Lecture 32

- Last time:

  CHAPTER 10 ... f RESPONSE OF CE, CC, CB.

  - Frequency response of the CE as voltage amp
  - The Miller approximation
- Today :

  CC CB

  - Frequency response of voltage and current buffers
  - Start multi-stage amplifiers: Chapter 9

  I - SOURCES.

$\boxed{\text{Miller Capacitance } C_M}$

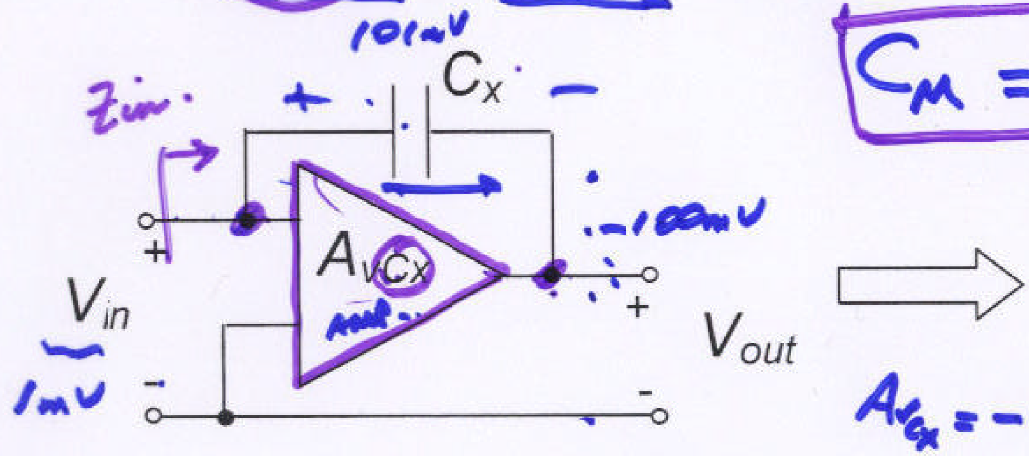
Effective input capacitance: $\swarrow Z_\mu$

"Z_{eff}"

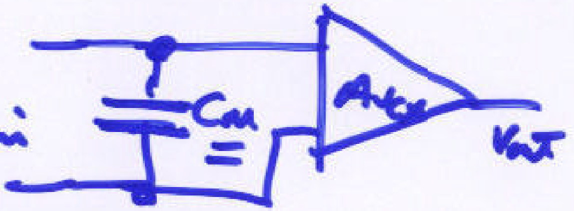
$$Z_{in} = \frac{1}{j\omega C_M} = \left(\frac{1}{1-A_{vC_\mu}}\right)\left(\frac{1}{j\omega C_\mu}\right) = \frac{1}{j\omega\left[\underbrace{\left(1-A_{vC\mu}\right)C_\mu}\right]}$$

$$\boxed{C_M = C_\mu\left(1 - A_{vC_\mu}\right)}$$

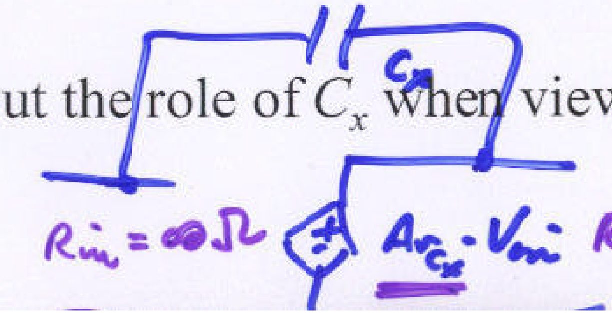
$$= C_\mu\left(1 + \underbrace{g_m R_{out}'}_{\sim 100}\right)$$

