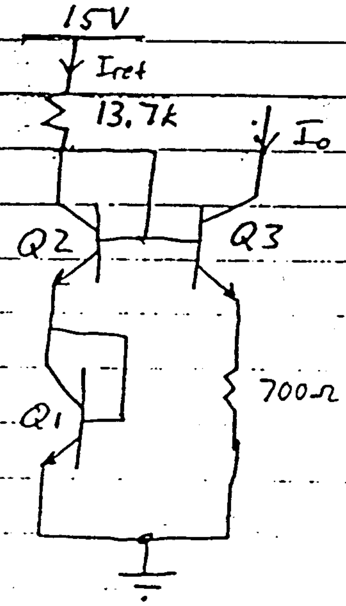
PS#5 HW SOLUTIONS 114

1) DETERMINE OUTPUT CURRENT AND OUTPUT RESISTANCE OF THE CKT BELOW

Assume $I_S = 5\times10^{-15}$, $\beta = 200$, $V_A = 130V$ } Fig 2.30



$$I_{ref} = \frac{15V - 1.4V}{13.7k\Omega} = 0.993mA$$

$$V_{BE_1} + V_{BE_2} \approx V_{BE_3} + I_o(700\Omega)$$

$$V_T \ln\frac{I_{ref}}{I_s} + V_T \ln\frac{I_{ref}}{I_s} = V_T \ln\frac{I_o}{I_s} + I_o(700\Omega)$$

$$V_T \ln\frac{I_{ref}^2}{I_s^2} = V_T \ln\frac{I_o}{I_s} + I_o(700)$$

$$V_T \ln\frac{I_{ref}^2}{I_s I_o} = I_o(700)$$

$$\text{so } I_o = \frac{V_T}{700}\ln\left(\frac{I_{ref}^2}{I_s I_o}\right) = \frac{.026}{700}\ln\frac{(.993\times10^{-3})^2}{(5\times10^{-15} I_o)}$$

$$I_o = \frac{.026}{700}\ln\left(\frac{1.9721\times10^{8}}{I_o}\right)$$

TRIAL & ERROR ⇒ $\boxed{I_o \approx .97mA}$

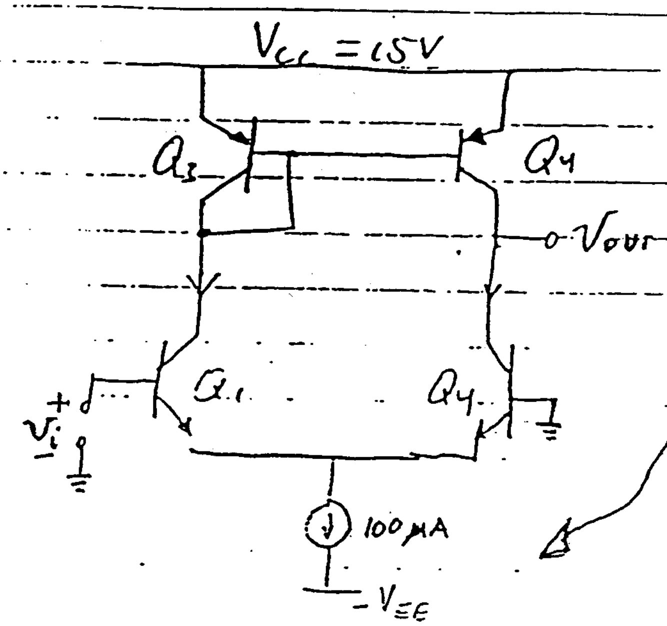
$$R_o = R_{o,\,CE\ w/\ deg} \cong r_o\left(1 + g_{m_3}R_E\cdot\frac{r_{\pi_3}}{r_{\pi_3} + R_{s_3} + R_E}\right)$$

$$= \frac{130V}{0.97mA}\cdot\left(1 + \frac{0.97mA}{26mV}\cdot(700\Omega)\cdot\frac{5.4k}{5.4k + 52 + 700}\right) \approx 3.2M\Omega$$

$$R_{s_3} = \left(\frac{1}{g_{m_2}} + \frac{1}{g_{m_1}}\right)\|13.7k\Omega = (2)\left(\frac{26mV}{0.993mA}\right)\|13.7k\Omega$$

$$\approx 52\Omega$$

2.) DETERMINE THE UNLOADED VOLTAGE GAIN AND OUTPUT RESISTANCE FOR THE CIRCUIT:



Note that $A_v = A_{dm}$ because $A_{cm} = 0$ because tail current is ideal current source.

