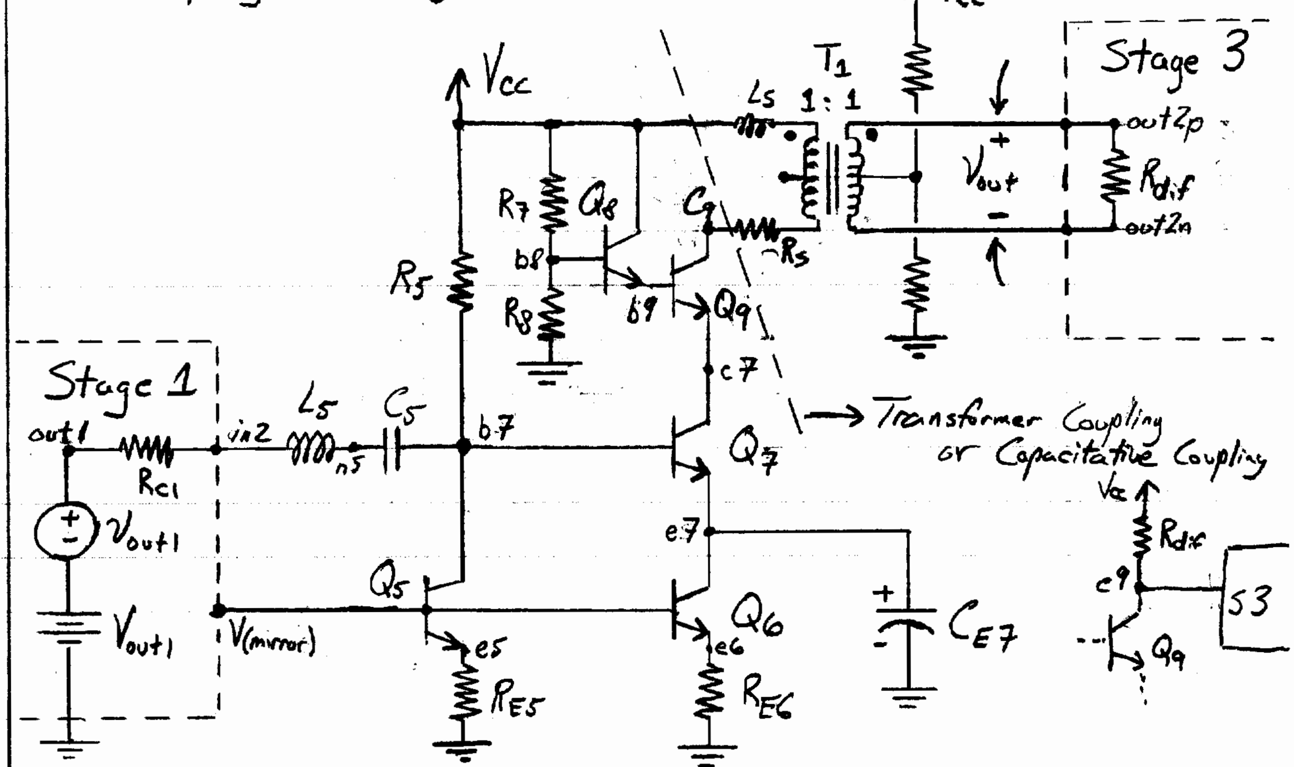
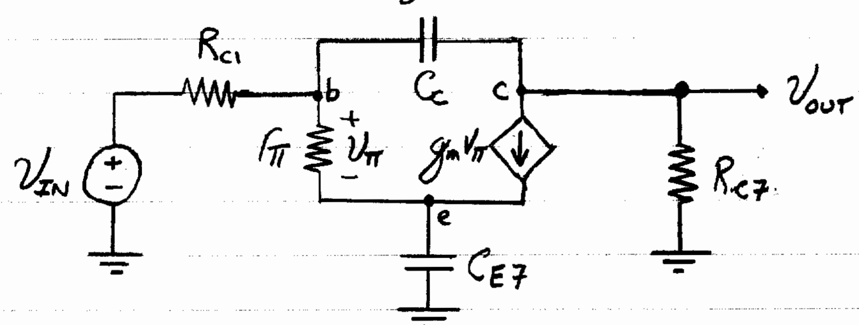
— Stage 2 Redesign —

for coupling with stages 1 & 3



Stage II Circuit



AC Equivalent Circuit of Stage II, when within the bandpass region of passive couplings.

