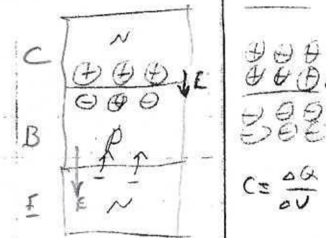
Transistors at RF

Problem 1 Device parasitics & Input Loading

Consider transistor structure:



(Similar issue in JFET & FET Ø)

Example: MMBV5179 at $I_c = 3mA$, $V_{cb} = 4V$

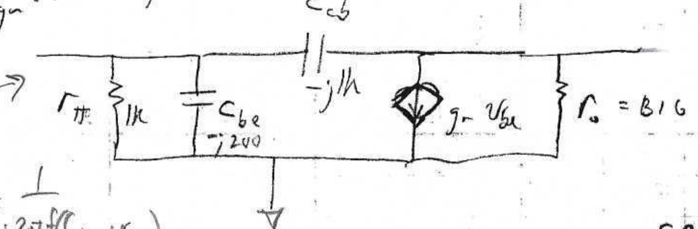
$C_{cb} = 1.5pF$ ($X_c = \frac{1}{2\pi fC}$ ⇒) $X_{C_{cb}} = 1K\Omega$ @ 100MHz

$C_{be} = 8pF$ $X_{C_{be}} = 200\Omega$ @ 100MHz

Recall $f_T = \frac{1}{2\pi \frac{1}{g_m} C}$ (w/ $g_m = 77mA/V$, $f_T = 1.5GHz$)

(compare w/ $r_\pi = h_{fe}\frac{1}{g_m} \approx 1K$)

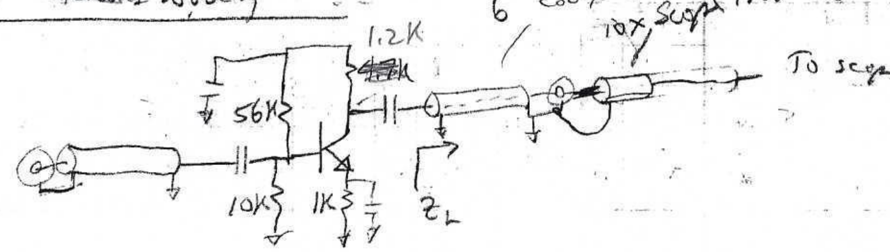
AC model @ 100MHz



$Z_{in} \approx \frac{1}{j2\pi f(C_{be} + C_{miller})}$

☆ Show Data Sheet

Problem 2 Capacitive Output Loading



☆ Show COAX Data

$\Rightarrow Z_L = 10M \parallel 15pF \parallel (30pF/ft \times .5ft)$

$\approx 10M \parallel 30pF$

$\approx \{10M\Omega$ @ DC

$(-j\,53\Omega$ @ 100MHz !

