Problem 10.1

a) CE & CB

b) B3 is the biasing current source

B4 is a current mirror, providing the biasing voltage of B3.

c) B5 is to provide the proper voltage bias for B2.

d) Common emitter amplifier, with emitter degeneration. It provides a large input resistance for the amplifier.

e) Common base amplifier, providing a large voltage gain.

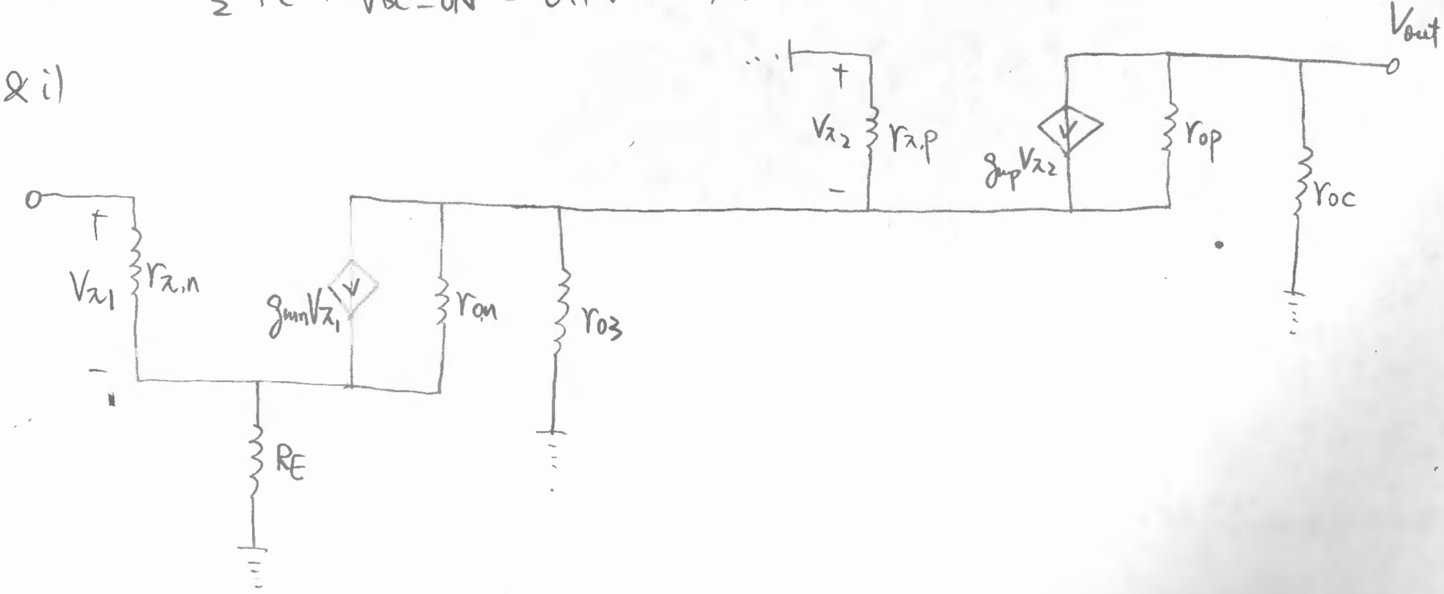
f) $V_2 = V_{DD} - V_{BE\_ON} = 5.0V - 0.7V = 4.3V$

$V_3 = V_{DD} - 2V_{BE\_ON} = 5.0V - 1.4V = 3.6V$

$V_1 = V_3 + V_{BE\_ON} = 3.6V + 0.7V = 4.3V$

g) $V_{BIAS} = \frac{I_{BIAS}}{2} R_E + V_{BE\_ON} = 0.1V + 0.7V = 0.8V$

h) & i)



The small signal model is a cascade of two stages

First stage

$$A_{v1} = \frac{V_{out}}{V_{in}} = -g_m \frac{r_{o,n} \| r_{o3}}{1 + g_m R_E \frac{r_{o,n}}{r_{o,n} + r_{o3}}}$$

$$R_{out1} = (r_{on} \| r_{o3}) \frac{1 + g_m R_E}{1 + g_m R_E \frac{r_{on}}{r_{on} + r_{o3}}}$$

Second stage

$$A_{v2} = g_{mp}(r_{op} \| r_{oc}) = \frac{V_{out}}{V_{in}} \qquad R_{in2} = \frac{1}{g_{mp}}\left(1 + \frac{r_{oc}}{r_o}\right)$$

For the whole circuit

$$V_{out} = A_{v2} \frac{R_{in2}}{R_{in2} + R_{out1}} V_{in} A_{v1} \Rightarrow A_v = A_{v1} A_{v2} \frac{R_{in2}}{R_{in2} + R_{out1}}$$

