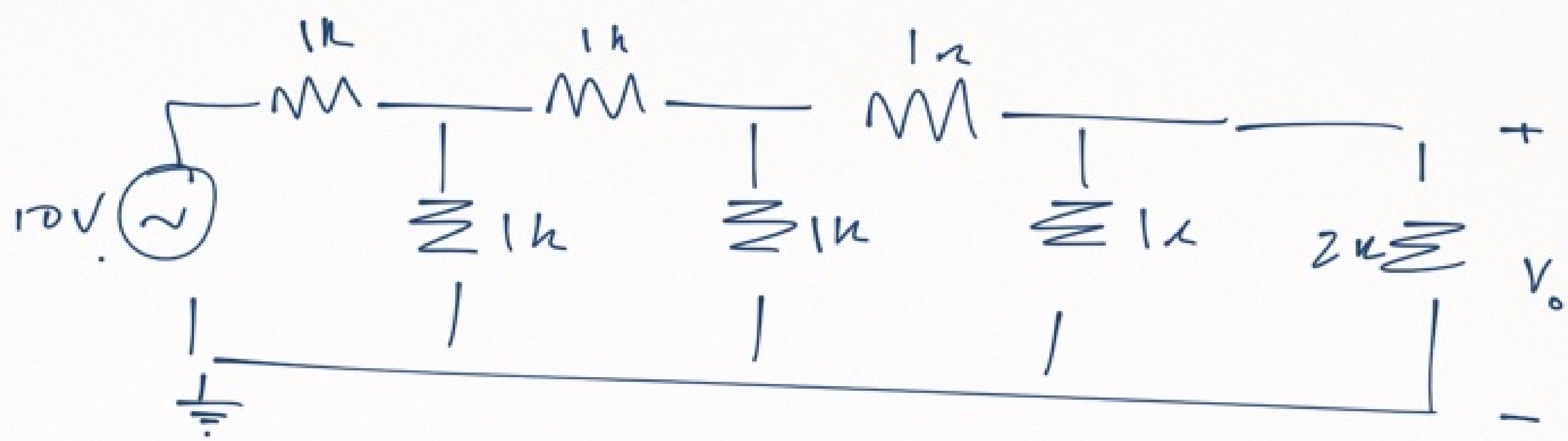
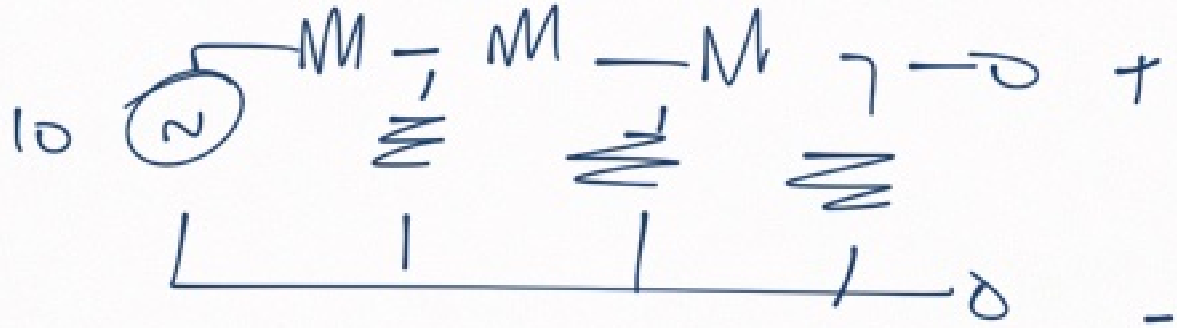
P1.1

THEV EQV.

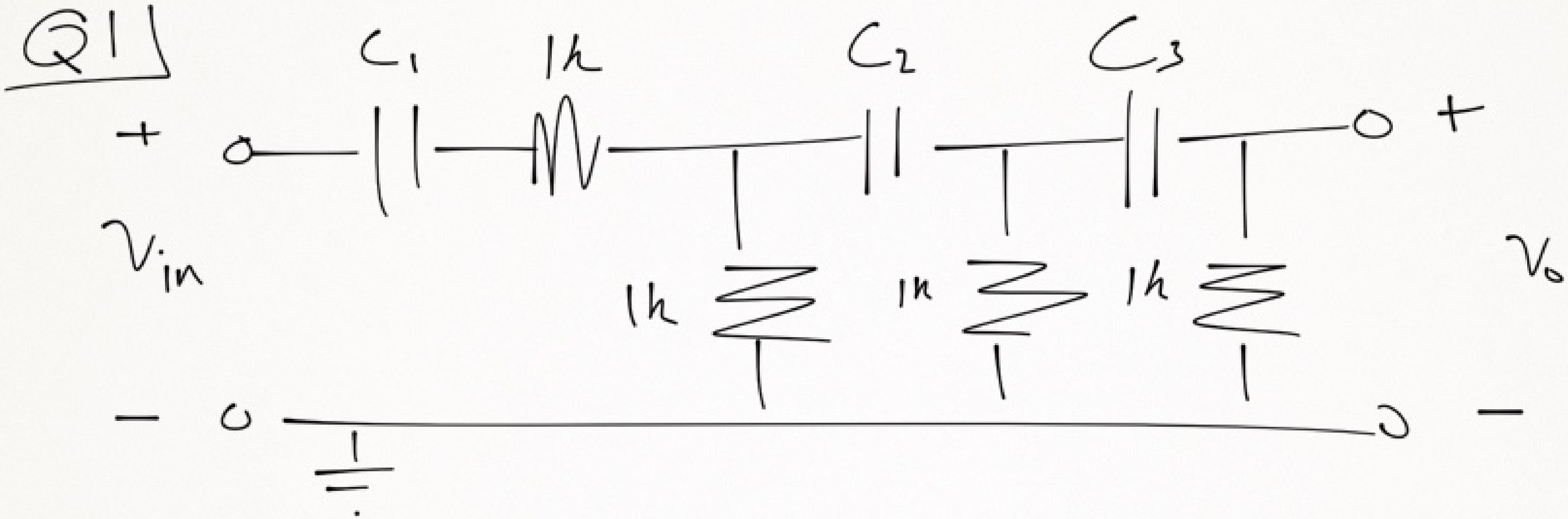


FOR V_{TH}



$(((2k \,//\, 1k) + 1k) \,//\, 1k) + 1k = 1.625k = R_{TH}$

Q1)



ASSUMING $w_a = \frac{1}{\tau_{c_1}}$

$\tau_{c_1} = C_1 \cdot 2k$

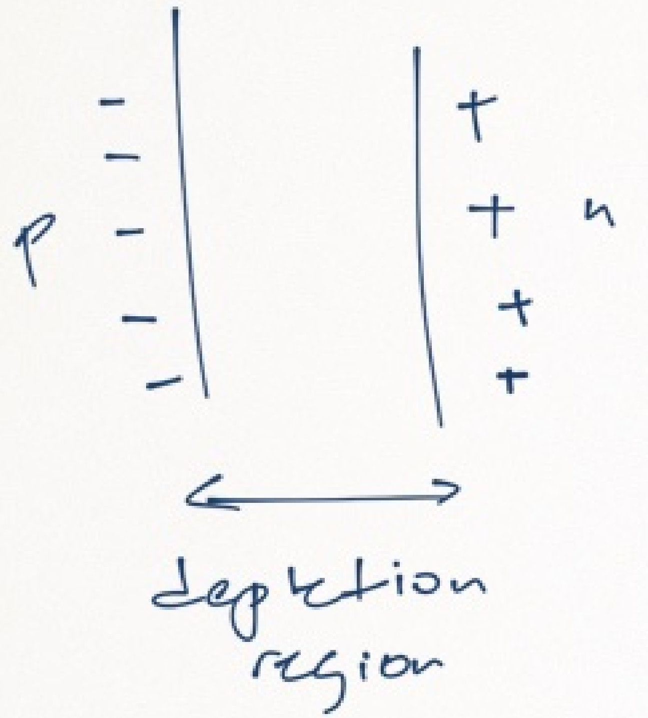
$\tau_{c_2} = C_2(1k + 1k // 1k) = C_2 \cdot 1.5k$

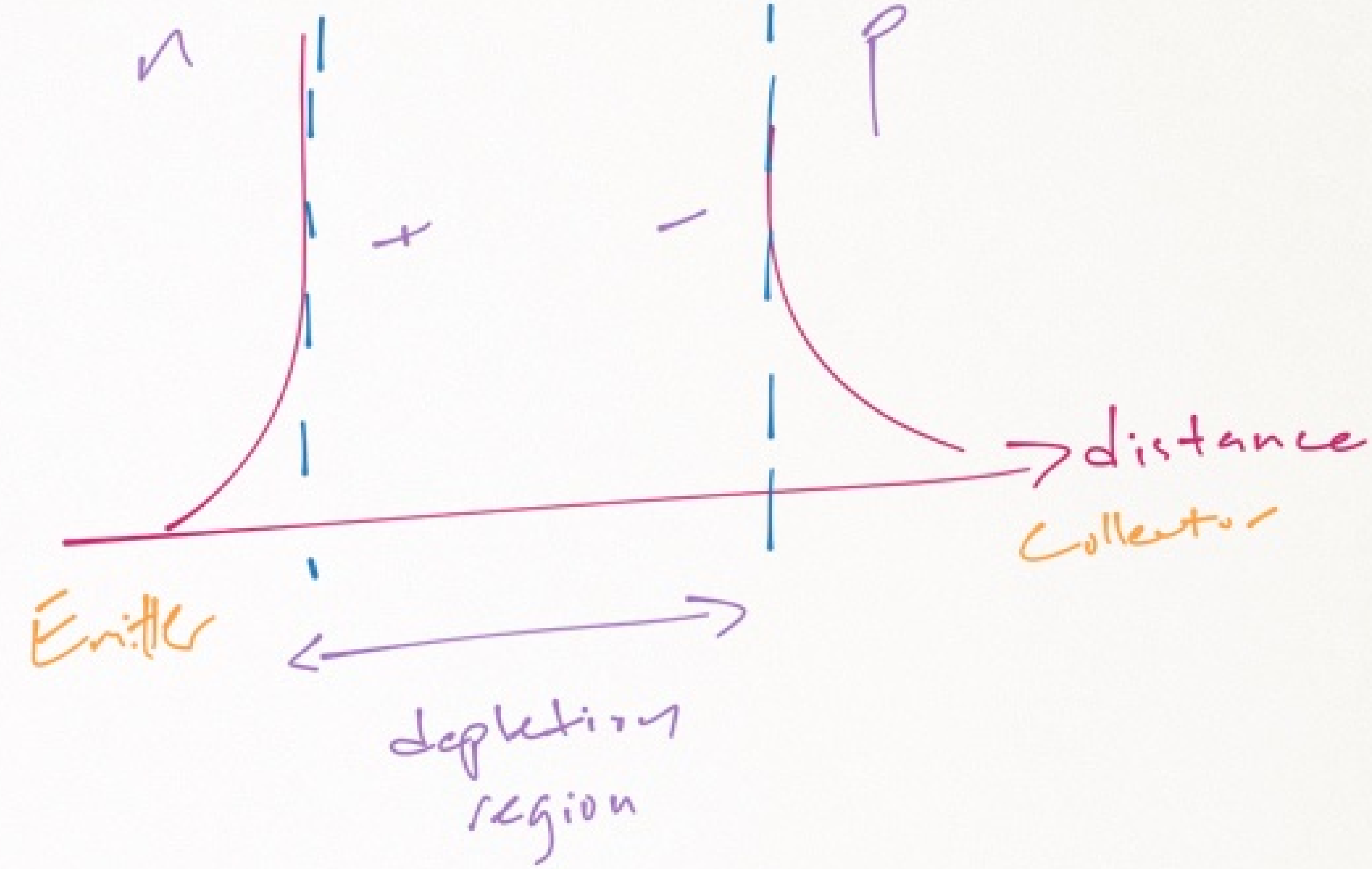
$\tau_{c_3} = C_3(1k + 1k // 1k // 1k) = C_3 \cdot \frac{4}{3}k$

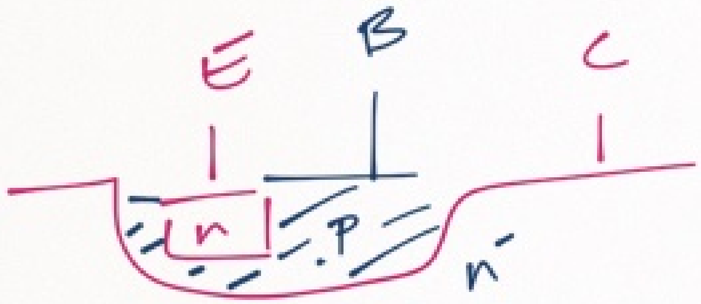
$w_a \simeq \frac{1}{\tau_{c_1}} = \frac{1}{C_1 \cdot 2k} = 10 \longrightarrow \boxed{C_1 = 50\mu F}$

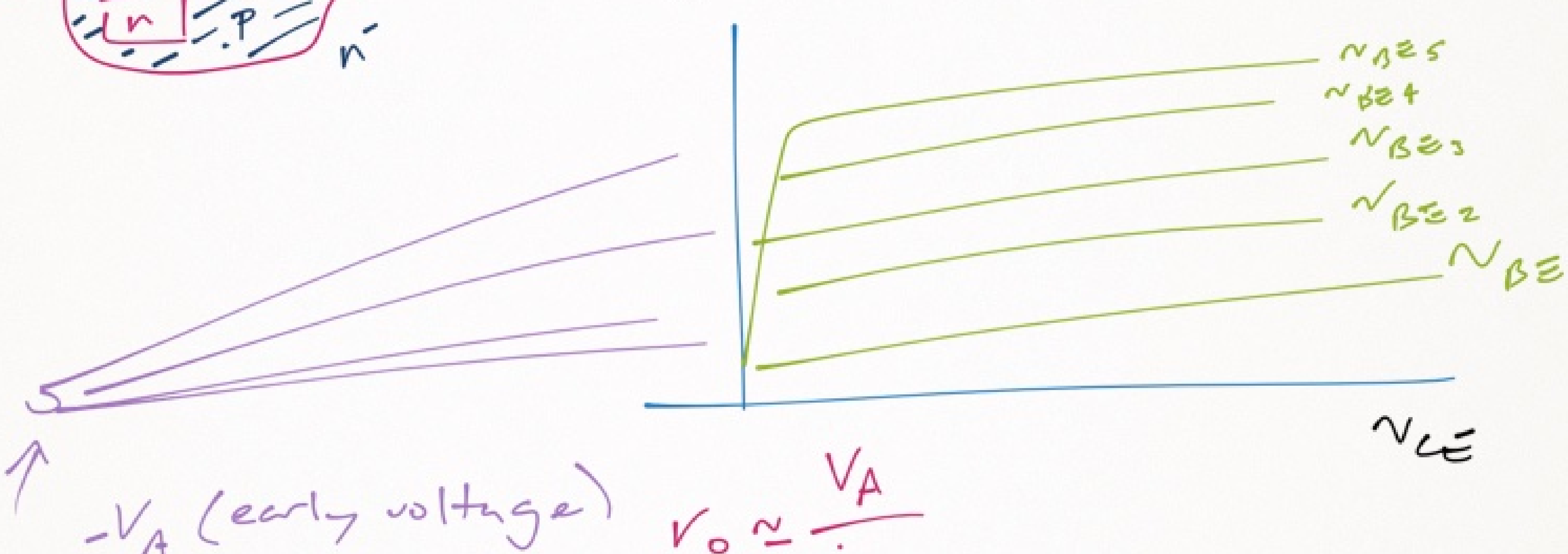
$w_b \simeq \frac{1}{\tau_{c_2}} = \frac{1}{C_2 \cdot 1.5k} = 100 \longrightarrow \boxed{C_2 = 6.66\mu F}$

$w_c \simeq \frac{1}{\tau_{c_3}} = \frac{1}{C_3 \cdot \frac{4}{3}k} = 100 \longrightarrow \boxed{C_3 = 0.75\mu F}$



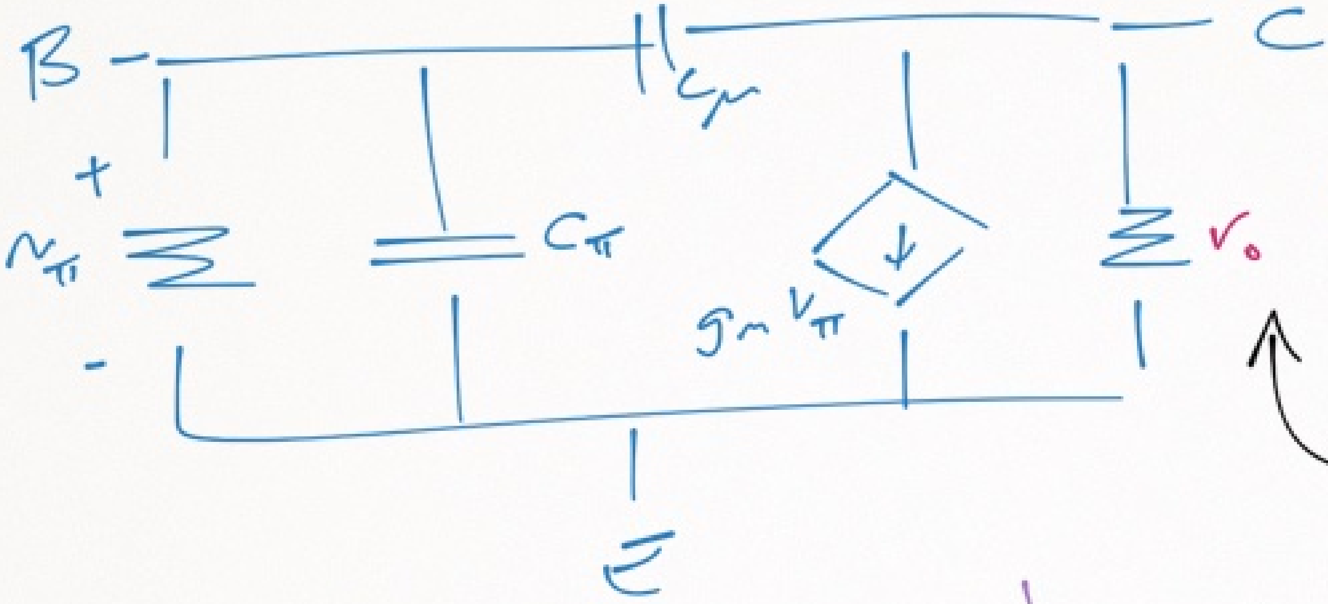






$r_o \simeq \frac{V_A}{i_C}$

bias I

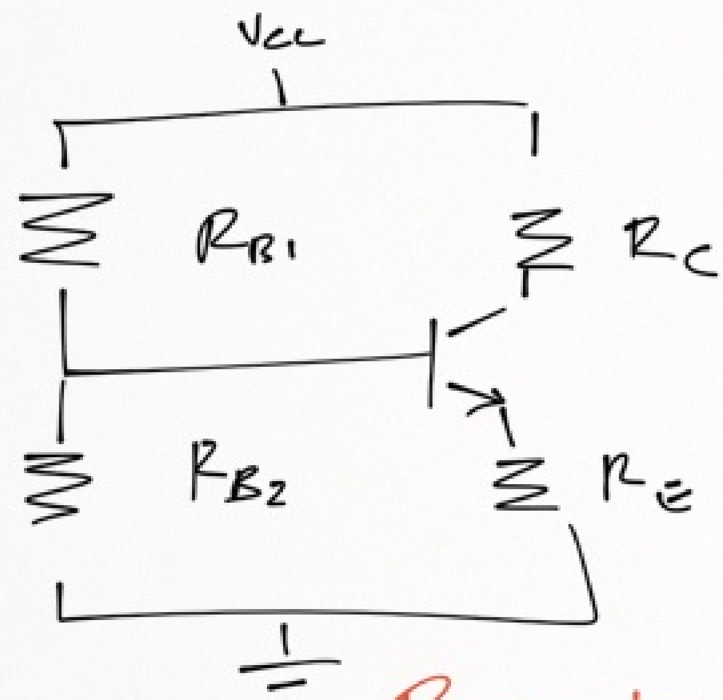


Small signal model

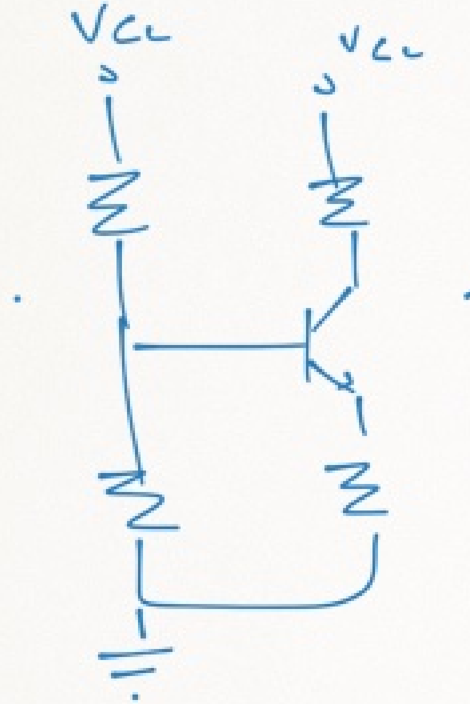
usually don't use, approx as 50k

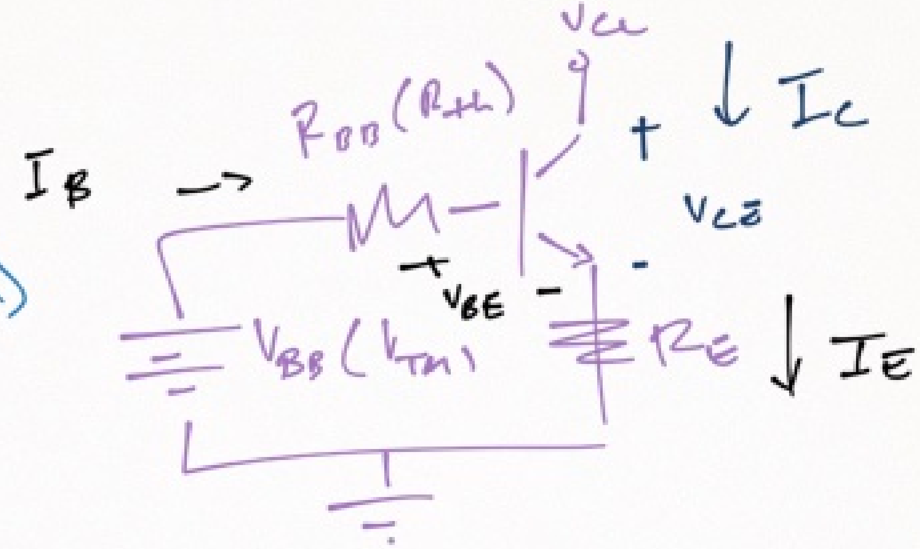
$$r_o = \left(\frac{\partial i}{\partial v_{CE}} \Bigg|_{v_{BE} = \text{constant}} \right)^{-1} \simeq \frac{V_A}{i_c}$$

1. how to bias using curve tracer
2. 1/3 rule (2 versions)



Basic bias circuit



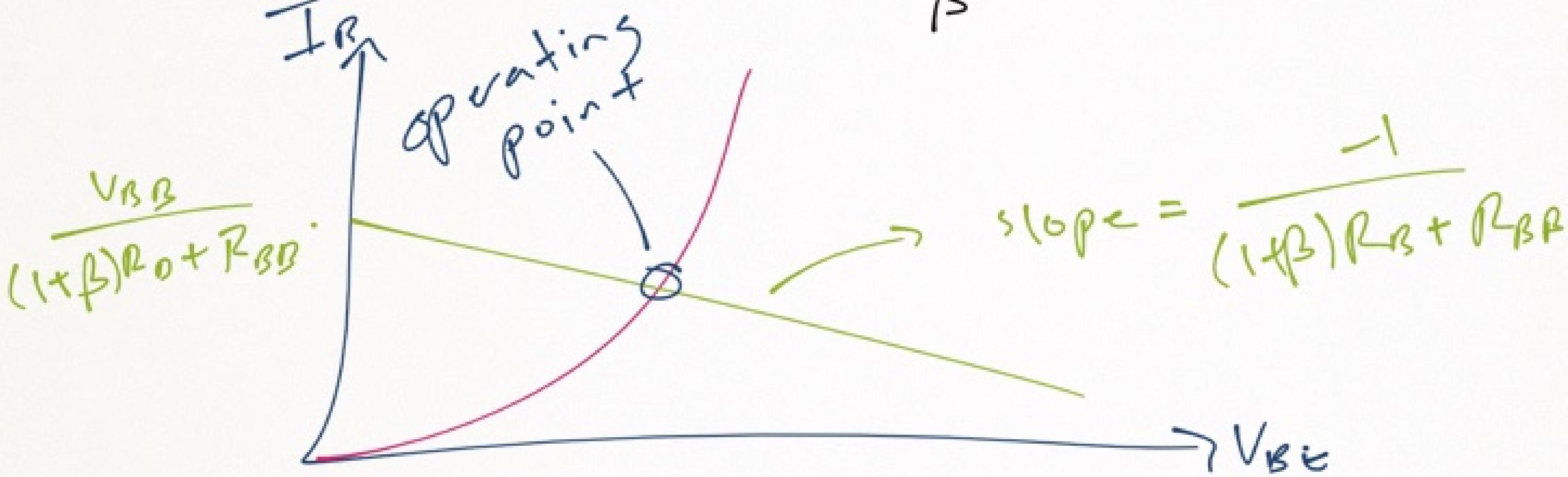


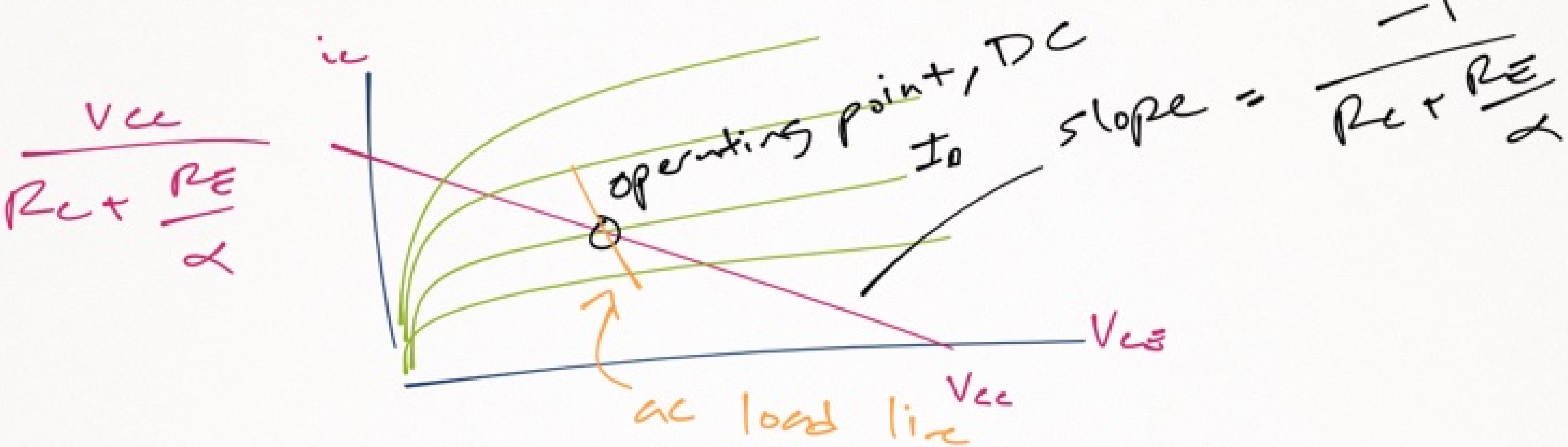
$$I_E = I_B + I_C = I_B + \beta I_B$$

$$I_B = \frac{-V_{BE}}{(1+\beta)R_E + R_{BB}} + \frac{V_{BB}}{(1+\beta)R_E + R_{BB}}$$

$$I_B = \frac{I_C}{\beta} = I_S e$$

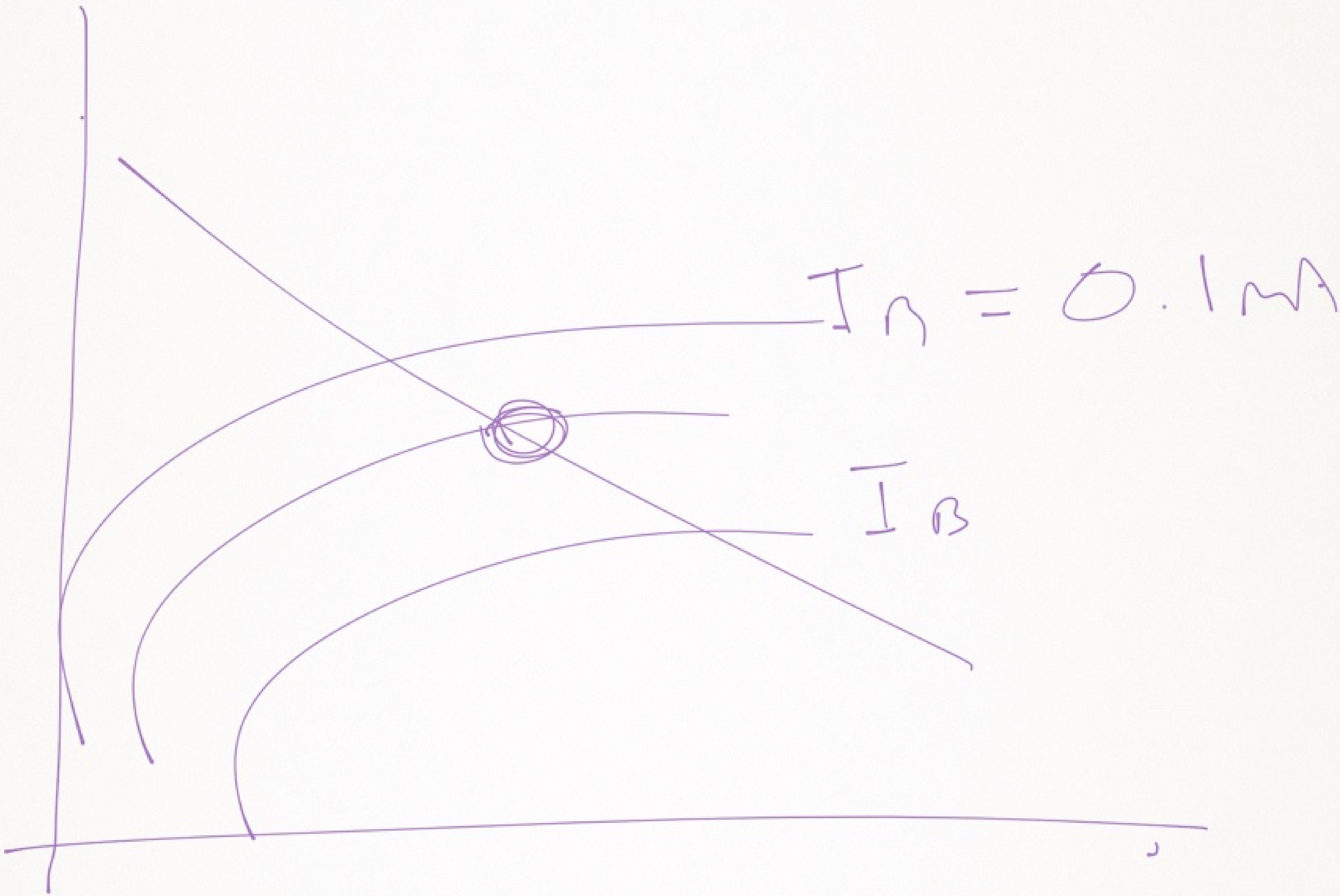
$\angle I_E = I_C$



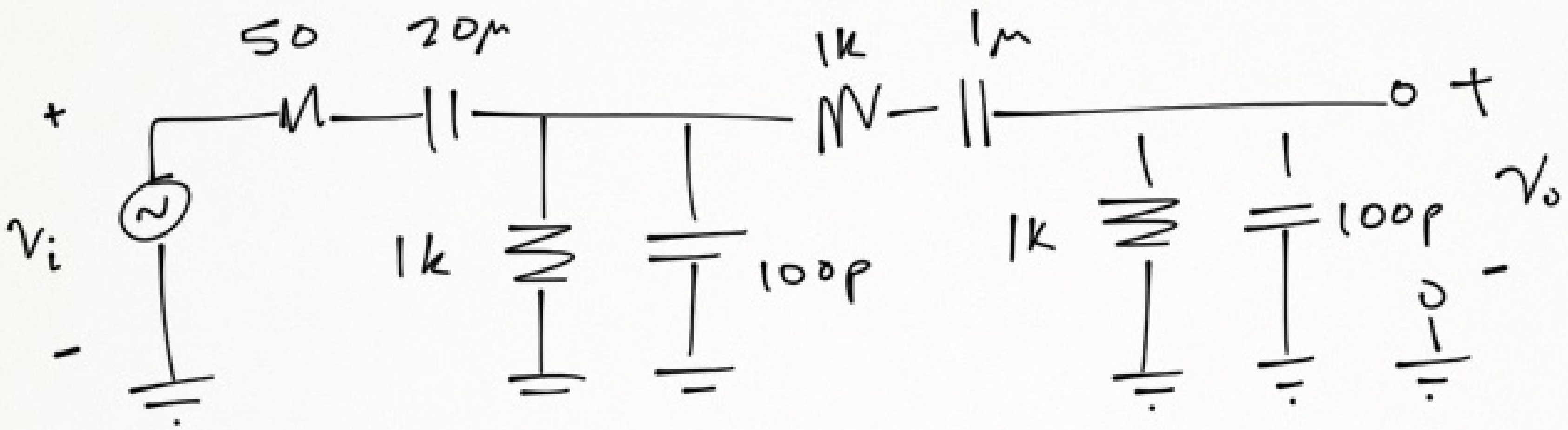


at DC coupling capacitors open circuit

∴ circuit on pg. is same as basic bias circuit



$I_B = 0.1mA$
I_B



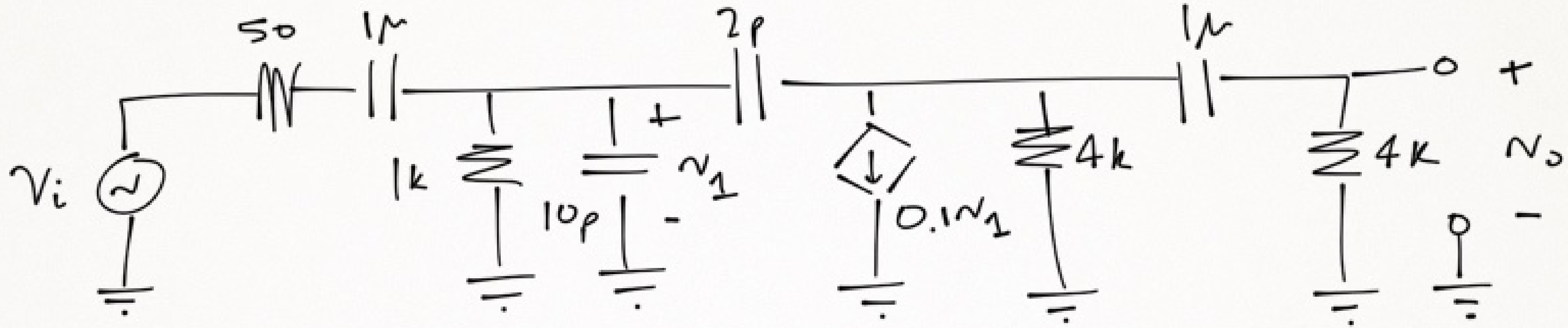
$$\omega_1 = \frac{1}{1.05k \cdot 20\mu} = 47.6 \ \frac{rad}{s}$$