$I_1 \cong I_2 \cong 50\mu A$

$R_{OUT} = r_{o_{pnp}} \parallel r_{o_{npn}}$

$r_{o_{pnp}} = \frac{V_A}{I_C} = \frac{50V}{50\mu A} = 1MEG$

$r_{o_{npn}} = \frac{130V}{50\mu A} = 2.6 M\Omega$

$R_{OUT} = 1MEG \parallel 2.6MEG$
$= 722k\Omega$ — Answer —

$G_m = g_m$

$A_v = g_m R_{OUT} = \frac{50\mu A}{.026}(722k)$

$A_v = 1388$ — Answer —

Alternately, $A_v = \frac{1}{\eta_{npn} + \eta_{pnp}}$ → $A_v = 1429$ Answer

simple bjt model (44V) | HSPICE : $A_v = 1456$

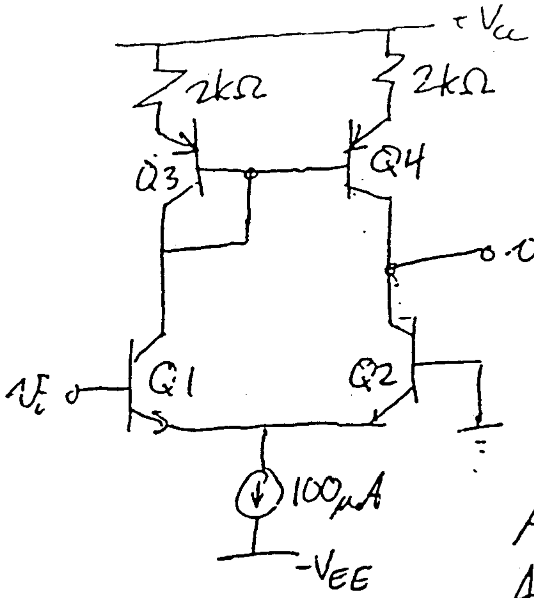
The discrepancy between these two values for A_v is due to roundoff error between the values for η and V_A given in Figures 2.30 and 2.37.

3

To solve this, we must go back to the single xstr. models used to solve the active load w/o degeneration case

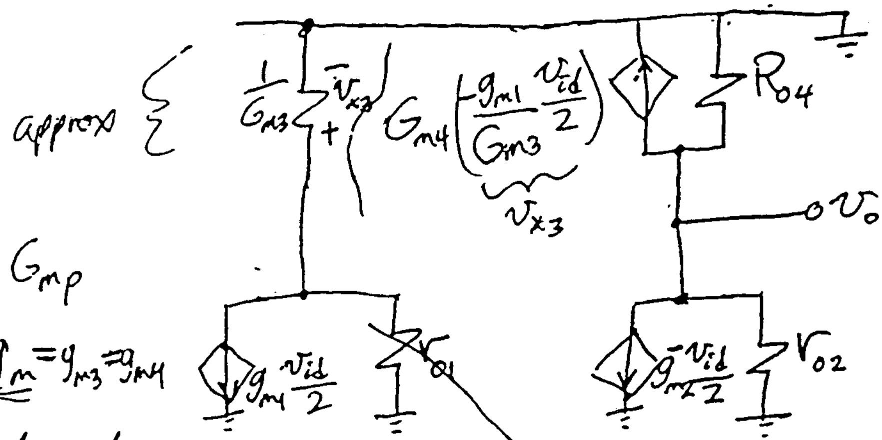
⇒ Now Q4 is no longer a CE xstr. ($G_m = g_m$, $R_o = r_o$), but a CEWD!

⇒ Use single xstr. handout for CEWD



Again, $A_{cm} = 0$

$\rightarrow A_v = A_{dm}$



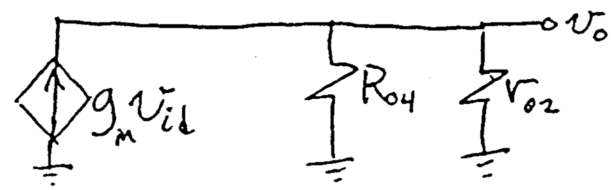
Since

$G_{m3} = G_{m4} = G_{mp}$

$g_{m1} = g_{m2} = g_m = g_{m3} = g_{m4}$

neglect compared to $\frac{1}{G_{m3}} = 2.56k$

The output side reduces to:



$g_m = \frac{50\mu A}{26mV} = 1.92m℧$

$r_{o2} = r_{o_{npn}} = \frac{130V}{50\mu A} = 2.6M\Omega$

$R_{o4} \approx r_{o_{pnp}}\left(1 + g_m R_E \frac{r_{\pi 4}}{r_{\pi 4} + R_{s4} + R_E}\right)$ where $r_{o_{pnp}} = 1M\Omega$, $R_E = 2k\Omega$, $r_{\pi 4} = 26k\Omega$