The output resistance of the circuit is the output resistance of CB with R_{out1}.

$$\frac{1}{R_{out}} = \frac{1}{r_{oc}} + \frac{r_{op} \| \frac{r_{\pi p}}{1+\beta_F} \| R_{out1}}{r_{op}(r_{\pi p} \| R_{out1})}$$

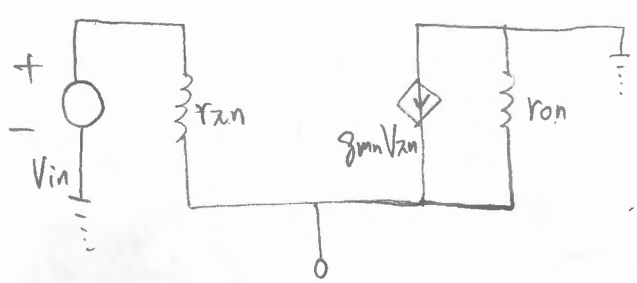
Problem 10.2

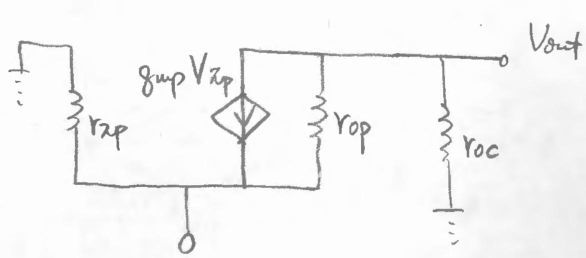
a) CC & CB

b) $V_{BIAS1} \geq V_{out} + V_{CE\_SAT} + V_{BE\_ON} = 3.0V + 0.2V + 0.7V = 3.9V$

$V_{BIAS2} = V_{BIAS1} - V_{BE\_ON} - V_{BE\_ON} \geq 3.9V - 1.4V = 2.5V$

c) & d) Two stages.





Second stage:

$$A_{v2} = g_{mp} (r_{op} \| r_{oc}) . \quad R_{in2} = \frac{1}{g_{mp}} \left(1 + \frac{r_{oc}}{r_o}\right)$$

First stage:

$$A_{v1} = 1 . \qquad R_{out1} = \frac{1}{g_{mn}}$$

For the whole circuit.

$$A_v = \frac{V_{out}}{V_{in}} = A_{v1} A_{v2} \frac{R_{in2}}{R_{in2} + R_{out1}}$$

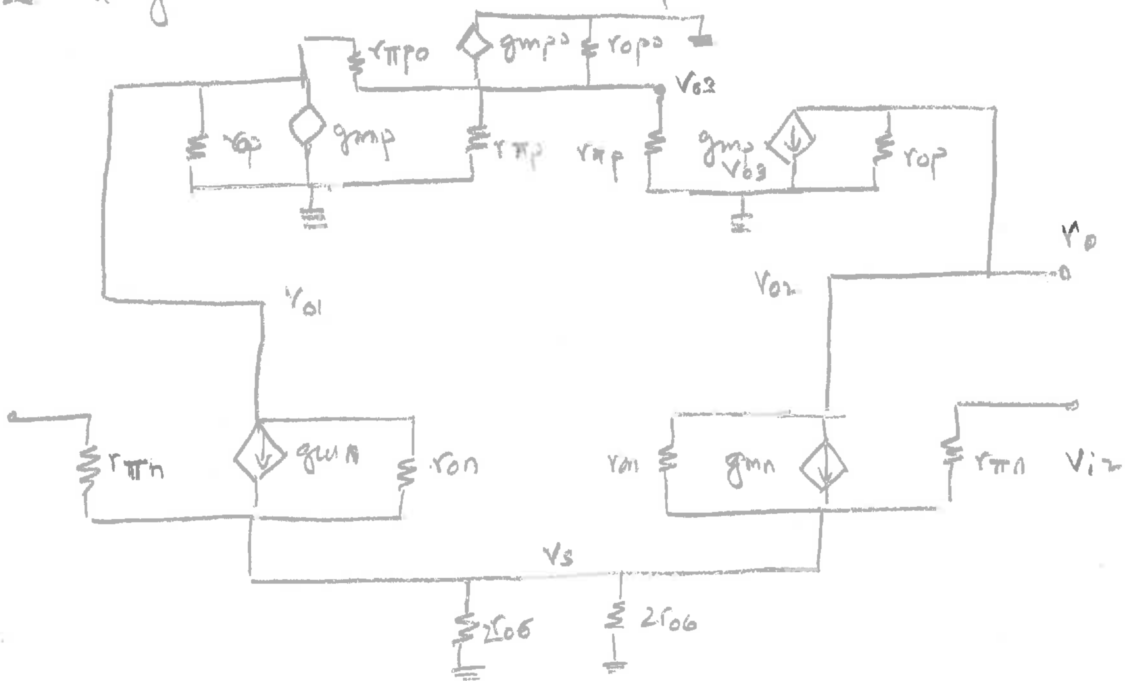
The output resistance $\frac{1}{R_{out}} = \frac{1}{r_{oc}} + \frac{r_{op} \| \frac{r_{\pi p}}{1+\beta_F} \| R_{out1}}{r_{op} (r_{\pi p} \| R_{out1})}$

