Microelectronic Circuit Design Sixth Edition - Part II Solutions to Exercises

CHAPTER 6

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$(a)\ A_P = |A_v||A_i| = 4x10^4\left(2.75x10^8\right) = 1.10x10^{13}$

$(b)\ V_o = \sqrt{2P_oR_L} = \sqrt{2(20W)(16\Omega)} = 25.3\ V$ | $A_v = \frac{V_o}{V_i} = \frac{25.3V}{0.005V} = 5.06x10^3$

$I_o = \frac{V_o}{R_L} = \frac{25.3V}{16\Omega} = 1.58\ A$ | $I_i = \frac{V_i}{R_S + R_{in}} = \frac{0.005V}{10k\Omega + 20k\Omega} = 0.167\mu A$ | $A_i = \frac{I_o}{I_i} = \frac{1.58A}{0.167\mu A} = 9.48x10^6$

$A_P = \frac{P_o}{P_S} = \frac{25.3V(1.58A)}{0.005V(0.167\mu A)} = 4.79x10^{10}$ | Checking: $A_p = \left(5.06x10^3\right)\left(9.48x10^6\right) = 4.80x10^{10}$

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$A_{vdB} = 20log(5060) = 74.1\ dB$ | $A_{idB} = 20log(9.48x10^6) = 140\ dB$ | $A_{PdB} = 20log(4.79x10^{10}) = 107\ dB$

$A_{vdB} = 20log(1210) = 61.7\ dB$ | $A_{idB} = 20log(2.51x10^6) = 128\ dB$ | $A_{PdB} = 20log(3.03x10^9) = 94.8\ dB$

$A_{vdB} = 20log(1210) = 61.7\ dB$

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$G_{in} = g_{11} = \frac{1}{20k\Omega + 76(50k\Omega)} = 0.262\ \mu S$ | $A = g_{21} = 0.262\mu S(76)(50k\Omega) = 0.995$

$R_{out} = g_{22} = \left[\frac{1}{50k\Omega} + \frac{1}{20k\Omega} + \frac{75}{20k\Omega}\right]^{-1} = 262\ \Omega$ | $g_{12} = -\frac{g_{22}}{(20k\Omega)} = -\frac{262\Omega}{(20k\Omega)} = -0.0131$

$R_{in} = \frac{1}{g_{11}} = 3.82\ M\Omega$ | $A = g_{21} = 0.995$ | $R_{out} = \frac{1}{g_{22}} = 262\ \Omega$

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$R_{in} = \infty \rightarrow I_1 = 0$ | $I_o \neq 0 \rightarrow A_i = \infty$

$$A_P = A_v A_i = A_v\left(A_v \frac{R_I + R_{in}}{R_L}\right) = A_v^2\left(\frac{R_I + R_{in}}{R_L}\right)$$

$$V_o = \sqrt{2PR_L} = \sqrt{2(100W)(8\Omega)} = 40\ V \quad | \quad V_o = AV_i\left(\frac{R_{in}}{R_I + R_{in}}\right)\left(\frac{R_L}{R_{out} + R_L}\right)$$

$$A = \frac{V_o}{V_i}\left(\frac{R_I + R_{in}}{R_{in}}\right)\left(\frac{R_{out} + R_L}{R_L}\right) = \frac{40V}{0.001V}\left(\frac{5k\Omega + 50k\Omega}{50k\Omega}\right)\left(\frac{0.5\Omega + 8\Omega}{8\Omega}\right) = 4.68x10^4$$

$$A_{db} = 20\log\left(4.68x10^4\right) = 93.4\ dB \quad | \quad P = \frac{I_o^2}{2}R_{out} = \left(\frac{40V}{8\Omega}\right)^2\frac{0.5\Omega}{2} = 6.25\ W$$

$$A_i = \frac{I_o}{I_i} = \frac{I_o}{V_i}\left(R_I + R_{in}\right) = \frac{5V}{0.001V}\left(5k\Omega + 50k\Omega\right) = 2.75x10^8$$

$$A_{db} = 20\log\left(2.75x10^8\right) = 169\ dB$$

$$A = \frac{40V}{0.001V}\left(\frac{5k\Omega + 5k\Omega}{5k\Omega}\right)\left(\frac{8\Omega + 8\Omega}{8\Omega}\right) = 1.6x10^5 \quad | \quad A_{dB} = 20\log\left(1.6x10^5\right) = 104\ dB$$

$$P = \frac{I_o^2}{2}R_{out} = \left(\frac{40V}{8\Omega}\right)^2\frac{8\Omega}{2} = 100\ W! \quad | \quad A_i = \frac{5V}{0.001V}\left(5k\Omega + 5k\Omega\right) = 5x10^7 \quad (154\text{ dB})$$

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(a) The constant slope region spanning a maximum input range is between $-0.5\text{ V} \leq v_{ID} \leq 1.5\ V$, and the bias voltage V_{ID} should be centered in this range: $V_{ID} = \frac{1.5 + (-0.5)}{2}V = +0.5\ V$.

$v_{ID} = V_{ID} + v_{id}$ | $-0.5\text{V} \leq 0.5V + v_{id} \rightarrow v_{id} \geq -1\ V$ and $0.5V + v_{id} \leq 1.5 \rightarrow v_{id} \leq +1\ V$

$\therefore -1\ V \leq v_{id} \leq +1\ V$ or $|v_{id}| \leq 1\ V$ and $|v_o| \leq 10\ V$

(b) For $V_{ID} = -1\ V$, the slope of the voltage transfer characteristics is zero, so $A = 0$.

$$v_O = 10\left(v_{ID} - 0.5V\right) = 10\left(-0.5 + 0.25 + 0.75\sin 1000\pi t\right) = \left(-2.5 + 7.5\sin 1000\pi t\right)\ V \quad | \quad V_O = -2.5\ V$$

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$$A_v(s) = -\frac{2\pi \, x \, 10^6}{s + 5000\pi} = \frac{-400}{1 + \dfrac{s}{5000\pi}} \rightarrow A_{mid} = -400 \quad | \quad f_H = \frac{5000\pi}{2\pi} = 2.50 \; kHz$$

$$BW = f_H - f_L = 2.50 \; kHz - 0 = 2.50 \; kHz \quad | \quad GBW = (400)(2.50kHz) = 1.00 \; MHz$$

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$$f_H = \frac{1}{2\pi} \frac{1}{(1k\Omega \| 100k\Omega)(200\,pF)} = 804 \; kHz$$

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$$A_v(s) = \frac{250}{1 + \dfrac{250\pi}{s}} \quad | \quad A_o = 250 \quad | \quad f_L = \frac{250\pi}{2\pi} = 125 \; Hz \quad | \quad f_H = \infty \quad | \quad BW = \infty - 125 = \infty$$

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$$f_L = \frac{1}{2\pi} \frac{1}{(1k\Omega \| 100k\Omega)(0.1\mu F)} = 15.8 \; Hz$$

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$$A_v(j1) = 50\frac{-1+4}{-1+2+j2} = \frac{150}{1+j2} \quad | \quad |A_v(j1)| = \frac{150}{\sqrt{(1)^2+(2)^2}} = 67.08$$

$$\mathrm{A_{vdB}} = 20\log(67.08) = 36.5\ dB \quad | \quad \angle A_v(j1) = \angle(50) + \angle(3) - \tan^{-1}\left[\frac{2}{1}\right] = 0 + 0 - 63.4^o = -63.4^o$$

$$A_v(j5) = 50\frac{-25+4}{-25+2+j10} = \frac{1050}{23-j10} \quad | \quad |A_v(j5)| = \frac{1050}{\sqrt{(-23)^2+(10)^2}} = 41.87$$

$$A_{vdB} = 20\log(41.87) = 32.4\ dB \quad | \quad \angle A_v(j5) = \angle(1050) + -\tan^{-1}\left[\frac{10}{-23}\right] = 0 - (-23.5^o) = +23.5^o$$

$$\mathrm{A_v}(j\omega) = \frac{20}{1 + j\dfrac{0.1\omega}{1-\omega^2}} \quad | \quad |A_v(j0.95)| = \frac{20}{\sqrt{1^2 + \dfrac{(0.1)^2(0.95^2)}{(1-0.95^2)^2}}} = 14.3$$

$$\angle A_v(j0.95) = \angle 20 - \tan^{-1}\left[\frac{0.1(0.95)}{1-0.95^2}\right] = 0 - (44.3^o) = -44.3^o$$

$$|A_v(j1)| = \frac{20}{\sqrt{1^2 + \dfrac{(0.1)^2(1^2)}{(1-1^2)^2}}} = 0 \quad | \quad \angle A_v(j1) = \angle 20 - \tan^{-1}\left[\frac{0.1(1)}{1-1^2}\right] = 0 - (90^o) = -90.0^o$$

$$|A_v(j1.1)| = \frac{20}{\sqrt{1^2 + \dfrac{(0.1)^2(1.1^2)}{(1-1.1^2)^2}}} = 17.7 \quad | \quad \angle A_v(j1.1) = \angle 20 - \tan^{-1}\left[\frac{0.1(1.1)}{1-1.1^2}\right] = 0 - (-27.6^o) = +27.6^o$$

$$(i)\ A_v(s) = \frac{-400}{\left(1+\dfrac{100}{s}\right)\left(1+\dfrac{s}{50000}\right)} \quad | \quad A_o = 400 \text{ or } 52\ dB$$

$$f_L = \frac{100}{2\pi} = 15.9\ Hz \quad | \quad f_H = \frac{50000}{2\pi} = 7.96\ kHz \quad | \quad BW = 7960 - 15.9 = 7.94\ kHz$$

CHAPTER 7

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(a) At the Q-point : $\beta_F = \frac{I_C}{I_B} = \frac{1.5mA}{15\mu A} = 100$

$$(b)\ I_S = \frac{I_C}{exp\left(\frac{V_{BE}}{V_T}\right)} = \frac{1.5mA}{exp\left(\frac{0.700V}{0.0259V}\right)} = 2.74\ fA$$

$(c)\ R_{in} = \frac{v_{be}}{i_b} = \frac{8mV}{5\mu A} = 1.6\ k\Omega$ (d) Yes. With the given applied signal, the smallest value of v_{CE} is $v_{CE}^{min} = 5V - 0.5mA(3.3k\Omega) = 3.35\ V$ which exceeds $v_{BE} = 0.708\ V$. $(e)\ A_{vdB} = 20\log|-206| = 46.3\ dB$

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(a) No: $v_{DS}^{min} \cong 2.7V$ with $v_{GS} - V_{TN} = 4 - 1 = 3V$, so the transistor has entered the triode region.

(b) Choose two points on the i-v characteristics. For example,

$$1.56mA = \frac{K_n}{2}\left(3.5 - V_{TN}\right)^2 \text{ and } 1.0mA = \frac{K_n}{2}\left(3.0 - V_{TN}\right)^2.$$

Solving for K_n and V_{TN} yields $500\frac{\mu A}{V^2}$ and 1 V respectively.

$(c)\ A_{vdB} = 20\log|-4.13| = 12.3\ dB$

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$$V_{EQ} = \frac{10k\Omega}{10k\Omega + 30k\Omega}12V = 3.00\ V \quad | \quad R_{EQ} = 10k\Omega \| 30k\Omega = 7.5\ k\Omega$$

$$I_C = \beta_F I_B = \beta_F \frac{V_{EQ} - V_{BE}}{R_{EQ} + \left(\beta_F + 1\right)R_4} = 100\frac{3.0V - 0.7V}{7.5k\Omega + (101)(1.5k\Omega)} = 1.45\ mA$$

$$V_{CE} = 12 - 4300 I_C - 1500 I_E = 12 - 4300(1.45mA) - 1500\left(\frac{101}{100}\right)(1.45mA) = 3.57\ V$$

$$V_B = V_{EQ} - I_B R_{EQ} = 3.00 - \frac{1.45mA}{100}(7.5k\Omega) = 2.89\ V$$

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$$v_C(t) = V_C + v_C = (5.8 - 1.1\sin 2000\pi t)\ V \quad | \quad v_E(t) = V_E + 0 = 1.45mA\left(\frac{101}{100}\right)(1.5k\Omega) = 2.20\ V$$

$$|i_c| = \frac{1.1V}{4.3k\Omega} = 0.256mA \quad | \quad \angle i_c = 180^o \quad | \quad i_c(t) = -0.26\sin 2000\pi t\ \ mA \quad | \quad v_B(t) = V_B + v_b(t)$$

$$V_B = V_{EQ} - I_B R_{EQ} = 3.00 - \frac{1.45mA}{100}(7.5k\Omega) = 2.89\ V \quad | \quad v_B(t) = (2.89 + 0.005\sin\sin 2000\pi)\ V$$

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$$X_C = \frac{1}{\omega C} = \frac{1}{2000\pi(500\mu F)} = 0.318\ \Omega \quad | \quad X_C << R_{in}$$

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$$R_B = 20k\Omega \| 62k\Omega = 15.1\ k\Omega \quad | \quad R_L = 8.2k\Omega \| 100k\Omega = 7.58\ k\Omega$$

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$$r_d = \frac{V_T}{I_D + I_S} \quad | \quad r_d = \frac{0.025V}{1fA} = 25.0\ T\Omega \quad | \quad r_d = \frac{0.025V}{50\mu A} = 500\ \Omega$$

$$r_d = \frac{0.025V}{2mA} = 12.5\ \Omega \quad | \quad r_d = \frac{0.025V}{3A} = 8.33\ m\Omega$$

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$$r_d = \frac{0.025V}{1.5mA} = 16.7\ \Omega \quad | \quad \frac{kT}{q} = \left(8.62x10^{-5}\frac{V}{K}\right)(373K) = 0.0322\ V \quad | \quad r_d = \frac{0.0322V}{1.5mA} = 21.4\ \Omega$$

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$$g_m = 40I_C = 40(50\mu A) = 2.00\ mS \quad | \quad r_\pi = \frac{\beta_o}{g_m} = \frac{75}{2mS} = 37.5\ k\Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{60V + 5V}{50\mu A} = 1.30\ M\Omega \quad | \quad \mu_f = g_m r_o = 2mS(1.30\,M\Omega) = 2600$$

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$$g_m = 40I_C = 40(250\mu A) = 10.0\ mS \quad | \quad r_\pi = \frac{\beta_o}{g_m} = \frac{50}{10mS} = 5.00\ k\Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{75V + 15V}{250\mu A} = 360\ k\Omega \quad | \quad \mu_f = g_m r_o = 10mS(360k\Omega) = 3600$$

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The slope of the output characteristics is zero, so $V_A = \infty$ and $r_o = \infty$.

$$\beta_{FO} = \frac{\beta_F}{1 + \frac{V_{CE}}{V_A}} = \beta_F = \frac{I_C}{I_B} = \frac{1.5mA}{15\mu A} = 100 \quad | \quad g_m = \frac{\Delta i_C}{\Delta v_{BE}} = \frac{0.5mA}{8mV} = 62.5\ mS$$

$$\beta_o = \frac{\Delta i_C}{\Delta i_B} = \frac{500\mu A}{5\mu A} = 100 \quad | \quad r_\pi = \frac{\beta_o}{g_m} = \frac{100}{62.5mS} = 1.60\ k\Omega \quad | \quad r_\pi = \frac{\Delta v_{BE}}{\Delta i_B} = \frac{8mV}{0.5mA/100} = 1.60\ k\Omega$$

$r_\mu = \beta_o r_o = 100 r_o$ | Multiply each entry by 100.

