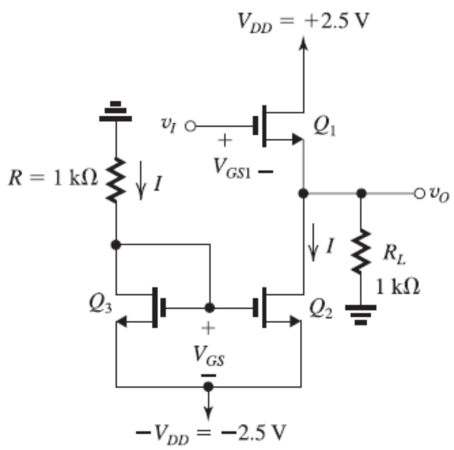
HW1

11.2

11.2 First we determine the bias current I as follows:



$$I = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

But

$$V_{GS} = 2.5 - IR = 2.5 - I$$

Thus

$$I = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(2.5 - I - V_t)^2$$

$$= \frac{1}{2} \times 20(2.5 - I - 0.5)^2$$

$$I = 10(2 - I)^2$$

$$\Rightarrow I^2 - 4.1I + 4 = 0$$

$$I = 1.6 \text{ mA and } V_{GS} = 0.9 \text{ V}$$

The upper limit on v_O is determined by Q_1 leaving the saturation region (and entering the triode region). This occurs when v_I exceeds V_{DD} by V_t volts:

$$v_{I\max} = 2.5 + 0.5 = 3 \text{ V}$$

To obtain the corresponding value of v_O, we must find the corresponding value of V_{GS1}, as follows:

$$v_O = v_I - V_{GS1}$$

$$i_L = \frac{v_O}{R_L} = \frac{v_I - V_{GS1}}{R_L} = \frac{v_I - V_{GS1}}{1}$$

$$i_L = 3 - V_{GS1}$$

$$i_{D1} = i_L + I = 3 - V_{GS1} + 1.6$$

$$= 4.6 - V_{GS1}$$

But,

$$i_{D1} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS1} - V_t)^2$$

$$4.6 - V_{GS1} = \frac{1}{2} \times 20(V_{GS1} - 0.5)^2$$

$$\Rightarrow V_{GS1}^2 - 0.9V_{GS1} - 0.21 = 0$$

$$V_{GS1} = 1.09 \text{ V}$$

$$v_{O\max} = v_{I\max} - V_{GS1}$$

$$= 3 - 1.09 = +1.91 \text{ V}$$

The lower limit of v_O is determined either by Q_1 cutting off,

$$v_O = -IR_L = -1.6 \times 1 = -1.6 \text{ V}$$

or by Q_2 leaving saturation,

$$v_O = -V_{DD} + V_{OV2}$$

where

$$V_{OV2} = V_{GS2} - V_t = 0.9 - 0.5 = 0.4 \text{ V}$$

Thus,

$$v_O = -2.5 + 0.4 = -2.1 \text{ V}$$

We observe that Q_1 will cut off before Q_2 leaves saturation, thus

$$v_{O\min} = -1.6 \text{ V}$$

and the corresponding value of v_I will be

$$v_{I\min} = v_{O\min} + V_t$$

$$= -1.6 + 0.5 = -1.1 \text{ V}$$

11.15

11.15 $V_{BB} = 2V_T \ln(I_Q/I_S)$

$= 2 \times 0.025 \ln(10^{-3}/10^{-14})$

$= 1.266$ V

At $v_I = 0$, $i_N = i_P = I_Q = 1$ mA, we have

$$r_{eN} = r_{eP} = \frac{25 \text{ mV}}{1 \text{ mA}} = 25\ \Omega$$

$$R_{out} = r_{eN} \parallel r_{eP} = 12.5\ \Omega$$

$$A_v = \frac{v_o}{v_i} = \frac{R_L}{R_L + R_{out}} = \frac{100}{100 + 12.5}$$

$= 0.889$ V/V

At $v_O = 10$ V, we have

$$i_L = \frac{10}{100} = 0.1 \text{ A} = 100 \text{ mA}$$

To obtain i_N, we use Eq. (11.27):

$$i_N^2 - i_L i_N - I_Q^2 = 0$$

$$i_N^2 - 100\ i_N - 1 = 0$$

$$\Rightarrow i_N = 100.01 \text{ mA}$$

$$i_P = i_N - i_L = 0.01 \text{ mA}$$

$$R_{out} = \frac{V_T}{i_P + i_N} \simeq \frac{25 \text{ mV}}{100 \text{ mA}} = 0.25\ \Omega$$

$$A_v = \frac{R_L}{R_L + R_{out}} = \frac{100}{100 + 0.25} = 0.998 \text{ V/V}$$

11.22

11.22 $I_Q \simeq I_{BIAS} = 1$ mA, neglecting the base current of Q_N. More precisely,

$$I_Q = I_{BIAS} - \frac{I_Q}{\beta + 1}$$

$$\Rightarrow I_Q = \frac{I_{BIAS}}{1 + \dfrac{1}{\beta + 1}} \simeq 0.98 \times 1 = 0.98 \text{ mA}$$