There are three nodes in the AC equivalent circuit, and they are base, emitter, collector. At the base,

$$\frac{V_B - V_{IN}}{R_{c1}} + \frac{V_B - V_E}{r_\pi} + \frac{V_B - V_c}{\frac{1}{j\omega C_c}} = \emptyset$$

[1] $$V_B\left[\frac{1}{R_{c1}} + \frac{1}{r_\pi} + j\omega C_c\right] + V_E\left[\frac{-1}{r_\pi}\right] + V_c\left[-j\omega C_c\right] = V_{IN}\left[\frac{1}{R_{c1}}\right]$$

At the emitter,

$$\frac{V_E - V_B}{r_\pi} + g_m(V_E - V_B) + \frac{V_E}{\left(\frac{1}{j\omega C_E}\right)} = \emptyset$$

$$V_B\left[\frac{-1}{r_\pi} - g_m\right] + V_E\left[\frac{1}{r_\pi} + g_m + j\omega C_E\right] = \emptyset$$

[2]

Third at the collector

$$(V_B - V_E)g_m + \frac{V_c - V_B}{\left(\frac{1}{j\omega C_c}\right)} + \frac{V_c}{R_{dif}} = \emptyset$$

[3] $$V_B\left[g_m - j\omega C_c\right] + V_E\left[-g_m\right] + V_c\left[\frac{1}{R_{C7}} + j\omega C_c\right] = \emptyset$$

Adding equations 2 and 3 to 1,

$$V_B\left[\frac{1}{R_{c1}} \cancel{+\frac{1}{r_\pi}} \cancel{+j\omega C_c} \cancel{-\frac{1}{r_\pi}} \cancel{-g_m} \cancel{+g_m} \cancel{-j\omega C_c}\right] + V_E\left[\cancel{\frac{-1}{r_\pi}} \cancel{+\frac{1}{r_\pi}} \cancel{+g_m} + j\omega C_E \cancel{-g_m}\right] + V_c\left[\cancel{-j\omega C_c} + \frac{1}{R_{THev}} \cancel{+j\omega C_c}\right] = V_{IN}\left[\frac{1}{R_{c1}}\right]$$

[1'] $$V_B\left[\frac{1}{R_{c1}}\right] + V_E\left[j\omega C_E\right] + V_c\left[\frac{1}{R_{C7}}\right] = V_{IN}\left[\frac{1}{R_{c1}}\right]$$

Assuming that $\beta >> 1$, then $\frac{1}{r_\pi} << g_m$ and equation 2 can be simplified.

[2'] $$V_B\left[-g_m\right] + V_E\left[g_m + j\omega C_E\right] = \emptyset$$

And adding this simplified equation to 3 yields a slight improvement.

[3'] $$V_B\left[-j\omega C_c\right] + V_E\left[j\omega C_E\right] + V_c\left[\frac{1}{R_{C7}} + j\omega C_c\right] = \emptyset$$

It would also be nice to scale 1' by R_{c1} before summarizing in an array.

[1''] $$V_B[1] + V_E\left[j\omega R_{c1} C_E\right] + V_c\left[\frac{R_{c1}}{R_{C7}}\right] = V_{IN}[1]$$

(1'') $V_B[1] + V_E[j\omega R_{C1} C_E] + V_C\left[\frac{R_{C1}}{R_{C7}}\right] = V_{IN}[1]$

(2') $V_B[-g_m] + V_E[g_m + j\omega C_E] + \emptyset = \emptyset$

(3') $V_B[-j\omega C_c] + V_E[j\omega C_E] + V_C\left[\frac{1}{R_{C7}} + j\omega C_c\right] = \emptyset$

Perhaps it would be best to scale 2' and 3' by $\frac{1}{g_m}$ and $\frac{1}{j\omega C_c}$ as well.

[2''] $V_B[-1] + V_E\left[1 + \frac{j\omega C_E}{g_m}\right] = \emptyset$

[3''] $V_B[-1] + V_E\left[\frac{C_E}{C_c}\right] + V_C\left[\frac{1}{j\omega R_{C7} C_c} + 1\right] = \emptyset$

And now adding equation 1'' to the scaled 2'' and 3''

[2'''] $V_E\left[j\omega R_{C1} C_E + 1 + \frac{j\omega C_E}{g_m}\right] + V_C\left[\frac{R_{C1}}{R_{C7}}\right] = V_{IN}$

[3'''] $V_E\left[\frac{C_E}{C_c} + j\omega R_{C1} C_E\right] + V_C\left[\frac{R_{C1}}{R_{C7}} + 1 + \frac{1}{j\omega R_{C7} C_c}\right] = V_{IN}$

We have now eliminated V_B. Lets look at what remains.

