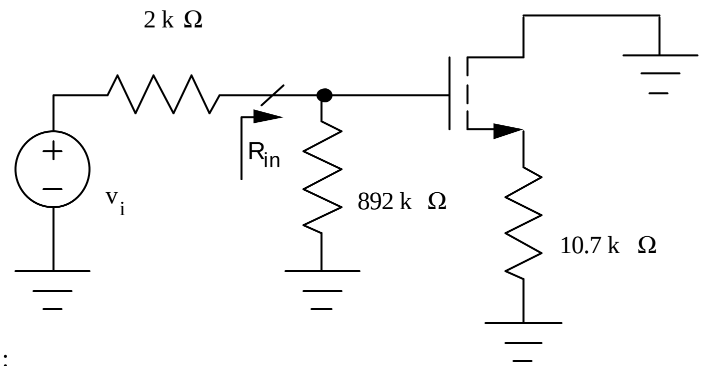
$$w_1 = \frac{1}{C_1(R_I + R_{in})} = \frac{1}{4.7x10^{-6}(2k\Omega + 3.53k\Omega)} = 38.5\frac{rad}{s} \quad | \quad w_2 = \text{doesn't matter since } \ i_g = 0!$$

$$w_3 = \frac{1}{C_3(R_3 + R_7)} = \frac{1}{10^{-7}(100k\Omega + 22k\Omega)} = 82.0\frac{rad}{s} \quad | \quad f_L \cong \frac{1}{2p}(38.5 + 82.0) = 19.2Hz$$

17.22



Low Frequency:



Mid-band:

$$g_m = \frac{2(0.1mA)}{0.75V} = 0.267mS \quad | \quad R_{in} = R_1 \| R_2 = 892k\Omega \quad | \quad R_L = 12k\Omega \| 100k\Omega = 10.7k\Omega$$

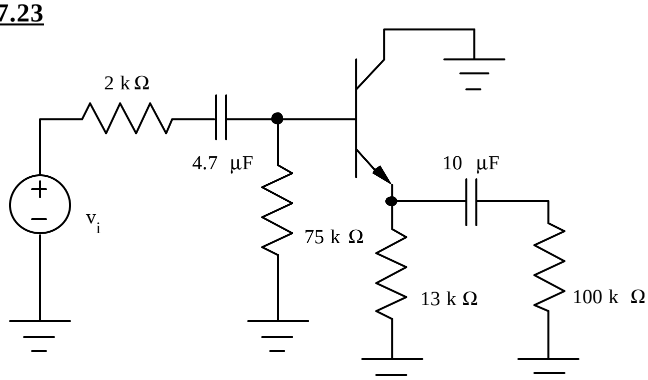
$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} \frac{g_m R_L}{1 + g_m R_L} = 0.998 \frac{(0.267mS)(10.7k\Omega)}{1 + (0.267mS)(10.7k\Omega)} = +0.739 \quad (-2.62\ dB)$$

$$w_1 = \frac{1}{C_1(R_I + R_{in})} = \frac{1}{4.7x10^{-6}(2k\Omega + 892k\Omega)} = 0.238\frac{rad}{s}$$

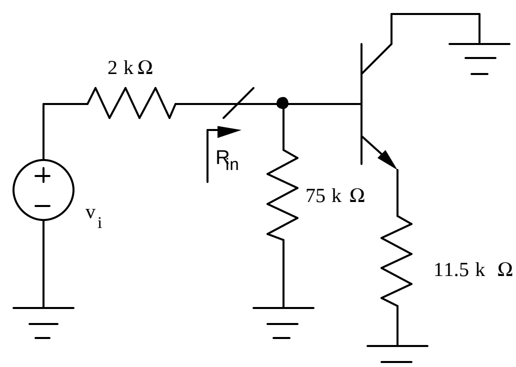
$$w_3 = \frac{1}{C_3\left[R_7 + \left(R_S \left\| \frac{1}{g_m}\right.\right)\right]} = \frac{1}{10^{-7}\left[100k\Omega + \left(12k\Omega \left\| \frac{1}{0.267mS}\right.\right)\right]} = 97.2\frac{rad}{s}$$

$$f_L \cong \frac{1}{2p}(0.238 + 97.2) = 15.5\ Hz$$

17.23



Low frequency



Mid-band

$$(b)\ R_{in} = R_1 \| R_2 \| r_p + (b_o + 1)R_L \quad | \quad R_L = 13k\Omega \| 100k\Omega = 11.5k\Omega \quad | \quad r_p = \frac{100}{40(0.25mA)} = 10.0k\Omega$$

$$R_{in} = R_1 \| R_2 \| \left[r_p + (b_o + 1)R_L \right] = 100k\Omega \| 300k\Omega \| \left[10.0k\Omega + (101)11.5k\Omega \right] = 70.5k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} \frac{(b_o + 1)R_L}{R_{in}} = 0.972 \frac{101(11.5k\Omega)}{\left[2 + 10.0 + 101(11.5) \right] k\Omega} = 0.963 \quad | \quad R_B = R_1 \| R_2 = 75k\Omega$$

$$R_{1S} = R_I + R_B \| \left[r_p + (b_o + 1)R_L \right] = 2k\Omega + 75k\Omega \| \left[10.0k\Omega + (101)11.5k\Omega \right] = 72.5k\Omega$$

$$w_1 = \frac{1}{(72.5k\Omega)4.7x10^{-6}} = 2.94 \frac{rad}{s}$$

$$R_{3S} = R_7 + R_E \left\| \frac{R_B \| R_I + r_p}{(b_o + 1)} \right. = 100k\Omega + 13k\Omega \left\| \frac{1.95k\Omega + 10.0k\Omega}{101} \right. = 100k\Omega$$

$$w_3 = \frac{1}{10^{-5}(10^5)} = 1 \frac{rad}{s} \qquad f_L \cong \frac{(2.94 + 1)}{2p} = 0.627Hz$$

17.24

$$\text{SCTC requires : } w_L \cong \sum_{i=1}^{3} \frac{1}{R_{is} C_i} = 2p(500) = 3140 \frac{rad}{s}$$

$$w_1 = \frac{1}{(10^{-7}F)(2.43M\Omega + 1k\Omega)} = 4.11 \frac{rad}{s} \quad | \quad w_2 = \frac{1}{(10^{-7}F)(43k\Omega + 1M\Omega)} = 9.59 \frac{rad}{s}$$

$$w_1 + w_2 << w_L \quad | \quad w_3 \text{ will be dominant } \quad \rightarrow w_3 \cong w_L$$

$$w_3 = \frac{1}{C_3 \left(R_S \left\| \frac{1}{g_m} \right. \right)} \quad | \quad g_m = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{2(0.2mA)}{1V} = 0.400mS \quad | \quad \frac{1}{g_m} = 2.50k\Omega$$

$$C_3 = \frac{1}{3140(13k\Omega \| 2.5k\Omega)} = 0.152\ mF \rightarrow 0.15\ mF \text{ from Appendix C}$$

17.25

$$\text{SCTC requires : } w_L \cong \sum_{i=1}^{3} \frac{1}{R_{is}C_i} = 2p\,(100) = 628\frac{rad}{s}$$

$$w_2 = \frac{1}{C_2(R_C + R_3)} = \frac{1}{(10^{-6}F)(2.2k\Omega + 51k\Omega)} = 18.8\frac{rad}{s} << w_L \quad | \quad w_1 \text{ will be dominant} \quad \rightarrow w_L \cong w_1$$

$$w_1 = \frac{1}{C_1\left(R_I + R_E \left\| \frac{1}{g_m}\right.\right)} \quad | \quad \frac{1}{g_m} = \frac{1}{40(10^{-3})} = 25\Omega$$

$$C_1 = \frac{1}{628(200\Omega + 4.3k\Omega \| 25\Omega)} = 7.08\ mF \rightarrow 6.8\ mF \text{ nearest value in Appendix C}$$

Note : We might want to choose 8.2 mF to insure that $f_L \leq 100\ Hz$.

$$(b)\ \text{SCTC requires : } w_L \cong \sum_{i=1}^{3} \frac{1}{R_{is}C_i} = 2p\,(100) = 628\frac{rad}{s}$$

$$w_2 = \frac{1}{(10^{-6}F)(220k\Omega + 510k\Omega)} = 1.37\frac{rad}{s} \quad | \quad w_1 \text{ will be dominant} \quad \rightarrow w_L \cong w_1$$

$$w_1 = \frac{1}{C_1\left(R_I + R_E \left\| \frac{1}{g_m}\right.\right)} \quad | \quad \frac{1}{g_m} = \frac{1}{40(10^{-5})} = 2.5k\Omega$$

$$C_1 = \frac{1}{628(200\Omega + 430k\Omega \| 2.5k\Omega)} = 0.592\ mF \rightarrow 0.56\ mF \text{ nearest value in Appendix C}$$

Note : We might want to use 0.68 mF to insure that $f_L \leq 100\ Hz$.

17.26

$$g_m = 40I_C = 40(0.164mA) = 6.56mS \quad | \quad r_p = \frac{b_o}{g_m} = \frac{100}{6.56mS} = 15.2k\Omega \quad | \quad r_o = \infty \ (V_A \text{ not given})$$

$$\text{SCTC requires : } \sum_{i=1}^{3} \frac{1}{R_{is}C_i} = 2p\,(20) = 126\frac{rad}{s}$$

$$R_{1S} = R_I + (R_B \| r_p) = 1k\Omega + (75k\Omega \| 15.2k\Omega) = 13.6k\Omega \quad | \quad w_1 = \frac{1}{5x10^{-6}(13.6k\Omega)} = 14.7$$

$$R_{3S} = R_C + R_3 = 43k\Omega + 43k\Omega = 86k\Omega \quad | \quad w_3 = \frac{1}{1x10^{-6}(86k\Omega)} = 11.6$$

$$w_2 = 126 - 14.7 - 11.6 = 99.7\frac{rad}{s} \quad | \quad R_{2S} = R_E \left\| \frac{(R_B \| R_I) + r_p}{b_o + 1} \right. = 13k\Omega \left\| \frac{987\Omega + 15.2k\Omega}{101} \right. = 158\Omega$$

$$C_2 \cong \frac{1}{99.7(158)} = 63.5\ mF \rightarrow 68\ mF \text{ from Appendix C}$$

17.27

SCTC requires : $\sum_{i=1}^{3} \frac{1}{R_{is}C_i} = 2p(1) = 6.28\frac{rad}{s}$

However, $R_{3S} = R_3 + R_7 = 22k\Omega + 100k\Omega = 122k\Omega$

$w_3 = \frac{1}{1x10^{-7}(122k\Omega)} = 82.0\frac{rad}{s} > 6.28\frac{rad}{s}$ | The design goal cannot be met.

It is not possible to force f_L below the limit set by C_3.

17.28

SCTC requires : $w_L \cong \sum_{i=1}^{3} \frac{1}{R_{is}C_i} = 2p(10) = 62.8\frac{rad}{s}$ | $R_G = R_1 \| R_2 = 892k\Omega$

$w_1 = \frac{1}{C_1(R_I + R_G)} = \frac{1}{4.7x10^{-6}(2k\Omega + 892k\Omega)} = 0.238\frac{rad}{s}$ | $w_L >> w_1 \rightarrow w_3$ is dominant

$w_L \cong w_3 = \frac{1}{C_3\left[R_7 + \left(R_S \left\| \frac{1}{g_m}\right.\right)\right]}$ | $\frac{1}{g_m} = \frac{0.75V}{2(0.1mA)} = 3.75k\Omega$

$C_3 = \frac{1}{62.8[100k\Omega + (12k\Omega \| 3.75k\Omega)]} = 0.155\frac{rad}{s} \rightarrow 0.15\ mF$ using Appendix C

17.29

SCTC requires : $w_L \cong \sum_{i=1}^{3} \frac{1}{R_{is}C_i} = 2p(5) = 31.4\frac{rad}{s}$

$R_L = 13k\Omega \| 100k\Omega = 11.5k\Omega$ | $r_p = \frac{100}{40(0.25mA)} = 10.0k\Omega$

$R_{1S} = R_I + R_B \| [r_p + (b_o + 1)R_L] = 2k\Omega + 75k\Omega \| [10.0k\Omega + (101)11.5k\Omega] = 72.5k\Omega$

$w_1 = \frac{1}{(72.5k\Omega)4.7x10^{-6}} = 2.94\frac{rad}{s}$ | $w_3 = 31.4 - 2.94 = 28.5\frac{rad}{s}$

$R_{3S} = R_7 + R_E \left\| \frac{(R_B \| R_I) + r_p}{(b_o + 1)} \right. = 100k\Omega + 13k\Omega \left\| \frac{1.95k\Omega + 10.0k\Omega}{101} \right. = 100k\Omega$

$C_3 = \frac{1}{28.5(100k\Omega)} = 0.351\ mF \rightarrow 0.39\ mF$ using the values from Appendix C.

17.30

$$f_T = \frac{1}{2p}\left(\frac{g_m}{C_p + C_m}\right) \quad | \quad C_p = \frac{g_m}{2pf_T} - C_m \quad | \quad g_m = 40I_C$$

I_C	f_T	C_π	C_μ	$1/2\pi r_x C_\mu$
10 μA	50 MHz	**0.733 pF**	0.5 pF	**1.27 GHz**
100 μA	300 MHz	0.75 pF	**1.37 pF**	**465 MHz**
50 μA	1 GHz	**2.93 pF**	0.25 pF	**2.55 GHz**
10 mA	**6.12 GHz**	10 pF	**0.400 pF**	1.59 GHz
1 μA	**3.18 MHz**	1 pF	1 pF	**636 MHz**
1.18 mA	5 GHz	1 pF	0.5 pF	**1.27 GHz**

17.31

$$C_p = g_m t_F \quad | \quad C_p = \frac{g_m}{w_T} - C_m \quad | \quad V_{CB} = 5 - 0.7 = 4.3V \quad | \quad C_m = \frac{C_{mo}}{\sqrt{1 + \frac{V_{CB}}{f_{jc}}}} = \frac{2pF}{\sqrt{1 + \frac{4.3V}{0.9V}}} = 0.832\,pF$$

$$C_p = \frac{40\left(2x10^{-3}\right)}{2p\left(5x10^{8}\right)} - 0.832\,pF = 24.6\ pF \quad | \quad t_F = \frac{C_p}{g_m} = \frac{24.6x10^{-12}}{40\left(2x10^{-3}\right)} = 0.308ns = 308\ ps$$

17.32

$$f_T = \frac{1}{2p}\left(\frac{g_m}{C_{GS} + C_{GD}}\right) \quad | \quad g_m = \sqrt{2K_n I_D}$$

I_D	f_T	C_{GS}	C_{GD}
10 μA	**11.3 MHz**	1.5 pF	0.5 pF
250 μA	**56.3 MHz**	1.5 pF	0.5 pF
4.93 mA	250 MHz	1.5 pF	0.5 pF

17.33

$$(a)\ f_T = \frac{3}{2}\frac{m_n\left(V_{GS} - V_{TN}\right)}{L^2} = \frac{3}{2}\frac{600(0.25V)}{\left(10^{-4}\right)^2}\frac{cm^2}{V - s} = 22.5\ GHz$$

$$(b)\ f_T = \frac{3}{2}\frac{m_n\left(V_{GS} - V_{TN}\right)}{L^2} = \frac{3}{2}\frac{250(0.25V)}{\left(10^{-4}\right)^2}\frac{cm^2}{V - s} = 9.38\ GHz$$

$$(c)\ \text{NMOS}: f_T = \frac{3}{2}\frac{m_n\left(V_{GS} - V_{TN}\right)}{L^2} = \frac{3}{2}\frac{600(0.25V)}{\left(10^{-5}\right)^2}\frac{cm^2}{V - s} = 2.25\ THz$$

$$\text{PMOS}: f_T = \frac{3}{2}\frac{m_n\left(V_{GS} - V_{TN}\right)}{L^2} = \frac{3}{2}\frac{250(0.25V)}{\left(10^{-5}\right)^2}\frac{cm^2}{V - s} = 938\ GHz$$

17.34

$$(a)\ r_p = \frac{100(0.025V)}{1mA} = 2.5k\Omega \ \ | \ \ R_{in} = 7.5k\Omega \| (r_x + r_p) = 2.01k\Omega \ | \ R_L = 4.3k\Omega \| 100k\Omega = 4.12k\Omega$$

$$g_m = 40(10^{-3}) = 40mS \ \ | \ \ A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\left(\frac{2.01k\Omega}{1k\Omega + 2.01k\Omega}\right)(40mS)(4.12k\Omega) = -110$$

$$(b)\ R_{in} = 7.5k\Omega \| r_p = 1.88k\Omega \ \ | \ \ A_{mid} = -\left(\frac{1.88k\Omega}{1k\Omega + 1.88k\Omega}\right)(40mS)(4.12k\Omega) = -108$$

17.35

$$r_p = \frac{100(0.025V)}{0.1mA} = 25k\Omega \ \ | \ \ g_m = 40(0.1mA) = 4mS$$

$$R_{in} = R_E \| \frac{r_x + r_p}{b_o + 1} = 43k\Omega \| \frac{250\Omega + 25k\Omega}{101} = 249\Omega \ \ | \ R_L = 22k\Omega \| 75k\Omega = 17.0k\Omega$$

$$(a)\ A_{mid} = \frac{R_{in}}{R_I + R_{in}} g_m R_L = \frac{249\Omega}{100\Omega + 249\Omega}(4mS)(17.0k\Omega) = 48.5$$

$$(b)\ R_{in} = R_E \| \frac{r_p}{b_o + 1} = 43k\Omega \| \frac{25k\Omega}{101} = 248\Omega \ \ | \ \ A_{mid} = \frac{248\Omega}{100\Omega + 248\Omega}(4mS)(17.0k\Omega) = 48.5$$

17.36

$$r_p = \frac{100(0.025V)}{1mA} = 2.5k\Omega \ \ | \ \ g_m = 40(1mA) = 40mS \ \ | \ R_L = 3k\Omega \| 47k\Omega = 2.82k\Omega$$

$$R_{in} = R_B \| \left[r_x + r_p + (b_o + 1)R_L\right] = 100k\Omega \| \left[0.25k\Omega + 2.5k\Omega + (101)2.82k\Omega\right] = 74.2k\Omega$$

$$(a)\ A_{mid} = A_{mid} = \frac{R_{in}}{R_I + R_{in}}\left[\frac{(b_o + 1)R_L}{r_x + r_p + (b_o + 1)R_L}\right] = \frac{74.2k\Omega}{1k\Omega + 74.2k\Omega}\left[\frac{101(2820)}{250 + 2500 + 101(2820)}\right] = 0.977$$

$$(b)\ R_{in} = R_B \| \left[r_p + (b_o + 1)R_L\right] = 100k\Omega \| \left[2.5k\Omega + (101)2.82k\Omega\right] = 74.2k\Omega$$

$$A_{mid} = \frac{74.2k\Omega}{1k\Omega + 74.2k\Omega}\left[\frac{101(2820)}{250 + 2500 + 101(2820)}\right] = 0.977$$

17.37

$$(a)\ s^2 + 5100s + 500000 \ \ | \ \ s_1 \cong -\frac{5100}{1} = -5100 \ \ | \ \ s_2 \cong -\frac{5x10^5}{5100} = -98.0$$

$$s = \frac{-5100 \pm \sqrt{5100^2 - 4(5x10^5)}}{2} = \frac{-5100 \pm 4900}{2} \rightarrow -100,\ -5000 \ \ | \ \ 2\% \text{ error}$$

$$(b)\ 2s^2 + 700s + 30000 = 2(s^2 + 350s + 15000)$$

$$s_1 \cong -\frac{350}{1} = -350 \ \ | \ \ s_2 \cong -\frac{15000}{350} = -42.9$$

$$s = \frac{-350 \pm \sqrt{350^2 - 4(15000)}}{2} = \frac{-350 \pm 250}{2} \rightarrow -50,\ -300 \ \ | \ \ 14\% \text{ error}$$

$$(c)\ 3s^2 + 3300s + 300000 \quad | \quad s_1 \cong -\frac{3300}{3} = -1100 \quad | \quad s_2 \cong -\frac{3x10^5}{3300} = -90.9$$

$$s = \frac{-3300 \pm \sqrt{3300^2 - 4(3)\left(3x10^5\right)}}{6} = \frac{-3300 \pm 2700}{6} \rightarrow -100,\ -1000 \quad | \quad 11\%\text{ error}$$

$$(d)\ 0.5s^2 + 300s + 40000 = 0.5\left(s^2 + 600s + 80000\right)$$

$$s_1 \cong -\frac{600}{1} = -600 \quad | \quad s_2 \cong -\frac{80000}{600} = -133$$

$$s = \frac{-600 \pm \sqrt{600^2 - 4(80000)}}{2} = \frac{-600 \pm 200}{2} \rightarrow -200,\ -400 \quad | \quad 34\%,\ 50\%\text{ error}$$

17.38

$$s^3 + 1110s^2 + 111000s + 1000000$$

$$s_1 \cong -\frac{1110}{1} = -1110 \quad | \quad s_2 \cong -\frac{111000}{1110} = -100 \quad | \quad s_3 \cong -\frac{1000000}{111000} = -9.01$$

Factoring the polynomial : $s^3 + 1110s^2 + 111000s + 1000000 = (s+10)(s+100)(s+1000)$

$s = -1000,\ -100,\ -10$ | 11% error in s_1 , 10% error in s_3

In MATLAB: roots([1 1110 111000 1000000])

17.39

$$f(s) = s^6 + 138s^5 + 4263s^4 + 4760s^3 + 235550s^2 + 94000s + 300000$$

$$f'(s) = 6s^5 + 690s^4 + 17052s^3 + 14280s^2 + 471100s + 94000$$

$$s^{i+1} = s^i - \frac{f\left(s^i\right)}{f'\left(s^i\right)}$$ | Using a spreadsheet, two real roots are found : - 46.7962, - 91.8478

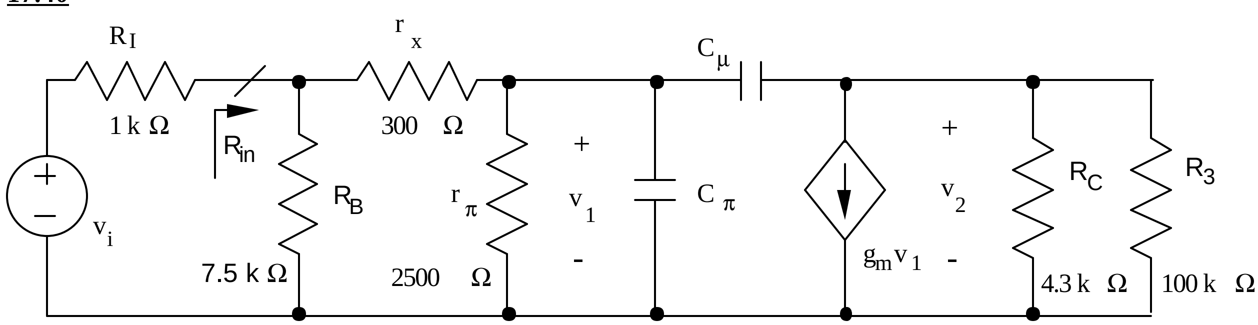
Using MATLAB: roots([1 138 4263 4760 235550 94000 300000])

ans = -91.8478, -46.7962, 0.5189 + 7.2789i, 0.5189 - 7.2789i, -0.1970 + 1.1278i, -0.1970 - 1.1278i

A better polynomial : $f(s) = s^6 + 142s^5 + 4757s^4 + 58230s^3 + 256950s^2 + 398000s + 300000$

Roots: -100, -20, -15, -5, -1+i, -1-i

17.40



$$(a)\ r_p = \frac{100(0.025)}{0.001} = 2500\Omega \quad | \quad C_m = 0.75\ pF \quad | \quad C_p = \frac{40\left(10^{-3}\right)}{2p\left(5x10^{8}\right)} - 0.75\,pF = 12.0\ pF$$

$$R_{in} = 7.5k\Omega \| (r_x + r_p) = 2.03k\Omega \quad | \quad R_L = 4.3k\Omega \| 100k\Omega = 4.12k\Omega$$