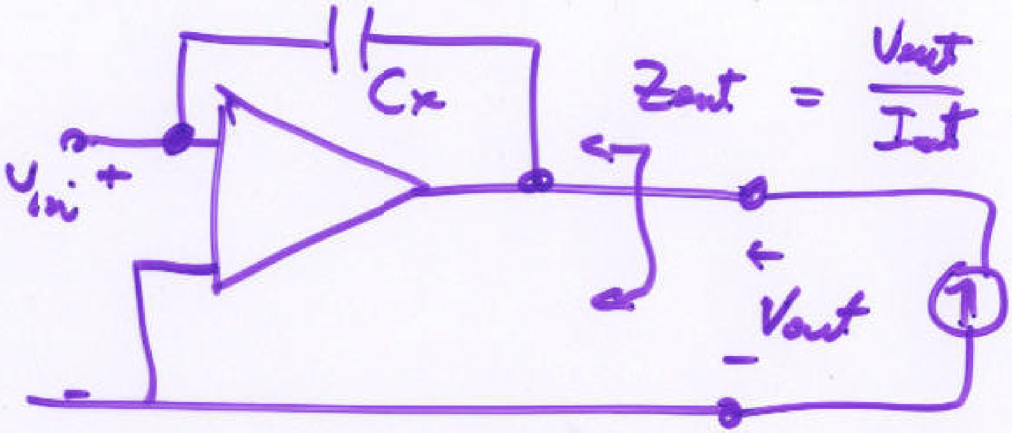


$A_{vCx} = -100$.



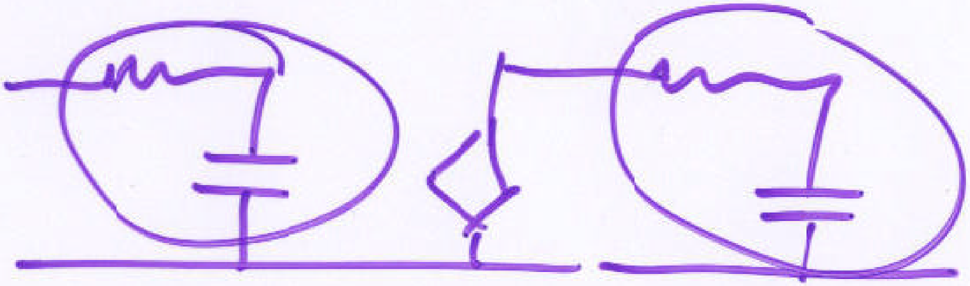
What about the role of C_x when viewed from the output port?



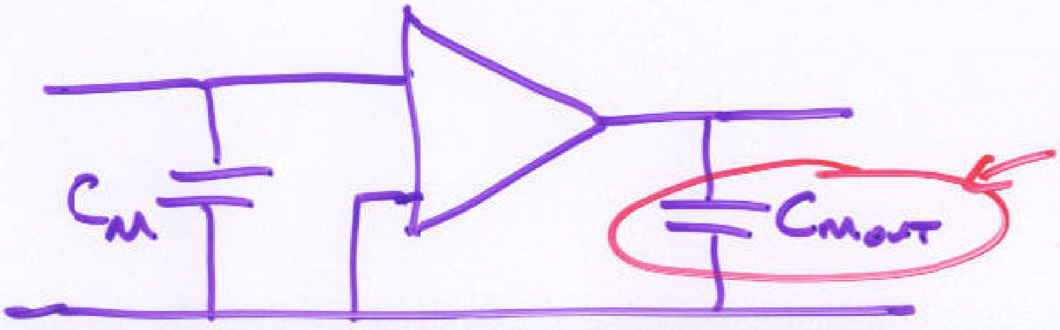


$$Z_{out} = \frac{V_{out}}{I_{out}} \;....$$

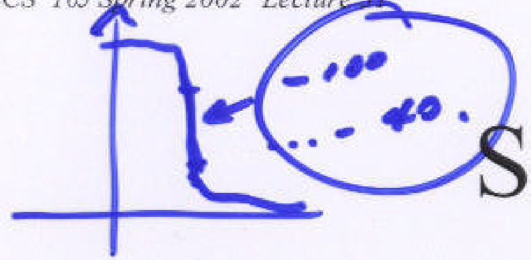
$$V_{out} = A_{v_{Cx}} V_{in}$$



$$\underline{C_{M_{out}}} = C_x \left(\frac{1}{1-(1/A_{v_{Cx}})}\right) \leftarrow$$ YOU DO THIS . . .