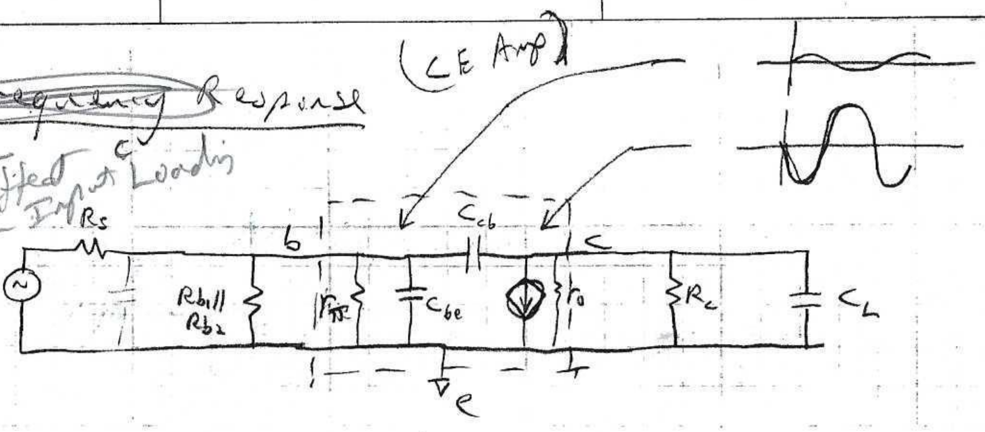
Compare with $R_c = 1.2K$

and recall $|A_v|$ is now $g_m|Z_c|$

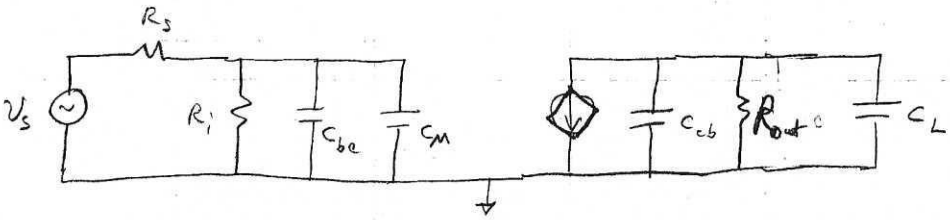
$<< g_m R_c$

~~High Frequency Response~~

~~[illegible]~~ Feedback & Miller Effect, Input C Loading, Magnification



⇓

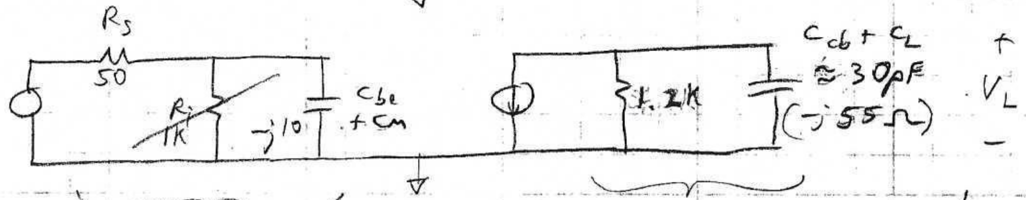


where $C_M = (1 + |A_V|)\, C_{cb}$

$= BIG!$ (152 pF for $A_V = 100$, $C_{cb} = 1.5\,pF$)

$= -j10\,\Omega$ @ 100 MHz !!

⇓



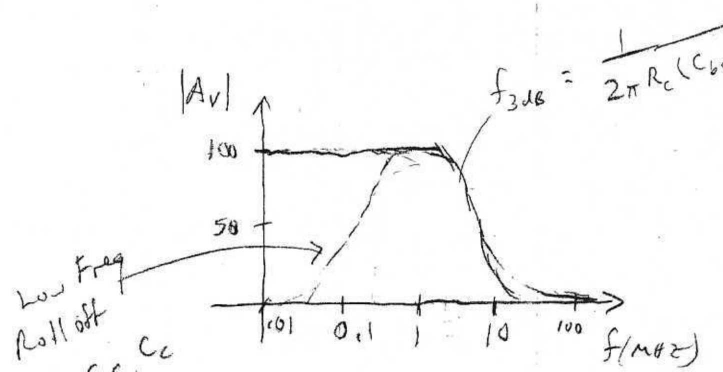
≈ 5:1 Gain Reduction

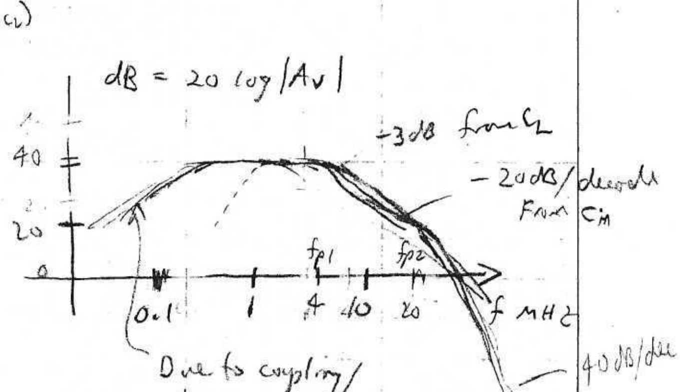
$|X_{C_{be}+C_M}| \approx 10\,\Omega$ at 100 MHz $<< R_S$ ☹

≃ 22:1 Gain Reduction!

$A_V = -g_m (R_C \| -jX_C) << g_m R_C$ @ 100 MHz ☹

$f_{3dB} = \frac{1}{2\pi R_C (C_{be} + C_L)} \simeq 4\,MHz$

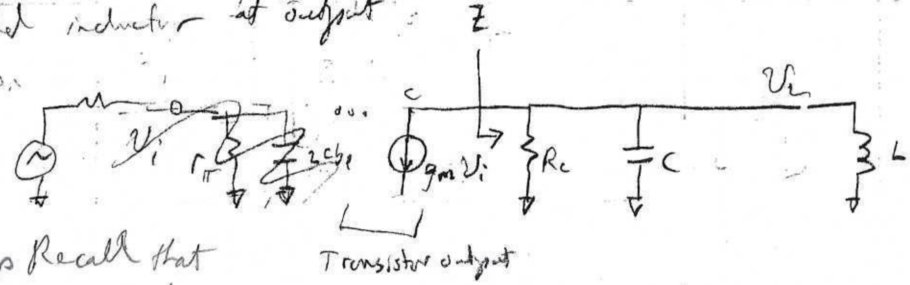




Might want to make lower corner = 100 kHz !