(2''') $V_E\left[1 + j\omega\left(R_{C1} C_E + \frac{C_E}{g_m}\right)\right] + V_C\left[\frac{R_{C1}}{R_{C7}}\right] = V_{IN}$

(3''') $V_E\left[\frac{C_E}{C_c} + j\omega R_{C1} C_E\right] + V_C\left[\frac{R_{C1}}{R_{C7}} + 1 + \frac{1}{j\omega R_{C7} C_c}\right] = V_{IN}$

Surprisingly (really though this is like a new way of systematically solving these algebra problems) this can be simplified by subtracting 2''' from 3'''.

$$V_E\left[\frac{C_E}{C_c} + j\omega R_{C1} C_E - 1 - j\omega R_{C1} C_E - \frac{j\omega C_E}{g_m}\right] + V_C\left[\frac{R_{C1}}{R_{C7}} + 1 + \frac{1}{j\omega R_{C7} C_c} - \frac{R_{C1}}{R_{C7}}\right] = V_{IN} - V_{IN}$$

$$V_E\left[\frac{C_E}{C_c} - 1 - \frac{j\omega C_E}{g_m}\right] + V_C\left[1 + \frac{1}{j\omega R_{C7} C_c}\right] = \emptyset$$

It is probably safe to assume that $\frac{C_E}{C_c} >> 1$, so this simplifies to

[3^{IV}] $V_E\left[\frac{C_E}{C_c} - \frac{j\omega C_E}{g_m}\right] + V_C\left[1 + \frac{1}{j\omega R_{C7} C_c}\right] = \emptyset$

(2''') $V_E\left[1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)\right]+V_C\left[\frac{R_{C1}}{R_{C7}}\right] = V_{IN}$

(3^{IV}) $V_E\left[\frac{C_E}{C_C}\left(1-\frac{j\omega C_C}{g_m}\right)\right] + V_C\left[1+\frac{1}{j\omega R_{C7}C_C}\right] = \emptyset$

Attempting to scale both equations to normalize V_E,

$$V_E[1]+V_C\left[\frac{R_{C1}}{R_{C7}\left(1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)\right)}\right] = V_{IN}\left[\frac{1}{1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)}\right]$$

and

$$V_E[-1]+V_C\left[\frac{-C_C\left(1+\frac{1}{j\omega R_{C7}C_C}\right)}{C_E\left(1-\frac{j\omega C_C}{g_m}\right)}\right]=\emptyset$$

Combining the two normalized equations

[3^{V}] $$V_C\left[\frac{R_{C1}}{R_{C7}\left[1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)\right]}-\frac{C_C\left(1+\frac{1}{j\omega R_{C7}C_C}\right)}{C_E\left(1-\frac{j\omega C_E}{g_m}\right)}\right]=V_{IN}\left[\frac{1}{1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)}\right]$$

Somehow it is always easier to solve for the inverse of the transfer function, $T^{-1} = V_{IN}/V_{OUT} = V_{IN}/V_C$

$$T_*^{-1} = \left[1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)\right]\left[\frac{\left(\frac{R_{C1}}{R_{C7}}\right)}{1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)}-\frac{C_C\left(1+\frac{1}{j\omega R_{C7}C_C}\right)}{C_E\left(1-\frac{j\omega C_C}{g_m}\right)}\right]$$

$$T_*^{-1} = \left[\frac{R_{C1}}{R_{C7}}-\frac{C_C}{C_E}\left[\frac{\left(1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)\right)\left(1+\frac{1}{j\omega R_{C7}C_C}\right)}{\left(1-\frac{j\omega C_C}{g_m}\right)}\right]\right]$$

$$T_*^{-1} = \frac{R_{C1}}{R_{C7}}\left[1-\frac{C_C R_{C7}}{C_E R_{C1}}\frac{\left(1+j\omega C_E\left(R_{C1}+\frac{1}{g_m}\right)\right)\left(1+\frac{1}{j\omega R_{C7}C_C}\right)}{\left(1-\frac{j\omega C_C}{g_m}\right)}\right]$$

This doesn't look too far off, but obviously the time constants are not distributed very well.

high pole, low pole

$$T_*^{-1} = \frac{R_{C1}}{R_{C7}}\left[1 - \frac{C_C R_{C7}\left(1 + j\omega C_E \left(D R_{C1}\right)\right)\left(1 + \frac{1}{j\omega R_{C7} C_C}\right)}{C_E R_{C1}\left(1 - \frac{j\omega C_C}{g_m}\right)}\right]$$

high zero

where

$$D = 1 + \frac{1}{g_m R_{C1}} = 1 + \frac{V_T}{R_{C1} I_{C7}}$$

So a couple of thoughts. We would have expected C_E to be involved in a low pole with g_m and C_c to be involved in a high zero with R_{C7}

$$T_*^{-1} = \frac{R_{C1}}{R_{C7}}\left[1 - \frac{\frac{1}{C_E R_{C1}}\left(1 + j\omega C_E D R_{C1}\right) R_{C7} C_c \left(1 + \frac{1}{j\omega R_{C7} C_c}\right)}{1 - \frac{j\omega C_c}{g_m}}\right]$$