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$A_{vt} = -g_m R_L = -9.80mS(18k\Omega) = -176$ | Ten percent of the input signal is being lost by voltage division between source resistance R_I and the amplifier input resistance.

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Assume the Q-point remains constant.

$(a)\ R_{iB} = r_\pi = \frac{125}{9.80mS} = 12.8\ k\Omega$ | $A_v = -9.80mS(18k\Omega)\left(\frac{104k\Omega \| 12.8k\Omega}{1k\Omega + 104k\Omega \| 12.8k\Omega}\right) = -162$

$(b)\ R_L^{max} = 1.1(18k\Omega) = 19.8\ k\Omega$ | $R_L^{min} = 0.9(18k\Omega) = 16.2\ k\Omega$

$$A_v^{min} = -9.80mS(16.2k\Omega)\left(\frac{104k\Omega \| 10.2k\Omega}{1k\Omega + 104k\Omega \| 10.2k\Omega}\right) = -143$$

$$A_v^{max} = A_v^{min}\left(\frac{19.8k\Omega}{16.2k\Omega}\right) = -143\left(\frac{19.8k\Omega}{16.2k\Omega}\right) = -175$$

Checking: $A_v^{min} = A_v^{nom}\left(\frac{16.2k\Omega}{18k\Omega}\right) = -159(0.9) = -143$ | $A_v^{max} = A_v^{nom}\left(\frac{19.8k\Omega}{18k\Omega}\right) = -159(1.1) = -175$

$(c)\ V_{CE} = 12V - 22k\Omega I_C - 13k\Omega I_E = 12V - 0.275mA\left(22k\Omega + \frac{101}{100}13k\Omega\right) = 2.34\ V$

$g_m = 40(0.275mA) = 11.0\ mS$ | $R_{iB} = r_\pi = \frac{100}{11.0mS} = 9.09\ k\Omega$

$$A_v = -11.0mS(18k\Omega)\left(\frac{104k\Omega \| 9.09k\Omega}{1k\Omega + 104k\Omega \| 9.09k\Omega}\right) = -177$$

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$A_v^{CE} \cong -10V_{CC} = -10(20) = -200$ | $g_m = 40I_C = 40(100\mu A) = 4.00\ mS$ | $R_{iB} = r_\pi = \frac{\beta_o}{g_m} = \frac{100}{4mS} = 25\ k\Omega$

$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{50V + 10V}{100\mu A} = 600\ k\Omega$ | $\mu_f = g_m r_o = 4mS(600k\Omega) = 2400$

$$A_v = -g_m(R_C \| r_o)\frac{R_B \| R_{iB}}{R_I + R_B \| R_{iB}} = -4.00mS(100k\Omega \| 600k\Omega)\left(\frac{150k\Omega \| 25k\Omega}{5k\Omega + 150k\Omega \| 25k\Omega}\right) = -278$$

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$$V_{EQ} = \frac{160k\Omega}{160k\Omega + 300k\Omega}12V = 4.17\ V \quad | \quad R_{EQ} = 160k\Omega \| 300k\Omega = 104\ k\Omega$$

$$I_C = \beta_F I_B = \beta_F \frac{V_{EQ} - V_{BE}}{R_{EQ} + (\beta_F + 1)R_E} = 100\frac{4.17V - 0.7V}{104k\Omega + (101)(13k\Omega)} = 0.245\ mA$$

$$V_{CE} = 12 - 22000 I_C - 13000 I_E = 12 - 22000(0.245mA) - 13000\left(\frac{101}{100}\right)(0.245mA) = 3.39\ V$$

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$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CB}}{V_A}\right) \quad | \quad V_T = \frac{kT}{q} = \frac{1.38x10^{-23}(300)}{1.6x10^{-19}} = .025875\ V$$

$$I_S = \frac{0.245mA}{\exp\left(\frac{0.7}{0.025875}\right)\left(1 + \frac{3.39 - 0.7}{75}\right)} = 422\ fA$$

There is a units error in the previous equation: I_S = 0.422 fA !

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$$(a)\ g_m = \sqrt{2K_n I_D(1 + \lambda V_{DS})} = \sqrt{2(1mA/V^2)(0.25mA)[1 + 0.02(5)]} = 0.742\ mS$$

$$r_o = \frac{\frac{1}{\lambda} + V_{DS}}{I_D} = \frac{50V + 5V}{250\mu A} = 220\ k\Omega \quad | \quad \mu_f = g_m r_o = 0.742mS(220k\Omega) = 163$$

$$g_m = \sqrt{2K_n I_D(1 + \lambda V_{DS})} = \sqrt{2(1mA/V^2)(5mA)[1 + 0.02(10)]} = 3.46\ mS$$

$$r_o = \frac{\frac{1}{\lambda} + V_{DS}}{I_D} = \frac{50V + 10V}{5mA} = 12\ k\Omega \quad | \quad \mu_f = g_m r_o = 3.46mS(12k\Omega) = 41.5$$

(b) The slope of the output characteristics is zero, so $\lambda = 0$ and $r_o = \infty$.

For the positive change in v_{gs}, $g_m = \frac{\Delta i_D}{\Delta v_{GS}} \cong \frac{\frac{2.1V}{3.3k\Omega}}{0.5V} = 1.3\ mS$

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$$|v_{gs}| \le 0.2(V_{GS} - V_{TN}) = 0.2\sqrt{\frac{2I_D}{K_n}} = 0.2\sqrt{\frac{2(25mA)}{2.0mA/V^2}} = 1.00\ V \quad | \quad |v_{be}| \le 0.005\ V$$

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$$\eta = \frac{\gamma}{2\sqrt{V_{SB} + 2\phi_F}} = \frac{0.75}{2\sqrt{0 + 0.6}} = 0.48 \quad | \quad \eta = \frac{0.75}{2\sqrt{3 + 0.6}} = 0.20$$

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$$I_D = I_{DO} exp\left(\frac{V_{GS} - V_{Tn}}{nV_T}\right) \quad | \quad g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{I_D}{nV_T} \quad | \quad \frac{g_m}{I_D} = \frac{1}{nV_T} = \frac{1}{1.5V_T} = 25.8/V$$

$$I_C = I_S exp\left(\frac{V_{BE}}{V_T}\right) \quad | \quad g_m = \frac{\partial I_D}{\partial V_{BE}} = \frac{I_C}{V_T} \quad | \quad \frac{g_m}{I_D} = \frac{1}{V_T} = \frac{1}{V_T} = 38.8/V$$

$$S = nV_T ln(10) = 1.5(0.0258mV) ln(10) = 89.1\ mV/dec$$

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$$g_m = 2\frac{\sqrt{I_{DSS} I_D (1 + \lambda V_{DS})}}{|V_P|} = 2\frac{\sqrt{5mA(2mA)[1 + 0.02(5)]}}{|-2|} = 3.32\ mS$$

$$r_o = \frac{\frac{1}{\lambda} + V_{DS}}{I_D} = \frac{50V + 5V}{2mA} = 27.5\ k\Omega \quad | \quad \mu_f = g_m r_o = 3.32mS(27.5k\Omega) = 91.3$$

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = -2V\left(1 - \sqrt{\frac{2mA}{5mA}}\right) = -0.735\ V$$

$$|v_{gs}| \le 0.2(V_{GS} - V_P) = 0.2(-0.735 + 2) = 0.253\ V$$

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$$V_{EQ} = \frac{1.5M\Omega}{1.5M\Omega + 2.2M\Omega} 12V = 4.87\ V \quad | \quad R_{EQ} = 1.5M\Omega \| 2.2M\Omega = 892\ k\Omega$$

Neglect λ in hand calculations of the Q - point.

$$4.87 = V_{GS} + 12000 I_D \quad | \quad 4.87 = V_{GS} + 12000\left(\frac{5x10^{-4}}{2}\right)(V_{GS} - 1)^2$$

$$3V_{GS}^2 - 5V_{GS} - 1.87 = 0 \rightarrow V_{GS} = 1.981\ V \quad | \quad I_D = 241\ \mu A$$

$$V_{DS} = 12 - 22000 I_D - 12000 I_D = 3.81\ V \quad | \quad \text{Q - point: } (241\ \mu A,\ 3.81\ V)$$

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The small-signal model appears in Fig. 7.27(c).

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$$V_{GS} - V_{TN} \cong \sqrt{\frac{2(241\mu A)}{2x10^{-3}}} = 0.491\ V \quad | \quad A_v^{CS} \cong -\frac{12V}{0.491V} = -24.4 \quad | \quad M = \frac{K_{n2}}{K_{n1}} = \frac{2x10^{-3}}{5x10^{-4}} = 4$$

$$V_{EQ} = \frac{1.5\,M\Omega}{1.5\,M\Omega + 2.2\,M\Omega} 12V = 4.87\ V \quad | \quad R_{EQ} = 1.5\,M\Omega \| 2.2\,M\Omega = 892\ k\Omega$$

Neglect λ in hand calculations of the Q-point.

$$4.87 = V_{GS} + 12000 I_D \quad | \quad 4.87 = V_{GS} + 12000\left(\frac{5x10^{-4}}{2}\right)\left(V_{GS} - 1\right)^2$$

$$3V_{GS}^2 - 5V_{GS} - 1.87 = 0 \rightarrow V_{GS} = 1.981\ V \quad | \quad I_D = 241\ \mu A$$

$$V_{DS} = 12 - 22000 I_D - 12000 I_D = 3.81\ V \quad | \quad \text{Q-point}: \left(241\ \mu A,\ 3.81\ V\right)$$

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The small-signal model appears in Fig. 13.27(c).

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$$V_{GS} - V_{TN} \cong \sqrt{\frac{2\left(241\mu A\right)}{2x10^{-3}}} = 0.491\ V \quad | \quad A_v^{CS} \cong -\frac{12V}{0.491V} = -24.4 \quad | \quad M = \frac{K_{n2}}{K_{n1}} = \frac{2x10^{-3}}{5x10^{-4}} = 4$$

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$$r_\pi = \frac{\beta_o V_T}{I_C} = \frac{100\left(0.025V\right)}{0.725mA} = 3.45\ k\Omega \quad | \quad R_{in}^{CE} = R_B \| r_\pi = 104k\Omega \| 3.45k\Omega = 3.34\ k\Omega$$

$$R_{in}^{CS} = 680k\Omega \| 1.0\,M\Omega = 405\ k\Omega \quad | \quad V_{EQnew} = \frac{680k\Omega}{680k\Omega + 1M\Omega} V_{DD} = 0.405 V_{DD}$$

$$V_{EQold} = \frac{1.5\,M\Omega}{1.5\,Mk\Omega + 2.2\,M\Omega} V_{DD} = 0.405 V_{DD}$$ | No change. The gate voltages are the same.

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From Ex. 13.6, $\mu_f = 230$ and $A_v = -20.3.$ $\left|A_v\right| << \mu_f$

– – –

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) = -1V\left(1 - \sqrt{\frac{0.25mA}{1mA}}\right) = -0.500\ V$$

$$\left|v_{gs}\right| \le 0.2\left(V_{GS} - V_P\right) = 0.2\left(-0.5 + 1\right) = 0.100\ V \quad | \quad \left|v_o\right| \le 20.3\left(0.1\right) = 2.03\ V$$

– – –

SPICE Results:

$\lambda = 0$: Q-point = $\left(250\ \mu A,\ 4.75\ V\right)$ | $\lambda = 0.02\ V^{-1}$: Q-point = $\left(257\ \mu A,\ 4.54\ V\right)$

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$I_C = 245\ \mu A \quad | \quad V_{CE} = 3.39\ V \quad | \quad I_E = 245\mu A\left(\frac{66}{65}\right) = 249\ \mu A$

$P_D = I_C V_{CE} + I_B V_{BE} = 245\mu A(3.39V) + \frac{245\mu A}{65}(0.7V) = 0.833\ mW$

$P_S = V_{CC}(I_C + I_2) \quad | \quad I_2 = \frac{V_{CC} - V_B}{R_2} = \frac{V_{CC} - (V_{BE} + I_E R_E)}{R_2} = \frac{12 - 0.7 - 0.249mA(13k\Omega)}{300k\Omega} = 26.9\ \mu A$

$P_S = 12V(245\mu A + 26.9\mu A) = 3.26\ mW$

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$P_D = I_D V_{DS} = 241\mu A(3.81V) = 0.918\ mW \quad | \quad P_S = V_{DD}(I_D + I_2)$

$I_2 = \frac{V_{DD}}{R_1 + R_2} = \frac{12V}{1.5M\Omega + 2.2M\Omega} = 3.24\ \mu A \quad | \quad P_S = 12V(241\mu A + 3.24\mu A) = 2.93\ mW$

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$(a)\ V_M \leq \min\left[I_C R_C, (V_{CE} - V_{BE})\right] = \min\left[245\mu A(22k\Omega), (3.39 - 0.7)V\right] = 2.69\ V$

V_M is limited by the value of V_{CE}.

