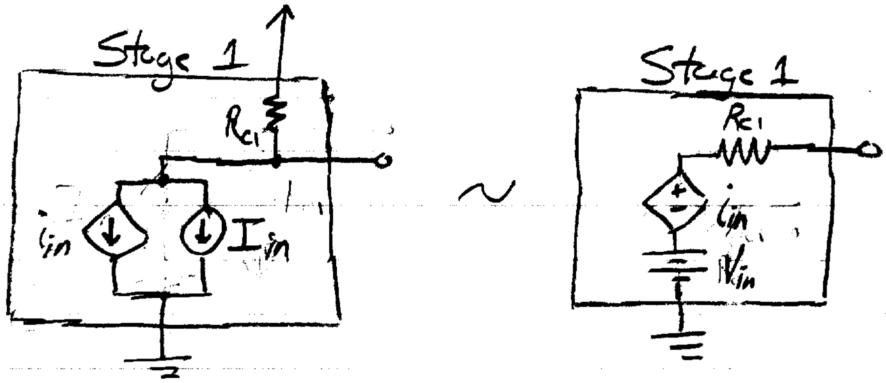
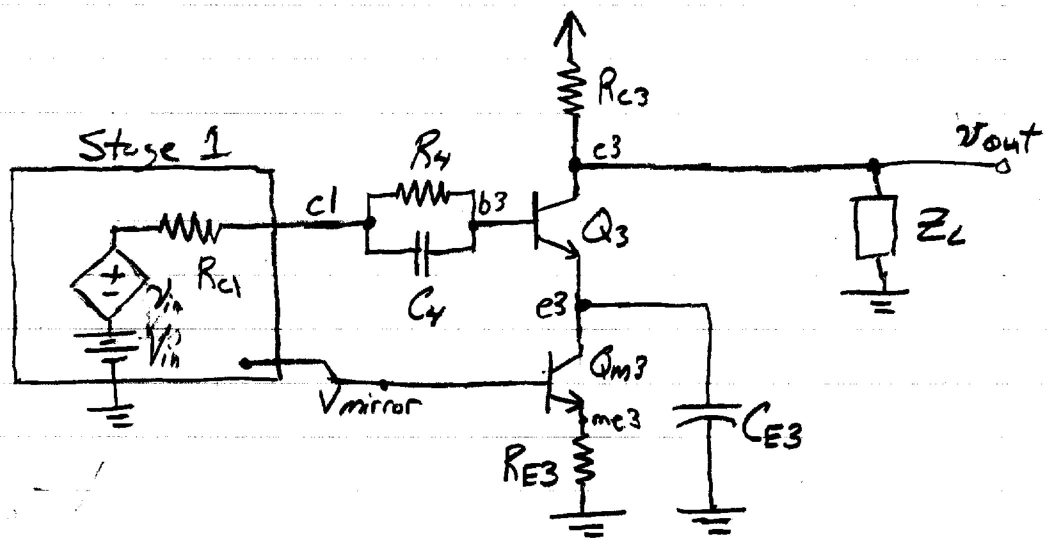
v_{in} net
v_{IN} small ac ?
V_{in} DC
V_{IN} phasor