The largest positive output is obtained when all of I_{BIAS} flows into the base of Q_N, resulting in

$$v_O = (\beta_N + 1) I_{BIAS} R_L$$

$= 51 \times 1 \times 100\ \Omega = 5.1$ V

The largest possible negative output voltage is limited by the saturation of Q_P to

$$-10 + V_{ECsat} = -10 \text{ V}$$

To achieve a maximum positive output of 10 V without changing I_{BIAS}, β_N must be

$$10 = (\beta_N + 1) \times 1 \times 10^{-3} \times 100\ \Omega$$

$$\Rightarrow \beta_N = 99$$

Alternatively, if β_N is held at 50, I_{BIAS} must be increased so that

$$10 = 51 \times I_{BIAS} \times 10^{-3} \times 100\ \Omega$$

$$\Rightarrow I_{BIAS} = 1.96 \text{ mA}$$

for which

$$I_Q = \frac{I_{BIAS}}{1 + \dfrac{1}{\beta + 1}} = 1.92 \text{ mA}$$

11.31

11.31 See figure on the next page.

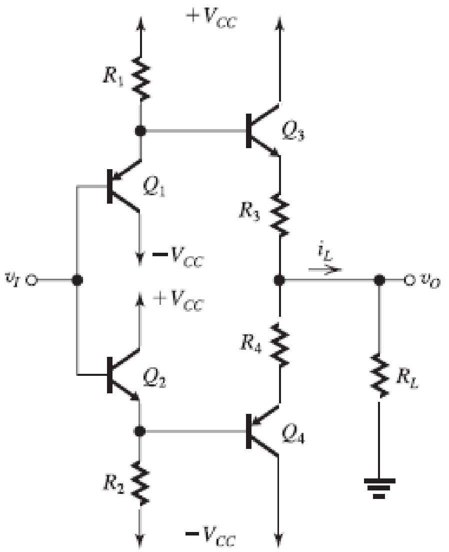
At $v_I = 5$ V, we have

$V_{E1} = +5.7$ V

$$I_{R1} = \frac{V_{CC} - V_{E1}}{R_1} = \frac{10 - 5.7}{R_1} = \frac{4.3}{R_1}$$

To allow for $I_{B3} = 10$ mA if needed while reducing I_{E1} by no more than half, then I_{R1} must be $2 \times 10 = 20$ mA. Thus,

$$R_1 = \frac{V_{R1}}{I_{R1}} = \frac{4.3}{20} = 0.215\ \text{k}\Omega = 215\ \Omega$$



Similarly,

$R_2 = 0.215\ \text{k}\Omega = 215\ \Omega$

Next, we determine the values of R_3 and R_4: At $v_I = 0$, assume $V_{EB1} = 0.7$. Then

$V_{E1} = 0.7$ V

$$I_{R1} = \frac{10 - 0.7}{0.215} = 43.3\ \text{mA}$$

$$V_{EB1} = 0.7 + 0.025 \times \ln\left(\frac{43.3}{10}\right)$$

$= 0.737$ V

$V_{E1} = 0.737$ V

Meanwhile Q_3 will be conducting $I_Q = 40$ mA. Since $I_{S3} = 3I_{S1}$ then Q_3 has $V_{BE} = 0.7$ V at $I_C = 30$ mA. At 40 mA,

$$V_{BE3} = 0.7 + 0.025 \times \ln\left(\frac{40}{30}\right)$$

$= 0.707$ V

For $v_O = 0$,

$V_{E1} - V_{BE3} - I_{E3}R_3 = 0$

$0.737 - 0.707 - 40R_3 = 0$

$\Rightarrow R_3 = 0.75\ \Omega$

Similarly,

$R_4 = 0.75\ \Omega$

$$R_{\text{out}} = \frac{1}{2}\left[R_3 + r_{e3} + \frac{R_1 \parallel r_{e1}}{\beta_3 + 1}\right]$$

where

$$r_{e3} = \frac{25\ \text{mV}}{40\ \text{mA}} = 0.625\ \Omega$$

$$r_{e1} = \frac{25 \text{ mV}}{20 \text{ mA}} = 1.25\ \Omega$$

$$R_{\text{out}} = \frac{1}{2}\left[0.75 + 0.625 + \frac{215 \parallel 1.25}{51}\right]$$