$(b)\ V_M \leq \min\left[I_D R_D, (V_{DS} - V_{DSSAT})\right] = \min\left[241\mu A(22k\Omega), (3.81 - 0.982)V\right] = 2.83\ V$

Limited by the value of V_{DS}.

CHAPTER 8

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$$V_{EQ}=\frac{160k\Omega}{160k\Omega+300k\Omega}12V=4.17\ V \quad | \quad R_{EQ}=160k\Omega\|300k\Omega=104\ k\Omega$$

$$I_C=\beta_F I_B=\beta_F\frac{V_{EQ}-V_{BE}}{R_{EQ}+(\beta_F+1)R_E}=100\frac{4.17V-0.7V}{104k\Omega+(101)(13k\Omega)}=0.245\ mA$$

$$V_{CE}=12-22000I_C-13000I_E=12-22000(0.245mA)-13000\left(\frac{101}{100}\right)(0.245mA)=3.39\ V$$

$$g_m=40I_C=40(0.245mA)=9.80\ mS \quad | \quad r_\pi=\frac{\beta_o}{g_m}=\frac{100}{9.80mS}=10.2\ k\Omega$$

$$r_o=\frac{V_A+V_{CE}}{I_C}=\frac{53.4V}{0.245mA}=218\ k\Omega \quad | \quad \mu_f=g_m r_o=2140$$

– – –

$$V_{EQ}=\frac{1.5M\Omega}{1.5M\Omega+2.2M\Omega}12V=4.87\ V \quad | \quad R_{EQ}=1.5M\Omega\|2.2M\Omega=892\ k\Omega$$

-

Neglect λ in hand calculations of the Q-point.

$$4.87=V_{GS}+12000I_D \quad | \quad 4.87=V_{GS}+12000\left(\frac{5x10^{-4}}{2}\right)(V_{GS}-1)^2$$

$$3V_{GS}^2-5V_{GS}-1.87=0\rightarrow V_{GS}=1.981\ V \quad | \quad I_D=241\ \mu A$$

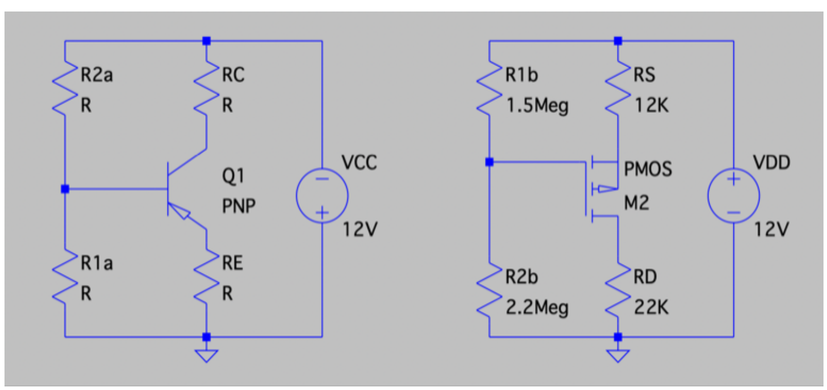
$$V_{DS}=12-22000I_D-12000I_D=3.81\ V \quad | \quad \text{Q-point: }(241\ \mu A,\ 3.81\ V)$$

$$g_m=\sqrt{2K_nI_D}=\sqrt{2(5x10^{-4})(2.41x10^{-4})}=0.491\ mS \quad | \quad r_o=\frac{\lambda^{-1}+V_{CE}}{I_C}=\frac{53.8V}{0.241mA}=223\ k\Omega$$

$$\mu_f=g_m r_o=110$$

- - -

LTSpice Circuit



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$R_B = 160k\Omega \| 300k\Omega = 104\ k\Omega$ | $R_E = 3.00\ k\Omega$ | $R_L = 22k\Omega \| 100k\Omega = 18.0\ k\Omega$

$R_G = 1.5M\Omega \| 2.2M\Omega = 892\ k\Omega$ | $R_S = 2.00\ k\Omega$ | $R_L = 22k\Omega \| 100k\Omega = 18.0\ k\Omega$

– – –

$R_B = 160k\Omega \| 300k\Omega = 104\ k\Omega$ | $R_L = 13k\Omega \| 100k\Omega = 11.5\ k\Omega$

$R_G = 1.5M\Omega \| 2.2M\Omega = 892\ k\Omega$ | $R_L = 12k\Omega \| 100k\Omega = 10.7\ k\Omega$

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$R_I = 2\ k\Omega$ | $R_6 = 13\ k\Omega$ | $R_L = 22k\Omega \| 100k\Omega = 18.0\ k\Omega$

$R_I = 2\ k\Omega$ | $R_6 = 12\ k\Omega$ | $R_L = 22k\Omega \| 100k\Omega = 18.0\ k\Omega$

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$(a)\ I_C \cong \dfrac{V_{EQ} - V_{BE}}{R_E + R_4}$ or $I_C \propto \dfrac{1}{R_E + R_4}$ | $I_C = 0.245mA\dfrac{13k\Omega}{R_E + R_4}$

For large $g_m R_E$, $A_{vt}^{CE} = -\dfrac{g_m R_L}{1 + g_m R_E} \cong -\dfrac{R_L}{R_E} = -\dfrac{R_C \| R_3}{R_E}$

For $A_{vt}^{CE\max}$ make R_C and R_3 large and R_E small. $R_L = 1.1(22k\Omega)\|1.1(100k\Omega) = 19.8\ k\Omega$

$R_E = 0.9(3k\Omega) = 2.7\ k\Omega$ | $I_C = 0.245mA\dfrac{13k\Omega}{12.7k\Omega} = 0.251\ mA$ | $g_m = 40(0.251\ mA) = 10.0\ mS$

$r_\pi = \dfrac{\beta_o}{g_m} = \dfrac{100}{10.0mS} = 10.0\ k\Omega$ | $R_{iB} = 10.0k\Omega + 101(2.7k\Omega) = 283\ k\Omega$

$$A_v^{CE\max} = -\frac{10.0mS(19.8k\Omega)}{1 + 10.0mS(2.7k\Omega)}\left(\frac{104k\Omega\|283k\Omega}{1k\Omega + 104k\Omega\|283k\Omega}\right) = -6.98$$

For $A_{vt}^{CE\min}$ make R_C and R_3 small and R_E large. $R_L = 0.9(22k\Omega)\|0.9(100k\Omega) = 16.2\ k\Omega$

$R_E = 1.1(3k\Omega) = 3.3\ k\Omega$ | $I_C = 0.245mA\dfrac{13k\Omega}{13.3k\Omega} = 0.239\ mA$ | $g_m = 40(0.239\ mA) = 9.56\ mS$

$r_\pi = \dfrac{\beta_o}{g_m} = \dfrac{100}{9.56mS} = 10.5\ k\Omega$ | $R_{iB} = 10.5k\Omega + 101(3.3k\Omega) = 344\ k\Omega$

$$A_v^{CE\min} = -\frac{9.56mS(16.2k\Omega)}{1 + 9.56mS(3.3k\Omega)}\left(\frac{104k\Omega\|344k\Omega}{1k\Omega + 104k\Omega\|344k\Omega}\right) = -4.70$$

(b) Assume the collector current does not change.

$r_\pi = \dfrac{\beta_o}{g_m} = \dfrac{125}{9.8mS} = 12.8\ k\Omega$ | $R_{iB} = 12.8k\Omega + 126(3.0k\Omega) = 391\ k\Omega$

$$A_v^{CE} = -\frac{9.80mS(18k\Omega)}{1 + 9.80mS(3k\Omega)}\left(\frac{104k\Omega\|391k\Omega}{1k\Omega + 104k\Omega\|391k\Omega}\right) = -5.73$$ The gain is essentially unchanged.

$(c)\ V_{CE} = V_{CC} - I_C R_C - I_E(R_E + R_4) = 12V - 0.275mA\left(22k\Omega + \dfrac{101}{100}13k\Omega\right) = 2.34\ V$

$2.34\ V > 0.7\ V$ Therefore the transistor is still in the active region.

$g_m = 40(0.275mA) = 11.0\ mS$ | $r_\pi = \dfrac{\beta_o}{g_m} = \dfrac{100}{11mS} = 9.09\ k\Omega$ | $R_{iB} = 9.09k\Omega + 101(3.0k\Omega) = 312\ k\Omega$

$$A_v^{CE} = -\frac{11.0mS(18k\Omega)}{1 + 11.0mS(3k\Omega)}\left(\frac{104k\Omega\|312k\Omega}{1k\Omega + 104k\Omega\|312k\Omega}\right) = -5.75$$ The gain is essentially unchanged.

Continued on the next page

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$$R_{iC} = 320k\Omega\left[1+\frac{100(2k\Omega)}{(1k\Omega\|104k\Omega)+10.2k\Omega+2k\Omega}\right]=5.17\ M\Omega \quad | \quad \mu_f R_E = 3140(2k\Omega)=6.28\ M\Omega$$

$$R_{iC} < \mu_f R_E \quad | \quad R_{out} = 5.17\,M\Omega\|22k\Omega = 21.9\ k\Omega \quad | \quad R_{out} << \mu_f R_E$$

– – –

$$\lim_{R_E\to\infty} R_{iC} = \lim_{R_E\to\infty} r_o\left(1+\frac{\beta_o R_E}{R_{th}+r_\pi+R_E}\right)=r_o\left(1+\frac{\beta_o R_E}{R_E}\right)=(\beta_o+1)r_o$$

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$$R_{iB} = 10.2k\Omega + 101(1k\Omega) = 111\ k\Omega$$

$$A_v = -\frac{9.80mS(18k\Omega)}{1+9.80mS(1k\Omega)}\left(\frac{104k\Omega\|111k\Omega}{1k\Omega+104k\Omega\|111k\Omega}\right)=-16.0 \quad | \quad R_4 = 13k\Omega - 1k\Omega = 12\ k\Omega.$$

– – –

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)\left(1+\frac{V_{CB}}{V_A}\right) \quad | \quad V_T = \frac{kT}{q} = \frac{1.38x10^{-23}(300)}{1.60x10^{-19}} = .025875\ V$$

$$I_S = \frac{0.245mA}{\exp\left(\frac{0.7}{0.025875}\right)\left(1+\frac{3.39-0.7}{100}\right)} = 425\ fA$$

The anwer above should be 0.425 fA.

– – –

$$A_v^{CE} \cong -10V_{CC} = -10(20) = -200 \quad | \quad g_m = 40I_C = 40(100\mu A) = 4.00\ mS \quad | \quad R_{iB} = r_\pi = \frac{\beta_o}{g_m} = \frac{100}{4mS} = 25\ k\Omega$$

$$r_o = \frac{V_A+V_{CE}}{I_C} = \frac{50V+10V}{100\mu A} = 600\ k\Omega \quad | \quad \mu_f = g_m r_o = 4mS(600k\Omega) = 2400$$

$$A_v^{CE} = -g_m(R_C\|r_o)\frac{R_B\|R_{iB}}{R_I+R_B\|R_{iB}} = -4.00mS(100k\Omega\|600k\Omega)\left(\frac{150k\Omega\|25k\Omega}{5k\Omega+150k\Omega\|25k\Omega}\right)=-278$$

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$$V_{EQ} = \frac{1.5\,M\Omega}{1.5\,M\Omega+2.2\,M\Omega}12V = 4.87\ V \quad | \quad R_{EQ} = 1.5\,M\Omega\|2.2\,M\Omega = 892\ k\Omega$$

Neglect λ in hand calculations of the Q-point.

$$4.87 = V_{GS} + 12000I_D \quad | \quad 4.87 = V_{GS} + 12000\left(\frac{5x10^{-4}}{2}\right)(V_{GS}-1)^2$$

$$3V_{GS}^2 - 5V_{GS} - 1.87 = 0 \rightarrow V_{GS} = 1.981\ V \quad | \quad I_D = 241\ \mu A$$

$$V_{DS} = 12 - 22000I_D - 12000I_D = 3.81\ V \quad | \quad \text{Q-point: } (241\ \mu A,\ 3.81\ V)$$