$$T_*^{-1} = \frac{R_{C1}}{R_{C7}}\left[1 - \frac{\left(\frac{1}{C_E R_{C1}} + j\omega D\right)\left(R_{C7} C_c + \frac{1}{j\omega}\right)}{1 - \frac{j\omega C_c}{g_m}}\right]$$

$$T_*^{-1} = \frac{R_{C1}}{R_{C7}}\left[1 - \frac{\left(D + \frac{1}{j\omega R_{C1} C_E}\right)\left(1 + j\omega R_{C7} C_c\right)}{\left(1 - j\frac{\omega C_c V_T}{I_{C7}}\right)}\right]$$

$$T_*^{-1} = \frac{R_{C1}}{R_{C7}}\left[1 - \frac{D\left(1 + \frac{1}{j\omega\left(R_{C1} + \frac{1}{g_m}\right) C_E}\right)\left(1 + j\omega R_{C7} C_c\right)}{\left(1 - j\frac{\omega C_c}{g_m}\right)}\right]$$

$$T_*^{-1} = \frac{-D R_{C1}}{R_{C7}}\left[\frac{\left(1 - j\frac{\omega_3}{\omega}\right)\left(1 + j\frac{\omega}{\omega_4}\right)}{\left(1 - j\frac{\omega}{\omega_5}\right)} - \frac{1}{D}\right]$$

$$\frac{-D R_{C1}}{R_{C7}} = \frac{-R_{C1}}{R_{C7}}\left(1 + \frac{V_T}{R_{C1} I_{C7}}\right) = \frac{-1}{R_{C7}}\left(R_{C1} + \frac{V_T}{I_{C7}}\right)$$

$$\frac{-1}{D} = \frac{-1}{1 + \frac{V_T}{R_{C1} I_{C7}}} = \frac{-R_{C1}}{R_{C1} + \left(\frac{V_T}{I_{C7}}\right)}$$

So finally we have

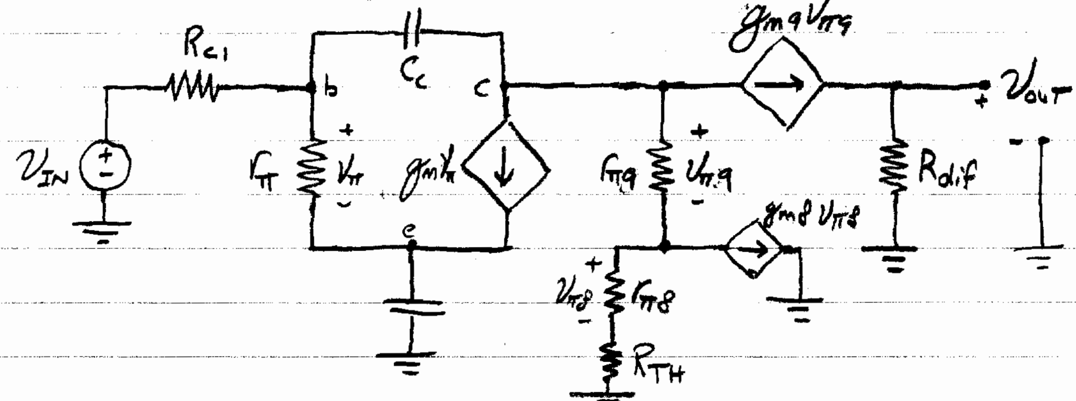
[4a] $$T_*^{-1} = \frac{-1}{R_{C7}} \cdot \left(R_{C1} + \frac{V_T}{I_{C7}}\right) \cdot \left[\frac{\left(1 - j\frac{\omega_3}{\omega}\right)\left(1 + j\frac{\omega}{\omega_4}\right)}{\left(1 - j\,\omega/\omega_5\right)} - \frac{R_{C1}}{R_{C1} + \frac{V_T}{I_{C7}}} \right]$$

where

[4b] $$\omega_3 = \frac{1}{\left(R_{C1} + V_T/I_{C7}\right) C_{E5}}, \quad \omega_4 = \frac{1}{R_{C7} C_c}, \quad \text{and} \quad \omega_5 = \frac{I_{C7}}{V_T C_c}$$

Low Pole High Pole High Zero

From [4a] and ω_4 of [4b], the collector resistance and miller capacitance are setting the midband gain and the bandwidth; and improving one hurts the other. A current buffer Q9 with voltage buffer Q8 is added to counter this effect



If one assumes that Q9 is sufficiently fast (ignore C_c and C_e), assume that the current gain is unity (β is large), and that the resistor reflection back is accurate, then the transfer function becomes