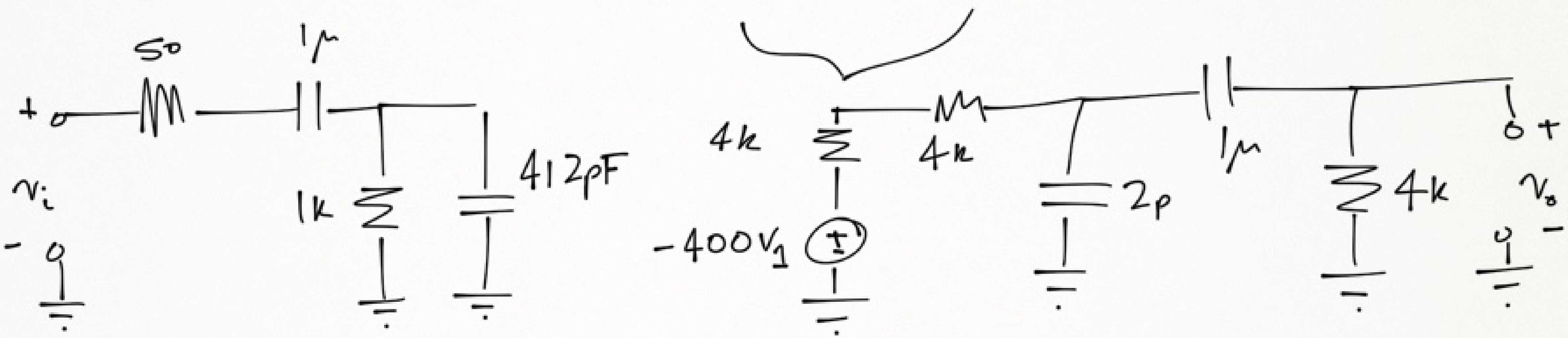
$$\omega_2 = \frac{1}{1\mu(2k + 1k /\!/ 50)} = 488.1 \ \frac{rad}{s} \longrightarrow \omega_{3dB_1} = \sqrt{488.1^2 + 47.6^2} = 490.4 \ \frac{rad}{s}$$

$$\omega_3 = \frac{1}{2\mu(2k + 1k /\!/ 50)} = 244.1 \ \frac{rad}{s} \longrightarrow \omega_{3dB_2} = 249.7 \ \frac{rad}{s}$$

$$\omega_4 = \frac{1}{5}\omega_1 = 97.6 \ \frac{rad}{s} \longrightarrow \omega_{3dB_2} = 108.6 \ \frac{rad}{s}$$

$$\omega_5 = \frac{1}{10}\omega_1 = 48.81 \ \frac{rad}{s} \longrightarrow \omega_{3dB_4} = 66.18 \ \frac{rad}{s}$$





$$\omega_{1\mu} = \frac{1}{1.05k \cdot 1\mu} = \boxed{952.4\ \frac{rad}{s}} \qquad \omega_{1\mu} = \frac{1}{8k \cdot 1\mu} = \boxed{125\ \frac{rad}{s}}$$

$$\omega_{412p} = \frac{1}{412p \cdot 50 // 1k} = \boxed{50.97\ M\ \frac{rad}{s}} \qquad \omega_{2p} = \frac{1}{2p \cdot 2k} = \boxed{250\ M\ \frac{rad}{s}}$$

$$T(s) = -190 \times \frac{s}{s+952} \times \frac{s}{s+125} \times \frac{51 \cdot 10^6}{s + 51 \cdot 10^6} \times \frac{250 \cdot 10^6}{s + 250 \cdot 10^6}$$

midband	
3dB calculated	
3dB measured	
ω_{L3dB}	150 Hz
ω_{H3dB}	8.025 MHz

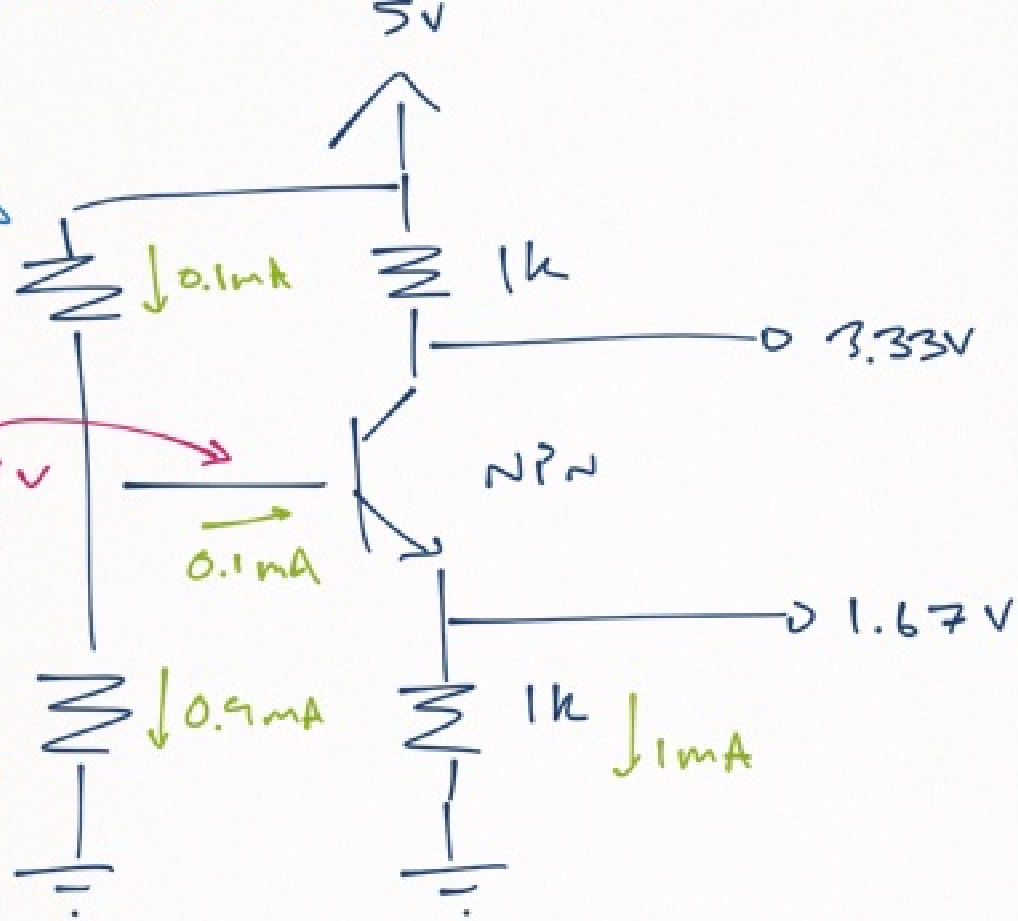
$$\omega_{L3dB} = \sqrt{\omega_p^2 + \omega_p^2}$$

$$= \sqrt{151.6^2 + \quad}$$

BIASING A TRANSISTOR

$26.3k = \frac{5-2.37}{0.1}$

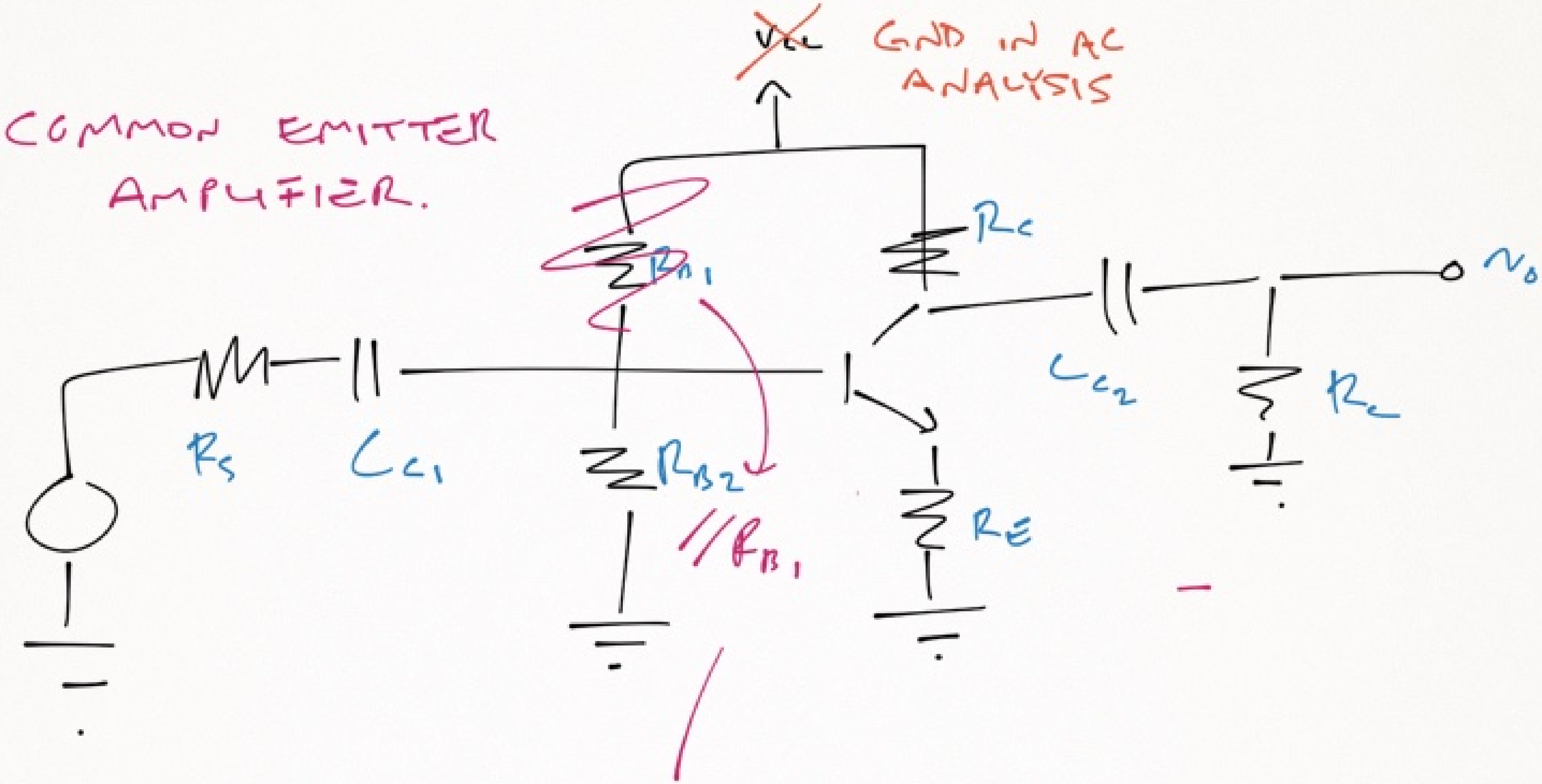
$1.67 + 0.7V$
$= 2.37V$

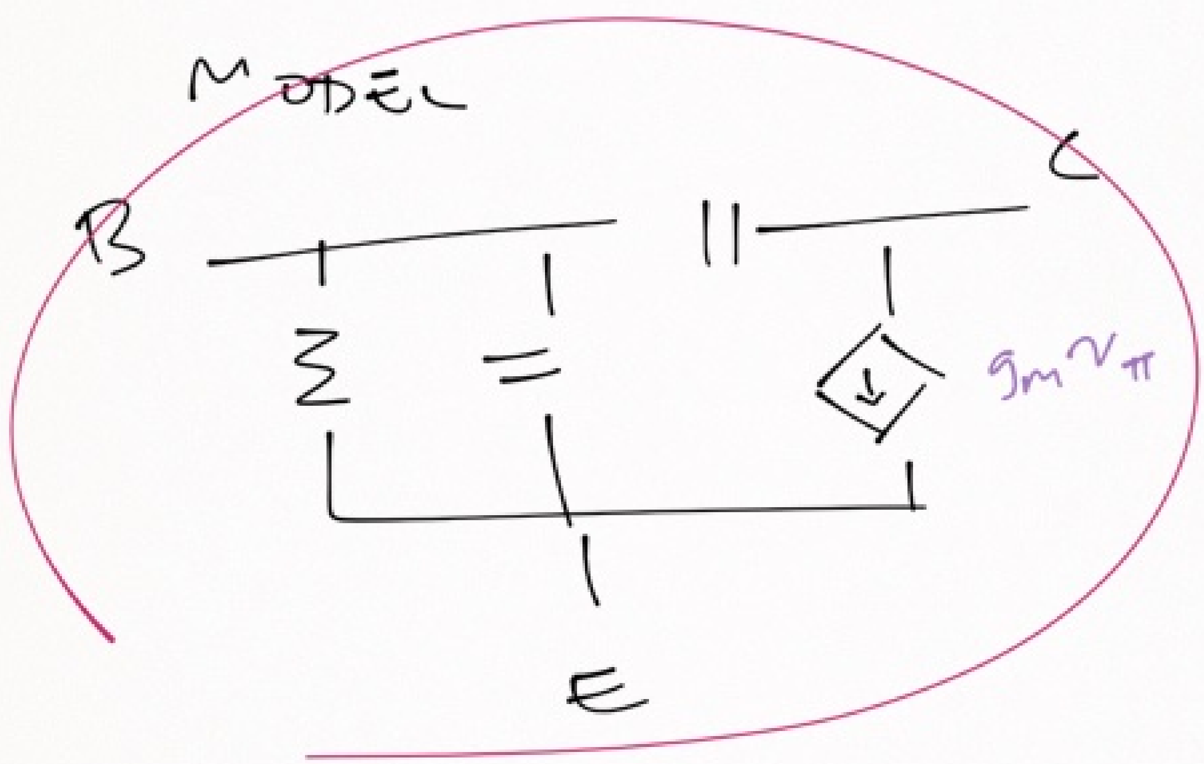


also
26.3K

(voltage isn't
that much higher
b/c we only picked
5V)

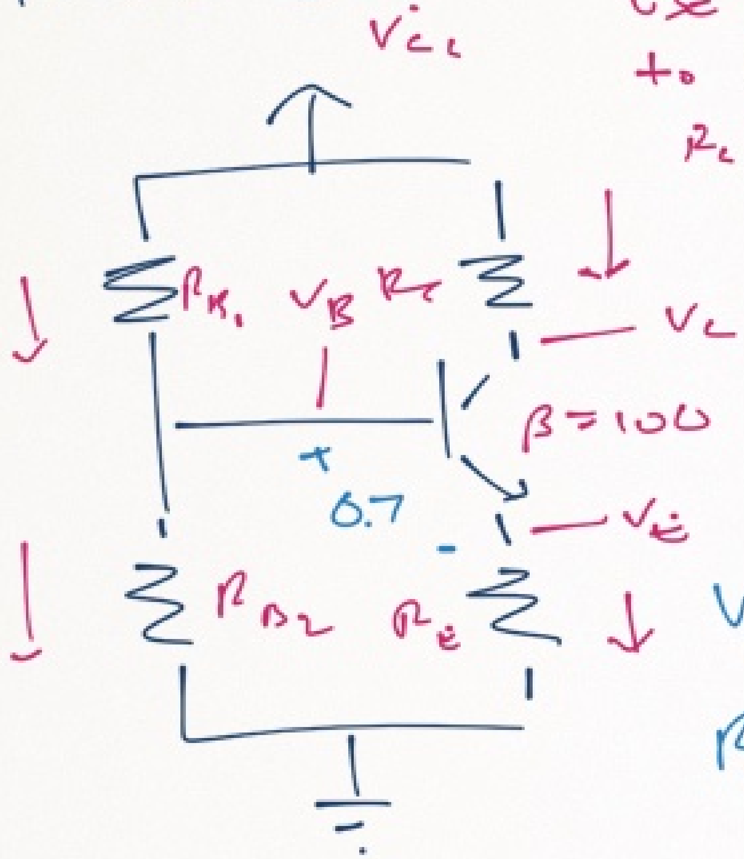
COMMON EMITTER AMPLIFIER.





TURNS INTO P10.4

Problem →



use $\frac{1}{3}$ rule to find R_{B1}, R_{B2}, R_C, R_E, given

$V_{CC} = 15V$

$I_C = 2mA$

$V_E = 4.3V$

$$R_C = \frac{5V}{2mA} = \boxed{2.5k\,\Omega}$$

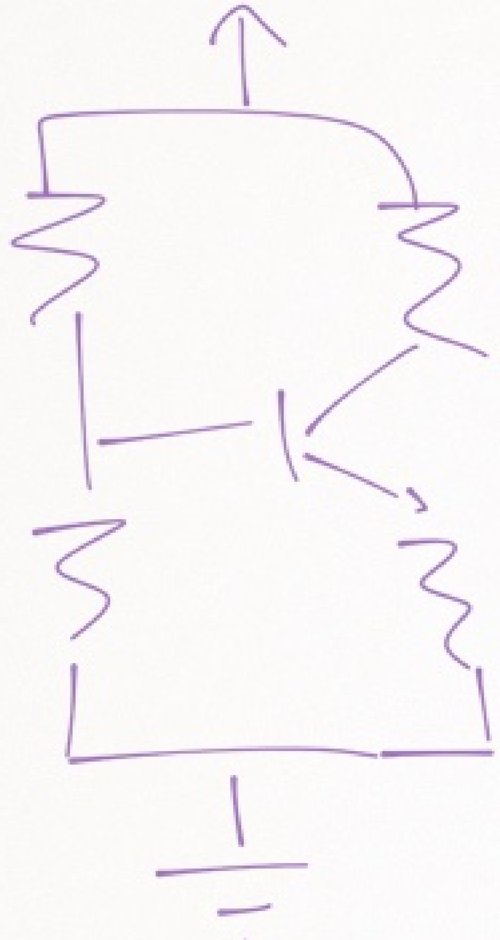
$$R_E = \frac{4.3V}{2mA} = \boxed{2.15k\,\Omega}$$

$V_B = 5V$

$V_C = 10V$

$$R_{B1} = \frac{15-5}{0.2mA} = \boxed{50k\,\Omega}$$

$$R_{B2} = \frac{5V}{0.18mA} = \boxed{27.8k}$$



$R_E = 8k$

$V_{cc} = 12V$

$V_c = 8V$

$I_E \approx I_c$

$V_E = 4V$

$I_E = \frac{4V}{8k} = \boxed{0.5mA}$

$R_{B_1} = \frac{12V - 4.7V}{0.05mA} = \boxed{146k\Omega}$

$R_{B_2} = \frac{4.7V}{0.045mA} = \boxed{104.4k\Omega}$

Oh freddled gruntbuggly
Thy micturations are to me
As plurdled gabblebotchits or a lurgid bee
...

DATASHEET 2N2222A.

$h_{ie} = 2 - 8\ k\Omega$ (input impedance)

$h_{oe} = 5 - 35\ \mu S$ (output admittance)

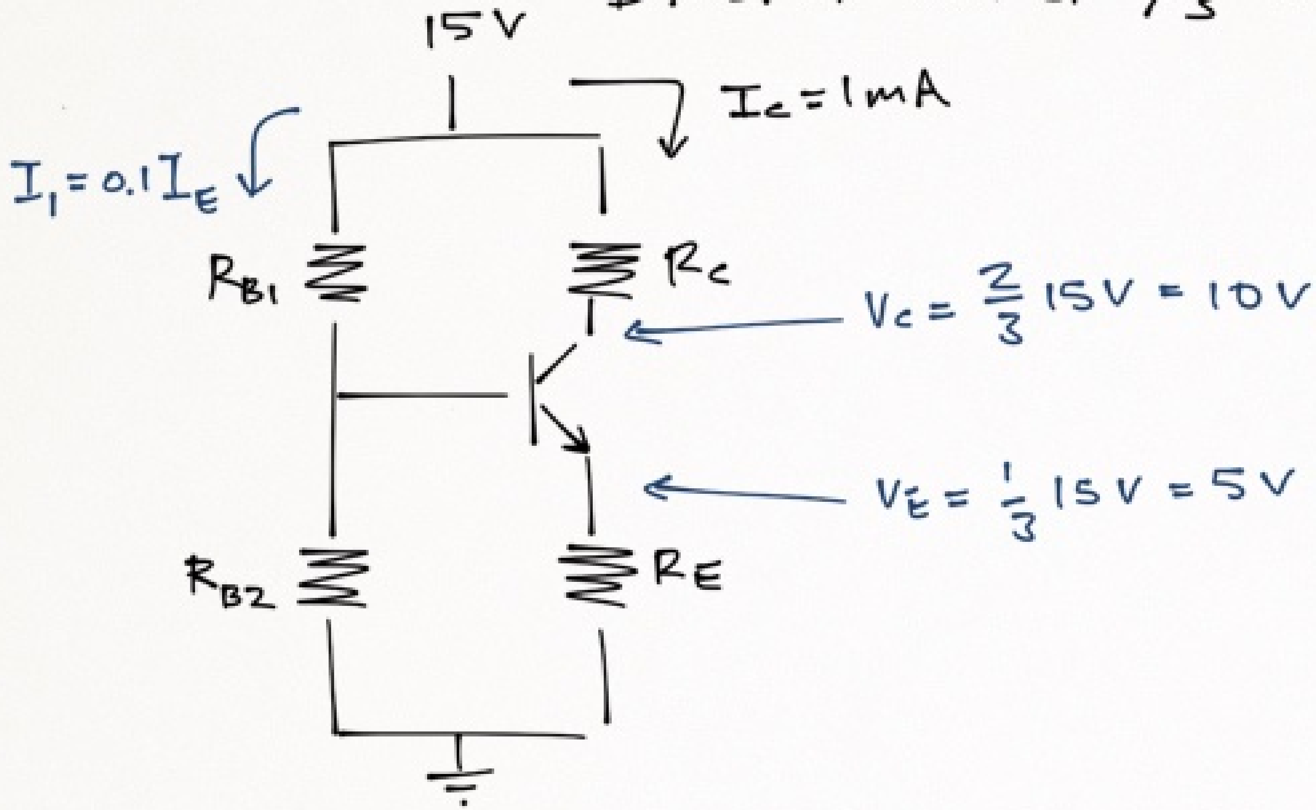
$V_{CE} = 10V$

$I_C = 1mA$

$f = 1kHz$

$T = 25°C$

BIASING USING 1/3 RULE APPROXIMATIONS



$$R_c = \frac{1}{3}\frac{V_{cc}}{I_c} = \frac{1}{3}\frac{15}{1\cdot 10^{-3}} = \boxed{5k\Omega}$$

$$R_E \simeq R_c = \boxed{5k\Omega}$$

$$R_{B1} = \frac{\frac{2}{3}V_{cc} - 0.7V}{0.1 I_E} = \boxed{93\ k\Omega}$$

$$R_{B2} \simeq \frac{\frac{1}{3}V_{cc} + 0.7V}{0.1 I_E} = \boxed{57k\Omega}$$

$V_{CE} = 5V$

$I_c = 1mA$

$$I_E = \frac{V_E}{R_E} = \frac{5V}{5k\Omega} = 1mA$$

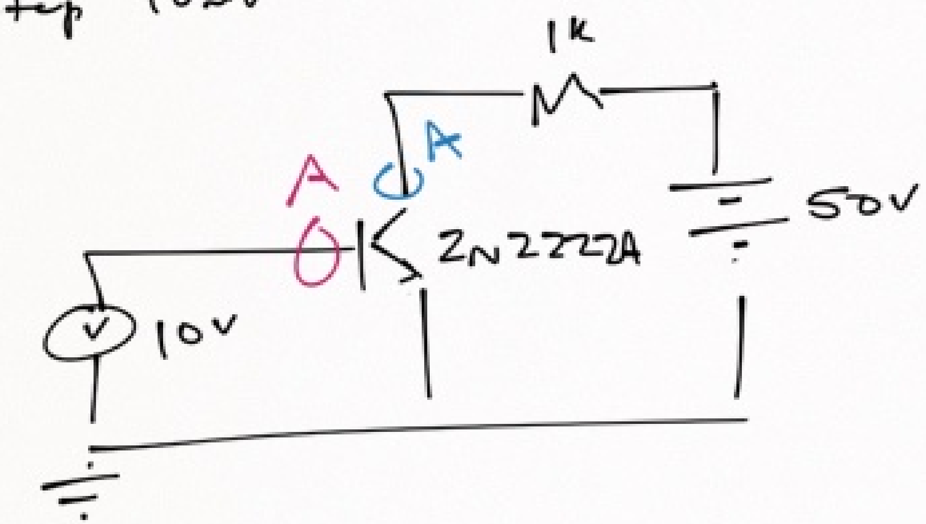
Source name

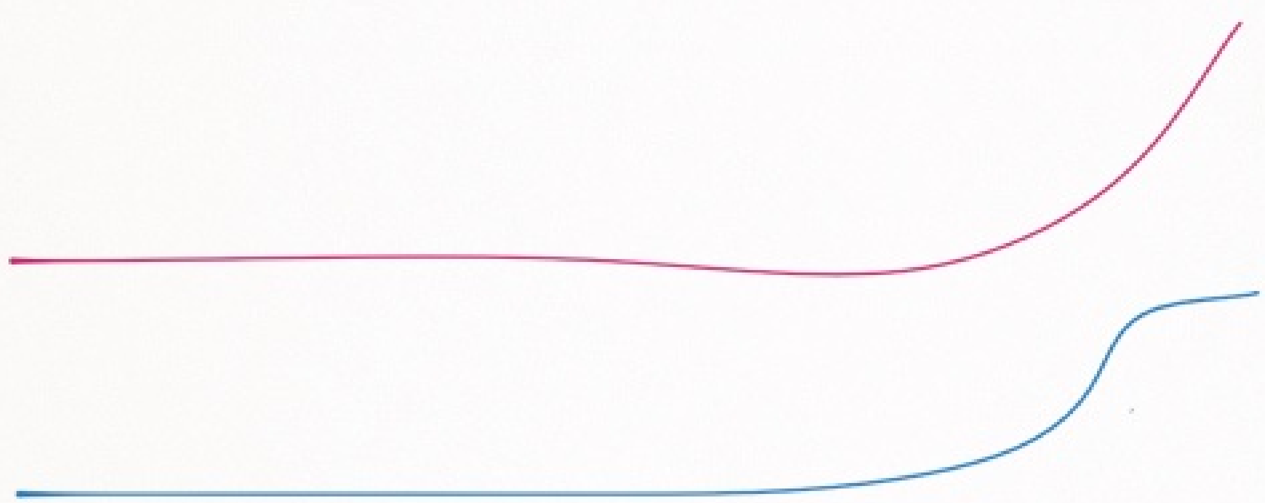
vs1

start sweep 0

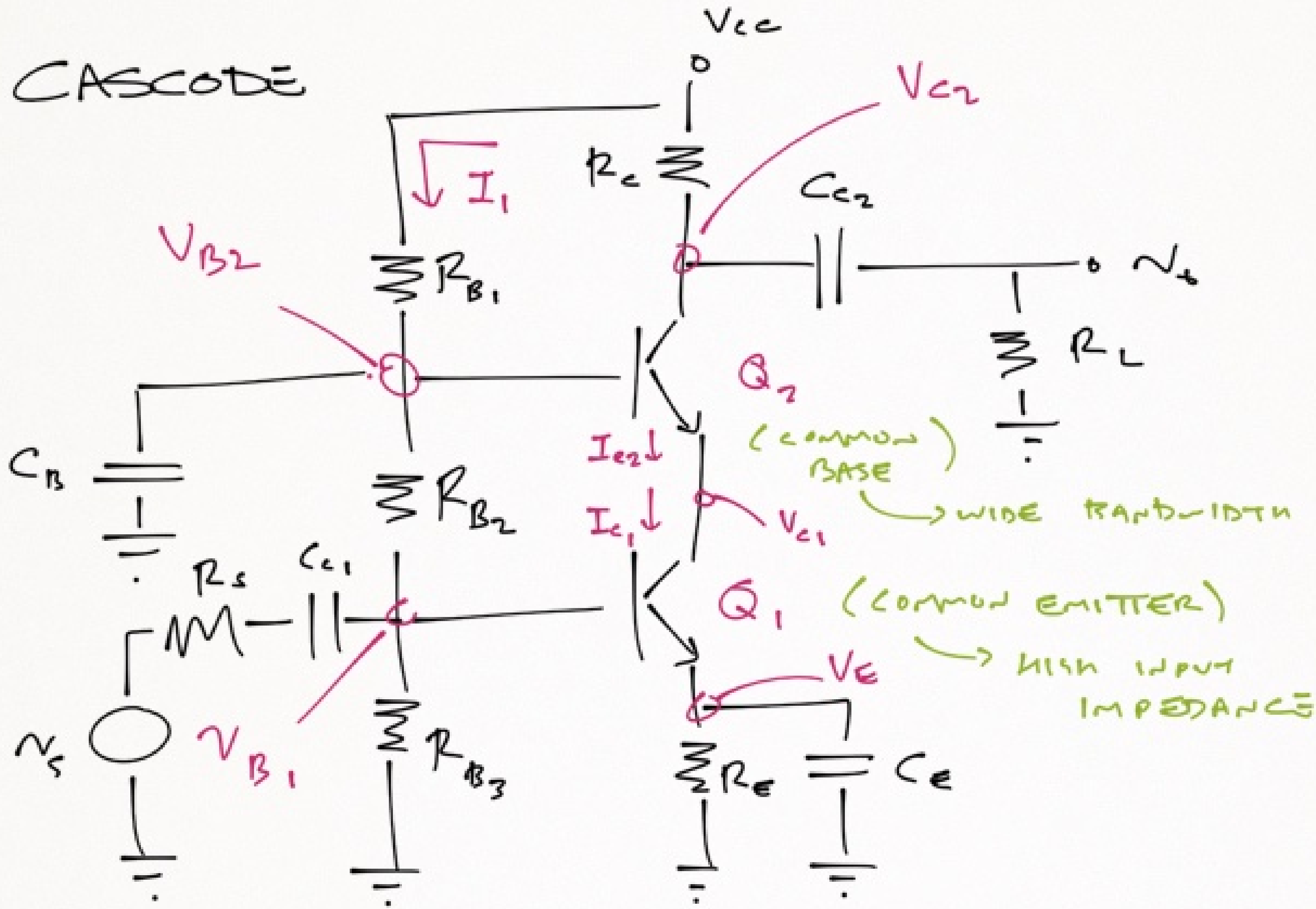
stop 750mV

step 10mV





CASCODE



PICK A BIG C_B → shoves pole to low freq.

USE $\frac{1}{4}$ RULE TO BIAS CASCODE, . DROP ACROSS EACH

$V_{C2} = \frac{3}{4} V_{CC}$, $V_{C1} = \frac{1}{2} V_{CC}$, $V_E = \frac{1}{4} V_{CC}$

$V_{B2} = \frac{1}{2} V_{CC} + V_{BE}$, $V_{B1} = \frac{1}{4} V_{CC} + V_{BE}$

$I_1 = 0.1 I_E$

@ MIDBAND

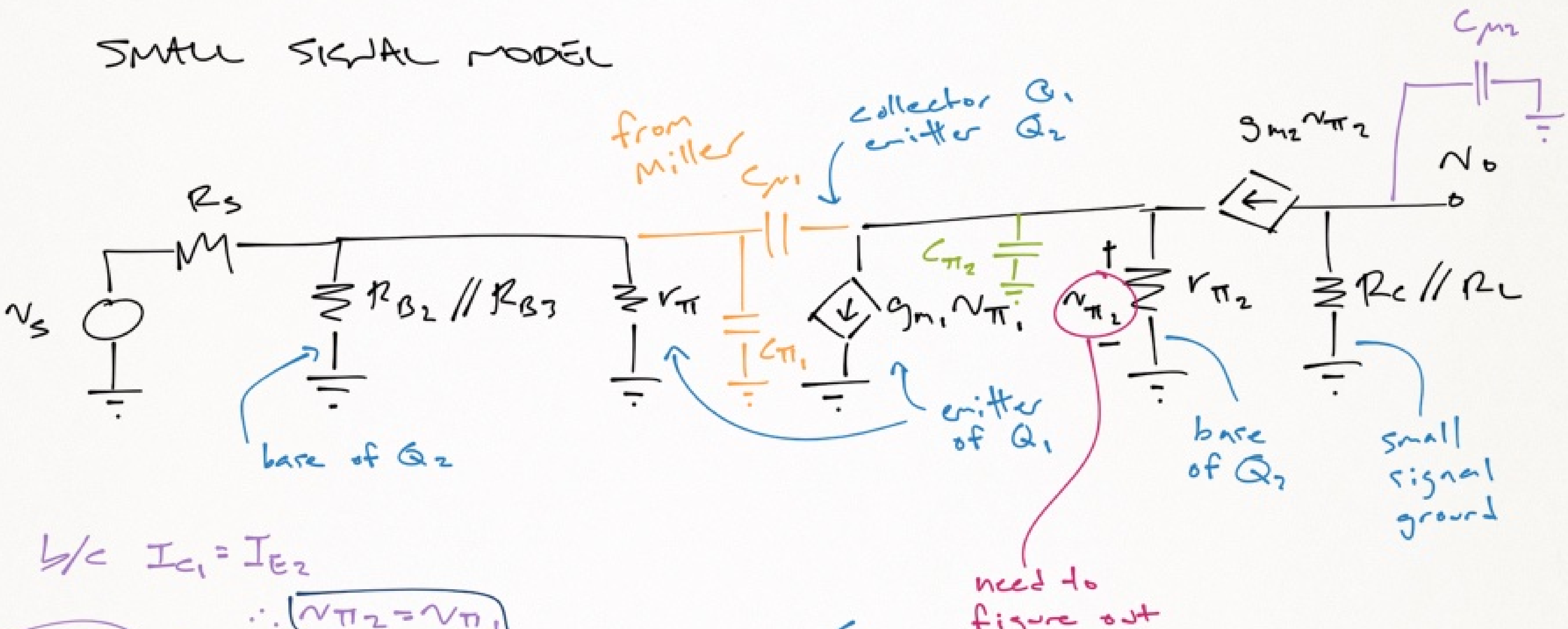
V_C @ MIDBAND

THERE TO ESTABLISH BIAS

C_{C1} IS S.C.