– – –

$$A_{vdB}^{CS} = 20\log|-4.50| = -13.1\ dB$$

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$$R_{iB} = 10.2k\Omega + 101(1k\Omega) = 111k\Omega$$

$$A_v^{CE} = -\frac{9.80mS(18k\Omega)}{1+9.80mS(1k\Omega)}\left(\frac{104k\Omega \| 111k\Omega}{1k\Omega + 104k\Omega \| 111k\Omega}\right) = -16.0 \quad | \quad R_4 = 13k\Omega - 1k\Omega = 12\ k\Omega$$

$$A_v^{CS} = -\frac{0.503mS(18k\Omega)}{1+0.503mS(1k\Omega)}\left(\frac{892k\Omega}{1k\Omega + 892k\Omega}\right) = -6.02 \quad | \quad R_4 = 12k\Omega - 1k\Omega = 11\ k\Omega$$

$$(iii)\ R_{iB} = 10.2k\Omega + 101(13k\Omega) = 1.32\ M\Omega$$

$$A_v^{CE} = -\frac{9.80mS(18k\Omega)}{1+9.80mS(13k\Omega)}\left(\frac{104k\Omega \| 1.32M\Omega}{1k\Omega + 104k\Omega \| 1.32M\Omega}\right) = -1.36 \quad | \quad A_v^{CE} \cong -\frac{R_L}{R_E + R_4} = -\frac{18k\Omega}{13k\Omega} = -1.38$$

$$A_v^{CS} = -\frac{0.503mS(18k\Omega)}{1+0.503mS(12k\Omega)}\left(\frac{892k\Omega}{1k\Omega + 892k\Omega}\right) = -1.29 \quad | \quad A_v^{CS} \cong -\frac{R_L}{R_S + R_4} = -\frac{18k\Omega}{12k\Omega} = -1.50$$

- - -

$$V_T = \left(\frac{1.381x10^{-23}}{1.602x10^{-19}}\frac{V}{K}\right)(273K + 27K) = 25.861\ mV \quad | \quad I_S = \frac{I_C}{\exp\left(\frac{V_{BE}}{V_T}\right)} = \frac{245\mu A}{\exp\left(\frac{0.700V}{0.025861V}\right)} = 0.430\,fA$$

– – –

$$g_m R_L = \text{-9.80mS}(18k\Omega) = -176 \quad | \quad A_v^{CE} \cong -\frac{18k\Omega}{3k\Omega} = -6.00 \quad | \quad 5.72 < 6.00$$

$$g_m R_L = \text{-0.503mS}(18k\Omega) = -9.05 \quad | \quad A_v^{CS} \cong -\frac{18k\Omega}{2k\Omega} = -9.00 \quad | \quad 4.50 < 9.00$$

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$$R_B = 160k\Omega \| 300k\Omega = 104k\Omega \quad | \quad R_{iB} \cong r_\pi(1 + g_m R_L) = \frac{2.5V}{0.25mA}\left[1 + 10mS(11.5k\Omega)\right] = 1.16\ M\Omega$$

$$v_i \le 0.005V(1 + g_m R_L)\frac{R_I + R_B \| R_{iB}}{R_B \| R_{iB}} = 0.005V\left[1 + 10mS(11.5k\Omega)\right]\frac{2k\Omega + 95.4k\Omega}{95.4k\Omega} = 0.592\ V$$

$$v_i \le 0.2(V_{GS} - V_{TN})(1 + g_m R_L)\frac{R_I + R_G}{R_G} = 0.2(1V)\left[1 + 0.5mS(10.7k\Omega)\right]\frac{2k\Omega + 892k\Omega}{892k\Omega} = 1.27\ V$$

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Add r_o either in parallel the dependent current source or in parallel with v_x.

$$i_x = \frac{v_x}{r_o} + \frac{v_x}{r_\pi + R_{TH}} - \beta_o i_x = \frac{v_x}{r_o} + \frac{v_x}{r_\pi + R_{TH}} - \beta_o\left(-\frac{v_x}{r_\pi + R_{TH}}\right)$$

$$\frac{i_x}{v_x} = \frac{1}{r_o} + \frac{\beta_o + 1}{r_\pi + R_{TH}} \quad | \quad R_{IE} = \frac{v_x}{i_x} = r_o || \frac{r_\pi + R_{TH}}{\beta_o + 1} \cong r_o || \left(\frac{1}{g_m} + \frac{R_{TH}}{\beta_o}\right) \cong \frac{1}{g_m}$$

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Replace v_x in Fig. 8.17 with a current source i_x. (r_o is also included but not in Eq. 8.68)

$$i_x = \frac{v_x}{r_o} \pm i_B - \beta_o i_B = \frac{v_x}{r_o} - (\beta_o + 1)i_B \quad | \quad v_x = -i_B(r_\pi + R_{TH})$$

$$i_x = v_x i_x = v_x\left(\frac{v_x}{r_o} + \frac{\beta_o + 1}{r_\pi + R_{TH}}\right) \quad | \quad R_{IE} = \frac{v_x}{i_x} = r_o || \frac{r_\pi + R_{TH}}{\beta_o + 1} \cong r_o || \left(\frac{1}{g_m} + \frac{R_{TH}}{\beta_o}\right) \cong \frac{1}{g_m}$$

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$$A_{vt} = \frac{2k\Omega + 892k\Omega}{892k\Omega}0.971 = 0.973 \quad | \quad \frac{(0.491ms)R_L}{1 + (0.491ms)R_L} = 0.973 \rightarrow R_L = 73.4k\Omega$$

$R_6 \| 100k\Omega = 73.4k\Omega \rightarrow R_6 = 276\ k\Omega$ | Note, however, that the 12 kΩ resistor can't simply be replaced with a 276 kΩ resistor because of Q-point problems.

– – –

$$R_{iB} = 10.2k\Omega + 101(13k\Omega) = 1.32M\Omega \quad | \quad R_{in}^{CC} = 104k\Omega \| 1.32M\Omega = 96.4k\Omega$$

$$A_v^{CE} = -\frac{9.80mS(13k\Omega)}{1 + 9.80mS(13k\Omega)}\left(\frac{96.4k\Omega}{2k\Omega + 96.4k\Omega}\right) = +0.972$$

$$A_v^{CS} = -\frac{0.491mS(12k\Omega)}{1 + 0.491mS(12k\Omega)}\left(\frac{892k\Omega}{2k\Omega + 892k\Omega}\right) = +0.853$$

– – –

BJT: $g_m R_L = 9.80mS(11.5k\Omega) = 113$ | FET: $g_m R_L = 0.491mS(10.7k\Omega) = 5.25$

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BJT: $v_i \le 0.005V(1 + g_m R_I)\dfrac{R_I + R_6}{R_6} = 0.005V[1 + 9.8mS(2k\Omega)]\left(\dfrac{2k\Omega + 13k\Omega}{13k\Omega}\right) = 119\ \text{m}V$

Neglecting R_6, $v_i \le 0.005V(1 + g_m R_I) = 0.005V[1 + 9.8mS(2k\Omega)] = 103\ mV$

FET: $v_i \le 0.2(V_{GS} - V_{TN})(1 + g_m R_I)\dfrac{R_I + R_6}{R_6} = 0.2(0.982)[1 + 0.491mS(2k\Omega)]\dfrac{2k\Omega + 12k\Omega}{12k\Omega} = 454\ \text{m}V$

Neglecting R_6, $v_i \le 0.2(V_{GS} - V_{TN})(1 + g_m R_I) = 0.2(0.982)[1 + 0.491mS(2k\Omega)] = 389\ \text{m}V$

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$$R_{iC} = r_o\left[1+\frac{\beta_o R_{th}}{R_{th}+r_\pi}\right] = 219k\Omega\left[1+\frac{100(1.73k\Omega)}{1.73k\Omega+10.2k\Omega}\right] = 3.40\ M\Omega$$

Or more approximately, $R_{iC} = r_o\left[1+g_m R_{th}\right] = 219k\Omega\left[1+9.8mS(1.73k\Omega)\right] = 3.93\ M\Omega$

$$R_{iD} = r_o\left[1+g_m R_{th}\right] = 223k\Omega\left[1+0.491(1.71k\Omega)\right] = 410\ k\Omega$$

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$$A_v^{CB} = g_m R_L \frac{\dfrac{R_6\left(\dfrac{1}{g_m}\right)}{R_6+\dfrac{1}{g_m}}}{R_I+\dfrac{R_6\left(\dfrac{1}{g_m}\right)}{R_6+\dfrac{1}{g_m}}} = g_m R_L \frac{\dfrac{R_6}{R_6+\dfrac{1}{g_m}}}{g_m R_I+\dfrac{R_6}{R_6+\dfrac{1}{g_m}}} = g_m R_L \frac{R_6}{R_6\left(1+g_m R_I\right)+R_I}$$

$$A_v^{CB} = g_m R_L \frac{R_6}{R_6+R_I}\frac{1}{1+\dfrac{g_m R_I R_6}{R_6+R_I}} = \frac{g_m R_L}{1+g_m R_{th}}\left(\frac{R_6}{R_6+R_I}\right)$$

– – –

The voltage gains are proportional to the load resistance

$$A_v^{CE} = +8.48\left(\frac{22k\Omega}{18k\Omega}\right) = +10.4 \quad | \quad A_v^{CG} = +4.12\left(\frac{22k\Omega}{18k\Omega}\right) = +5.02$$

– – –

CB: $A_v^{CB} \le g_m R_L = 176 \quad | \quad A_v^{CB} \cong \frac{R_L}{R_{th}} = \frac{R_L}{R_I \| R_6} = \frac{18k\Omega}{1.73k\Omega} = 10.4 \quad | \quad 8.48 < 10.4 << 176$

CG: $A_v^{CG} \le g_m R_L = 8.84 \quad | \quad A_v^{CB} \cong \frac{R_L}{R_{th}} = \frac{R_L}{R_I \| R_6} = \frac{18k\Omega}{1.71k\Omega} = 10.5 \quad | \quad 4.11 < 8.84 < 10.5$

– – –

$$R_{iE} \cong \frac{1}{g_m} = \frac{1}{40I_C} \quad | \quad R_{iS} = \frac{1}{g_m} = \frac{V_{GS}-V_{TN}}{2I_D} \quad | \quad \frac{R_{iE}}{R_{iS}} = \frac{1}{40I_C}\left(\frac{2I_D}{V_{GS}-V_{TN}}\right) = \frac{2}{40(1)} = \frac{1}{20}$$

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$$A_v^{CS} = \frac{1}{1+\eta}\sqrt{\frac{(W/L)_1}{(W/L)_2}} \quad | \quad 10^{\frac{26}{20}} = \frac{1}{1+0.2}\sqrt{\frac{(W/L)_1}{4}} = \frac{2290}{1}$$

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$\eta = 0$ | $I_{D2} = I_{D1}$ | Both transistors are in the active region since $V_{DS} = V_{GS}$.

Neglecting λ: $\frac{10^{-4}}{2}\left(\frac{2}{1}\right)(5 - V_O - 1)^2 = \frac{10^{-4}}{2}\left(\frac{8}{1}\right)(V_O - 1)^2 \rightarrow V_O = 2.00\ V$

Keeping λ: $\frac{10^{-4}}{2}\left(\frac{2}{1}\right)(5 - V_O - 1)^2\left[1 + 0.02(5 - V_O)\right] = \frac{10^{-4}}{2}\left(\frac{8}{1}\right)(V_O - 1)^2(1 + 0.02V_O) \rightarrow$

$V_O = 2.0064\ V,\ I_D = 421.39\ \mu A \rightarrow$ Q – point : $(2.01\ V,\ 421\ \mu A)$

$$g_m = \frac{2I_D}{V_{GS} - V_{TN}} \ \ | \ \ g_{m1} = \frac{2(421\mu A)}{2 - 1} = 8.42x10^{-4} A/V \ \ | \ \ g_{m2} = \frac{2(421\mu A)}{3 - 1} = 4.21x10^{-4} A/V$$

$$r_o = \frac{1/\lambda + V_{DS}}{I_D} \ \ | \ \ r_{01} = \frac{50V + 2V}{421\mu A} = 123.5\ k\Omega \ \ | \ \ r_{02} = \frac{50V + 3V}{421\mu A} = 125.9\ k\Omega$$

$$A_v = -g_{m1}\left(\frac{1}{g_{m2}}||r_{01}||r_{02}||R_F\right) = -8.42x10^{-4}/V(2.375k\Omega||123.5k\Omega||125.9k\Omega||1M\Omega) = -1.92$$

Note Eq. 8.100: For $\eta = 0, A_v \cong \frac{g_{m1}}{g_{m2}} = \frac{8.42}{4.21} = 2.00 \ \ or \ \ A_v \cong \sqrt{\frac{W/L_1}{W/L_2}} = \sqrt{\frac{8/1}{2/1}} = 2.00$

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$I_{D2} = I_{D1}$ | Both transistors are in the active region since $V_{DS} = V_{GS}$.

$K_n = 10^{-4}\left(\frac{20}{1}\right) = 2x10^{-3}\ \frac{A}{V^2}$ | $K_p = 4x10^{-5}\left(\frac{50}{1}\right) = 2x10^{-3}\ \frac{A}{V^2}$ | The transistors are symmetrical.

$\therefore\ V_O = \frac{V_{DD}}{2} = \frac{3.3V}{2} = 1.65\ V$ | $I_D = \frac{10^{-4}}{2}\left(\frac{20}{1}\right)(1.65 - 0.7)^2\left[1 + 0.02(1.65)\right] = 932\ \mu A$

Q – point : $(1.65\ V,\ 932\ \mu A)$

$$g_m = \frac{2I_D}{V_{GS} - V_{TN}} \ \ | \ \ g_{m1} = \frac{2(932\mu A)}{1.65 - 0.7} = 1.97x10^{-3} A/V \ \ | \ \ g_{m2} = \frac{2(932\mu A)}{3.3 - 1.65 - 1} = 1.97x10^{-3} A/V$$

$$r_o = \frac{1/\lambda + V_{DS}}{I_D} \ \ | \ \ r_{01} = r_{02} = \frac{50V + 1.65V}{932\mu A} = 55.4\ k\Omega \ \ | \ \ A_v = -(g_{m2} + g_{m2})(r_{01}||r_{02}||R_F)$$

$$A_v = -3.94x10^{-3}/V(55.4k\Omega||55.4k\Omega||560k\Omega) = -3.94(26.4) = -104$$

(Compare this to the gain of the circuit in Fig. 8.30 on page 480!!)