[5a] $$T^{-1} = \frac{-1}{R_{dif}} \cdot \left(R_{C1} + \frac{V_T}{I_{C7}}\right) \cdot \left[\frac{\left(1 - j\frac{\omega_3}{\omega}\right)\left(1 + j\frac{\omega}{\omega_4}\right)}{\left(1 - j\frac{\omega}{\omega_5}\right)} - \frac{R_{C1}}{R_{C1} + \frac{V_T}{I_{C7}}} \right]$$

where

[5b] $$\omega_3 = \frac{1}{\left(R_{C1} + \frac{V_T}{I_{C7}}\right) C_{E5}}, \quad \omega_4 = \frac{1}{R_{eq} C_c}, \quad \omega_5 = \frac{I_{C7}}{V_T C_c}$$

and

$$R_{eq} = \frac{r_{\pi 9} + \frac{r_{\pi 8} + R_{TH}}{\beta_8}}{\beta_9} = \frac{\left(\frac{V_T \beta_9}{I_{C7}}\right) + \frac{1}{\beta_8}\left(\frac{V_T \beta_8}{I_{C8}} + R_{TH}\right)}{\beta_9}$$

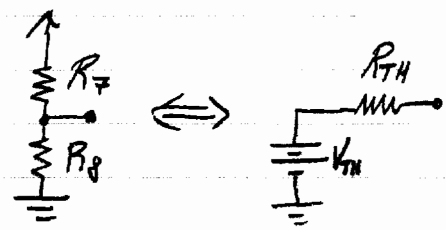
$$= \frac{V_T}{I_{C7}} + \frac{V_T}{\beta_9 I_{C8}} + \frac{R_{TH}}{\beta_8 \beta_9}, \qquad I_{C8} = \frac{I_{C7}}{\beta_9}$$

$$= \frac{V_T}{I_{C7}} + \frac{V_T}{I_{C7}} + \frac{R_{TH}}{\beta_8 \beta_9}$$

[5c] $$R_{eq} = \frac{2V_T}{I_{C7}} + \frac{R_{TH}}{\beta_8 \beta_9}$$

If we design R_{TH} such that it is negligible relative to $2V_T/I_{C7}$, in other words

$$\frac{R_{TH}}{\beta_8 \beta_9} = \frac{1}{100} \cdot \frac{2V_T}{I_{C7}}$$



[6a] $$R_{TH} = \frac{\beta_8 \beta_9 V_T}{50 I_{C7}}$$

[6b] $$R_7 = \frac{\beta_8 \beta_9 V_T}{50 I_{C7}} \cdot \frac{V_{cc}}{V_{b8}}$$

[6c] $$R_8 = \frac{\beta_8 \beta_9 V_T}{50 I_{C7}} \cdot \frac{V_{cc}}{V_{cc} - V_{b8}}$$

then the transfer function becomes

$$T^{-1} = \frac{-1}{R_{dif}} \cdot \left(R_{C1} + \frac{V_T}{I_{C7}}\right) \cdot \left[\frac{\left(1 - j\frac{\omega_3}{\omega}\right)\left(1 + j\frac{\omega}{\omega_4}\right)}{\left(1 - j\frac{\omega}{\omega_5}\right)} - \frac{R_{C1}}{R_{C1} + \frac{V_T}{I_{C7}}}\right]$$

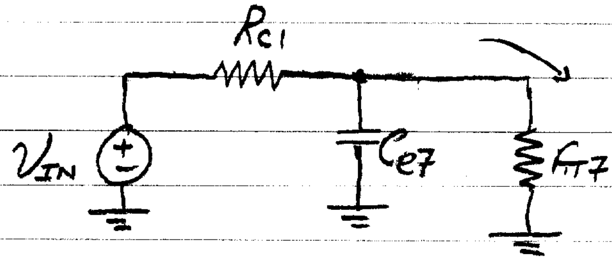
where $\omega_3 = \frac{1}{\left(R_{C1} + \frac{V_T}{I_{C7}}\right) C_{E7}}$, $\omega_4 = \frac{I_{C7}}{2V_T C_c}$, $\cancel{\omega_5 = \frac{I_{C7}}{V_T C_c}}$.

We notice that ω_5 is now somewhat redundant, being $2 \times \omega_4$.

[6d] $$T^{-1} = \frac{-1}{R_{dif}} \cdot \left(R_{C1} + \frac{V_T}{I_{C7}}\right) \cdot \left[\frac{\left(1 - j\frac{\omega_3}{\omega}\right)\left(1 + j\frac{\omega}{\omega_4}\right)}{\left(1 - j\frac{\omega}{2\omega_4}\right)} - \frac{R_{C1}}{R_{C1} + \frac{V_T}{I_{C7}}}\right]$$

[6e] where $\omega_3 = \frac{1}{(R_{C1} + V_T/I_{C7}) C_{E7}}$ and $\omega_4 = \frac{I_{C7}}{2 V_T C_c}$

Continuing to assume we are well within the bandpass region of the passive coupling between stage 1 and 2, signal power entering Q_7 can be maximized by impedance matching R_{C1} and $r_{\pi 7}$. There is also the affect of Q_7's input capacitance that has been ignored.