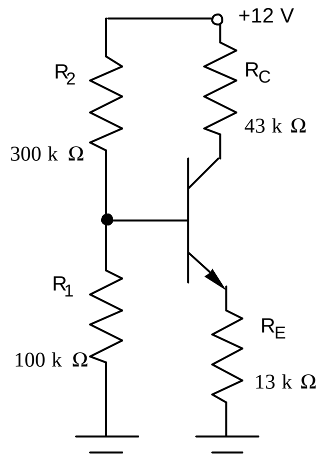
$$g_m = 40\left(10^{-3}\right) = 40mS \quad | \quad A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\left(\frac{2.03k\Omega}{1k\Omega + 2.03k\Omega}\right)(40mS)(4.12k\Omega) = -110$$

$$w_H = \frac{1}{r_{po}C_T} \quad | \quad r_{po} = r_p \| \left[r_x + \left(R_B \| R_I\right)\right] = 2500 \| \left[300 + (7500 \| 1000)\right] = 803\ \Omega$$

$$C_T = 12.0 + 0.75\left[1 + 40\left(10^{-3}\right)(4120) + \frac{4120}{803}\right] = 140\,pF \quad | \quad f_H = \frac{1}{2p\,(803)\left(1.4x10^{-10}\right)} = 1.42\ MHz$$

$$(b)\ GBW = 110(1.42MHz) = 142\ MHz \quad | \quad GBW \le \frac{1}{2p}\left(\frac{1}{r_x C_m}\right) = \frac{1}{2p\,(300\Omega)(0.75\,pF)} = 707\ MHz$$

17.41



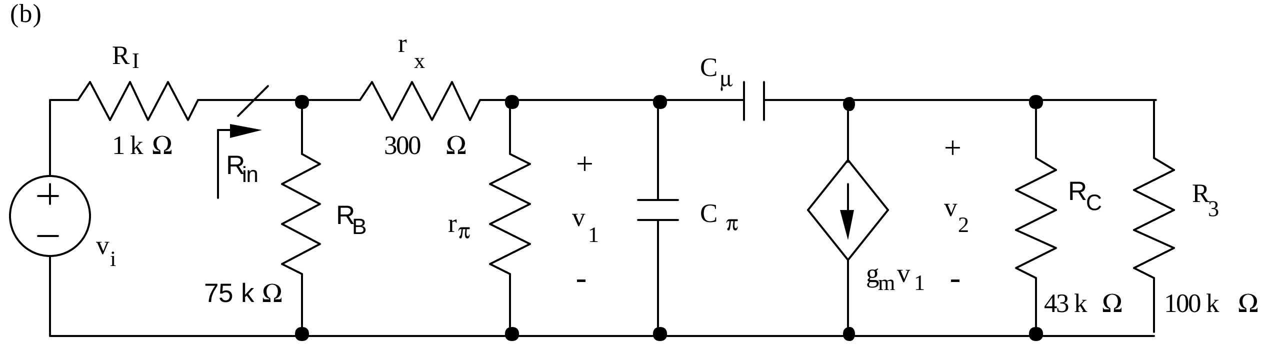
$$V_{EQ} = 12V\frac{100k\Omega}{100k\Omega + 300k\Omega} = 3V \quad | \quad R_{EQ} = 100k\Omega \| 300k\Omega = 75k\Omega$$

$$I_C = b_F I_B = b_F \frac{V_{EQ} - V_{BE}}{R_{EQ} + (b_F + 1)R_E} = 100\frac{(3 - 0.7)V}{75k\Omega + (101)13k\Omega} = 166\ mA$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E = 12 - (166mA)\left(43k\Omega + \frac{101}{100}13k\Omega\right) = 2.68\ V$$

$$\text{Q - Point}: \ (166\ mA,\ 2.68\ V)$$

(b)



Note: As designers, we are free to change the amplifier design, but we typically cannot change the characteristics of the source and load resistances.

$$r_\pi = \frac{100(0.025)}{0.166mA} = 15.1k\Omega \quad | \quad C_\mu = 0.75\ pF \quad | \quad C_\pi = \frac{40\left(0.166x10^{-3}\right)}{2\pi\left(5x10^{8}\right)} - 0.75pF = 1.36\ pF$$

$$R_{in} = 75k\Omega \| (r_x + r_\pi) = 12.8k\Omega \ | \ R_L = 43k\Omega \| 100k\Omega = 30.1k\Omega$$

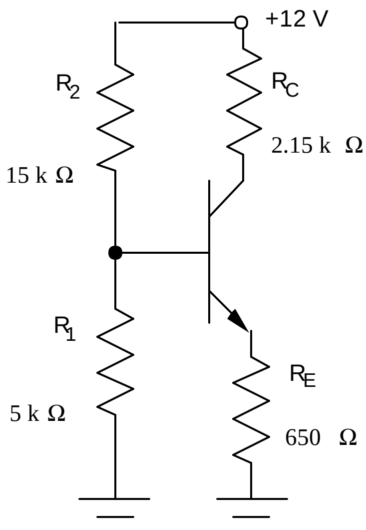
$$g_m = 40\left(0.166x10^{-3}\right) = 6.64mS \quad | \quad A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\left(\frac{12.8k\Omega}{1k\Omega + 12.8k\Omega}\right)(6.64mS)(30.1k\Omega) = -185$$

$$\omega_H = \frac{1}{r_{\pi o} C_T} \quad | \quad r_{\pi o} = r_\pi \| \left[r_x + \left(R_B \| R_I\right)\right] = 15.1k\Omega \| \left[300 + \left(75k\Omega \| 1k\Omega\right)\right] = 1.19k\Omega$$

$$C_T = 1.36 + 0.75\left[1 + (6.64mS)(30.1k\Omega) + \frac{30.1k\Omega}{1.19k\Omega}\right] = 171pF \quad | \quad f_H = \frac{1}{2\pi(1190)\left(1.71x10^{-10}\right)} = 0.782\ MHz$$

$$(c)\ GBW = 185(0.782MHz) = 145\ MHz \quad | \quad GBW \le \frac{1}{2\pi}\left(\frac{1}{r_x C_\mu}\right) = \frac{1}{2\pi(300\Omega)(0.75pF)} = 707\ MHz$$

17.42 (a)

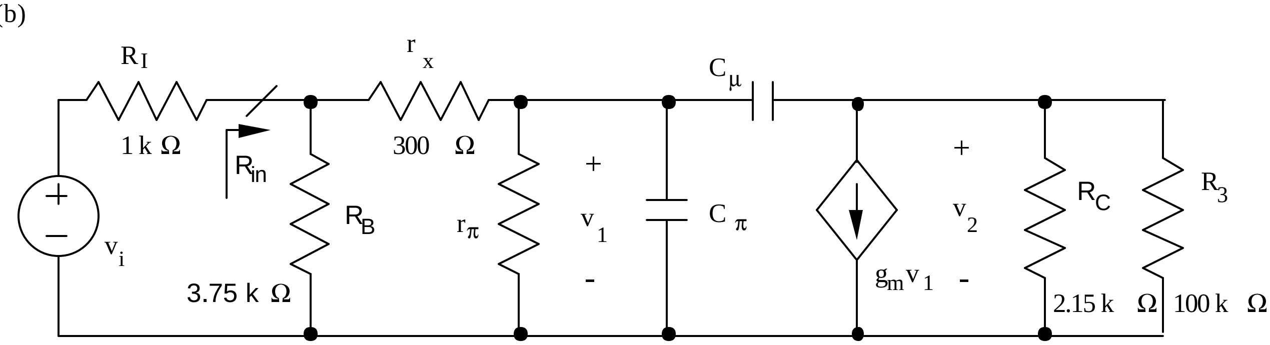


$$V_{EQ} = 12V \frac{5k\Omega}{5k\Omega + 15k\Omega} = 3V \quad | \quad R_{EQ} = 5k\Omega \| 15k\Omega = 3.75k\Omega$$

$$I_C = \beta_F I_B = \beta_F \frac{V_{EQ} - V_{BE}}{R_{EQ} + (\beta_F + 1)R_E} = 100 \frac{(3 - 0.7)V}{3.75k\Omega + (101)(0.65k\Omega)} = 3.31\ mA$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E = 12 - (3.31mA)\left(2.15k\Omega + \frac{101}{100}0.65k\Omega\right) = 2.71\ V \quad | \quad \text{Q-Point}: \ (3.31\ mA,\ 2.71\ V)$$

(b)



Note: As designers, we are free to change the amplifier design, but we typically cannot change the characteristics of the source and load resistances.

$$r_p = \frac{100(0.025)}{3.31mA} = 755\Omega \ \ | \ \ C_m = 0.75\ pF \ \ | \ \ C_p = \frac{40\left(3.31x10^{-3}\right)}{2p\left(5x10^{8}\right)} - 0.75pF = 41.4\ pF$$

$$R_{in} = 3.75k\Omega \| (r_x + r_p) = 823\Omega \ \ | \ \ R_L = 2.15k\Omega \| 100k\Omega = 2.11k\Omega$$

$$g_m = 40\left(3.31x10^{-3}\right) = 132mS \ \ | \ \ A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\left(\frac{823\Omega}{1000\Omega + 823\Omega}\right)(132mS)(2.11k\Omega) = -126$$

$$w_H = \frac{1}{r_{po}C_T} \ \ | \ \ r_{po} = r_p \| \left[r_x + (R_B \| R_I)\right] = 755\Omega \| \left[300 + (3.75k\Omega \| 1k\Omega)\right] = 260\Omega$$

$$C_T = 41.4 + 0.75\left[1 + (132mS)(2.11k\Omega) + \frac{2.11k\Omega}{0.260k\Omega}\right] = 312pF \ \ | \ \ f_H = \frac{1}{2p(260\Omega)\left(3.12x10^{-10}F\right)} = 1.96\ MHz$$

$$(c)\ GBW = 126(1.96MHz) = 247\ MHz \ \ | \ \ GBW \le \frac{1}{2p}\left(\frac{1}{r_x C_m}\right) = \frac{1}{2p(300\Omega)(0.75pF)} = 707\ MHz$$

17.43

$$R_{in} = R_1 \| R_2 = 4.3M\Omega \| 5.6M\Omega = 2.43M\Omega \ \ | \ \ R_L = 43k\Omega \| 1M\Omega = 41.2k\Omega$$

$$g_m = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{2(0.2mA)}{1} = 0.400mS \ \ |$$

$$A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\frac{2.43M\Omega}{1k\Omega + 2.43M\Omega} 0.400mS(41.2k\Omega) = -16.5$$

$$f_H = \frac{1}{2pr_{po}C_T} \ \ | \ \ r_{po} = R_1 \| R_2 \| R_I = 1.00k\Omega$$

$$C_T = 2.5pF + 2.5pF\left[1 + (0.400mS)(41.2k\Omega) + \frac{41.2k\Omega}{1k\Omega}\right] = 149pF$$

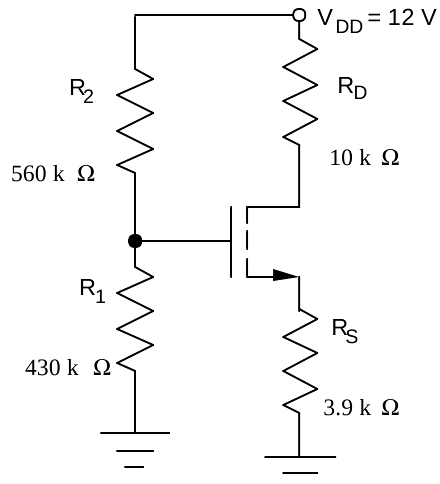
$$f_H = \frac{1}{2p(1k\Omega)\left(1.49x10^{-10}F\right)} = 1.07\ MHz$$

17.44

```
*Problem 17.44 - Common-Source Amplifier
VDD 7 0 DC 0
VS 1 0 AC 1
RS 1 2 1K
C1 2 3 0.1UF
R1 3 0 4.3MEG
R2 3 7 5.6MEG
RD 7 5 43K
R4 4 0 13K
C3 4 0 10UF
C2 5 6 0.1UF
R3 6 0 1MEG
*Small-Signal FET Model
GM 5 4 3 4 0.4MS
CGS 3 4 2.5PF
CGD 3 5 2.5PF
*
.AC DEC 20 1 10MEG
.PRINT AC VM(6)
.PROBE
.END
```

Results: A_{mid} = -16.5, f_L = 7.9 Hz, f_H = 1.06 MHz

17.45 (a) Use V_{DD} = 12 V and R_D = 10 kΩ.



$$V_{EQ} = 12V\frac{430k\Omega}{430k\Omega + 560k\Omega} = 5.21V \quad | \quad R_{EQ} = 430k\Omega \| 560k\Omega = 243k\Omega$$

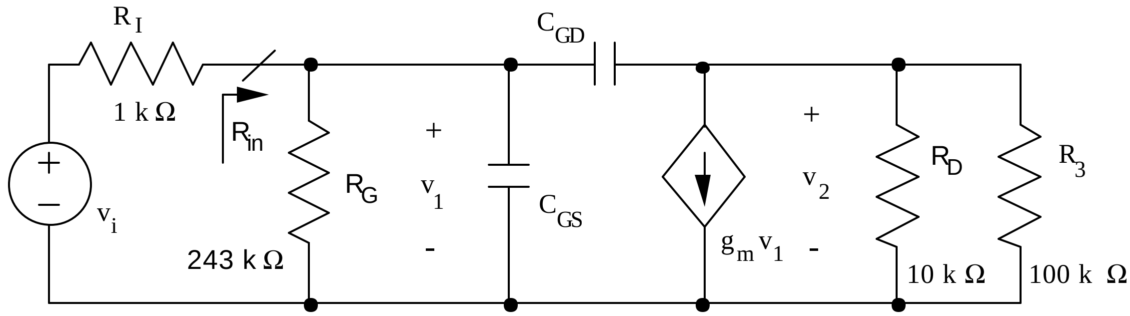
Assume active region operation : $I_D = \frac{K_n}{2}(V_{GS} - V_{TN})^2 \quad | \quad V_{EQ} = V_{GS} + I_D R_S$

$$5.21 = V_{GS} + 3.9k\Omega\left(\frac{0.5mA}{2}\right)(V_{GS} - 1)^2 \rightarrow V_{GS} = 2.629V \text{ and } I_D = 663mA$$

$$V_{DS} = V_{DD} - I_D R_D - I_S R_S = 12 - (663mA)(13k\Omega + 3.9k\Omega) = 0.795\ V$$

The transistor is not in pinch off! Reduce R_D to 10 kΩ.

$$V_{DS} = V_{DD} - I_D R_D - I_S R_S = 12 - (663mA)(10k\Omega + 3.9k\Omega) = 2.78\ V \text{ - Active region is correct.}$$



(b)

$$R_{in} = R_1 \| R_2 = 430k\Omega \| 560k\Omega = 243k\Omega \quad | \quad R_L = 10k\Omega \| 100k\Omega = 9.09k\Omega$$

$$g_m = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{2(0.663mA)}{1} = 1.33mS$$

$$A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\frac{243k\Omega}{1k\Omega + 243k\Omega}(1.33mS)(9.09k\Omega) = -12.0$$

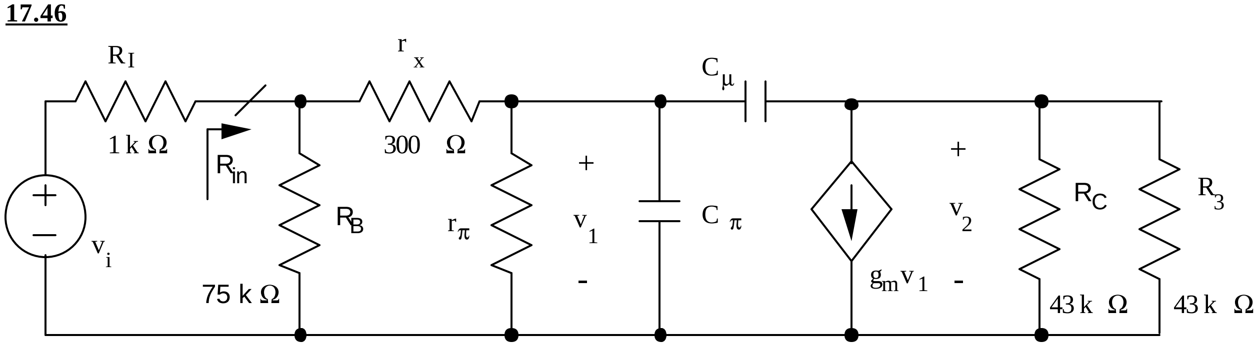
$$f_H = \frac{1}{2\pi r_{po} C_T} \quad | \quad r_{po} = R_1 \| R_2 \| R_I = 243k\Omega \| 1k\Omega = 0.996k\Omega$$

$$C_T = 2.5pF + 2.5pF\left[1 + (1.33mS)(9.09k\Omega) + \frac{9.09k\Omega}{0.996k\Omega}\right] = 58.1pF$$

$$f_H = \frac{1}{2\pi(0.996k\Omega)(58.1x10^{-11}F)} = 2.75\ MHz$$

$$(c)\ GBW = 12.0(2.75\ MHz) = 33\ MHz$$

17.46



$$g_m = 40I_C = 40(0.164mA) = 6.56mS \quad | \quad r_\pi = \frac{\beta_o}{g_m} = \frac{100}{6.56mS} = 15.2k\Omega \quad | \quad r_o = \infty\ (V_A\ not\ given)$$

$$R_{in} = R_1 \| R_2 \| r_\pi = 100k\Omega \| 300k\Omega \| 15.2k\Omega = 12.6k\Omega \quad | \quad R_L = R_C \| R_3 = 43k\Omega \| 43k\Omega = 21.5k\Omega$$

$$A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\frac{12.6k\Omega}{1k\Omega + 12.6k\Omega}(6.56mS)(21.5k\Omega) = -131$$

$$C_p = \frac{g_m}{w_T} - C_m = \frac{6.56mS}{2p\left(5x10^8 Hz\right)} - 0.75 = 1.34\ pF$$

$$w_H = \frac{1}{r_{po} C_T} \quad | \quad r_{po} = r_p \| \left(r_x + R_1 \| R_2 \| R_I\right) = 15.2\ k\Omega \| (300 + 987) = 1.19\ k\Omega$$

$$C_T = C_p + C_m\left(1 + g_m R_L + \frac{R_L}{r_{po}}\right) = 1.34\,pF + 0.75\,pF\left[1 + 6.56mS(21.5k\Omega) + \frac{21.5k\Omega}{1.19k\Omega}\right] = 121pF$$

$$f_H \cong \frac{1}{2p(1.19k\Omega)\left(1.21x10^{-10}F\right)} = 1.10\ MHz$$

<u>17.47</u>

```
*Problem 17.47 - Common-Emitter Amplifier
VCC 7 0 DC 0
VS 1 0 AC 1
RS 1 2 1K
C1 2 3 5UF
R1 3 0 300K
R2 3 7 100K
RC 5 0 43K
R4 7 4 13K
C2 7 4 22UF
C3 5 6 1UF
R3 6 0 43K
*Small-signal Model for the BJT
GM 5 4 8 4 6.56MS
RX 3 8 0.3K
RPI 8 4 15.24K
CPI 8 4 1.34PF
CU 8 5 0.75PF
*
.AC DEC 100 1 10MEG
.PRINT AC VM(6)
.PROBE
.END
```

Results: A_{mid} = -128, f_L = 47 Hz, f_H = 1.10 MHz

17.48

(a) See Eqs. (17.74 - 17.83).

$$\begin{bmatrix} I_S(s) \\ 0 \end{bmatrix} = \begin{bmatrix} s(C_p + C_m) + g_{po} & -sC_m \\ -(sC_m - g_m) & s(C_m + C_L) + g_L \end{bmatrix} \begin{bmatrix} V_1(s) \\ V_2(s) \end{bmatrix}$$

$$\Delta = s^2\left[C_p(C_m + C_L) + C_mC_L\right] + s\left[C_pg_L + C_m(g_m + g_{po} + g_L) + C_Lg_{po}\right] + g_Lg_{po}$$

$$(b)\ w_{P1} \cong \frac{g_Lg_{po}}{C_pg_L + C_m(g_m + g_{po} + g_L) + C_Lg_{po}} = \frac{1}{r_{po}\left[C_p + C_m(1 + g_mR_L) + (C_m + C_L)\frac{R_L}{r_{po}}\right]}$$

$$w_{P2} \cong \frac{C_pg_L + C_m(g_m + g_{po} + g_L) + C_Lg_{po}}{C_p(C_m + C_L) + C_mC_L} = \frac{g_m}{C_p\left(1 + \frac{C_L}{C_m}\right) + C_L}$$

(c) The three capacitors form a loop, and there are only two independent voltage among the three capacitors.

17.49

$$C_T = C_p + C_m(1 + g_mR_L) = 20\,pF + 0.5\,pF\left[1 + 40(1mA)(1k\Omega)\right] = 40.5\ pF$$

$$f_T = \frac{1}{2p}\left(\frac{g_m}{C_p + C_m}\right) = \frac{1}{2p}\left[\frac{40(1mA)}{20\,pF + 0.5\,pF}\right] = 311\ MHz$$

17.50 Using Eq. (17.98),

$$A_v(s) = \frac{\left(\frac{1}{RC}\right)\frac{A(s)}{1 + A(s)}}{s + \frac{1}{RC\left[1 + A(s)\right]}} \quad | \quad A(s) = \frac{10A_o}{s + 10} \quad | \quad A_v(s) = \left(\frac{1}{RC}\right)\frac{\frac{\frac{10A_o}{s+10}}{1 + \frac{10A_o}{s+10}}}{s + \frac{1}{RC\left(1 + \frac{10A_o}{s+10}\right)}}$$

$$A_v(s) = \left(\frac{1}{RC}\right)\frac{10A_o}{s^2 + s(1 + A_o)10 + \frac{s+10}{RC}} = \frac{\left(\frac{10A_o}{RC}\right)}{s^2 + s\left[\frac{1}{RC} + 10(1 + A_o)\right] + \frac{10}{RC}}$$

$$(a)\ A_v(s) = \frac{\left(\frac{10^6}{RC}\right)}{s^2 + s\left[\frac{1}{RC} + 10^6\right] + \frac{10}{RC}} \cong \frac{\left(\frac{10^6}{RC}\right)}{(s + 10^6)\left(s + \frac{1}{10^5RC}\right)};\ w_L = \frac{1}{10^5RC}$$

$$(b)\ A_v(s) = \frac{\left(\frac{10^7}{RC}\right)}{s^2 + s\left[\frac{1}{RC} + 10^7\right] + \frac{10}{RC}} \cong \frac{\left(\frac{10^6}{RC}\right)}{(s + 10^7)\left(s + \frac{1}{10^6RC}\right)};\ w_L = \frac{1}{10^6RC}$$

$$(c)\ \lim_{A_o \to \infty} A_v(s) = \frac{\left(\frac{10A_o}{RC}\right)}{10A_o s} = \frac{1}{sRC}$$

17.51

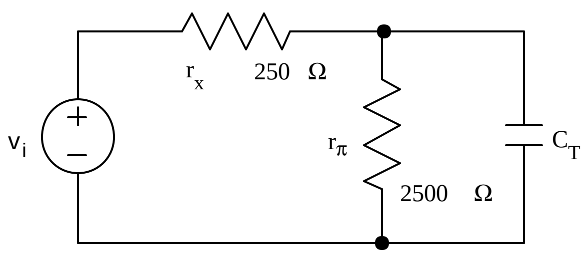
$$(a)\ \ Y_{in} = \frac{1+A}{Z(s)} = \frac{1+A}{\frac{1}{sC}} = sC(1+A)\ \ |\ \ C_{in} = C(1+A) = 10^{-10}F\left(1+10^5\right) = 10\ mF$$

$$(b)\ Z_{in} = \frac{1}{Y_{in}} = \frac{Z(s)}{1+A(s)} = \frac{10^5}{1+\frac{10^6}{s+10}} = 10^5\frac{s+10}{s+10+10^6} \cong 10^5\frac{s+10}{s+10^6}$$

Using MATLAB : $Z_{in}(j2000p) = (4.95 + j6.28)\ \Omega$

$Z_{in}\left(j10^5 p\right) = (8.98 + j28.6)\ k\Omega\ \ |\ \ Z_{in}\left(j2px10^6\right) = (97.5 + j15.5)\ k\Omega$

17.52



$$r_{po} = 2500\Omega \| 250\Omega = 227\Omega\ \ \ |\ \ \ C_T = 15 + 1\left[1 + 0.04(2500) + \frac{2500}{227}\right] = 127\ pF$$

(a) At 1 kHz, $Z_C = \dfrac{1}{j(2p)\left(10^3\right)(127\,pF)} = -j\left(1.25x10^6\right)$

Using MATLAB : $Z = 250 + \dfrac{2500Z_C}{2500+Z_C} = (2750 - j4.99)\ \Omega$ | SPICE : $(2750 - j4.56)\ \Omega$

(b) At 50 kHz, $Z_C = \dfrac{1}{j(2p)\left(5x10^4\right)(127\,pF)} = -j2.51x10^4\,\Omega$

Using MATLAB : $Z = 250 + \dfrac{2500Z_C}{2500+Z_C} = (2730 - j247)\ \Omega$ | SPICE : $(2730 - j226)\ \Omega$

(c) At 1 MHz, $Z_C = \dfrac{1}{j(2p)\left(10^6\right)(127\,pF)} = -j(12.53)$

Using MATLAB : $Z = 250 + \dfrac{2500Z_C}{2500+Z_C} = (752 - j1000)\ \Omega$ | SPICE : $(836 - j1040)\ \Omega$

(d)

```
*Problem 17.52 - Common-Emitter Amplifier
IS 0 1 AC 1
RX 1 2 0.25K
RPI 2 0 2.5K
CPI 2 0 15PF
CU 2 3 1PF
GM 3 0 2 0 40MS
```

```
RL 3 0 2.5K
.AC LIN 1 1KHZ 1KHZ
*.AC LIN 1 50KHZ 50KHZ
*.AC LIN 1 1MEG 1MEG
.PRINT AC VR(1) VI(1) VM(1) VP(1)
.END
```

Note that the C_T approximation does not provide as good an estimate of Z_{in} at high frequencies (note the discrepancy at 1 MHz).