10.3

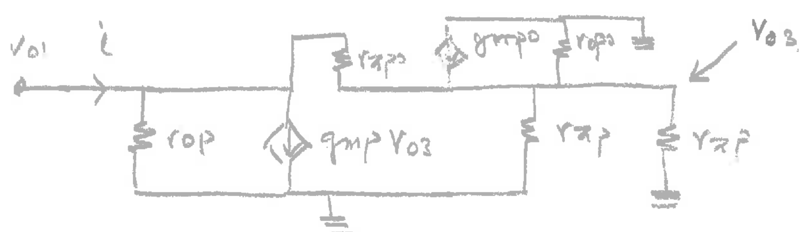
a) M7 provides for the base currents of M3 and M4 and ensures that the drain currents of M1 and M2 are matched accurately.

Might be a good idea to solve parts (e) and (f) next.

e)



First look at this part:



- M3, M7 and M4
- rπpo, gmpo and gopo

belong to M7.

What is V_{o3} in terms of V_{o1}?

What is the current i?

Note that $|I_{C7}| \approx |I_{E7}| = 2I_{B3} = 2I_{B4}$

$$\Rightarrow \quad g_{mpo} = \frac{qI_{C7}}{KT} = 2g_{\pi p}$$

We have (KCL at node V_{o3}):

$$(V_{o1}-V_{o3})g_{\pi p o} + g_{mpo}(V_{o1}-V_{o3}) + (0-V_{o3})g_{opo} = V_{o3}\, 2g_{\pi p}$$

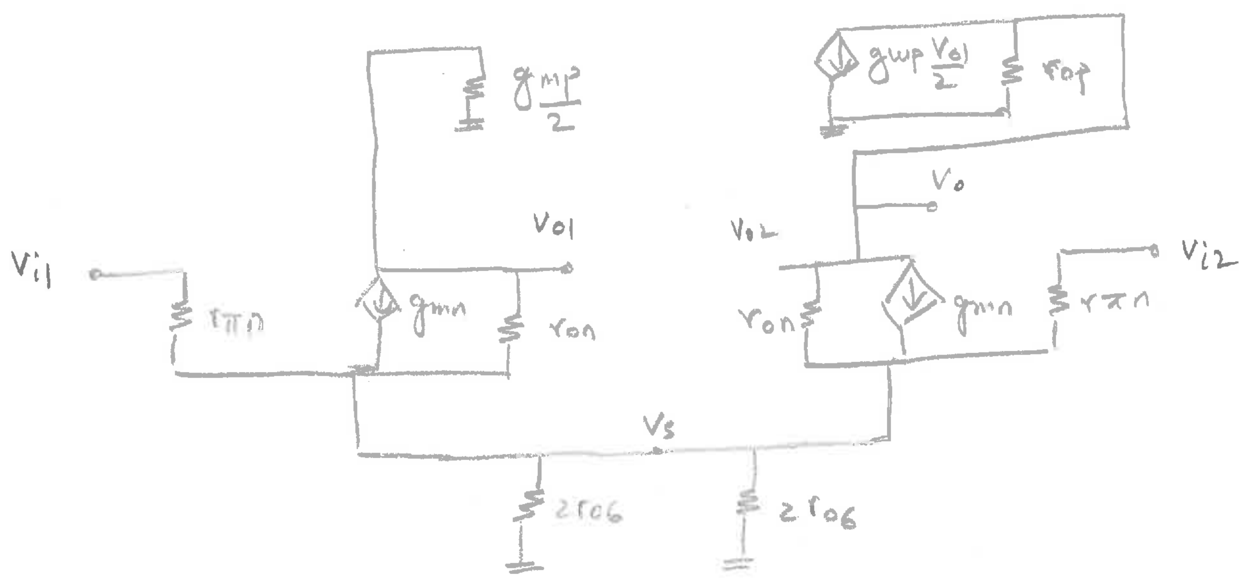
$$\Rightarrow \quad V_{o3} \approx V_{o1}\frac{g_{mpo}}{g_{mpo}+2g_{\pi p}} = \frac{V_{o1}}{2}.$$

Also: $i = V_{o1}\, g_{op} + g_{mp} V_{o3} + (V_{o1}-V_{o3})\, g_{\pi p o}$

$$\approx V_{o1}\, g_{op} + g_{mp}\frac{V_{o1}}{2} + \frac{V_{o1}}{2} g_{\pi p o}$$

$$\approx \frac{g_{mp}}{2} V_{o1}$$

So we can redraw the circuit:



Now suppose $V_{i1} = \frac{V_{id}}{2}$ $\quad V_{i2} = -\frac{V_{id}}{2}$

KCL at node V_{o1} gives:

$$V_{o1}\frac{g_{mp}}{2} + g_{mn}\left(\frac{V_{id}}{2} - V_s\right) + \underset{\uparrow}{(V_{o1}-V_s)\, g_{on}} = 0$$

small compared to $V_{o1}\frac{g_{mp}}{2}$.

