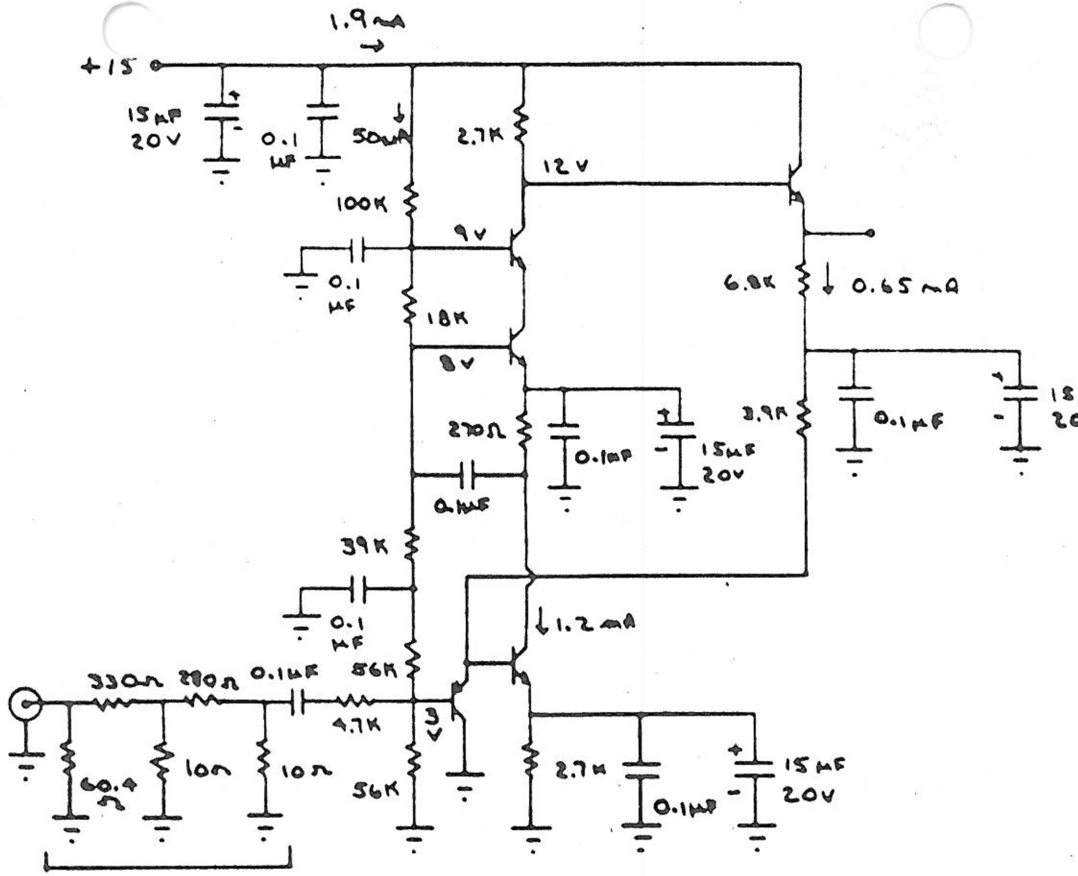
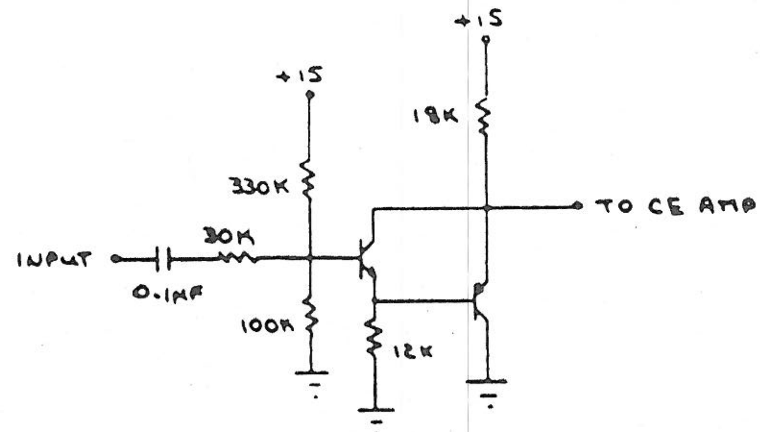


NPN'S ARE 2N3904
PNP'S ARE 2N3906



ALTERNATE FOLLOWER

LAB 2

55A

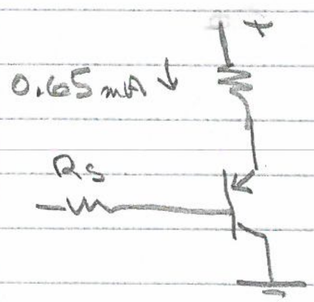
4/15 Discussion of my lab 2.

What do the specs imply for the design?