C_E SHORTED TO GND

SMALL SIGNAL MODEL



b/c $I_{C1} = I_{E2}$

$\therefore \boxed{v_{\pi 2} = v_{\pi 1}}$

$I_{C1} v_{\pi 1} = v_{\pi 2} I_{E2}$

$$\frac{v_{\pi 1}\beta_1}{\cancel{V_T}} v_{\pi 1} = v_{\pi 2} I_{B2} \frac{1+\beta}{\cancel{V_T}}$$

$$I_{C1}\frac{\cancel{\beta_1}}{\cancel{\beta_1}} v_{\pi 1} = v_{\pi 2} I_{C2}\left(\frac{1+\beta_2}{\beta_2}\right)$$

$$= v_{\pi 2}\frac{I_{C2}}{\alpha_2}$$

sum currents:

$$g_{m1} v_{\pi 1} = \frac{v_{\pi 2}}{r_{\pi 2}} + g_{m2} v_{\pi 2}$$

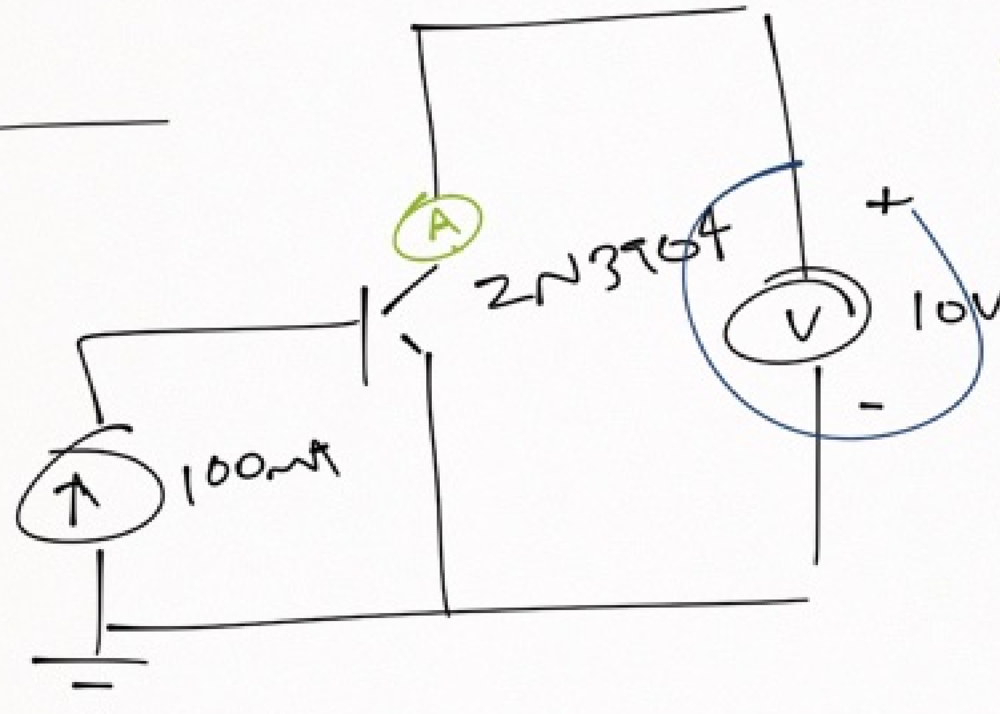
$$v_{\pi 1}\frac{\beta_1}{r_{\pi 1}} = v_{\pi 2}\left(\frac{1+\beta}{r_{\pi 2}}\right)$$

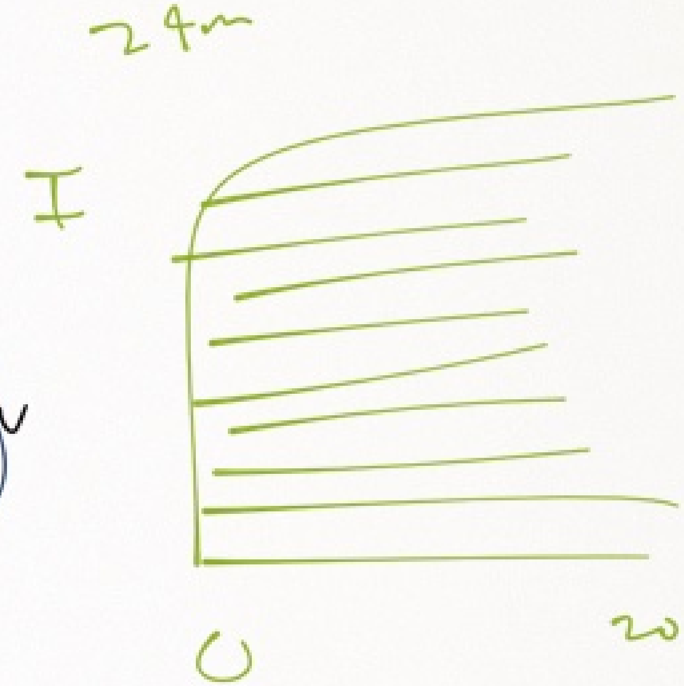
$g_m = \beta / r_\pi$ $\quad r_\pi = \frac{V_T}{I_B}$

$$\omega_{mp3} = \frac{1}{C_{\mu_2} \underbrace{R_C \,//\, R_L}_{\simeq r_{o2} // R_C // R_L}}$$

$$\omega_{mp2} = \frac{1}{(C_{\pi_2} + 2C_{\mu_1}) \frac{r_{\pi_2}}{1+\beta}} \quad \left(\simeq ? \; \frac{1}{(C_{\pi 2} + 2C_{\mu 1})(r_{e2} // r_{o1})} \right.$$

$$\omega_{mp1} = \frac{1}{(R_S // R_{B2} // R_{B1} // r_\pi)(C_{\pi_1} + 2C_{\mu_1})}$$





Vs1

0 → 20

step 10m

DC
ANALYSIS
SETUP

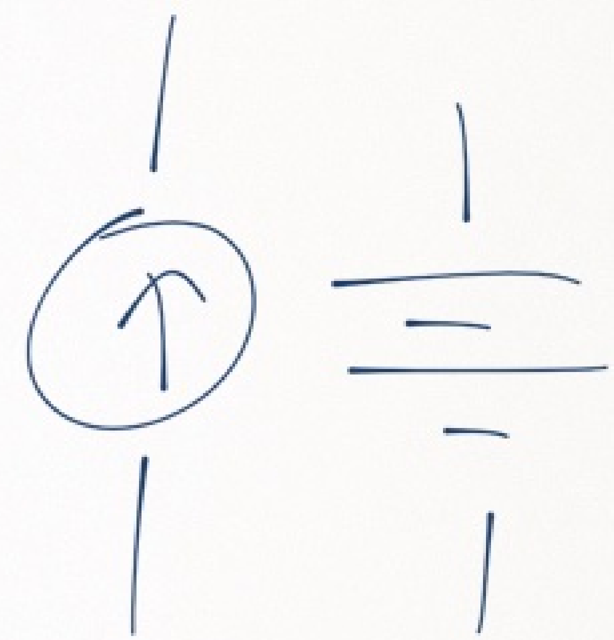
Is1

20

0 → ~~200~~µ

~~10~~µ step

1



b) transconductance, $g_m = \left.\frac{\delta i_c}{\delta v_{BE}}\right|_{i_c = 1mA}$

$I_c = 1mA$ $\quad r_\pi, \beta, r_o$ UNKNOWN

$V_{CE} = 5V$

$V_T = 25.8mV$

$$r_\pi = \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \beta \frac{V_T}{I_c} = \frac{\beta}{\beta}\frac{V_T}{I_B}$$

$$\beta = \frac{i_c}{i_B}$$

i_c ← instantaneous value

i_B ← DC value

$$r_o = \left[\left.\frac{\delta}{\delta v_{CE}} i_c \right|_{v_{BE} = \text{constant}}\right]^{-1} \simeq \frac{V_A}{I_C}$$

$$m = \frac{(3.850 - 3.568)\,mA}{(11.1 - 2.265)\,V} = 0.031919 \frac{mA}{V}$$

$$y = mx + b \longrightarrow b = 3.496mA$$

$$-V_A = x = \frac{-3.496\,mA}{0.031919\,\frac{mA}{V}} = -109.5V$$

$$r_o \simeq \frac{V_A}{I_C} = \frac{109.5\,V}{1mA} = \boxed{109.5\,k\Omega}$$

$$\beta = \frac{I_C}{I_B} = \frac{1mA}{5.986\mu A} = \boxed{167.1}$$

$$r_\pi = \beta \frac{V_T}{I_C} = 167.1 \frac{25.2mV}{1mA} = \boxed{4.21k\Omega}$$

2N2222A:

calculated $h_{ie} = r_\pi = 4.21k\Omega$
datasheet $h_{ie} = 2-8k\Omega$
THESE AGREE

calculated $h_{oe} = \frac{1}{r_o} = \frac{1}{109.5k\Omega} = 9.132\mu S$
datasheet $h_{oe} = 5-35\mu S$
THESE AGREE

calculated $h_{fe} = \beta = 167.1$
datasheet $h_{fe} = 50-300$
THESE ALSO AGREE

$$I_B = \frac{I_C}{\beta} = \frac{1mA}{167.1} \simeq 6.0\mu \neq i_b$$

$$v_{be} = r_\pi i_b$$

$$i_c = I_C + \frac{I_C}{V_T} \cdot v_{be}$$

$$I_B = \frac{I_C}{\beta} = \frac{I_S}{\beta} e^{\frac{V_{BE}}{V_T}}$$

iv)

(1) FINDING DC-OPERATING POINT OF TRANSISTOR ($\frac{1}{3}$ BIAS VERSION)

$$V_B = V_{cc}\left(\frac{R_{B2}}{R_{B1}+R_{B2}}\right) = 15V\cdot\left(\frac{57k\Omega}{93k\Omega+57k\Omega}\right) = 5.7V$$

$$R_{B_T} = R_{B_1} \,//\, R_{B2} = 35.3K\,\Omega$$

$$I_Q = \frac{V_B - V_{BE}}{\frac{R_{B_T}}{\beta+1}+R_E} = \frac{5.7V - 0.7V}{\frac{35.3k}{167.1+1}+5k} = 960\mu A$$

$$V_Q = V_{cc} - I_Q(R_c+R_E) = 15v - 960\mu A(5k\Omega+5k\Omega) = 5.40V$$

$$\boxed{\text{Q-POINT} = (V_Q, I_Q) = (5.40V, 0.960mA)}$$

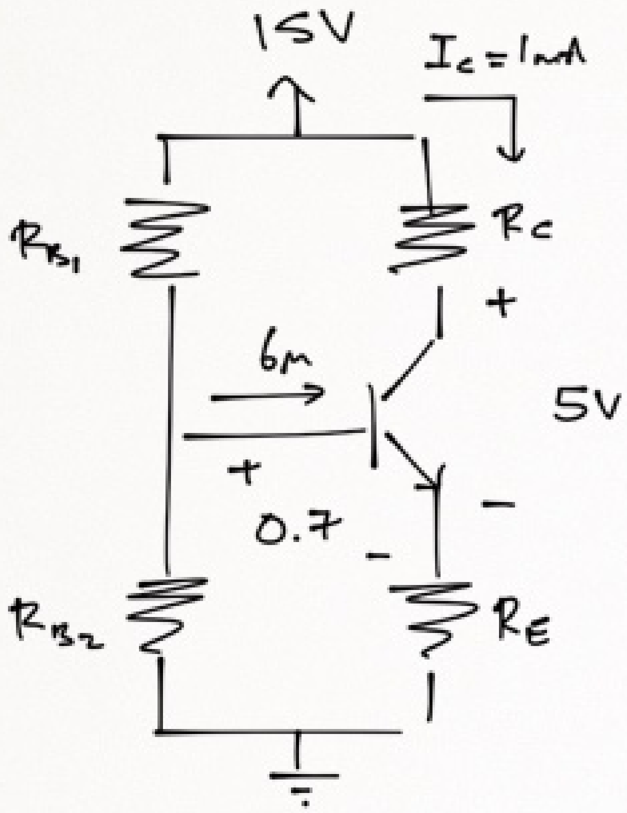
(2) FINDING DC-OPERATING POINT FROM APPROXIMATE RESISTANCES

$$V_B = V_{cc}\left(\frac{R_{B2}}{R_{B1}+R_{B2}}\right) = 15V\left(\frac{56k}{91k+56k}\right) = 5.71V$$

$$V_E = 5.71V - 0.7V = 5.01\ V$$

$$I_Q = \frac{V_E}{R_E} = \frac{5.01V}{5.1k\Omega} = \underline{983}\mu A,\quad V_Q \simeq V_{cc} - V_E - I_Q\cdot R_c = 15 - 5.01 - 983\mu\cdot 5.1k = 4.98V$$

$$\boxed{\text{Q-POINT} = (4.98V, 0.983mA)}$$



BIASING USING r_π, r_o, & β

$$I_B = \frac{I_c}{\beta} = \frac{1mA}{167.1} = 6\mu A$$

ASSUMPTIONS:

① $V_B = V_E + 0.7$

The voltage drop across R_c is approximately equal to R_e and current through R_c is approximately equal to current through R_e.

$\therefore$ safe assumption to chose

② $R_c = R_e$

INSTEAD OF THIS ASSUMPTION MAYBE JUST PICK AN R

$$\frac{15 - V_c}{R_c} = 1mA$$

$$\frac{V_E}{R_E} = 1mA + 6\mu A$$

$$R_c = R_E$$

$$V_B = V_E + 0.7$$

$$V_c = V_E + 5V$$

LINEAR ALGEBRA $\longrightarrow$

$R_c = 4.99k\Omega$

$V_c = 10V$

$V_E = 5.01V$

$V_B = 5.71V$

$$\underbrace{\frac{15V - 5.71V}{R_{B_1}}}_{I_{B_1}} = 6\mu + \underbrace{\frac{5.71}{R_{B_2}}}_{I_{B_2}}$$

$$I_{B_1} = \frac{I_c}{\sqrt{\beta}} = \frac{1mA}{\sqrt{167.1}} = 77.4\mu A$$

$$\boxed{\begin{array}{ll} R_c = 4.99k\Omega & R_{B_1} = 120k\Omega \\ R_e = 4.99k\Omega & R_{B_2} = 80k\Omega \end{array}}$$

③ DC-OPERATING POINT FROM MEASURED VALUES

$$V_B = 15\,\frac{80k}{80k + 120k} = 6V$$

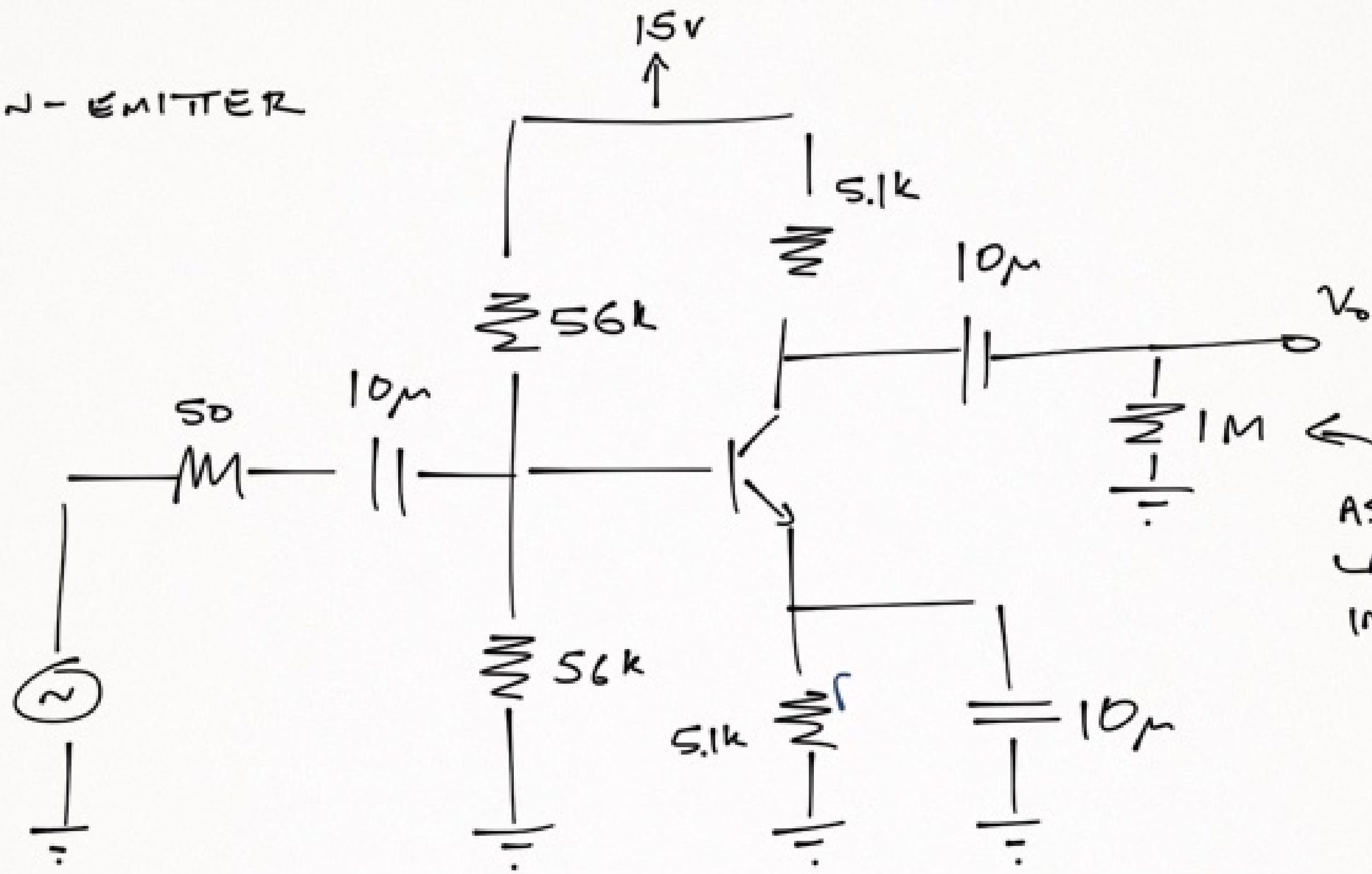
$$R_{B_T} = 80k \,//\, 120k = 48k$$

$$I_Q = \frac{5.71 - 0.7}{\frac{48k}{167.1+1} + 4.99k} = 950\mu A$$

$$V_Q = 15V - 950\mu A(4.99k + 4.99k) = 5.52V$$

$$\text{Q-POINT} = (5.52V,\ 0.950\,mA)$$

COMMON-EMITTER



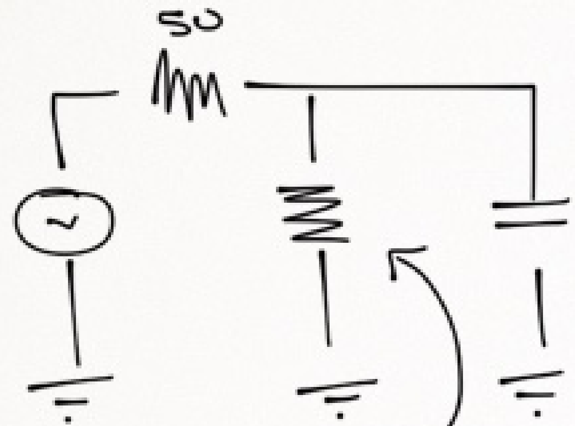
ASSUMING LARGE LOAD IMPEDANCE

FROM DATASHEET: $C_\mu = C_{CB} = 8\,pf$, $C_\pi = C_{EB} = 25\,pf$

REVISIT. USE CALC. FROM BOOK

P10.4

HIGH FREQ. MODEL



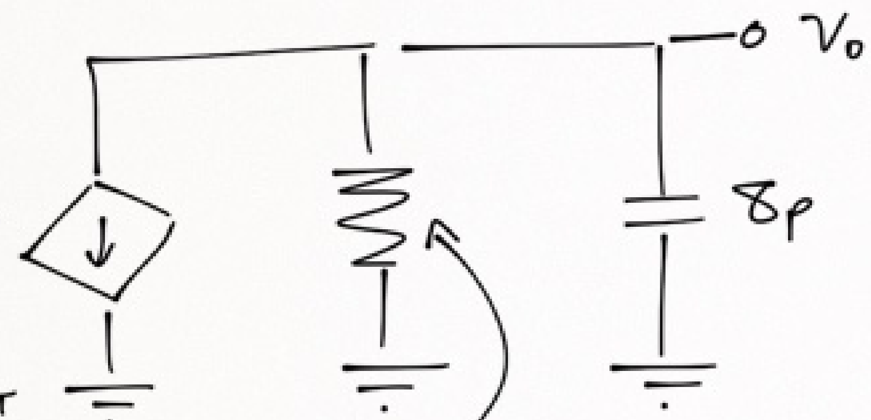
NOTE: WE ARE ASSUMING A VERY LARGE LOAD IMPEDANCE, 1M

$$C_\pi + C_\mu(1 + g_m R_L \| R_C) = 25p + 8p\left(1 + \frac{167.1}{4.21k} 5.1k\Omega\right) = 1.65nF$$

$$R_B = r_\pi \| R_{B_1} \| R_{B_2} = 4.21k \| 56k \| 91k = 3.75k\Omega$$

$$\omega_{Hp1} = \frac{1}{1.65n(R_S \| R_B)} = \frac{1}{1.65n(50 \| 3.75k)} = 12.3M\,\frac{rad}{s} = \boxed{1.95MHz}$$

POLE



$$g_m v_\pi = \frac{\beta}{r_\pi} v_\pi = \frac{167.1}{4.21k} v_\pi$$

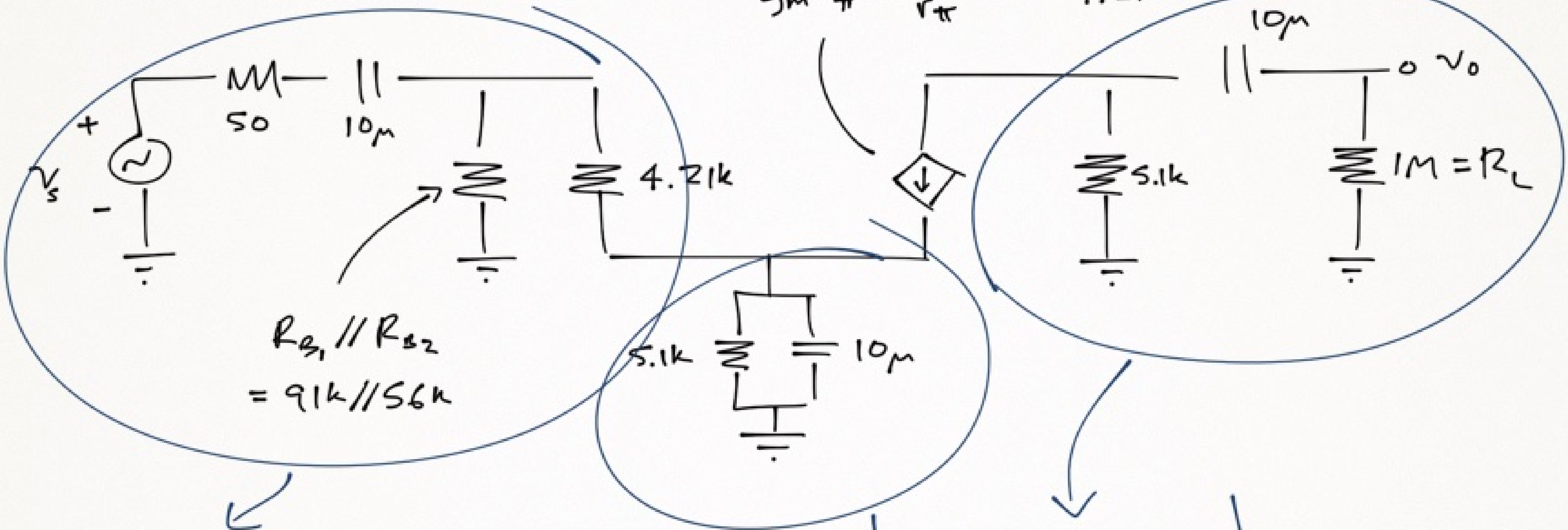
$$R_L \| R_C = 5.1k \| 1M = 5.07\mu F$$

$$\omega_{Hp2} = \frac{1}{R_L \| R_C \cdot C_\mu} = \frac{1}{1M \| 5.1k \cdot 8p} = 24.6M\,\frac{rad}{s} = \boxed{3.92MHz}$$

POLE

LOW FREQ. MODEL

$$g_m v_\pi = \frac{\beta}{r_\pi} v_\pi = \frac{167.1}{4.21k} v_\pi$$



$$w_{p2_L} = \frac{1}{R_s + R_{BB} // (r_\pi + (1+\beta)R_E)] C_{C_1}}$$

$$= \frac{1}{50 + (56k // 91k) // (4.21k + 168.1 \cdot 5.1k)] 10\mu}$$

$$= 3 \frac{rad}{s} = \boxed{477 \, mHz} \leftarrow \text{POLE}$$

$$w_{p3_L} = \frac{1}{\left(R_E // \frac{r_\pi + R_{BB} // R_s}{1+\beta}\right) C_E} = 3.97k \frac{rad}{s}$$

$$= \boxed{631 \, Hz} \leftarrow \text{POLE}$$

$$w_{LP_2} = \frac{1}{10\mu(5.1k + 1M)}$$

$$= 100m \frac{rad}{s} = \boxed{15.8 \, mHz}$$

POLE

$$w_{z_{1L}} = w_{z_{2L}} = \emptyset$$

$$w_{z_{3L}} = \frac{1}{R_E C_E} = \frac{1}{5.1k \cdot 10\mu}$$

$$= 19.6 \frac{rad}{s} = \boxed{3.12 \, Hz}$$

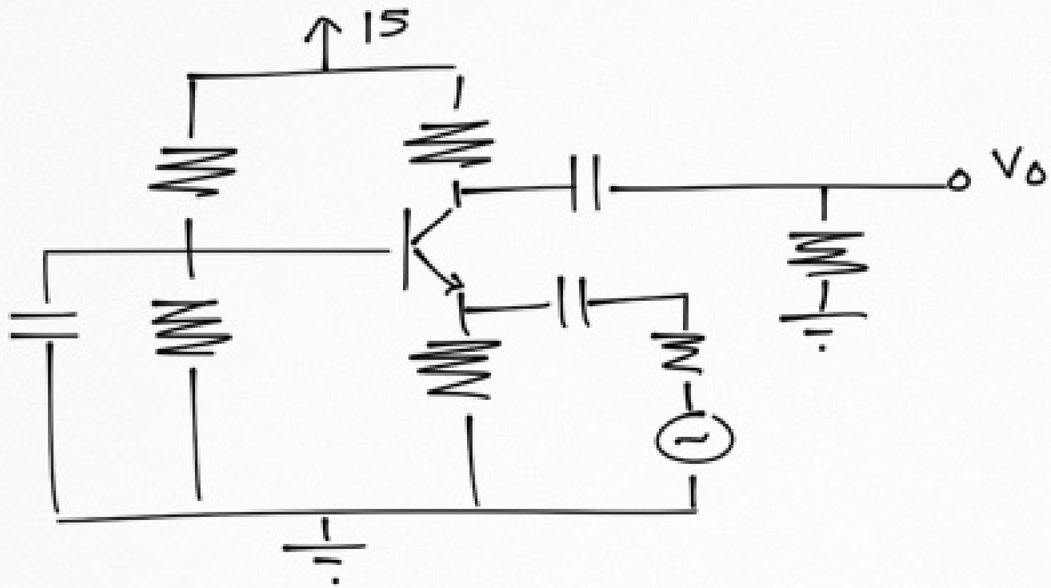
ZERO

INPUT IMPEDANCE MEASURED FROM WAVE FUNCTIONS

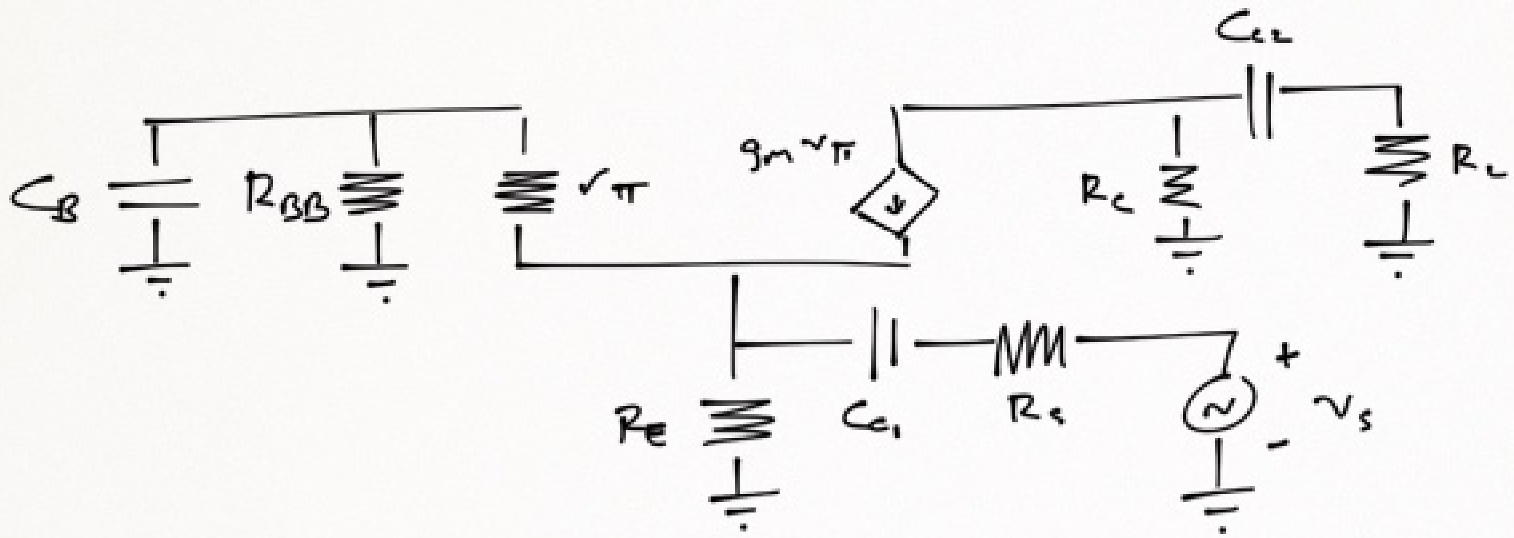
$$Z_{in} = \frac{V_{cc1}}{I_{cc1}} = \frac{986.7\mu V}{333.3nA} = \boxed{2.96k\Omega}$$

INPUT IMPEDANCE CALCULATED

$$Z_{in} = r_\pi // R_{BB} = r_\pi // R_{B1} // R_{B2} = \boxed{3.76k\Omega}$$


15
Vo

LOW FREQ. SMALL-SIGNAL MODEL



$$\omega_{LZ} = \frac{1}{C_B R_{BB}} = \frac{1}{10\mu(91k//56k)} = 2.88\ \frac{rad}{s} = \boxed{459\,mHz}$$

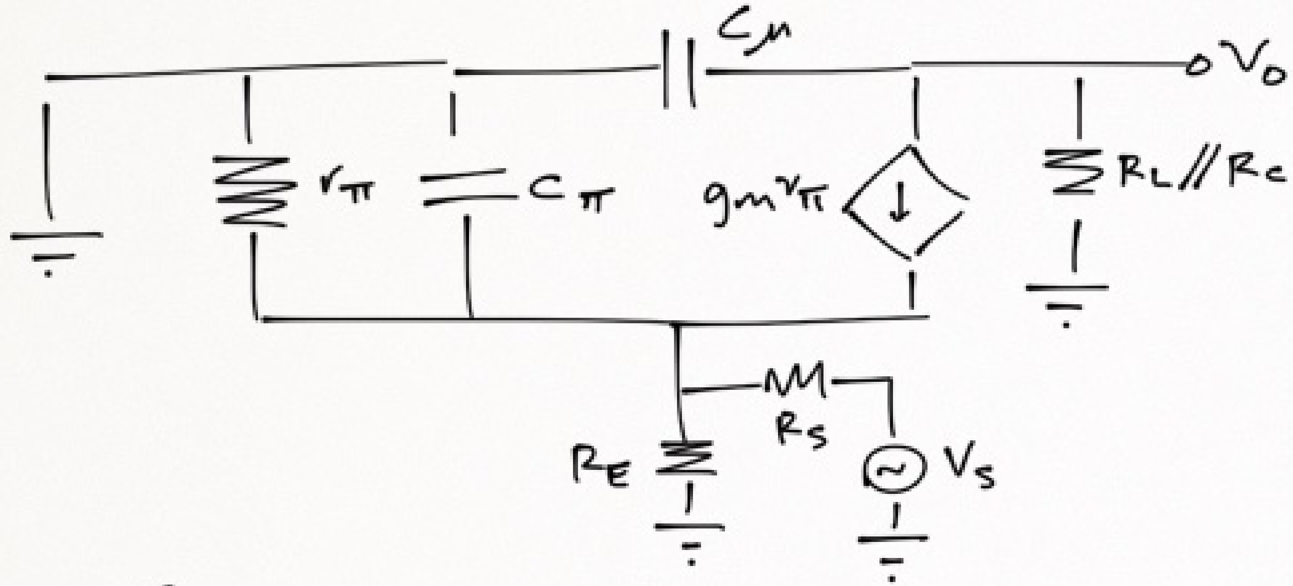
$$\omega_{LP1} = \frac{1}{(R_C+R_L)C_{C2}} = \frac{1}{(5.1k+1M)10\mu} = 99.5m\ \frac{rad}{s} = \boxed{15.8\,mHz}$$

$$\omega_{LP2} = \frac{1}{(R_{BB}//[r_\pi+(1+\beta)(R_E//R_s)])C_B} = \frac{1}{(35.2k//[4.21k+168.1(5.1k//50)])10\mu}$$

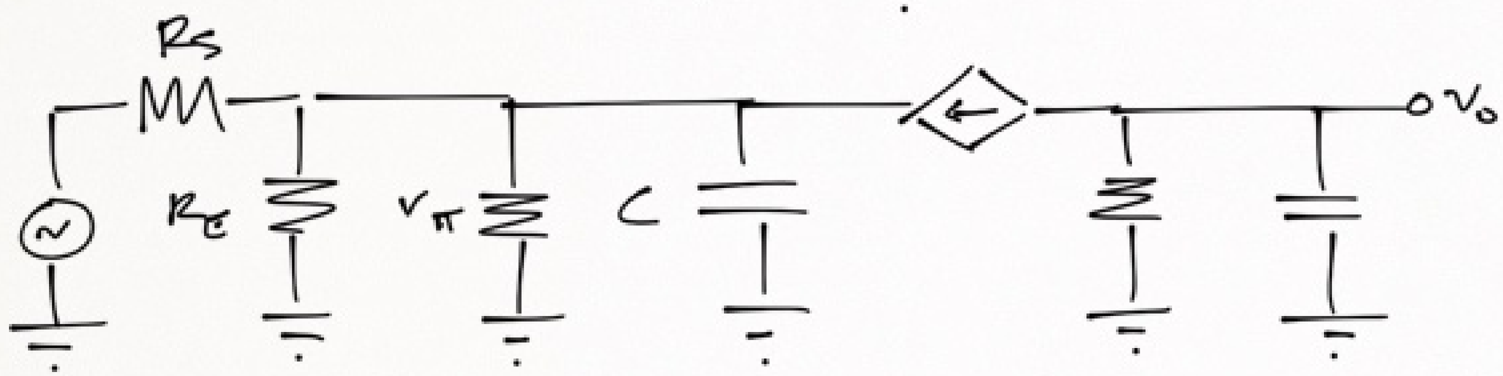
$$= 10.9\ \frac{rad}{s} = \boxed{1.73\,Hz}$$

$$\omega_{LP3} = \frac{1}{\left(\frac{r_\pi}{1+\beta}//R_E+R_s\right)C_{C1}} = \frac{1}{\left(\frac{4.21k}{168.1}//5.1k+50\right)10\mu} = 1.33\ \frac{rad}{s} = \boxed{212\,Hz}$$

HIGH FREQ. SMALL-SIGNAL MODEL



COMMON-BASE AMPLIFER WITH HYBRID MODEL & COUPLING & BYPASS CAPACITORS



CIRCUIT REORGANIZED FOR READABILITY

$$\omega_{PH1} = \frac{1}{\left(R_E // R_S // \frac{r_\pi}{1+\beta}\right) C_\pi} = \frac{1}{\left(5.1k // 50 // \frac{4.21k}{1+167.1}\right) 25pF} = 2.40\,G\,\frac{rad}{s} = \boxed{383 MHz}$$

$$\omega_{PH2} = \frac{1}{(R_L // R_c) C_\mu} = \frac{1}{(1M // 5.1k)\, 8pF} = 24.6\,M\,\frac{rad}{s} = \boxed{3.92 MHz}$$

OCT 20 2014

PROBLEM SET #3

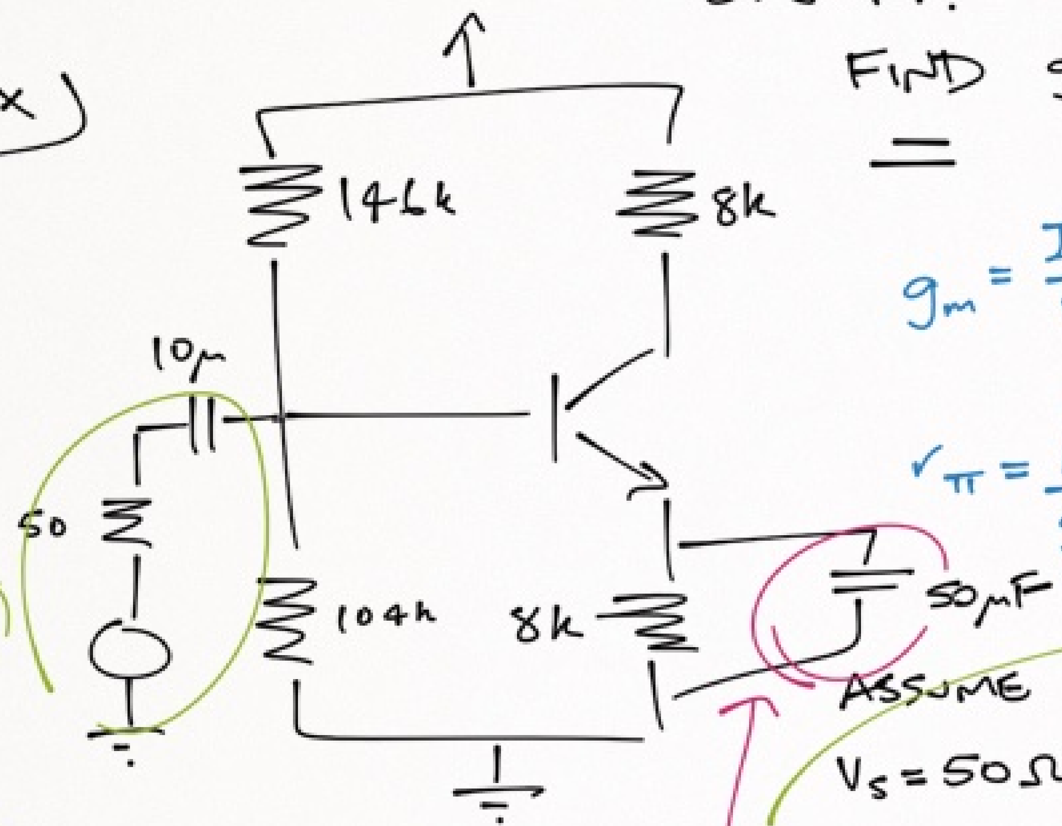
Q.3 + 4.