KCL at node V_{o2} gives:

$$V_{o2}\, g_{op} + g_{mp} \frac{V_{o1}}{2} + (V_{o2} - V_s)\, g_{on} + g_{mn}\left(-\frac{V_{id}}{2} - V_s\right) = 0$$

Subtract the above eq. from the previous one:

$$g_{mn} V_{id} - V_{o2}(g_{op} + g_{on}) = 0$$

$$\Rightarrow V_o = V_{o2} = g_{mn}(r_{op} \| r_{on})\, V_{id}$$

$$\Rightarrow A_{vd} = \frac{V_o}{V_{id}} = g_{mn}(r_{op} \| r_{on})$$

f) Now suppose $V_{i1} = V_{i2} = V_{ic}$

The current mirror will ensure that the collector currents of M1 and M2 are the same when $V_{i1} = V_{i2} = V_{ic}$. Therefore, we can safely assume that the two halves are perfectly symmetric and that no current flows in the bottom wire connecting the two halves. The left half is now a CE amplifier with a degenerate emitter, and we get (approximations made in the handouts assume R_E is small and will not work here):

$$\frac{V_{o1}}{V_{ic}} \approx -\frac{\frac{2g_{mn}}{g_{mp}}}{1+\frac{2r_{o6}}{(r_{\pi n}\|r_{on})}+g_{mn}(2r_{o6})}$$

Since the circuit is symmetric, $V_{o1} \approx V_{o2}$

$$\Rightarrow \frac{V_o}{V_{ic}} = \frac{V_{o2}}{V_{ic}} \approx -\frac{\frac{2g_{mn}}{g_{mp}}}{1+\frac{2r_{o6}}{(r_{\pi n}\|r_{on})}+g_{mn}(2r_{o6})}$$

b) When $V_{i1} = \frac{V_{id}}{2} = -V_{i2}$, $V_s \approx 0$ and $R_{in} \approx r_{\pi n}$

c) When $V_{i1} = V_{ic} = V_{i2}$, each half is a CE amplifier with a degenerate emitter. So R_{in} becomes (analysis in the handouts assume R_E is small and will not work here)

$$R_{in} = r_{\pi n} + 2r_{o6} + 2r_{o6}\, g_{mn} \frac{r_{on}\, r_{\pi n}}{r_{on}+2r_{o6}}$$

$$\cong r_{\pi n}\left[1+g_{mn}\frac{r_{on}}{r_{on}+2r_{o6}}(2r_{o6})\right] + 2r_{o6}$$

d). Suppose $V_{i1} = \frac{V_{id}}{2} = -V_{i2}$. First we find the short circuit output current.

KCL at node V_{o1} gives:

$$V_{o1}\frac{g_{mp}}{2} + g_{mn}\left(\frac{V_{id}}{2} - V_s\right) + \underset{\uparrow \text{ small}}{(V_{o1} - V_s)g_{on}} = 0$$

KCL at node V_{o2} gives (include i_{out}):

$$V_{o2}\, g_{op} + g_{mp}\frac{V_{o1}}{2} + (V_{o2} - V_s)g_{on} + g_{mn}\left(-\frac{V_{id}}{2} - V_s\right) + i_{out} = 0$$

But output is shorted to ground, so $V_o = V_{o2} = 0$.

$$g_{mp}\frac{V_{o1}}{2} - V_s g_{on} + g_{mp}\left(-\frac{V_{id}}{2} - V_s\right) + i_{out} = 0.$$

Subtract from the above equation obtained for node V_{o1}:

$$g_{mp} V_{id} - i_{out} = 0$$

$$\Rightarrow \quad i_{out} = g_{mp} V_{id}$$

Now we use: $\{\text{short circuit output current}\}\, R_{out} = \left\{\begin{matrix}\text{open circuit}\\ \text{output voltage}\end{matrix}\right\}$

$$\Rightarrow \quad g_{mn} V_{id} R_{out} = g_{mn}(r_{op} \| r_{on}) V_{id}$$

$$\Rightarrow \quad R_{out} = (r_{op} \| r_{on})$$