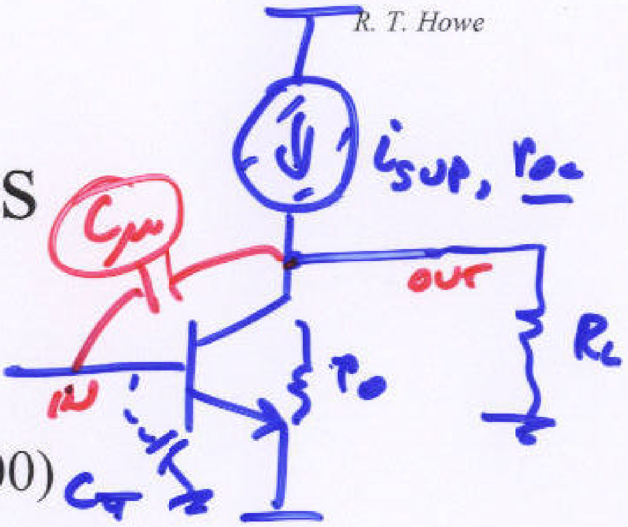


OMIT OUTPUT FROM <u>H&S.</u>



NONLINEAR:

Some Examples



Common emitter/source amplifier:

DISASTER!!

$R_S = 0.$

A_{vC_μ} = Negative, large number (-100)

$$= -g_m\left(r_o \| r_{oc} \| R_L\right) \approx -\text{BIG}.$$

$$C_M = C_\mu\left(1 - \left[-g_m \underbrace{r_o \| r_{oc} \| R_L}_{R_{out}}\right]\right) = \underbrace{101\, C_\mu}_{\text{BIG}}$$

$\gg C_\pi$..

Common collector/drain amplifier:

A_{vC_π} = Slightly less than 1 ≈ 1

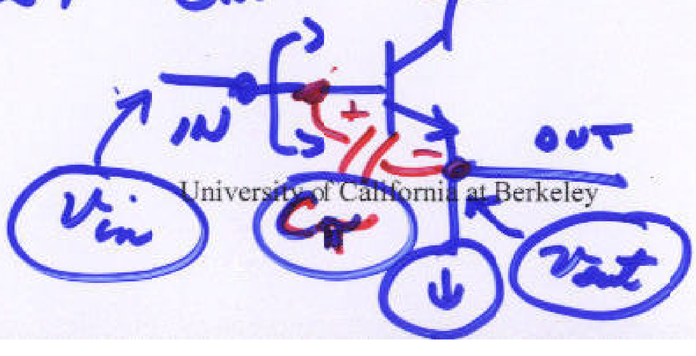
"BOOTSTRAPPING".

