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ALL SPECIAL CASES.

Lecture 31

- Last time: CHAPTER 10 $A_i(j\omega)$
  - Short-circuit current gain of CE and CS amps
  - Unity-gain frequency ω_T.

  TODAY $|A_i(j\omega)|$
- Today :
  - Frequency response of the CE as voltage amp
  - The Miller approximation

FRIDAY'S LECTURE $\begin{cases} CD ✓ \\ CG ✓ \end{cases}$

$(100) = 40dB$

$\omega = \omega_T$

$|A_i(j\omega_T)| = 1$

Transition Frequency ω_T

- $$\boxed{\omega_T = \cancel{\frac{\omega_\beta}{\beta_o}} = \frac{g_m}{C_\pi + C_\mu}}$$ $\beta_o \omega_\beta$

$$\begin{cases} g_m = \dfrac{I_C}{V_{th}} \\ \underline{C_\pi} = \underline{C_{jE}} + \underline{g_m \tau_F} \end{cases}$$

#7 C_{diff} #7

Dependence on DC collector current:

$$\omega_T = \frac{I_C/V_{th}}{C_{jE} + \underbrace{(I_C/V_{th})}\tau_F + C_\mu} = \frac{1}{\dfrac{V_{th}C_{jE}}{I_C} + \tau_F + \dfrac{V_{th}}{I_C}\cdot C_\mu}$$