FIND g_m & r_π

$$g_m = \frac{I_C}{V_T} = \frac{1\,mA}{25.2\,mV}$$

$$r_\pi = \frac{\beta}{g_m}$$

Ex)



ASSUME SMALL-SIGNAL AC VOLTAGE w/ $V_S = 50\Omega$ IS COUPLED TO AMP VIA $10\mu F$ COUPLING CAP.

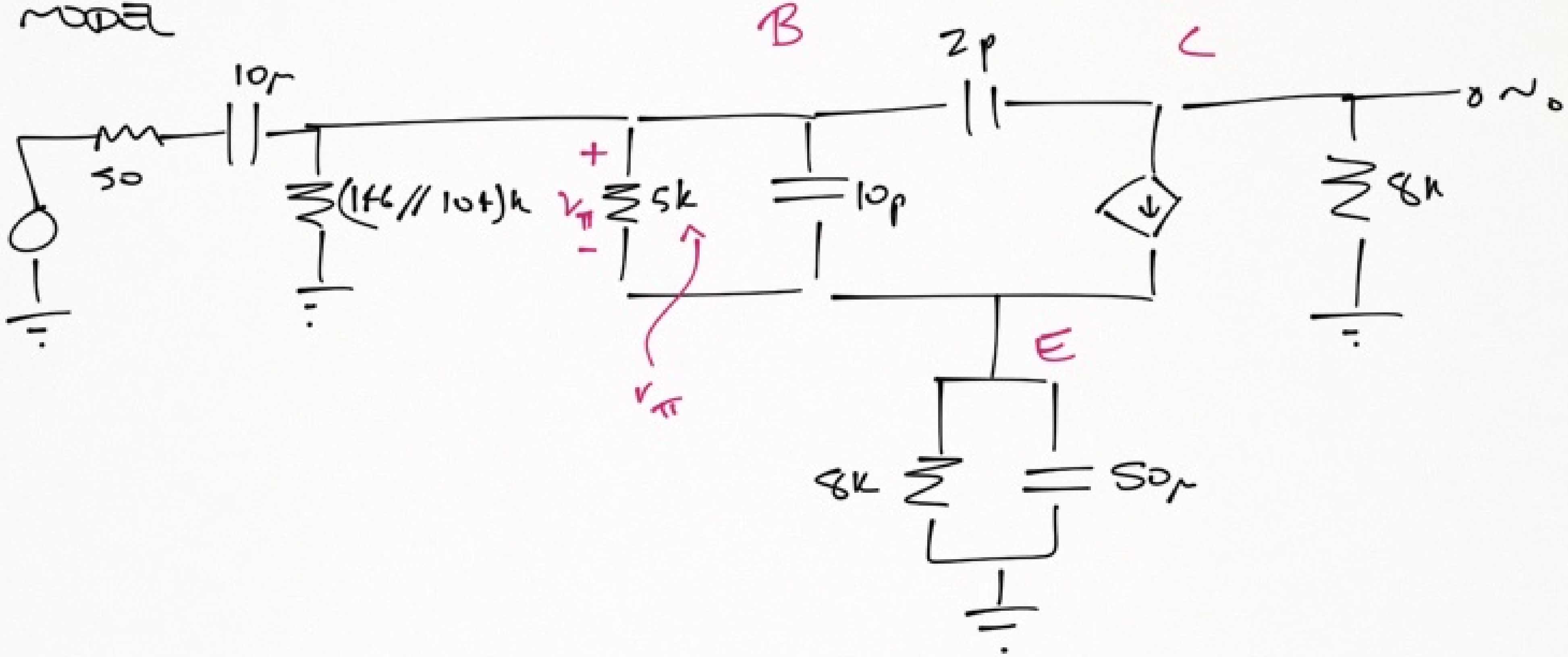
R_E IS BYPASSED USING $50\mu F$ CAPACITOR.

$C_\pi = 10pF$, $C_\mu = 2pF$, $r_o = \infty$

FIND A_m, ω_{3dBL}, ω_{3dBH}.

EX) CONT'D

DRAW MODEL

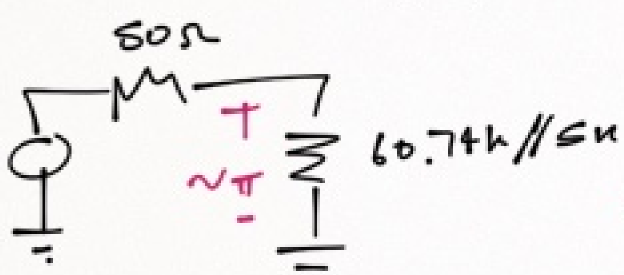


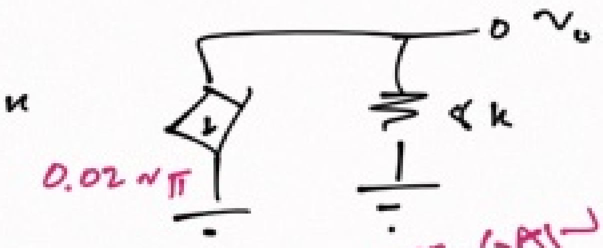
CALC. MIDBAND GAIN FIRST

↳ ALL CAPACITORS GONE:

10μ, 50μ → SHORTS

10p, 2p → OPEN CIRCS.



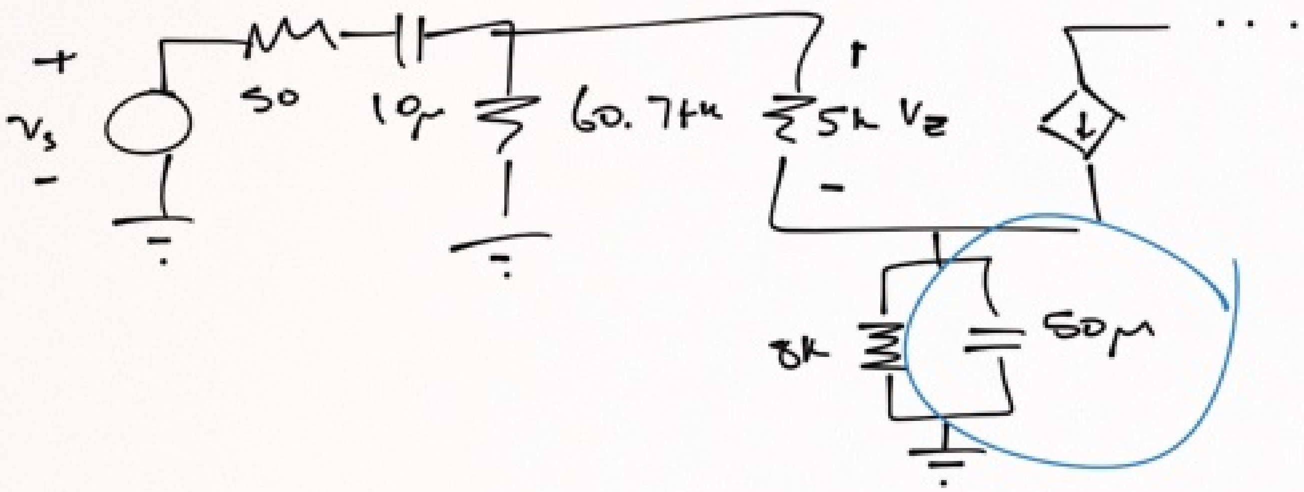


MILLER GAIN $\left(\frac{v_o}{v_\pi}\right)$

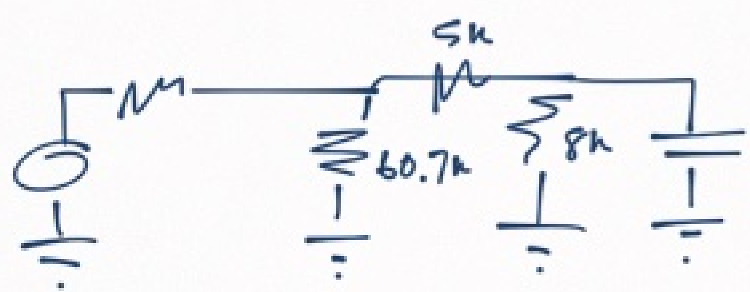
MIDBAND GAIN:

$$A_M = \frac{v_o}{v_\pi} \times \frac{v_\pi}{v_s} = \overline{-160} \cdot 0.99 = \overline{-158}$$

LOW FREQ.



① TRY SHORT-CIRCUIT 10μ ∴ 50μ "SEES" R?



$$R = 8k \,//\, \frac{[5k + 60.7k \,//\, 50\Omega]}{1+\beta}$$

$$\omega_{p1} = \frac{1}{R \cdot 50\mu} \approx \boxed{400 \frac{rad}{s}}$$

IF LOOKING FROM EMITTER TO BASE, EVERYTHING LOOKS $\beta+1$ SMALLER. (i.e. $\overline{\beta+1}$)

BASE TO EMITTER, EVERYTHING LOOKS $\beta+1$ BIGGER i.e. $(\beta+1)\times$

② TRY O.S. 50μ ∴ 10μ "SEES"?

$$R = [60.7 \,//\, (5k + 8k(\beta+1))] + 50 \approx 56.5k\Omega$$

$$\omega_{p2} = \frac{1}{10\mu \cdot 56.8k} \approx \boxed{1.8 \frac{rad}{s}}$$

VERY DIFF & CONSISTENT w/ ASSUMPTIONS

HIGHER f GOES w/ HIGHER CAP.

③ WHAT IF YOU SHORT CE, 50μ? THEN 0.5 CC₁, 10μ

$\omega_L = 21.4 \frac{rad}{s}$,

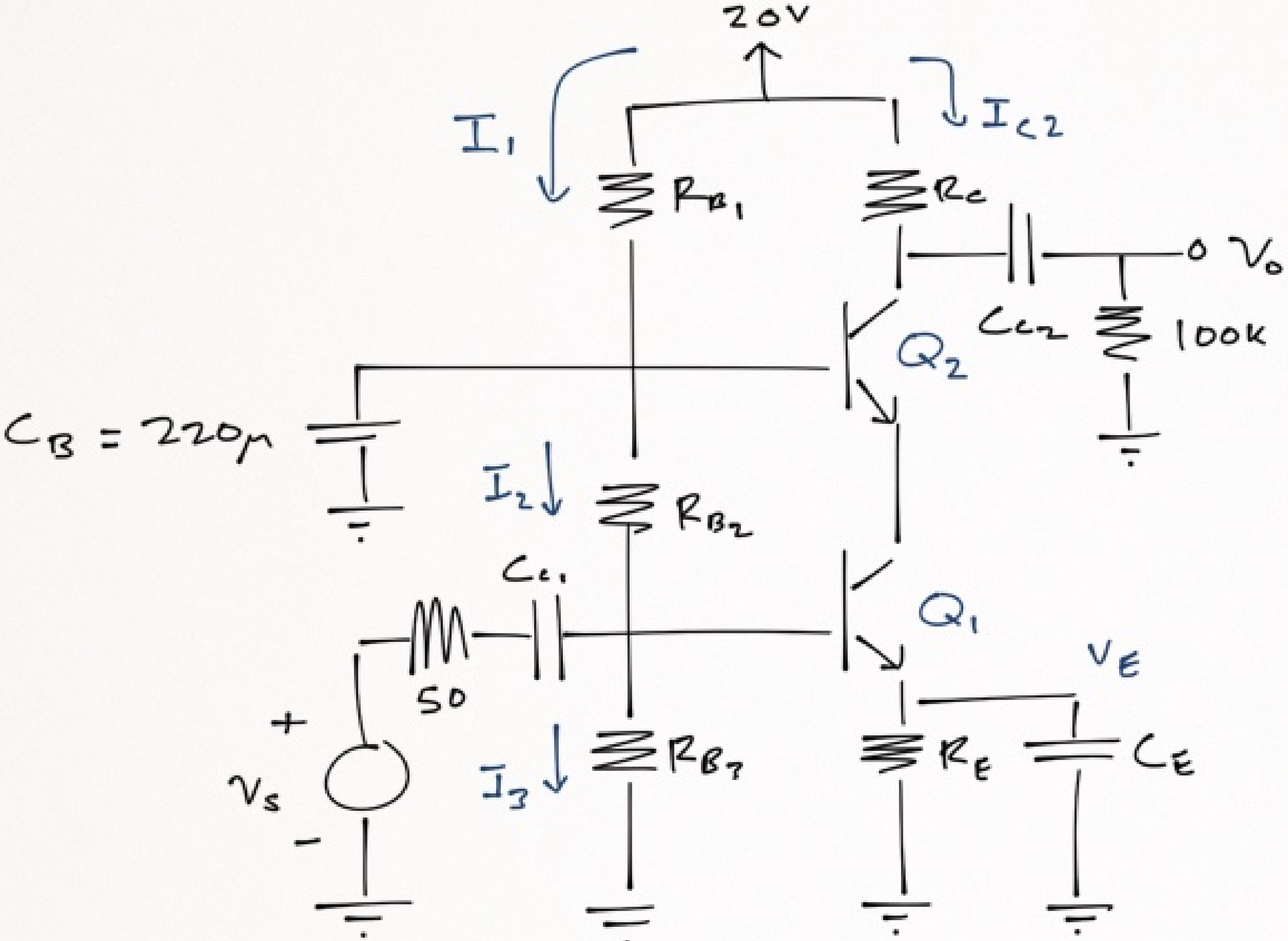
ω_{3dB} is highest freq. pole

$$\tau_{3dB} = \sqrt{\tau_{p1}^2 + \tau_{p2}^2}$$

ASSUME C_1 IS FIRST POLE & CALC. ω

ASSUME C_2 IS FIRST POLE & CALC. ω

WHICHEVER HAS LOWER ω, IS FIRST POLE



GAW = 45dB

ASSUMPTIONS

$R_C \simeq R_E$

$V_{BE_1} = V_{BE_2} = 0.7V$

$I_1 = 0.1 I_E \ , \ \beta = 150$

$V_T = 26mV$

FROM 1/4 RULE

$V_{C_1} = \frac{1}{2} V_{cc} = \boxed{10V} = V_{E_2}$

$V_{C_2} = \frac{3}{4} V_{cc} = \boxed{15V}$

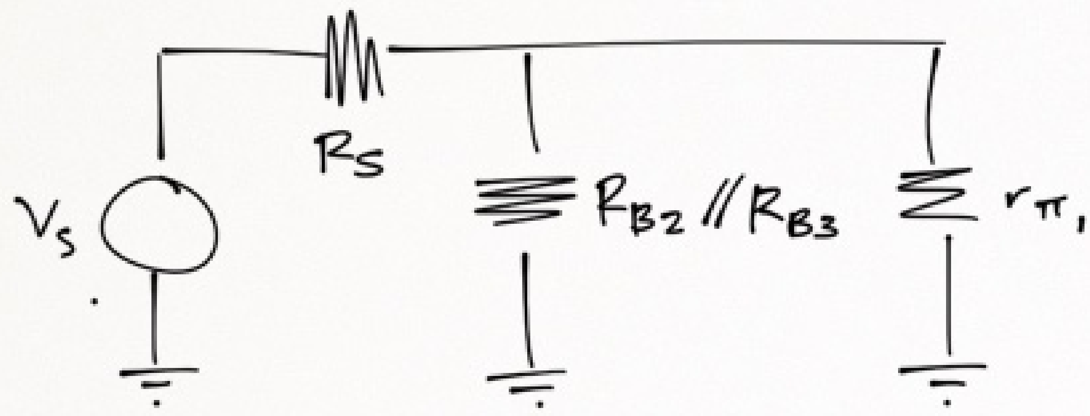
$V_{E_2} = \frac{1}{4} V_{cc} = \boxed{5V}$

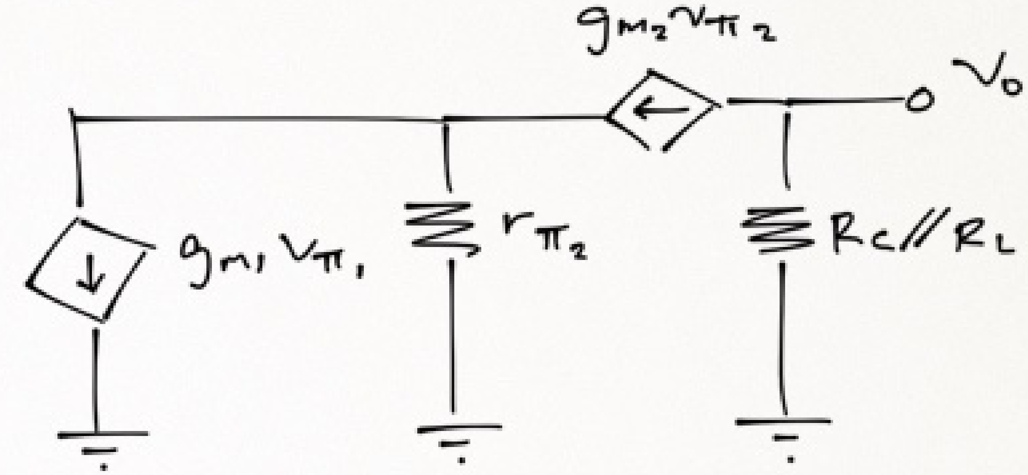
$V_{B_1} = \frac{1}{4} V_{cc} + V_{BE} = \boxed{5.7V}$

$V_{B_2} = \frac{1}{2} V_{cc} + V_{BE} = \boxed{10.7V}$

$I_{E_1} \simeq I_{C_1} \simeq I_{E_2} \simeq I_{C_2}$

AT MIDBAND





$$A_v = \frac{v_o}{v_i} = \frac{v_o}{v_{\pi_1}} \geq -50 \longrightarrow \sim 34\,dB$$

$$v_{\pi_1} = v_{\pi_2}$$

MEASURED INPUT IMPEDANCE @ MIDBAND $= r_{in} = \left.\frac{\text{MEASURED } v_{in}}{\text{MEASURED } i_{in}}\right|_{\substack{V_S = 1mA \\ f = 50kHz}} = \frac{706\mu V}{94.2nA}$

$$\boxed{r_{in_{MEASURED}} = 7.5k\Omega}$$

$$I_{C_2} = \frac{V_{CC} - V_{C2}}{R_C} = \frac{5V}{10k} = 500\mu A \simeq I_{C_1} = I_{E_1} = I_{E_2}$$

$$I_1 = 0.1 \cdot I_E \simeq 0.1\, I_{C_2} = 50\mu A$$

$$R_{B_1} = \frac{V_{CC} - V_{B2}}{I_{B_1}} = \frac{20 - 10.7}{50\mu} = \boxed{186k\Omega}$$

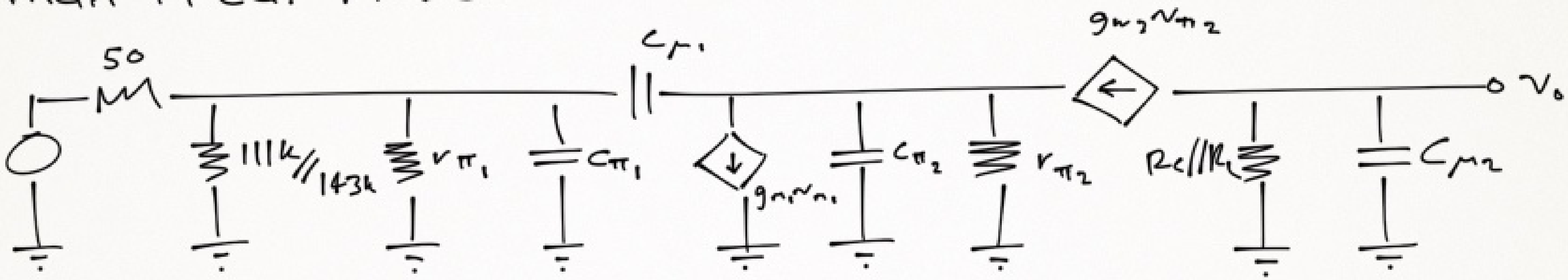
$$I_{B_1} = I_{B_2} = \frac{I_{C1}}{\beta_1} = \frac{I_{C2}}{\beta_2} = \frac{500\mu A}{100} = 5\mu A$$

$$R_{B2} = \frac{V_{B2} - V_{B_1}}{I_1 - I_{B_1}} = \frac{5}{45\mu} = \boxed{111k\Omega}$$

$$R_{B_3} = \frac{V_{B_1}}{I_1 - 2I_{B_1}} = \frac{5.7}{40\mu} = \boxed{143k\Omega}$$

$$R_E = \frac{V_E}{I_{E_2} + 2I_B} = \frac{5}{510\mu} = \boxed{9.8k\Omega}$$

HIGH FREQ. MODEL



$$r_{\pi 1,2\,\text{MEASURED}} = 7.33k\,\Omega$$

$$\omega_{HP1} = \frac{1}{C_{\mu 2}\, R_C /\!/ R_L} = \frac{1}{8p(10k /\!/ 100k)} = \boxed{2.19\,MHz}$$

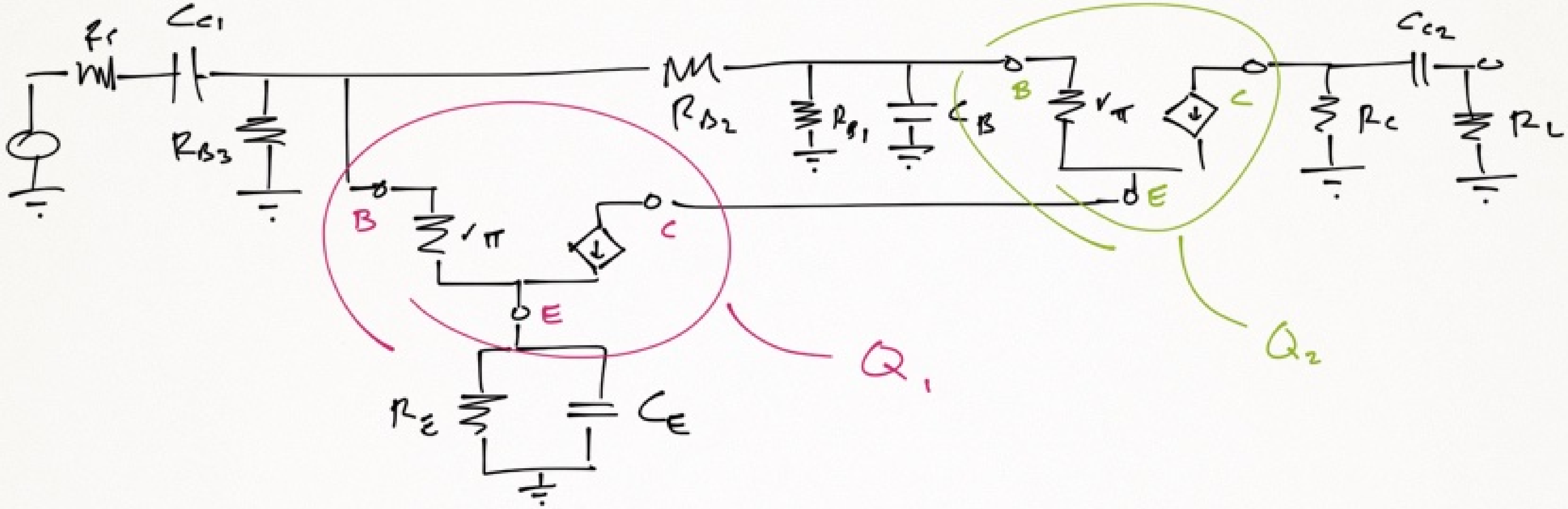
$$\omega_{HP2} = \frac{1}{(C_{\pi 2} + 2C_{\mu 1})\dfrac{r_{\pi 2}}{1+\beta}} = \frac{1}{(25p + 2.8p)\left(\dfrac{7.33k}{1+100}\right)} = \boxed{53.5\,MHz}$$

$$\omega_{HP3} = \frac{1}{(R_S /\!/ R_{B2} /\!/ R_{B3} /\!/ r_{\pi 1})(C_{\pi 1} + 2C_{\mu 1})} = \frac{1}{(50 /\!/ 110k /\!/ 140k /\!/ 7.33k)(25p + 2.8p)}$$

$$= \boxed{78.2\,MHz}$$

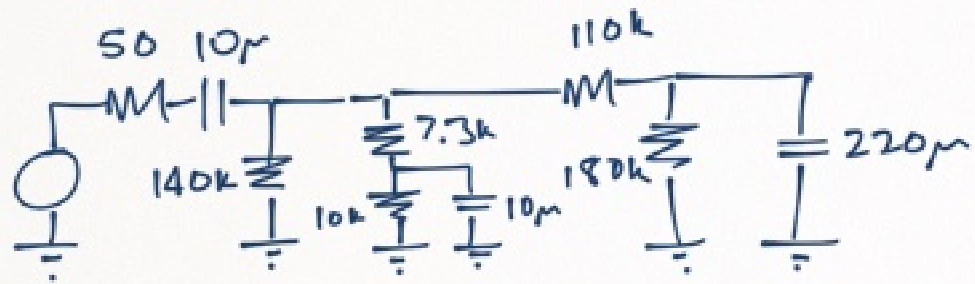
MEASURED VALUES

MIDBAND GAIN ~ 45 dB



LOW FREQUENCY ANALYSIS

$$\omega_{LP1} = \frac{1}{C_{c2}(R_C+R_L)} = \frac{1}{10\mu(10k+100k)} = 909\,m\,\frac{rad}{s} = \boxed{145\,mHz}$$



OPENING C_{c1} & C_E

$$\omega_{PH1} = \frac{1}{C_B\left[(R_{B3}//(r_\pi+R_E)+R_{B2})//R_{B1}\right]}$$

$$= \frac{1}{220\mu\left[(140k//17.3k+110k)//180k\right]}$$

$$= 61.46\,m\,\frac{rad}{s} = \boxed{9.78\,mHz}$$

SHORTING C_B & OPENING C_E

$$\omega_{PH2} = \frac{1}{C_{c1}\left[R_{B2}//(r_\pi+(\beta+1)R_E)//R_{B3}+R_S\right]}$$

$$= \left(10\mu\left[110k//(7.3k+101\cdot 10k)//140k+50\right]\right)^{-1}$$

$$= 1.72\,\frac{rad}{s} = \boxed{274\,mHz}$$

$r_\pi = 4.21k$

$r_o = 109.5k$

$\beta = 167.1$

1. BIAS USING 1, FIND Q
2. BIAS USING 2, FIND Q
3. BIAS USING 3, FIND Q

1/3 RULE BIAS SAME FOR ALL TRANSISTORS

2N3904

$$m = \frac{(1.18 - 1.35)m}{(1.05 - 16.2)} = 11.7\mu \frac{A}{V}$$

$$y = mx + b$$

$$1.352 \cdot 10^{-3} = (11.667\mu)(16.22) + b$$

$$1.1628 \cdot 10^{-3} = b$$

$$-V_A = x = \frac{-1.1628m}{11.667\mu} = 99.66$$

$$r_o = \frac{99.66}{1m} = \boxed{99.66k}$$

$$\beta = \frac{1mA}{I_B} = \frac{1m}{8.121\mu}$$

$$= \boxed{123.14}$$

$$r_\pi = 123.14 \cdot 25m = \boxed{3.10k\Omega}$$

$$m = \frac{3.819m - 4.360m}{2.434 - 18.21} = 34.293\mu \frac{A}{V}$$

$$y = mx + b$$

$$(3.819m) = (39.293\mu)(2.434) + b$$

$$b = 3.7234\ m$$

$$-V_A = x = \frac{-b}{m} = \frac{-3.7234m}{34.293\mu} = 108.57k$$

$$\beta = \frac{I_C}{I_B} = \frac{1mA}{6.531\mu A} = 153.12$$

$$r_\pi = \beta \frac{25.2mV}{1mA} = 153.12 \frac{25.2mV}{1mA} = \boxed{3.86k}$$

2N3904 BIAS #1

$I_B = \frac{I_C}{\beta} = \frac{1mA}{123.1} = 8.12\mu A$

$V_C = 10.02$

$V_B = 5.7207$

$V_E = 5.0202$

$R_E = R_C = 4.9798k$

$R_{B_1} = 102.96k$

$R_{B2} = 69.75k$

$V_B = 6.0578V$

$I_Q = 1.0081mA$

$V_Q = 15 - I_Q(R_C + R_E) =$

$V_Q = 4.9599$

2N4401 BIAS #1

$I_B = \frac{1mA}{153.1} = 6.53\mu A$

$V_C = 10.016$

$V_B = 5.7163$

$V_E = 5.0163$

$R_C = R_E = 4.9837k$

$R_{B_1} = 114.87k$

$R_{B2} = 76.947k$

$V_B = \frac{R_{B2}}{R_{B_1} + R_{B_2}} \cdot V_{CC} = 6.0172$

$I_Q = \frac{V_B - V_{BE}}{\frac{R_{B_1} // R_{B2}}{\beta + 1} + R_E} = 1.0063mA$

$V_Q = V_{CC} - I_Q(R_C + R_E) = 4.9697$

FOR BOTH TRANSISTORS:

2d)

COMPARE:

BODE POLES + ZEROS

CALC. POLES + ZEROS

PICK MIDBAND FREQ

→ DO SATURATION THING

$r_\pi = 3.10k$

$r_o = 79.66k$

$\beta = 123.1$

$$\omega_{P1L} = \frac{1}{C_{C2}(3.1k + 1M)} = 15.8 mHz$$

$$\omega_{P2L} = \frac{1}{[R_S + R_{BB} // (r_\pi + (1+\beta)R_E)] C_{C1}} = 483 mHz$$

478mHz

$$\omega_{P2L} = \frac{1}{\left(R_E // \frac{r_\pi + R_{BB}//R_S}{1+\beta}\right) C_E} = 630Hz$$

$= 630Hz$

$r_\pi = 3.86k$

$r_o = 108.1k$

$\beta = 153.1$

$$\omega_{Z3L} = \frac{1}{R_E C_E} = 3.1Hz$$

89.17kHz

86.82kHz

$$\omega_{HP2} = \frac{1}{R_L // R_C \cdot C_\mu} = 3.92MHz$$

$$\omega_{HP1} = \frac{1}{\left[C_\pi + C_\mu\left(1 + \frac{\beta}{r_\pi} R_L // R_C\right)\right](R_S // R_B)}$$

5^{th} ed. pg 490

FAIRCHILD DATASHEETS

$$C_\pi = C_{de} + C_{je}$$

$$C_{de} = \tau_F g_m$$

$$C_{je} = \frac{C_{je0}}{\left(1 - \frac{V_{BE}}{V_{0e}}\right)^m}$$

$$g_m = \frac{I_c}{V_T} \qquad r_o = \frac{|V_A|}{I_c} \qquad r_\pi = \frac{\beta_0}{g_m}$$

$$C_{je} \cong 2\, C_{je0}$$

$$C_\mu = \frac{C_{je0}}{\left(1 + \frac{V_{CB}}{V_{0E}}\right)^m}$$

2N2222A

$$C_\mu = \frac{C_{jc0}}{\left(1 + \frac{V_{CB}}{V_{0c}}\right)^m}$$

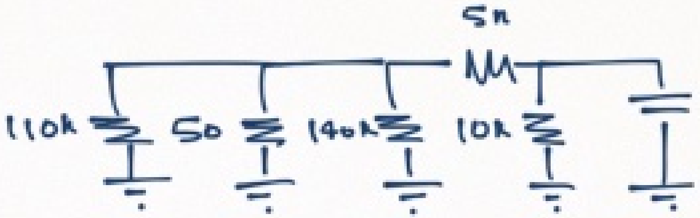
$$C_\pi = \frac{g_m}{2\pi f_T} - C_\mu$$

unity gain bandwidth

(DATASHEET)

FUNCTION OF $I_C + V_{CE}$

TRY SHORTING C_B & C_{C1}



$$\omega_{PH3} = \frac{1}{C_E\left[\left(\frac{(R_S // R_{B3} // R_{B2}) + r_\pi}{\beta + 1}\right) // R_E\right]} = \frac{1}{10\mu\left[\left(\frac{(50 // 140k // 110k) + 7.3k}{101}\right) // 10k\right]} = 23.7\ \frac{rad}{s} = \boxed{3.77\ Hz}$$

TRY SHORTING C_B & OPENING C_{C1}

$$\omega_{HP3} = \frac{1}{C_E\left[\left(\frac{(R_{B3} // R_{B2}) + r_\pi}{\beta + 1}\right) // R_E\right]} = \frac{1}{10\mu\left[\left(\frac{(140k // 110k) + 7.3k}{101}\right) // 10k\right]} = 22.6\ \frac{rad}{s} = \boxed{3.60\ Hz}$$