$$= C_\pi\left(1 - \cancel{A_{vC_\pi}}\right)$$

$$= C_\pi(1 - 1)$$

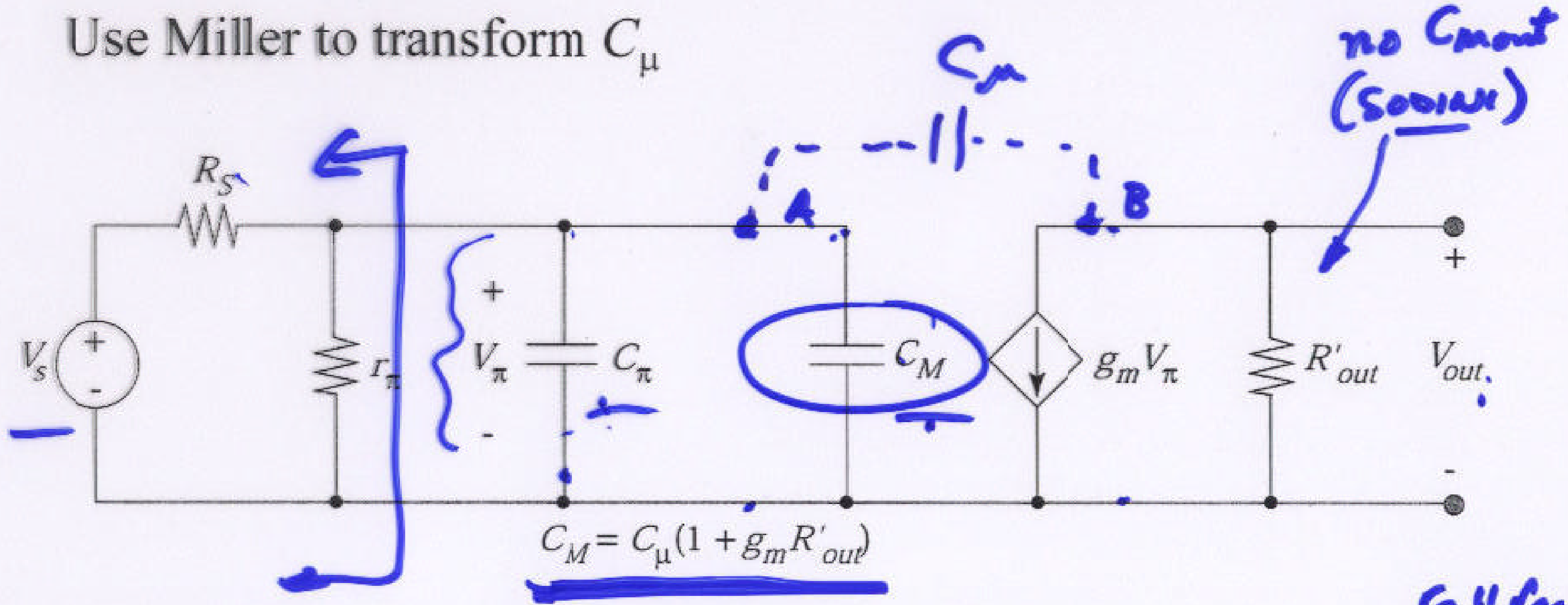
$$= 0$$

$C_M \approx 0$



CE Amplifier using Miller Approx.

Use Miller to transform C_μ



$C_M = C_\mu(1 + g_m R'_{out})$

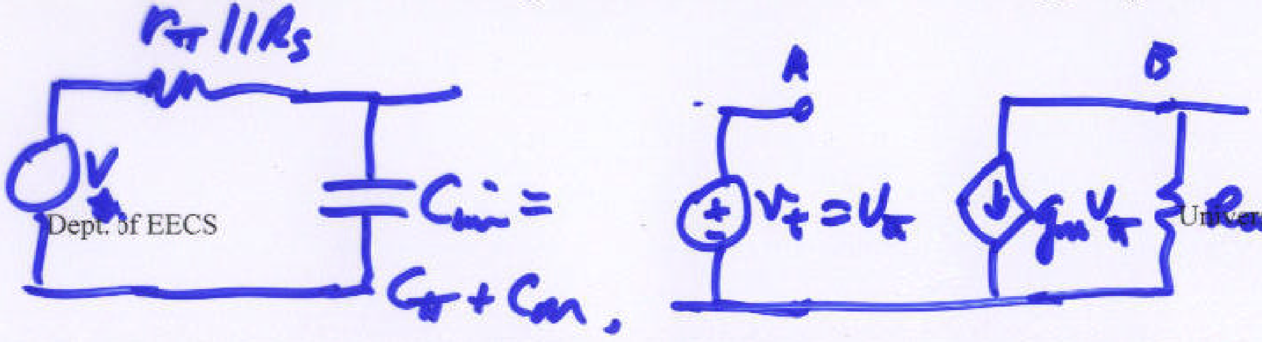
$r_o \| r_{oc} \| R_L$

↓

Analysis is straightforward now … single pole!