$$R_{\text{out}} = 0.7\ \Omega$$

Next, consider the situation when

$v_I = +1$ V and $R_L = 2\ \Omega$

Let $v_O \simeq 1$ V, then

$$i_L = \frac{1 \text{ V}}{2\ \Omega} = 0.5 \text{ A} = 500 \text{ mA}$$

Now if we assume that $i_{E4} \simeq 0$, then

$$i_{E3} = i_L = 500 \text{ mA}$$

$$V_{BE3} = 0.7 + 0.025 \ln\frac{500}{30}$$

$$= 0.770 \text{ V}$$

$$i_{B3} = \frac{500}{51} \simeq 10 \text{ mA}$$

Assuming that $V_{EB1} \simeq 0.7$ V, then

$$v_{E1} = 1 + 0.7 = 1.7 \text{ V}$$

$$i_{R1} = \frac{10 - 1.7}{0.215} = 38.6 \text{ mA}$$

$$i_{E1} = i_{R1} - i_{B2} = 38.6 - 10 = 28.6 \text{ mA}$$

$$V_{EB1} = 0.7 + 0.025 \ln\frac{28.6}{10}$$

$$= 0.726 \text{ V}$$

$$V_{E1} = 1.726 \text{ V}$$

$$i_L = \frac{V_{E1} - V_{BE3}}{R_3 + R_L}$$

$$= \frac{1.726 - 0.770}{0.75 + 2}$$

$$= 0.348 \text{ A}$$

$$v_O = i_L R_L$$

$$= 0.348 \times 2 = 0.695 \text{ V}$$

Let's check that i_{E4} is zero. The voltage at the base of Q_4 is

$$V_{B4} = 1 - V_{BE2}$$

$$\simeq 1 - 0.74 = 0.26 \text{ V}$$

The voltage across R_4 and V_{EB4} is

$$= v_O - 0.26 = 0.695 - 0.26 = 0.435 \text{ V}$$

which is sufficiently small to keep Q_4 cutoff, verifying our assumption that $i_{E4} \simeq 0$.

Let's now do more iterations to refine our estimate of v_O:

$$i_L = 0.35 \text{ A}$$

$$i_{B3} = \frac{0.35}{51} \simeq 7 \text{ mA}$$

$$i_{E1} = \frac{10 - 1 - 0.726}{0.215} - 7 = 31.5 \text{ mA}$$

$$V_{EB1} = 0.7 + 0.025 \ln\left(\frac{31.5}{10}\right)$$

$$= 0.729 \text{ V}$$

$$V_{E1} = 1 + 0.729 = 1.729 \text{ V}$$

$$i_{E3} = i_L = 350 \text{ mA}$$

$$V_{BE3} = 0.7 + 0.025 \ln\left(\frac{350}{30}\right)$$

$$= 0.761 \text{ V}$$

$$i_L = \frac{V_{E1} - V_{BE3}}{R_3 + R_2}$$

$$= \frac{1.729 - 0.761}{0.75 + 2} = 0.352 \text{ A}$$

$$v_O = i_L R_L$$

$$= 0.352 \times 2 = 0.704 \text{ V}$$

11.39

11.39 Refer to Fig. 11.22.

At 125°C, we have

$V_Z = 6.8 + (125 - 25) \times 2 = 7.0$ V

Since $I_{C2} = 200$ µA, then

$$V_{BE1} = 0.7 + 0.025 \ln\left(\frac{200}{100}\right) - 2 \text{ mV} \times 100$$

$= 0.517$ V

Similarly, for Q_2 to conduct 200 µA, we need

$V_{BE2} = 0.517$ V

Now, the voltage across R_1 and R_2 is

$V_{(R_1+R_2)} = V_Z - V_{BE1}$

$= 7 - 0.517 = 6.483$ V

The voltage across R_2 is equal to V_{BE1}, thus

$$R_2 = \frac{0.517}{0.2 \text{ mA}} = 2.59 \text{ k}\Omega$$

The voltage across R_1 is given by
$6.487 - 0.517 = 5.966$ V. Thus,

$$R_1 = \frac{5.966 \text{ V}}{0.2 \text{ mA}} = 29.8 \text{ k}\Omega$$

Now, at 25°C, we have

$V_Z = 6.8$ V

Assume $V_{BE1} = 0.7$ V, then

$V_{(R_1+R_2)} = 6.8 - 0.7 = 6.1$ V

$$I_{(R_1+R_2)} = \frac{6.1}{2.59 + 29.8} = 0.188 \text{ µA}$$

Thus

$$V_{BE1} = 0.7 + 0.025 \ln\frac{188}{100} = 0.716 \text{ V}$$

$V_{(R_1+R_2)} = 6.8 - 0.716 = 6.084$

$$V_{BE2} = 6.084 \times \frac{R_2}{R_1 + R_2}$$

$$= 6.084 \times \frac{2.59}{2.59 + 29.8} = 0.486 \text{ V}$$

Thus,

$I_{C2} = 100\, e^{(486-700)/25} = 0.019$ µA

HW2

11.40

11.40 (a) Refer to the circuit in Fig. 11.23.