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Since we need high gain, the emitter should be bypassed, and $R_{in}^{CE} = R_B \| r_\pi = 250k\Omega$.

If we choose $R_B \cong r_\pi$, $I_C = \frac{\beta_o}{40r_\pi} \cong \frac{100}{40(500k\Omega)} = 5\ \mu\text{A}$

– – –

$R_{in}^{CG} \cong \frac{1}{g_m}$ | $I_C \cong \frac{1}{40(2k\Omega)} = 12.5\ \mu A$

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Common – Emitter :

$$C_1 >> \frac{1}{2\pi(250Hz)(1k\Omega + 77.9k\Omega)} = 8.07nF \quad | \quad \text{Choose } C_1 = 82\ nF = 0.082\ \mu F$$

$$C_2 >> \frac{1}{2\pi(250Hz)(21.9k\Omega + 82k\Omega)} = 6.13nF \quad | \quad \text{Choose } C_2 = 68\ nF = 0.068\ \mu F$$

$$C_3 >> \frac{1}{2\pi(250Hz)\left[10k\Omega \| \left(3k\Omega + \frac{1}{9.80mS}\right)\right]} = 0.269\mu F \quad | \quad \text{Choose } C_3 = 2.7\ \mu F$$

Common – Source :

$$C_1 >> \frac{1}{2\pi(250Hz)(1k\Omega + 892k\Omega)} = 713pF \quad | \quad \text{Choose } C_1 = 8200\ pF$$

$$C_2 >> \frac{1}{2\pi(250Hz)(21.5k\Omega + 82k\Omega)} = 6.15nF \quad | \quad \text{Choose } C_2 = 68\ nF = 0.068\ \mu F$$

$$C_3 >> \frac{1}{2\pi(250Hz)\left[10k\Omega \| \left(2k\Omega + \frac{1}{0.491mS}\right)\right]} = 0.221\mu F \quad | \quad \text{Choose } C_3 = 2.2\ \mu F$$

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Common – Collector :

$$C_1 >> \frac{1}{2\pi(250Hz)(1k\Omega + 95.5k\Omega)} = 6.60nF \quad | \quad \text{Choose } C_1 = 68\ nF = 0.068\ \mu F$$

$$C_2 >> \frac{1}{2\pi(250Hz)(120\Omega + 82k\Omega)} = 7.75nF \quad | \quad \text{Choose } C_2 = 82\ nF = 0.082\ \mu F$$

Common – Drain :

$$C_1 >> \frac{1}{2\pi(250Hz)(1k\Omega + 892k\Omega)} = 713pF \quad | \quad \text{Choose } C_1 = 8200\ pF$$

$$C_2 >> \frac{1}{2\pi(250Hz)(1.74k\Omega + 82k\Omega)} = 7.60nF \quad | \quad \text{Choose } C_2 = 82\ nF = 0.082\ \mu F$$

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Common – Base:

$$C_1 >> \frac{1}{2\pi(250Hz)(1k\Omega + 0.1k\Omega)} = 0.579\mu F \quad | \quad \text{Choose } C_1 = 6.8\ \mu F$$

$$C_2 >> \frac{1}{2\pi(250Hz)(21.9k\Omega + 82k\Omega)} = 6.13nF \quad | \quad \text{Choose } C_2 = 0.068\ \mu F$$

$$C_3 >> \frac{1}{2\pi(250Hz)\left(160k\Omega \| 300k\Omega \| \left[10.2k\Omega + 101(13k\Omega \| 1k\Omega)\right]\right)} = 12.2nF \quad | \quad \text{Choose } C_3 = 0.12\ \mu F$$

Common – Gate:

$$C_1 >> \frac{1}{2\pi(250Hz)(1k\Omega + 1.74k\Omega)} = 0.232\mu F \quad | \quad \text{Choose } C_1 = 2.2\ \mu F$$

$$C_2 >> \frac{1}{2\pi(250Hz)(20.9k\Omega + 82k\Omega)} = 6.19nF \quad | \quad \text{Choose } C_2 = 0.068\ \mu F$$

$$C_3 >> \frac{1}{2\pi(250Hz)(1.5M\Omega \| 2.2M\Omega)} = 714pF \quad | \quad \text{Choose } C_3 = 8200\ pF$$

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(a) Common – Source:

$$C_3 = \frac{1}{2\pi(1000Hz)\left[10k\Omega \left\| \left(2k\Omega + \frac{1}{0.491mS}\right)\right.\right]} = 55.3nF \quad | \quad \text{Choose } C_3 = 0.056\ \mu F$$

(b) Common – Collector:

$$C_2 >> \frac{1}{2\pi(2000Hz)(120\Omega + 100k\Omega)} = 795pF \quad | \quad \text{Choose } C_2 = 820\ pF$$

(c) Common – Gate:

$$C_1 >> \frac{1}{2\pi(1000Hz)(2k\Omega + 1.74k\Omega)} = 42.6nF \quad | \quad \text{Choose } C_1 = 0.042\ \mu F$$

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$$20V = V_{GS} + 3600 I_D \quad | \quad 20 = V_{GS} + 3600\frac{0.020}{2}\left(V_{GS} - 1.5\right)^2 \rightarrow V_{GS} = 2.203\ V \quad | \quad I_D = 4.94\ mA$$

$$V_{DS} = 5 - \left(-V_{GS}\right) = 7.20\ V \quad | \quad \text{Q-point: } (4.94\text{ mA},\ 7.20\text{ V}) \quad | \quad R_{\text{in}} = R_G = 22\ M\Omega$$

$$A_v^{CD} = \frac{g_m R_L}{1 + g_m R_L} \quad | \quad g_m = \frac{2\left(4.94 mA\right)}{\left(2.20 - 1.50\right)V} = 14.2\ mS \quad | \quad R_L = 3600\Omega \| 3000\Omega = 1630\ \Omega \quad | \quad A_v^{CD} = 0.959$$

– – –

$$R_{\text{out}}^{\text{CD}} = 3.6k\Omega \left\| \frac{1}{g_m} \right. = 3.6k\Omega \left\| \frac{1}{0.0142} \right. = 69.1\ \Omega \quad | \quad v_{gs} \le 0.2\left(2.20 - 1.50\right)\left[1 + 0.0142\left(1630\right)\right] = 3.38\ V$$

– – –

$$r_o = \frac{\frac{1}{\lambda} + V_{DS}}{I_D} = \frac{\frac{1}{0.015} + 5 + 2.21}{0.005} = 14.8\ k\Omega \quad | \quad R_L = 3600\Omega \| 3000\Omega \| 14.8k\Omega = 1470\ \Omega \quad | \quad A_v^{CD} = 0.954$$

– – –

$$\frac{W}{L} = \frac{K_n}{K_n'} = \frac{2x10^{-2}}{5x10^{-5}} = \frac{400}{1}$$

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$$A = \frac{g_m R_S}{1 + g_m R_S} \quad | \quad g_m = \frac{2\left(4.94 mA\right)}{\left(2.20 - 1.50\right)V} = 14.2\ mS \quad | \quad R_S = 3600\ \Omega \quad | \quad A_v^{CD} = 0.981 \quad | \quad R_{\text{in}} = R_G = 22\ M\Omega$$

$$R_{\text{out}}^{\text{CD}} = 3.6k\Omega \left\| \frac{1}{g_m} \right. = 3.6k\Omega \left\| \frac{1}{0.0142} \right. = 69.1\ \Omega \quad | \quad A_v^{CD} = A\frac{3000\Omega}{69.1\Omega + 3000\Omega} = 0.959$$

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Reverse the direction of the arrow on the emitter of the transistor as well as the values of V_{EE} and V_{CC}.

– – –

$$R_{in}^{CG} = R_E \left\| \frac{1}{g_m} = 13k\Omega \right\| \frac{1}{40(331\mu A)} = 75.1\ \Omega \ \ | \ \ A_v^{CB} = \frac{75.1\Omega}{75\Omega + 75.1\Omega}(13.2mS)(7.58k\Omega) = 50.1$$

– – –

For $v_{CB} \geq 0$, we require $v_C \geq 0$. $V_C = 5 - I_C R_C = 2.29\ V \quad \therefore |v_c| \leq 2.29\ V$

$v_o \leq 5mV(g_m R_L) = 5mV(13.2mS)(7580\Omega) = 0.500\ V$

– – –

$R_E = 75\Omega[1 + 40(7.5 - 0.7)] = 20.5\ k\Omega$ (a standard 1% value) | $I_C \cong \frac{6.8V}{20.5k\Omega} = 332\ \mu A$

$50 = 40(332\mu A) R_L \frac{75}{75+75} \rightarrow R_L = 7.53k\Omega \rightarrow R_C = 8.14\ k\Omega \rightarrow 8.06\ k\Omega$ (a standard 1% value)

$V_{EC} = 0.7 + 7.5 - I_C R_C = 5.52\ V$

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$$f_1 = \frac{1}{2\pi(R_I + R_{in})C_1} = \frac{1}{2\pi(75\Omega + 75.1\Omega)(0.022\mu F)} = 48.2\ kHz$$

$$f_2 = \frac{1}{2\pi(R_3 + R_{out})C_2} = \frac{1}{2\pi(100k\Omega + 8.2k\Omega)(33pF)} = 44.6\ kHz$$

We have two almost identical poles and can estimate f_L by applying the bandwidth shrinkage factor from Table 14.13 to the mean of the two frequencies: $f_L \cong 1.55\left(\frac{48.2+44.6}{2}\right)kHz = 72\ kHz$

Using the design value: $f_L \cong 1.55\left(\frac{50+50}{2}\right)kHz = 77.5\ kHz$

- - -

5% tolerances $I_C^{max} \cong \frac{V_{EE}^{max} - 0.7V}{R_E^{min}} = \frac{5(1.05) - 0.7V}{13k\Omega(0.95)} = 368\mu A$

$V_C^{min} = V_{CC}^{min} - I_C^{max} R_C^{max} = 5V(0.95) - 368\mu A(8.2k\Omega)(1.05) = 1.58\ V$ | $1.58 \geq 0$, so active region is ok.

10% tolerances $I_C^{max} \cong \frac{V_{EE}^{max} - 0.7V}{R_E^{min}} = \frac{5(1.1) - 0.7V}{13k\Omega(0.9)} = 410\mu A$

$V_C^{min} = V_{CC}^{min} - I_C^{max} R_C^{max} = 5V(0.90) - 410\mu A(8.2k\Omega)(1.1) = 0.802\ V$ | $0.802 \geq 0$, so active region is ok.

– – –

$$v_{th} = v_i \frac{R_{in}^{CB}}{75\Omega + R_{in}^{CB}} g_m R_C = v_i \frac{75}{75\Omega + 75}(13.2mS)(8200\Omega) = 54.1 v_i \quad | \quad R_{th} = R_{out}^{CB} = 8.2\ k\Omega$$

$$A_v^{CG} = \frac{v_o}{v_i} = \frac{v_{th}}{v_i}\frac{100k\Omega}{R_{th} + 100k\Omega} = 54.1\frac{100k\Omega}{8.2k\Omega + 100k\Omega} = 50.0$$

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$$f_1 = \frac{1}{2\pi\left(R_I + R_{in}\right)C_1} = \frac{1}{2\pi\left(75\Omega + 75\Omega\right)\left(0.022\mu F\right)} = 48.2\ kHz$$

$$f_2 = \frac{1}{2\pi\left(R_7 + R_{out}\right)C_2} = \frac{1}{2\pi\left(100k\Omega + 100k\Omega\right)\left(20pF\right)} = 39.8\ kHz$$

$$f_3 = \frac{1}{2\pi\left(R_s \| 1/g_m\right)C_3} = \frac{1}{2\pi\left(9.1k\Omega \| 500\Omega\right)\left(0.0068\mu F\right)} = 49.4\ kHz$$

We have three almost identical poles and can estimate f_L by applying the bandwidth shrinkage factor from Table 14.13 to the mean of the three frequencies: $f_L \cong 1.95\left(\frac{48.2 + 39.8 + 49.4}{3}\right)kHz = 89\ kHz$

$$r_o \cong r_o = \frac{1}{\lambda I_D} = \frac{1}{0.015\left(2x10^{-4}\right)} = 333\ k\Omega$$

or more exactly $V_{DS} = 25 - 10^5 I_D - 9.1x10^3 I_D = 25 - 1.09x10^5\left(0.2mA\right) = 3.18\ V$

$$r_o = \frac{\frac{1}{\lambda} + V_{DS}}{I_D} = \frac{\frac{1}{0.015} + 3.18}{2x10^{-4}} = 349\ k\Omega \quad | \quad R_L = 100k\Omega \| 100k\Omega \| 349k\Omega = 43.7\ k\Omega$$

$$A_v^{CS} = -\left(g_m R_L\right)\frac{R_{in}}{R_I + R_{in}} = -\frac{2\left(0.2mA\right)}{0.2V}\left(43.7k\Omega\right)\left(\frac{75\Omega}{75\Omega + 75\Omega}\right) = -43.7$$

$$I_D = \frac{0.01}{2}\left(0.25\right)^2 = 0.3125\ mA \quad | \quad V_{GS} - V_{TN} = 0.25\ V \quad | \quad V_{GS} = 0.25 - 2 = -1.75\ V$$

$$R_S = \frac{-V_{GS}}{I_D} = \frac{1.75V}{0.3125mA} = 5.60k\Omega \rightarrow 5.6\ k\Omega \ | \ R_L = 2\frac{A_v}{g_m} = \frac{50\left(0.25V\right)}{0.3125mA} = 40\ k\Omega \ | \ R_D \| 100k\Omega = 40\ k\Omega$$