17.53

$$(a)\ g_m = 40I_C = 40(1mA) = 40.0mS \ \mid\ r_\pi = \frac{\beta_o V_T}{I_C} = \frac{100(0.025)}{1mA} = 2.5k\Omega \ \mid\ r_o = \infty\ (V_A\ not\, given)$$

$$r_{\pi o} = r_\pi \| [r_x + (R_B \| R_I)] = 2.5k\Omega \| (250 + (7.5k\Omega \| 1k\Omega)) = 779\Omega \ \mid\ R_L = R_C \| R_3 = 4.3k\Omega \| 100k\Omega = 4.12k\Omega$$

$$C_\pi = \frac{g_m}{\omega_T} - C_\mu = \frac{40.0mS}{2\pi(5x10^8 Hz)} - 0.75pF = 12.0pF \ \mid\ f_H \cong \frac{1}{2\pi r_{\pi o} C_T}$$

$$C_T = C_\pi + C_\mu\left(1 + g_m R_L + \frac{R_L}{r_{\pi o}}\right) = 12.0pF + 0.75pF\left[1 + 40.0mS(4.12k\Omega) + \frac{4.12k\Omega}{0.779k\Omega}\right] = 140pF$$

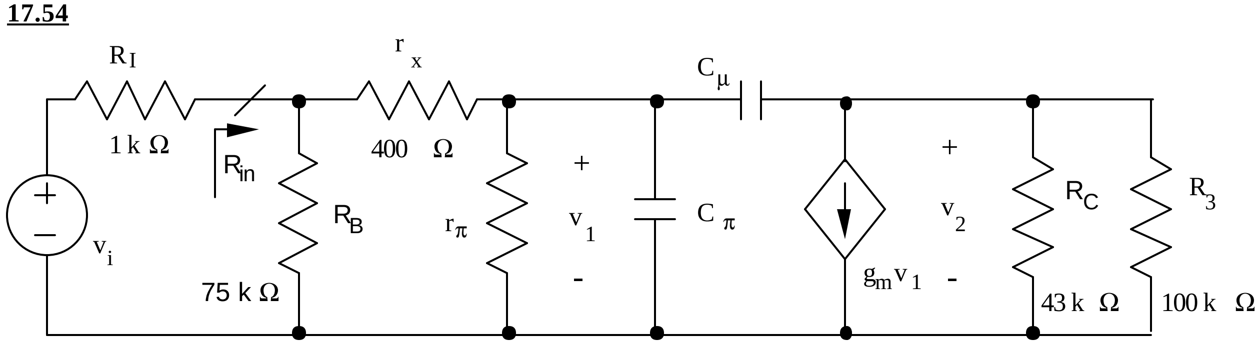
$$f_H \cong \frac{1}{2\pi(779\Omega)(1.40x10^{-10}F)} = 1.46\ MHz$$

$$(b)\ r_{\pi o} = r_\pi \| [r_x + (R_B \| R_I)] = 2.5k\Omega \| (0 + (7.5k\Omega \| 1k\Omega)) = 652\Omega$$

$$C_T = 12.0pF + 0.75pF\left[1 + 40.0mS(4.12k\Omega) + \frac{4.12k\Omega}{0.652k\Omega}\right] = 141pF$$

$$f_H \cong \frac{1}{2\pi(652\Omega)(1.41x10^{-10}F)} = 1.73\ MHz$$

17.54



$$(a)\ g_m = 40 I_C = 40(0.1mA) = 4.00mS \ \ | \ \ r_p = \frac{b_o V_T}{I_C} = \frac{100(0.025)}{0.1mA} = 25k\Omega \ \ | \ \ r_o = \infty \ (V_A \ not\,given)$$

$$r_{po} = r_p \| \left[r_x + (R_B \| R_I) \right] = 25k\Omega \| \left(400 + (75k\Omega \| 1k\Omega)\right) = 1.31k\Omega$$

$$R_{in} = R_1 \| R_2 \| (r_x + r_p) = 100k\Omega \| 300k\Omega \| 25.4k\Omega = 19.0k\Omega \ \ | \ \ R_L = R_C \| R_3 = 43k\Omega \| 100k\Omega = 30.1k\Omega$$

$$A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\frac{19.0k\Omega}{1k\Omega + 19.0k\Omega}(4.00mS)(30.1k\Omega) = -114$$

$$C_p = \frac{g_m}{w_T} - C_m = \frac{4.00mS}{2p\left(5x10^8 Hz\right)} - 0.75pF = 0.523pF \ \ | \ \ f_H \cong \frac{1}{2p\ r_{po} C_T}$$

$$C_T = C_p + C_m\left(1 + g_m R_L + \frac{R_L}{r_{po}}\right) = 0.523pF + 0.75pF\left[1 + 4.00mS(30.1k\Omega) + \frac{30.1k\Omega}{1.31k\Omega}\right] = 109\,pF$$

$$f_H \cong \frac{1}{2p(1.31k\Omega)\left(1.09x10^{-10}F\right)} = 1.12\ MHz$$

$$(b)\ GBW = 114(1.12MHz) = 128\ MHz \ \ | \ \ \frac{1}{2p\ r_x C_m} = \frac{1}{2p(400\Omega)(0.75pF)} = 531\ MHz$$

$$\text{Note}: \frac{1}{2p\ (R_S + r_x)C_m} = \frac{1}{2p(1.71k\Omega)(0.75pF)} = 124\ MHz$$

17.55 A_{mid} = 39.2 dB, f_L = 0 Hz, f_H = 5.53 MHz

17.56

$$R_{in} = R_1 \| R_2 = 4.3M\Omega \| 5.6M\Omega = 2.43M\Omega \quad | \quad R_L = 43k\Omega \| 1M\Omega = 41.2k\Omega$$

$$g_m = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{2(0.2mA)}{1} = 0.400mS \quad |$$

$$A_{mid} = -\frac{R_{in}}{R_I + R_{in}} g_m R_L = -\frac{2.43M\Omega}{1k\Omega + 2.43M\Omega} 0.400mS(41.2k\Omega) = -16.5$$

$$f_H = \frac{1}{2\pi r_{po} C_T} \quad | \quad r_{po} = R_1 \| R_2 \| R_I = 1.00k\Omega$$

$$C_T = 5pF + 2pF\left[1 + (0.400mS)(41.2k\Omega) + \frac{41.2k\Omega}{1k\Omega}\right] = 122pF$$

$$f_H = \frac{1}{2\pi(1k\Omega)(1.22x10^{-10}F)} = 1.31\ MHz \quad | \quad GBW = 16.5(1.31\ MHz) = 21.5\ MHz$$

17.57

$$f_H = \frac{1}{2\pi r_{po} C_T} = \frac{1}{2\pi(656\Omega)C_T} \quad | \quad C_T = \frac{1}{2\pi(656\Omega)(5MHz)} = 48.5pF$$

$$C_T = C_\pi + C_\mu\left[1 + g_m R_L + \frac{R_L}{r_{po}}\right] \quad | \quad R_L\left(g_m + \frac{1}{r_{po}}\right) = \frac{C_T - C_\pi}{C_\mu} - 1 = \frac{48.5pF - 19.9pF}{0.5pF} - 1 = 56.2$$

$$R_L = \frac{56.2}{\left(.064S + \frac{1}{656\Omega}\right)} = 858\Omega \quad | \quad R_L = R_C \| 100k\Omega \rightarrow R_C = 865\Omega$$

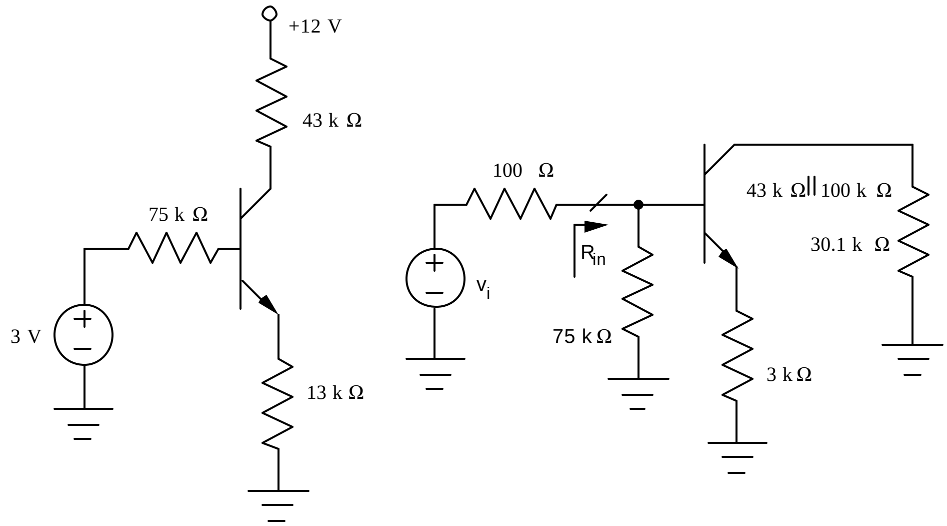
$$A_{mid} = -\frac{100(858\Omega)}{882\Omega + 250\Omega + 1560\Omega} = -31.9 \quad | \quad GBW = 31.9(5MHz) = 160\ MHz$$

The nearest 5% value is $R_C = 820\ \Omega \quad | \quad R_L = 820\Omega \| 100k\Omega = 813\Omega$

$$A_{mid} = -\frac{100(813\Omega)}{882\Omega + 250\Omega + 1560\Omega} = -30.2 \quad | \quad C_T = 19.9 + 0.5\left[1 + 0.064(813) + \frac{813}{656}\right] = 47.0pF$$

$$f_H = \frac{1}{2\pi r_{po} C_T} = \frac{1}{2\pi(656\Omega)(47.0pF)} = 5.16\ MHz \quad | \quad GBW = 156\ MHz$$

17.58



Short-Circuit Time Constants

$$R_{1S} = 100\Omega + 75k\Omega \| \left[300\Omega + 15.1k\Omega + 101(3k\Omega)\right] = 60.8k\Omega$$

$$R_{2S} = 43k\Omega + 100k\Omega = 143k\Omega$$

$$R_{3S} = 10k\Omega \left\| \left(3k\Omega + \frac{15.1k\Omega + 99.9\Omega}{101}\right)\right. = 2.40k\Omega$$

$$f_L \approx \frac{1}{2\pi}\left[\frac{1}{(60.8k\Omega)(1\mu F)} + \frac{1}{(143k\Omega)(0.1\mu F)} + \frac{1}{(2.40k\Omega)(2.2\mu F)}\right] = 43.9Hz$$

Open-Circuit Time Constants

Using the results from Table 17.2 on page 1334 : $R_{th} + r_x = 99.9\Omega + 300\Omega = 400\Omega$

$$C_{TB} = \frac{3.02pF}{1 + (6.63mS)(3k\Omega)}\left(1 + \frac{3k\Omega}{400\Omega}\right) + 0.5pF\left[1 + \frac{(6.63mS)(30.1k\Omega)}{1 + (6.63mS)(3k\Omega)} + \frac{30.1k\Omega}{400\Omega}\right]$$

$$C_{TB} = 44.1pF \quad | \quad f_H = \frac{1}{2\pi(400\Omega)(44.1pF)} = 9.02\ MHz$$

$$(b)\ GBW = 9.45(9.02MHz - 43.9Hz) = 85.2\ MHz$$

17.59

Using the results from Table 17.2 on page 1334 : $R_{th} + r_x = 99.9\Omega + 300\Omega = 400\Omega$

$$C_{TB} = \frac{1}{2p\,(400\Omega)(7.5MHz)} = 53.1\ pF$$

$$C_{TB} = \frac{3.02\,pF}{1+(6.63mS)R_E}\left(1+\frac{R_E}{400\Omega}\right)+0.5\,pF\left[1+\frac{(6.63mS)(30.1k\Omega)}{1+(6.63mS)R_E}+\frac{30.1k\Omega}{400\Omega}\right] = 53.1\ pF$$

Using MATLAB : $R_E = 957\ \Omega$

$$A_{mid} = 0.999\frac{-100(30.1k\Omega)}{99.9\Omega+300\Omega+15.1k\Omega+101(957\Omega)} = -26.8 \quad | \quad GBW = 201\ MHz$$

The closest 5% resistor values are $R_E = 1\ k\Omega$ and $R_6 = 12\ k\Omega$

$$C_{TB} = \frac{3.02\,pF}{1+(6.63mS)1k\Omega}\left(1+\frac{1k\Omega}{400\Omega}\right)+0.5\,pF\left[1+\frac{(6.63mS)(30.1k\Omega)}{1+(6.63mS)1k\Omega}+\frac{30.1k\Omega}{400\Omega}\right] = 52.6\ pF$$

$$f_H = \frac{1}{2p(400\Omega)(52.6\ pF)} = 7.56MHz$$

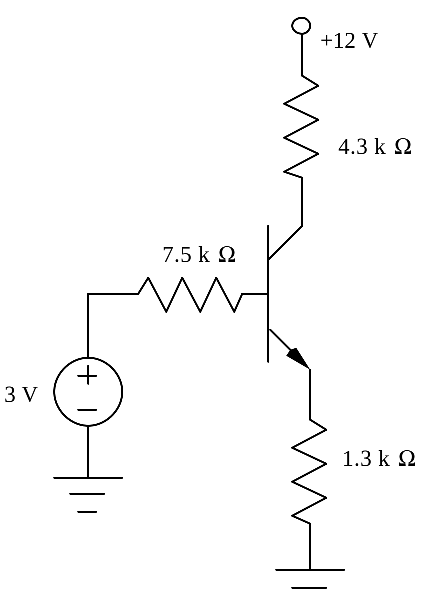
$$A_{mid} = 0.999\frac{-100(30.1k\Omega)}{99.9\Omega+300\Omega+15.1k\Omega+101(1k\Omega)} = -25.8 \quad | \quad GBW = 195\ MHz$$

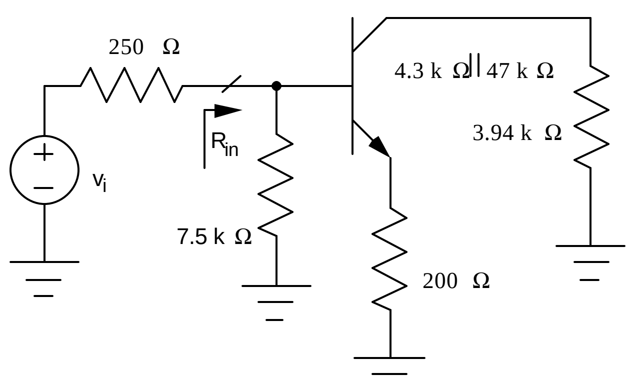
17.60 (a)

$$I_C = 100\left[\frac{3-0.7}{7.5k\Omega+101(1.3k\Omega)}\right] = 1.66mA \ | \ V_{CE} = 12-4.3k\Omega(I_C)-1.3k\Omega\left(\frac{I_C}{a_F}\right) = 2.69V$$

$2.69V \geq 0.7V$ Active region operation is correct. | $r_p = \dfrac{100(0.025)}{1.66\ mA} = 1.51\ k\Omega$

$$g_m = 40(1.66\ mA) = 66.4mS \ | \ C_p = \frac{66.4\,mS}{2p\left(2x10^8\right)} - 1 = 51.8\ pF \ | \ r_x = 300\Omega \ | \ C_m = 1.0\,pF$$





$$R_{in} = R_1 \| R_2 \| \left[r_x + r_p + (b_o + 1) R_{E1} \right] = 10k\Omega \| 30k\Omega \| \left[0.300k\Omega + 1.51k\Omega + (101)200\Omega \right] = 5.59\ k\Omega$$

$$R_{th} = 7.5k\Omega \| 250\Omega = 242\Omega \quad | \quad R_L = 4.3k\Omega \| 47k\Omega = 3.94k\Omega$$

$$A_{mid} = -\frac{R_{in}}{R_I + R_{in}} \left[\frac{b_o R_L}{r_x + r_p + (b_o + 1) R_{E1}} \right] = -\frac{5.59k\Omega}{250\Omega + 5.59k\Omega} \left[\frac{100(3.94k\Omega)}{22.0k\Omega} \right] = -17.1$$

(b) Using the Short-Circuit Time Constants:

$$R_{1S} = 250\Omega + 7.5k\Omega \| \left[300\Omega + 1.51k\Omega + 101(200\Omega) \right] = 5.84k\Omega$$

$$R_{2S} = 4.3k\Omega + 43k\Omega = 47.3k\Omega$$

$$R_{3S} = 1.1k\Omega \| \left(200\Omega + \frac{1.51k\Omega + 300 + 242\Omega}{101} \right) = 184\Omega$$

$$f_L \cong \frac{1}{2p} \left[\frac{1}{(5.84k\Omega)(5mF)} + \frac{1}{(47.3k\Omega)(1mF)} + \frac{1}{(184\Omega)(4.7mF)} \right] = 193Hz$$

(c) Using the Open-Circuit Time Constants:

Using the results from Table 17.2 on page 1334 : $R_{th} + r_x = 242\Omega + 300\Omega = 542\Omega$

$$C_{TB} = \frac{51.8pF}{1 + (66.4mS)(200\Omega)} \left(1 + \frac{200\Omega}{542\Omega} \right) + 1pF \left[1 + \frac{(66.4mS)(3.94k\Omega)}{1 + (66.4mS)(200\Omega)} + \frac{3.94k\Omega}{542\Omega} \right]$$

$$C_{TB} = 31.6pF \qquad f_L = \frac{1}{2p(542\Omega)(31.6pF)} = 9.29\ MHz$$

17.61

Using the results in Table 17.2 on page 1334 and the values from Prob. 17.43 :

$$R_{th} + r_x = 242\Omega + 300\Omega = 542\Omega \quad | \quad C_{TB} = \frac{1}{2p(542\Omega)(10MHz)} = 29.4\ pF$$

$$C_{TB} = \frac{51.8}{1 + (66.4mS)R_E} \left(1 + \frac{R_E}{542\Omega} \right) + 1pF \left[1 + \frac{(66.4mS)(3.94k\Omega)}{1 + (66.4mS)R_E} + \frac{3.94k\Omega}{542\Omega} \right] = 29.4\ pF$$

Using MATLAB : $R_E = 224\ \Omega$

The closest 5% resistor values are $R_E = 220\ \Omega$ and $R_6 = 1.1\ k\Omega$

$$C_{TB} = \frac{51.8pF}{1 + (66.4mS)220\Omega} \left(1 + \frac{220\Omega}{542\Omega} \right) + 1pF \left[1 + \frac{(66.4mS)(3.94k\Omega)}{1 + (66.4mS)220\Omega} + \frac{3.94k\Omega}{542\Omega} \right] = 29.7\ pF$$

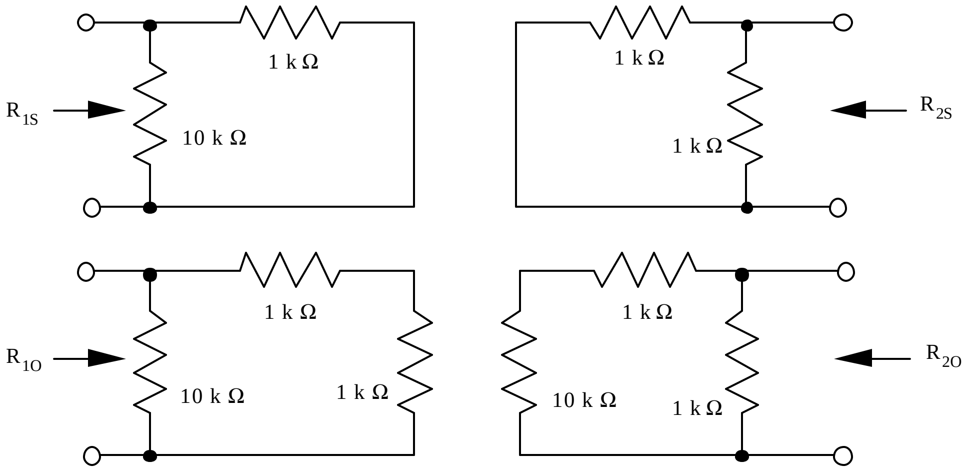
$$f_H = \frac{1}{2p(542\Omega)(29.7pF)} = 9.89MHz$$

$$R_{in} = R_1 \| R_2 \| \left[r_x + r_p + (b_o + 1) R_{E1} \right] = 10k\Omega \| 30k\Omega \| \left[0.300k\Omega + 1.51k\Omega + (101)220\Omega \right] = 5.72\ k\Omega$$

$$R_{th} = 7.5k\Omega \| 250\Omega = 242\Omega \quad | \quad R_L = 4.3k\Omega \| 47k\Omega = 3.94k\Omega$$

$$A_{mid} = -\frac{R_{in}}{R_I + R_{in}} \left[\frac{b_o R_L}{r_x + r_p + (b_o + 1) R_{E1}} \right] = -\frac{5.72k\Omega}{250\Omega + 5.72k\Omega} \left[\frac{100(3.94k\Omega)}{24.0k\Omega} \right] = -15.7$$

17.62



(a) SCTC:

$$R_{1S} = 10k\Omega \| 1k\Omega = 909\Omega \quad | \quad R_{2S} = 1k\Omega \| 1k\Omega = 500\Omega \quad | \quad w_L = \frac{1}{909\left(10^{-6}\right)} + \frac{1}{500\left(10^{-5}\right)} = 1300\frac{rad}{s}$$

(b) OCTC:

$$R_{1O} = 10k\Omega \| 2k\Omega = 1.67k\Omega \ | \ R_{2O} = 1k\Omega \| 11k\Omega = 917\Omega \ | \ w_L = \frac{1}{1670\left(10^{-6}\right) + 917\left(10^{-5}\right)} = 92.3\frac{rad}{s}$$

(c) There are two poles. The SCTC technique assumes both are at low frequency and yields the largest pole. The OCTC assumes both are at high frequency and yields the smallest pole.