$v_t/v_\pi = -g_m \cdot R'_{out}$

$= A_v C_m$



Comparison with "Exact Analysis"

UNDERSTANDING

Miller result:

$$\omega_{p1}^{-1} \cong R_{in} C_{in} = \underline{(R_S \| r_\pi)}\left(C_\pi + \underbrace{(1 + g_m \underline{R'_{out}}) C_\mu}_{C_M}\right)$$

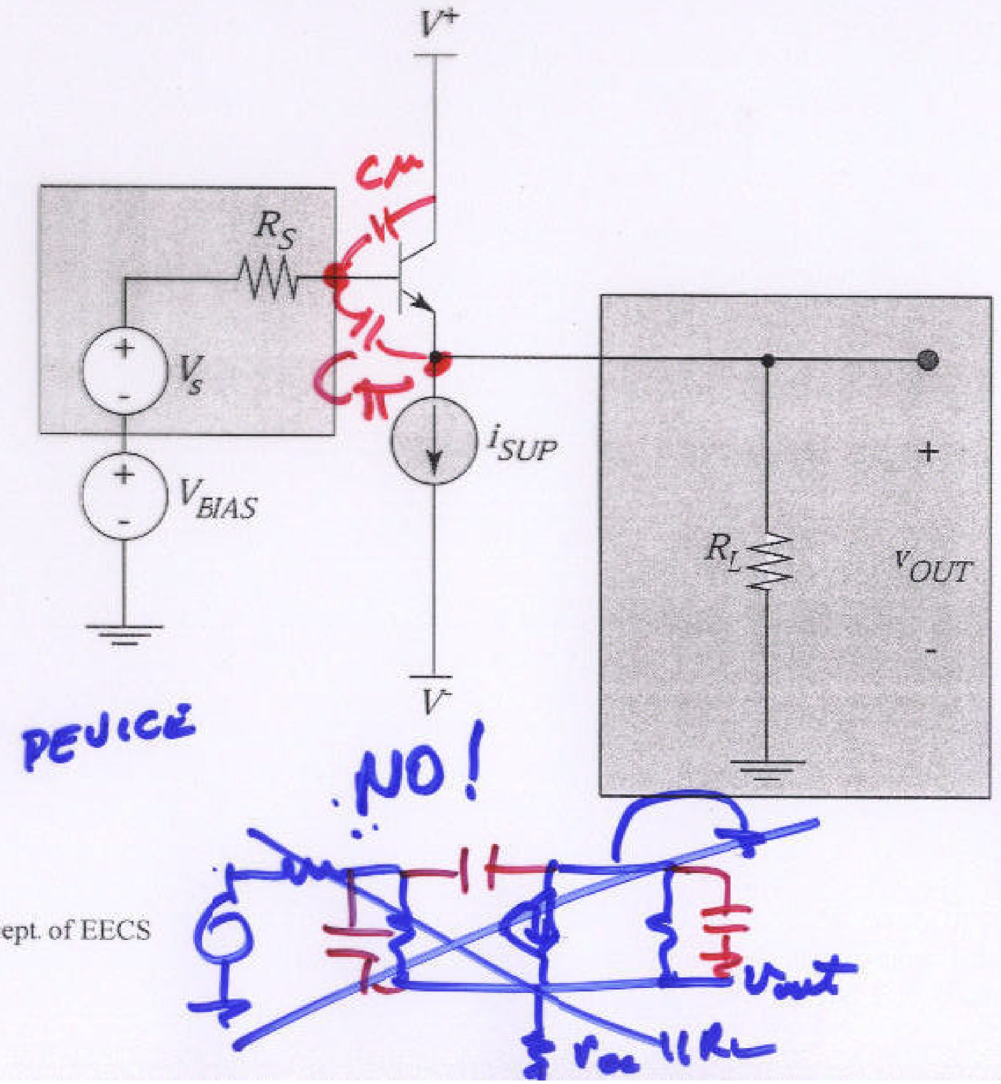
missing

"Exact result:"

$$\omega_{p1}^{-1} \cong (R_S \| r_\pi)\{C_\pi + (1 + g_m R'_{out}) C_\mu\} + \boxed{\underline{R'_{out}} C_\mu}$$