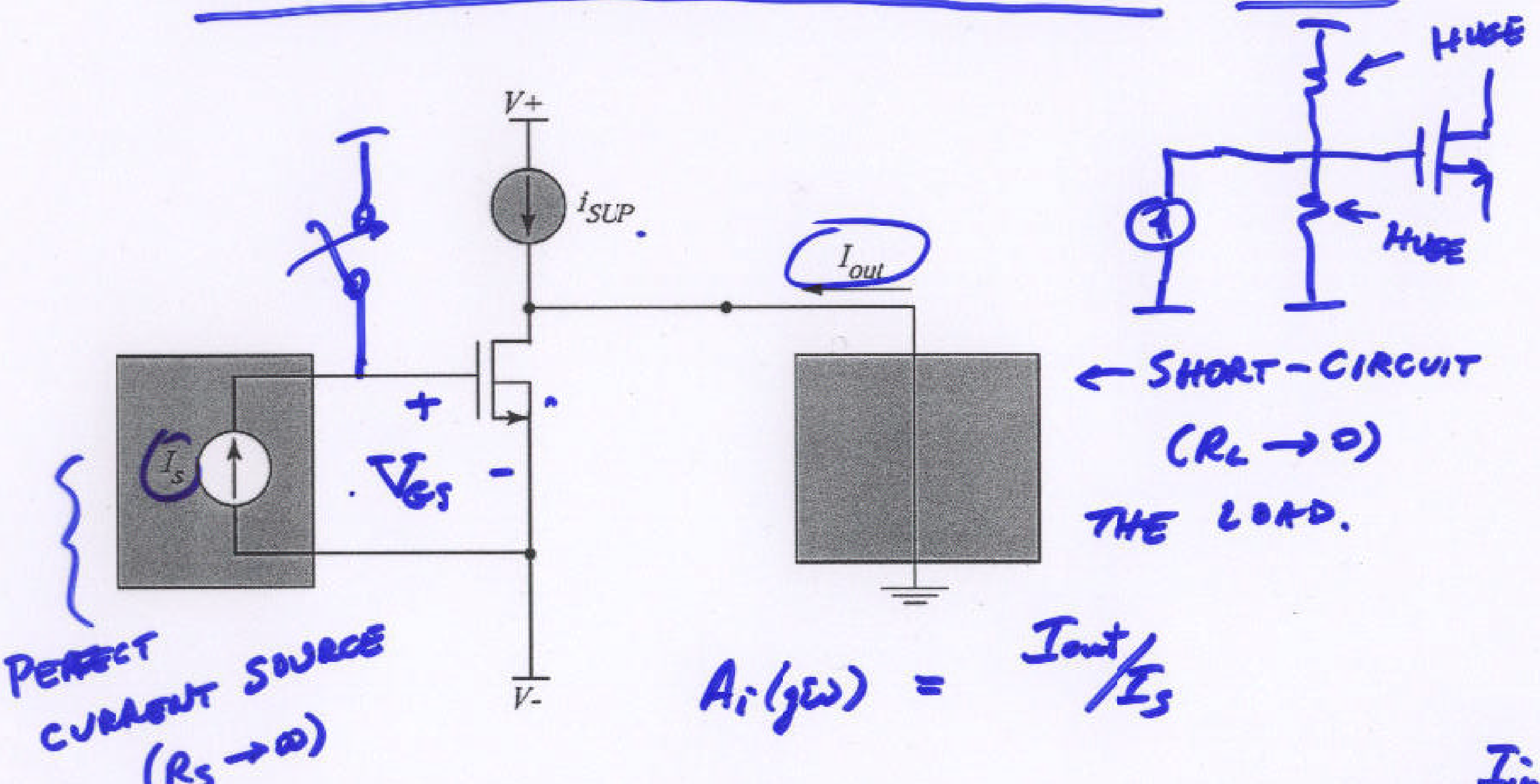
SMALL SMALL

$\omega_T \uparrow$ ... LET'S INCREASE I_C

$\omega_T \rightarrow \dfrac{1}{\tau_F}$ $(I_C \rightarrow \infty)$

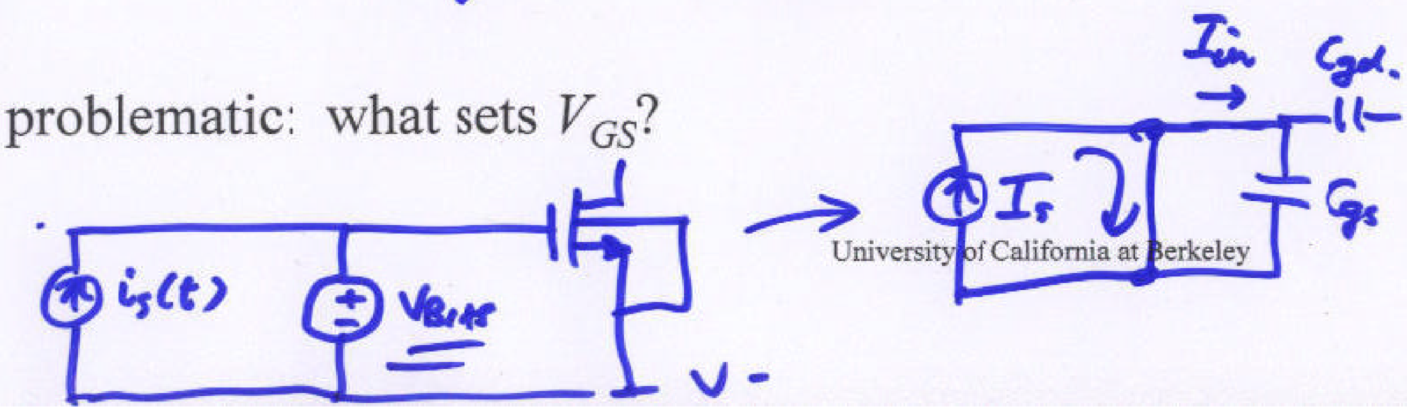
Limiting case: $f_T = \dfrac{\omega_T}{2\pi} \rightarrow \dfrac{1}{2\pi\tau_F}$ Current record:

Common Source Amplifer: $A_i(j\omega)$

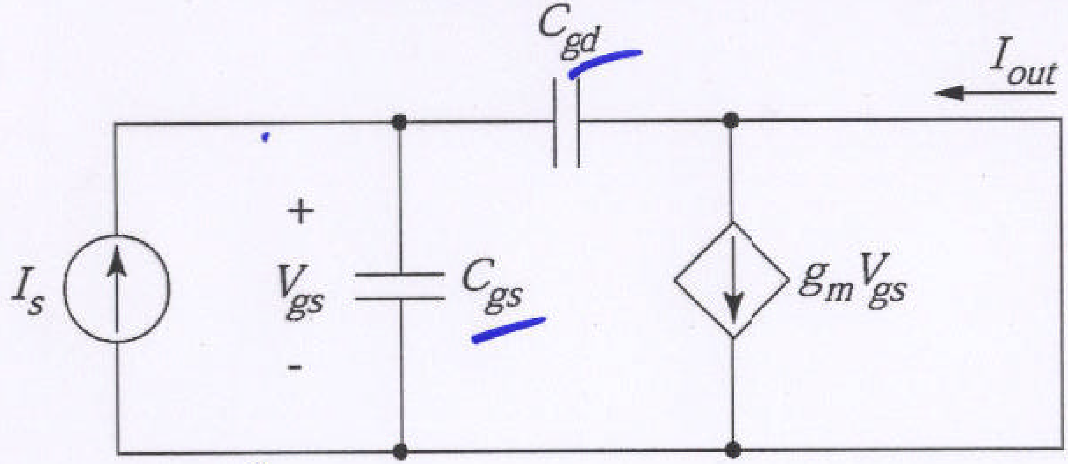


$A_i(j\omega) = I_{out}/I_s$

DC Bias is problematic: what sets V_{GS}?