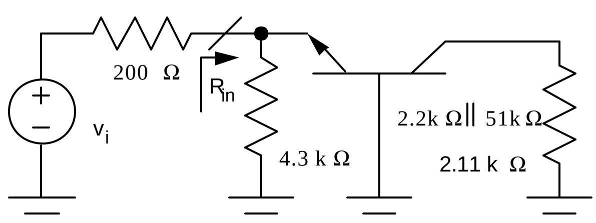
$$(d) \quad \begin{bmatrix} (sC_1 + G_1 + G_2) & -G_2 \\ -G_2 & (sC_2 + G_2 + G_3) \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = 0$$

$$\Delta = s^2 C_1 C_2 + s\left[C_2(G_1 + G_2) + C_1(G_2 + G_3)\right] + G_1G_2 + G_2G_3 + G_1G_3$$

$$\Delta = s^2 10^{-11} + s\left(1.30x10^{-8}\right) + 1.20x10^{-6}$$

$$\Delta = s^2 + 1300s + 1.20x10^5 \rightarrow s = -1200, -100 \ \frac{rad}{s}$$

17.63



$$g_m = 40(1\ mA) = 0.04S \quad | \quad r_x = 300\Omega \quad | \quad r_p = \frac{100(0.025)}{1\ mA} = 2.50k\Omega \quad | \quad C_m = 0.6pF$$

$$C_p = \frac{40\left(10^{-3}\right)}{2p\left(5x10^8\right)} - 0.6 = 12.1\ pF \quad | \quad R_{th} = 4.3k\Omega \| 200\Omega = 191\Omega \quad | \quad R_L = 2.2k\Omega \| 51k\Omega = 2.11k\Omega$$

$$R_{in} = R_E \| \frac{(r_x + r_p)}{b_o + 1} = 4.3k\Omega \| \frac{(0.3k\Omega + 2.50k\Omega)}{101} = 27.6\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}}\left(\frac{b_o R_L}{r_x + r_p}\right) = \frac{27.6\Omega}{200\Omega + 27.6\Omega}\frac{100(2.11k\Omega)}{2.80k\Omega} = +9.14$$

$$w_H = \frac{1}{191\frac{12.1pF}{1+0.04(191)}\left(1+\frac{300}{191}\right) + 0.6pF(300\Omega)\left[1+\frac{0.04(2110)}{1+0.04(191)}\right] + 0.6pF(2110\Omega)}$$

$$f_H = \frac{1}{2p}\left(\frac{1}{6.876x10^{-10} + 1.938x10^{-9} + 1.266x10^{-9}}\right) = 40.9MHz$$

<u>17.64</u> First, estimate the required SPICE parameters:

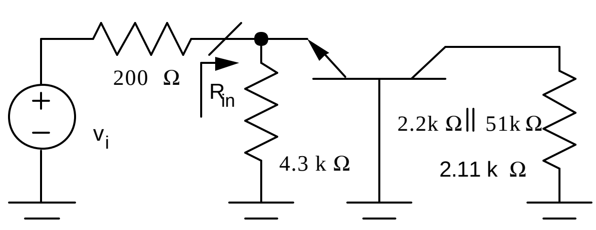
$$C_m = \frac{CJC}{\left(1+\frac{V_{CB}}{PHIE}\right)^{ME}} \quad | \quad CJC = CJC = 0.6pF\left(1+\frac{2.8}{0.75}\right)^{0.333} \cong 1.01pF$$

$$t_F = \frac{C_p}{g_m} = \frac{1}{w_T} - \frac{C_m}{g_m} = \frac{1}{10^9 p} - \frac{0.6pF}{40(1mA)} = 303\ ps$$

```
*Figure 17.94 - Common-Base Amplifier
VCC 6 0 DC 5
VEE 7 0 DC -5
VI 1 0 AC 1
RI 1 2 200
C1 2 3 4.7UF
RE 3 7 4.3K
Q1 4 0 3 NBJT
RC 4 6 2.2K
C2 4 5 1UF
R3 5 0 51K
.MODEL NBJT NPN BF=100 RB=300 CJC=1.01PF TF=303PS
.OP
.AC DEC 50 1 50MEG
.PRINT AC VM(5)
.PROBE
.END
```

Results: A_{mid} = 19.1 dB, f_L = 149 Hz, f_H = 43.8 MHz

<u>17.65</u>



$$I_C = a_F I_E = \frac{100}{101}\left[\frac{-0.7-(-10)}{4300}\right] = 2.14\ mA \quad | \quad V_{CE} = 10 - (2.14mA)(2.2k\Omega) - (-0.7) = 5.99\ V$$

$$g_m = 40(2.14mA) = 85.6mS \quad | \quad r_x = 300\Omega \quad | \quad r_p = \frac{100(0.025)}{2.14\ mA} = 1.17k\Omega \quad | \quad C_m = 0.6pF$$

$$C_p = \frac{85.6mS}{2p\left(5x10^8\right)} - 0.6 = 26.7\ pF \quad | \quad R_{th} = 4.3k\Omega \| 200\Omega = 191\Omega \quad | \quad R_L = 2.2k\Omega \| 51k\Omega = 2.11k\Omega$$

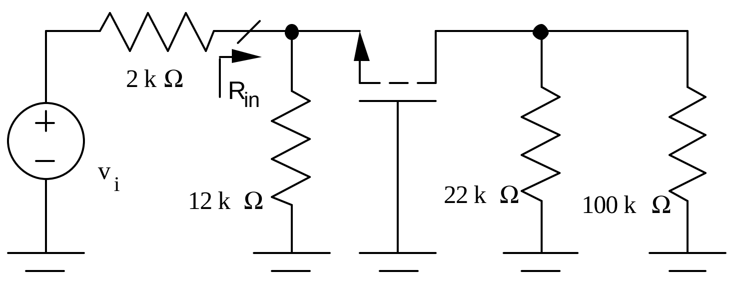
$$R_{in} = R_E \left\| \frac{(r_x + r_p)}{b_o + 1} = 4.3k\Omega \right\| \frac{(0.3k\Omega + 1.17k\Omega)}{101} = 14.5\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}}\left(\frac{b_o R_L}{r_x + r_p}\right) = \frac{14.5\Omega}{200\Omega + 14.5\Omega}\frac{100(2.11k\Omega)}{1.47k\Omega} = +9.70$$

$$w_H = \frac{1}{191\dfrac{26.7pF}{1+0.0856(191)}\left(1+\dfrac{300}{191}\right) + 0.6pF(300\Omega)\left[1+\dfrac{0.0856(2110)}{1+0.0856(191)}\right] + 0.6pF(2110\Omega)}$$

$$f_H = \frac{1}{2p}\left(\frac{1}{7.556x10^{-10} + 2.054x10^{-9} + 1.266x10^{-9}}\right) = 39.1\ MHz$$

17.66



$$R_{th} = 12k\Omega \| 2k\Omega = 1.71k\Omega \quad | \quad R_L = 22k\Omega \| 100k\Omega = 18.0k\Omega \quad | \quad C_{GS} = 3.0pF \quad | \quad C_{GD} = 0.6pF$$

$$g_m = \frac{2(0.1mA)}{1V} = 0.2mS \quad | \quad R_{in} = 12k\Omega \left\| \frac{1}{g_m} = 12k\Omega \right\| \frac{1}{0.2mS} = 3.53k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} g_m R_L = \frac{3.53k\Omega}{2k\Omega + 3.53k\Omega}(0.2ms)(18.0k\Omega) = +2.30$$

$$f_H = \frac{1}{2p}\left(\frac{1}{\dfrac{C_{GS}}{G_{th} + g_m} + C_{GD}R_L}\right) = \frac{1}{2p}\left(\frac{1}{\dfrac{3.0pF}{(0.5848 + 0.2)mS} + 0.6pF(18.0k\Omega)}\right) = 10.9\ MHz$$

17.67 First, calculate the SPICE parameters require to achieve $I_D = 0.1mA$:

$$V_{GG} = \frac{1.5M\Omega}{1.5M\Omega + 2.2M\Omega}12V = 4.87V \quad | \quad V_{GG} - V_{GS} = 0.1mA(12k\Omega) \rightarrow V_{GS} = 3.67V$$

$$V_{GS} - V_{TN} = 1V \rightarrow V_{TN} = 2.67V \quad | \quad K_n = \frac{2I_D}{(V_{GS} - V_{TN})^2} = \frac{2(0.1mA)}{1^2} = 0.2mS$$

```
*Problem 17.21 - Common-Source Amplifier
VDD 7 0 DC 12
VS 1 0 AC 1
RS 1 2 2K
```

```
C1 2 3 4.7UF
R4 3 0 12K
R1 4 0 1.5MEG
R2 7 4 2.2MEG
C2 4 0 0.1UF
R3 7 5 22K
C3 5 6 0.1UF
R7 6 0 100K
M1 5 4 3 3 NFET
.MODEL NFET NMOS VTO=2.67 KP=0.200M CGSO=30NF CGDO=6NF
.OP
.AC DEC 100 1 50MEG
.PRINT AC VM(6) VP(6)
.END
```

Results: $A_{mid} = 2.30$, $f_L = 15.5$ Hz, $f_H = 13.2$ MHz

17.68

(a) First find V_{TN} and K_n based upon Problem 17.21

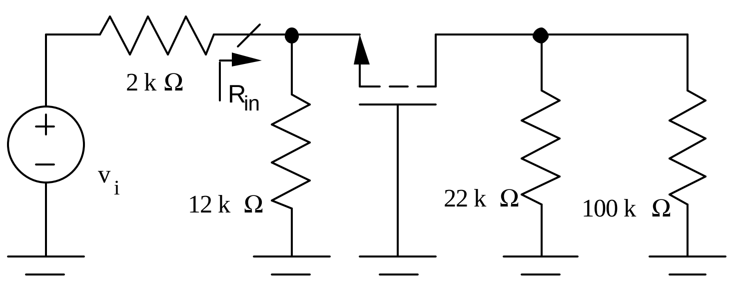
$$V_{GG} = \frac{1.5M\Omega}{1.5M\Omega + 2.2M\Omega}12V = 4.87V \quad | \quad V_{GG} - V_{GS} = 0.1mA(12k\Omega) \rightarrow V_{GS} = 3.67V$$

$$V_{GS} - V_{TN} = 1V \rightarrow V_{TN} = 2.67V \quad | \quad K_n = \frac{2I_D}{(V_{GS} - V_{TN})^2} = \frac{2(0.1mA)}{1^2} = 0.2mS$$

Now, find the Q - point for $V_{DD} = 18V$: $V_{GG} = \dfrac{1.5M\Omega}{1.5M\Omega + 2.2M\Omega}18V = 7.30V$

$$R_{GG} = 1.5M\Omega \| 2.2M\Omega = 892k\Omega \quad | \quad V_{GG} - V_{GS} = I_D R_S$$

$$7.30 - V_{GS} = (12k\Omega)\left(\frac{0.2mS}{2}\right)(V_{GS} - 2.67)^2 \rightarrow V_{GS} = 4.73V \quad | \quad I_D = 0.254\ mA \quad | \quad V_{DS} = 9.37V \text{ ok}$$



$$R_{th} = 12k\Omega \| 2k\Omega = 1.71k\Omega \quad | \quad R_L = 22k\Omega \| 100k\Omega = 18.0k\Omega \quad | \quad C_{GS} = 3.0pF \quad | \quad C_{GD} = 0.6pF$$

$$g_m = \frac{2(0.254mA)}{(4.26-2.67)V} = 0.320mS \quad | \quad R_{in} = 12k\Omega \| \frac{1}{g_m} = 12k\Omega \| \frac{1}{0.320mS} = 2.48k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} g_m R_L = \frac{2.48k\Omega}{2k\Omega + 2.48k\Omega}(0.320ms)(18.0k\Omega) = +3.19$$

$$f_H = \frac{1}{2p}\left(\frac{1}{\frac{C_{GS}}{G_{th}+g_m} + C_{GD}R_L}\right) = \frac{1}{2p}\left(\frac{1}{\frac{3.0pF}{(0.5848+0.32)mS} + 0.6pF(18.0k\Omega)}\right) = 11.3\ MHz$$

17.69 First, calculate the SPICE parameters required to achieve $I_D = 0.1mA$:

$$V_{GG} = \frac{1.5M\Omega}{1.5M\Omega + 2.2M\Omega}10V = 4.05V \quad | \quad V_{GG} - V_{GS} = 0.1mA(12k\Omega) \rightarrow V_{GS} = 2.85V$$

$$V_{GS} - V_{TN} = 0.75V \rightarrow V_{TN} = 2.10V \quad | \quad K_n = \frac{2I_D}{(V_{GS}-V_{TN})^2} = \frac{2(0.1mA)}{(0.75)^2} = 0.356\frac{mA}{V^2}$$

$$g_m = \frac{2(0.1mA)}{0.75V} = 0.267mS \quad | \quad R_{in} = R_1 \| R_2 = 892k\Omega \quad | \quad R_L = 12k\Omega \| 100k\Omega = 10.7k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}} \frac{g_m R_L}{1 + g_m R_L} = 0.998\frac{(0.267mS)(10.7k\Omega)}{1+(0.267mS)(10.7k\Omega)} = +0.739 \quad (-2.62\ dB)$$

From Table 17.2 on page 1334 : $f_H = \dfrac{1}{2p(2k\Omega \| 892k\Omega)\left[\dfrac{3pF}{1+(0.267mS)(10.7k\Omega)} + 0.6pF\right]} = 57.9\ MHz$

Note that a low frequency RHP zero makes the calculation of f_H a very poor estimate for the FET case. See the analysis in Prob. 17.73 which shows $\omega_z = -g_m/C_{GS}$.

```
*Problem 17.69 - Common-Drain Amplifier
VDD 6 0 DC 10
VS 1 0 AC 1
RS 1 2 2K
C1 2 3 4.7UF
R1 3 0 1.5MEG
R2 6 3 2.2MEG
M1 6 3 4 4 NFET
R4 4 0 12K
C3 4 5 0.1UF
R7 5 0 100K
.MODEL NFET NMOS VTO=2.10 KP=0.356MS CGSO=30NF CGDO=6NF
.OP
.AC DEC 100 1 500MEG
.PRINT AC VM(5) VP(5)
.END
```

Results: $A_{mid} = 0.740$, $f_L = 15.5$ Hz, $f_H = 195$MHz - Note that there is peaking in the response.

17.70

First find V_{DD}, V_{TN} and K_n from Prob. 17.22: $V_{DD} = V_{DS} + I_D R_S = 10\ V$

$$V_{GG} = \frac{1.5M\Omega}{1.5M\Omega + 2.2M\Omega}10V = 4.05V \ \ | \ \ V_{GG} - V_{GS} = 0.1mA(12k\Omega) \rightarrow V_{GS} = 2.85V$$

$$V_{GS} - V_{TN} = 0.75V \rightarrow V_{TN} = 2.10V \ \ | \ \ K_n = \frac{2I_D}{(V_{GS} - V_{TN})^2} = \frac{2(0.1mA)}{(0.75)^2} = 0.356\frac{mA}{V^2}$$

Now find the new Q - point with $V_{DD}\ =\ 18\ V$.

$$V_{GG} = \frac{1.5M\Omega}{1.5M\Omega + 2.2M\Omega}18V = 7.30V \ \ | \ \ R_{GG} = 1.5M\Omega \| 2.2M\Omega = 892k\Omega \ \ | \ \ V_{GG} - V_{GS} = I_D R_S$$

$$7.30 - V_{GS} = (12k\Omega)\left(\frac{0.356mA}{2V^2}\right)(V_{GS} - 2.10)^2 \rightarrow V_{GS} = 3.44V \ \ | \ \ I_D = 0.321\,mA \ \ | \ \ V_{DS} = 14.2\ V \ \text{ ok}$$

$$g_m = \frac{2(0.321mA)}{(3.44 - 2.10)V} = 0.479mS \ \ | \ \ R_{in} = R_1 \| R_2 = 892k\Omega \ \ | \ \ R_L = 12k\Omega \| 100k\Omega = 10.7k\Omega$$

$$A_{mid} = \frac{R_{in}}{R_I + R_{in}}\frac{g_m R_L}{1 + g_m R_L} = 0.998\frac{(0.479mS)(10.7k\Omega)}{1 + (0.479mS)(10.7k\Omega)} = +0.835 \quad (-1.57\ dB)$$

From Table 17.2 on page 1334 : $f_H = \dfrac{1}{2p\left(2k\Omega \| 892k\Omega\right)\left[\dfrac{3pF}{1 + (0.479mS)(10.7k\Omega)} + 0.6pF\right]} = 73.0\ MHz$

17.71

$$g_m = 40(0.25\ mA) = 10.0mS \ \ | \ \ r_x = 300\Omega \ \ | \ \ r_p = \frac{100(0.025)}{0.25\ mA} = 10.0k\Omega$$

$$C_m = 0.6pF \ \ | \ \ C_p = \frac{0.01}{2p\left(5x10^8\right)} - 0.6 = 2.58\ pF \ \ | \ \ R_B = 100k\Omega \| 300k\Omega = 75.0k\Omega$$

$$R_L = 13k\Omega \| 100k\Omega = 11.5k\Omega \ \ | \ \ R_{th} = 75k\Omega \| 2k\Omega = 1.95k\Omega$$

$$R_{in} = R_B \| \left[r_x + r_p + (b_o + 1)R_L\right] = 75.0k\Omega \| \left[300\Omega + 10.0k\Omega + (101)11.5k\Omega\right] = 70.5k\Omega$$

$$A_{mid} = \left(\frac{R_{in}}{R_I + R_{in}}\right)\frac{(b_o + 1)R_L}{r_x + r_p + (b_o + 1)R_L} = 0.972\frac{101(11.5k\Omega)}{\left[0.300 + 10.0 + 101(11.5)\right]k\Omega} = 0.964$$

$$f_H \cong \frac{1}{2p}\frac{1}{(1950 + 300)\left[\dfrac{2.58pF}{1 + 10mS(11.5k\Omega)} + 0.6pF\right]} = \frac{1}{2p}\frac{1}{(2250)(0.622pF)} = 114\ MHz$$

(b) Calculating the required SPICE parameters:

$$C_m = \frac{CJC}{\left(1 + \dfrac{V_{CB}}{PHIE}\right)^{ME}} \ \ | \ \ CJC = 0.6pF\left(1 + \frac{11.8}{0.75}\right)^{0.333} \cong 1.54\ pF$$

$$t_F = \frac{C_p}{g_m} = \frac{1}{w_T} - \frac{C_m}{g_m} = \frac{1}{10^9 p} - \frac{0.6pF}{40(0.25mA)} = 260\ ps \ \ | \ \ TF = 260\ ps$$

*Problem 17.71 - Common-Collector Amplifier

```
VCC 6 0 DC 15
VS 1 0 AC 1
RS 1 2 2K
C1 2 3 4.7UF
R1 3 0 100K
R2 6 3 300K
Q1 6 3 4 NBJT
R4 4 0 13K
C3 4 5 10UF
R7 5 0 100K
.MODEL NBJT NPN BF=100 TF=260PS CJC=1.54PF RB=300
.OP
.AC DEC 100 0.1 200MEG
.PRINT AC VM(5) VP(5)
.END
```

Results: A_{mid} = 0.962, f_L = 0.52 Hz, f_H = 110 MHz

17.72

$$V_{BB} = 9V\frac{100k\Omega}{100k\Omega + 300k\Omega} = 2.25V \quad | \quad R_B = 100k\Omega \| 300k\Omega = 75.0k\Omega$$

$$I_C = 100\frac{(2.25 - 0.7)V}{75.0k\Omega + 101(13k\Omega)} = 0.251mA$$

$$g_m = 40(0.251mA) = 10.0mS \quad | \quad r_x = 300\Omega \quad | \quad r_p = \frac{100(0.025)}{0.251mA} = 9.96k\Omega$$

$$C_m = 0.6pF \quad | \quad C_p = \frac{0.01}{2p\left(5x10^8\right)} - 0.6 = 2.58\ pF$$

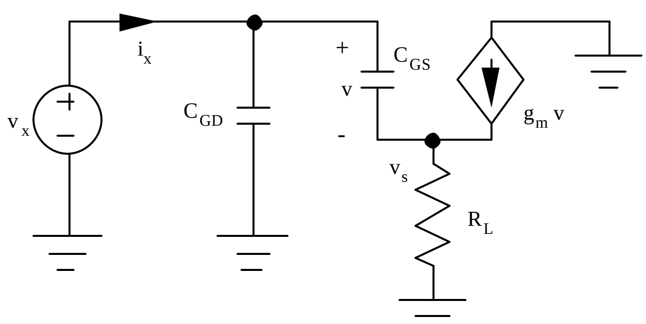
$$R_L = 13k\Omega \| 100k\Omega = 11.5k\Omega \quad | \quad R_{th} = 75k\Omega \| 2k\Omega = 1.95k\Omega$$

$$R_{in} = R_B \| \left[r_x + r_p + (b_o + 1)R_L\right] = 75.0k\Omega \| \left[300\Omega + 9.96k\Omega + (101)11.5k\Omega\right] = 70.5k\Omega$$

$$A_{mid} = \left(\frac{R_{in}}{R_I + R_{in}}\right)\frac{(b_o + 1)R_L}{r_x + r_p + (b_o + 1)R_L} = 0.972\frac{101(11.5k\Omega)}{\left[0.300 + 9.96 + 101(11.5)\right]k\Omega} = 0.964$$

$$f_H \cong \frac{1}{2p}\frac{1}{(1950 + 300)\left[\dfrac{2.58pF}{1 + 10mS(11.5k\Omega)} + 0.6pF\right]} = \frac{1}{2p}\frac{1}{(2250)(0.622pF)} = 114\ MHz$$

17.73



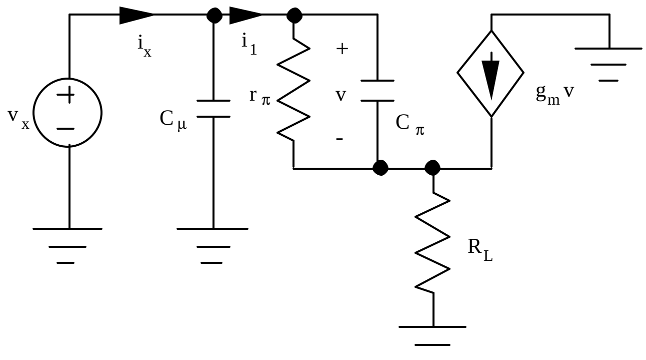
$$I_x = sC_{GD}V_x + sC_{GS}(V_x - V_S) \quad | \quad V_x = V + (sC_{GS}V + g_m V)R_L \quad | \quad V = \frac{V_x}{(1 + g_m R_L + sC_{GS}R_L)}$$

$$I_x = sC_{GD}V_x + sC_{GS}\frac{V_x}{(1 + g_m R_L + sC_{GS}R_L)} \quad | \quad Note:\ V_S = \frac{(sC_{GS} + g_m)R_L}{(1 + g_m R_L + sC_{GS}R_L)}V_x$$

$$\frac{I_x}{V_x} = s\left[C_{GD} + \frac{C_{GS}}{1 + g_m R_L}\frac{1}{1 + s\frac{C_{GS}R_L}{1 + g_m R_L}}\right] \quad | \quad \frac{C_{GS}R_L}{1 + g_m R_L} \approx \frac{C_{GS}R_L}{g_m R_L} = \frac{C_{GS}}{g_m} \quad \& \quad \frac{g_m}{C_{GS}} > w_T$$

Assuming $w << w_T :\ C_{IN} \approx C_{GD} + \frac{C_{GS}}{1 + g_m R_L}$ | Note the zero in $\mathbf{V_S}$ at $w_z = -\frac{g_m}{C_{GS}}$

17.74



$$I_x = sC_m V_x + I_1 \quad | \quad V_x = \frac{I_1}{(sC_p + g_p)} + \left(I_1 + g_m \frac{I_1}{(sC_p + g_p)}\right)R_L$$

$$Z_1 = \frac{V_x}{I_1} = \frac{sC_p r_p R_L + R_L + r_p + b_o R_L}{sC_p r_p + 1} = \frac{sC_p r_p R_L + r_p + (b_o + 1)R_L}{sC_p r_p + 1}$$

$$Y_1 = \frac{1}{Z_1} = \frac{\dfrac{sC_p r_p}{r_p + (b_o + 1)R_L} + \dfrac{1}{r_p + (b_o + 1)R_L}}{s\dfrac{C_p r_p R_L}{r_p + (b_o + 1)R_L} + 1} \cong \frac{\dfrac{sC_p}{(1 + g_m R_L)} + \dfrac{1}{r_p + (b_o + 1)R_L}}{s\dfrac{C_p R_L}{(1 + g_m R_L)} + 1} \quad for\ b_o >> 1$$

$$w\frac{C_p R_L}{(1 + g_m R_L)} << 1 \rightarrow w << \frac{1}{C_p}\left(\frac{1}{R_L} + g_m\right) \quad but \quad \frac{1}{C_p}\left(\frac{1}{R_L} + g_m\right) > w_T$$

$$\text{So, for } w << w_T,\ Y_1 \cong s\frac{C_p}{(1 + g_m R_L)} + \frac{1}{r_p + (b_o + 1)R_L}$$

$$C_{in} = C_m + \frac{C_p}{(1 + g_m R_L)} \quad \text{and} \quad R_{in} = r_p + (b_o + 1)R_L$$

w_H is determined by the input capacitance C_{in} and the source resistance $R_{th} + r_x$.