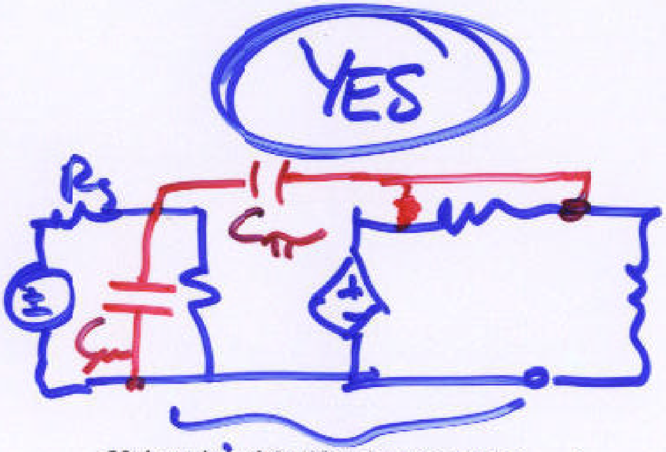
$\boxed{\omega_{p(CE)} << \omega_T.}$ NARROWBAND.

» Common-Collector Amplifier .



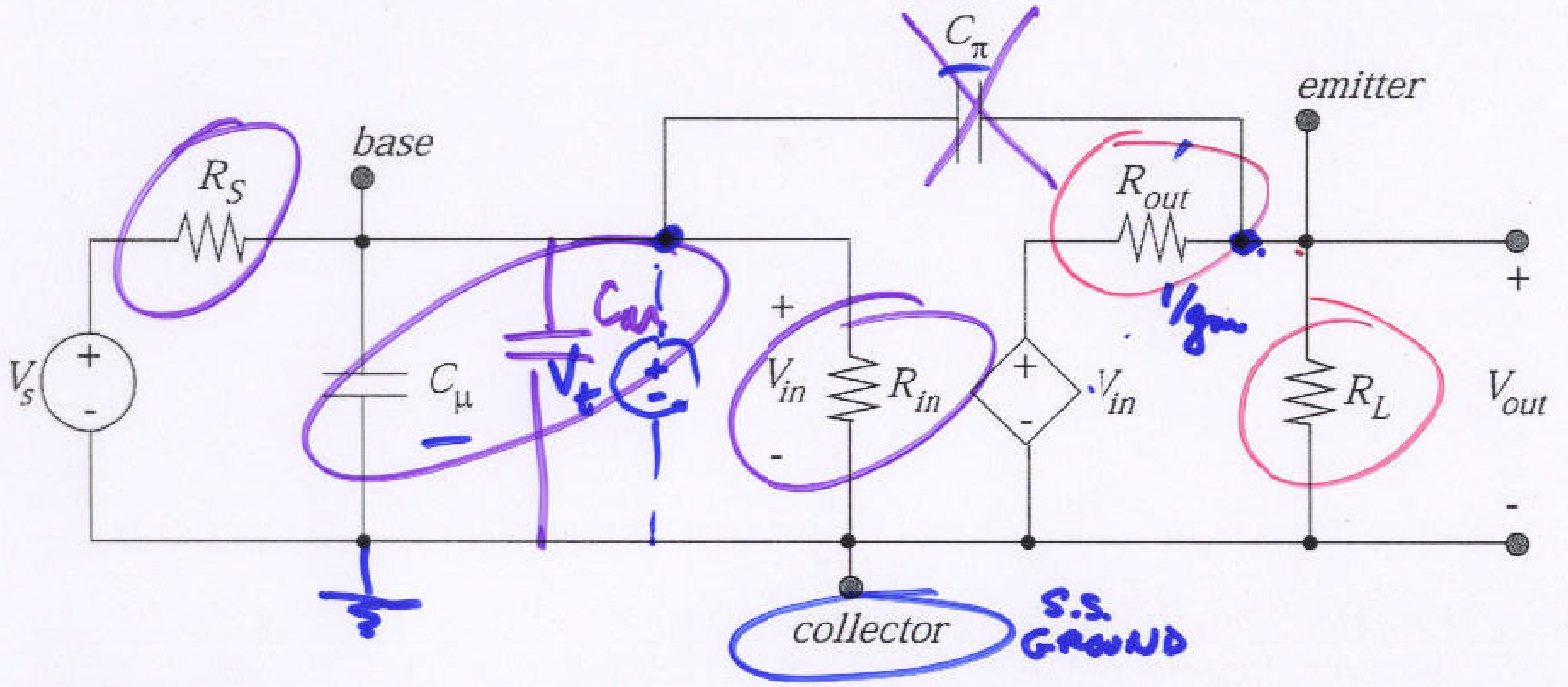
Procedure:

1. {Small-signal two-port model}
2. Add device (and other) capacitors



2-PORT!