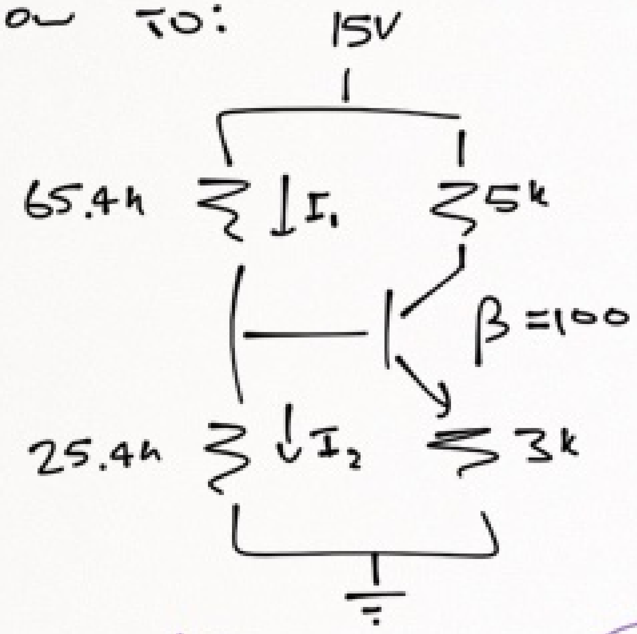
POLE CORRESPONDING TO C_E IS AT $\boxed{\sim 3.7\ Hz}$

OCT 24/2014

DON'T DO 1/3'rd RULE ON BIASED/PREVIOUSLY DESIGNED CIRCUITS

HOW TO:

Ex)



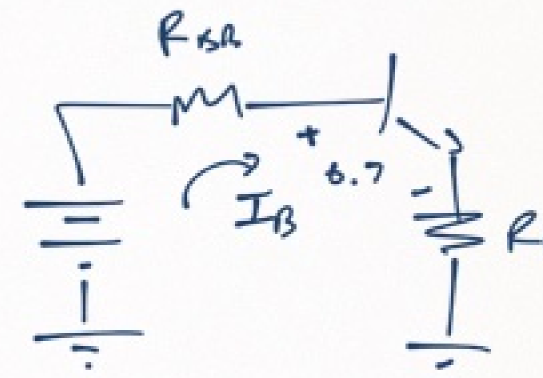
FIND $I_1, I_2, I_C, I_E, g_m, \, \& \, r_\pi$

═

DO THEV. ON LEFT SIDE OF CIRCUIT:

$$V_{BB} = 15V \cdot \frac{25.4k}{654k + 25.4k} = 4.2V$$

$$R_{BB} = 65.4k \,//\, 25.4k = 18.3k$$



$\downarrow (\beta+1) I_B = I_E$

TO GET I_E / I_C

$$V_{BB} = I_B R_{BB} + 0.7 + (1+\beta) I_B R_E$$

$$I_B = \frac{\overset{4.2V}{V_{BB}} - 0.7V}{\underset{100}{(1+\beta)}\underset{3k}{R_E} + \underset{18.3k}{R_{BB}}} = \frac{3.5V}{303k + 18.3k} = 11\mu A$$

$$I_C = \beta I_B = \boxed{1.1mA}$$

$$I_E = (1+\beta) I_B = \boxed{1.111mA}$$

TO GET $I_1 \,\&\, I_2$

$$V_E = R_E \cdot I_E = 3k \cdot 1.111mA = 3.33V$$

$$V_B = V_E + 0.7 = 4.03V \simeq 4V$$

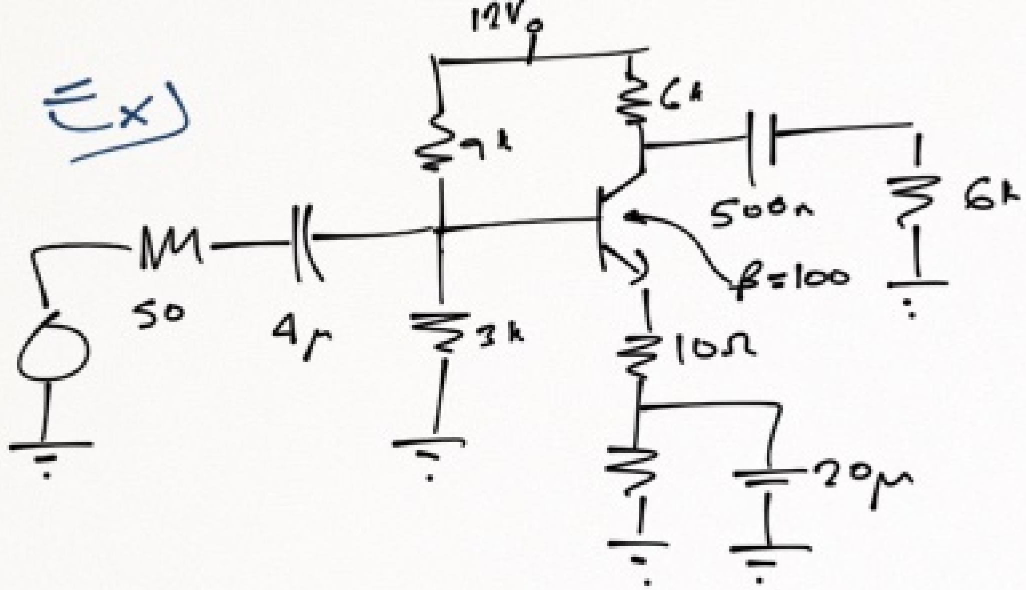
$$I_1 = \frac{15 - V_B}{65.4k} = \frac{15 - 4V}{65.4k} = \boxed{0.165mA}$$

$$I_2 = \frac{4V}{25.4k} = \boxed{0.157mA}$$

$$g_m = \frac{I_C}{V_T} = \frac{1.1\,mA}{25mV} = \boxed{44\,mS}$$

$$r_\pi = \beta \frac{V_T}{I_C} = \frac{\beta}{g_m} = \frac{100}{44mS} = \boxed{2.27k}$$

Ex)



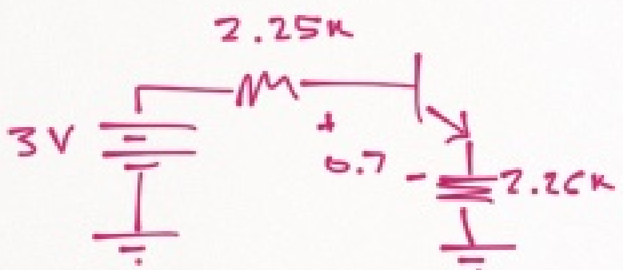
DRAW LOW f CIRCUIT, MIDBAND, AND HIGH f CIRCUIT.

DERIVE MIDBAND GAIN A_m & $F_L(s)$

$$V_{BB} = V_{cc}\frac{R_{B2}}{R_{B1}+R_{B2}} = 12\cdot\frac{3}{9+3} = 3V$$

$$R_{BB} = 9k\cdot\frac{3}{9+3} = 2.25k$$

$$R_{B1} /\!/ R_{B2} = R_{B1}\left(\frac{R_{B2}}{R_{B1}+R_{B2}}\right)$$



$I_E = (1+\beta)I_B$

$$I_B = \frac{V_{BB} - V_{BE}}{(1+\beta)R_E + R_{BB}} = \frac{2.3V}{(101\cdot 2.26k) + 2.25k} \approx 10\mu A$$

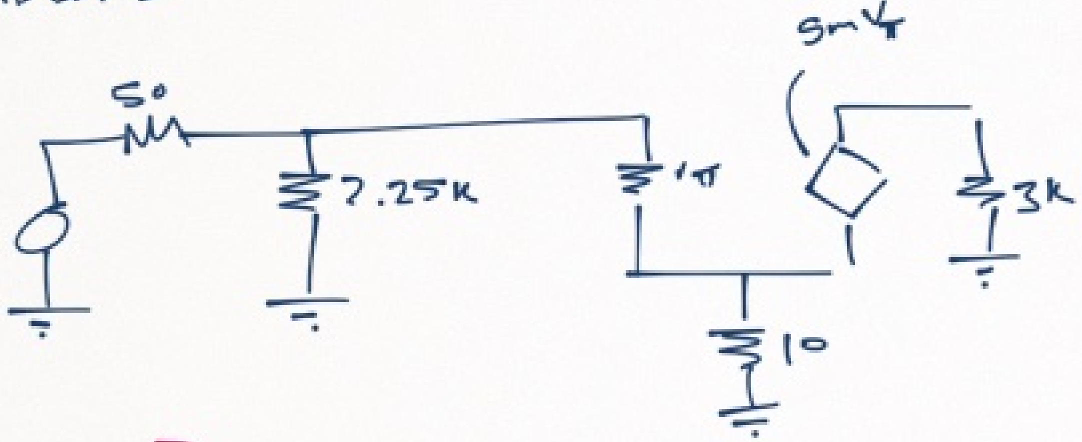
$I_C = 1mA$

$$g_m = 40mS = \left(\frac{I_C}{V_T} = \frac{1mA}{25mV}\right)$$

$r_\pi = 2.5k$

EX CONT'D

MIDBAND



$V_\pi = V_B \cdot \dfrac{r_\pi}{r_\pi + (1+\beta)10} = 0.712 \cdot V_B$

MAGNIFYING LOOKING INTO EMITTER

$v_o = -g_m v_\pi \cdot 3k = -120\, v_\pi$

$v_B = v_s \cdot \dfrac{2.25k // 3.51k}{50 + 2.25k // 3.51k} = v_s \cdot \dfrac{1.38}{1.43}$

$A_M = \dfrac{v_o}{v_s} = \dfrac{v_o}{v_\pi} \cdot \dfrac{v_\pi}{v_B} \cdot \dfrac{v_B}{v_s}$

$= -120 \cdot 0.712 \cdot \dfrac{1.38}{1.43} = \boxed{-82 \dfrac{V}{V}}$

POLES?

POLE FOR 500nF CAP $= \dfrac{1}{500nF \cdot 12k}$

POLE FOR 4μF CAP $= \dfrac{}{4\mu F(50 + 2.25k)}$ (?)

↳ O.S. 20μ

$3k // 50 \approx 50$

POLE FOR 20μF CAP $= \dfrac{1}{20\mu F\left(2.25k // \left[10 + \dfrac{r_\pi + 2.25k//50}{101}\right]\right)}$

ZEROS?

LOOK AT WHEN $I_B = \emptyset$

WHEN ADMITTANCE TO R_E & $C_E = \emptyset$
$(Y_E = \emptyset)$

$\therefore I_B = \emptyset$

$\omega_z = \dfrac{1}{20\mu \cdot 2.25k}$

B → E

MAG r π

C_{C1} & C_{C2} DON'T LET ANY I THROUGH AT DC ∴ THEIR ZEROS ARE AT ZERO

MIDTERM #1 REVIEW

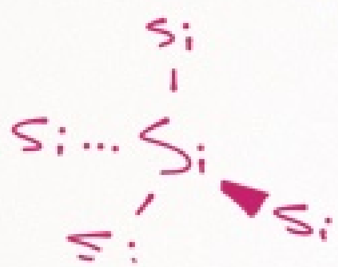
AC { DC SOURCES APPEAR LIKE GROUNDS
@ HIGH FREQUENCY → CAPACITOR IS SHORT
@ LOW FREQUENCY → CAPACITOR IS BREAK }

DC → @ SS CAPACITORS ARE OPEN CIRCUITS

- PASSIVE DEVICES WORK AT ANY VOLTAGE/CURRENT
  - ex. RESISTORS, CAPACITORS
- ACTIVE DEVICES NEED CERTAIN VOLTAGES/CURRENTS TO WORK RIGHT (BIASING)
  - ex. TRANSISTORS

TRANSISTOR REVIEW

- NO MOVING PARTS, INCREDIBLY TINY



Si HAS 4 VALENCE e^- ∴ FORMS TETRAHEDRAL CRYSTAL

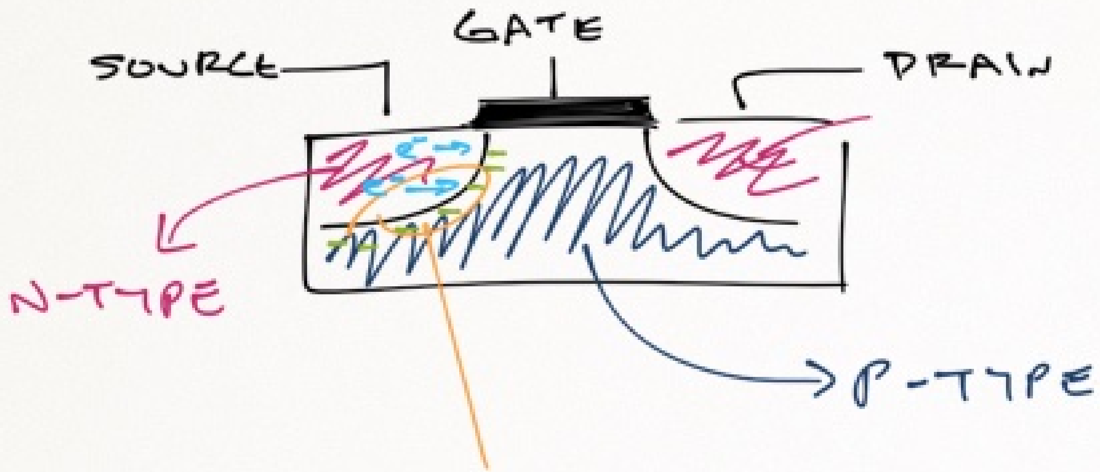
→ SINCE ALL BONDED, NOT MANY FREE e^- ∴ PURE Si IS NOT CONDUCTIVE

→ DOPE w/ PHOSPHORUS (5 VALENCE e^-) ∴ EXTRA FREE e^- TO CONDUCT

→ N-TYPE (moving Negative charge)

→ DOPE w/ BORON (3 VALENCE e^-) ∴ EXTRA h^+ FOR e^- TO MOVE

→ P-TYPE ("moving" Positive charge)



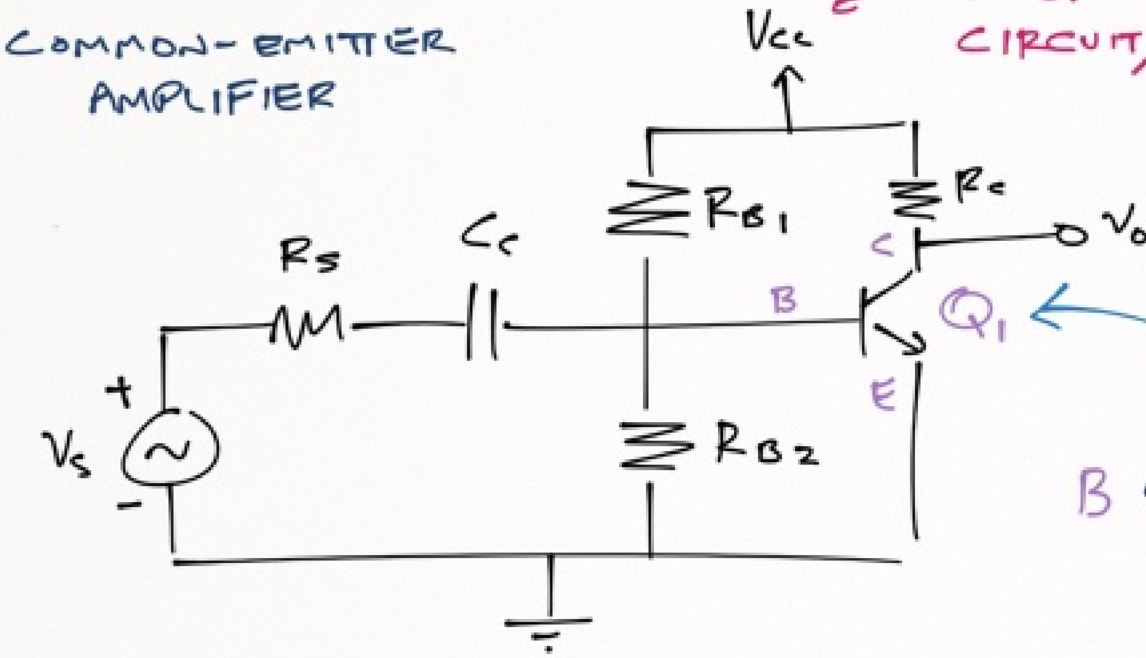
DEPLETION LAYER

- → WHERE ALL FREE e^- IN N-TYPE HAVE FILLED NEARBY h^+ IN P-TYPE
  - ↳ THIS RESULTS IN P-TYPE BEING NEGATIVELY CHARGED AND REPELLING ANY MORE e^- DRAIN OFFERS
    - ↳ "OPEN CIRCUIT"
  - ↳ HOWEVER, IF YOU APPLY +VOLTAGE FROM GATE THEN NEGATIVE CHARGE BALANCED & e^- FROM SOURCE ATTRACTED & DEPLETION LAYER SHRINKS
    - → SO e^- CAN MOVE TO h^+ IN AREA NEXT TO GATE CREATING A CONNECTION B/W SOURCE & DRAIN
      - ↳ "SHORT CIRCUIT"

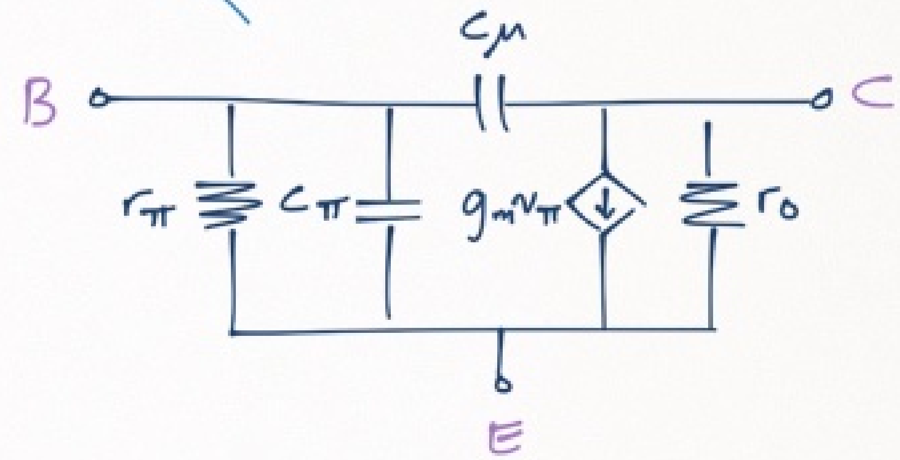
NOTES PRE MIDTERM #1

COMMON-EMITTER AMPLIFIER

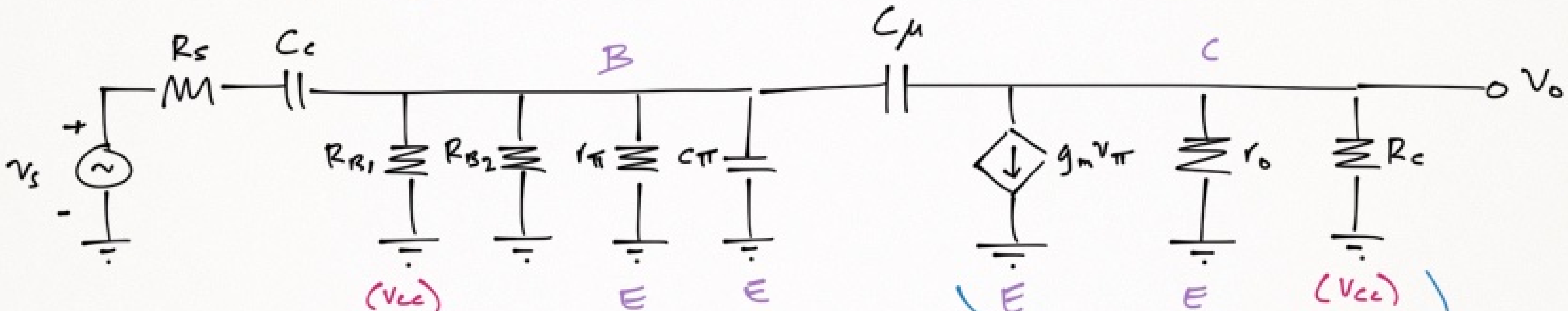
← WHEN MODELING SMALL SIGNAL EQUIVALENT CIRCUIT, DC SOURCE IS SEEN AS GROUND BY AC



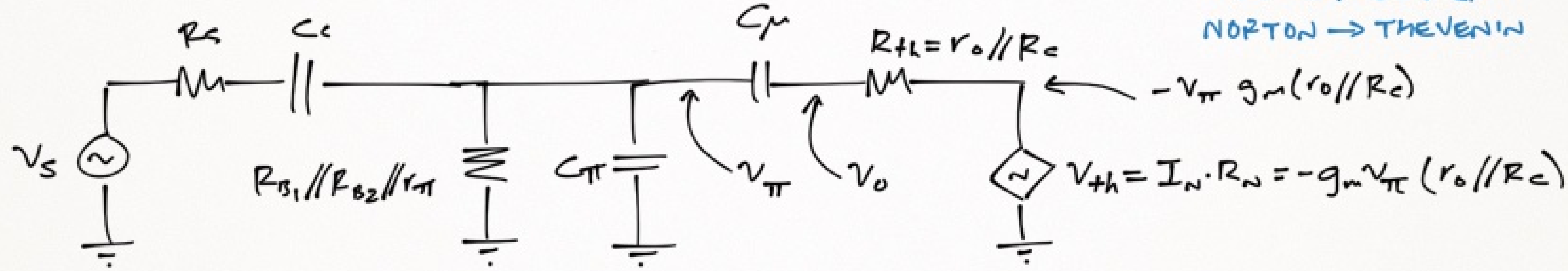
FOR TRANSISTORS, WE USE THE HYBRID-π SMALL SIGNAL MODEL



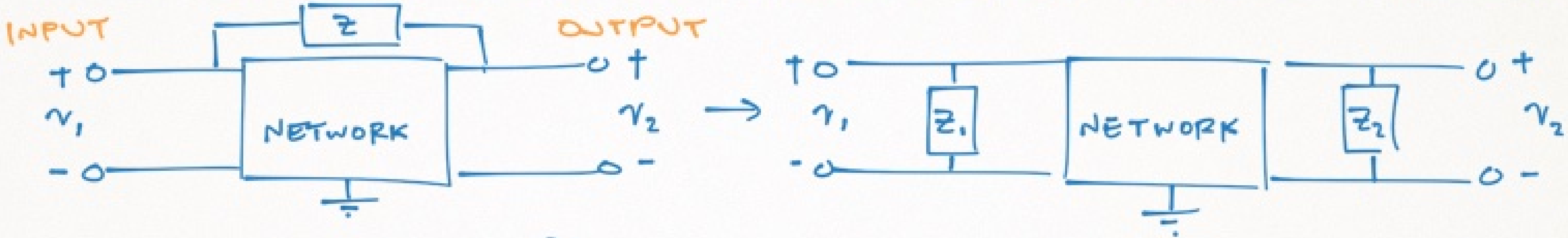
SMALL SIGNAL MODEL



SIMPLIFY USING NORTON → THEVENIN



REMOVE CAPACITOR SEPARATING BRANCHES USING MILLER'S THEOREM



MILLER'S GAIN, $k = \frac{v_2}{v_1}$

$$Z_1 = Z\,\frac{1}{1-k} \qquad Z_2 = Z\,\frac{k}{k-1}$$

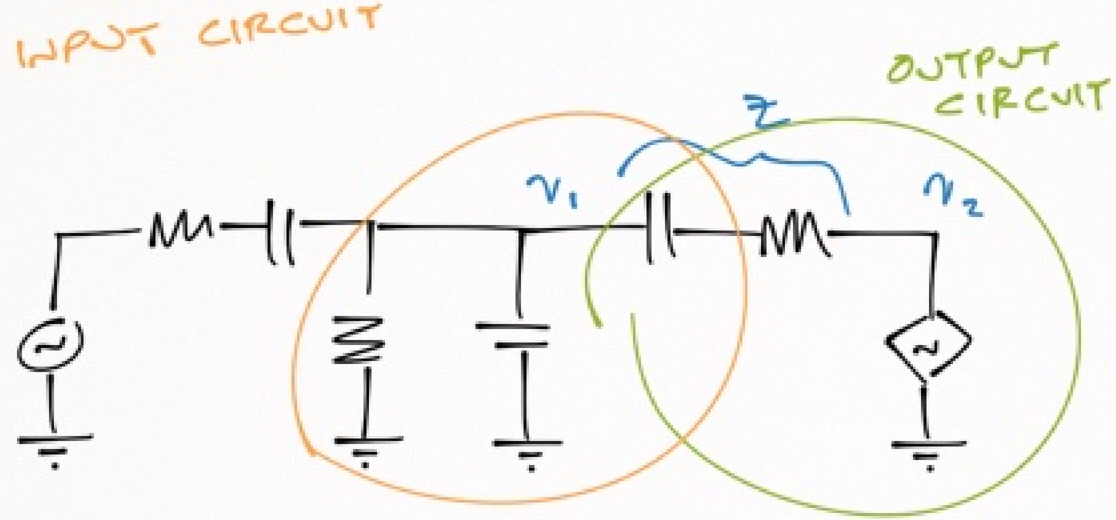
$$Z = \frac{1}{j\omega C_\mu} + r_o /\!/ R_c$$

$$k = \frac{V_2}{V_1} = \frac{-\cancel{v_\pi}\, g_m(r_o/\!/R_c)}{\cancel{v_\pi}} = -g_m(r_o/\!/R_c)$$

$$Z_1 = \frac{Z}{1-k} = \frac{\frac{1}{j\omega C_\mu} + r_o/\!/R_c}{1-k}$$

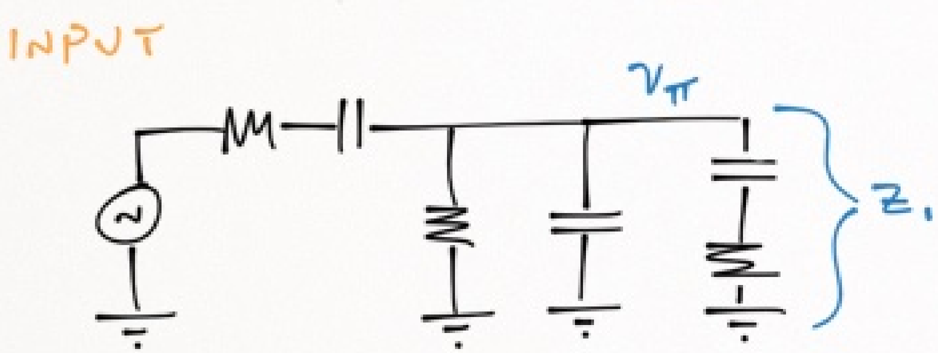
$$= \frac{1}{j\omega C_\mu(1-k)} + \frac{r_o/\!/R_c}{1-k}$$

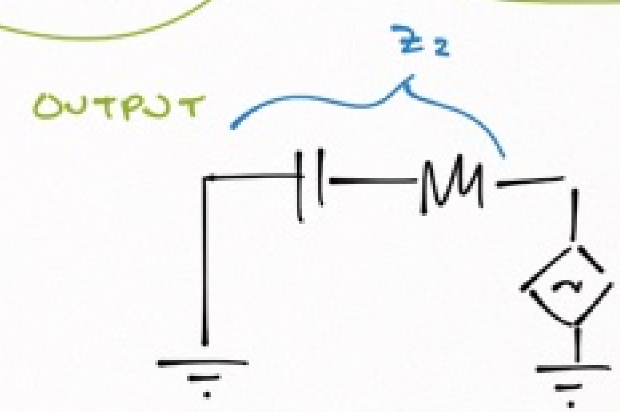
$$= \boxed{\frac{1}{j\omega C_\mu(1+g_m(r_o/\!/R_c))} + \frac{r_o/\!/R_c}{1+g_m(r_o/\!/R_c)}}$$

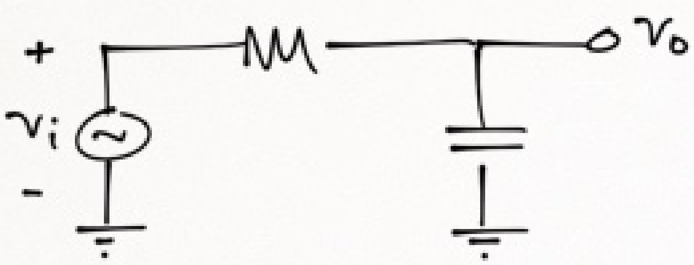


$$Z_2 = Z\,\frac{k}{k-1} = \frac{Z}{1-\frac{1}{k}}$$

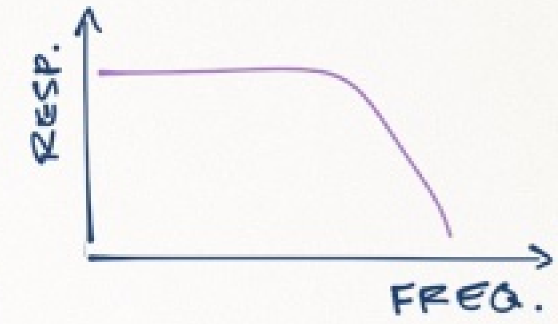
$$= \boxed{\frac{1}{j\omega C_\mu(1-1/k)} + \frac{r_o/\!/R_c}{1-1/k}}$$

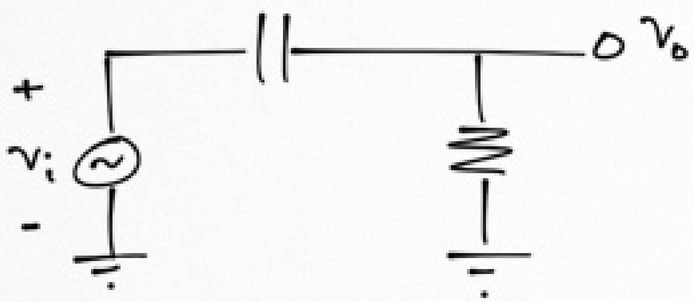




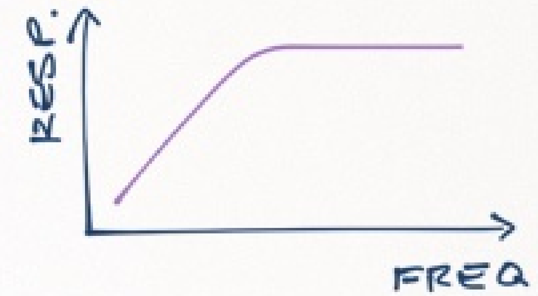


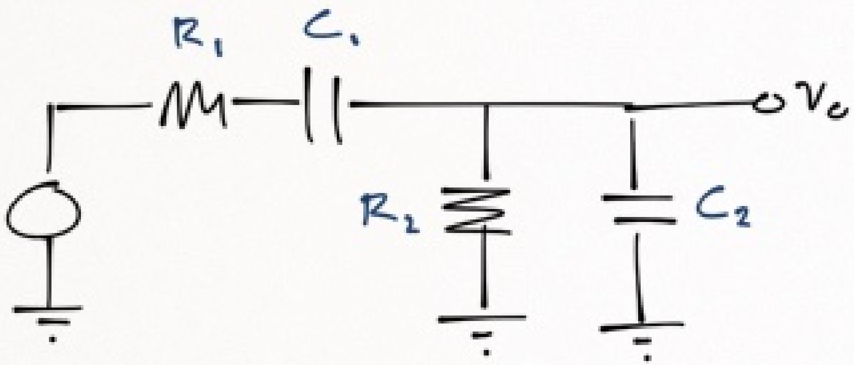
LOW PASS FILTER





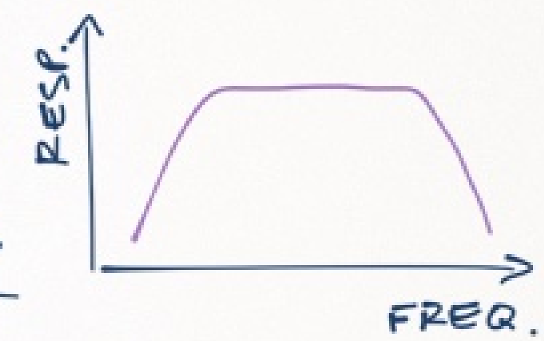
HIGH PASS FILTER



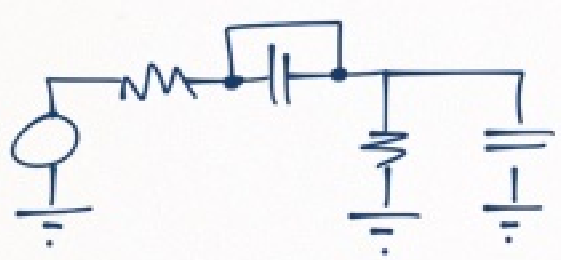


BAND PASS FILTER

$C_1 \gg C_2$ REQUIRED



@ HIGH FREQ, LARGE C = SHORT CIRCUIT



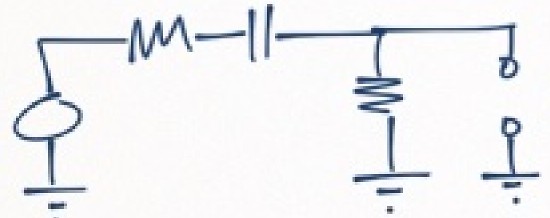
→ HIGH PASS

BANDPASS POLES

$$\omega_{p_1} \simeq \frac{1}{C_1(R_1+R_2)}$$

$$\omega_{p_2} \simeq \frac{1}{C_2(R_1 /\!/ R_2)}$$

@ LOW FREQ, SMALL C = OPEN CIRCUIT



→ LOW PASS

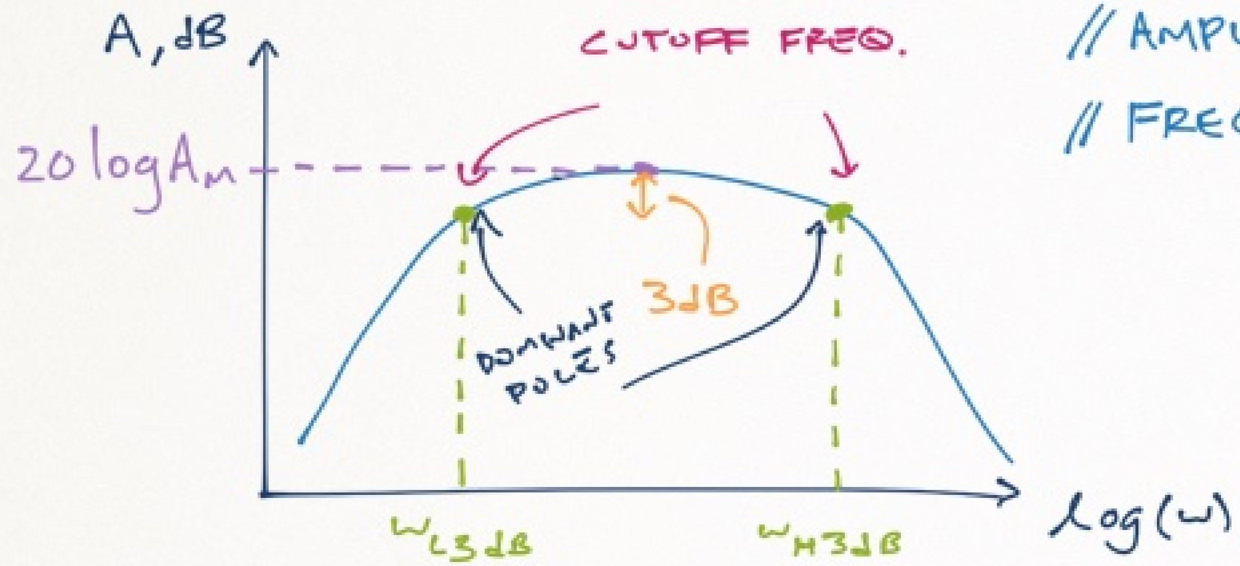
DC GAIN

$$A_M = \frac{R_2}{R_1+R_2}$$

TRANSFER FUNCTION

$$\boxed{T(s) = \frac{V_o}{V_i} = \frac{R_2}{R_1+R_2}\,\frac{s}{s+\omega_{p_1}}\,\frac{\omega_{p_2}}{s+\omega_{p_2}}}$$