17.75

$$w_H = \frac{g_{m1}}{C_{GS1} + C_{GS2} + C_{GD2}(1 + g_{m1} r_{o2} + g_{m2} r_{o2})}$$

$$g_{m1} = g_{m2} = \sqrt{2\left(25x10^{-6}\right)\left(\frac{5}{1}\right)\left(10^{-4}\right)} = 158\ mS \quad | \quad r_{o2} \cong \frac{50V}{0.1mA} = 500k\Omega$$

$$C_{GS1} = 3pF \quad | \quad C_{GS2} = 3pF \quad | \quad C_{GD1} = 0.5pF \quad | \quad C_{GD2} = 0.5pF$$

$$f_H = \frac{1}{2p}\frac{158mS}{3pF + 3pF + 0.5pF\left[1 + 2(0.158mS)500k\Omega\right]} = 294\ kHz$$

17.76

$$w_H = \frac{g_{m1}}{C_{GS1} + C_{GS2} + C_{GD2}\left(1 + g_{m1}r_{o2} + g_{m2}r_{o2}\right)} \quad | \quad I_{D2} = 5I_{D1} = 1.00mA \quad | \quad r_{o2} = \frac{50V}{1mA} = 50k\Omega$$

$$g_{m1} = \sqrt{2\left(25x10^{-6}\right)\left(\frac{5}{1}\right)\left(2x10^{-4}\right)} = 224mS \quad | \quad g_{m2} = \sqrt{2\left(25x10^{-6}\right)\left(\frac{25}{1}\right)\left(1x10^{-3}\right)} = 1.12mS$$

$$C_{GS}\ \&\ C_{GD} \propto W : C_{GS1} = 3pF \quad | \quad C_{GS2} = 15pF \quad | \quad C_{GD1} = 1pF \quad | \quad C_{GD2} = 5pF$$

$$f_H = \frac{1}{2p}\frac{0.224mS}{3pF + 15pF + 5pF\left[1 + \left(1.12mS + 0.224mS\right)50k\Omega\right]} = 99.3\ kHz$$

17.77 The most probable answer that will be produced is

$$w_H = \frac{g_{m1}}{C_{p1} + C_{p2} + C_{m2}\left[1 + \left(g_{m1} + g_{m2}\right)r_{o2}\right]} \quad | \quad I_{C2} \cong 10I_{C1} = 1.00mA \quad | \quad r_{o2} = \frac{60V}{1.00mA} = 60k\Omega$$

$$C_{p1} = \frac{40\left(10^{-4}\right)}{1.2x10^9 p} - 0.5pF = 0.561pF \quad | \quad C_{p2} = \frac{40\left(10^{-3}\right)}{1.2x10^9 p} - 0.5pF = 10.1pF$$

$$f_H = \frac{1}{2p}\frac{40\left(10^{-4}\right)}{0.561pF + 10.1pF + 0.5pF\left[1 + 40\left(1.1mA\right)60k\Omega\right]} = 478\ kHz$$

However, C_μ should be approximately proportional to emitter area:

$$C_{m2} = 10C_{m1} = 5.00pF \quad | \quad C_{p2} = \frac{40\left(10^{-3}\right)}{1.2x10^9 p} - 5.00pF = 5.10pF$$

$$f_H = \frac{1}{2p}\frac{40\left(10^{-4}\right)}{0.561pF + 5.10pF + 5.00pF\left[1 + 40\left(1.1mA\right)60k\Omega\right]} = 48.2\ kHz$$

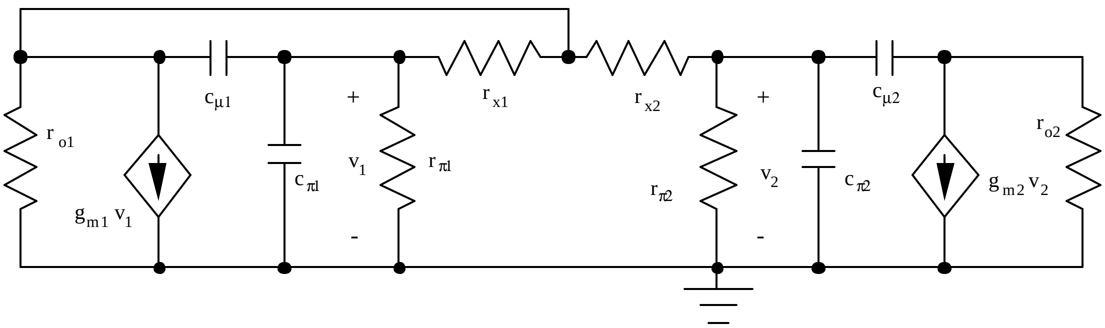
17.78

$$w_H = \frac{g_{m1}}{C_{p1} + C_{p2} + C_{m2}\left[1 + \left(g_{m1} + g_{m2}\right)r_{o2}\right]} \quad | \quad I_{C2} \cong I_{C1} = 100mA$$

$$r_{o2} = \frac{60V}{100mA} = 600k\Omega \quad | \quad C_{p2} = C_{p1} = \frac{40\left(10^{-4}\right)}{10^8 p} - 2pF = 10.7pF$$

$$f_H = \frac{1}{2p}\left[\frac{40\left(10^{-4}\right)}{10.7pF + 10.7pF + 2pF\left(1 + 2(40)\left(0.100mA\right)600k\Omega\right)}\right] = 66.2\ kHz$$

17.79 With the addition of r_x, we must re-evaluate the open-circuit time constants.



Assume: $r_x << r_o$

$$C_{p2} \ \& \ C_{m2} \text{ are part of a common - emitter stage with } \quad r_{po2} = r_{p2} \| \left(r_{x2} + \frac{1}{g_{m1}} \right) \cong \frac{1 + g_{m1} r_{x2}}{g_{m1}}$$

$$C_{p1}: \ R_{p1o}^{-1} = g_{p1} + g_{x1} \left(1 + \frac{g_{m1}}{g_{x1} + g_{o1} + \dfrac{1}{r_{x2} + r_{p2}}} \right) \quad | \quad R_{p1o} \cong \frac{r_{x1}}{1 + g_{m1} r_{x1}} \cong \frac{1}{g_{m1}}$$

$$C_{m1}: \ R_{m1o} = \frac{r_{x1}}{1 + \dfrac{1}{b_o} + \dfrac{1}{g_m R}} \quad with \ R = r_{o1} \| \left(r_{x2} + r_{p2} \right) \quad | \quad R_{m1o} \cong r_{x1}$$

$$w_H = \left\{ C_{p1} \frac{r_{x1}}{1 + g_{m1} r_{x1}} + C_{m1} r_{x1} + \frac{1 + g_{m1} r_{x2}}{g_{m1}} \left[C_{p2} + C_{m2} \left(1 + g_{m2} r_{o2} \right) \right] \right\}^{-1}$$

$$\text{The last term will be dominant} \quad : \ w_H \cong \frac{1}{\dfrac{1 + g_{m1} r_{x2}}{g_{m1}} C_{m2} \left(1 + g_{m2} r_{o2} \right)}$$

The most probable answer that will be generated is

$$I_{C2} \cong 4 I_{C1} = 1.00mA \quad | \quad r_{o2} = \frac{50V}{1.00mA} = 50k\Omega \quad | \quad g_{m2} = 40(0.001) = 40mS$$

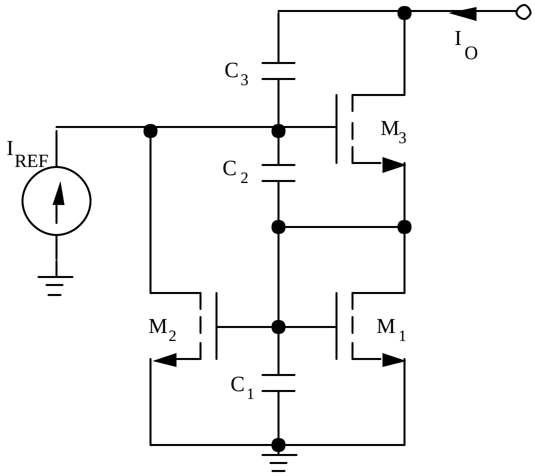
$$C_{p1} = \frac{40\left(2.5x10^{-4}\right)}{10^9 p} - 0.3pF = 2.88pF \quad | \quad C_{p2} = \frac{40\left(10^{-3}\right)}{10^9 p} - 0.3pF = 9.73pF$$

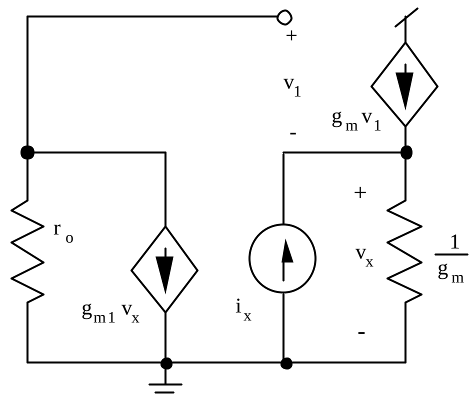
$$f_H \cong \frac{1}{2p} \frac{1}{\dfrac{1 + 0.01S(175\Omega)}{0.01S} 0.3pF \left[1 + 40mS(50k\Omega) \right]} = 964 \ kHz$$

However, C_μ should be approximately proportional to emitter area:

$$C_{m2} = 4 C_{m1} = 1.2pF \quad | \quad f_H \cong \frac{1}{2p} \frac{1}{\dfrac{1 + 0.01S(175\Omega)}{0.01S} 1.2pF \left[1 + 40mS(50k\Omega) \right]} = 241 \ kHz$$

17.80

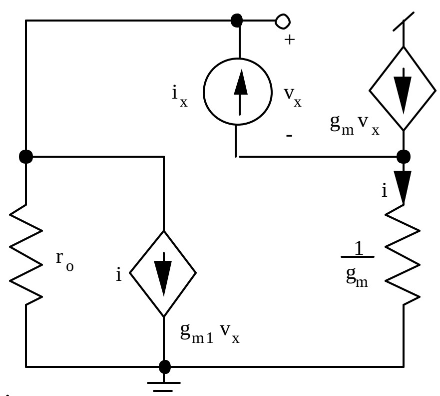


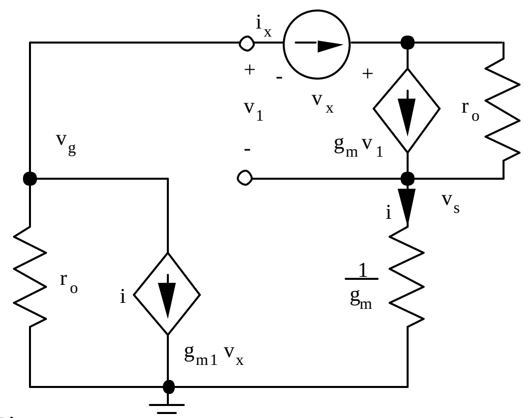


C1:

$$C_1 = C_{GS1} + C_{GS2} \quad | \quad C_2 = C_{GD2} + C_{GS3} \quad | \quad C_1 = C_{GD3}$$

$$R_{1O}: \ v_x = (i_x + g_m v_1)\frac{1}{g_m} \quad | \quad v_1 = -m_f v_x - v_x \quad | \quad R_{1O} = \frac{v_x}{i_x} = \frac{1}{g_m(m_f + 2)}$$





C2:

C3:

$$R_{2O}: \ v_x = (i_x - i)r_o - (g_m v_x - i_x)\frac{1}{g_m} \quad | \quad i = g_m v_x - i_x$$

$$2v_x = i_x\left(r_o + \frac{1}{g_m}\right) - r_o(g_m v_x - i_x) \quad | \quad R_{2O} = \frac{v_x}{i_x} = \frac{2r_o + \frac{1}{g_m}}{m_f + 2} \cong \frac{2}{g_m}$$

$$R_{3O}: \quad v_x = (i_x - g_m v_1) r_o + \frac{i_x}{g_m} - (i_x + i) r_o \quad | \quad i = i_x \quad | \quad v_1 = -2 i_x r_o - \frac{i_x}{g_m}$$

$$R_{3O} = \frac{v_x}{i_x} = 2\mu_f r_o + 4 r_o + \frac{1}{g_m} \cong 2(\mu_f + 2) r_o \cong 2\mu_f r_o$$

$$\omega_H \cong \frac{1}{\frac{2C_{GS}}{g_m \mu_f} + 2\frac{C_{GS}+C_{GD}}{g_m} + 2\mu_f r_o C_{GD}} \cong \frac{1}{2\mu_f r_o C_{GD}} = \frac{1}{2 g_m r_o^2 C_{GD}}$$

$$f_H \cong \frac{1}{2\pi} \frac{1}{2\sqrt{2(2.5x10^{-4})(2.5x10^{-4})}\left(\frac{50}{2.5x10^{-4}}\right)^2 (10^{-12})} = 5.63 \ kHz$$

Note: R_{3O} neglects any attached load resistance. If a load exists, essentially all of i_x will go through the load R_L, and the frequency response will significantly improve. For that case, $R_{3O} \sim R_L + r_o \sim r_o$.

17.81

$$(a) \ r_\pi = \frac{100(0.025)}{15x10^{-6}} = 167k\Omega \quad | \quad C_\mu = 0.5 \ pF \quad | \quad C_\pi = \frac{40(15x10^{-6})}{2\pi(75x10^6)} - 0.5pF = 0.773 \ pF$$

$$r_{\pi o} = r_\pi \| r_x = 167k\Omega \| 500\Omega = 499 \ \Omega \quad | \quad g_m = 40(15x10^{-6}) = 0.6mS \quad | \quad \omega_H = \frac{1}{r_{\pi o} C_T} \quad |$$

$$C_T = 0.773 + 0.5\left[1 + 0.6mS(430k\Omega) + \frac{430k\Omega}{499\Omega}\right] = 561pF \quad | \quad f_H = \frac{1}{2\pi(499)(5.61x10^{-10})} = 568 \ kHz$$

$$(b) \ r_\pi = \frac{100(0.025)}{5x10^{-5}} = 50.0k\Omega \quad | \quad C_\mu = 0.5 \ pF \quad | \quad C_\pi = \frac{40(5x10^{-5})}{2\pi(75x10^6)} - 0.5pF = 3.74 \ pF$$

$$r_{\pi o} = r_\pi \| r_x = 50k\Omega \| 500\Omega = 495 \ \Omega \quad | \quad g_m = 40(5x10^{-5}) = 2.00mS \quad | \quad \omega_H = \frac{1}{r_{\pi o} C_T} \quad |$$

$$C_T = 3.74 + 0.5\left[1 + 2.0mS(140k\Omega) + \frac{140k\Omega}{495\Omega}\right] = 285pF \quad | \quad f_H = \frac{1}{2\pi(495)(2.85x10^{-10})} = 1.13 \ MHz$$

17.82

$$(a) \ C_\mu = 1 \ pF \quad | \quad C_\pi = \frac{40(125x10^{-6})}{2\pi(100x10^6)} - 1pF = 6.96 \ pF \quad | \quad r_x = 500\Omega \quad | \quad g_m = 40(125x10^{-6}) = 5.00mS$$

$$C_T = 6.96 + 1.0\left[2 + \frac{5.00mS(62k\Omega)}{2} + \frac{62k\Omega}{0.500k\Omega}\right] = 288pF \quad | \quad f_H = \frac{1}{2\pi(500)(2.88x10^{-10})} = 1.11 \ MHz$$

$$(b) \ C_\pi = \frac{40(1x10^{-3})}{2\pi(100x10^6)} - 1pF = 62.7 \ pF \quad | \quad r_x = 500\Omega \quad | \quad g_m = 40(1x10^{-3}) = 40.0mS$$

$$C_T = 62.7 + 1.0\left[2 + \frac{40.0mS(7.5k\Omega)}{2} + \frac{7.5k\Omega}{0.500k\Omega}\right] = 230pF \quad | \quad f_H = \frac{1}{2\pi(500)(2.30x10^{-10})} = 1.39 \ MHz$$

17.83

$$(a)\ C_m = 1\ pF \quad | \quad C_p = \frac{40\left(100x10^{-6}\right)}{2p\left(100x10^{6}\right)} - 1pF = 5.37\ pF \quad | \quad r_x = 500\Omega \quad | \quad g_m = 40\left(100x10^{-6}\right) = 4.00mS$$

$$r_p = \frac{100(0.25)}{10^{-4}} = 25k\Omega \quad | \quad r_{po} = 500\Omega \| 25k\Omega = 490\Omega$$

$$f_H = \frac{1}{2p\left[(490\Omega)(5.37+2)pF + (500+75k\Omega)1pF\right]} = 2.01\ MHz$$

$$(b)\ C_m = 1\ pF \quad | \quad C_p = \frac{40\left(1x10^{-3}\right)}{2p\left(100x10^{6}\right)} - 1pF = 62.7\ pF \quad | \quad r_x = 500\Omega \quad | \quad g_m = 40\left(1x10^{-4}\right) = 40.0mS$$

$$r_p = \frac{100(0.25)}{10^{-3}} = 2.5k\Omega \quad | \quad r_{po} = 500\Omega \| 2.5k\Omega = 417\Omega$$

$$f_H = \frac{1}{2p\left[(417\Omega)(62.7+2)pF + (500+7.5k\Omega)1pF\right]} = 4.55\ MHz$$

17.84

For A_{mid}, refer to Section 15.1.1 : $R_1 = 39k\Omega,\ R_2 = 11k\Omega,\ R_{E21} = 800\Omega,\ R_{C2} = 2.35k\Omega$

$$r_{p2} = \frac{2.39k\Omega}{2} = 1.40k\Omega \quad | \quad R_{I1} = 620\Omega \| 39k\Omega \| 11k\Omega = 578\Omega \quad | \quad A_{vt1} = -10mS\left(578\Omega \| 1.20\Omega\right) = -3.91$$

$$R_{I2} = 2.35\Omega \| 51.8k\Omega = 2.25k\Omega \quad | \quad A_{vt2} = -62.8mS\left(2.25k\Omega \| 19.8k\Omega\right) = -127 \quad | \quad A_{vt3} \text{ doesn't change}$$

$$A_v = \frac{1M\Omega}{1.01M\Omega}(-3.91)(-127)(0.95) = +467 \quad \text{or} \quad 53.4 \text{ dB}$$

For f_L, refer to Section 17.9.3

$$\mathrm{R_{3S}} = \left(620\Omega \| 12.2k\Omega\right) + \left(\frac{17.2k\Omega}{2} \middle\| \frac{2.39k\Omega}{2}\right) = 1.64k\Omega \quad | \quad R_{th} = \frac{17.2k\Omega}{2} \| 620\Omega \| 12.2k\Omega = 552\Omega$$

$$R_{4S} = 750 \| \frac{552 + 1195}{151} = 11.4\Omega \quad | \quad \mathrm{R_{5S}} = \left(\frac{R_{C2}}{2} \middle\| \frac{r_{o2}}{2}\right) + \left(R_{B3} \| R_{in3}\right) = 16.3k\Omega$$

$$R_{th3} = 51.8k\Omega \| 2.35\Omega \| 27.1k\Omega = 2.08k\Omega \quad | \quad R_{6S} = 250 + 3.3k\Omega \| \frac{2.08k\Omega + 1.00k\Omega}{81} = 288\Omega$$

$$f_L = \frac{1}{2p}\left(99 + 319 + 610 + 3987 + 61.4 + 158\right) = 833\ Hz$$

For f_H, refer to Section 17.9.3

$$R_{L1} = 598\Omega \| \frac{2.39k\Omega}{2} = 399\Omega \quad | \quad R_{th}C_{T1} = (9.9k\Omega)\left[5pF + 1pF\left(1 + 0.01S(399\Omega) + \frac{399\Omega}{9900\Omega}\right)\right] = 9.92x10^{-8}s$$

$$R_{th2} = 598\Omega \| \frac{12.2k\Omega}{2} = 544\Omega \quad | \quad \mathrm{r}_{po2} = R_{4S} = \frac{2.39k\Omega}{2} \| \left(544\Omega + 250\Omega\right) = 596\Omega$$

$$R_{L2} = 51.8k\Omega \| \frac{4.7k\Omega}{2} \| R_{in2} = 2.25k\Omega \| 19.8k\Omega = 2.02k\Omega$$

$$\mathrm{C}_p + C_m = \frac{g_m}{w_T} \propto I_C \rightarrow C_{p2} = 2\left(40pF\right) - 1pF = 79pF$$

$$r_{po2}C_{T2} = (544)\left[79pF + 1pF\left(1 + 136mS(2.02k\Omega) + \frac{2.02k\Omega}{0.544k\Omega}\right)\right] = 1.95x10^{-7}s$$

$$R_{th3} = \frac{54.2k\Omega}{2} \| \frac{4.7k\Omega}{2} \| 51.8k\Omega = 2.08k\Omega$$

$$\frac{2.08k\Omega + 250\Omega}{1 + 79.6mS(0.232k)}50pF + \left(2.08k\Omega + 250\Omega\right)1pF = 8.31x10^{-9}s$$

$$f_H = \frac{1}{2p\left(9.92x10^{-8}s + 1.95x10^{-7}s + 8.31x10^{-9}s\right)} = 526\ \mathrm{k}Hz$$

17.85

For A_{mid}, refer to Section 15.1.1 : $R_{B3} = 2(51.8k\Omega) = 104\text{k}\,\Omega,\ R_{E3} = 6.6k\Omega,\ r_{p3} = \dfrac{1k\Omega}{2} = 500\,\Omega$

$A_{vt1} = \text{doesn't change} \quad | \quad R_{L2} = 4.7k\Omega \| 104\,k\Omega \| \left[500\,\Omega + 81(6.6k\Omega \| 250\Omega)\right] = 3.67k\Omega$

$A_{vt2} = -62.8mS(3.67\,k\Omega) = -231 \quad | \quad A_{vt3} = \dfrac{81(241)}{500 + 81(241)} = 0.975$

$A_v = \dfrac{1M\Omega}{1.01M\Omega}(-4.78)(-231)(0.975) = +1070 \quad \text{or} \quad 60.6 \text{ dB}$

For f_L, refer to Section 17.9.3

$\text{R}_{5S} = (4.7k\Omega \| 54.2\,k\Omega) + 104\,k\Omega \| \left[500\,\Omega + 81(6.6k\Omega \| 250\,\Omega)\right] = 21.1k\Omega$

$R_{th3} = 104\,k\Omega \| 4.7\Omega \| 54.2k\Omega = 4.15\,k\Omega \quad | \quad R_{6S} = 250 + 6.6k\Omega \| \dfrac{4.15k\Omega + 0.5k\Omega}{81} = 307\,\Omega$

$$f_L = \frac{1}{2p}\left(99 + 319 + 372 + 2340 + \frac{1}{21.1k\Omega(1mF)} + \frac{1}{307\,\Omega(22mF)}\right) = 529\ Hz$$

For f_H, refer to Section 17.9.3

$\text{R}_{L2} = 54.2k\Omega \| 4.7k\Omega \| 104\,k\Omega \| \left[500\,\Omega + 81(6.6k\Omega \| 250\,\Omega)\right] = 3.44\,k\Omega$

$$R_{po2}C_{T2} = (610\,\Omega)\left[39\,pF + 1\,pF\left(1 + 67.8mS(3.44\,k\Omega) + \frac{3.44\,k\Omega}{0.610\,k\Omega}\right)\right] = 1.70x10^{-7}s$$

$\text{C}_p + C_m = \dfrac{g_m}{w_T} \propto I_C \rightarrow C_{p3} = 2(51\,pF) - 1pF = 101\,pF \quad | \quad R_{th3} = 104\,k\Omega \| 4.7\Omega \| 54.2\,k\Omega = 4.15\,k\Omega$

$$\frac{4.15\,k\Omega + 250\,\Omega}{1 + 159.4mS\,(0.241k)}101\,pF + (4.15\,k\Omega + 250\,\Omega)1\,pF = 1.57\,x10^{-8}s$$

$$f_H = \frac{1}{2p\left(1.07x10^{-7}\,s + 1.70x10^{-7}\,s + 1.57\,x10^{-8}s\right)} = 544\ \text{k}Hz$$

17.86

$A_v = -100\ (40dB) \quad | \quad f_H = 5x10^6\,Hz \quad | \quad f_T \geq 2(100)(5x10^6) = 1.00\ GHz$

$GBW \leq \dfrac{1}{r_x C_m} \quad | \quad r_x C_m \leq \dfrac{1}{2p(10^9\,Hz)} = 159\ ps$

17.87

$A_v = 100\ (40dB) \quad | \quad f_H = 20\,x10^6\,Hz \quad | \quad f_T \geq 2(100)(2x10^7) = 4.00\ GHz$

$GBW \leq \dfrac{1}{r_x C_m} \quad | \quad r_x C_m \leq \dfrac{1}{2p(4x10^9\,Hz)} = 39.8\ ps$

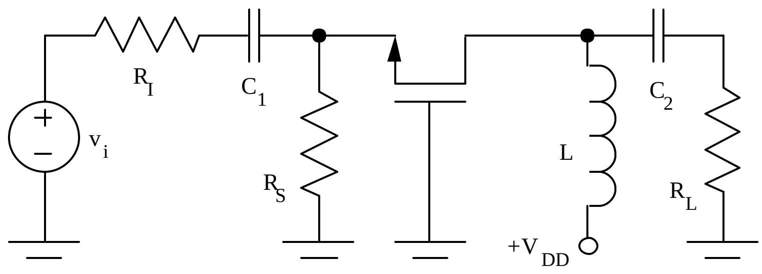
17.88

$$\omega_H \cong \frac{1}{\left(R_I \| \frac{1}{g_m}\right) C_{GS} + R_L C_{GD}} \quad | \quad A_{mid} = \frac{R_{in}}{R_I + R_{in}} g_m R_L \cong \frac{g_m R_L}{1 + g_m R_I} \quad | \quad R_L = A_{mid}\left(\frac{1}{g_m} + R_I\right) = 20\left(\frac{1}{g_m} + 100\right)$$

$$2\pi\left(25x10^6\right) = \frac{1}{\left[\frac{100\Omega}{1 + g_m(100\Omega)}\right]10^{-11}F + 20\left(\frac{1}{g_m} + 100\Omega\right)3x10^{-12}F} \rightarrow g_m = 190mS$$

$$R_L = 20\left(\frac{1}{0.190} + 100\right) = 2.11\ k\Omega \quad | \quad I_D = \frac{g_m^2}{2K_n} = \frac{(190mS)^2}{2\left(25\frac{mS}{V}\right)} = 722\ mA$$

Note that we cannot supply I_D through R_L since $I_D R_L = 1520V > V_{DD}$.