$R_D = 66.7k\Omega \rightarrow 68\ k\Omega$ | C_1 remains unchanged.

$$C_2 >> \frac{1}{10^6\pi\left(68k\Omega + 100k\Omega\right)} = 1.90pF \rightarrow \text{Choose } C_2 = 20\ pF$$

$$C_3 >> \frac{1}{10^6\pi\left(5.6k\Omega \| \frac{1}{2.5mS}\right)} = 0.853nF \rightarrow \text{Choose } C_3 = 8200\ pF$$

$$v_{th} = v_i\frac{R_{\text{in}}^{\text{CG}}}{75\Omega + R_{\text{in}}^{\text{CG}}}g_m R_D = v_i\frac{75\Omega}{75\Omega + 75\Omega}\left(2mS\right)\left(100k\Omega\right) = 100v_i \quad | \quad R_{th} = R_{\text{out}}^{\text{CG}} = 100\ k\Omega$$

$$A_v^{CG} = \frac{v_o}{v_i} = \frac{v_{th}}{v_i}\frac{100k\Omega}{R_{th} + 100k\Omega} = 100\frac{100k\Omega}{100k\Omega + 100k\Omega} = 50.0$$

Χοντινυεδ ον τηε νεξτ παγε …

$(c)\quad v_{th} = v_i \frac{75\Omega}{75\Omega + 75\Omega}(2mS)(100k\Omega||100k\Omega) = 50.0 \quad | \quad R_{th} = 100k\Omega||100k\Omega = 50k\Omega$

$$A_v^{CG} = 50\frac{100k\Omega}{50k\Omega + 100k\Omega} = 33.3$$

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$M_1: \ I_D = \frac{K_n}{2}\left(V_{GS} - V_{TN}\right)^2 \ | \ V_{GS} = -R_{S1}I_D \ | \ I_D = \frac{0.01}{2}\left(-200I_D + 2\right)^2 \rightarrow I_D = 5.00\ mA$

$V_{DS} = 15 - 5mA\left(820\Omega\right) = 10.9\ V$

$g_m = \sqrt{2K_nI_D} = \sqrt{2(0.01)(0.005)} = 10.0\ mS \ | \ r_o = \frac{1+\lambda V_{DS}}{\lambda I_D} = \frac{1+0.02(10.9)}{0.02(5mA)} = 12.2\ k\Omega$

$Q_2: \ V_{EQ} = \frac{22k\Omega}{22k\Omega + 78k\Omega}(15V) = 3.30\ V \ | \ R_{EQ} = 22k\Omega \| 78k\Omega = 17.2\ k\Omega$

$I_C = 150\frac{(3.30-0.6)V}{17.2k\Omega + 151(1.6k\Omega)} = 1.57\ mA \ | \ V_{CE} = 15 - 1.57mA\left(4.7k\Omega + \frac{151}{150}1.6k\Omega\right) = 5.09V$

$g_m = (1.57mA)40/V = 62.8\ mS \ | \ r_\pi = \frac{150}{62.8mS} = 2.39\ k\Omega \ | \ r_o = \frac{80+5.09}{1.57mA} = 54.2\ k\Omega$

$Q_3: \ V_{EQ} = \frac{120k\Omega}{120k\Omega + 91k\Omega}(15V) = 8.53\ V \ | \ R_{EQ} = 120k\Omega \| 91k\Omega = 51.8\ k\Omega$

$I_C = 80\frac{(8.53-0.6)V}{51.8k\Omega + 81(3.3k\Omega)} = 1.99\ mA \ | \ V_{CE} = 15 - 1.99mA\left(\frac{81}{80}3.3k\Omega\right) = 8.35\ V$

$g_m = (1.96mA)40/V = 78.4\ mS \ | \ r_\pi = \frac{80}{78.4mS} = 2.39\ k\Omega \ | \ r_o = \frac{80+8.35}{1.99mA} = 34.4\ k\Omega$

A typical op-amp gain is at least 10,000 which exceeds the amplification factor of a single transistor.

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$R_{L1} = 478\Omega \| 12.2k\Omega = 460\ \Omega \quad | \quad R_{L2} = 3.53k\Omega \| 54.2k\Omega = 3.31\ k\Omega \quad | \quad R_{L3} = 232\Omega \| 34.4k\Omega = 230\ \Omega$

$$A_v = -10mS(460\Omega)(-62.8mS)(3.31k\Omega)\left[\frac{79.6mS(230\Omega)}{1 + 79.6mS(230\Omega)}\right]\left(\frac{1M\Omega}{10k\Omega + 1M\Omega}\right) = 898$$

$20\ \log(898) = 59.1\ dB$

$$A_v \cong \left(-\frac{V_{DD}}{V_{GS} - V_{TN}}\right)\left(-10V_{CC}\right)(1) = -\frac{15}{1}(-10)(15)(1) = 2250$$

$$A_v = -10mS(2.39k\Omega)(-62.8mS)(19.8k\Omega)(0.95)(0.99) = 28000$$

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$$R_{out} = 3300 \| \left(\frac{1}{0.0796S} + \frac{3990}{90.1} \right) = 55.9\ \Omega$$

– – –

Note that the answers are obtained directly from SPICE.

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$$A_{v1} = -g_m R_{L1} = -\sqrt{2(0.01)(0.001)}\left(3k\Omega \| 17.2k\Omega \| 2.39k\Omega\right) = 5.52$$

$$A_v = -5.52(-222)(3.31k\Omega)(0.95)(0.99) = 1150$$

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(a) $V_{D1} = 15V - 620\Omega(5mA) = 11.9\ V \ \ |\ \ V_{C2} = 15V - 4.7k\Omega(1.57mA) = 7.62\ V$

$$V_{TH2} = 15V \frac{22k\Omega}{22k\Omega + 78k\Omega} = 3.3V \ \ |\ \ R_{TH2} = (22k\Omega || 78k\Omega) = 17.1k\Omega$$

$$V_{B2} = 3.3V - \frac{1.57mA}{150}(17.16k\Omega) = 3.12\ V$$

$$V_{TH3} = 15V \frac{120k\Omega}{91k\Omega + 120k\Omega} = 8.53V \ \ |\ \ R_{TH3} = (120k\Omega || 91k\Omega) = 51.75k\Omega$$

$$|\ \ V_{B3} = 8.53V - \frac{1.99mA}{80}(51.75k\Omega) = 7.24\ V$$

(b) $3.1V = 15V - R_D\left(5mA + \frac{1.57mA}{150}\right) \rightarrow R_D = 2.37k\Omega \rightarrow 2.4k\Omega$

$$7.2V = 15V - R_{C2}\left(1.57mA + \frac{1.99mA}{80}\right) \rightarrow R_{C2} = 4.89k\Omega \rightarrow 5.1\ k\Omega\ \ or\ \ 4.7\ k\Omega$$

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(a) $I_{REF} = \frac{K_n'\left(\frac{W}{L}\right)_1}{2}(V_{GS} - V_{TN})^2 \ \ |\ \ I_{D2} = \frac{K_n'\left(\frac{W}{L}\right)_2}{2}(V_{GS} - V_{TN})^2$

$$\frac{I_{D2}}{I_{REF}} = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1} \quad or \quad I_{D2} = I_{REF}\frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1}$$

(b) $I_{REF} = I_{C1} = I_{S1} exp\left(\frac{V_{BE}}{V_T}\right) \ \ |\ \ I_O = I_{C2} = I_{S2} exp\left(\frac{V_{BE}}{V_T}\right)$

$$\frac{I_O}{I_{REF}} = \frac{I_{S2}}{I_{S1}} \quad or \quad I_O = I_{REF}\frac{I_{S2}}{I_{S1}} = I_{REF}\frac{A_{E2}}{A_{E1}}$$

CHAPTER 9

Page 547

$$f_L \cong \frac{1}{2\pi}\sqrt{10^2+1000^2-2(50)^2-2(0)^2} = 159\ Hz \quad | \quad f_L \cong \frac{1}{2\pi}\sqrt{100^2+1000^2-2(500)^2-2(0)^2} = 114\ Hz$$

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$$\left|\frac{200s}{(s+1000)}\right| \geq 0.9\left|\frac{200s(s+100)}{(s+10)(s+1000)}\right| \quad | \quad 1 \geq 0.9\frac{\sqrt{\omega^2+100^2}}{\sqrt{\omega^2+10^2}} \rightarrow 0.81 \leq \frac{\omega^2+10^2}{\omega^2+100^2} \rightarrow \omega \geq 205 \text{ rad/s}$$

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$$f_H \cong \frac{10^6}{2\pi} = 159\ kHz$$

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$$f_H \cong \frac{1}{2\pi}\frac{1}{\sqrt{\left(\frac{1}{10^5}\right)^2+\left(\frac{1}{5x10^5}\right)^2-2\left(\frac{1}{2x10^5}\right)^2-2\left(\frac{1}{\infty}\right)^2}} = 21.7\ kHz$$

As s approaches 0, $A_H(s) = 100$ or $20\log(100) = 40$ dB

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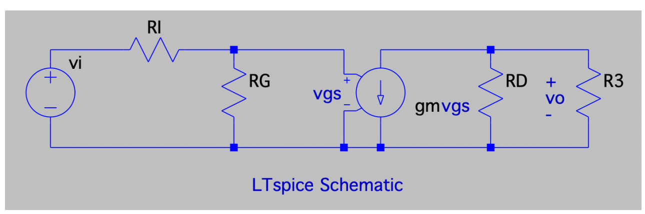

$$v_{gs} = v_i\frac{R_G}{R_I+R_G} \quad | \quad v_o = -g_m v_{gs}(R_D||R_3) \quad | \quad A_{dm} = \frac{v_o}{v_{gs}} = -g_m(R_D||R_3) + \frac{R_G}{R_I+R_G}$$

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The value of C_3 does not change A_{mid}, ω_{P1}, ω_{P2}, ω_{z1}, or ω_{Z2}.

$$\omega_{P3} = -\frac{1}{2\mu F\left(1.3k\Omega \| \frac{1}{1.23mS}\right)} = -1000 \text{ rad/s} \quad | \quad \omega_{Z3} = -\frac{1}{2\mu F(1.3k\Omega)} = -385 \text{ rad/s}$$

$$f_L = \frac{1}{2\pi}\sqrt{41.0^2 + 95.9^2 + 1000^2 - 2\left(0^2 + 0^2 + 385^2\right)} = 135\ Hz$$

– – –

$$A_{mid} = 10^{\frac{13.5}{20}} = 4.732 \quad | \quad 4.3k\Omega \| 100k\Omega \| r_o = \frac{4.732}{1.23mS} \rightarrow r_o = 57.5\ k\Omega$$

Note that the SPICE value of g_m probably differs from 1.23 mS as well.

– – –

$$\omega_{P2} = -\frac{1}{0.1\mu F\left(4.3k\Omega \| 57.5k\Omega + 100k\Omega\right)} = -96.2 \text{ rad/s}$$

$$f_L = \frac{1}{2\pi}\sqrt{41.0^2 + 96.2^2 + 202^2 - 2\left(0^2 + 0^2 + 76.9^2\right)} = 31.8\ Hz$$

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$$r_\pi = \frac{140(0.025V)}{175\mu A} = 20.0\ k\Omega \quad | \quad R_{1S}C_1 = \left(1k\Omega + 75k\Omega \| 20.0k\Omega\right)2\mu F = 33.6\ ms \quad | \quad R_{th} = 75k\Omega \| 1k\Omega = 987\ \Omega$$

$$R_{2S}C_2 = \left(43k\Omega + 100k\Omega\right)0.1\mu F = 14.3\ ms \quad | \quad R_{3S}C_3 = \left(13k\Omega \| \frac{20.0k\Omega + 987\Omega}{141}\right)10\mu F = 1.47\ ms$$

$$f_L \cong \frac{1}{2\pi}\left(\frac{1}{33.6ms} + \frac{1}{1.47ms} + \frac{1}{14.3ms}\right) = 124\ Hz$$

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$$A_v = -\frac{R_{in}}{R_I + R_{in}}\left(\frac{\beta_o}{r_\pi}R_L\right) \cong -\left(\frac{1260}{2260}\right)\left(\frac{100}{1.51k\Omega}\right)\left(4.3k\Omega \| 100k\Omega\right) = -157$$

$$A_v = -\frac{R_{in}}{R_I + R_{in}}\left(\frac{\beta_o}{r_\pi}R_L\right) \cong -\left(\frac{1260}{2260}\right)\left(\frac{100}{1.51k\Omega}\right)\left(4.3k\Omega \| 100k\Omega \| 46.8k\Omega\right) = -140$$

r_o is responsible for most of the discrepancy. r_π and β_o will also be differ from our hand calculations.

Note that 45% of the gain is lost because of the amplifier's low input resistance.