CS Short-Circuit Current Gain



ZERO

Transfer function: $A_i(j\omega) = \dfrac{g_m\left(1 - j\omega C_{gd} / g_m\right)}{j\omega(C_{gs} + C_{gd})}$ (SEE CHAPTER 10)

$\dfrac{1}{j\omega\left[\underbrace{[C_{gs}+C_{gd}]/g_m}_{1/\omega_T}\right]}$

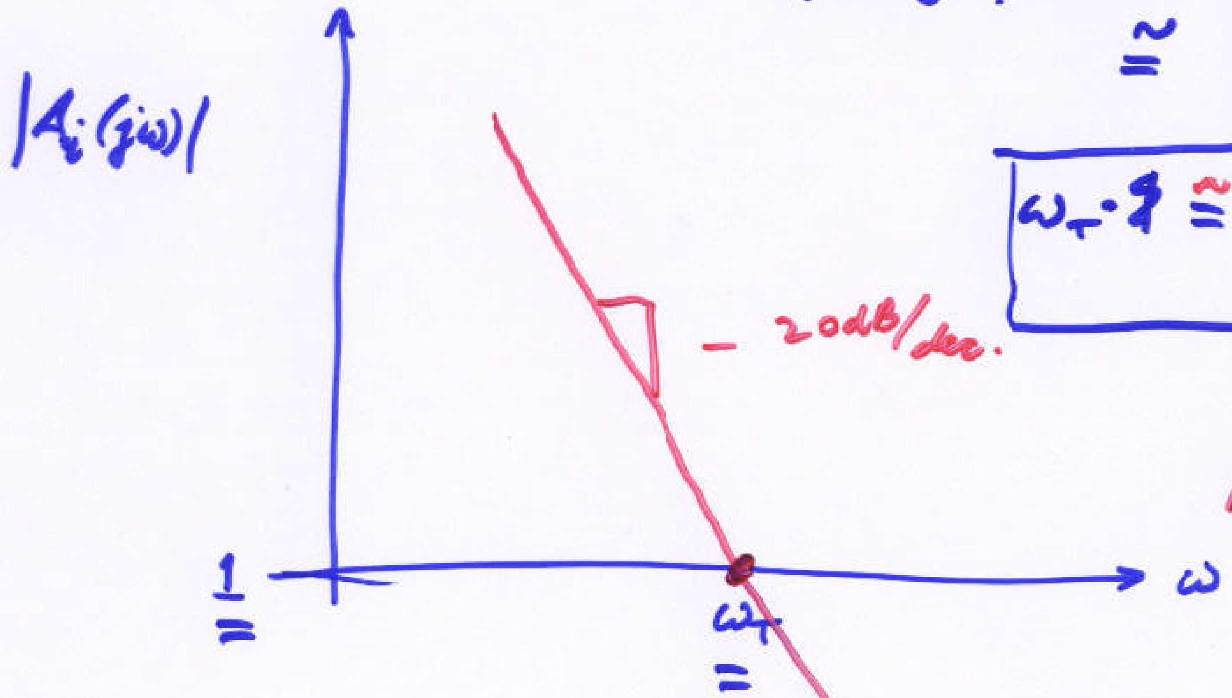
$\omega_z = g_m/C_{gd}$. (MUCH HIGHER THAN ω_T)

ω_T = UNITY-GAIN FREQUENCY (RAD/S)

$$|A_i(j\omega_T)| = 1 \cong \left| \frac{g_m}{j\omega_T (C_{gs} + C_{gd})} \right|$$

$$\boxed{\omega_T \cong \frac{g_m}{C_{gs} + C_{gd}}}$$

BJT $\dfrac{g_m}{C_\pi + C_\mu}$.



$$\omega_z = \frac{g_m}{C_{gd}} \gg \omega_T = \frac{g_m}{C_{gs} + C_{gd}}$$

$$C_{gs} = \frac{2}{3} C_{ox} W \cdot L + C_{ov}.$$

$$C_{gd} = C_{ov} \ll C_{gs}.$$

• ASK ABOUT HOW/WHAT ~~TO~~ TO DO TO CONTROL/DESIGN MOSFET FOR $\omega_T \uparrow\uparrow$.