17.89

$$A_{mid} = g_m R_L \quad | \quad g_m = \frac{100}{100k\Omega} = 1.00mS \quad | \quad r_\pi = \frac{\beta_o}{g_m} \cong \frac{100}{1.00mS} = 100k\Omega$$

Assume $r_\pi >> r_x$ | $r_{\pi o} = r_\pi \| r_x \cong r_x$

$$\omega_H = \frac{1}{r_x\left[C_\pi + C_\mu\left(1 + g_m R_L + \frac{R_L}{r_x}\right)\right]} \cong \frac{1}{r_x C_\mu\left(1 + g_m R_L + \frac{R_L}{r_x}\right)} = \frac{1}{r_x C_\mu(1 + g_m R_L) + R_L C_\mu}$$

$$r_x C_\mu(1 + g_m R_L) + R_L C_\mu = \frac{1}{\omega_H} \quad | \quad r_x C_\mu(1 + 100) + 10^5 C_\mu = \frac{1}{2\pi\left(10^6\right)} = 1.59x10^{-7}$$

$$C_\mu = \frac{1.59\ pF}{1 + 1.01x10^{-3} r_x}$$ | C_μ cannot exceed 1.59 pF for an ideal transistor with $r_x = 0$.

Other more realistic possibilities (C_u, r_x): $(1\text{pF}, 584\Omega)$ $(0.75\text{pF}, 1.11\text{k}\Omega)$ $(0.5\text{pF}, 2.16\text{k}\Omega)$

17.90

$$w_H = \frac{1}{R_{th}\left[C_{GS} + C_{GD}\left[1 + g_m R_L + \frac{R_L}{R_{th}}\right]\right]} = \frac{1}{100\left[15pF + 5pF\left[1 + g_m R_L + \frac{R_L}{100}\right]\right]}$$

$$2p\left(25x10^6\right) = \frac{1}{100\left[20pF + 5pF\left[g_m R_L + \frac{R_L}{100}\right]\right]} \quad | \quad g_m R_L + \frac{R_L}{100} = \left[\frac{1}{2p\left(25x10^6\right)(100)10^{-12}} - 20\right]\frac{1}{5}$$

$$g_m = \frac{8.73}{R_L} - 0.01 \rightarrow R_L \le 873\Omega \quad | \quad I_D = \frac{g_m^2}{2K_n} = \frac{g_m^2}{0.05} = 20g_m^2$$

For strong inversion (for the square - law model to be valid), we desire

$$\left(V_{GS} - V_{TN}\right) \ge 0.25V \rightarrow I_D \ge \frac{0.025}{2}(0.25)^2 = 781\ mA.$$

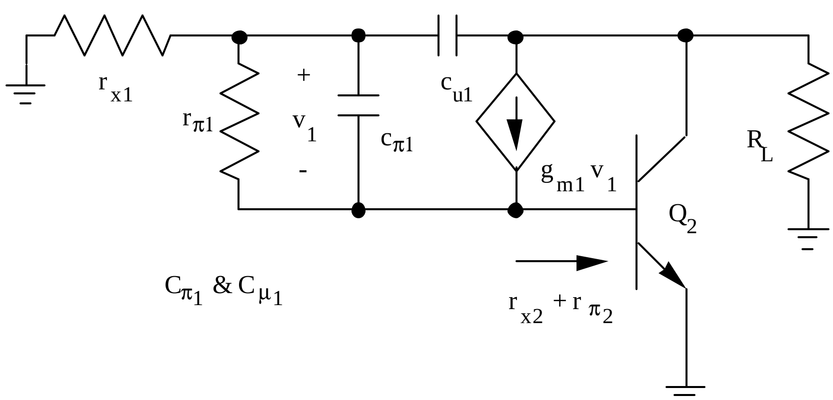
We normally would like $g_m R_L$ to be as large as possible, so set $I_D = 781\ mA$.

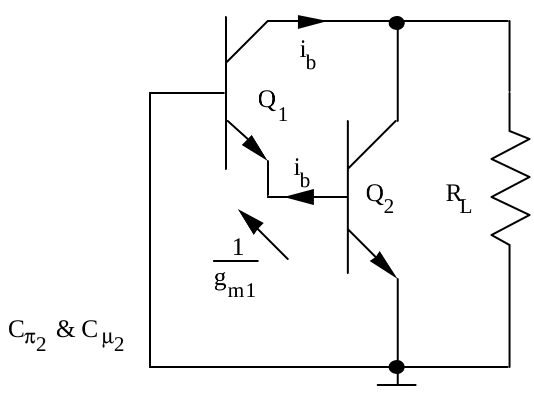
$$g_m = \sqrt{2K_n I_D} = \sqrt{2(0.025)\left(7.81x10^{-4}\right)} = 6.25mS \quad | \quad R_L = \frac{8.73}{g_m - .01} = 537\Omega \quad | \quad g_m R_L = 3.36$$

17.91

$$f_H \le \frac{1}{2pR_L C_m} = \frac{1}{2p\left(12k\Omega \| 47k\Omega\right)\left(2\,pF\right)} \rightarrow f_H \le 8.33\ MHz$$

17.92





$$(a)\ R_{m1O}:\ v_x \cong i_x r_{x1} - i_x r_{x1}\left[\frac{(b_o+1)(r_{x2}+r_{p2})}{r_{p1}+(b_o+1)(r_{x2}+r_{p2})}\right]\left(-\frac{b_o}{r_{x2}+r_{p2}}R_L\right)-(-i_x R_L)$$

$$R_{m1O} \cong i_x\left[R_L + r_{x1}\left(1+\frac{b_o r_{p2}}{r_{p1}+b_o r_{p2}}g_{m2}R_L\right)\right] \text{ assuming } \ r_{x2} << r_{p2}.$$

$$r_{p1} \cong 10 r_{p2}\ \ |\ \ b_o = 100\ \ |\ g_{m1} \cong \frac{b_o}{r_{p1}} = \frac{10}{r_{p2}}\ \ |\ \ R_{m1O} = \frac{v_x}{i_x} = R_L + r_{x1}\left(1+\frac{10}{11}g_{m2}R_L\right)$$

R_{p1O}: Split i $_x$ and use superposition with $r_{x2} << r_{p2}$:

$$v_x \cong i_x r_{x1}\left[1-\frac{(b_o+1)(r_{x2}+r_{p2})}{r_{p1}+(b_o+1)(r_{x2}+r_{p2})}\right]+\frac{i_x}{g_{p2}+g_{m1}} \cong i_x r_{x1}\frac{r_{p1}}{r_{p1}+b_o r_{p2}}+\frac{i_x}{g_{p2}+10g_{p2}}$$

$$R_{p1O} = \frac{v_x}{i_x} \cong \frac{10 r_{x1}+r_{p2}}{11}$$

R_{p2O}: The circuit is the same as that used for the C $_T$ calculation.

$$R_{p2O} = r_{p2}\left\|\left(r_{x2}+\frac{1}{g_{m1}}\right) = r_{p2}\right\|\left(r_{x2}+\frac{r_{p2}}{10}\right)$$

R_{m2O}: The circuit is the same as that used for the C $_T$ calculation except the additional i $_b$ = i$_x$/2 is returned back to the output :

$$R_{m2O} = R_{p2O} + R_{p2O}g_{m2}R_L + \frac{R_L}{2} = R_{p2O}\left(1+g_{m2}R_L+\frac{R_L}{2R_{p2O}}\right)$$

$$w_H = \frac{1}{C_{p1}\left(\frac{10r_{x1}+r_{p2}}{11}\right)+C_{m1}r_{x1}\left(1+\frac{10}{11}g_{m2}R_L+\frac{R_L}{r_{x1}}\right)+R_{p2O}\left[C_{p2}+C_{m2}\left(1+g_{m2}R_L+\frac{R_L}{2R_{p2O}}\right)\right]}$$

$$r_{p2} = \frac{100(0.025V)}{1mA} = 2.50k\Omega\ \ |\ \ Use\ R_L = \frac{r_{o2}}{2} = \frac{50V}{2mA} = 25.0k\Omega$$

$$C_{p1} = \frac{40(10^{-4})}{6x10^8 p} - 0.5pF = 1.62pF\ \ |\ \ C_{p2} = \frac{40(10^{-3})}{6x10^8 p} - 0.5pF = 20.7pF$$

$$R_{p2O} = r_{p2}\left\|\left(r_{x2}+\frac{r_{p2}}{10}\right) = 2.50k\Omega\right\|\left(300+\frac{2.50k\Omega}{10}\right) = 451\Omega$$

$$f_H = \frac{1}{2p}\left\{\begin{matrix}1.62pF\left(\frac{3k\Omega+2.5k\Omega}{11}\right)+0.5pF(300\Omega)\left[1+40mS(25k\Omega)+\frac{25k\Omega}{300\Omega}\right] \\ +451\Omega\left[20.7pF+0.5pF\left(1+40mS(25k\Omega)+\frac{25k\Omega}{902\Omega}\right)\right]\end{matrix}\right\}^{-1} = 393\ kHz$$

(b) The circuit is almost the same except for two important changes : $C_{\mu 1}$ sees only r_{x1}, and the $i_b = i_x/2$ is not returned to the output for $C_{\mu 2}$.

$$\omega_H = \frac{1}{C_{\pi 1}\dfrac{10 r_{x1} + r_{\pi 2}}{11} + C_{\mu 1} r_{x1} + R_{\pi 2O}\left[C_{\pi 2} + C_{\mu 2}\left(1 + g_{m2}R_L + \dfrac{R_L}{R_{\pi 2O}}\right)\right]}$$

$$f_H = \frac{1}{2\pi}\left\{\begin{array}{l} 1.62\,pF\left(\dfrac{3k\Omega + 2.5k\Omega}{11}\right) + 0.5\,pF(300\Omega) \\ +451\Omega\left[20.7\,pF + 0.5\,pF\left(1 + 40\,mS(25k\Omega) + \dfrac{25k\Omega}{451\Omega}\right)\right]\end{array}\right\}^{-1} = 640\,kHz$$

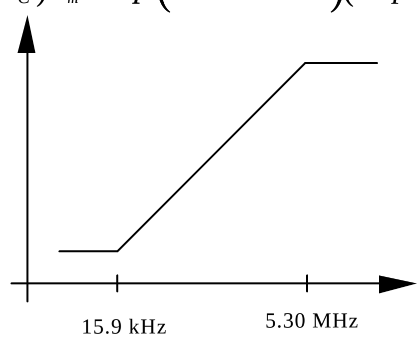
(c) The C - C/C - E cascade offers significantly better bandwidth than the Darlington configuration because $C_{\mu 1}$ is not subject to Miller multiplication.

(d) Improved bandwidth is one reason for the use of the C - C/C - E cascade in the 741 op - amp.

17.93 Use $R_C = 100\ k\Omega$

$$f_Z = \frac{1}{2\pi R_{EE}C_{EE}} = \frac{1}{2\pi\left(10^7\Omega\right)(1pF)} = 15.9\,kHz$$

$$f_p \cong \frac{1}{2\pi\left(r_x + R_C\right)C_\mu} = \frac{1}{2\pi\left(175\Omega + 10^5\Omega\right)(0.3pF)} = 5.30\ MHz$$



17.94

```
*Problem 17.94 - Bipolar Differential Amplifier CMRR
VIC 1 0 AC 5M
RX 1 2 175
RPI 2 3 25K
CPI 2 3 2.88PF
CU 2 4 0.3PF
GM 4 3 2 3 4MS
RO  4 3 500K
REE 3 0 10MEG
CEE 3 0 1PF
RL 4 0 100K
.AC DEC 100 10 20MEG
.PRINT AC VM(4) VP(4)
```

```
.PROBE
.END
```

The results agree with the drawing in Problem 17.93

17.95

$$(a)\ f_T = \frac{g_{m1}}{2pC_C} = \frac{\sqrt{2(0.001)(125x10^{-6})}}{2p(7.5x10^{-12})} = 10.6\ MHz$$ | Since $I_2 > I_1$, the slew rate is approximately symmetrical. | $$SR = \frac{I_1}{C_C} = \frac{250x10^{-6}}{7.5x10^{-12}} = 33.3x10^6\frac{V}{s} = 33.3\frac{V}{ms}$$

$$(b)\ f_T = \frac{g_{m1}}{2pC_C} = \frac{\sqrt{2(0.001)(250x10^{-6})}}{2p\ (10^{-11})} = 11.3\ MHz$$ | Since $I_2 > I_1$, the slew rate is asymmetrical. | $$SR_+ = \frac{I_1}{C_C} = \frac{500mA}{10\,pF} = 50\frac{V}{ms}$$ | $$SR_- = \frac{250mA}{10\,pF} = 25\frac{V}{ms}$$

17.96

$$f_T = \frac{g_{m1}}{2pC_C} = \frac{\sqrt{2(0.001)(250x10^{-6})}}{2p\ (10^{-11})} = 11.3\ MHz$$ | Since $I_2 > I_1$, the slew rate is symmetrical. | $$SR = \frac{I_1}{C_C} = \frac{500x10^{-6}}{10^{-11}} = 50x10^6\frac{V}{s} = 50\frac{V}{ms}$$

17.97

```
*Problem 17.97 - CMOS Op-amp
VDD 8 0 DC 10
VSS 9 0 -10
I1 1 9 250U
I2 6 9 500U
I3 7 9 2M
V1 4 0 DC -2.23M AC 0.5
V2 2 0 AC -0.5
M1 3 2 1 1 NFET W=20U L=1U
M2 5 4 1 1 NFET W=20U L=1U
M3 3 3 8 8 PFET W=40U L=1U
M4 5 3 8 8 PFET W=40U L=1U
M5 6 5 8 8 PFET W=160U L=1U
M6 8 6 7 7 NFET W=60U L=1U
CC 5 6 7.5PF
*CC 5 10 7.5PF
*RZ 10 6 1K
.MODEL NFET NMOS KP=2.5E-5 VTO=0.70 GAMMA=0.5
+LAMBDA=0.05 TOX=20N
+CGSO=4E-9 CGDO=4E-9 CJ=2.0E-4 CJSW=5.0E-10
.MODEL PFET PMOS  KP=1.0E-5 VTO=-0.70 GAMMA=0.75
+LAMBDA=0.05 TOX=20N
+CGSO=4E-9 CGDO=4E-9 CJ=2.0E-4 CJSW=5.0E-10
.OP
.TF V(7) V1
.AC DEC 100 1 20MEG
.PRINT AC VM(7) VP(7)
```

```
.PROBE
.END
```

Results: 8.1 MHz, -110 degrees; 8.0 MHz, -92 degrees

17.98

$$(a)\ f_T = \frac{g_m}{2pC_C} = \frac{40I_{C1}}{2pC_C} \quad | \quad I_{C1} = \frac{I_1}{2} \quad | \quad f_T = \frac{40(25mA)}{2p(12pF)} = 13.3\ MHz$$

$$SR = \frac{I_1}{C_C} = \frac{25mA}{12pF} = 2.09\frac{MV}{s} = 2.09\frac{V}{ms}$$ since $I_2 > I_1$. The slew rate is symmetrical.

$$(b)\ f_T = \frac{40(100mA)}{2p\,(12pF)} = 53.1\ MHz \quad | \quad SR = \frac{I_1}{C_C} = \frac{100mA}{12pF} = 8.33\frac{MV}{s} = 8.33\frac{V}{ms}$$

17.99

$$f_T = \frac{g_m}{2pC_C} = \frac{40I_{C1}}{2pC_C} \quad | \quad I_{C1} = \frac{I_1}{2} \quad | \quad f_T = \frac{40(250mA)}{2p\,(10pF)} = 159\ MHz$$

$$SR = \frac{I_1}{C_C} = \frac{500mA}{10pF} = 50\frac{MV}{s} = 50\frac{V}{ms}$$ since $I_2 > I_1$. The slew rate is symmetrical.

17.100

$$SR = \frac{I_1}{C_C} = \frac{40mA}{5pF} = 8x10^6\frac{V}{s} = 8\frac{V}{ms}$$

```
*Problems 17.100 - Bipolar Op-amp
VCC 8 0 DC 10
VEE 9 0 -10
I1 1 9 40U
I2 6 9 400U
I3 7 9 500U
V1 4 0 DC 0 PWL (0 0 5U 0 5.1U 5 10U 5 10.2U -5 15U -5 15.2U 5 20U 5)
VF 2 7 DC -0.0045
Q1 3 2 1 NBJT
Q2 5 4 1 NBJT
Q3 3 10 8 PBJT
Q4 5 10 8 PBJT
Q11 0 3 10 PBJT
Q5 6 5 8 PBJT
Q6 8 6 7 NBJT
CC 5 6 5PF
.MODEL NBJT NPN BF=100 IS=1FA VAF=80 RB=250 TF=0.65NS CJC=2PF
.MODEL PBJT PNP  BF=100 IS=1FA VAF=80 RB=250 TF=0.65NS CJC=2PF
.OP
.TRAN .05U 20U
.PROBE V(4) V(5) V(6) V(7)
.END
```

Results: -8V/μs, +6V/μs

17.101

$$SR = \frac{I_1}{C_C} = \frac{100mA}{8pF} = 12.5x10^6\frac{V}{s} = 12.5\frac{V}{ms}$$

17.102

$$f_T = \frac{g_m}{2pC_C} = \frac{40 I_{C1}}{2pC_C} \quad | \quad I_{C1} = \frac{I_1}{2} \quad | \quad f_T = \frac{40(50mA)}{2p(15pF)} = 21.2\ MHz$$

```
*Problem 17.101 - Bipolar Op-amp
VCC 8 0 DC 10
VEE 9 0 -10
I1 1 9 100U
I2 6 9 500U
I3 7 9 500U
V1 4 0 DC 2.10M AC 0.5
V2 2 0 DC 0 AC -0.5
Q1 3 2 1 NBJT
Q2 5 4 1 NBJT
Q3 3 10 8 PBJT
Q4 5 10 8 PBJT
Q11 0 3 10 PBJT
Q5 6 5 8 PBJT
Q6 8 6 7 NBJT
CC 5 6 15PF
.MODEL NBJT NPN BF=100 IS=1FA VAF=80 RB=250 TF=0.65NS CJC=2PF
.MODEL PBJT PNP  BF=100 IS=1FA VAF=80 RB=250 TF=0.65NS CJC=2PF
.OP
.TF V(7) V1
.AC DEC 100 1 20MEG
.PRINT AC VM(7) VP(7)
.PROBE
.END
```

Spice Results: (a) 16.2MHz (b) 16.3 MHz - 15 pF does not represent the effective value of C_C.