$R_{out} = R_{on} \parallel R_{op}$

where

$$R_{on} = \frac{1}{g_{mn}} \parallel r_{on} \simeq 1/g_{mn}$$

$$R_{op} = \frac{1}{g_{mp}} \parallel r_{op} \simeq 1/g_{mp}$$

$$R_{out} = R_{on} \parallel R_{op} \simeq \frac{1}{g_{mn}} \parallel \frac{1}{g_{mp}}$$

Thus,

$$R_{out} \simeq \frac{1}{g_{mn} + g_{mp}} \qquad \text{Q.E.D.}$$

For matched devices, we have

$$g_{mn} = g_{mp} = g_m$$

$$R_{out} = \frac{1}{2g_m} \qquad \text{Q.E.D.}$$

(b) $R_{out} = 20\ \Omega$

$$\frac{1}{2g_m} = 20$$

$$\Rightarrow g_m = \frac{1}{40}\ \text{A/V} = 25\ \text{mA/V}$$

But,

$$g_m = k'(W/L)V_{OV}$$

$$25 = 200V_{OV}$$

$$\Rightarrow V_{OV} = \frac{25}{200} = 0.125\ \text{V}$$

$$V_{GG} = 2V_{GS}$$

$$= 2(|V_t| + |V_{OV}|)$$

$$= 2(0.5 + 0.125)$$

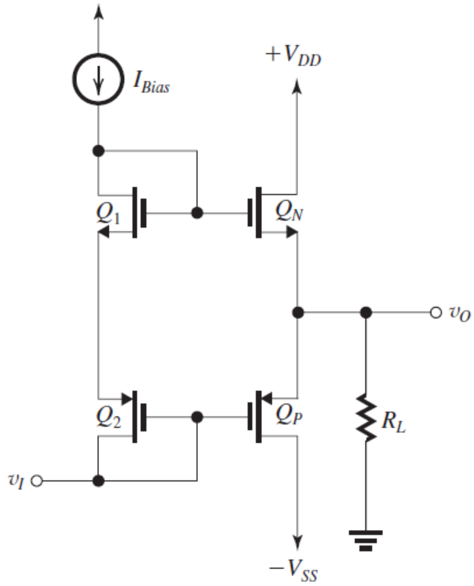
$$= 2 \times 0.625 = 1.25\ \text{V}$$

$$I_Q = \frac{1}{2}k'\left(\frac{W}{L}\right)V_{OV}^2$$

$$= \frac{1}{2} \times 200 \times 0.125^2 = 1.56\ \text{mA}$$

11.41

11.41



(a) Equation (11.43)

$$I_Q = I_{Bias}\frac{(W/L)_n}{(W/L)_1}$$

$$1 = 0.1\frac{(W/L)_n}{(W/L)_1}$$

$$\frac{(W/L)_n}{(W/L)_1} = 10$$

$$Q_1\!: I_{Bias} = \frac{1}{2}k_n'\left(\frac{W}{L}\right)_1 V_{OV}^2$$

$$0.1 = \frac{1}{2} \times 0.250 \times \left(\frac{W}{L}\right)_1 \times (0.15)^2$$

$$\Rightarrow \left(\frac{W}{L}\right)_1 = 35.6$$

$$Q_2\!: 0.1 = \frac{1}{2} \times 0.100 \times \left(\frac{W}{L}\right)_2 \times (0.15)^2$$

$$\Rightarrow \left(\frac{W}{L}\right)_2 = 88.9$$

$$Q_N\!: 1 = \frac{1}{2} \times 0.250 \times \left(\frac{W}{L}\right)_N \times (0.15)^2$$

$$\Rightarrow \left(\frac{W}{L}\right)_N = 356$$

$$Q_P\!: 1 = \frac{1}{2} \times 0.100 \times \left(\frac{W}{L}\right)_P \times (0.15)^2$$