Two-Port CC Model with Capacitors



Find Miller capacitor for C_π -- note that the base-emitter capacitor is Between the input and output.

$$R'_{out}\Big|_{\text{omit } R_S} = \frac{1}{g_m} + \cancelto{0}{\frac{R_S}{\beta_o}} \doteq \frac{1}{g_m}.$$

$$Av_{C_\pi} = \frac{R_L}{\frac{1}{g_m} + R_L}$$

$$= \frac{g_m R_L}{1 + g_m R_L}$$

Voltage Gain $A_{vC\pi}$ Across C_π

$$A_{vC_\pi} = \frac{g_m R_L}{1+g_m R_L} \; ; \; \left(1 - A_{vC_\pi}\right) = \frac{1+\cancel{g_m R_L}}{1+g_m R_L} - \frac{\cancel{g_m R_L}}{1+g_m R_L} = \frac{1}{1+g_m R_L}.$$

Note: this voltage gain is neither the two-port gain nor the "loaded" voltage gain

$$C_{in} = C_\mu + C_M = C_\mu + (1 - A_{vC_\pi})C_\pi$$

$$\frac{C_\pi}{C_\mu} \gtrsim \underline{10.}$$

$$= C_\mu + \underbrace{\frac{C_\pi}{1+\underbrace{g_m R_L}_{100}}}_{\text{BOOTSTRAP } C_\pi.}$$

Bandwidth of CC Amplifier

Input low-pass filter's –3 dB frequency:

$$\omega_p^{-1} = \left(\underline{R_S} \,||\, R_{in}\right)\left(C_\mu + \frac{C_\pi}{1+g_m \underline{R_L}}\right)$$

$R_{in} = r_\pi + (\beta_o + 1)(R_L || r_o || r_{oc})$
$= BIG.$

- Substitute favorable values of R_S, R_L: BEST CASE
  - $\underline{\underline{R_S \approx 1/g_m}}$ $\underline{R_L >> 1/g_m}$

0, SMALL

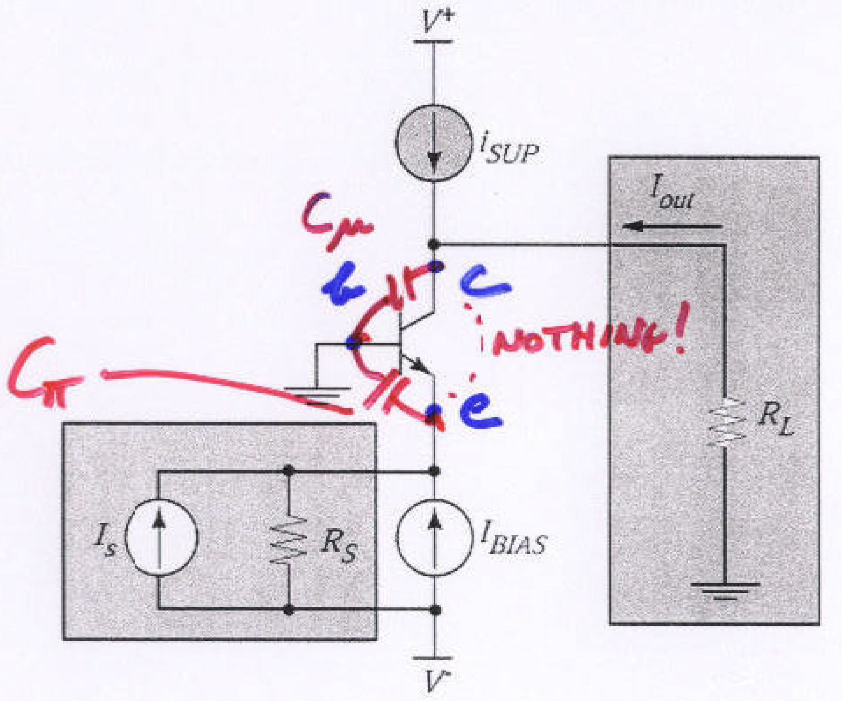
$$\omega_p^{-1} \approx \underbrace{(1/g_m)}\left(C_\mu + \cancel{\frac{C_\pi}{1+BIG}}\right) \approx \boxed{C_\mu/g_m}$$

CC ...