– – –

$$g_m = \frac{2(1.5mA)}{0.5V} = 6.00\ mS \quad | \quad R_{1S}C_1 = \left(1k\Omega + 243k\Omega\right)0.1\mu F = 24.4\ ms$$

$$R_{2S}C_2 = \left(4.3k\Omega + 100k\Omega\right)0.1\mu F = 10.4\ ms \quad | \quad R_{3S}C_3 = \left(1.3k\Omega \| \frac{1}{6.00mS}\right)10\mu F = 1.48\ ms$$

$$f_L \cong \frac{1}{2\pi}\left(\frac{1}{24.4ms} + \frac{1}{1.48ms} + \frac{1}{10.4ms}\right) = 129\ Hz$$

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$g_m = 40(0.1mA) = 4.00\ mS$ | $R_{1S}C_1 = \left(100\Omega + 43k\Omega \Big\| \frac{1}{4.00mS}\right)4.7\mu F = 1.64\ ms$

$R_{2S}C_2 = (22k\Omega + 75k\Omega)1\mu F = 97.0\ ms$ | $f_L \cong \frac{1}{2\pi}\left(\frac{1}{1.64ms} + \frac{1}{97.0ms}\right) = 98.7\ Hz$

$$A_{mid} = \frac{43k\Omega \| 250\Omega}{100\Omega + 43k\Omega \| 250\Omega}(4.00mS)(22k\Omega \| 75k\Omega) = 48.5$$

$g_m = \frac{2(1.5mA)}{0.5V} = 6.00\ mS$ | $R_{1S}C_1 = \left(100\Omega + 1.3k\Omega \Big\| \frac{1}{6.00mS}\right)1\mu F = 0.248\ ms$

$R_{2S}C_2 = (4.3k\Omega + 75k\Omega)0.1\mu F = 7.93\ ms$ | $f_L \cong \frac{1}{2\pi}\left(\frac{1}{0.248ms} + \frac{1}{7.93ms}\right) = 662\ Hz$

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$g_m = 40(1mA) = 40.0\ mS$ | $r_\pi = \frac{100}{.04S} = 2.50\ k\Omega$

$$R_{1S}C_1 = \left(1k\Omega + 100k\Omega \big\| \left[2.5k\Omega + 101(3k\Omega \| 47k\Omega)\right]\right)0.1\mu F = 7.52\ ms$$

$R_{2S}C_2 = \left(47k\Omega + 3k\Omega \Big\| \frac{2.5k\Omega + (100k\Omega \| 1k\Omega)}{101}\right)100\mu F = 4.70\ s$ | $f_L \cong \frac{1}{2\pi}\left(\frac{1}{7.52ms} + \frac{1}{4.7s}\right) = 21.2\ Hz$

$$A_{mid} \cong \frac{(\beta_o + 1)R_L}{R_{th} + r_\pi + (\beta_o + 1)R_L}\left(\frac{R_I}{R_I + R_B}\right) = \frac{101(3k\Omega \| 47k\Omega)}{990\Omega + 2.5k\Omega + 101(3k\Omega \| 47k\Omega)}\left(\frac{100k\Omega}{1k\Omega + 100k\Omega}\right) = +0.978$$

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$R_{1S}C_1 = (1k\Omega + 243k\Omega)0.1\mu F = 24.4\ ms$ | $R_{2S}C_2 = \left(24k\Omega + 1.3k\Omega \Big\| \frac{1}{1mS}\right)47\mu F = 1.15\ s$

$$f_L \cong \frac{1}{2\pi}\left(\frac{1}{24.4ms} + \frac{1}{1.15s}\right) = 6.66\ Hz$$

$$A_{mid} = +\left(\frac{R_G}{R_I + R_G}\right)\frac{g_m R_L}{1 + g_m R_L} = +\left(\frac{243k\Omega}{244k\Omega}\right)\left[\frac{1mS(1.3k\Omega \| 24k\Omega)}{1 + 1mS(1.3k\Omega \| 24k\Omega)}\right] = +0.550$$

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$$C_\pi = \frac{g_m}{\omega_T} - C_\mu \qquad C_\mu = \frac{C_{\mu o}}{\sqrt{1+\frac{V_{CB}}{\varphi_{jc}}}}$$

$$(100\ \mu A,\ 8\ V):\ C_\mu = \frac{2pF}{\sqrt{1+\frac{7.3V}{0.6V}}} = 0.551\ pF \quad | \quad C_\pi = \frac{40\left(10^{-4}\right)}{2\pi\left(500MHz\right)} - 0.551x10^{-12} = 0.722\ pF$$

$$(2\ mA,\ 5\ V):\ C_\mu = \frac{2pF}{\sqrt{1+\frac{4.3V}{0.6V}}} = 0.700\ pF \quad | \quad C_\pi = \frac{40\left(2x10^{-3}\right)}{2\pi\left(500MHz\right)} - 0.700x10^{-12} = 24.8\ pF$$

$$(50\ mA,\ 8\ V):\ C_\mu = \frac{2pF}{\sqrt{1+\frac{7.3V}{0.6V}}} = 0.551\ pF \quad | \quad C_\pi = \frac{40\left(5x10^{-2}\right)}{2\pi\left(500MHz\right)} - 0.551x10^{-12} = 636\ pF$$

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$$C_{GS} = C_{GD} = \frac{1}{2}C_{ISS} = 0.5\ pF$$

– – –

$$C_{GS} + C_{GD} = \frac{g_m}{\omega_T} \quad | \quad 5C_{GD} + C_{GD} = \frac{\sqrt{2(0.01)(0.01)}}{2\pi\left(200MHz\right)} = 11.3\ pF \quad | \quad C_{GD} = 1.88\ pF \quad | \quad C_{GS} = 9.38\ pF$$

– – –

$$C_\mu = \frac{C_{\mu o}}{\sqrt{1+\frac{V_{CB}}{\varphi_{jc}}}} = \frac{2pF}{\sqrt{1+\frac{7.3V}{0.6V}}} = 0.551\ pF \quad | \quad C_\pi = \frac{g_m}{\omega_T} - C_\mu = \frac{40\left(20\mu A\right)}{2\pi\left(500MHz\right)} - 0.551pF = -0.296\ pF$$

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$$A_v = -\frac{R_{in}}{R_I + R_{in}}\left(\frac{\beta_o}{r_x + r_\pi}R_L\right) \quad | \quad R_{in} = 7.5k\Omega \| \left(1.51k\Omega + 250\Omega\right) = 1.43k\Omega$$

$$\cong -\left(\frac{1430}{2430}\right)\left(\frac{100}{1.76k\Omega}\right)\left(4.3k\Omega \| 100k\Omega\right) = -139$$

$$A_v = -\frac{R_{in}}{R_I + R_{in}}\left(\frac{\beta_o}{r_\pi}R_L\right) \cong -\left(\frac{1260}{2260}\right)\left(\frac{100}{1.51k\Omega}\right)\left(4.3k\Omega \| 100k\Omega\right) = -157$$

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The term $C_L \frac{R_L}{r_{\pi o}}$ is added to the value of C_T.

$$C_L \frac{R_L}{r_{\pi o}} = 3pF\left(\frac{4120}{656}\right) = 18.8\ pF \quad | \quad f_{P1} = \frac{1}{2\pi(656\Omega)(156+18.8)pF} = 1.39\ MHz$$

$$f_{P2} = \frac{g_m}{2\pi(C_\pi + C_L)} = \frac{0.064S}{2\pi(19.9+3)pF} = 445\ MHz$$

$$C_\pi = \frac{0.064}{2\pi(500MHz)} - 10^{-12} = 19.4\ pF$$

$$C_T = 19.4 + 1\left[1 + 0.064(4120) + \frac{4120}{656}\right] = 290\ pF \quad | \quad f_{P1} = \frac{1}{2\pi(656\Omega)290pF} = 837\ kHz$$

$$f_{P2} = \frac{g_m}{2\pi C_\pi} = \frac{0.064S}{2\pi(19.4pF)} = 525\ MHz \quad | \quad f_Z = \frac{g_m}{2\pi C_\mu} = \frac{0.064S}{2\pi(1pF)} = 10.2\ GHz$$

$A_{mid} = -135$ is not affected by the value of f_T.

$$\Delta = s^2\left[C_\pi(C_\mu + C_L) + C_\mu C_L\right] + s\left[C_\pi g_L + C_\mu(g_m + g_{\pi 0} + g_L) + C_L g_{\pi 0}\right] + g_L g_{\pi 0}$$

$C_\pi = 19.9\ pF \quad C_\mu = 0.5\ pF \quad C_L = 3\ pF \quad r_{\pi 0} = 656\ \Omega \quad R_L = 4.12\ k\Omega \quad g_m = 64.0\ mS$

$C_L = 0: \quad 9.95x10^{-24}s^2 + 3.77x10^{-14}s + 3.700x10^{-7} = 0$

MATLAB: roots([9.950E-24 3.771E-14 3.700E-7]) → $-3.7801\text{x}10^9$rad/s , $-9.8373x10^6$rad/s

$C_L = 3\ pF: \quad 9.95x10^{-24}s^2 + 3.77x10^{-14}s + 3.700x10^{-7} = 0$

MATLAB: roots([7.115E-23 4.240E-14 3.700E-7]) → $-5.8707\text{x}10^8$rad/s , $-8.8581x10^6$rad/s

---

$$(a)\quad C_T = 10 + 2\left[1 + 1.23mS(4.12k\Omega) + \frac{4120}{996}\right] = 30.4\ pF \quad | \quad f_{P1} = \frac{1}{2\pi(996\Omega)30.4pF} = 5.26\ MHz$$

$$f_{P2} = \frac{g_m}{2\pi C_{GS}} = \frac{1.23mS}{2\pi(10pF)} = 19.6\ MHz \quad | \quad f_Z = \frac{g_m}{2\pi C_{GD}} = \frac{1.23mS}{2\pi(2pF)} = 97.9\ MHz$$

$$f_T = \frac{g_m}{2\pi(C_{GS} + C_D)} = \frac{1.23mS}{2\pi(12pF)} = 16.3\ MHz$$

$$(b)\quad C_T = 10 + 2\left[1 + 1.23mS(4.12k\Omega) + \frac{4120}{1296}\right] = 28.5\ pF \quad | \quad f_{P1} = \frac{1}{2\pi(1296\Omega)28.5pF} = 4.31\ MHz$$

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$1+g_mR_E = 1+0.064(100) = 7.40 \quad | \quad R_{iB} = 250+1560+101(100) = 11.9\ k\Omega$

$r_{\pi 0} = 11.9k\Omega \| (882+250) = 1030\ \Omega \quad | \quad A_i = \dfrac{10k\Omega \| 30k\Omega \| 11.9k\Omega}{1k\Omega + 10k\Omega \| 30k\Omega \| 11.9k\Omega} = 0.821$

$A_{mid} = -0.821\left(\dfrac{264}{7.4}\right) = -29.3 \quad | \quad f_H = \dfrac{1}{2\pi(1.03k\Omega)\left[\dfrac{19.9pF}{7.4} + 0.5pF\left(1+\dfrac{264}{7.4}+\dfrac{4120}{1030}\right)\right]} = 6.70\ MHz$

$GBW = 29.3(6.70MHz) = 196\ MHz$

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$A_{mid} \cong \dfrac{g'_mR_L}{1+g'_mR_E} \quad | \quad g'_m = \dfrac{\beta_o}{r_x+r_\pi} = \dfrac{100}{250+\dfrac{100}{40(0.1mA)}} = 3.96\ mS \quad | \quad A_{mid} \cong \dfrac{3.96mS(17.0k\Omega)}{1+3.96mS(100\Omega)} = +48.2$

$f_H \cong \dfrac{1}{2\pi(17.0k\Omega)(0.5pF)} = 18.7\ MHz \quad | \quad GBW = 903\ MHz$

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$R_{iS} = R_4 \| \dfrac{1}{g_m} = 1.3k\Omega \| \dfrac{1}{3mS} = 265\ \Omega$

$A_{mid} = 0.726(g_mR_L) = 0.726(3mS)(4.12k\Omega) = 8.98 \quad | \quad f_H \cong \dfrac{1}{2\pi(4.12k\Omega)(4pF)} = 9.66\ MHz$

$GBW = 86.7\ MHz \quad | \quad f_T \cong \dfrac{3mS}{2\pi(11pF)} = 43.4\ MHz$

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$$g_m = 40(1.5mA) = 60.0\ mS \quad r_\pi = \frac{100}{.06} = 1.67\ k\Omega \quad C_\pi = \frac{60.0mS}{2\pi(500MHz)} - 0.5pF = 18.6\ pF$$

Using Eq. (17.138): $\omega_{P1} = \dfrac{1}{\left\{(990\Omega + 150\Omega) \| [1.67k\Omega + 101(2.82k\Omega)]\right\}\left[0.5pF + \dfrac{18.6pF}{1 + 60.0mS(2.82k\Omega)}\right]}$

$$f_{P1} = \frac{\omega_{P1}}{2\pi} = 230\ MHz \quad | \quad A_{be} = \frac{60.0mS(2.82k\Omega)}{1 + 60.0mS(2.82k\Omega)} = 0.9941$$

$$A_i = \frac{100k\Omega \| [150\Omega + 1.67k\Omega + 101(2.82k\Omega)]}{1k\Omega + 100k\Omega \| [150\Omega + 1.67k\Omega + 101(2.82k\Omega)]} = 0.9867 \quad | \quad A_v = 0.9867(0.9941) = 0.981$$

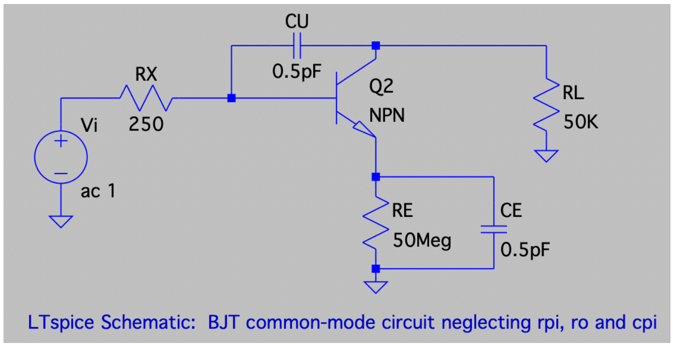
– – –

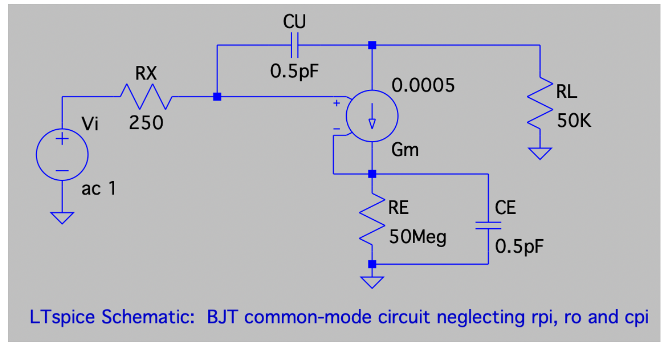
$$(a)\ R_L = 1.3k\Omega \| 24k\Omega = 1.23k\Omega \quad | \quad A_{mid} = 0.998\frac{3mS(1.23k\Omega)}{1 + 3mS(1.23k\Omega)} = 0.785$$

$$f_H \cong \frac{1}{2\pi}\frac{1}{(1k\Omega \| 430k\Omega)\left(1pF + \dfrac{10pF}{1 + 3.69}\right)} = 50.9\ MHz$$