$$\left(\frac{W}{L}\right)_P = 889$$

(b) From the circuit we get $v_I = v_O - V_{SGP}$

Since $v_O = 0$, we have

$v_I = -V_{SGP}$

$V_{SGP} = |V_{OV}| + |V_t|$

$= 0.15 + 0.45$

$= 0.6$ V

$\therefore\ v_I = -V_{SGP} = -0.6$ V

(c) Using Eq. (11.46), we obtain

$v_{O\max} = V_{DD} - V_{OV}|_{\text{Bias}} - V_{GSN}$

To find V_{GSN}, use the equations

$$i_{DN\max} = \frac{1}{2}k_n'\frac{W}{L}(V_{GSN} - V_t)^2$$

$$10 = \frac{1}{2} \times 0.250 \times 356\,(V_{GSN} - V_t)^2$$

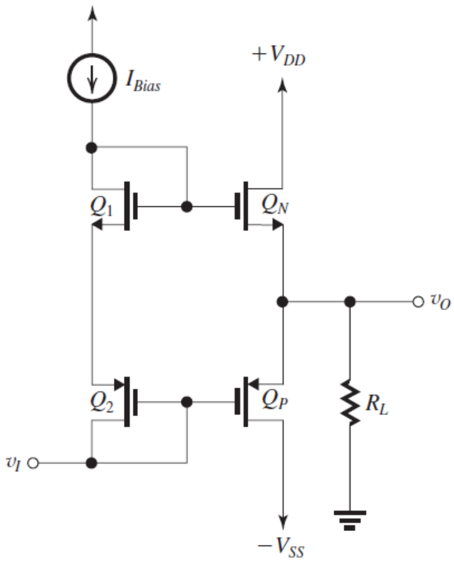
$\Rightarrow V_{GSN} - V_t = 0.47$ V

$V_{GSN} = V_t + 0.47 = 0.45 + 0.47 \simeq 0.92$ V

$\therefore\ v_{O\max} = 2.5 - 0.2 - 0.92 = 1.38$ V

11.42

11.42



(a) under quiescent condition

$$\text{Voltage gain} = \frac{v_o}{v_i} = \frac{R_L}{R_L + R_{\text{out}}}$$

As shown in problem 11.40, for matched transistors we have

$$R_{\text{out}} = \frac{1}{2g_m}$$

Substituting for R_{out} above, we obtain for $\dfrac{v_o}{v_i}$

$$\frac{v_o}{v_i} = \frac{R_L}{R_L + \dfrac{1}{2g_m}} \qquad \text{Q.E.D.}$$

(b) $\text{Voltage gain} = 0.98 = \dfrac{R_L}{R_L + \dfrac{1}{2g_m}}$

$$0.98 = \frac{1000}{1000 + \dfrac{1}{2g_m}}$$

$\Rightarrow g_m = 24.5$ mA/V

For Q_1, we have $I_{Bias} = I_D$.

$$\therefore 0.2 = \frac{1}{2}k_1 V_{OV}^2$$

$$0.2 = \frac{1}{2} \times 20 \times V_{OV}^2$$

$\Rightarrow V_{OV} = 0.14$ V

For Q_N, we have

$$g_m = k_n V_{OV}$$

$$24.5 = k_n \times 0.14$$

$$k_n = 173 \text{ mA/V}^2$$

$$n = \frac{k_n}{k_1} = \frac{173}{20}$$

$$= 8.66$$

and $I_Q = nI_{\text{bias}}$

$$= 8.66 \times 0.2$$

$$= 1.73 \text{ mA}$$

11.44

11.44 From Eq. (11.57), we obtain

$$R_{\text{out}} = 1/\mu(g_{mp} + g_{mn})$$

where

$$g_{mp} = g_{mn} = \frac{2I_Q}{|V_{OV}|} = \frac{2 \times 2}{0.2} = 20 \text{ mA/V}$$

$$R_{\text{out}} = \frac{1}{5(20+20)} = \frac{1}{200} \text{ k}\Omega = 5\ \Omega$$

11.47

11.47 (a) $I_Q = \frac{1}{2}k'\frac{W}{L}V_{OV}^2$

$$1.5 = \frac{1}{2} \times 0.1\left(\frac{W}{L}\right)_P (0.15)^2$$

$$\Rightarrow \left(\frac{W}{L}\right)_P = 1333.3$$

$$\left(\frac{W}{L}\right)_N = \frac{(W/L)_P}{k_n'/k_p'}$$

$$\left(\frac{W}{L}\right)_N = \frac{1333.3}{2.5} = 533.3$$

(b) $g_m = \frac{2I_Q}{V_{OV}} = \frac{2 \times 1.5}{0.15} = 20$ mA/V

$$R_{out} = \frac{1}{2\mu g_m} \text{ (where } g_{mn} = g_{mp} = g_m)$$

$$2.5 = \frac{1}{2\mu \times 20 \times 10^{-3}}$$

$$\Rightarrow \mu = 10 \text{ V/V}$$

(c) Gain error $= -\frac{1}{2\mu g_m R_L}$

$$= -\frac{1}{2 \times 10 \times 20 \times 10^{-3} \times 50} = -0.05$$

or -5%

(d) In the quiescent state the dc voltage at the output of each amplifier must be of the value that causes the current in Q_N and Q_P to be I_Q. Thus, for the Q_P amplifier the output voltage is

$$V_{DD} - V_{SG} = V_{DD} - |V_{tp}| - |V_{OV}|$$

$$= 2.5 - 0.5 - 0.15 = 1.85 \text{ V}$$

Similarly, the voltage at the output of the Q_N amplifier must be

$$-V_{SS} + V_{GS} = -2.5 + 0.5 + 0.15$$

$$= -1.85 \text{ V}$$

(e) Q_P will be supplying all the load current when Q_N cuts off. From Eq. (11.62) we see that Q_N cuts off when

$$\mu\frac{v_O - v_I}{V_{OV}} = -1$$

Substituting this in Eq. (11.61), we find the current i_{DP} to be

$$i_{DP} = I_Q(1 + 1)^2 = 4I_Q$$

Since in this situation

$$i_L = i_{DP}$$

then

$$i_L = 4I_Q$$

and

$$v_O = 4I_Q R_L$$

$$= 4 \times 1.5 \times 10^{-3} \times 50 = 0.3 \text{ V}$$

Similarly, when $v_O = -0.3$ V, Q_P will cut off and all the current ($4I_Q = 6$ mA) will be supplied by Q_N.