Max power when $I_{(Ce7)} = 0$ and $r_\pi = R_{C1}$ (Impedance Matching)

Input resistance $r_{\pi 7}$ goes as $\frac{1}{I_{C7}}$ and the size of R_{C1} is limited to a small value in stage one, so it may not be practical to actually match R_{C1} and r_π. In case it is not, we define a matching factor α, such that

[7a] $$\alpha = \frac{R_{C1}}{r_{\pi 7}}$$

[7b] $$I_{C7} = \frac{\alpha \beta_7 V_T}{R_{C1}}$$

where ideally α is 1 but will probably end up being between Ø and 1.

The pole affect of C_{e7} occurs when $\left|\frac{1}{j\omega C_{e7}}\right| = r_{\pi 7}$, assuming no ~~other~~ interferences with other poles. Repurposing ω_5 for this,

[7c] $$\omega_5 = \frac{1}{r_{\pi 7} C_{e7}} = \frac{\alpha}{R_{C1} C_{e7}} = \frac{I_{C7}}{\beta_7 V_T C_{e7}}$$

Crudely incorporating this into the gain equation,

[8a] $$T^{-1} = \frac{-R_{C1}}{R_{dif}}\left(1 + \frac{1}{\alpha\beta}\right) \cdot \left[\frac{\left(1 - j\frac{\omega_3}{\omega}\right)\left(1 + j\frac{\omega}{\omega_4}\right)}{\left(1 - j\frac{\omega}{2\omega_4}\right)} - \frac{\alpha\beta}{1 + \alpha\beta} \right] \cdot \left(1 + j\frac{\omega}{\omega_5}\right)$$

[8b] where $\omega_3 = \dfrac{1}{\left(1 + \frac{1}{\alpha\beta}\right) R_{C1} C_{E7}}$, $\omega_4 = \dfrac{\alpha\beta_7}{2 R_{C1} C_C}\left(= \dfrac{I_{C7}}{2 V_T C_C}\right)$, $\omega_5 = \dfrac{\alpha}{R_{C1} C_{e7}}$

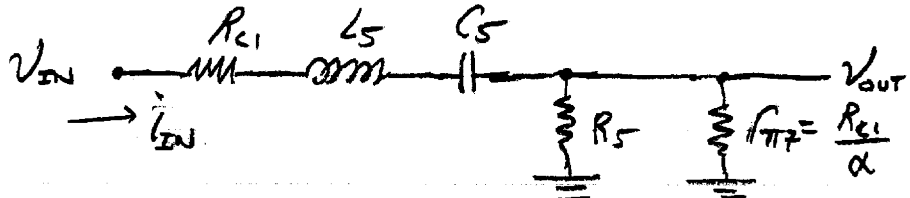
If we assume that $\alpha \geq 0.1$, then T and ω_3 simplify

[9a] $$T^{-1} = \frac{-R_{C1}}{R_{dif}} \cdot \left[\frac{\left(1 - j\frac{\omega_3}{\omega}\right)\left(1 + j\frac{\omega}{\omega_4}\right)}{\left(1 - j\frac{\omega}{2\omega_4}\right)} - \frac{\alpha\beta_7}{1+\alpha\beta_7} \right] \cdot \left(1 + j\frac{\omega}{\omega_5}\right)$$

[9b] where $\omega_3 = \frac{1}{R_{C1}C_{E7}}$, $\omega_4 = \frac{\alpha\beta_7}{2R_{C1}C_c}$, $\omega_5 = \frac{\alpha}{R_{C1}C_{E7}}$.

The impedance matching factor α relates I_{C7} and R_{C1}. Other factors which may constrain α are the availability of large capacitors for C_5 and small inductors for L_5.

It is now time to consider these poles.