$= (1M\Omega)\left[1 + (1.92m℧)(2k\Omega)\left(\frac{26k\Omega}{26k + 2.52k + 2k}\right)\right]$ $\quad R_{s4} = \left(\frac{1}{g_m} + 2k\Omega\right) \| r_{o1} \approx 2.52k\Omega$

$= \underline{4.28M\Omega}$

∴ $R_{OUT} = R_{o4} \| r_{o2} = 4.28M\Omega \| 2.6M\Omega \Rightarrow$ $\boxed{R_{OUT} = 1.62M\Omega}$ -Answer-

$A_v = A_{dm} = g_m(R_{o4} \| r_{o2}) = (1.92m℧)(1.62M\Omega) \Rightarrow$ $\boxed{A_v = 3110}$ -Answer

(continued)

Alternate Method

You may have noticed in the solution that the only thing that changed from problem #2 is the R_{OUT} of the active load. i.e. $r_{o_{pnp}} \rightarrow (R_{out})_{CEWD}$

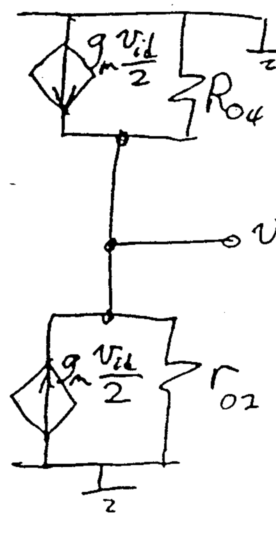
This shows an alternate and <u>much</u> <u>simpler</u> method:

Method #2.

Notice that the pnp mirror <u>IS</u> a mirror, i.e. the current on the left is repeated on the right (since emitter resistors are matched also). This works for <u>ac</u> as well as dc currents ∴ if Q1 produces small signal output current $\left(g_m \frac{v_{id}}{2}\right)$, then

Q4 must mirror approximately $g_m \frac{v_{id}}{2}$.

∴ <u>only R_{OUT} changes for Q4; the dependent current generator remains the same!*</u>



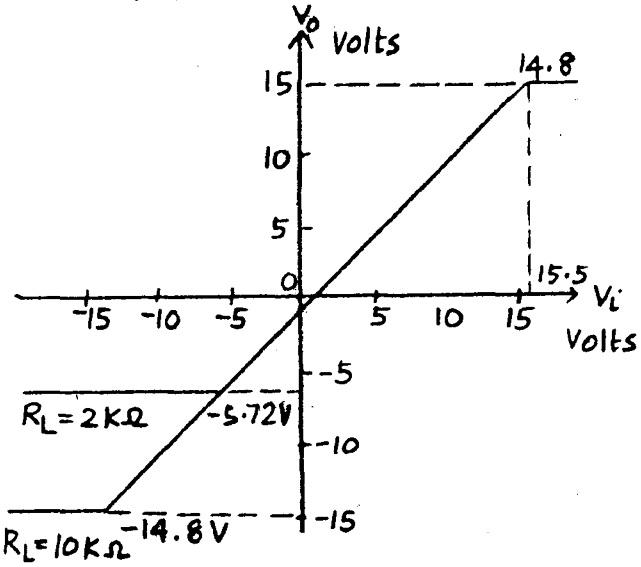
*R_{o4} must still be calculated as before using $(R_o)_{CEWD}$.

4)

(a) $I_R = \frac{V_{CC} - V_{BE_3}}{R_3} = \frac{15 - 0.7}{5K} = 2.86\ mA$

Thus, $I_Q = 2.86\ mA$

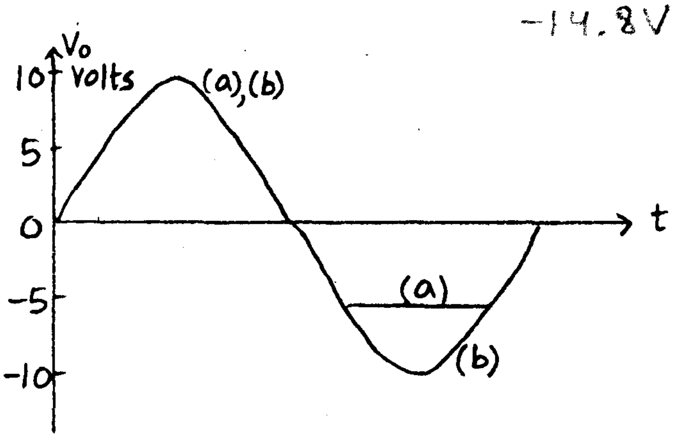
$I_Q R_L = 2.86\ (2) = 5.72\ V$



(b) $I_Q R_L = 2.86 \times 10 = 28.6\ V$

Thus, the lower limit on V_o is $(-V_{cc} + |V_{CE_{SAT}}|)$ $= -14.8V$

(C)



(a): output clips at $-5.72V$

(b): no clipping