FREQUENCY RESPONSE



// AMPLIFIERS CAN AMPLIFY MANY DIFFERENT
// FREQUENCIES SIMULTANEOUSLY ex. MUSIC

IF YOU KNOW THE LOCATIONS OF THE POLES & ZEROS, YOU CAN APPROXIMATE THE CUTOFF FREQUENCIES.

$$\omega_{L3dB} = \sqrt{\omega_{P1L}^2 + \omega_{P2L}^2 \cdots + \omega_{PNL}^2 - 2\omega_{Z1L}^2 - 2\omega_{Z2L}^2 \cdots - 2\omega_{ZNL}^2}$$

$$\frac{1}{\omega_{H3dB}^2} = \frac{1}{\omega_{P1H}^2} + \cdots + \frac{1}{\omega_{PNH}^2} - \frac{2}{\omega_{Z1H}^2} - \cdots - \frac{2}{\omega_{ZNH}^2}$$

IF YOU DON'T KNOW THE POLES/ZEROS USE OPEN-CIRCUIT/CLOSED-CIRCUIT TIME CONSTANT METHOD

$$\omega_{L3dB} \simeq \sum_{i=1}^{N} \frac{1}{C_i R_{is}}$$

R_{is} IS THE RESISTANCE SEEN BY THE i^{th} LOW-FREQUENCY CAPACITOR → ALL OTHERS BEING SHORTS

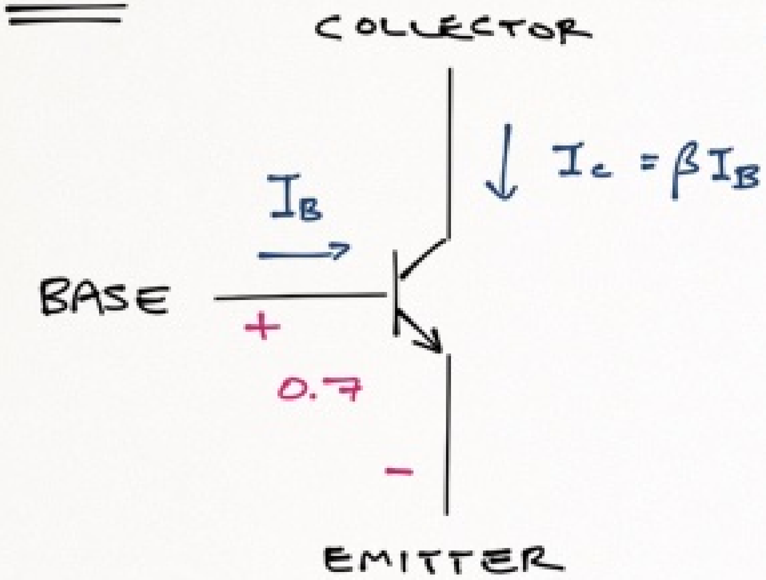
↳ ie. large

$$\omega_{H3dB} \simeq \frac{1}{\sum_{i=1}^{n} C_i R_{io}}$$

R_{io} IS THE RESISTANCE SEEN BY THE i^{th} HIGH-FREQUENCY CAPACITOR → ALL OTHERS BEING BREAKS

↳ ie. small

BJT



TRANSISTOR PARAMETERS

current gain factor

$$\alpha = \frac{I_C}{I_E} \qquad \beta = \frac{I_C}{I_B} \qquad \alpha = \frac{\beta}{\beta + 1}$$

$V_T = 25\text{ mV}$ (@T = 300K) — thermal voltage

$V_{BE} = 0.7$ (FOR Si BJT)

$\beta = 100$ (UNLESS TOLD OTHERWISE)

NOTATION:

- A_B → DC VALUE
- A_b → COMPLEX VALUE
- a_B → INSTANTANEOUS VALUE
- a_b → SMALL SIGNAL AC VALUE

ex. $i_C = I_C + i_c$

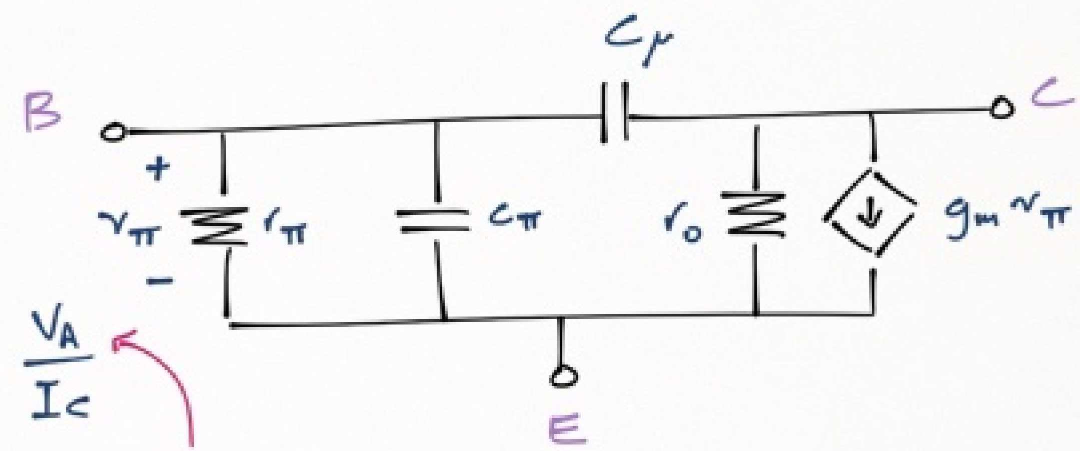
HYBRID-PI MODEL FOR BJT

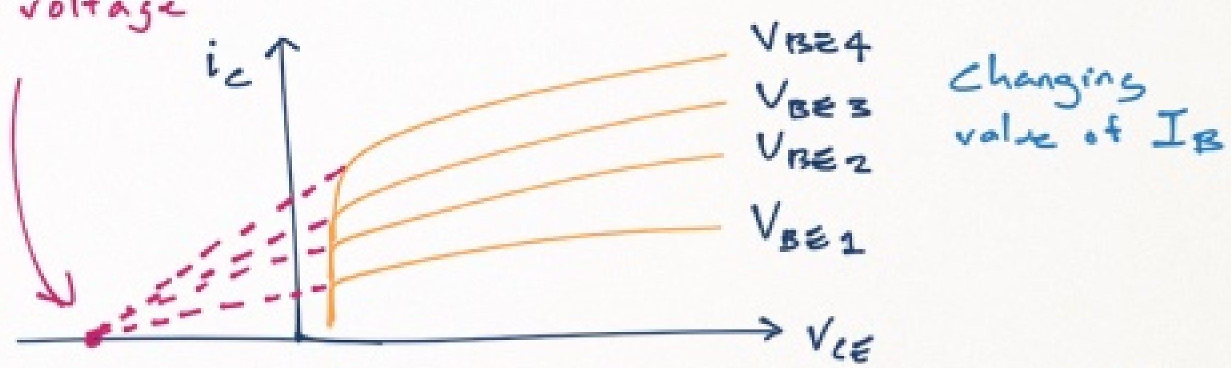
$$r_\pi = \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \frac{V_T}{I_B}$$

$$r_o = \left[\frac{\delta}{\delta v_{CE}} i_C \Big|_{v_{BE} = \text{constant}} \right]^{-1} \simeq \frac{V_A}{I_C}$$

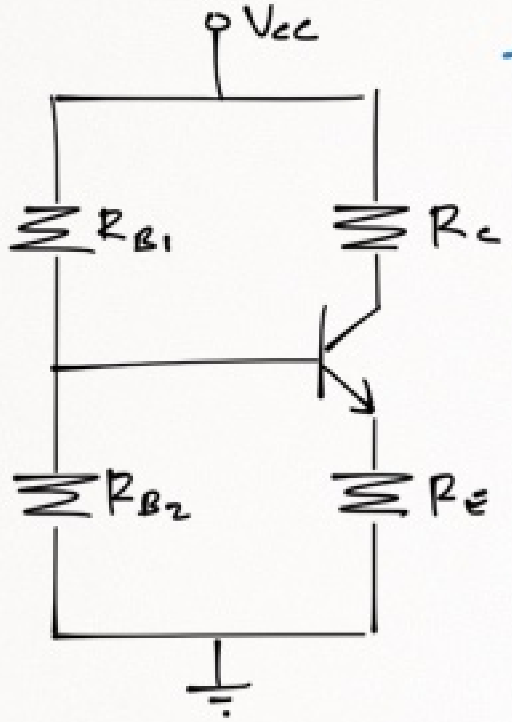
much of the time, we can get away with assuming this is infinite

early voltage



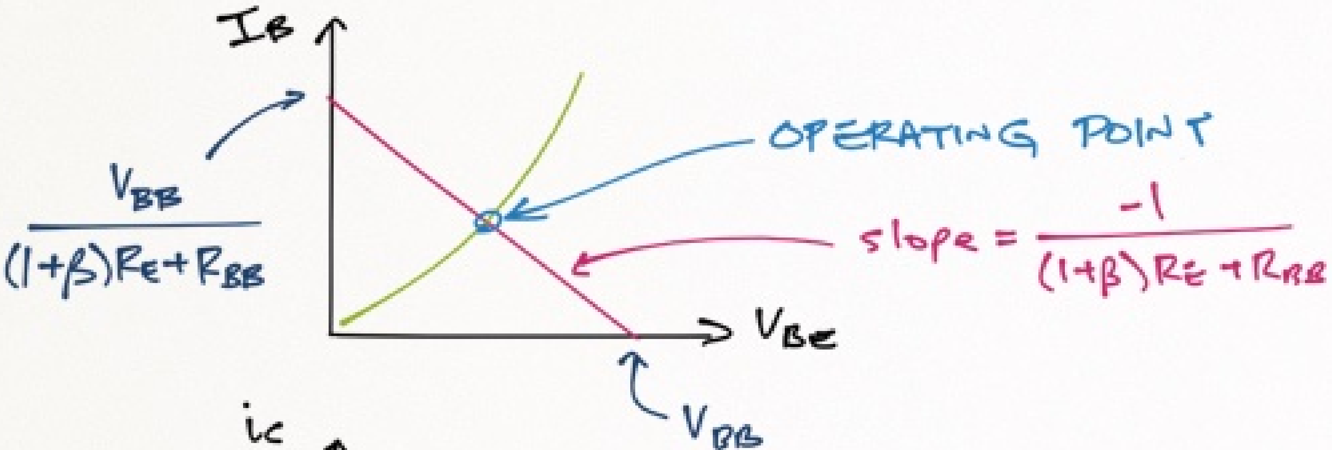


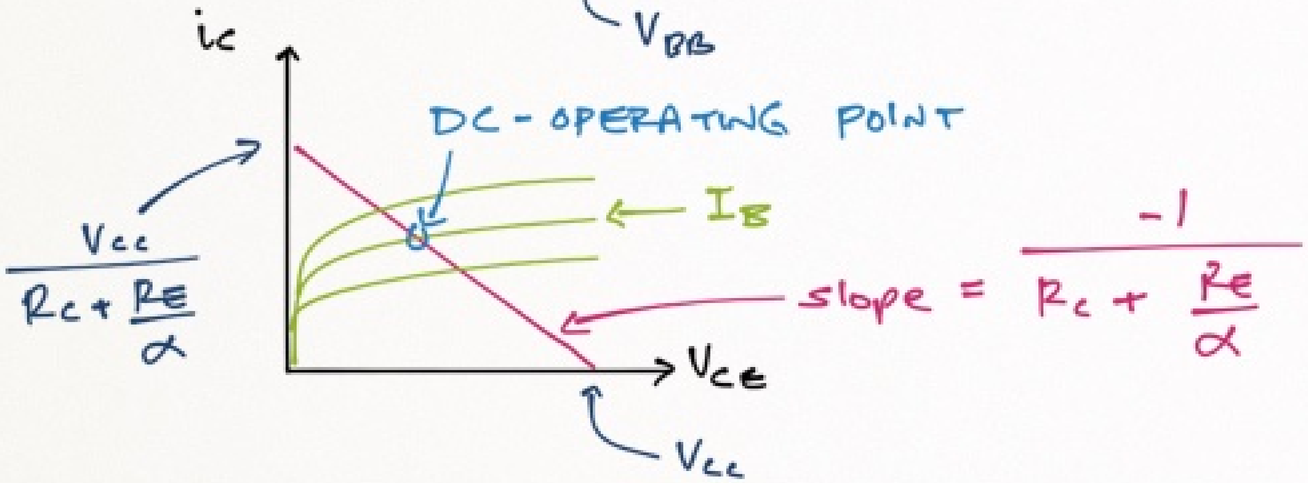
BIASSING THE BJT



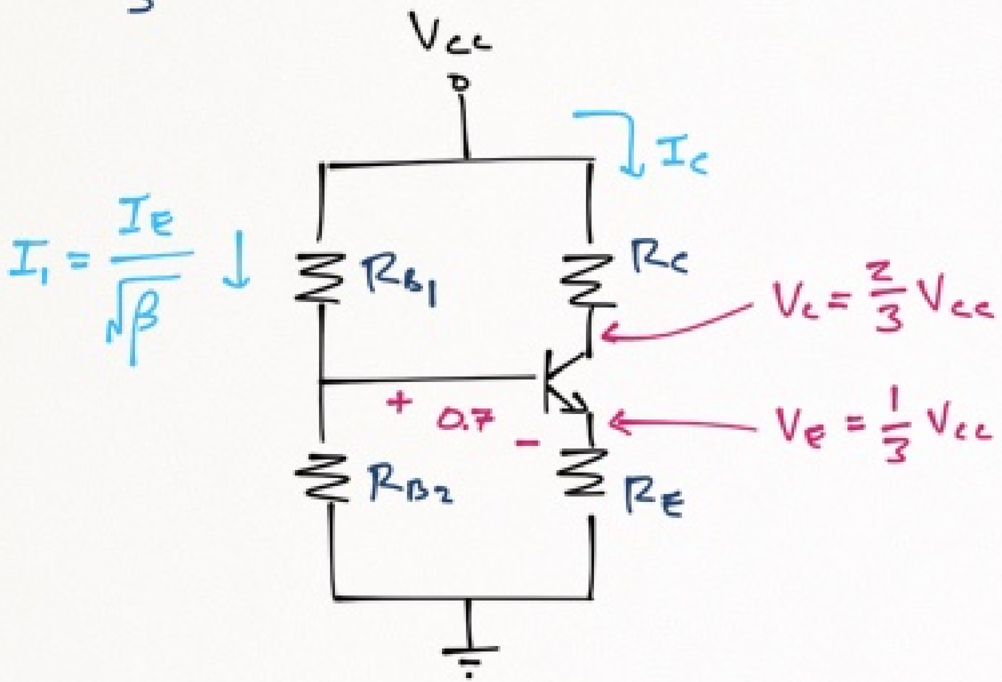
BASIC BIAS-CIRCUIT FOR COMMON-EMITTER/COMMON-BASE

FINDING THE DC OPERATING POINT





$\frac{1}{3}$rd RULE TO BIAS TRANSISTOR



$$R_c = \frac{1}{3}\frac{V_{cc}}{I_c}$$

$$R_E \simeq R_c$$

$$V_E = \frac{1}{3} V_{cc}$$

$$V_B = V_E + 0.7$$

$$I_B = \frac{I_c}{\beta}$$

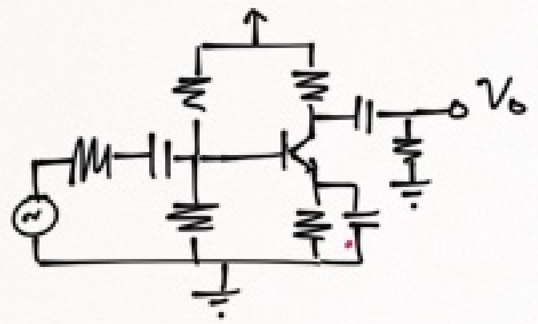
$$I_E = I_B(\beta+1) = \frac{V_E}{R_E}$$

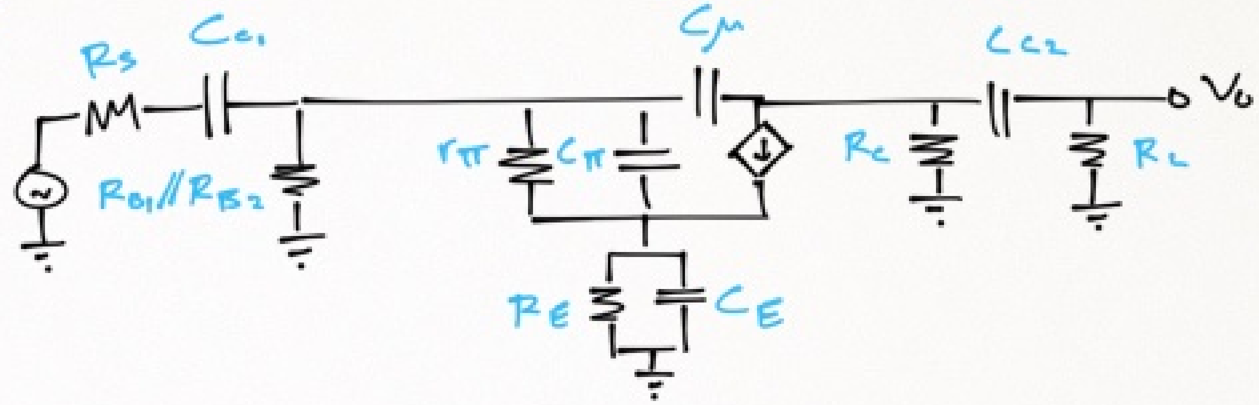
$$R_{B_1} = \frac{\frac{2}{3}V_{cc} - 0.7\,V}{\frac{I_E}{\sqrt{\beta}}}$$

$$I_1 = \frac{I_E}{\sqrt{\beta}}$$

$$R_{B_2} = \frac{\frac{1}{3}V_{cc} + 0.7\,V}{I_E\left(\frac{1}{\sqrt{\beta}} - \frac{1}{\beta+1}\right)}$$

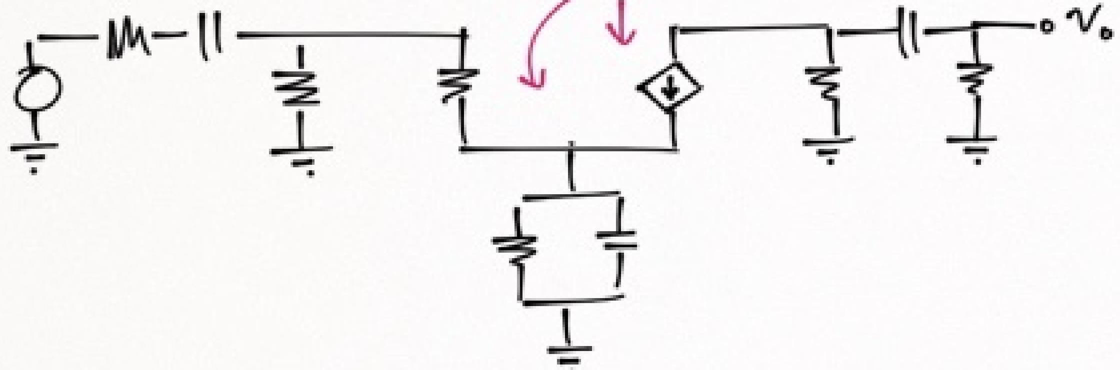
COMMON EMITTER AMPLIFIER





LOW FREQUENCY SMALL-SIGNAL MODEL

small capacitors breaks



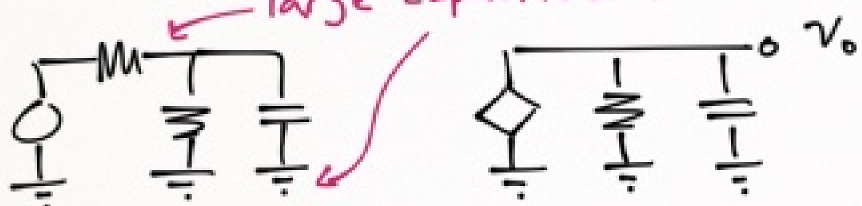
$$r_\pi = \frac{V_T}{I_B} = V_T \frac{(R_{B1}//R_{B2} + (\beta+1)R_E)}{V_{CC}\frac{R_{B2}}{R_{B1}+R_{B2}} - 0.7}$$

$$A_M = -\frac{\beta}{r_\pi}(R_C//R_L)\,\frac{R_{B1}//R_{B2}//r_\pi}{R_{B1}//R_{B2}//r_\pi + R_s}$$

$$\omega_{z1L} = \omega_{z2L} = \emptyset \qquad \omega_{z3L} = \frac{1}{R_E C_E}$$

HIGH FREQUENCY SMALL-SIGNAL MODEL

large capacitors shorts

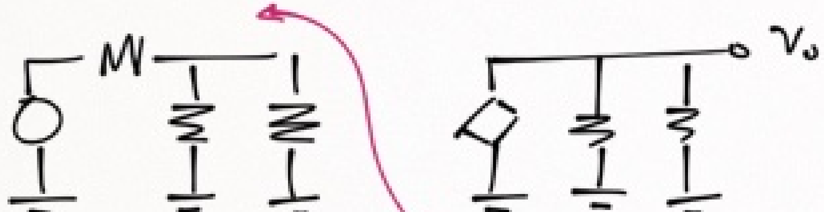


$$\omega_{p1L} = \frac{1}{(R_C+R_L)C_{C2}}$$

$$\omega_{p2L} = \frac{1}{(R_S + R_{B1}//R_{B2}//r_\pi)C_{C1}}$$

if C_E OPEN: $r_\pi + (1+\beta)R_E$

MIDBAND SMALL-SIGNAL MODEL



large capacitors shorts
AND small capacitors breaks

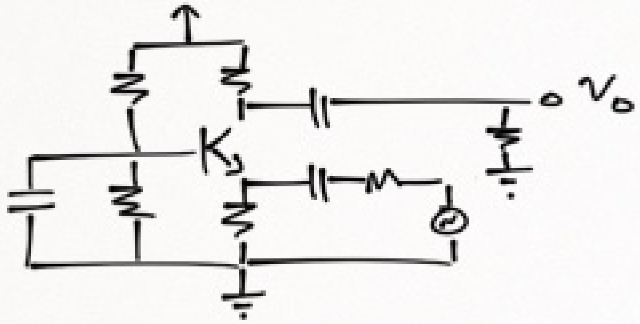
$$\omega_{p3L} = \frac{1}{\left(R_E // \frac{r_\pi + R_{B1}//R_{B2}}{1+\beta}\right)C_E}$$

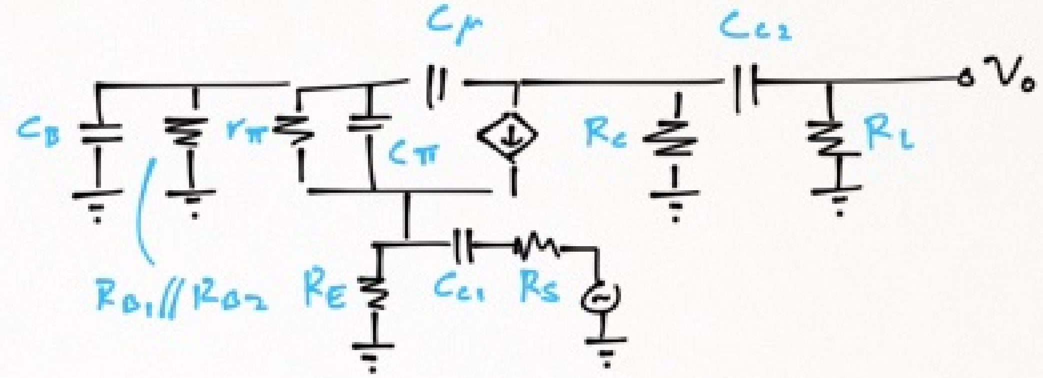
if C_{C1} SHORT: //50

$$\omega_{p1H} = \frac{1}{C_\mu[R_L//R_C]}$$

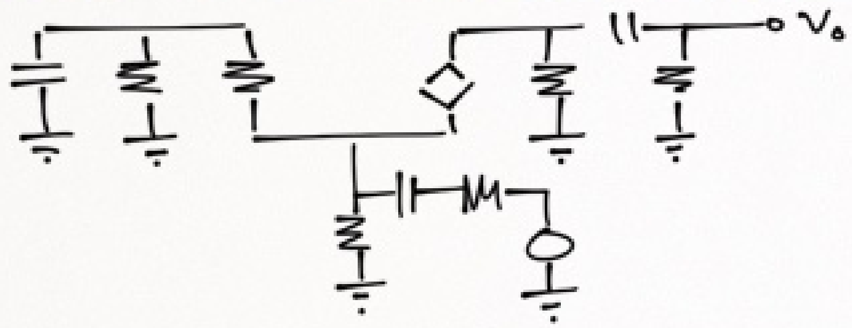
$$\omega_{p2H} = \frac{1}{[C_\pi + C_\mu(1+g_m R_L//R_C)](R_s//R_B)}$$

COMMON BASE AMPLIFIER





LOW FREQUENCY SMALL SIGNAL MODEL

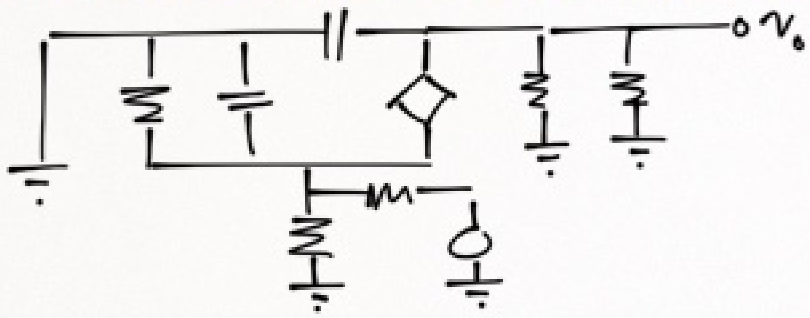


FORMULAS

$$A_M = \frac{-\beta}{r_\pi}\,(R_C \parallel R_L)\,\frac{\frac{r_\pi}{1+\beta} \parallel R_E}{R_s + \frac{r_\pi}{1+\beta} \parallel R_E}$$

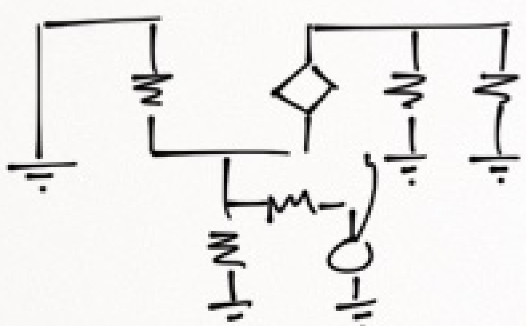
$$\omega_{LZ} = \frac{1}{(R_{B1} \parallel R_{B2})\,C_B}$$

HIGH FREQUENCY SMALL SIGNAL MODEL



$$\omega_{PH1} = \frac{1}{\left(R_E \parallel R_S \parallel \frac{r_\pi}{1+\beta}\right) C_\pi} \qquad \omega_{PH2} = \frac{1}{(R_L \parallel R_C)\,C_\mu}$$

MIDBAND SMALL SIGNAL MODEL



$$\omega_{PL1} = \frac{1}{\left[R_{B1} \parallel R_{B2} \parallel \left(r_\pi + (1+\beta)(R_E \parallel R_S)\right)\right] C_B}$$

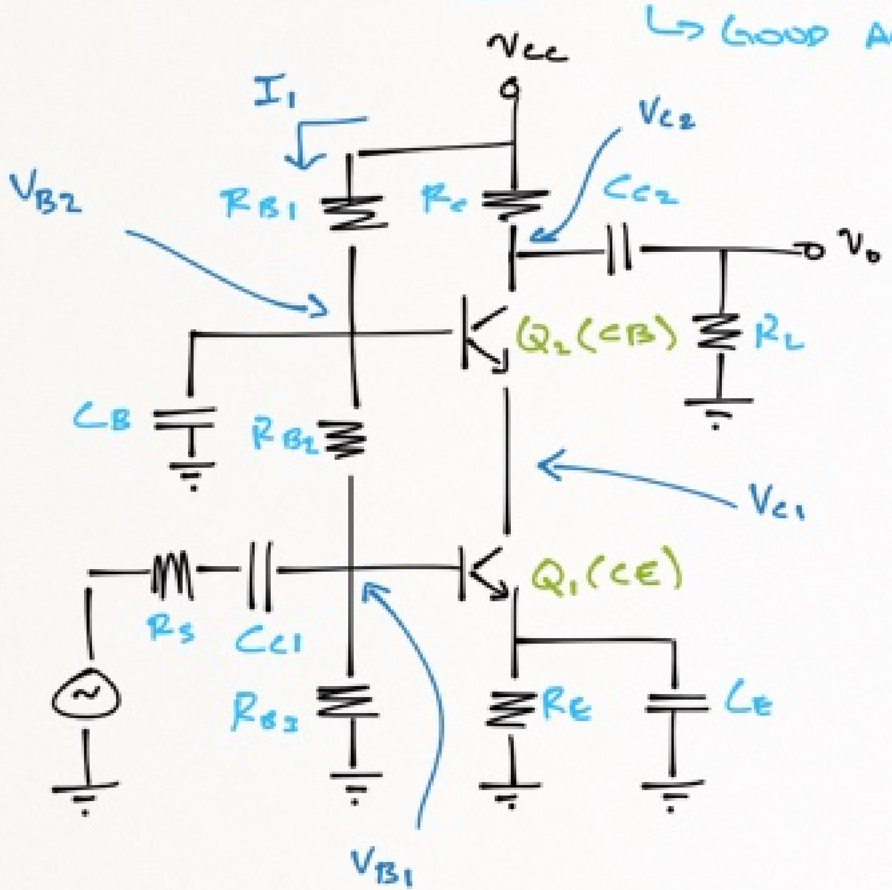
$$\omega_{PL2} = \frac{1}{\left[\frac{r_\pi + R_{B1} \parallel R_{B2}}{1+\beta} \parallel R_E + R_s\right] C_{C1}}$$

$$\omega_{PL3} = \frac{1}{(R_C + R_L)\,C_{C2}}$$

CASCODE

↳ COMBINES WIDE BANDWITH OF COMMON BASE & HIGH INPUT IMPEDANCE OF COMMON EMITTER

↳ GOOD AMPLIFICATION, DOESN'T REQUIRE MUCH I



BIAS USING $\frac{1}{4}$'s RULE

$$V_{C2} = \frac{3}{4} V_{CC} \qquad V_{B2} = \frac{1}{2} V_{CC} + 0.7$$

$$V_{C1} = \frac{2}{4} V_{CC} \qquad V_{B1} = \frac{1}{4} V_{CC} + 0.7$$

$$V_E = \frac{1}{4} V_{CC} \qquad I_1 = \frac{I_E}{\sqrt{\beta}}$$

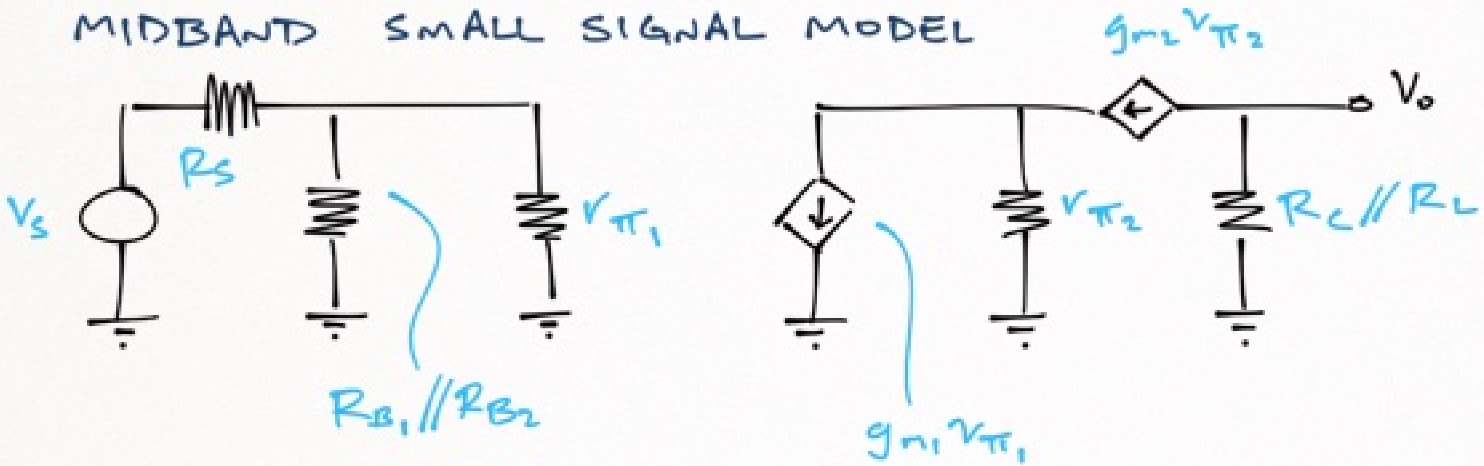
$$I_{E1,2} \simeq I_{C1,2} = \frac{V_{CC} - V_{C2}}{R_C} \qquad R_{B1} = \frac{V_{CC} - V_{B2}}{I_{B1}}$$

$$I_{B1,2} \simeq \frac{I_{C1}}{\beta_1} \simeq \frac{I_{C2}}{\beta_2} \qquad R_{B2} = \frac{V_{B2} - V_{B1}}{I_1 - I_{B1}}$$

$$R_{B3} = \frac{V_{B1}}{I_1 - 2I_{B1}}$$

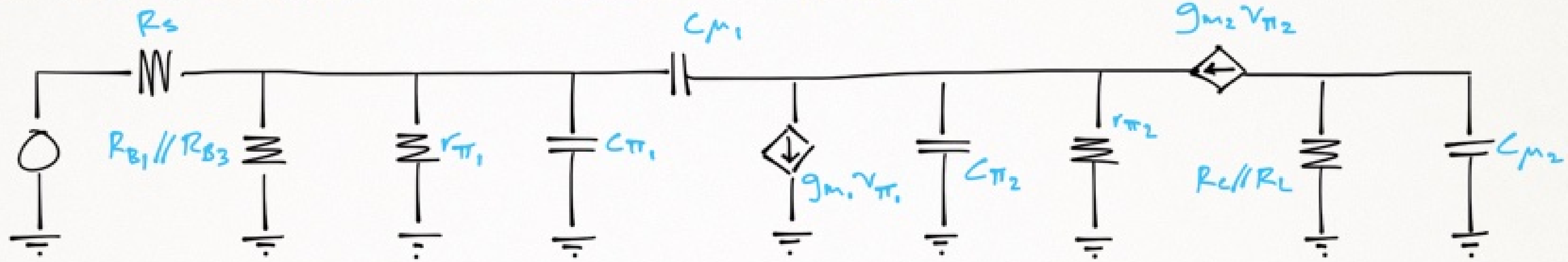
$$R_E = \frac{V_E}{I_{E2} + 2I_{B1}}$$

MIDBAND SMALL SIGNAL MODEL



$$A_M = -g_m \frac{(R_C // R_L)(R_{B2} // R_{B3})}{(R_{23} + R_S)} \times \frac{r_\pi}{r_\pi + R_{B2} // R_{B3} // R_S} \quad (?)$$

HIGH FREQUENCY SMALL SIGNAL MODEL OF CASCODE



$$\omega_{HP1} = \frac{1}{C_{\mu_2}(R_C // R_L)}$$

$$\omega_{HP2} = \frac{1}{(C_{\pi_2} + 2C_{\mu_1})\frac{r_{\pi_2}}{1+\beta}}$$

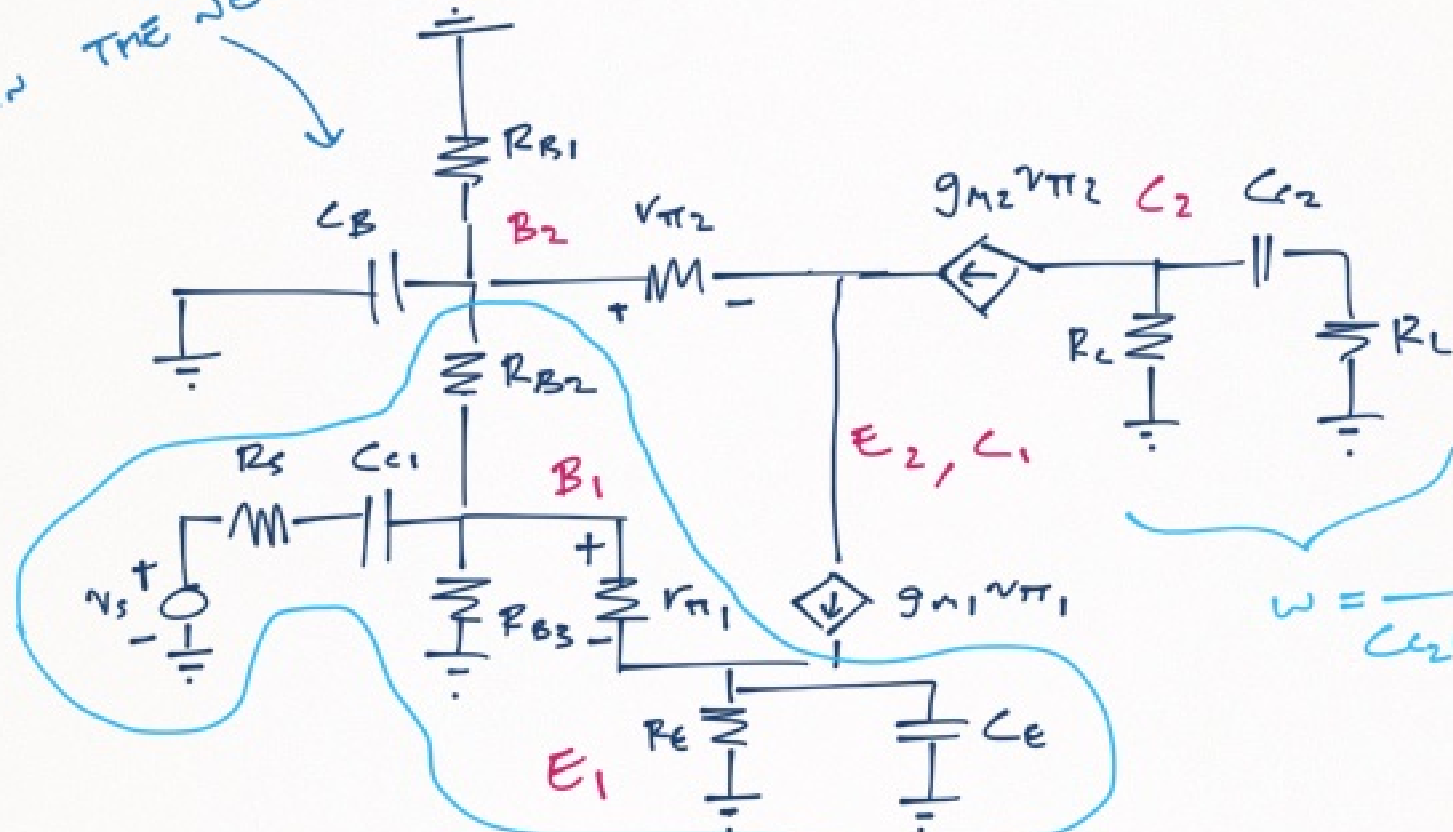
$$\omega_{HP3} = \frac{1}{(R_S // R_{B_1} // R_{B_2} // r_{\pi_2})(C_{\pi_1} + 2C_{\mu_1})}$$

$r_{\pi_1} = r_{\pi_2}$?

r_{π_1} A_M CASCODE?