This AC circuit can be simplified by judicious choice of R_5. It should be small enough to stiffly pin the Q_7 base potential, but large enough to force most of i_{IN} through $r_{\pi 7}$.

$$r_\pi \ll R_5 \ll \frac{V_{cc} - V_{b7}}{I_{b7}}$$

$$\frac{V_T\beta_7}{I_{c7}} \ll R_5 \ll \frac{(V_{cc} - V_{b7})\beta_7}{I_{c7}}$$

$$1 \ll \frac{R_5 I_{c7}}{V_T\beta_7} \ll A \quad , \text{ where } A = \frac{V_{cc} - V_{b7}}{V_T}$$

The best way to satisfy both of these conditions simultaneously is to let

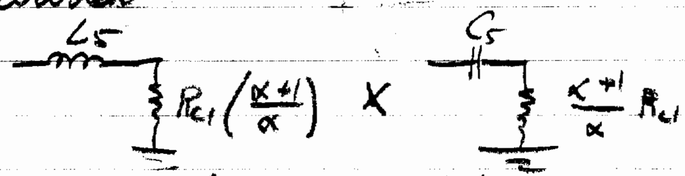
$$\frac{R_5 I_{c7}}{V_T\beta_7} = \sqrt{A} \qquad \text{i.e.} \qquad \frac{R_5\,\alpha\cancel{\beta_7}\cancel{V_T}}{R_{C1}\cancel{V_T}\cancel{\beta_7}} = \sqrt{A}$$

in other words (again)

[10a] $$R_5 = \frac{R_{C1}}{\alpha}\sqrt{\frac{V_{cc} - V_{b7}}{V_T}}$$

This simplifies the passive AC circuit to

Assuming that the poles due to L_5 and C_5 are far apart and do not resonate, then the impedance can be written



$$Z = R_c\left(\frac{\alpha+1}{\alpha}\right)\left(1 + j\omega\frac{L\alpha}{R_c(\alpha+1)}\right)\left(1 - j\frac{\alpha}{R_c(\alpha+1)C_5\omega}\right)$$

[10b] $$Z = R_c\left(\frac{\alpha+1}{\alpha}\right)\left(1 - j\frac{\omega_6}{\omega}\right)\left(1 + j\frac{\omega}{\omega_7}\right)$$

[10c] where $\omega_6 = \frac{\alpha}{(1+\alpha)R_{c1}C_5}$ and $\omega_7 = \frac{R_{c1}(\alpha+1)}{\alpha L}$

Naively assuming that these poles do not interfere with ω_{3-5}, then the transfer function is now

[11a] $$T^{-1} = \frac{-R_{c1}}{R_{dif}}\cdot\left[\frac{\left(1-j\frac{\omega_3}{\omega}\right)\left(1+j\frac{\omega}{\omega_4}\right)}{\left(1-j\frac{\omega}{2\omega_4}\right)} - \frac{\alpha\beta_7}{1+\alpha\beta_7}\right]\cdot\left(1+j\frac{\omega}{\omega_5}\right)\left(1-j\frac{\omega_6}{\omega}\right)\left(1+j\frac{\omega}{\omega_7}\right)$$

where

[11b] $\omega_3 = \frac{1}{R_{c1}C_{E7}}$, $\omega_4 = \frac{\alpha\beta_7}{2R_{c1}C_c}$, $\omega_5 = \frac{\alpha}{R_{c1}C_{e7}}$, $\omega_6 = \frac{\alpha}{(1+\alpha)R_{c1}C_5}$, $\omega_7 = \frac{(\alpha+1)R_{c1}}{\alpha\cdot L}$

and

(7b) $$I_{C7} = \frac{\alpha\beta_7 V_T}{R_{c1}}$$

High poles/zeros: $\omega_4, 2\omega_4, \omega_5, \omega_7$
Low poles: ω_3, ω_6

DC Analysis

$$\begin{cases} R_{E5} = \dfrac{V_{mirror} - V_{BE(on)}}{I_{C5}} \\ I_{C5}^{-1} = \dfrac{R_5}{V_{b7}} = \dfrac{R_{C1}}{\alpha V_{b7}} \sqrt{\dfrac{V_{CC} - V_{b7}}{V_T}} \end{cases}$$

$$R_7 = \frac{\beta_8 \beta_9 V_T V_{CC}}{50 V_{b8}} \cdot \frac{R_{C1}}{\alpha \beta_7 V_T} = \frac{\beta_8 \beta_9}{50 \beta_7} \cdot \frac{V_{CC}}{V_{b8}} \cdot \frac{R_{C1}}{\alpha}$$

$$R_8 = \frac{\beta_8 \beta_9}{50 \beta_7} \cdot \frac{V_{CC}}{V_{CC} - V_{b8}} \cdot \frac{R_{C1}}{\alpha}$$

[12a] $$R_{E5} = \frac{R_{C1}}{\alpha} \cdot \frac{V_{mirror} - V_{BE(on)}}{V_{b7}} \cdot \sqrt{\frac{V_{CC} - V_{b7}}{V_T}}$$

$$R_{E6} = \frac{V_{mirror} - V_{BE(on)}}{I_{C7}} = \frac{R_{C1}}{\alpha \beta_7 V_T} \left(V_{mirror} - V_{BE(on)} \right)$$

[12b] $$R_{E6} = \frac{R_{C1}}{\alpha \beta_7} \cdot \frac{V_{mirror} - V_{BE(on)}}{V_T}$$