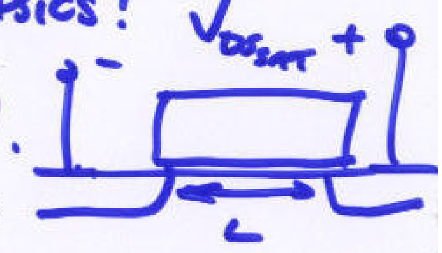
$$\omega_T = \frac{g_m}{C_{gs} + C_{gd}}.$$

$$\frac{1}{\omega_T} = \tau_T = \frac{C_{gs} + C_{gd}}{g_m} \approx \frac{C_{gs}}{g_m} \qquad C_{gd} \ll C_{gs}$$

$$C_{gs} \cong \frac{2}{3} C_{ox} W \cdot L \quad (C_{ov} \to 0)$$

THINK BASICS!

$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_Q \approx \mu_n C_{ox} \left(\frac{W}{L}\right)(V_{GS} - V_{TN}).$$



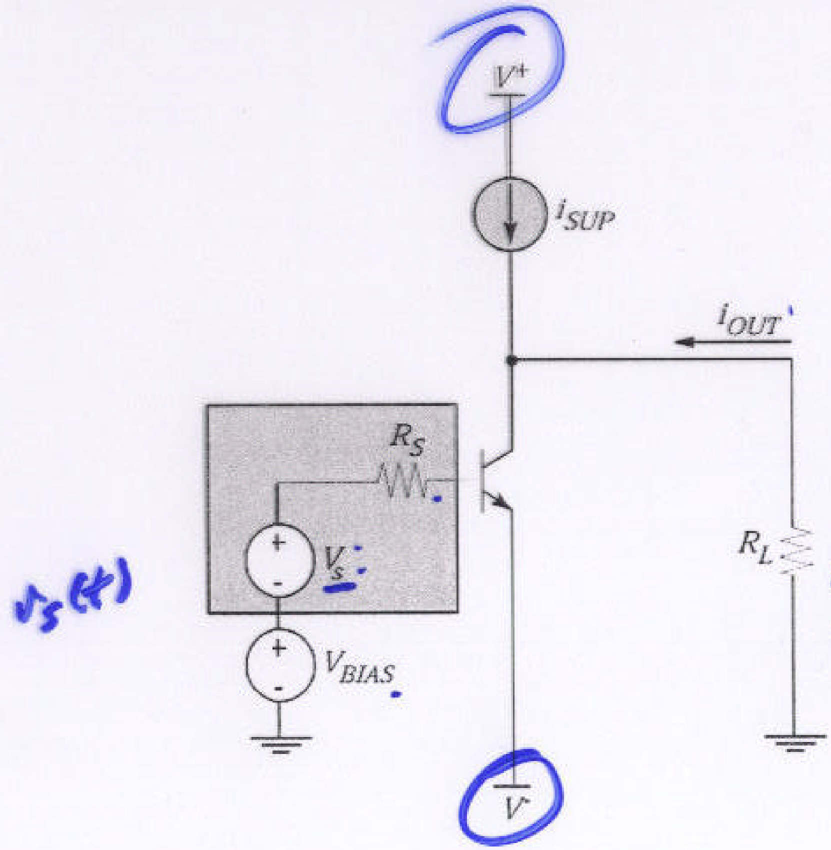
$$\therefore \quad \tau_T = \frac{\frac{2}{3} \cancel{C_{ox}} \cancel{W} \cdot L}{\mu_n \cancel{C_{ox}} \left(\frac{\cancel{W}}{L}\right)(V_{GS} - V_{TN})} = \frac{L}{\left(\frac{3}{2}\right) \mu_n \underbrace{\left[\frac{V_{GS} - V_{TN}}{L}\right]}_{E}} \cong \frac{L}{\bar{v}_{dr}}$$