Solution: 1 Resonance (at output)

Add inductor at output:



For Basic Amp Recall that

$$|A_V| = \left|\frac{V_L}{V_i}\right| = g_m Z$$

$$= g_m\left(R_c \,\|\, -jX_c \,\|\, jX_L\right)$$

$$= g_m \frac{1}{\frac{1}{R_c} + \underbrace{\frac{1}{-jX_c} + \frac{1}{jX_L}}_{\text{goes to zero when } X_c = X_L}}$$

Pick L so $|X_L| = |X_c|$ at $f = f_0$

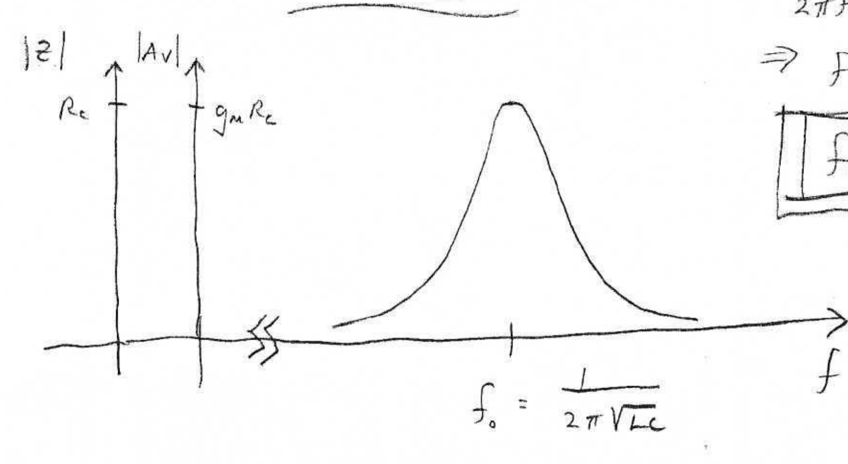
Then $\left.\frac{V_L}{V_i}\right|_{f_0} = -g_m R_c$! Gain Fully Restored!

Plot $A_V(f)$:
- At $f \to 0$, $X_L \to 0 \Rightarrow Z_L \to 0 \Rightarrow A_V \to 0$
- At $f \to \infty$, $X_c \to 0 \Rightarrow A_V \to 0$
- At f_0: $X_c = X_L \Rightarrow Z = R_c \Rightarrow |A_V| = g_m R_c$

What is f_0? $X_c = X_L \Rightarrow \frac{1}{2\pi f C} = 2\pi f L$

$$\Rightarrow f^2 = \frac{1}{(2\pi)^2 LC}$$

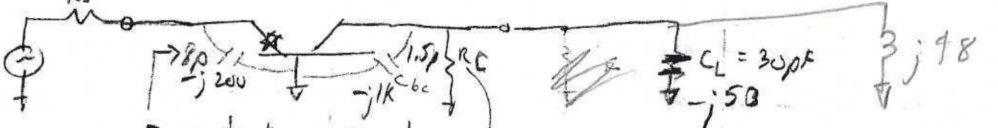
$$\boxed{f_0 = \frac{1}{2\pi\sqrt{LC}}}$$



Solution 2 Use CB or Cascode configuration to address Miller Effect & Reduce C_{in}

CB AC SS Ckt:

CB Amp $A_v = +g_m(R_c \| -j\frac{1}{\omega C_L})$



$Z_{in} = \frac{1}{g_m} \| -jX_{C_{be}} \approx \frac{1}{g_m}$

$f_{3dB} = \frac{1}{2\pi (R_{in} \| R_s) C_{be}}$ (Small)

$f_{3dB} = \frac{1}{2\pi R_C (C_{cb} + C_L)}$ (Large)

Explain "time constant method"

Not much problem

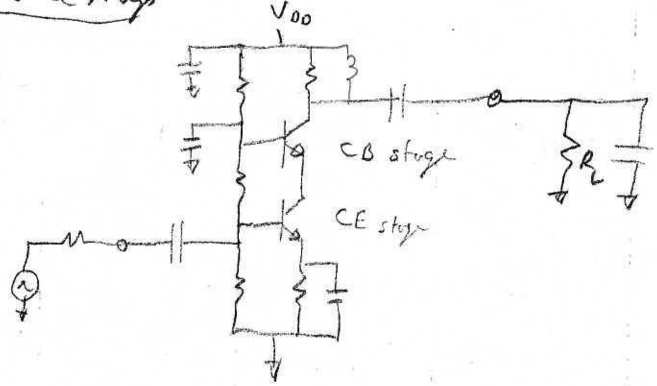
Still a problem

Since $R_S \| R_{in}$ is small compared w/ $-jX_{C_{be}} = -j200$

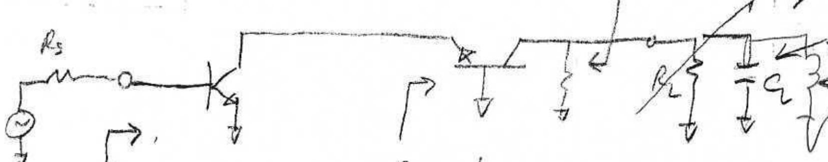
And ... No miller effect!