$\omega = 2\pi f$





From the stage 1 design,

$$V_{mirror} = I_{C1}R_{E1} + V_{BE} = I_{C3}R_{E3} + V_{BE}$$

[1] $$\boxed{R_{E3} = R_{E1}\frac{I_{C1}}{I_{C3}}}$$

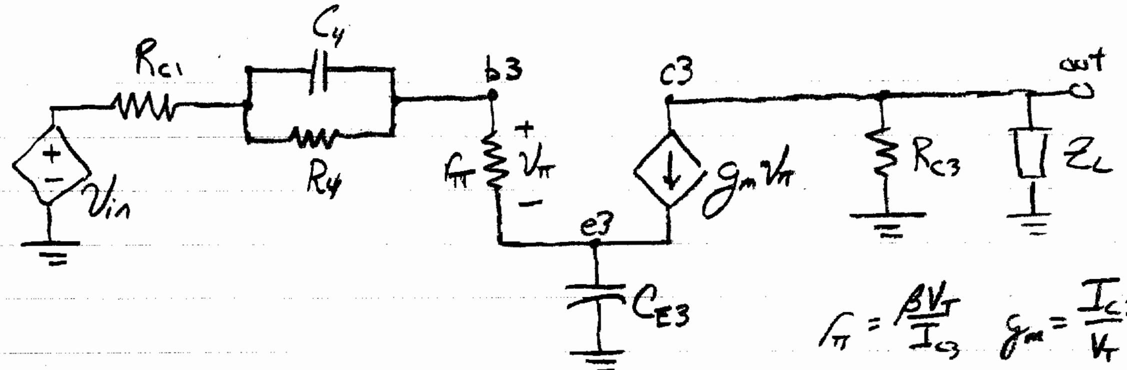
The base of Q_3 is similarly designed

$$V_{B3} = I_{C1}R_{E1} + 2V_{BE} + V_{margin} \approx 2V_{BE} + V_{margin}$$

$$R_4 = \frac{V_{in} - (2V_{BE} + V_{margin})}{I_{B3}} - R_{C1}$$

[2] $$\boxed{R_4 = \frac{\beta(V_{in} - 2V_{BE} - V_{margin})}{I_{C3}} - R_{C1}}$$

[3] $$\boxed{R_{C3} = \frac{V_{CC} - 2V_{BE} - 2V_{margin}}{I_{C3}}}$$



$$r_\pi = \frac{\beta V_T}{I_{c3}} \quad g_m = \frac{I_{c3}}{V_T}$$

$$Z_4 = \frac{R_4 \frac{1}{C_4 j\omega}}{R_4 + \frac{1}{j\omega C_4}} = \frac{\frac{1}{j\omega C_4}}{1 + \frac{1}{j\omega R_4 C_4}} = \frac{-j}{\omega C_4}\left(\frac{1}{1 - \frac{j}{\omega R_4 C_4}}\right) = \frac{1}{\omega C_4}\left(\frac{1}{\frac{1}{\omega R_4 C_4} + j}\right)$$

$$= \frac{1}{\omega C_4}\left(\frac{1}{\sqrt{1+\left(\frac{1}{\omega R_4 C_4}\right)^2} \cdot e^{j\tan^{-1}\omega R_4 C_4}}\right) = \frac{1}{\omega C_4}\left(\frac{e^{-j\angle\tan^{-1}(\omega/\omega_4)}}{\sqrt{1+(\omega_4/\omega)^2}}\right)$$

$$= \frac{R_4}{1 + j\omega R_4 C_4} = R_4\left(\frac{e^{-j\tan^{-1}(\omega/\omega_4)}}{\sqrt{1+(\omega/\omega_4)^2}}\right)$$

[4] $$I_{in} = \frac{V_{in} - V_E}{R_{c1} + r_\pi + R_4 \cdot \left(\frac{e^{-j\tan\angle \omega/\omega_4}}{\sqrt{1+(\omega/\omega_4)^2}}\right)} \Rightarrow I_{IN}\left(R_{c1} + r_\pi + R_4(\cdots)\right) = V_{IN} - V_E$$

[5] KCL at Emitter: $I_{in}(\beta+1) = V_E j\omega C_{E3} \Rightarrow -V_E = \frac{j I_{in}(\beta+1)}{\omega C_{E3}}$

Substituting [5] into [4]

$$I_{IN}\left(R_{c1} + r_\pi + R_4(\cdots)\right) = V_{IN} + \frac{j I_{IN}(\beta+1)}{\omega C_{E3}}$$

[4'] $$I_{IN}\left[R_{c1} + r_\pi + R_4(\cdots) - \frac{j(\beta+1)}{\omega C_{E3}}\right] = V_{IN}$$