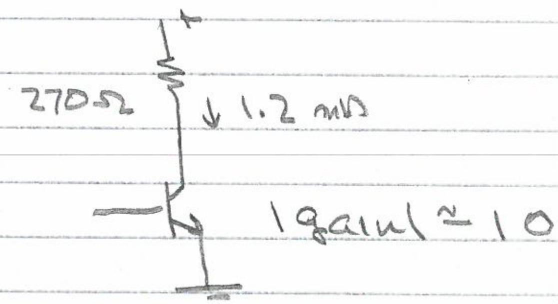
Because of the high source resistance, we need at least a simple emitter follower at the input. The circuit also requires a follower at the output, since the 10pF capacitor would probably contribute an unacceptable open-circuit time constant otherwise.

The low power requirement is complicated by having only 15-volt supplies available, which are far in excess of what is required for a 2-V peak to peak output swing.

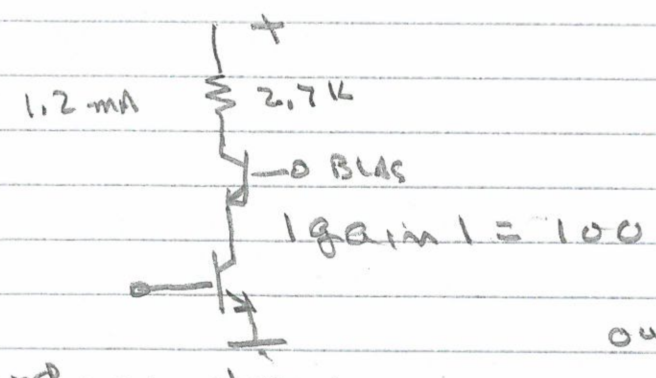
I used two voltage gain stages — a CE amp followed by a cascode. My stages are (describe topology).



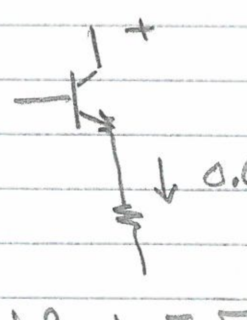
Input EF



1st gain stage



2nd gain stage



output EF

The circuit has 4 nodes that have important impact on the bandwidth. One is the input to the first emitter follower. This time constant is $\sim (R_s + r_b) C_\mu$. The next is at the input to the 1st voltage gain stage.

$$\left[r_b + \frac{(R_s + r_b + r_\pi)}{\beta + 1} \right] C_{T1}$$

Input to 2nd voltage gain stage. This is $(R_{L1} + r_b) C_{T2}$

Output node of 2nd gain stage.
$R_{L2} \times 2 C_\mu$.

There are a number of other contributions to Σ OCT, but they are not very important. Examples include those associated with C_π of the two emitter followers, and of the cascode. These are $\sim \frac{1}{\omega_t}$.

We can reduce the sum of the open-circuit time constants by trading off the gains in the two stages subject to the constraint that

$g_m R_{L1} g_m R_{L2} \sim 1000$, or $R_{L1} \times R_{L2} = 7.5 \times 10^5$

$$R_{L1} \sim \frac{1000}{g_m^2 R_{L2}}.$$

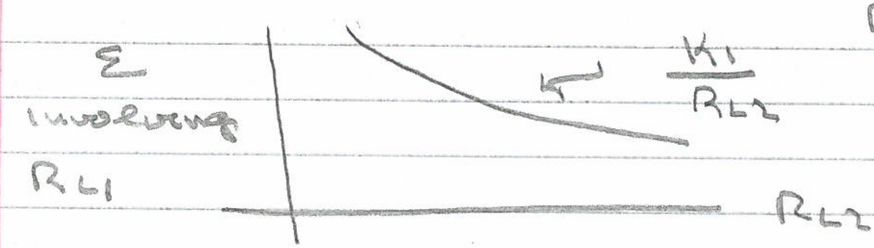
To minimize these contributions to Σ OCT, we want to get all of the parts of the sum that involve R_{L1} and R_{L2}.
For example, one term that includes R_{L1} is
$(R_i + R_{L1} + g_{m1} R_i R_{L1}) C_{\mu 1}$

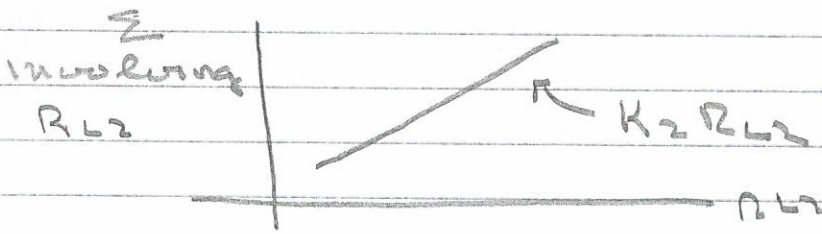
input to 1st gain stage

Term involving $C_{\pi 2}$ is $(R_{L1} + r_{b2})\,C_{\pi 2}$.
Another term is

$$\left[R_{L1} + r_{b2} + \left(g_m \times \frac{1}{g_m}\right)(R_{L1} + r_{b2}) + \frac{1}{g_m}\right] C_{\mu 2}$$