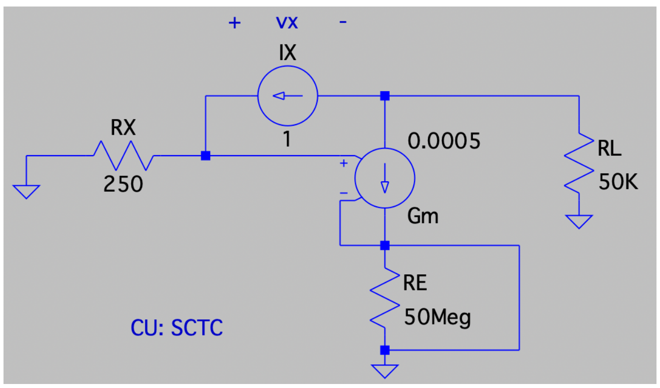
$$(b)\ f_H \cong \frac{1}{2\pi}\frac{1}{(250\Omega + 1k\Omega \| 430k\Omega)\left(1pF + \dfrac{10pF}{1 + 3.69}\right)} = 40.7\ MHz$$

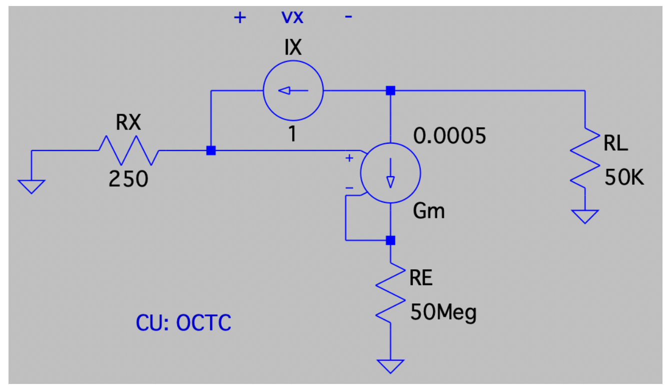
Page 599 This exercise should refer to Fig. 9.46(c).





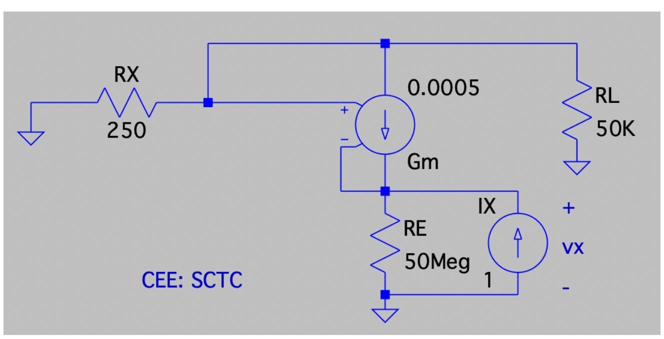
In this case, C_π is not specified as it is negligible relative to the $C_\mu g_m R_L$ terms. We find f_Z and f_P using the SCTC and OCTC time constant methods. Note: Gm = g_m and $R_E = 2R_{EE}$

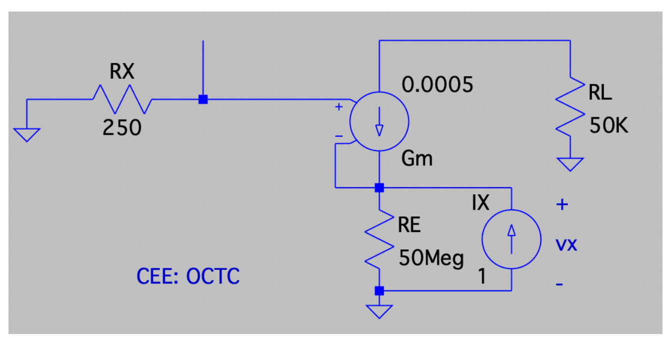




$$SCTC: \quad v_x = i_x r_x + (i_x + g_m i_x r_x) R_L \quad | \quad \frac{v_x}{i_x} = r_x + R_L(1 + g_m r_x) \cong r_x + R_L$$

$$OCTC: \quad v_x = i_x r_x + i_x R_L + i_x r_x \left(\frac{g_m}{1 + 2g_m R_{EE}}\right) R_L \quad | \quad \frac{v_x}{i_x} \cong r_x + R_L + R_L\left(\frac{r_x}{2R_{EE}}\right) \cong r_x + R_L$$





Note that the BJT is now connected as a diode in the left-hand figure, but not the right!

$$SCTC: \quad v_x = i_x\left[2R_{EE} || \left(\frac{1}{g_m} + r_x || R_L\right)\right] \quad | \quad \frac{v_x}{i_x} \cong \frac{1}{g_m} + r_x$$

$$OCTC: \quad v_x = i_x\left[2R_{EE} || \left(\frac{1}{g_m}\right)\right] \quad | \quad \frac{v_x}{i_x} \cong \frac{1}{g_m}$$

Continued on next page

$$SCTC:\ \omega_Z = \frac{1}{C_\mu(r_x + R_L) + 0.5C_{EE}\left(\frac{1}{g_m} + r_x\right)} \ \mid\ f_Z = \frac{1}{2\pi(0.5pF)[500 + 50k + 2k]\Omega} = 6.06\ MHz$$

$$OCTC:\ \omega_P \cong \frac{1}{C_\mu(r_x + R_L)} + \frac{1}{C_{EE}/2g_m} \cong \frac{1}{C_{EE}/2g_m} \ \mid\ f_P = \frac{1}{2\pi(1000\Omega)0.5pF} = 318\ MHz$$

It would be good practice to directly derive the four SCTC and OCTC terms!

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$$\text{Differential Pair}: A_{dm} = -g_m R_C = -40(99.0\mu A)(50k\Omega) = -198$$

$$C_\pi = \frac{40(99.0\mu A)}{2\pi(500\,MHz)} - 0.5\,pF = 0.761\,pF \quad | \quad r_\pi = \frac{100}{40(99.0\mu A)} = 25.3\ k\Omega$$

$$f_H = \frac{1}{2\pi(250\Omega)\left[0.761pf + 0.5\,pF\left(1 + 198 + \frac{50k\Omega}{250\Omega}\right)\right]} = 3.18\ MHz$$

$$\text{CC} - \text{CB Cascade}: A_v = \frac{g_{m1}\left(\frac{1}{g_{m2}}\right)}{1 + g_{m1}\left(\frac{1}{g_{m2}}\right)}\left(g_m R_C\right) = +\frac{198}{2} = +99.0$$

$$f_H \cong \frac{1}{2\pi(50k\Omega)(0.5pF)} = 6.37\ MHz$$

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$$g_m = 40(1.6mA) = 64.0\ mS \quad | \quad r_\pi = \frac{100}{64mS} = 1.56\ k\Omega \quad | \quad C_\pi = \frac{64.0mS}{2\pi(500\,MHz)} - 0.5\,pF = 19.9\ pF$$

$$A_{mid} = \frac{r_\pi}{R_I + r_x + r_\pi}\left(-g_m R_L\right) = \frac{1.56\ k\Omega}{882\Omega + 250\Omega + 1.56\ k\Omega}\left(-64.0mS\right)\left(4.12k\Omega\right) = -153$$

$$f_{P1} \cong \frac{1}{2\pi\, r_{\pi 0}\left(C_\pi + 2C_\mu\right)} = \frac{1}{2\pi\left(656\Omega\right)\left(19.9 + 1\right)pF} = 11.6\ MHz$$

$$f_{P2} \cong \frac{1}{2\pi\, R_L\left(C_\mu + C_L\right)} = \frac{1}{2\pi\left(4120\Omega\right)\left(0.5 + 5\right)pF} = 7.02\ MHz$$

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$$f_{P1} \cong \frac{1}{4\pi\, C_{GGD} r_{o2}} = \frac{0.02(100\mu A)}{4\pi\left(1\text{pF}\right)} = 159\ kHz \quad | \quad f_{P1} \cong \frac{1}{4\pi\, C_{GGD} r_{o2}} = \frac{0.02(25\mu A)}{4\pi\left(1\text{pF}\right)} = 39.8\ kHz$$

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$$X_C = \frac{1}{2\pi(530Hz)39pF} = 7.69\ M\Omega >> 2.39\ k\Omega$$

$$X_C = \frac{1}{2\pi(530Hz)1pF} = 300\ M\Omega \quad | \quad 51.8k\Omega \| 19.8k\Omega = 14.3\ k\Omega \quad | \quad 300\ M\Omega >> 14.3\ k\Omega$$

– – –

$$X_1 = \frac{1}{2\pi(667kHz)0.01\mu F} = 23.9\ \Omega << 1.01\ M\Omega \quad | \quad X_2 = \frac{1}{2\pi(667kHz)47\mu F} = 5.08\ \text{m}\Omega << 66.7\ \Omega$$

$$X_3 = \frac{1}{2\pi(667kHz)1\mu F} = 239\ \text{m}\Omega << 2.69\ k\Omega$$

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$$Z_C = \frac{1}{2\pi\, j(5MHz)0.01\mu F} = -j3.18\ \Omega$$

– – –

$$f_o = \frac{1}{2\pi\sqrt{(10\mu H)(100pF + 20pF)}} = 4.59\ MHz \quad | \quad r_o = \frac{50V + 15V - 1.6V}{3.2mA} = 19.8\ k\Omega$$

$$Q = \frac{100k\Omega \| 100k\Omega \| r_o}{2\pi(4.59\ MHz)(10\mu H)} = 49.2 \quad | \quad BW = \frac{4.59MHz}{49.2} = 93.3\ \text{kHz}$$

$$A_{mid} = -g_m\left(100k\Omega \| 100k\Omega \| r_o\right) = -\sqrt{2(0.005)(0.0032)}\left(100k\Omega \| 100k\Omega \| 19.8k\Omega\right) = -80.2$$

– – –

f_o is unchanged | $r_o = \frac{50V + 10V - 1.6V}{3.2mA} = 18.3\ k\Omega$ | $Q = \frac{100k\Omega \| 100k\Omega \| r_o}{2\pi(4.59\ MHz)(10\mu H)} = 46.4$

$\phi_o = 4.59\ MH\zeta$

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$$L_S \cong \frac{R_{EQ}}{\omega_T} = \frac{L^2 R_{EQ}}{\mu_n(V_{GS} - V_{TN})} = \frac{(5x10^{-5}cm)^2 75\Omega}{(400cm^2/V-s)(0.25V)} = 1.88\text{x}10^{-9} H$$

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$f_{osc} = 100MHz + 10.7MHz = 110.7\ MHz \quad f_U = 100MHz + 110.7MHz = 210.7\ MHz$

– – –

$(a)\ f_{osc} = 104.7MHz \pm 10.7MHz \rightarrow 94.0\ MHz$ or 115.4 MHz

$(b)\ f_{osc} = 88.1MHz \pm 10.7MHz \rightarrow 77.4\ MHz$ or 98.8 MHz

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$$A_{CG} = \frac{1}{A}\frac{A}{\pi} = \frac{1}{\pi} \quad | \quad 20\log\left(\frac{1}{\pi}\right) = -9.94\ dB$$

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$$A_{CG} = \frac{1}{A}\frac{2A}{\pi} = \frac{2}{\pi} \quad | \quad 20\log\left(\frac{2}{\pi}\right) = -3.92\ dB$$

Page 6.28

From Fig. 9.81(a), the amplitude of the output signal is approximately 70 mV, so the conversion gain is approximately:

$$A_{CG} = \frac{1}{100mV}(0.7)\left(\frac{200mV}{\pi}\right) = \frac{1.4}{\pi} \quad | \quad 20\log\left(\frac{1.4}{\pi}\right) = -7.02\ dB$$

From Fig. 9.81(b), the spectral components at 46 and 54 kHz have amplitudes of approximately 45 mV, so the conversion gain is:

$$A_{CG} = \frac{45mV}{100mV} = 0.45 \quad | \quad 20\log(0.45) = -6.93\ dB \quad | \quad \text{Note}: \frac{1.4}{\pi} = 0.446$$

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$$f_C - f_m = 20 - 0.01 = 19.99\ MHz \quad | \quad f_C + f_m = 20 + 0.01 = 20.01\ MHz$$
$$3f_C - f_m = 60 - 0.01 = 59.99\ MHz \quad | \quad 3f_C + f_m = 60 + 0.01 = 60.01\ MHz$$
$$5f_C - f_m = 100 - 0.01 = 99.99\ MHz \quad | \quad 5f_C + f_m = 100 + 0.01 = 100.01\ MHz$$

– – –

$$A_{f_C+f_m} = A_{f_C-f_m} = 3\ V$$

$$A_{3f_C+f_m} = A_{3f_C-f_m} = \frac{A_{f_C-f_m}}{3} = 1\ V$$

$$A_{5f_C+f_m} = A_{5f_C-f_m} = \frac{A_{f_C-f_m}}{5} = 0.6\ V$$