17.103

Zero output voltage occurs when the current through the base - collector admittance is exactly equal to the current in the controlled source :

$$g_m v = sC_{GD} v + \frac{v}{R_Z + \frac{1}{sC_C}} \quad | \quad sC_{GD} - g_m + \frac{sC_C}{sC_C R_Z + 1} = 0$$

The numerator polynomial becomes : $s^2 C_{GD} C_C R_Z + s(C_{GD} + C_C - C_C R_Z g_m) - g_m = 0$

For widely spaced roots, $z_1 \cong \dfrac{g_m}{C_{GD} + C_C - C_C R_Z g_m}$

z_1 can be eliminated by setting : $R_Z = \dfrac{1}{g_m}\left(1 + \dfrac{C_{GD}}{C_C}\right)$

17.104

$$f_o = \frac{1}{2p\sqrt{LC_{GD}}} = \frac{1}{2p\sqrt{10^{-5}\left(5x10^{-12}\right)}} = 22.5\ MHz$$

$$g_m = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{0.02}{2} = 0.01S \qquad r_o = \frac{\frac{1}{0.0167} + 10}{0.01} = 59.9k\Omega$$

$$A_v = -g_m\left(r_o \| R_L\right) = -0.01S\left(59.9k\Omega \| 10k\Omega\right) = -85.7$$

$$BW = \frac{1}{2pR_P C_{GD}} = \frac{1}{2p\left(8.57k\Omega\right)\left(5pF\right)} = 3.71\,MHz \quad Q = \frac{22.5}{3.71} = 6.06$$

17.105

$$(a)\ f_o = \frac{1}{2p\sqrt{\left(C + C_m\right)L}} \rightarrow C = \frac{1}{\left(2pf_o\right)^2 L} - C_m = \frac{1}{\left[2p\left(10.7x10^6 Hz\right)\right]^2 10^{-5} H} - 2pF = 20.1pF$$

$$(b)\ r_o = \frac{75V + 10V}{10mA} = 8.50k\Omega \ \ | \ \ BW = \frac{1}{2p\left(8.5k\Omega\right)\left(22.1pF\right)} = 847kHz \ \ | \ \ Q = \frac{10.7}{0.847} = 12.6$$

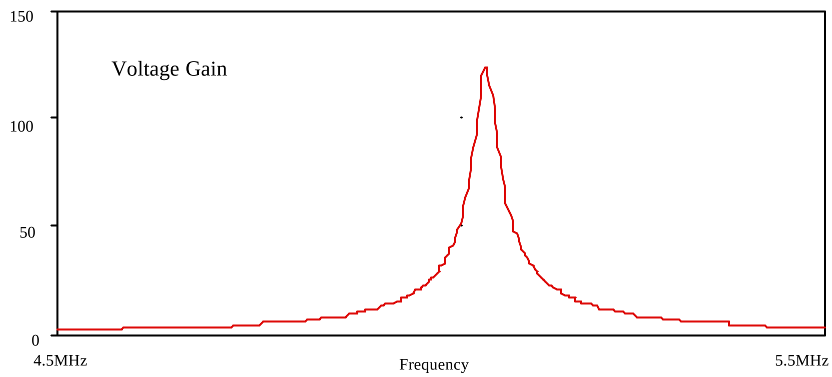
$$(c)\ Q = 100 \ \ | \ \ BW = \frac{f_o}{Q} = 107kHz \ \ | \ \ r_o = \frac{1}{w_o\left(C + C_m\right)} = \frac{1}{2p\left(107kHz\right)\left(22.1pF\right)} = 67.3k\Omega$$

$$n^2 = \frac{67.3k\Omega}{8.50k\Omega} = 7.918 \ \ | \ \ n = 2.81$$

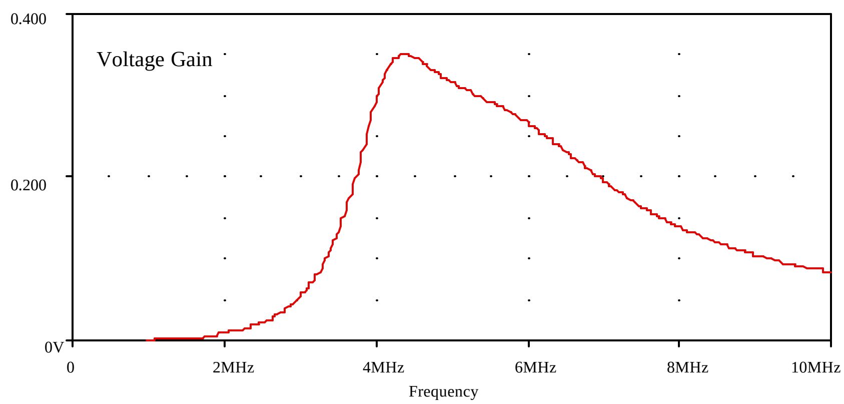
$$(d)\ C_m^{'} = \frac{C_m}{n^2} = \frac{2pF}{7.918} = 0.253pF \ \ | \ \ C = 22.1 - 0.253 = 21.9pF$$

17.106

```
*Problem 17.106(a) - Double-Tuned Common-Source Amplifier
VDD 4 0 DC 15
VS 1 0 AC 12.65M
C1 1 2 25PF
L1 2 0 20UH
RG 2 0 100K
M1 3 2 0 0 NFET
CGS 2 0 25PF
L2 3 4 20UH
C2 3 4 50PF
RD 3 4 100K
.MODEL NFET NMOS VTO=-1 KP=20M LAMBDA=0.02
.OP
.AC LIN 500 4.5MEG 5.5MEG
.PRINT AC VM(2) VP(2) VM(3) VP(3)
.PROBE
.END
```




```
*Problem 17.106(b) - Double-Tuned Common-Source Amplifier
VDD 4 0 DC 15
VS 1 0 AC 12.65M
C1 1 2 25PF
L1 2 0 20UH
RG 2 0 100K
M1 3 2 0 0 NFET
CGS 2 0 25PF
CGD 2 3 1PF
L2 3 4 20UH
C2 3 4 50PF
RD 3 4 100K
.MODEL NFET NMOS VTO=-1 KP=20M LAMBDA=0.02
.OP
.AC LIN 500 1MEG 10MEG
.PRINT AC VM(2) VP(2) VM(3) VP(3)
.PROBE
.END
```



Note that the synchronous tuning and gain are ruined by the Miller multiplication of C_{GD}.

In fact, the circuit is now an oscillator!

Define : $C_3 = C_1 + C_{GS}$

$$\begin{bmatrix} sC_1V_i \\ 0 \end{bmatrix} = \begin{bmatrix} s(C_3 + C_{GD}) + G_G + \dfrac{1}{sL_1} & -sC_{GD} \\ s(sC_{GD} - g_m) & s(C_2 + C_{GD}) + G_L + \dfrac{1}{sL_2} \end{bmatrix} \begin{bmatrix} V_{gs} \\ V_o \end{bmatrix}$$

$$\Delta(s) = s^4 \left[C_2C_3 + (C_2 + C_3)C_{GD}\right] + s^3 \left[(C_3 + C_{GD})G_L + (C_2 + C_{GD})G_G + g_mC_{GD}\right]$$
$$+ s^2\left[G_GG_L + \frac{(C_3 + C_{GD})}{L_2} + \frac{(C_2 + C_{GD})}{L_1}\right] + s\left[\frac{G_G}{L_2} + \frac{G_L}{L_1}\right] + \frac{1}{L_1L_2}$$

$$I_D = \frac{0.02}{2}(0+1)^2\left[1 + 0.02(15)\right] = 13.0\ mA \ \ | \ \ g_m = \frac{2(.013)}{1} = 26.0\ mS \ \ | \ \ r_o = \frac{50+15}{.013} = 5.00\ k\Omega$$

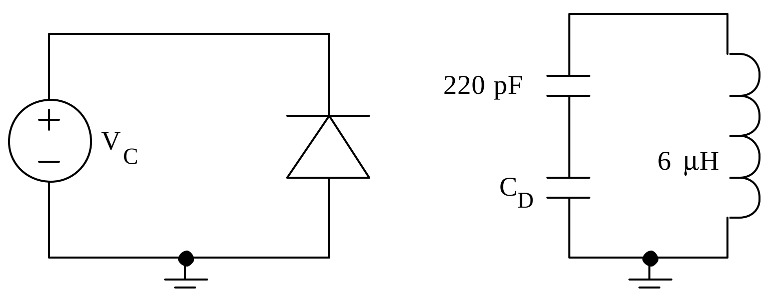
$$G_L = \frac{1}{5k\Omega \| 100k\Omega} = 0.210\ mS \ \ | \ \ \frac{V_o}{V_i} = \frac{s^2C_1(sC_{GD} - g_m)}{\Delta(s)}$$

$$\Delta(s) = 2.60x10^{-21}s^4 + 3.72x10^{-14}s^3 + 5.10x10^{-6}s^2 + 11.00s + 2.5x10^9$$

Using the roots function in MATLAB : $(-1.06 \pm j3.74)\ x\,10^7\,rad/s, (+0.318 \pm j2.55)\ x\,10^7\,rad/s$

The positive real parts indicate that the circuit will oscillate!

17.107



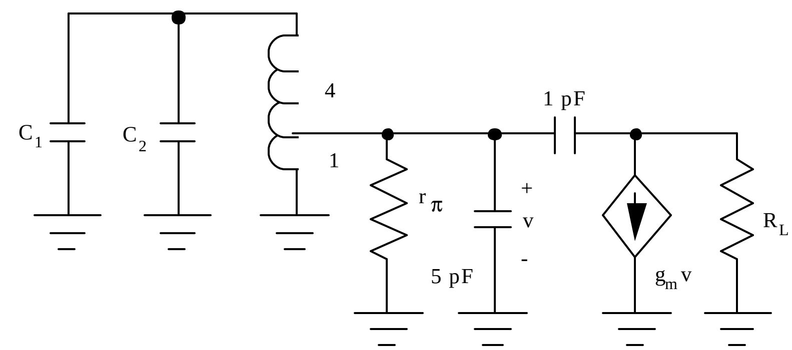
$$C_D = \frac{20pF}{\sqrt{1 + \dfrac{V_C}{0.9}}} \quad (a)\ C_D = \frac{20pF}{\sqrt{1 + \dfrac{0}{0.9}}} = 20pF \ \ | \ \ C = \frac{20(220)}{20 + 220}pF = 18.3pF$$

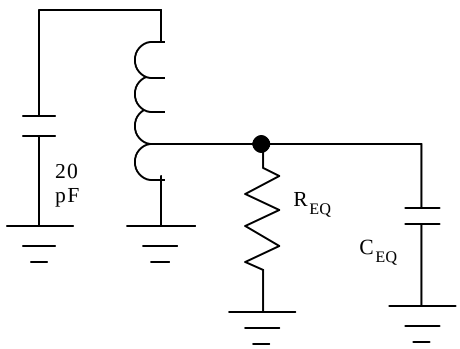
$$f_o = \frac{1}{2p\sqrt{LC}} = \frac{1}{2p\sqrt{(6mH)(18.3pF)}} = 15.2MHz$$

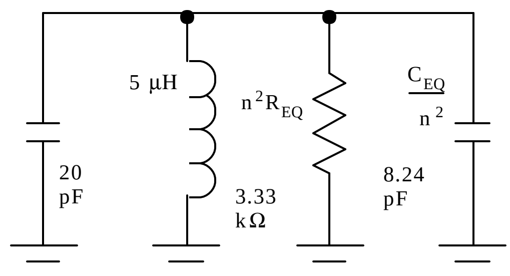
$$(b)\ C_D = \frac{20pF}{\sqrt{1 + \dfrac{10}{0.9}}} = 5.75pF \ \ | \ \ C = \frac{5.75(220)}{5.75 + 220}pF = 5.60pF$$

$$f_o = \frac{1}{2p\sqrt{LC}} = \frac{1}{2p\sqrt{(6mH)(5.60pF)}} = 27.5MHz$$

17.108 (a)







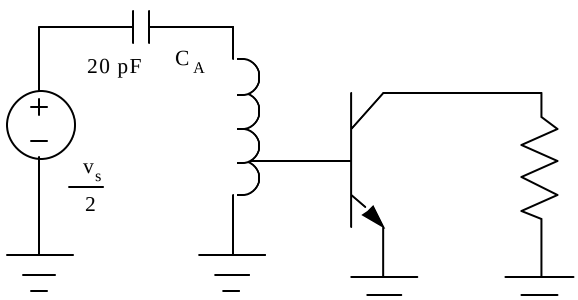
$$C_{EQ} = C_\pi + C_\mu\left[1 + g_m R_L\right] = 5\,pF + 1pF\left[1 + 40(1mA)(5k\Omega)\right] = 206\ pF$$

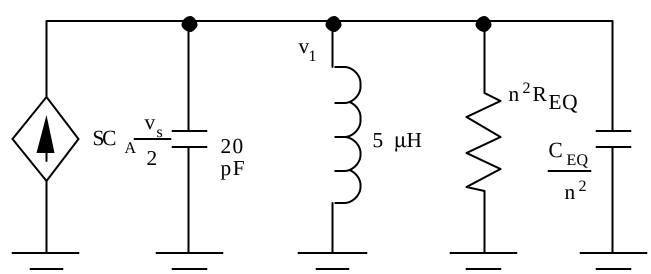
$$C_P = 20\,pF + \frac{C_{EQ}}{n^2} = 20\,pF + \frac{206\,pF}{5^2} = 28.2\,pF \quad | \quad f_o = \frac{1}{2\pi\sqrt{(5mH)(28.2\,pF)}} = 13.4\ MHz$$

$$R_{EQ} = r_\pi \left\| \frac{R_L}{(1+g_m R_L)(\omega R_L C_\mu)^2} = 2.5k\Omega \right\| \frac{5000}{(1+200)\left[2\pi(13.4\,MHz)(5k\Omega)(1pF)\right]^2} = 2.5k\Omega \| 140\Omega = 133\Omega$$

$$R_P = n^2 R_{EQ} = 25(133\Omega) = 3.33k\Omega \quad | \quad BW = \frac{1}{2\pi\,(3.33k\Omega)(28.2\,pF)} = 1.70\ MHz \quad | \quad Q = \frac{13.4}{1.70} = 7.88$$

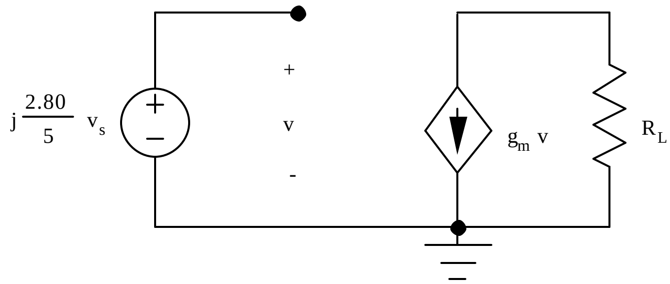
Note the huge error that would be caused by using only r_π as the input resistance term.



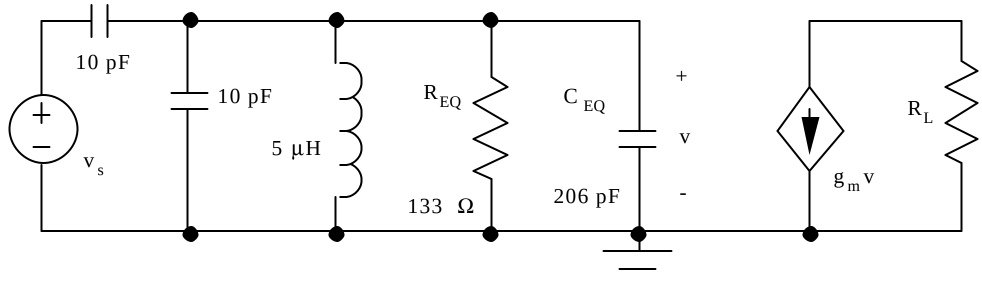


$$v_1 = j2p\,(13.4MHz)(20\,pF)\left(\frac{1}{2}\right)(3.33k\Omega)v_i = j2.80v_s$$

$$v_o = (-g_m R_L)\frac{j2.80v_s}{5} = -40\left(10^{-3}\right)(5k\Omega)j0.560v_i \quad | \quad A_v = 112\angle -90^o$$



17.108 (b)



$$C_T = 5\,pF + 1\,pF\left[1 + 40(1mA)(5k\Omega)\right] = 206\,pF \quad | \quad C_P = 20\,pF + 206\,pF = 226\,pF$$

$$f_o = \frac{1}{2p\sqrt{(5mH)(226\,pF)}} = 4.74\,MHz$$

$$R_{EQ} = r_p \left\| \frac{R_L}{(1+g_m R_L)(wR_L C_m)^2} = 2.5k\Omega \right\| \frac{5000}{(1+200)\left[2p\,(4.74\,MHz)(5k\Omega)(1pF)\right]^2}$$

$$R_{EQ} = 2.5k\Omega \| 1.12k\Omega = 774\Omega \quad | \quad BW = \frac{1}{2p\,(774\Omega)(226\,pF)} = 910\;kHz \quad | \quad Q = \frac{4.74}{0.910} = 5.21$$

$$v_o = j2p\,(4.74\,MHz)(10\,pF)(774\Omega)(-g_m R_L)v_i$$

$$v_o = j2p\,(4.74\,MHz)(10\,pF)(774\Omega)\left[-0.04\,mS(5k\Omega)\right]v_i \quad | \quad A_v = 46.1\angle -90^o$$

17.109

$$(a)\; C_{EQ} = C_{GS1} + C_{GD1}(1 + g_{m1}R_L) = C_{GS1} + C_{GD1}\left(1 + \frac{g_{m1}}{g_{m2}}\right)$$

$$I_{D2} = I_{D1} = \frac{0.01}{2}\left[0 - (-1)\right]^2 = 5.00\,mA \quad | \quad V_{GS2} = -4 + \sqrt{\frac{2(0.005)}{0.01}} = -3V$$

$V_{DS1} = V_{SG2} = +3V > 1V \rightarrow$ Saturation region is ok. $\quad | \quad g_{m2} = g_{m1} = \sqrt{2(0.01)(0.005)} = 10.0mS$

$$C_{EQ} = 20\,pF + 5\,pF[1+1] = 30\,pF \;\; | \;\; C_P = C_1 + C_{EQ} = 30\,pF + 20\,pF + 20\,pF = 70\,pF$$

Require $C_2 + C_{GD} = C_P \rightarrow C_2 = 70\,pF - 5\,pF = 65\,pF$

$$(b)\ f_o = \frac{1}{2p\sqrt{LC_P}} = \frac{1}{2p\sqrt{(10mH)(70pF)}} = 6.02\ MHz \quad | \quad R_{L1} = \frac{1}{g_{m2}}$$

$$R_P = R_G \left\| \frac{R_{L1}}{(1+g_{m1}R_{L1})(wR_{L1}C_{GD1})^2} = 100k\Omega \right\| \frac{100}{(1+1)[2p(6.02MHz)(100)(5pF)]^2}$$

$$R_P = 100k\Omega \| 140k\Omega = 58.3k\Omega \quad | \quad BW_1 = \frac{1}{2pR_PC_P} = \frac{1}{2p(58.3k\Omega)(70pF)} = 39.0kHz$$

$BW_2 \cong BW_1\sqrt{2^{\frac{1}{2}}-1} = 25.1kHz$ | Note that this is an approximation since $R_P = 100k\Omega$ at the output and 58.3 k Ω at the input. | $Q = \frac{6.02\ MHz}{25.1kHz} = 240$ | $v_o = (wC_3v_i)(R_P)(-g_mR_D)$

$$A_{mid} = 2p(6.02MHz)(20pF)(58.3k\Omega)(-10.0mS)(100k\Omega) = 4.41x10^4$$

17.110

```
*Problem 17.110 - Synchronously-Tuned Cascode Amplifier
VDD 5 0 DC 12
VS 1 0 AC 1
C3 1 2 20PF
L1 2 0 10UH
C1 2 0 20PF
RG 2 0 100K
M1 3 2 0 0 NFET1
CGS1 2 0 20PF
CGD1 2 3 5PF
M2 4 0 3 3 NFET2
CGS2 3 0 20PF
CGD2 4 3 5PF
L2 4 5 10UH
C2 4 5 65PF
RD 4 5 100K
.MODEL NFET1 NMOS VTO=-1 KP=10M
.MODEL NFET2 NMOS VTO=-4 KP=10M
.OP
.AC LIN 200 5.5MEG 6.5MEG
.PRINT AC VM(2) VP(2) VM(3) VP(3) VM(4) VP(4)
.PROBE
.END
```

Results: A_{mid} = 279, f_o = 6.10 MHz, Q = 24

The amplifier is actually stagger-tuned. Note that the loop of capacitors around M_1 messes up the hand results based upon the C_{EQ} approximation. The C_{EQ} approximation itself may not be accurate enough for precise synchronous tuning. Plot a graph of V(2) and V(3) to show the problem. Evidence of the problem is also provided by the huge error in the mid-band gain.

17.111

From Prob. 17.109 : $C_{P2} = \frac{1}{(2\pi f_o)^2 L} = \frac{1}{\left(2\pi \frac{1.02}{\sqrt{LC_{P1}}}\right)^2 L} = \frac{C_{P1}}{(1.02)^2} = \frac{70\,pF}{(1.02)^2} = 67.3\ pF$

$C_2 = C_{P2} - C_{GD2} = 67.3pF - 5\,pF = 62.3pF \quad | \quad R_{p2} = 100\,k\Omega$

$BW_1 = \frac{1}{2\pi (58.3k\Omega)(70\,pF)} = 39.0kHz \quad | \quad BW_2 = \frac{1}{2\pi (10^5\Omega)(67.3pF)} = 23.7kHz$

$BW \cong \frac{BW_1}{2} + 0.02 f_{o1} + \frac{BW_2}{2} = \frac{39.0kHz}{2} + 0.02(6.02\,MHz) + \frac{23.7kHz}{2} = 152kHz$

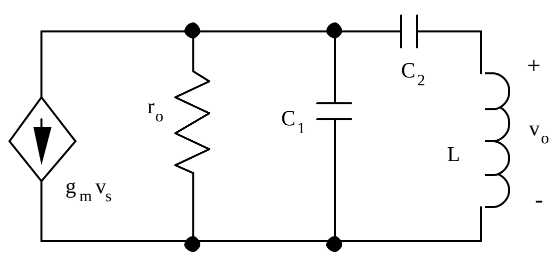
The new $f_o \cong \frac{f_{o1} + 1.02 f_o}{2} = 6.08\ MHz \quad | \quad Q = \frac{6.08\ MHz}{152kHz} = 40$

17.112

```
*Problem 17.112 - Stagger-Tuned Cascode Amplifier
VDD 5 0 DC 12
VS 1 0 AC 1
C3 1 2 20PF
L1 2 0 10UH
C1 2 0 20PF
RG 2 0 100K
M1 3 2 0 0 NFET1
CGS1 2 0 20PF
CGD1 2 3 5PF
M2 4 0 3 3 NFET2
CGS2 3 0 20PF
CGD2 4 3 5PF
L2 4 5 10UH
C2 4 5 62.3PF
RD 4 5 100K
.MODEL NFET1 NMOS VTO=-1 KP=10M
.MODEL NFET2 NMOS VTO=-4 KP=10M
.OP
.AC LIN 200 5.5MEG 6.5MEG
.PRINT AC VM(2) VP(2) VM(3) VP(3) VM(4) VP(4)
.PROBE
.END
```

Results: $A_{mid} = 512$, $f_o = 6.19$ MHz, BW = 0.19 MHz, Q = 33

17.113



$$(a)\begin{bmatrix}-g_mV_s\\0\end{bmatrix}=\begin{bmatrix}s(C_1+C_2)+g_o & -sC_2\\ -sC_2 & sC_2+\dfrac{1}{sL}\end{bmatrix}\begin{bmatrix}V_1\\V_o\end{bmatrix}\quad|\quad A_V(jw)=\frac{V_o}{V_s}=-\frac{jwC_2g_m}{\Delta}$$

$$\Delta(s)=C_1C_2\left[s^2+s\frac{g_o}{C_1}+\frac{g_o}{sC_1C_2L}+\frac{C_1+C_2}{C_1C_2}\frac{1}{L}\right]$$

$$\Delta(jw)=C_1C_2\left[\frac{C_1+C_2}{C_1C_2}\frac{1}{L}-w^2+jw\frac{g_o}{C_1}+\frac{g_o}{jwC_1C_2L}\right]\quad|\quad w_o^2=\frac{C_1+C_2}{C_1C_2}\frac{1}{L}$$

$$A_v(jw_o)=-\frac{w_o\dfrac{g_m}{C_1}}{w_o\dfrac{g_o}{C_1}-\dfrac{g_o}{w_oC_1C_2L}}=-\frac{g_mr_o}{1-\dfrac{1}{w_o^2LC_2}}=-\frac{m_f}{1-\dfrac{C_1}{C_1+C_2}}=-m_f\left(1+\frac{C_1}{C_2}\right)$$

Referring to Eqs. (17.192 - 17.193): $BW=\dfrac{w_o}{Q}=\dfrac{g_o}{C_1}-\dfrac{g_o}{w_o^2C_1C_2L}=\dfrac{1}{r_oC_1}\left(1-\dfrac{1}{w_o^2LC_2}\right)=\dfrac{1}{r_oC_1\left(1+\dfrac{C_1}{C_2}\right)}$

$$C_{EQ}=\frac{45(40)}{45+40}pF=21.2pF\quad|\quad f_o=\frac{1}{2\pi\sqrt{(10mH)(21.2pF)}}=10.9MHz$$

$$r_o=\frac{1}{0.02(20mA)}=2.50k\Omega\quad|\quad BW=\frac{1}{2\pi(2.50k\Omega)(45pF)\left(1+\dfrac{45}{40}\right)}=666\ kHz$$

$$Q=\frac{10.9}{0.666}=16.4\quad|\quad A_{mid}=-m_f\left(1+\frac{C_1}{C_2}\right)=-\sqrt{2(0.005)(0.02)}(2500)\left(1+\frac{45pF}{40pF}\right)=-75.1$$

$$(b)\ f_o=\frac{1}{2\pi\sqrt{(10mH)(25pF)}}=10.1\ MHz\quad|\quad BW=\frac{1}{2\pi(2.5k\Omega)(25pF)}=2.55\ MHz$$

$$Q=\frac{10.1}{2.55}=3.96\quad|\quad A_{mid}=-g_mr_o=-m_f=-35.4$$

17.114

$$C_{EQ}=\frac{(C_1+5pF)C_2}{C_1+5pF+C_2}=25pF\quad|\quad C_2=50pF\quad|\quad C_1=45pF$$

$$f_o=\frac{1}{2\pi\sqrt{(10mH)(25pF)}}=10.1\ MHz\quad|\quad r_o=\frac{1}{0.02(20mA)}=2.50k\Omega$$