Cascode Amp

Full ckt:



AC Small Signal model $R_o = R_c$



$R_{in_2} = \frac{1}{g_{m2}}$

$R_{in_1} \approx r_\pi \| -jX_{C_{be}}$

$A_{v_1} \approx -g_{m1} R_{in2}$

$= -g_{m1} \frac{1}{g_{m2}}$

$= -1$

(Very small miller effect)

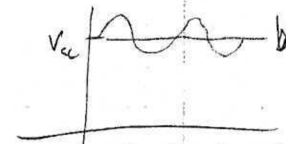
⇒ input roll off fixed, mostly

$A_{v_2} = +g_{m2}(R_c \| ...)$ ⇒ Overall gain from V_s to V_o same as CE amp

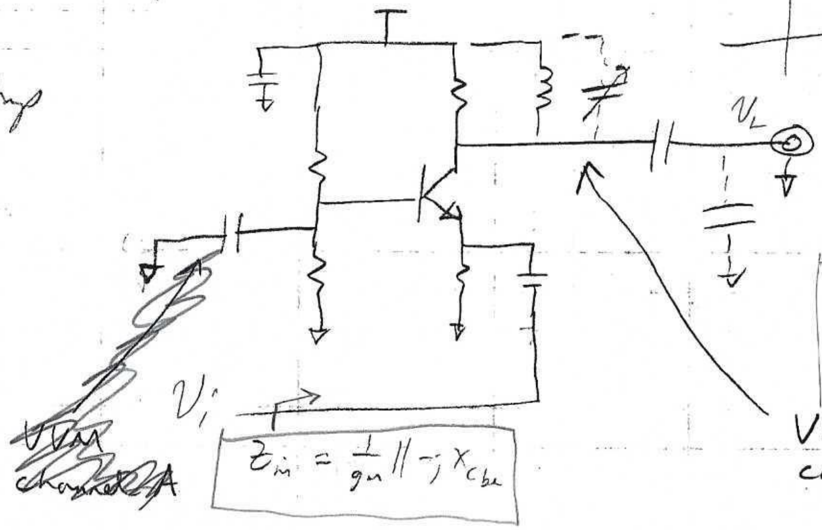
Total $A_v = A_{v_1} A_{v_2} \approx -g_m R_c$

But still have C_L problem at output

Complete ckts (Project 1b)



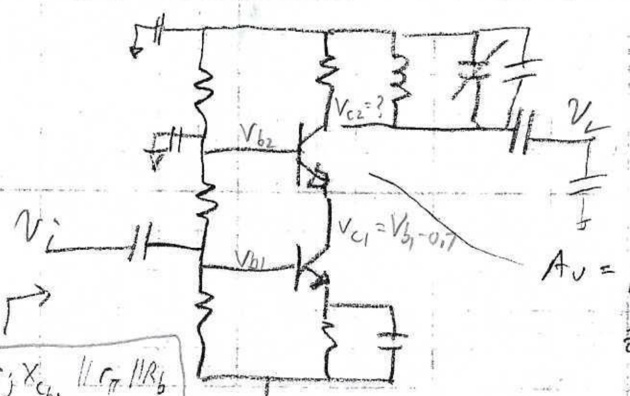
CB RF Amp



$$Z_{in} = \frac{1}{g_m} \parallel -jX_{C_{be}}$$

$$\frac{V_L}{V_i} = +g_m Z(f)$$

Cascode RF Amp



$$\frac{V_L}{V_i} = -g_m Z(f)$$

$$Z_{in} \approx -jX_{C_{be}} \parallel r_\pi \parallel R_b$$

$A_v = g_m Z$

$Z = R_c \parallel X_L \parallel X_c \parallel R_L$

$= R_c \parallel R_L$

at f where $X_c = X_L$

Find f where $X_c = X_L$

$$\frac{1}{2\pi f C} = 2\pi f L$$

$$\Rightarrow f^2 = \frac{1}{(2\pi)^2 LC}$$

$$\Rightarrow \boxed{f = \frac{1}{2\pi\sqrt{LC}}}$$

☆ Show μTrans LNA + inductor construction sheets