LOW FREQUENCY MODEL OF CASCODE

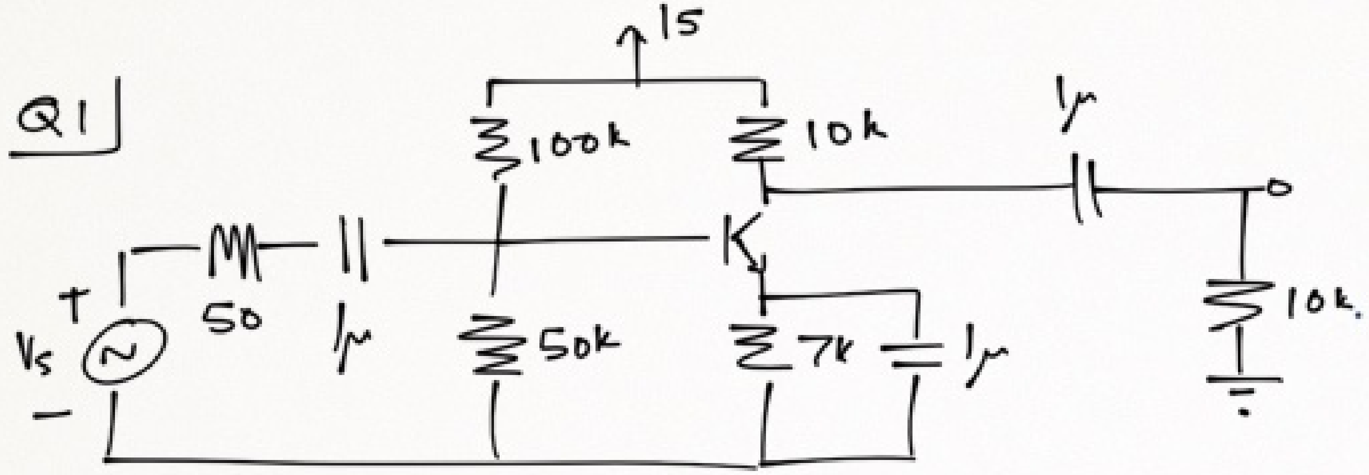
PAIN IN THE NECK, SO MAKE IT BIG & SHORT TO GROUND



$$\omega = \frac{1}{C_{c2}(R_C + R_L)}$$

FOR C_E & C_{c1}, if C_B IS SHORTED TO GND LEFT w/ SAME CIRCUIT AS FOR C.E.

Q1



ASSUMING C_E OPEN

COMMON EMITTER

$$r_\pi = V_t \frac{R_{B1}//R_{B2} + (\beta+1)R_E}{V_{cc}\frac{R_{B2}}{R_{B1}+R_{B2}} - 0.7}$$

$$= 25mV \frac{100k//50k + (101)7k}{15\frac{50k}{150k} - 0.7}$$

$$\boxed{= 4.3043k\Omega}$$

$$g_m = \frac{\beta}{r_\pi} = \frac{100}{4.3043k} = \boxed{23.233mS}$$

$$\omega_{LZ1} = \emptyset$$
$$\omega_{LZ2} = \emptyset$$

$$\omega_{LZ3} = \frac{1}{R_E C_E} = \frac{1}{7k \cdot 1\mu F} = \boxed{142.86 \frac{rad}{s}}$$

$$\omega_{LP1} = \frac{1}{(R_C+R_L)C_{C2}} = \frac{1}{(10k+10k)1\mu} = \boxed{50 \frac{rad}{s}}$$

$r_\pi + (101)R_E$

$$\boxed{31.357 \frac{rad}{s}}$$

ASSUMING C_E CLOSED

$$\omega_{LP2} = \frac{1}{(R_S + R_{B1}//R_{B2}//r_\pi)C_{C1}}$$

$$= \frac{1}{(50 + 100k//50k//4.3k)1\mu} = \boxed{259.16 \frac{rad}{s}}$$

$$\omega_{LP3} = \frac{1}{\left(R_E // \frac{r_\pi + R_{B1}//R_{B2}}{1+\beta}\right)C_E}$$

ASSUMING C_{C1} OPEN

$$= \frac{1}{\left(7k//\frac{4.3k + 100k//50k}{1+100}\right)1\mu} = \boxed{2826 \frac{rad}{s}}$$

ASSUMING C_{C1} CLOSED

//50

$$\boxed{23.362 \times 10^3 \frac{rad}{s}}$$

WHICH TO CHOOSE?

$\frac{1}{3}$rd RULE VERSION 1

$$V_B = \frac{1}{3} V_{cc}$$

$$V_C = \frac{2}{3} V_{cc}$$

$$I_1 = \frac{I_E}{\sqrt{\beta}} = \frac{V_{cc} - V_B}{R_{B1}} = \frac{V_{cc} - \frac{1}{3}V_{cc}}{R_{B1}} = \frac{2}{3}\frac{V_{cc}}{R_{B1}}$$

$$I_C = \frac{V_{cc} - V_C}{R_C} = \frac{1}{3}\frac{V_{cc}}{R_C}$$

$$I_B = I_1 - \frac{V_B}{R_{B2}} = I_1 - \frac{1}{3}\frac{V_{cc}}{R_{B2}} = \frac{I_E}{\sqrt{\beta}} - \frac{1}{3}\frac{V_{cc}}{R_{B2}}$$

$$I_E = \frac{V_E}{R_E} = \frac{\frac{1}{3}V_{cc} - 0.7}{R_E}$$

$$R_C = \frac{1}{3}\frac{V_{cc}}{I_C}$$

$$R_{B1} = \frac{\frac{2}{3}V_{cc}}{I_1} = \frac{\frac{2}{3}V_{cc}}{\frac{I_E}{\sqrt{\beta}}}$$

$$R_E = \frac{\frac{1}{3}V_{cc} - 0.7}{I_E}$$

$$R_{B2} = \frac{\frac{1}{3}V_{cc}}{I_1 - I_B} = \frac{\frac{1}{3}V_{cc}}{\frac{I_E}{\sqrt{\beta}} - \frac{I_E}{\beta}} = \frac{R_{B1}}{2}\left(\frac{1}{1 - \frac{1}{\sqrt{\beta}}}\right)$$

MIDTERM

2 QUESTIONS
75 MINUTES

IF BETA NOT SPECIFIED, $\beta = 100$

IF C_π & C_μ NOT SPECIFIED, COMPLAIN

DEMAG r_π IF GOING FROM E TO B
DON'T MAG r_π IF GOING FROM B TO E

$$\omega_{PH2} = \frac{1}{50 \| 2k\left(10p + 1p\left(1 + \frac{100}{1.515k} 4k \| 12k\right)\right)} = 10 \cdot 10^{\wedge}$$

$$\omega_{PH1} = \frac{1}{R_L \| R_C \quad C_M}$$

$$= \frac{1}{2k \| 14k \quad 1pF} = 750M \frac{rad}{s}$$

Q2)

$$V_B = \frac{1}{3} V_{CC} = 4V$$

$$V_C = \frac{2}{3} V_{CC} = 8V$$

$$I_E = \frac{\frac{1}{3}V_{CC} - 0.7}{R_E} = 1.65mA$$

HOW TO

E

$$R_{B1} = \frac{\frac{2}{3}V_{CC}}{\frac{I_E}{\sqrt{\beta}}} = \frac{8}{0.1 \cdot 1.65mA} = 48.485k$$

$$R_{B2} = \frac{\frac{1}{3}V_{CC}}{\frac{I_E}{\sqrt{\beta}} - \frac{I_E}{\beta}} = 26.936k$$

$$\cancel{R_C = \frac{1}{3}\frac{V_{CC}}{I_C} =}$$

$$R_C = R_L = 2k$$

$$r_\pi = \frac{V_T}{I_B} = \frac{25mV}{16.5\mu A} = 1.5152k$$

$$\frac{I_E}{\sqrt{\beta}} - \frac{1}{3}\frac{V_{CC}}{R_{B2}}$$

$$A_M = -\frac{100}{1.5152k} \cdot 2k \| 4k \frac{2k \| \frac{1.5152k}{101}}{2k \| \frac{1.5152k}{101} + 50} = -20.19 \frac{V}{V}$$

$\frac{1}{3}$ rule (2nd V)

AM CASCODE

UPDATE

CB

$

CE

FOR OPEN VS. CLOSED TESTS

A) E C

B FROM WHERE?

$1k + 0.1k$

$1.1k$ Ok?

B) c) ASSUMING 11nF S.C.

$10\mu \rightarrow 910\,k\ \frac{rad}{s}$

11nF O.C.

$90\ \frac{rad}{s}$

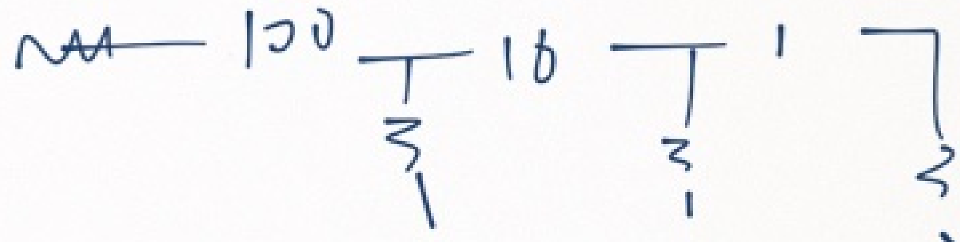
ASSUMING $10\mu F$ SHORTS

$1M\ \frac{rad}{s}$

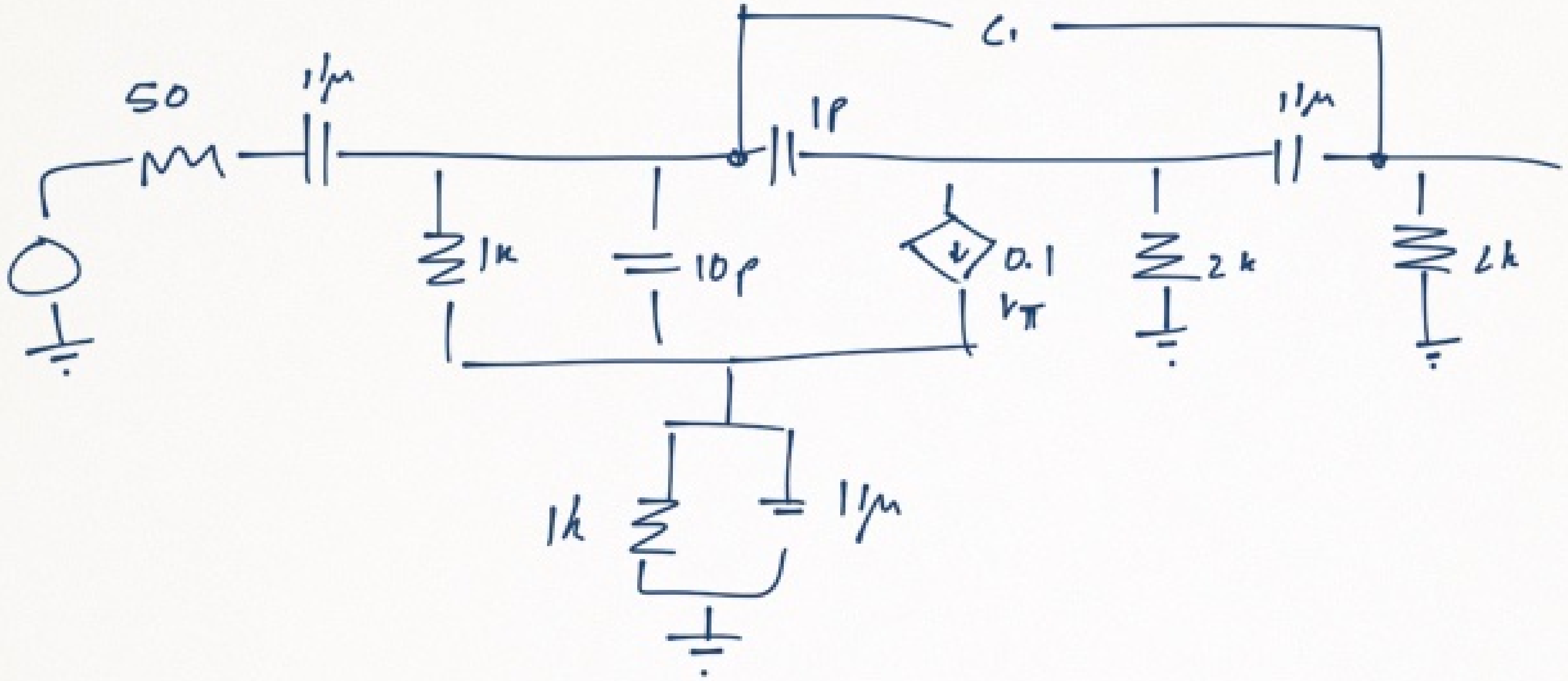
ASSUMING $10\mu F$ OPEN

$90\,k\ \frac{rad}{s}$

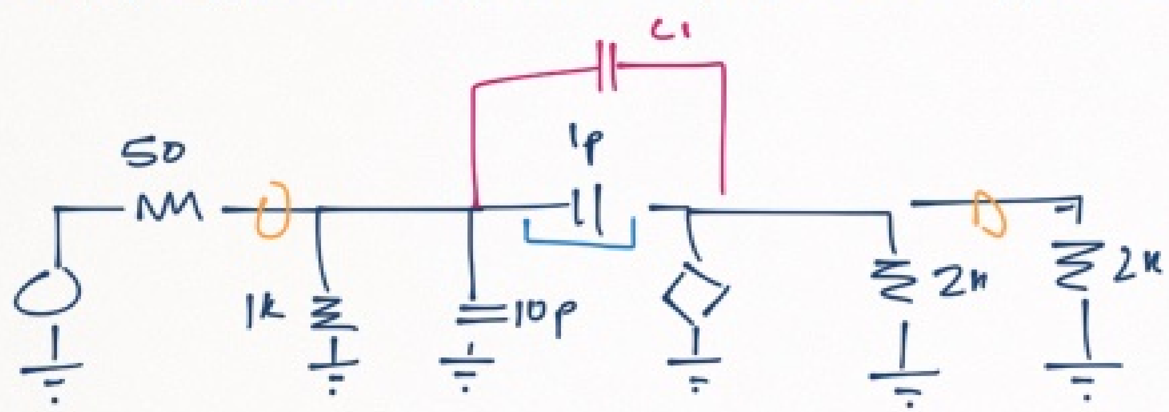
e, f, b,



$20\ \frac{rad}{s} = \frac{1}{}$



@ HIGH FREQ. LARGE CAPACITORS ARE SHORTS



10p ASSUMING 1p S.C. $\omega_{hp_1} = \dfrac{1}{10p(50\,\|\,1k\,\|\,2k\,\|\,2k)} = 2.2 \cdot 10^9 \ \frac{rad}{s}$

ASSUMING 1p O.C. $\omega_{hp_1} = \dfrac{1}{10p(50\,//\,1k)} = 2.1 \cdot 10^9 \ \frac{rad}{s}$

1p ASSUMING 10p SC $\omega_{hp_2} = \dfrac{1}{1p(2k\,//\,2k)} = 1 \cdot 10^9 \ \frac{rad}{s}$

10p OP $\omega_{hp_2} = \dfrac{1}{1p(50\,//\,1k\,//\,2k\,//\,2k)} = 22 \cdot 10^9$

PROJECT TUTORIAL

INERTIA IS FELT AT A ROTATING SHAFT

↳ "HOW MASSY DOES THIS FEEL?"

↳ FUNCTION OF RADIUS & MASS

Mr^2 $\qquad J \neq M$

Ex) ?

IF NEGATIVE F.B. THE C.E. IS →

$$1 + \frac{Ks(s+4)}{s^2+2s+2} = 0$$

FIND POLES & ZEROS
FIND ROOT LOCUS

VERIFY CLOSED LOOP SYSTEM.

$$\frac{Y}{U} = \frac{KG}{\underbrace{1+KGH}}$$

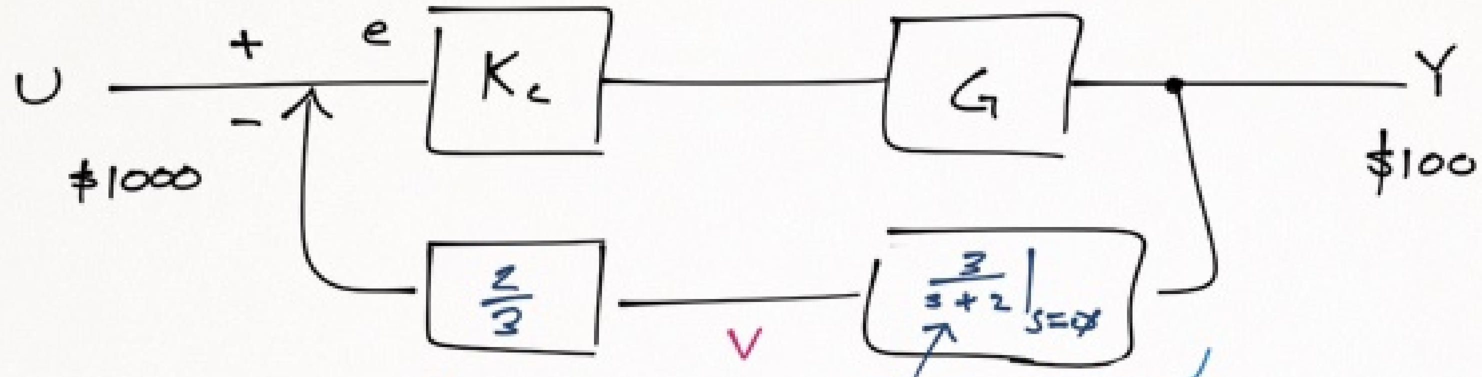
THIS IS C.E. OF CLOSED LOOP SYS.

Ex) ?

$H(s) = 1$ w/ NEG. FB & $L(s) = G_c G = \dfrac{1}{s(s+2)(s^2+4s+5)}$

OPEN-LOOP GAIN IS SHORTENED TO "LOOP GAIN", ie L

G IS USED FOR FORWARD PATH STUFF
G_c IS FOR CONTROLLER



UNITY GAIN

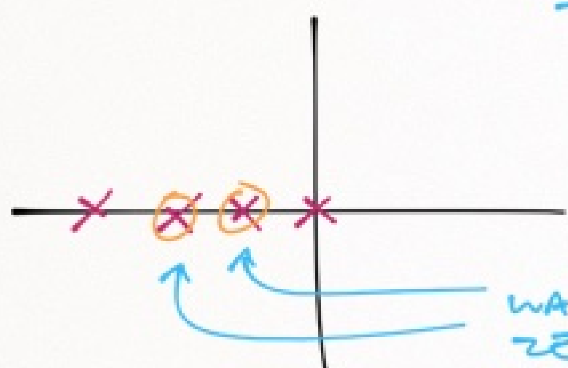
time dependent stuff

1.5 DC-GAIN

$$PID = k_D \frac{s^2 + \frac{k_P}{k_D}s + \frac{k_i}{k_D}}{s}$$

PLACE THE ZEROS RIGHT ON TOP OF THE POLES

$$(s+1)(s+2) = s^2 + 3s + 2$$



WANT TO PUT OUR ZEROS OVER OUR POLES @ 1 & 2

$k_P = 25$

$k_I = 17$

$k_D = 12$

$k_P = 3 \times k_D$

$k_I = 2 \times k_D$

EECE 352 — ASSIGNMENT 3

CHARLES CLAYTON
#21518139

1. Si — $E_g = 1.12eV$, $n_i = 1 \cdot 10^{10} \frac{1}{cm^3}$, @ $T = 300K$

Ge — $E_g = 0.67eV$, $n_i = 2.3 \cdot 10^{13} \frac{1}{cm^3}$, @ $T = 300K$

a) CALC. n, p @ $T = 348.15K$ $(75°C)$

$$n_i(300) = 10^{10} \frac{1}{cm^3} = Be^{\frac{-Eg}{2kT}} = Be^{\frac{-1.12eV}{2k300}} \longrightarrow B = 2.56 \cdot 10^{19}$$

$$n_i(348.15) = Be^{\frac{-1.12eV}{2k348.15}} = 2.56 \cdot 10^{19} e^{\frac{-1.12eV}{2k \cdot 348.15K}}$$

$$= \boxed{2.003 \cdot 10^{11} \frac{1}{cm^3}} = n_i = p_i \quad Si$$

$$n_i(300) = 2.3 \cdot 10^{13} \frac{1}{cm^3} = Be^{\frac{-0.67eV}{2k \cdot 300}} \longrightarrow B = 9.761 \cdot 10^{18}$$

$$n_i(348.15) = 9.761 \cdot 10^{18} e^{\frac{-0.67eV}{2k \cdot 348.15K}}$$

$$= \boxed{1.38 \cdot 10^{14} \frac{1}{cm^3}} = n_i = p_i \quad Ge$$

b) CALC CONDUCTIVITIES @ $T = 348.15K$

Si — $\mu_n = 1350 \frac{cm^2}{Vs}$, $\mu_p = 450 \frac{cm^2}{Vs}$

Ge — $\mu_n = 3900 \frac{cm^2}{Vs}$, $\mu_p = 1900 \frac{cm^2}{Vs}$

$$\sigma_{Si} = q\mu_n n_i + q\mu_p p_i = 4.332 \frac{mS}{m} + 1.444 \frac{mS}{m} = 5.776 \frac{mS}{m} = \boxed{57.8 \frac{\mu S}{cm}}$$

$$\sigma_{Ge} = q\mu_n n_i + q\mu_p p_i = 12.82 \frac{mS}{mm} = \boxed{0.128 \frac{S}{cm}}$$

c) Si & Ge wafer doped with $N_D = 10^{16} \frac{1}{cm^3}$

FIND DENSITIES OF MAJORITY/MINORITY CARRIERS

$n_o p_o = n_i^2$

$n_o = N_D = \boxed{10^{16} \frac{1}{cm^3}}$ MAJORITY

$p_o = \frac{n_i^2}{n_o} = \frac{10^{20}}{10^{16}} = \boxed{10^4 \frac{1}{cm^3}}$ MINORITY

} Silicon

$\sigma_{Si} = q\mu_n p_i + q\mu_p n_i$

$= q(1350 \frac{cm^2}{Vs} 10^4 \frac{1}{cm^3} + 450 \frac{cm^2}{Vs} 10^{16} \frac{1}{cm^3})$

$= \boxed{0.72 \frac{S}{cm}}$

$n_o = N_D = \boxed{10^{16} \frac{1}{cm^3}}$

$p_o = \frac{(2.3 \cdot 10^{13})^2}{10^{16}} = \boxed{5.29 \cdot 10^{10} \frac{1}{cm^3}}$

} Germanium

$\sigma_{Ge} = q\mu_n p_i + q\mu_p n_i$

$= q[3900(5.29 \cdot 10^{10}) + 1900(10^{16})]$

$= \boxed{3.044 \frac{S}{cm}}$

d) $N_A = 9.9 \cdot 10^{15} \frac{1}{cm^3}$

$n_o = N_D - N_A = 10^{16} - 9.9 \cdot 10^{15} = \boxed{10^{14} \frac{1}{cm^3}}$

$p_o = \frac{n_i^2}{n_o} = \frac{10^{20}}{10^{14}} = \boxed{10^6 \frac{1}{cm^3}}$

} Silicon

$n_o = \boxed{10^{14} \frac{1}{cm^3}}$

$p_o = \frac{(2.3 \cdot 10^{13})^2}{10^{14}} = \boxed{5.29 \cdot 10^{12} \frac{1}{cm^3}}$

} Germanium

SAME AS ABOVE PROCEDURE

$\sigma_{Si} = \boxed{2.163 \frac{S}{m}}$

$\sigma_{Ge} = \boxed{3.375 \frac{S}{m}}$

2. Si PN JUNCTION $A = 1\,mm^2$, $N_D = 10^{16}\frac{1}{cm^3}$, $N_A = 4\cdot10^{15}\frac{1}{cm^3}$

thickness of n & p-type regions is $10\mu m$, $\tau_n = 1\,ns$, $\tau_p = 0.2\,ns$ $\left(n_i = 10^{10}\frac{1}{cm^3}, \mu_n = 1350, \mu_p = 450\frac{cm^2}{Vs}\right)$

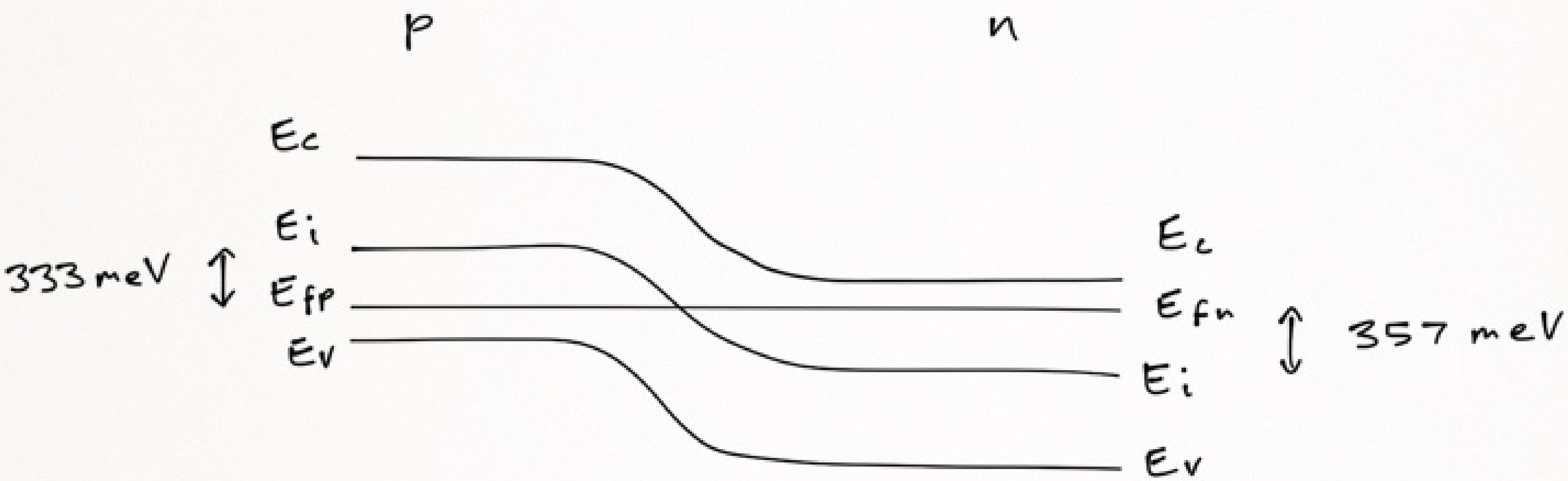
middle of the band gap

a) E_{fp} & $E_{fn} = ?$ W.R.T. E_i @ T=300K

$$E_{fp} = E_i - kT\ln\left(\frac{N_A}{n_i}\right) = E_i - k300\ln\left(\frac{4\cdot10^{15}}{10^{10}}\right) = \boxed{E_i - 333.47\,meV}$$

$$E_{fn} = E_i + kT\ln\left(\frac{N_D}{n_i}\right) = E_i + k300\ln\left(\frac{10^{16}}{10^{10}}\right) = \boxed{E_i + 357.159\,meV}$$

b) DRAW JUNCTION BAND DIAGRAM FOR PN AT EQUILIBRIUM



c)

$$V_o = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right) = \frac{k\cdot300k}{q}\ln\left(\frac{4\cdot10^{15}\cdot10^{16}}{10^{10}\cdot10^{10}}\right) = \boxed{690.63\,mV}$$

$$E_o = \frac{-q}{\varepsilon}x_n N_D = \frac{-q}{\varepsilon}\left(5.59\cdot10^{-7}\frac{4\cdot10^{15}\frac{1}{cm^3}}{4\cdot10^{15}\frac{1}{cm^3} + 10^{16}\frac{1}{cm^3}}\right)10^{16}\frac{1}{cm^3} = \boxed{2.471\cdot10^{6}\frac{V}{m}}$$

$$W_o = \left(\frac{V_o 2\varepsilon}{q}\frac{N_A + N_D}{N_A N_D}\right)^{\frac{1}{2}} = \left(\frac{2\cdot11.7\cdot8.85\cdot10^{-14}\frac{F}{cm}}{q}\frac{4\cdot10^{15} + 10^{16}}{4\cdot10^{15}\cdot10^{16}}\,690.63\,mV\right)^{\frac{1}{2}} = \boxed{5.59\cdot10^{-7}\,m}$$

d) FIND FORWARD CURRENT & DEPLETION WIDTH @ $V_A = 0.6V$ DRAW BAND DIAGRAM
FIND TOTAL STORAGE CAPACITANCE FOR NEUTRAL n & p REGIONS AT THIS BIAS VOLTAGE

$$I_{diode} = Aqn_i^2\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right)\left(e^{\frac{V_A}{V_{th}}} - 1\right)$$

$L_p = \sqrt{D_p \tau_p}$, $L_n = \sqrt{D_n \tau_n}$

$D_n = \mu_n \cdot V_{th}$, $D_p = \mu_p \cdot V_{th}$

$C_s = I\frac{\tau_p}{V_{th}}$

$$\frac{\mu_p \cdot V_{th}}{\sqrt{\mu_p V_{th} \tau_p}\, N_D} + \frac{\mu_n \cdot V_{th}}{\sqrt{\mu_n V_{th} \tau_n}\, N_A} = 6.76 \cdot 10^{-11} \frac{cm^4}{s}$$

$$1mm^2 \cdot q \cdot \left(10^{10}\frac{1}{cm^3}\right)^2 = 1.602 \cdot 10^{-7} \frac{sA}{m^4}$$

$$\frac{\frac{m^2}{\cancel{V} \cdot s} \cdot \cancel{V}}{\sqrt{\frac{m^2}{\cancel{V} \cdot s} \cdot \cancel{V} \cdot \cancel{s} \cdot \frac{1}{m^3}}} = \frac{\frac{m^2}{s}}{\cancel{m} \cdot \frac{1}{m^{\cancel{3}2}}} = \frac{m^4}{s}$$

$$m^2 \cdot C \cdot \frac{1}{m^6} = \frac{C}{m^4} = \frac{As}{m^4}$$

$$\boxed{I_{diode} = 4.608 \cdot 10^{-13} A}$$

$$C_s = 4.608 \cdot 10^{-13}\left(\frac{0.2ns}{25mV}\right) = \boxed{3.686 \cdot 10^{-21} F}$$

$$W = \left(\frac{2\varepsilon}{q}\frac{N_A + N_D}{N_A N_D}(V_0 - V_A)\right)^{\frac{1}{2}} = \boxed{2.025 \cdot 10^{-7} m}$$