(f) The situation at $v_O = v_{O\max}$ is illustrated in Fig. 1. Analysis of this circuit provides

$$i_{DP} = \frac{1}{2} \times k_n'\left(\frac{W}{L}\right)_n [2.5 - (v_{O\max} - 0.5) - 0.5]^2$$

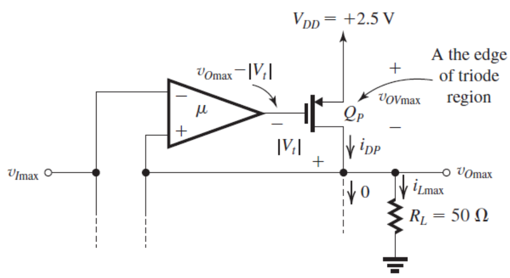
$$\frac{v_{O\max}}{R_L} = \frac{1}{2} \times 0.25 \times 533.3(2.5 - v_{O\max})^2$$

$$\Rightarrow v_{O\max} = 1.77 \text{ V}$$

Similarly,

$$v_{O\min} = -1.77 \text{ V}$$

This figure belongs to part(f).



HW3

12.3

12.3 For the op amp to not have a systematic offset voltage, the condition in Eq. (12.1) must be satisfied, that is,

$$\frac{(W/L)_6}{(W/L)_4} = 2\frac{(W/L)_7}{(W/L)_5}$$

$$\frac{W/0.3}{6/0.3} = 2\frac{45/0.3}{30/0.3}$$

$$\Rightarrow W = 18\ \mu\text{m}$$

Refer to Fig. 12.1:

$$I_{D8} = I_{\text{REF}} = 40\ \mu\text{A}$$

$$I = I_{D5} = I_{\text{REF}}\frac{W_5}{W_8} = 40 \times \frac{30}{6} = 200\ \mu\text{A}$$

$$I_{D7} = I_{\text{REF}}\frac{W_7}{W_8} = 40 \times \frac{45}{6} = 300\ \mu\text{A}$$

$$I_{D6} = 300\ \mu\text{A}$$

$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = \frac{I}{2} = 100\ \mu\text{A}$$

The overdrive voltage at which each transistor is operating is determined from

$$I_D = \frac{1}{2}\mu C_{ox}\frac{W}{L}V_{OV}^2$$

Then V_{GS} is found from

$$|V_{GS}| = |V_t| + |V_{OV}|$$

The transconductance at which each transistor is operating is obtained from

$$g_m = \frac{2I_D}{V_{OV}}$$

The output resistance of each transistor is found from

$$r_o = \frac{|V_A|}{I_D}$$

$$A_1 = -g_{m1,2}(r_{o2} \parallel r_{o4})$$

$$= -1.33(150 \parallel 150) = -100\ \text{V/V}$$

$$A_2 = -g_{m6}(r_{o6} \parallel r_{o7})$$

$$= -3.16(50 \parallel 50) = -79\ \text{V/V}$$

$$A = A_1A_2 = 7900\ \text{V/V}$$

Using Eq. (12.2), we obtain

$$V_{ICM\,\text{min}} = -V_{SS} + V_{tn} + V_{OV3} - |V_{tp}|$$

$$V_{ICM\,\text{min}} = -1 + 0.45 + 0.19 - 0.45$$

$$= -0.81\ \text{V}$$

Using Eq. (12.3), we get

$$V_{ICM\,\text{max}} = V_{DD} - |V_{OV5}| - |V_{tp}| - |V_{OV1}|$$

$$= 1 - 0.24 - 0.45 - 0.15$$

$$= +0.16\ \text{V}$$

The results are summarized in the following table:

	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
I_D (μA)	100	100	100	100	200	300	300	40
$\lvert V_{OV}\rvert$ (V)	0.15	0.15	0.19	0.19	0.24	0.19	0.24	0.24
$\lvert V_{GS}\rvert$ (V)	0.6	0.6	0.64	0.64	0.69	0.64	0.69	0.69
g_m (mA/V)	1.33	1.33	1.05	1.05	1.67	3.16	2.5	0.33
r_o (kΩ)	150	150	150	150	75	50	50	375

Thus,

$$-0.8\ \text{V} \le V_{ICM} \le +0.16\ \text{V}$$

Using Eq. (12.5), we obtain

$$-V_{SS} + V_{OV6} \le v_O \le V_{DD} - |V_{OV7}|$$

Thus,

$$-1 + 0.19 \le v_O \le 1 - 0.24$$

$$-0.81\ \text{V} \le v_O \le 0.76\ \text{V}$$

12.6

12.6 From Eq. (12.36), we obtain

$$f_t = \frac{G_{m1}}{2\pi C_C}$$

Thus,

$$C_C = \frac{G_{m1}}{2\pi f_t} = \frac{0.8 \times 10^{-3}}{2\pi \times 120 \times 10^6} = 1.06 \text{ pF}$$

From Eq. (12.35), we get

$$f_{P2} = \frac{G_{m2}}{2\pi C_2}$$

$$= \frac{2.4 \times 10^{-3}}{2\pi \times 1.2 \times 10^{-12}} = 318.3 \text{ MHz}$$

From Eq. (12.31), we get

$$f_Z = \frac{G_{m2}}{2\pi C_C}$$

$$= \frac{2.4 \times 10^{-3}}{2\pi \times 1.06 \times 10^{-12}} = 360 \text{ MHz}$$