[12c] R_{dif} Will analyze R_{dif} and parasitics of transformer in design of stage 2

Midband Gain

$$T^{-1} = \frac{-R_{C1}}{R_{dif}} \left(1 - \frac{\alpha \beta_7}{1 + \alpha \beta_7} \right)$$

$$= \frac{-R_{C1}}{R_{dif}} \left(\frac{1 + \cancel{\alpha \beta_7} - \cancel{\alpha \beta_7}}{1 + \alpha \beta_7} \right)$$

$$T^{+1} = \frac{-R_{dif}}{R_{C1}} \left(\frac{1 + \alpha \beta_7}{1} \right)$$

[13] $$T_{Midband} = \frac{-R_{dif}}{R_{C1}} \left(1 + \alpha \beta_7 \right)$$

Component Design

[with $V_{mirror} = 1$, $V_{BE(on)} = 0.75V$, $V_{b7} = 2$, $V_{b8} = 3.75$, $V_{CC} = 5$, and $\beta_8 = \beta_9 = 100$]

$$R_7 = (266) \cdot \left(\frac{R_{C1}}{\alpha \beta_7} \right)$$

$$R_8 = (800) \left(\frac{R_{C1}}{\alpha \beta_7} \right) \qquad R_{E5} = (1.369) \left(\frac{R_{C1}}{\alpha} \right)$$

$$R_5 = (10.95) \left(\frac{R_{C1}}{\alpha} \right) \qquad R_{E6} = \left(\frac{10 R_{C1}}{\alpha \beta_7} \right)$$

$R_5 = (10.95)\left(\frac{R_{c1}}{\alpha}\right)$ $R_7 = (266)\cdot\left(\frac{R_{c1}}{\alpha\beta_7}\right)$ $R_8 = (800)\cdot\left(\frac{R_{c1}}{\alpha\beta_7}\right)$ $R_{E5} = (1.369)\left(\frac{R_{c1}}{\alpha}\right)$ $R_{E6} = \frac{10 R_{c1}}{\alpha\beta_7}$

$$A_{Midband} = \frac{-R_{dif}}{R_{c1}}(1+\alpha\beta_7)$$

Stage 2 Design Summary

Components: $R_{E5}, R_{E6}, R_5, R_7, R_8, L_5, C_5, C_{E7}, Q_{5-9}$

Design Parameters: R_{c1}, α

Low poles: ω_3, ω_6,

High poles: ω_4, ω_5, ω_7

$(C_{E7})\ (C_c)\ (C_e)\ (C_5)\ (L_5)$

Design parameter R_{c1} has a limited domain from stage I:

(I.14) $$\boxed{R_{c1} \le \frac{V_{b1}}{I_{c1}}}$$

Design parameter α is the maximum power/impedance matching factor of the input circuit:

(7a) $$\boxed{\alpha = \frac{R_{c1}}{r_{\pi 7}}}$$

A value of unity for α is desirable, unless the current consumption becomes to large:

(7b) $$\boxed{I_{c7} = \frac{\alpha\beta_7 V_T}{R_{c1}}}$$

The poles, reactive components, and design parameters are related in the following table:

Design Table

Low	$f_3 = \frac{1}{2\pi R_{c1} C_{E7}}$	$C_{E7} = \frac{1}{2\pi R_{c1} f_3}$	$R_{c1} = \frac{1}{2\pi C_{E7} f_3}$	N/A
High	$f_4 = \frac{\alpha\beta}{4\pi R_{c1} C_c}$	N/A	$R_{c1} = \frac{\alpha\beta}{4\pi C_c f_4}$	$\alpha = \frac{4\pi}{\beta} R_{c1} C_c f_4$
High	$f_5 = \frac{\alpha}{2\pi R_{c1} C_e}$	N/A	$R_{c1} = \frac{\alpha}{2\pi C_e f_5}$	$\alpha = 2\pi R_{c1} C_e f_5$
Low	$f_6 = \frac{\alpha}{2\pi(\alpha+1) R_{c1} C_5}$	$C_5 = \frac{\alpha}{2\pi(\alpha+1) R_{c1} f_6}$	$R_{c1} = \frac{\alpha}{2\pi(\alpha+1) C_5 f_6}$	$\alpha \overset{*}{=} 2\pi R_{c1} C_5 f_6$
High	$f_7 = \frac{(\alpha+1) R_{c1}}{2\pi\alpha L_5}$	$L_5 = \frac{(\alpha+1) R_{c1}}{2\pi\alpha f_7}$	$R_{c1} = \frac{2\pi\alpha L_5 f_7}{\alpha+1}$	$\alpha \overset{*}{=} \frac{R_{c1}}{2\pi L_5 f_7}$

*only for small α; $\alpha \ll 1$