WIDEBAND

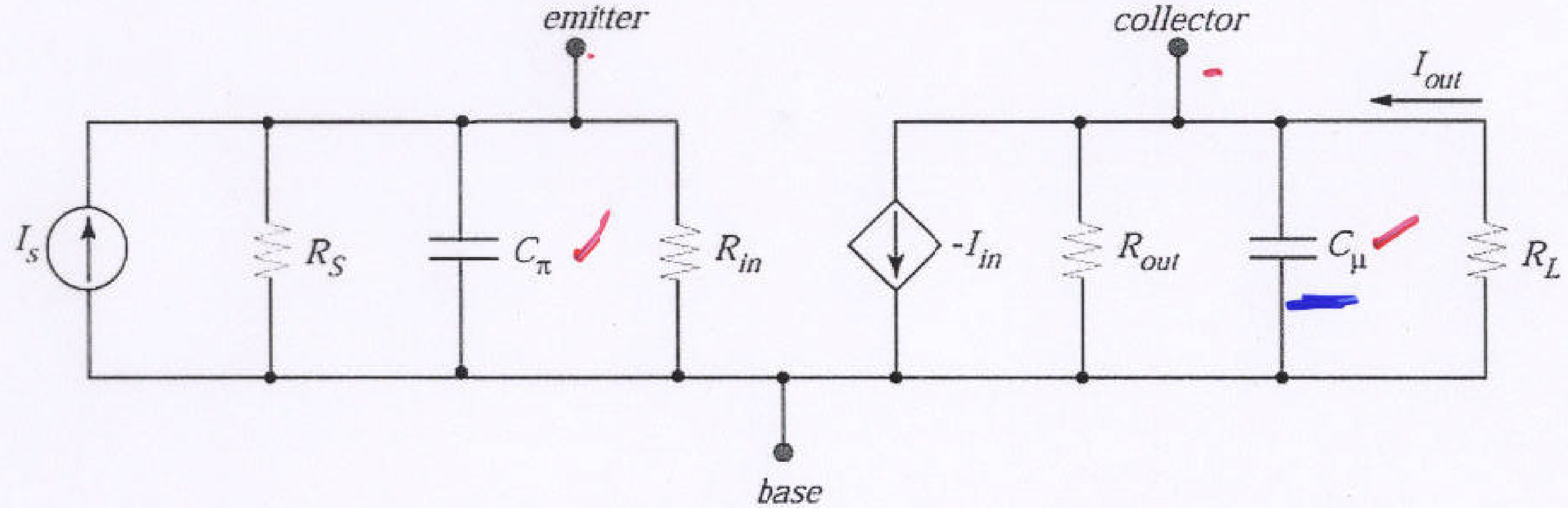
$$\boxed{\omega_p = g_m/C_\mu. \approx \omega_T}$$

Bandwidth of the Common-Base Current Buffer



Same procedure: start with two-port model and capacitors

Two-Port CB Model with Capacitors



No Miller-transformed capacitor! GOOD!

Unity-gain frequency is on the order of ω_T for small R_L

$$\omega_p^{-1} = (\overset{1/g_m}{\cancel{R_{in}}} \| R_S)\, C_\pi = C_\pi / g_m$$

$$\omega_p = g_m / C_\pi \approx \omega_T$$

Summary of Single-Stage Amplifier Frequency Response

N.B.

- CE, CS: suffer from Miller-magnified capacitor for high-gain case

W.B.

- CC, CD: Miller transformation → nulled capacitor → “wideband stage” *
- CB, CG: no Millerized capacitor → wideband stage (for low load resistance) *