12.8

12.8 $G_{m1} = 0.3$ mA/V

$G_{m2} = 0.6$ mA/V

$r_{o2} = r_{o4} = 222 \text{ k}\Omega$

$r_{o6} = r_{o7} = 111 \text{ k}\Omega$

$C_2 = 1$ pF

(a) $A = G_{m1}(r_{o2} \parallel r_{o4})G_{m2}(r_{o6} \parallel r_{o7})$

$= 0.3(222 \parallel 222) \times 0.6(111 \parallel 111)$

$= 33.3 \times 33.3 = 1109$ V/V

(b) $$f_{P2} = \frac{G_{m2}}{2\pi C_2}$$

$$= \frac{0.6 \times 10^{-3}}{2\pi \times 1 \times 10^{-12}} = 95.5 \text{ MHz}$$

(c) $$R = \frac{1}{G_{m2}} = \frac{1}{0.6 \times 10^{-3}} = 1.67 \text{ k}\Omega$$

(d) $$\text{Phase margin} = 180 - 90 - \tan^{-1}\left(\frac{f_t}{f_{P2}}\right)$$

$$80^\circ = 90 - \tan^{-1}\left(\frac{f_t}{f_{P2}}\right)$$

$f_t = f_{P2} \tan 10^\circ$

$= 95.5 \times 0.176 = 16.8$ MHz

Using Eq. (12.36), we obtain

$$C_C = \frac{G_{m1}}{2\pi f_t} = \frac{0.3 \times 10^{-3}}{2\pi \times 16.8 \times 10^6} = 2.84 \text{ pF}$$

The dominant pole will be at a frequency

$$f_{P1} = \frac{f_t}{\text{DC Gain}} = \frac{16.8 \times 10^6}{1109}$$

$= 15.1$ kHz

(e) Since

$$f_t = \frac{G_{m1}}{2\pi C_C}$$

to double f_t, C_C must be reduced by a factor of 2,

$$C_C = \frac{2.84}{2} = 1.42 \text{ pF}$$

At the new $f_t = 2 \times 16.8 = 33.6$ MHz, we have

$$\phi_{P2} = -\tan^{-1}\frac{f_t}{f_{P2}}$$

$$= -\tan^{-1}\left(\frac{33.6}{95.5}\right) = -19.4^\circ$$

To reduce this phase lag to -10°, we need to change R so that the zero moves to the negative real axis and introduces a phase lead of 9.4°. Thus,

$$\tan^{-1}\frac{f_t}{f_Z} = 9.4^\circ$$

$$f_Z = \frac{f_t}{\tan 9.4} = \frac{33.6}{0.166} = 203 \text{ MHz}$$

$$f_Z = \frac{1}{2\pi C_C\left(R - \frac{1}{G_{m2}}\right)}$$

$$\Rightarrow R - \frac{1}{G_{m2}} = \frac{1}{2\pi \times 203 \times 10^6 \times 1.42 \times 10^{-12}}$$

$= 552\ \Omega$

$R = 1670 + 552 = 2222\ \Omega$

$= 2.22 \text{ k}\Omega$

12.10

12.10 Using Eq. (12.46), we obtain

$$SR = 2\pi f_t V_{OV1,2}$$

$$= 2\pi \times 100 \times 10^6 \times 0.2$$

$$= 125.6 \text{ V}/\mu\text{s}$$

Using Eq. (12.45),

$$SR = \frac{I}{C_C}$$

$$\Rightarrow C_C = \frac{I}{SR} = \frac{100 \times 10^{-6}}{125.6 \times 10^6}$$

$$= 0.8 \text{ pF}$$

12.14

12.14 $G_{m1} = 0.8$ mA/V, $G_{m2} = 2$ mA/V

(a) Using Eq. (12.36), we obtain

$$f_t = \frac{g_{m1}}{2\pi C_C}$$

$$\Rightarrow C_C = \frac{G_{m1}}{2\pi f_t} = \frac{0.8 \times 10^{-3}}{2\pi \times 100 \times 10^6} = 1.27 \text{ pF}$$

(b) Phase margin =

$$90^\circ - \tan^{-1}\left(\frac{f_t}{f_{P2}}\right) - \tan^{-1}\left(\frac{f_t}{f_Z}\right)$$

$$60^\circ = 90 - \tan^{-1}\left(\frac{f_t}{f_{P2}}\right) - \tan^{-1}\left(\frac{f_t}{f_Z}\right)$$

Thus,

$$\tan^{-1}\left(\frac{f_t}{f_{P2}}\right) + \tan^{-1}\left(\frac{f_t}{f_Z}\right) = 30^\circ$$

where

$$f_{P2} = \frac{G_{m2}}{2\pi C_2}$$

$$f_Z = \frac{1}{2\pi C_C\left(\frac{1}{G_{m2}} - R\right)}$$

$$= \frac{1}{2\pi \times 1.27 \times 10^{-12}(0.5 - 0.5) \times 10^3} = \infty$$

Thus,

$$\tan^{-1}\left(\frac{f_t}{f_{P2}}\right) = 30^\circ$$

$$f_{P2} = \frac{f_t}{\tan 30} = 173.2 \text{ MHz}$$

We now can obtain C_2 from

$$173.2 \times 10^6 = \frac{2 \times 10^{-3}}{2\pi C_2}$$

$$\Rightarrow C_2 = \frac{2 \times 10^{-3}}{2\pi \times 173.2 \times 10^6} = 1.84 \text{ pF}$$