SAME AS PREVIOUS PAGE EXCEPT $-V_A$

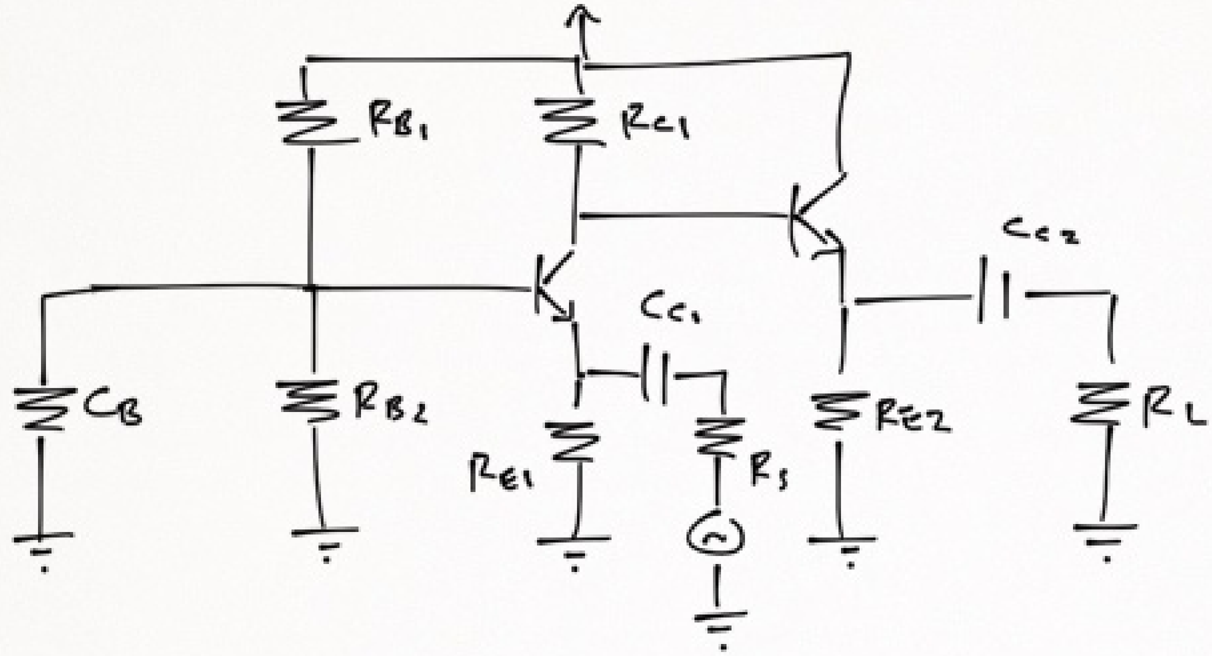
e) $V_A = -0.6V$

$W = \boxed{7.641 \cdot 10^{-7} m}$

$I = \boxed{-4.42 \cdot 10^{-13} A}$

USING SAME FORMULAS AS ON PREV. PAGE BUT $V_A = -0.6V$

$C_s = -4.42 \cdot 10^{-13} \dfrac{0.2 nS}{25 mV} = \boxed{-3.536 \cdot 10^{-21} F}$



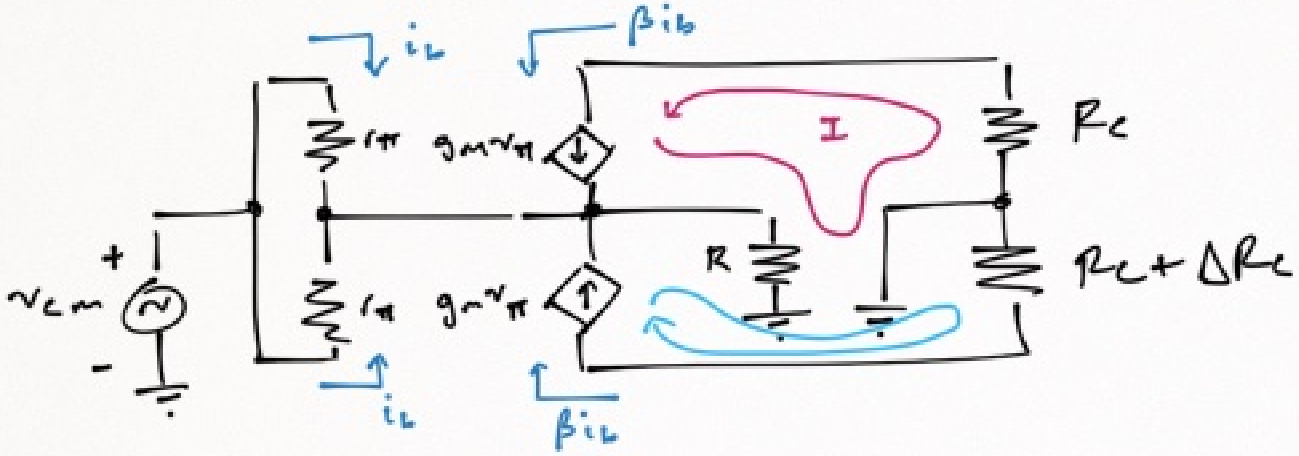
LOW FREQUENCY

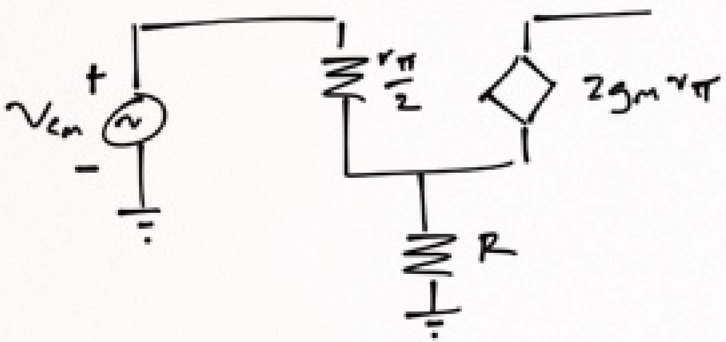
NOT TESTING ON
SLEW RATE/ FULL POWER BANDWIDTH

NOT TESTING OSCILLATORS & FILTERS

TESTING FEEDBACK

SMALL SIGNAL MODEL FOR DIFFERENTIAL INPUT





$$v_\pi = \frac{v_{cm} \cdot \frac{r_\pi}{2}}{\frac{r_\pi}{2} + R(1+\beta)} = \frac{r_\pi v_{icm}}{r_\pi + 2R(1+\beta)}$$

$$v_o = \frac{v_{cm} \Delta R_c}{\frac{1}{g_m} + 2R\frac{(1+\beta)}{\beta}} \simeq v_{cm} \frac{\Delta R_c}{2R}$$

$$A_{cm} = \frac{\Delta R_c}{2R}$$

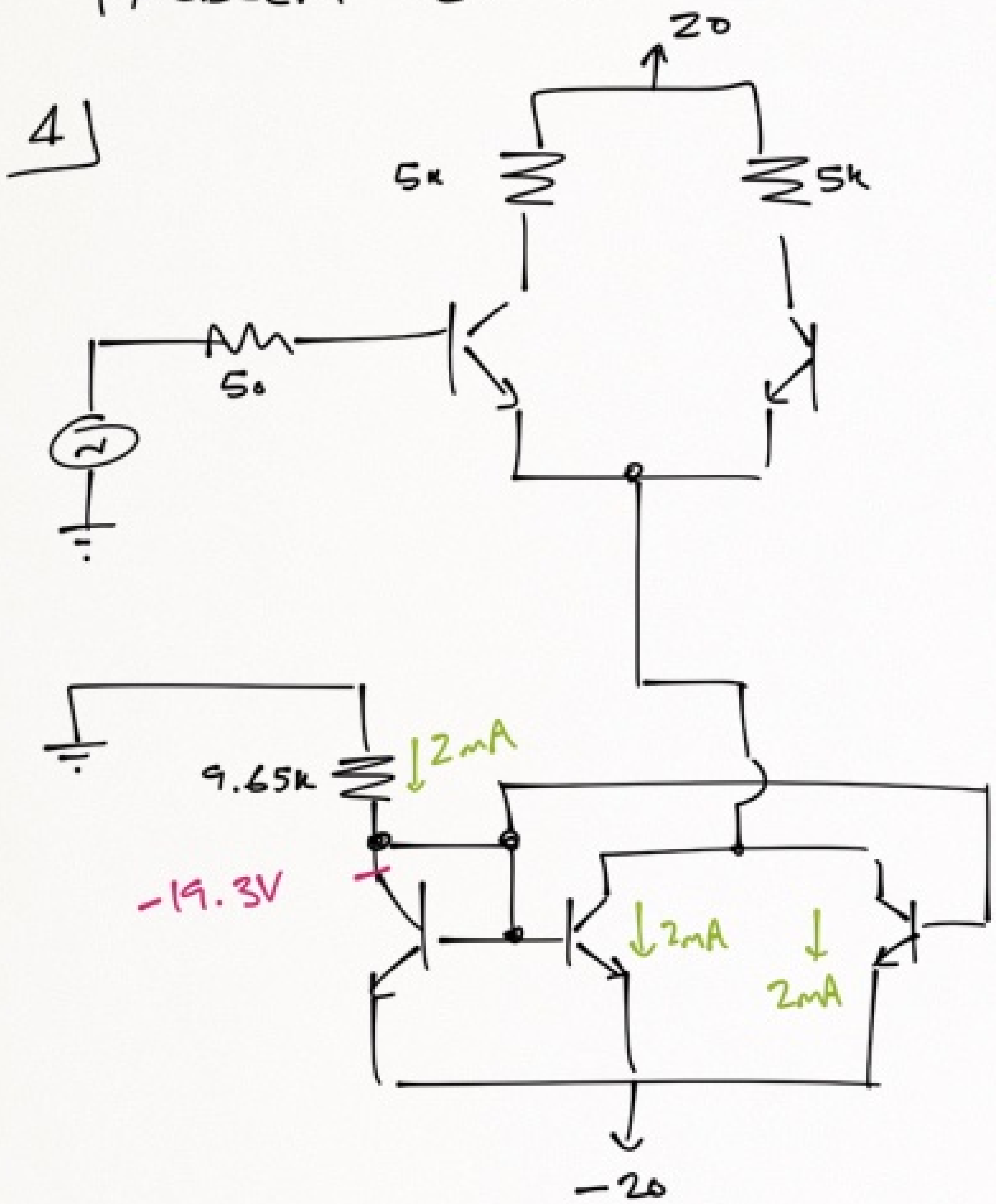
COMMON-MODE REJECTION RATIO

$$CMRR = \left| \frac{A_d}{A_{cm}} \right| = g_m 2R \frac{R_c}{\Delta R_c} \simeq 100{,}000$$

in example op-amp

PROBLEM SET 5

4)

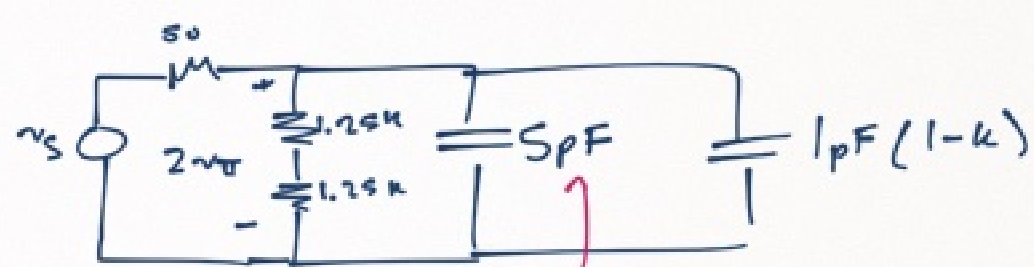


$I_{E1} = I_{E2} = 2mA \approx I_{C1}, I_{C2}$

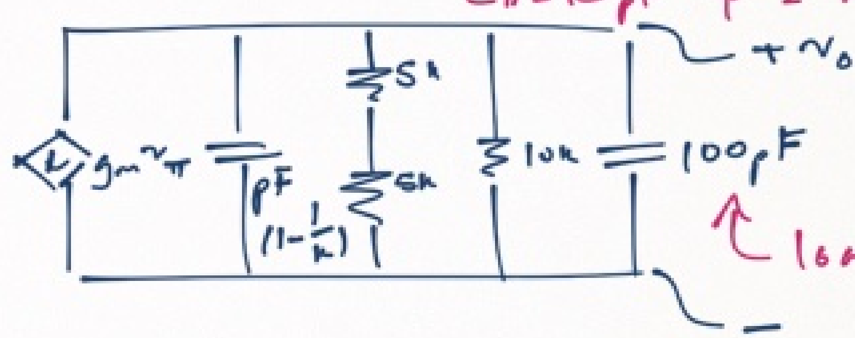
$g_{m1} = g_{m2} = 80 m\mho$

$r_{\pi 1} = r_{\pi 2} = 1.25k$

SMALL SIGNAL CIRCUIT



$C_\pi = 10pF$ & 2 IN SERIES



load capacitance

$$\omega_{H3dB} = \frac{1}{101pF \cdot 5k\Omega} = 2M\frac{rad}{s}$$

"BIG RESISTANCE, SMALL FREQ."

$\therefore$ v_o IS THE ONE WE CALC.

(?)

MILLER'S

$$k = \frac{v_o}{2v_\pi} = \frac{-g_m\, 10k /\!/ 10k}{2v_\pi} = \frac{-400\,\cancel{v_\pi}}{2\cancel{v_\pi}} = -200$$

sees $\sim 49\Omega$ $\quad \therefore\ C_1 = 206pF$ & $C_2 = 101pF$ sees $\sim 5k$

1. A feedback amplifier is designed using a gain of 10^4 for the basic amplifier and $\beta = 10^{-2}$. However, the basic amplifier actually has a gain of 7×10^3.
a) What percentage of the intended gain does the actual gain represent?
b) Derive an expression for $\partial A_f / \partial A$ in terms of A and β.
c) By deriving the transfer function with feedback, explain why, for an amplifier having a low pass, single time-constant, frequency response, for every 20 dB of gain sacrificed by the application of negative feedback the 3dB bandwidth is extended by a decade. (Assume the feedback is purely real, i.e., frequency independent).

2. Use feedback techniques to show that the circuit shown in figure1 has a gain of $-R_2/R_1$.

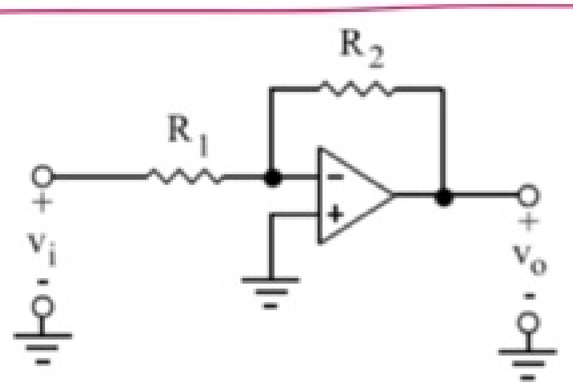
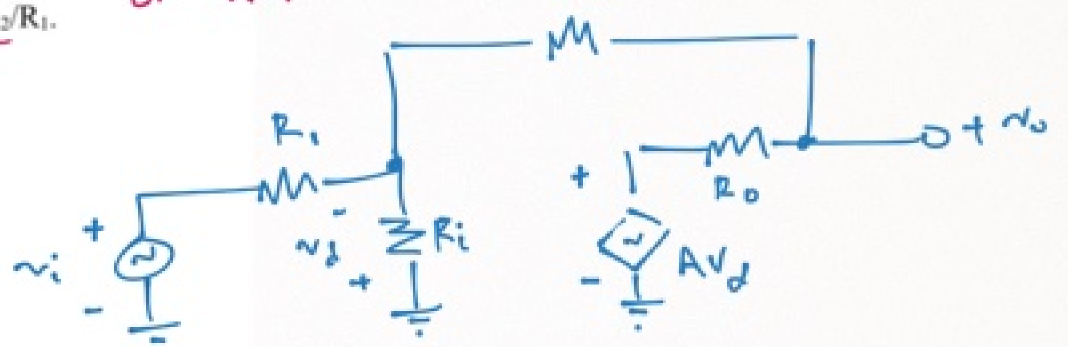


Figure 1.

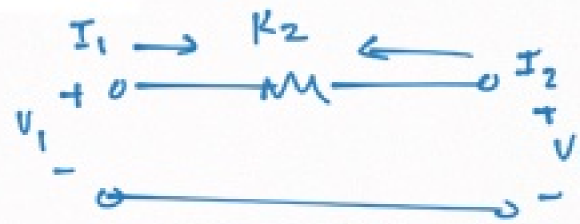
P7-2

OP AMP model



USE SHUNT-SHUNT → Y PARAMETER (will be told best topology)

FEEDBACK NETWORK



voltage are indep.
currents are dep.

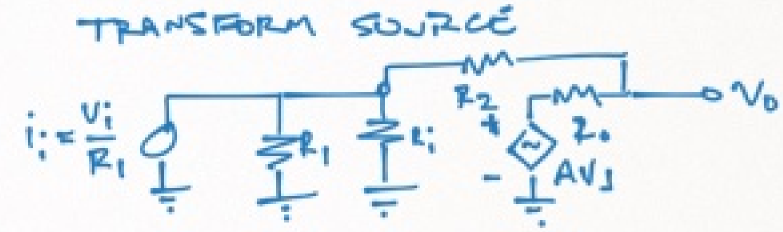
means if V_2 is shorted

$$y_{11} = \frac{I_1}{V_1}\bigg|_{V_2=0} = \frac{1}{R_2}$$

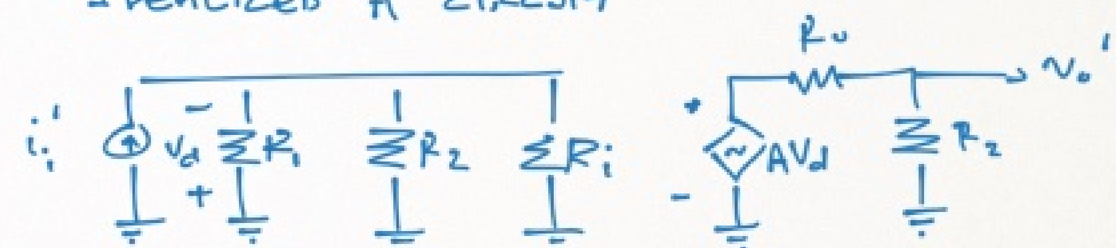
$$y_{12} = y_{21} = \frac{I_1}{V_2}\bigg|_{V_1=0} = -\frac{1}{R_2}$$

$$y_{22} = \frac{I_2}{V_2}\bigg|_{V_1=0} = \frac{1}{R_2}$$

TRANSFORM SOURCE



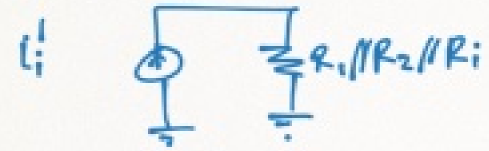
IDEALIZED A CIRCUIT

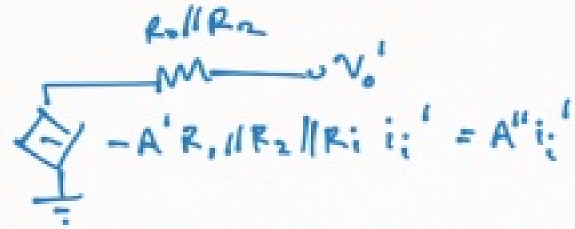


let $V_d' = -V_d$

$$A' = \frac{AR_2}{R_o + R_2}$$

P7-2 CONT'D



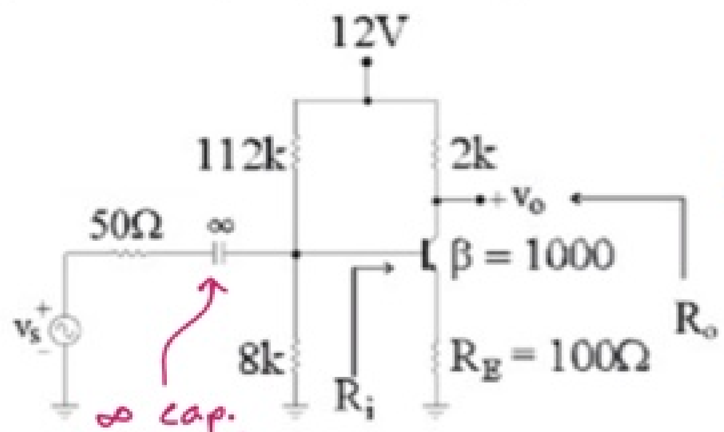


$$A_f = \frac{v_o}{i_i} = \frac{-A''}{1 - A''B} \simeq \frac{1}{\beta} = -R_2$$

accurate for very large A

$$A_{fv} = \frac{v_o}{v_i} = \frac{v_o}{i_i R_1} = \frac{-R_2}{R_1}$$

5. Analyze the circuit shown in figure 4 using feedback techniques (the best topology is the series-series topology) with RE forming the feedback network and for the transistor having an ro = 50 kΩ to find the small-signal voltage gain of the amplifier, Av = vo/vs, Ri and Ro all at mid band.



∞ cap. lets everything but DC through

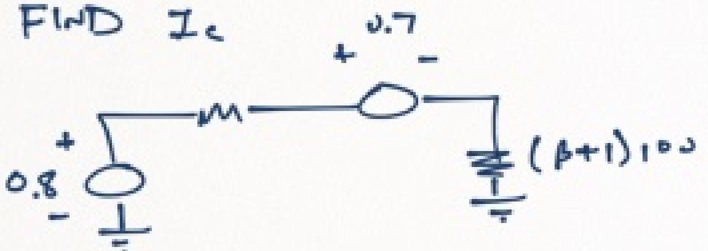
series-series

$V_1 = z_{11} I_1 + z_{12} I_2$
$V_2 = z_{21} I_1 + z_{22} I_2$

for fun we include ro in this problem

↳ error for doing so is about 1% b/c of magnification due to feedback.

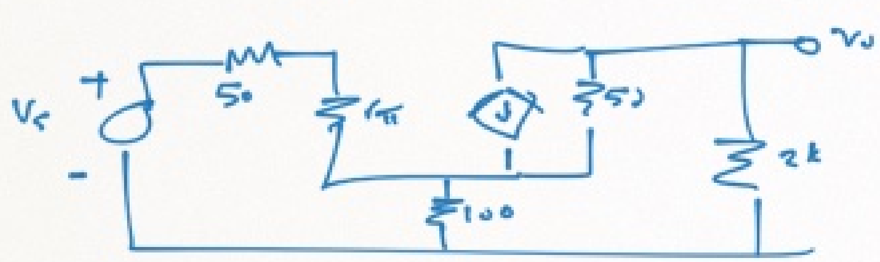
FIND I_C



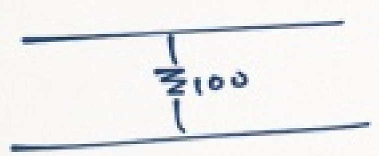
$$I_B = \frac{0.8 - 0.7}{100.1k + 7.47k} = 0.93\,\mu A$$

$I_C = 0.93\,mA$ $\quad r_\pi = 26.9k$ $\quad g_m = 37.2\,m℧$

small signal



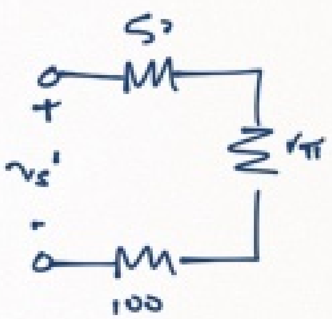
FEED BACK NETWORK

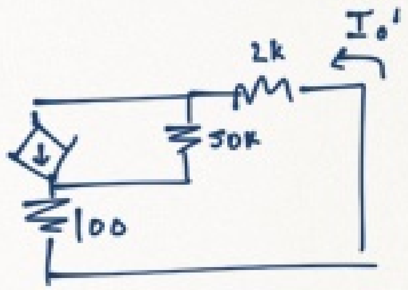


$$z_{11} = \frac{V_1}{I_1}\Big|_{I_2=0} = 100$$

$$z_{12} = \frac{V_1}{I_2}\Big|_{I_1=0} = 100$$

$$z_{22} = \frac{V_2}{I_2}\Big|_{I_1=0} = 100$$





$$A' = \frac{I_o'}{V_s'} = \frac{g_m v_\pi \dfrac{50k}{50k + 2k + 0.1k}}{\dfrac{v_\pi (r_\pi + 50 + 100)}{r_\pi}} = 35.4\,m℧$$

$$A_f' = \frac{I_o}{V_s} = \frac{35.4\,m℧}{1 + 100\,(35.4\,m℧)}$$

since $V_o = -I_o \cdot 2k$

$$\therefore\ A_v = \frac{v_o}{v_s} = \frac{-I_o\, 2k}{v_s} = -A_f \cdot 2k = -15.6$$

in notes he put Vs here. it shouldn't be

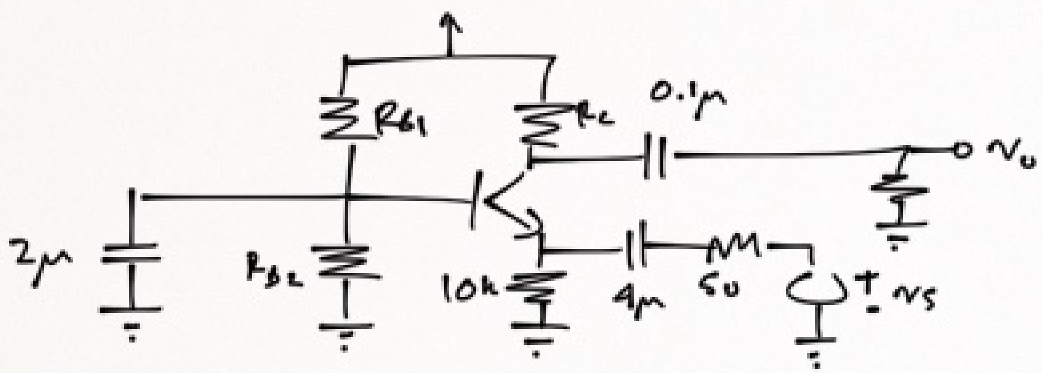
$R_{inf} = (1 + A'B)(50 + r_\pi + 100) = 123k$

$R_i = 123k - 50 = 123k$

$R_{outf} = (1 + A'B) \cdot R_{out} = 4.54(50k + 2k + 100) = 236.6k$

$R_o' = 236.5k - 2k = 234.5k$ $\qquad R_o = 2k // 234.5k = 1.98k$

MIDTERM Q2



$V_E = 10k(0.5mA) = \frac{1}{3}V_{cc} - V_B = 5.7$

$I_C \simeq I_E \rightarrow R_C = 10k$

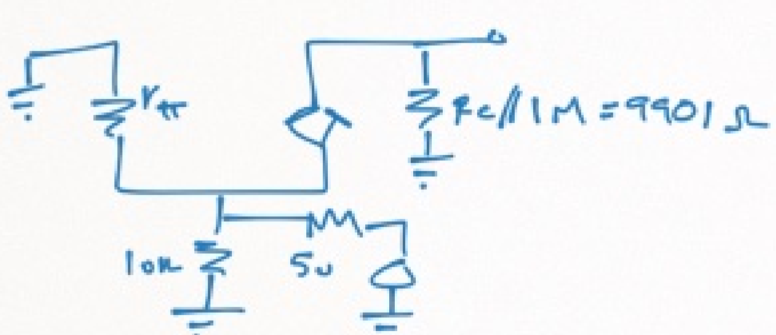
$I_1 = 0.1 I_E$

$g_m = 20mV$
$r_\pi = 5k$

$R_{B1} = \frac{15-5.7}{0.05mA} = 186k$

$R_{B2} = \frac{5.7}{I_1 - I_B} = \frac{5.7}{0.045mA} = 127k$

$A_M = 55M$ @ midband



$A_M = \frac{v_o}{v_\pi} \cdot \frac{v_\pi}{v_s}$

$\frac{v_o}{v_\pi} = -g_m \frac{v_\pi}{v_\pi} \cdot 9901 = -198 \frac{V}{V}$

$v_\pi = -\left(-v_s \frac{r_\pi}{1+\beta} // 10k\right) \Big/ \left(\frac{r_\pi}{1+\beta} // 10k + 50\right) = \frac{-v_s 49.2}{99.2} = -0.495 v_s$

$\omega_{Hp2} = \frac{1}{1pF \cdot 9.9k} = 1.01 \cdot 10^8 \frac{rad}{s}$

$\omega_{Hp1} = \frac{1}{10pF \; 49.2 // 50} = 4.03(10^9) \frac{rad}{s}$

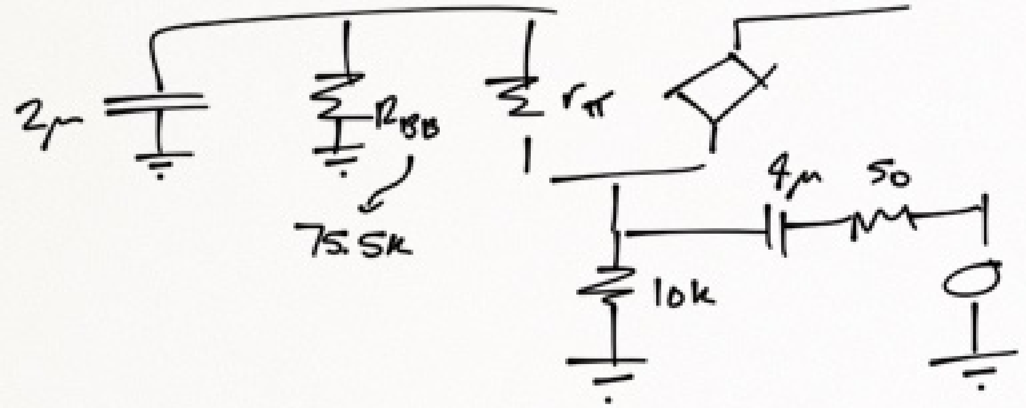
$\omega_{H3dB} = 1.01(10^8) \frac{rad}{s}$ ← B/C ω_{Hp1} & ω_{Hp2} are more than a decade apart

$\omega_{L2} = \frac{1}{C_B R_{BB}} = \frac{1}{2\mu F \cdot 75.5k} = 6.6 \frac{rad}{s}$

$\omega_{Lp3} = \frac{1}{0.1\mu F \cdot 1.01M} = 9.9 \frac{rad}{s}$

$A_M = 98 \frac{V}{V}$

Ex CONT'D



$$\tau_{C_{c1}}^{sc}\Big|_{C_B \text{ short}} = 4\mu F(49.5+50)$$

$$\tau_{C_B}^{sc}\Big|_{C_{c1} \text{ short}} = 2\mu\big(\underbrace{R_{BB}/\!/\big(r_\pi + (10k/\!/50)(1+\beta)\big)}_{\sim 75.5k/\!/10k}\big) =$$

$$\therefore\ \omega_{L3dB} = \frac{1}{C_{c1}(99.5)} = 2.5(10^3)\frac{rad}{s}$$

Missing conclusion

OPEN-LOOP $\quad G = \frac{1}{poly}$

$$\frac{Y}{U} = k \frac{1}{poly + k}$$

$$k = k_d \frac{\left(s^2 + s\frac{k_p}{k_d} + \frac{k_i}{k_d}\right)}{s} \qquad P + \frac{I}{s} + \frac{Ds}{\frac{1}{100s} + 1}$$

$$s^2 + s\frac{k_p}{k_d} + \frac{k_i}{k_d} = \emptyset$$

$$s = \pm\sqrt{\frac{k_p - 4k_pk_i + k_i}{2k_d}} \qquad k_d \neq 0$$

$$\frac{\dfrac{k_d\left(s^2 + \frac{k_p}{k_d}s + \frac{k_i}{k_d}\right)}{s}}{\left(s + \frac{120}{13}\right)\left(s + \frac{7}{570}\right)\left(6700 s^2\right) + k_d\dfrac{\left(s^2 + \frac{k_p}{k_d}s + \frac{k_i}{k_d}\right)}{s}}$$

pick k_p, k_i, k_d such that zeros = poles

$$\frac{K}{67H + 1}$$

ZN

$R\text{-}H \rightarrow K_u$

$T_u = \frac{2\pi}{\omega}$ @ $K = K_u$

$$CE: \left(x + \frac{120}{13}\right)\left(x + \frac{7}{310}\right)\left(6700x^2\right)$$

$$: 6700x^4 + 61997.4x^3 + 1396.53x^2 + 0x + K_c$$

4 QUESTIONS

100 min designed for
150 to do it

PROBLEM # 2
MIDTERM

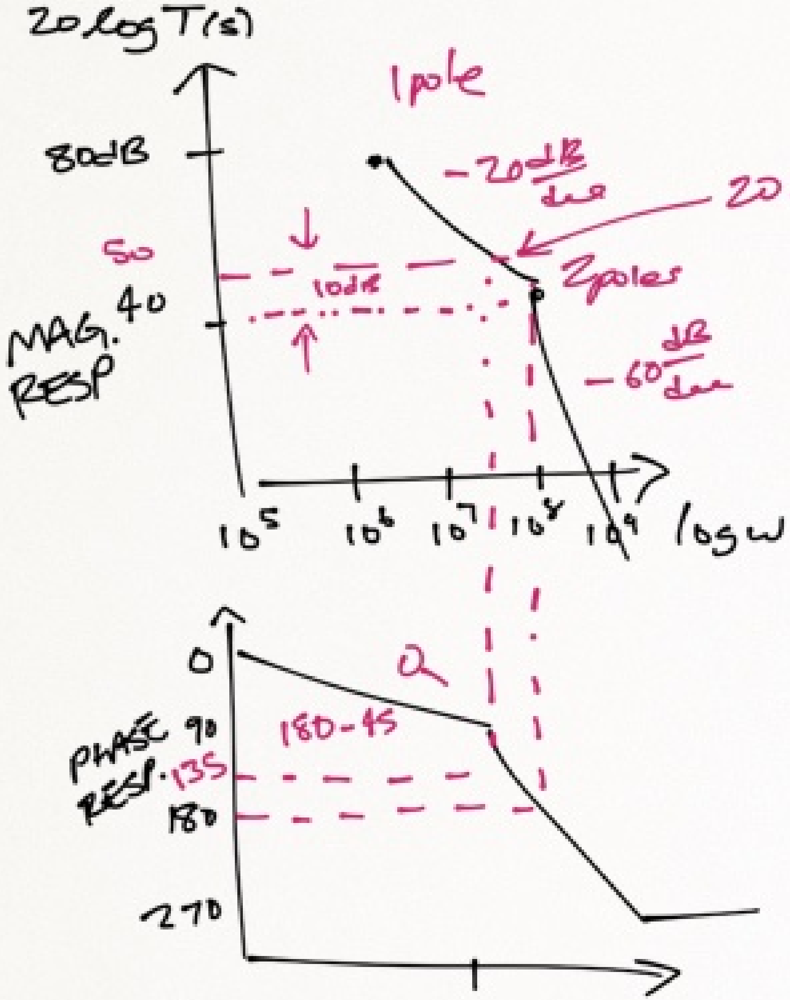
common collector

nothing on set 21/22

$2+2j$

$2-2j$

$(s+(3,2))(s+(3,2))$



$\rightarrow$ 50dB = 20log$\left(\frac{1}{\beta}\right)$

b) $\beta = 0.00316$

c) 10dB

d) $20\log\left(\frac{1}{\beta}\right) = 40dB$

$\hookrightarrow 0.01 = \beta$

e) $20\log\frac{1}{\beta} = 60dB = 10^3$

$\phi_M = 90°$, $G_M = 20dB$

#7 his solution annotated

STABILITY USING BODE PLOTS