[6] KCL at the output: $\beta I_{IN} + \frac{V_{out}}{R_c \| Z_L} = \emptyset \Rightarrow I_{IN} = \frac{-V_{out}}{\beta(R_c \| Z_L)}$

Substituting [6] into [4']

$$\frac{-V_{OUT}}{\beta(R_c \| Z_L)}\left[R_{c1} + \frac{V_T \beta}{I_{c3}} + R_4(\cdot\cdot) - \frac{j(\beta+1)}{\omega C_{E3}}\right] = V_{IN}$$

$$G^{-1} = \frac{-1}{R_c \| Z_L}\left[\frac{V_T}{I_{c3}} + \frac{R_{c1}}{\beta} + \frac{R_4 e^{-j\tan^{-1}\omega/\omega_4}}{\beta\sqrt{1+(\omega/\omega_4)^2}} - \frac{j}{\omega C_{E3}}\right]$$

$$G^{-1} = \frac{-1}{R_c \| Z_L} \cdot \frac{V_T}{I_{c3}}\left[\left(1 + \frac{R_{c1} I_{c3}}{\beta V_T} + \frac{R_4 I_{c3} e^{-j\tan^{-1}\omega/\omega_4}}{\beta V_T \sqrt{1+(\omega/\omega_4)^2}}\right) - \frac{j I_{c3}}{\omega V_T C_{E3}}\right]$$

So the inverse of the gain for the 2^{nd} BJT Stage is

$$G^{-1} = \frac{V_T}{I_{c3}} \cdot \frac{-1}{(R_c \| Z_L)} \left[\left(1 + \frac{R_{c1} I_{c3}}{\beta V_T} + \left(\frac{V_{in} - 2V_{BE} - V_{margin}}{V_T} - \frac{R_{c1} I_{c3}}{\beta V_T} \right) \frac{e^{-j\tan^{-1}\left(\frac{\omega}{\omega_4}\right)}}{\sqrt{1+(\omega/\omega_4)^2}} \right. \right.$$
$$\left. - j \frac{I_c}{\omega V_T C_{E3}} \right]$$

Making some scale assumptions...

$$G^{-1} = \frac{V_T}{I_{c3}} \cdot \frac{-1}{R_c \| Z_L} \left[\left(\frac{V_{in} - 2V_{BE} - V_{margin}}{V_T} \right) \frac{e^{-j\tan^{-1}\frac{\omega}{\omega_4}}}{\sqrt{1+(\omega/\omega_4)^2}} - j \frac{I_c}{\omega V_T C_{E3}} \right]$$

[7] $$G^{-1} = \frac{V_{in} - 2V_{BE} - V_{margin}}{I_{c3}} \cdot \frac{-1}{R_c \| Z_L} \left[\frac{e^{-j\tan^{-1}\omega/\omega_4}}{\sqrt{1+(\omega/\omega_4)^2}} - j \frac{\omega_3}{\omega} \right]$$

where $\omega_3 = \dfrac{I_c}{(V_{in} - 2V_{BE} - V_{margin}) C_{E3}}$ and $\omega_4 = \dfrac{1}{R_4 C_4}$

Now we can design C_{E3} and C_4 so that both poles occur below the lowest operating freq.

$$\omega_3 = \frac{I_{c3}}{(\cdots) C_{E3}} \leq \frac{1}{10} 2\pi f_{L3}$$

$$\boxed{C_{E3} \geq \frac{5 I_{c3}}{\pi (V_{in} - 2V_{BE} - V_{margin}) f_{L3}}}$$

$$\omega_4 = \frac{1}{R_4 C_4} = \frac{I_{c3}}{\beta (V_{in} - 2V_{BE} - V_{margin}) C_4} \leq \frac{1}{10} 2\pi f_{L4}$$

$$\boxed{C_4 \geq \frac{5 I_{c3}}{\pi \beta (V_{in} - 2V_{BE} - V_{margin}) f_{L4}}}$$