HW4
12.20

12.20 $G_m = g_{m1} = g_{m2} = \dfrac{2(I/2)}{V_{OV}}$

$$= \frac{I}{V_{OV}} = \frac{0.4}{0.2} = 2 \text{ mA/V}$$

$$I_{D4} = I_B - \frac{I}{2} = 0.25 - 0.2 = 0.05 \text{ mA}$$

$$g_{m4} = \frac{2I_{D4}}{|V_{OV}|} = \frac{2 \times 0.05}{0.2} = 0.5 \text{ mA/V}$$

$$r_{o4} = \frac{|V_A|}{I_{D4}} = \frac{10}{0.05} = 200 \text{ k}\Omega$$

$$r_{o2} = \frac{|V_A|}{I_{D2}} = \frac{|V_A|}{I/2} = \frac{10}{0.2} = 50 \text{ k}\Omega$$

$$r_{o10} = \frac{|V_A|}{I_{D10}} = \frac{|V_A|}{I_B} = \frac{10}{0.25} = 40 \text{ k}\Omega$$

$$R_{o4} = (g_{m4} r_{o4})\ (r_{o2} \parallel r_{o10})$$

$$= 0.5 \times 200\ (50 \parallel 40)$$

$$= 2.22 \text{ M}\Omega$$

$$I_{D6} = 50\ \mu\text{A} = 0.05 \text{ mA}$$

$$g_{m6} = \frac{2 \times 0.05}{0.2} = 0.5 \text{ mA/V}$$

$$r_{o6} = \frac{|V_A|}{I_{D6}} = \frac{10}{0.05} = 200 \text{ k}\Omega$$

$$r_{o8} = \frac{|V_A|}{I_{D8}} = \frac{10}{0.05} = 200 \text{ k}\Omega$$

$$R_{o6} = g_{m6} r_{o6} r_{o8}$$

$$= 0.5 \times 200 \times 200 = 20 \text{ M}\Omega$$

$$R_o = R_{o4} \parallel R_{o6}$$

$$= 2.22 \parallel 20 = 2 \text{ M}\Omega$$

$$A_v = G_m R_o$$

$$= 2 \times 2000 = 4000 \text{ V/V}$$

For the closed-loop amplifier:

$$A = A_v = 4000$$

$$\beta = \frac{C}{C + 9C} = 0.1$$

$$\frac{V_o}{V_i} = A_f = \frac{A}{1 + A\beta} = \frac{4000}{1 + 4000 \times 0.1}$$

$$= \frac{4000}{401} = 9.975 \text{ V/V}$$

$$R_{\text{out}} = R_{of} = \frac{R_o}{1 + A\beta} = \frac{2 \text{ M}\Omega}{401} \simeq 5 \text{ k}\Omega$$

12.25

12.25 First we determine V_{OV}:

$$90 = \frac{1}{2} \times 400 \times 20\ V_{OV}^2$$

$$\Rightarrow V_{OV} = 0.15\ \text{V}$$

$$V_{\text{BIAS}} = V_t + 2V_{OV} = 0.45 + 2 \times 0.15$$

$$= 0.75\ \text{V}$$

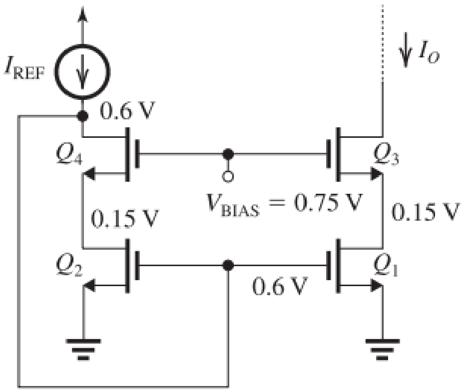


Figure 1

Figure 1 shows the voltages at the various nodes in the mirror circuit. The minimum voltage allowable at the output terminal is

$$v_{O\min} = V_{\text{BIAS}} - V_{tn}$$

$$= 0.75 - 0.45 = 0.3\ \text{V}$$

which is $2V_{OV}$.

The output resistance is

$$R_o \simeq g_{m3} r_{o3} r_{o1}$$

where

$$r_{o1} = r_{o3} = \frac{V_A}{I_D} = \frac{10}{0.09} = 111.1\ \text{k}\Omega$$

$$g_{m3} = \frac{2I_D}{V_{OV}} = \frac{2 \times 0.09}{0.15} = 1.2\ \text{mA/V}$$

$$R_o = 1.2 \times 111.1 \times 111.1 = 14.8\ \text{M}\Omega$$