We can do the same thing with R_{L2}. Here we get $2(R_{L2} + r_b)\,C_{\mu 2}$. Since R_{L1} and R_{L2} must be reciprocally related to get the correct gain, we can plot $R_{L1} = \dfrac{7.5 \times 10^5}{R_{L2}}$





Since these are of the form $\dfrac{K_1}{R_{L2}}$ and $K_2 R_{L2}$,

their contribution to the sum is

$$\frac{K_1}{R_{L2}} + K_2 R_{L2}.$$

$$\frac{d}{dR_{L2}} = -\frac{K_1}{R_{L2}^2} + K_2 = 0, \quad R_{L2} = \sqrt{\frac{K_1}{K_2}}$$

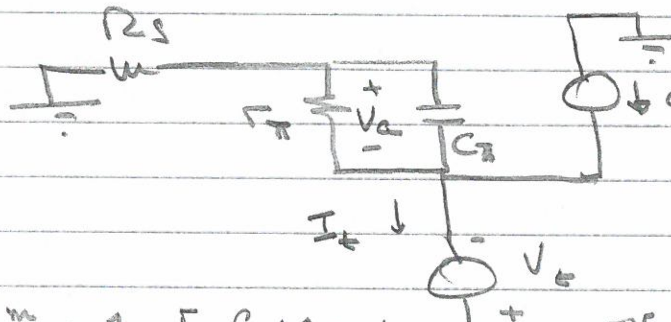
This is the value of R_{L2} that makes the two contributions equal. This happens with $R_{L1} \approx 0.1\,R_{L2}$ in my design, and with $R_{L1} = 270\,\Omega$, $R_{L2} = 2.7K$

With this constraint, all 4 of the critical time constants have about the same value $\sim 10\,ns$. This would predict

Recitations 4/6 & 4/8 - more circuit examples.

an $\omega_h \simeq \frac{1}{40ns} = 25 Mr \simeq 4 MHz$.
we actually get ~ 8MHz. Most of the reason is the pessimism associated
4/7 with the OCT calculation when we have coincident poles. I showed earlier that with 4 coincident poles, the actual bandwidth is ~1.7x the prediction. There is also at least one pair of complex conjugate poles. Reason is probably that the output impedance of an emitter follower with a large source resistance looks inductive at some frequencies.

We can show this (sort of) as follows.



$\frac{g_m}{C_\pi \omega} \gg 1$, $r_\pi C_\pi \omega \gg 1$ or $\frac{g_m}{C_\pi} \gg \omega \gg \frac{1}{r_\pi C_\pi} = \frac{g_m}{\beta C_\pi}$

$$I_t = \frac{V_t}{R_s + \frac{r_\pi}{r_\pi C_\pi s+1}} + \frac{g_m \frac{r_\pi}{r_\pi C_\pi s+1}}{R_s + \frac{r_\pi}{r_\pi C_\pi s+1}} V_t$$

If $R_s \gg r_\pi$, $r_\pi C_\pi \omega \gg 1$, $\frac{g_m r_\pi}{r_\pi C_\pi \omega} = \frac{g_m}{C_\pi \omega} \gg 1$

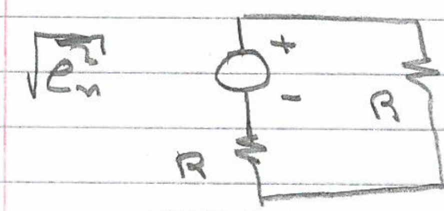
2nd condition is that we are past the β cutoff frequency, 3rd is below ω_t.

$I_t \simeq \frac{g_m}{R_s C_\pi s} V_t$, $\frac{V_t}{I_t} = \frac{R_s C_\pi s}{g_m}$ (looks like an inductor)

The numbers are reasonable for a transistor (2N3904) with $\beta = 200$, $f_T = 200$ MHz.

Alternate with a higher source resistance, bootstrapped emitter follower.

Noise. A resistor has noise associated with it. A model is



← noise power delivered is $kTB = \dfrac{\left[\dfrac{\sqrt{\overline{e_n^2}}}{2}\right]^2}{R}$

or $\sqrt{\overline{e_n^2}} = \sqrt{4kTBR}$. This is about $1\ \mathrm{nV}/\sqrt{\mathrm{Hz}}$

for $50\ \Omega$. We have $5K \Rightarrow 10\ \mathrm{nV}/\sqrt{\mathrm{Hz}}$

and $B = 9 \times 10^6$, $\sqrt{B} = 3 \times 10^3$, so we get $30\ \mu V$ rms at the input, 30 mV rms at output.