Using the results from Prob. 17.113 : $BW=\dfrac{1}{2\pi(2.50k\Omega)(50pF)\left(1+\dfrac{50pF}{50pF}\right)}=635\ kHz$

$$Q=\frac{10.1}{0.635}=15.9\quad|\quad A_{mid}=-m_f\left(1+\frac{C_1}{C_2}\right)=-\sqrt{2(0.005)(0.02)}(2500)\left(1+\frac{50pF}{50pF}\right)=-70.7$$

17.115

```
*Problem 17.115(a) - Fig. P17.121(a)
VS 1 0 AC 1
CGD 1 2 5PF
GM 2 0 1 0 14.1MS
RO 2 0 2.5K
C1 2 0 40PF
C2 2 3 40PF
L1 3 0 10UH
.AC LIN 400 8MEG 12MEG
.PRINT AC VM(2) VP(2) VM(3) VP(3)
.PROBE V(2) V(3)
.END
```

Results: $A_{mid} = 75.1$, $f_o = 10.1$ MHz, BW = 670 kHz

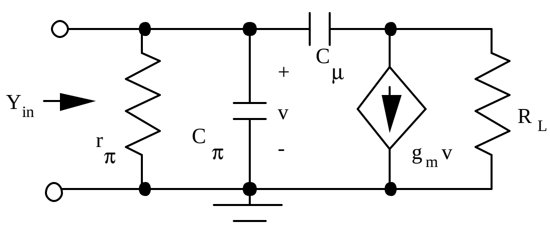
```
*Problem 17.115(b) - Fig. P17.8121b)
VS 1 0 AC 1
CGD 1 2 5PF
GM 2 0 1 0 14.1MS
RO 2 0 2.5K
C1 2 0 20PF
L1 2 0 10UH
.AC LIN 400 8MEG 12MEG
.PRINT AC VM(2) VP(2)
.PROBE V(2)
.END
```

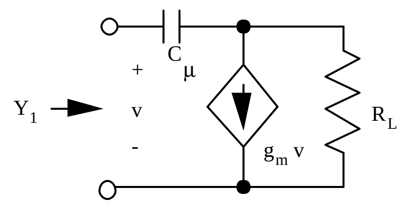
Results: $A_{mid} = 35.3$, $f_o = 10.1$ MHz, BW = 2.50 MHz

```
*Problem 17.115(c) - Problem 17.114
VS 1 0 AC 1
CGD 1 2 5PF
GM 2 0 1 0 14.1MS
RO 2 0 2.5K
C1 2 0 45PF
C2 2 3 50PF
L1 3 0 10UH
.AC LIN 400 8MEG 12MEG
.PRINT AC VM(2) VP(2) VM(3) VP(3)
.PROBE V(2) V(3)
.END
```

Results: $A_{mid} = 70.7$, $f_o = 10.1$ MHz, BW = 640 kHz

17.116





$$Y_{in} = g_p + sC_p + Y_1 \quad | \quad (sC_m - g_m)V = (sC_m + G_L)V_o \quad | \quad V_o = \frac{(sC_m - g_m)}{(sC_m + G_L)}V$$

$$I = sC_m(V - V_o) = sC_m \frac{g_m + G_L}{(sC_m + G_L)}V \quad | \quad Y_1 = \frac{I}{V} = sC_m \frac{g_m + G_L}{(sC_m + G_L)} = sC_m \frac{1 + g_m R_L}{(sC_m R_L + 1)}$$

$$Y_1(jw) = jwC_m \frac{1 + g_m R_L}{(jwC_m R_L + 1)} = jwC_m (1 + g_m R_L) \frac{1 - jwC_m R_L}{(wC_m R_L)^2 + 1} \quad | \quad For\ (wC_m R_L)^2 << 1,$$

$$Y_1(jw) \cong jwC_m (1 + g_m R_L) + \frac{(1 + g_m R_L)}{R_L}(wC_m R_L)^2$$

From the results we see that the input capacitance is correctly modeled by the total Miller input capacitance, but the input resistance is not correctly modeled by just r_π:

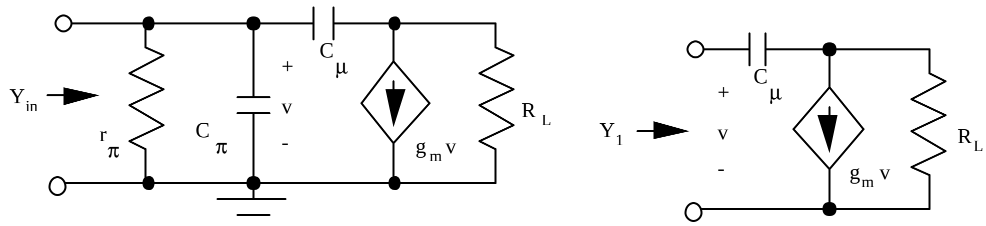
$$C_{in} = C_p + C_m(1 + g_m R_L) \quad | \quad R_{in} = r_p \left\| \frac{R_L}{(1 + g_m R_L)(wC_m R_L)^2} \right.$$

$$(b)\ C_{in} = C_{GS} + C_{GD}(1 + g_m R_L) = 6pF + 2pF[1 + 5mS(10k\Omega)] = 108pF$$

$$R_{in} = \frac{R_L}{(1 + g_m R_L)(wC_{GD} R_L)^2} = \frac{10k\Omega}{[1 + 5mS(10k\Omega)][2p(5x10^6)(2pF)(10k\Omega)]^2} = 497\Omega\ !$$

Note also that $X_{C_{in}} = \dfrac{1}{2p(5x10^6)(108pF)} = 295\ \Omega$ | Both values are far less than infinity.

Although the C_T approximation gives an excellent estimate for the dominant pole of the common-emitter amplifier, it does not do a good job of representing the input admittance at high frequencies. An improved estimate is needed for several of the problems to come.



$$Y_{in} = g_p + sC_p + Y_1 \quad | \quad (sC_m - g_m)V = (sC_m + G_L)V_o \quad | \quad V_o = \frac{(sC_m - g_m)}{(sC_m + G_L)}V$$

$$I = sC_m(V - V_o) = sC_m \frac{g_m + G_L}{(sC_m + G_L)}V \quad | \quad Y_1 = \frac{I}{V} = sC_m \frac{g_m + G_L}{(sC_m + G_L)} = sC_m \frac{1 + g_m R_L}{(sC_m R_L + 1)}$$

$$Y_1(jw) = jwC_m \frac{1 + g_m R_L}{(jwC_m R_L + 1)} = jwC_m (1 + g_m R_L) \frac{1 - jwC_m R_L}{(wC_m R_L)^2 + 1} \quad | \quad For\ (wC_m R_L)^2 << 1,$$

$$Y_1(jw) \cong jwC_m (1 + g_m R_L) + \frac{(1 + g_m R_L)}{R_L}(wC_m R_L)^2$$

From the results we see that the input capacitance is correctly modeled by the total Miller input capacitance, but the input resistance is not correctly modeled by just r_π:

$$C_{in} = C_p + C_m(1 + g_m R_L) \quad | \quad R_{in} = r_p \left\| \frac{R_L}{(1+g_m R_L)(wC_m R_L)^2} \right.$$

17.117

$$(a)\ f_S = 900MHz \quad | \quad f_{LO} = 1000MHz \quad | \quad f_{VHF} = f_{LO} - f_S = 100MHz \quad | \quad f_{IM} = f_{LO} + f_S = 1900MHz$$

$$(b)\ f_S = 900MHz \quad | \quad f_{LO} = 800MHz \quad | \quad f_{VHF} = f_S - f_{LO} = 100MHz \quad | \quad f_{IM} = f_S + f_{LO} = 1700MHz$$

17.118

$$\text{Using Eq. }(17.192):\ T(s) = A_{mid}\frac{s\frac{w_o}{Q}}{s^2 + s\frac{w_o}{Q} + w_o^2} \quad | \quad f_o = 100MHz \quad | \quad f = 1900MHz \quad | \quad Q = 75$$

$$T(jw) = A_{mid}\frac{jw\frac{w_o}{Q}}{w_o^2 - w^2 + jw\frac{w_o}{Q}} = A_{mid}\frac{j\frac{w_o}{wQ}}{\frac{w_o^2}{w^2} - 1 + j\frac{w_o}{wQ}} = A_{mid}\frac{j\frac{f_o}{fQ}}{\frac{f_o^2}{f^2} - 1 + j\frac{f_o}{fQ}}$$

$$|T(jw)| = |A_{mid}|\frac{\frac{f_o}{fQ}}{\sqrt{\left(\frac{f_o^2}{f^2} - 1\right)^2 + \left(\frac{f_o}{fQ}\right)^2}} = |A_{mid}|\frac{\frac{100}{1900(75)}}{\sqrt{\left[\left(\frac{100}{1900}\right)^2 - 1\right]^2 + \left(\frac{100}{1900(75)}\right)^2}} = 7.04x10^{-3}|A_{mid}|$$

$$\text{Relative gain at 1900MHz} \quad = 20\log\left(7.04x10^{-3}\right) = -63.1\ dB \quad | \quad \text{Attenuation} \quad = 63.1\ dB$$

17.119

$$\text{Using Eq. }(17.192):\ T(s) = A_{mid}\frac{s\frac{w_o}{Q}}{s^2 + s\frac{w_o}{Q} + w_o^2} \quad | \quad f_o = 10.7\ MHz \quad | \quad f = 189.3\ MHz \quad | \quad Q = 50$$

$$T(jw) = A_{mid}\frac{jw\frac{w_o}{Q}}{w_o^2 - w^2 + jw\frac{w_o}{Q}} = A_{mid}\frac{j\frac{w_o}{wQ}}{\frac{w_o^2}{w^2} - 1 + j\frac{w_o}{wQ}} = A_{mid}\frac{j\frac{f_o}{fQ}}{\frac{f_o^2}{f^2} - 1 + j\frac{f_o}{fQ}}$$

$$|T(jw)| = |A_{mid}|\frac{\frac{f_o}{fQ}}{\sqrt{\left(\frac{f_o^2}{f^2} - 1\right)^2 + \left(\frac{f_o}{fQ}\right)^2}} = |A_{mid}|\frac{\frac{10.7}{189.3(50)}}{\sqrt{\left[\left(\frac{10.7}{189.3}\right)^2 - 1\right]^2 + \left(\frac{10.7}{189.3(75)}\right)^2}} = 1.13x10^{-3}|A_{mid}|$$

$$\text{Relative gain at 189.3 MHz} \quad = 20\log\left(1.13x10^{-3}\right) = -58.9\ dB \quad | \quad \text{Attenuation} \quad = 58.9\ dB$$

17.120

$(a)\, f_S = 1800 \leftrightarrow 2000 MHz \quad | \quad f_{IF} = 70 MHz$

$f_{LO}^{\min} = f_S^{\min} - f_{IF} = 1800 - 70 = 1730\ MHz \quad | \quad f_{LO}^{\max} = f_S^{\max} - f_{IF} = 2000 - 70 = 1930\ MHz$

$f_{IM}^{\min} = f_S^{\min} + f_{LO}^{\min} = 1800 + 1730 = 3530\ MHz \quad | \quad f_{IM}^{\min} = f_S^{\max} + f_{LO}^{\max} = 2000 + 1930 = 3930\ MHz$

$(b)\, f_S = 1800 \leftrightarrow 2000 MHz \quad | \quad f_{IF} = 70 MHz$

$f_{LO}^{\min} = f_S^{\min} + f_{IF} = 1800 + 70 = 1870\ MHz \quad | \quad f_{LO}^{\max} = f_S^{\max} + f_{IF} = 2000 + 70 = 2070\ MHz$

$f_{IM}^{\min} = f_S^{\min} + f_{LO}^{\min} = 1800 + 1870 = 3670\ MHz \quad | \quad f_{IM}^{\min} = f_S^{\max} + f_{LO}^{\max} = 2000 + 2070 = 4070\ MHz$

(c) In both cases, the LO range overlaps the received frequency range which is not the most desirable choice for LO. Because of the low IF frequency, there is not much difference in the image frequencies.

17.121

$$(a)\ V_{EQ} = -12\frac{30k\Omega}{10k\Omega + 30k\Omega} = -9V \quad | \quad R_{EQ} = 10k\Omega \| 30k\Omega = 7.5k\Omega$$

$$I_{EE} = 100\frac{-9 - 0.7 - (-12)}{7500 + (101)2200} = 1.00\ mA \quad | \quad I_1 = g_m v_{r_p} = g_m \frac{r_p}{r_p + (b_o + 1)R_E} V_1 = \frac{b_o}{r_p + (b_o + 1)R_E} V_1$$

$$r_p = \frac{100(0.025V)}{1.00mA} = 2.5k\Omega \quad | \quad I_1 = \frac{100(0.25V)}{2.5k\Omega + (101)2.2k\Omega} = 111\ mA \quad | \quad f_2 = 2kHz \quad | \quad f_1 = 1MHz$$

$$(b)\ v_O(t) = \sum_{n\ odd} \frac{4}{np}\left[6.2\sin nw_2 t + 0.344\sin(nw_2 - w_1)t - 0.344\sin(nw_2 + w_1)t\right]$$

$$n = 1: \quad \frac{4}{p}\left[6.2\sin 2p(1.00MHz)t + 0.344\sin 2p(0.998MHz)t - 0.344\sin 2p(1.002MHz)t\right]$$

$$n = 3: \quad \frac{4}{3p}\left[6.2\sin 2p(3.00MHz)t + 0.344\sin 2p(2.998MHz)t - 0.344\sin 2p(3.002MHz)t\right]$$

$$0.998\text{ MHz}: \ \frac{1.38}{p} = 0.438\ V \quad | \quad 1.000\text{ MHz}: \ \frac{24.8}{p} = 7.89\ V \quad | \quad 1.002\text{ MHz}: \ -\frac{1.38}{p} = -0.438\ V$$

$$2.998\text{ MHz}: \ \frac{1.38}{3p} = 0.146\ V \quad | \quad 3.000\text{ MHz}: \ \frac{24.8}{3p} = 2.63\ V$$

$$(c)\ V_1^{\max} = 5mV(1 + g_m R_E) = 0.005\left[1 + 40(1.00mA)(2.2k\Omega)\right] = 0.445\ V$$

17.122

$$v_O(t)=\sum_{n\,odd}\frac{4}{np}\left[5\sin nw_1t+0.5\sin(n-1)w_1t-0.5\sin(n+1)w_1t\right]$$

$$n=1:\quad \frac{4}{p}\left[5\sin w_1t-0.5\sin 2w_1t\right]$$

$$n=3:\quad \frac{4}{3p}\left[5\sin 3w_1t+0.5\sin 2w_1t-0.5\sin 4w_1t\right]$$

$$n=5:\quad \frac{4}{5p}\left[5\sin 5w_1t+0.5\sin 4w_1t-0.5\sin 6w_1t\right]$$

$$n=7:\quad \frac{4}{7p}\left[5\sin 7w_1t+0.5\sin 6w_1t-0.5\sin 8w_1t\right]$$

$$w_1:\ \frac{20}{p}=6.37\ V\quad|\quad 2w_1:\ -\frac{2}{p}+\frac{2}{3p}=-\frac{4}{3p}=0.424\ V\quad|\quad 3w_1:\ \frac{20}{3p}=2.12\ V$$

$$4w_1:\ -\frac{2}{3p}+\frac{2}{5p}=-\frac{4}{15p}=0.9849\ V\quad|\quad 5w_1:\ \frac{4}{p}=1.27\ V$$

17.123 The amplitude of each of the first two sidebands is 1/2 the amplitude of the carrier.

17.124

(a) For n = 2, the output is zero.

$$v_O(t)=0.01\left(\frac{5k\Omega}{0.5k\Omega}\right)\left(\frac{2}{p}\right)\left[\cos\left(1.6x10^8pt\right)-\cos\left(2.0x10^8pt\right)\right]$$

$$v_O(t)=0.0637\ \left[\cos\left(1.6x10^8pt\right)-\cos\left(2.0x10^8pt\right)\right]V$$

(b) Using the result for the differential pair in Section 15.3.3,

$$V_1\le 0.027V\left[1+40(2mA)(0.5k\Omega)\right]=1.11\ V$$

17.125

$$(a)\ v_O(t)=V_m\left(\frac{1k\Omega}{0.1k\Omega}\right)\left(\frac{2}{p}\right)\left[\cos(w_c-w_m)t-\cos(w_c+w_m)t\right]$$

$$v_O(t)=\frac{20}{p}V_m\ \left[\cos\left(1.6x10^8pt\right)-\cos\left(2.0x10^8pt\right)\right]V$$

$$A_v=\frac{20V_m}{pV_m}=\frac{20}{p}=6.37$$

(b) Using the result for the differential pair in Section 15.3.3,

$$V_1\le 0.027V\left[1+40(5mA)(0.1k\Omega)\right]=0.567\ V$$

17.126

$$v_O(t)=V_m\frac{R_C}{R_1}\sum_{n\,odd}\frac{4}{np}\cos nw_ct\cos w_mt=V_m\frac{R_C}{R_1}\left[\sum_{n\,odd}\frac{2}{np}\cos(nw_c-w_m)t\cos(nw_c-w_m)t\right]$$

17.127

$$v_O(t) = \sum_{n\ odd} \frac{4}{np}\left[5\sin nw_1 t + 0.5\sin(n-1)w_1 t - 0.5\sin(n+1)w_1 t\right]$$

$$n = 1: \quad \frac{4}{p}\left[5\sin w_1 t - 0.5\sin 2w_1 t\right]$$

$$n = 3: \quad \frac{4}{3p}\left[5\sin 3w_1 t + 0.5\sin 2w_1 t - 0.5\sin 4w_1 t\right]$$

$$n = 5: \quad \frac{4}{5p}\left[5\sin 5w_1 t + 0.5\sin 4w_1 t - 0.5\sin 6w_1 t\right]$$

$$n = 7: \quad \frac{4}{7p}\left[5\sin 7w_1 t + 0.5\sin 6w_1 t - 0.5\sin 8w_1 t\right]$$

$$w_1: \ \frac{20}{p} = 6.37\ V \quad | \quad 2w_1: \ -\frac{2}{p} + \frac{2}{3p} = -\frac{4}{3p} = 0.424\ V \quad | \quad 3w_1: \ \frac{20}{3p} = 2.12\ V$$

$$4w_1: \ -\frac{2}{3p} + \frac{2}{5p} = -\frac{4}{15p} = 0.9849\ V \quad | \quad 5w_1: \ \frac{4}{p} = 1.27\ V$$

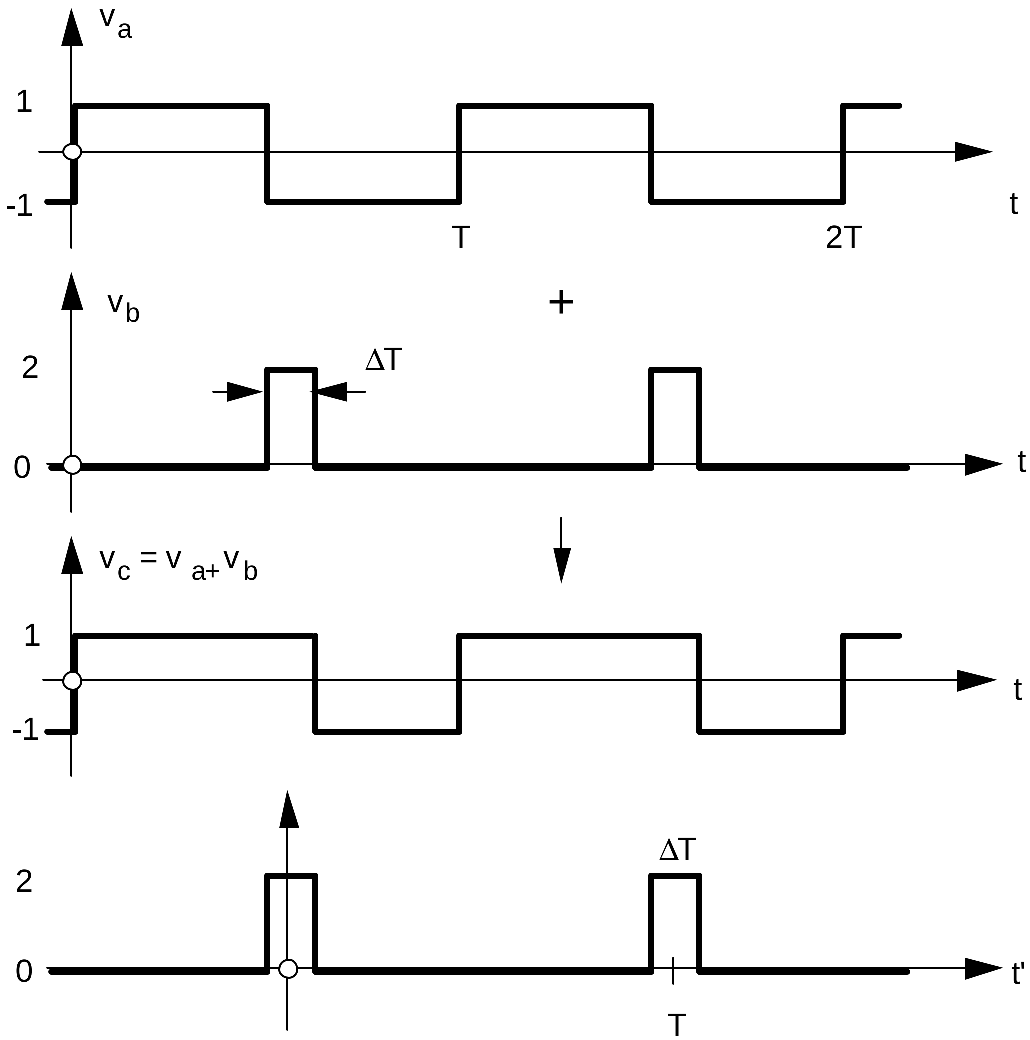
<u>17.128</u>

For this case, the output switches between 0 and v_1, and v_1 is multiplied by the function

$$v_2 = 1 + \sum_{n\ odd} \frac{4}{np}\sin\ nw_2 t \quad \text{and}$$

$$v_O(t) = I_{EE}R_C + I_1R_C\sin\ nw_1 t + \sum_{n\ odd}\frac{4}{np}\left[I_{EE}R_C\sin\ nw_2 t + \frac{I_1R_C}{2}\cos\ (nw_2 - w_1)t - \frac{I_1R_C}{2}\cos\ (nw_2 + w_1)t\right]$$

17.129



$$v_p(t) = 2\frac{\Delta T}{T} + \frac{4}{p}\sum_1^\infty \frac{(-1)^n}{n}\sin(nw_2\Delta T)\cos(nw_2 t)$$

The new undesired term at w_1 in the output is caused by the dc offset term in $v_p(t)$.

$v_{o1}(t) = 2\frac{\Delta T}{T} I_1 R_C \sin w_1 t$. For a 60/40 duty cycle, $v_{o1}(t) = \frac{I_1 R_C}{5}\sin w_1 t$

whereas the desired output component is $v_{o1}(t) = \frac{2}{p} I_1 R_C \cos(w_2 - w_1)t$

17.130

Referring to the previouos problem, $v_p(t) = \frac{\Delta T}{T} + \frac{2}{p}\sum_1^\infty \frac{(-1)^n}{n}\sin(nw_c\Delta T)\cos(nw_c t)$

$$v_o(t) = \mathrm{V_m}\left(\frac{R_C}{R_1}\right)\left[\frac{\Delta T}{T} + \frac{2}{p}\sum_1^\infty \frac{(-1)^n}{n}\sin(nw_c\Delta T)\cos(nw_c t)\right]\sin(w_m)$$

There still is not output at the carrier frequency w_c. The imbalance occurs at w_m.