τ_T = DISTANCE / VELOCITY

$$V_{GS} - V_{TN} = V_{DSSAT}$$

SPECIAL CASE

- Common-Emitter Voltage Amplifier



Small-signal model: omit C_{cs} due to avoid complicated analysis

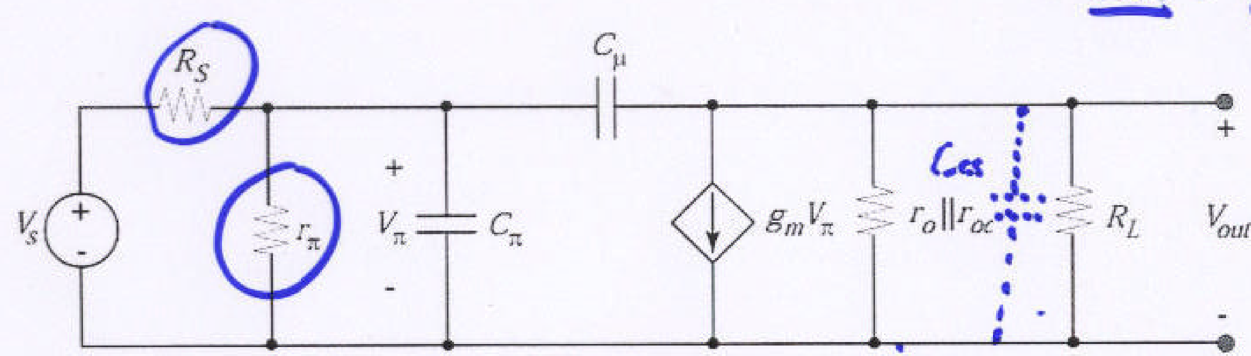
$v_{out}(t) = v_{OUT}(t)$

+ $\cancel{v_{OUT}}$ v_{out}

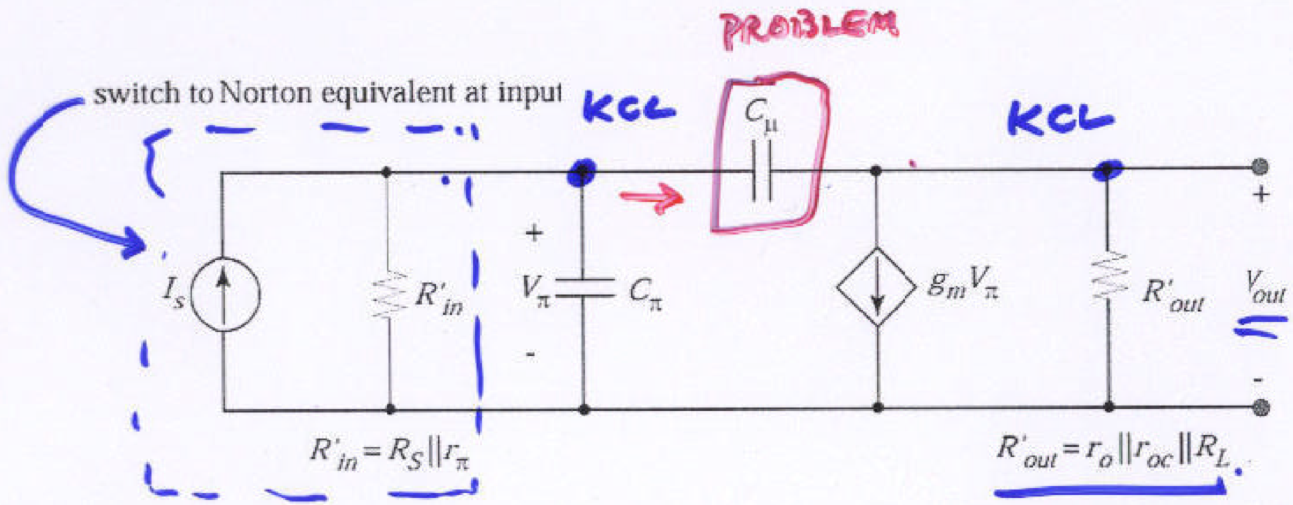
$V_{OUT} = 0\,V.$

CE Voltage Amp Small-Signal Model

- $\underline{C_{CS}}$: BETWEEN COLL. & SUBS.... CAN'T HANDLE THE MESSY ANALYSIS.



switch to Norton equivalent at input



$R'_{in} = R_S \| r_\pi$

$R'_{out} = r_o \| r_{oc} \| R_L$.

CHAPTER 8.

A_{v0} ← low ω:

Frequency Response

KCL at input and output nodes; analysis is made complicated due to Z_μ branch → see H&S pp. 639-640.

PLOTTING

$$\frac{V_{out}}{V_{in}} = \frac{\boxed{-g_m\left(\frac{r_\pi}{r_\pi + R_S}\right)\left[r_o \,||\, r_{oc} \,||\, R_L\right]}\left(1 - \cancel{j\omega/\omega_z}\right)}{\left(1 + j\omega/\omega_{p1}\right)\left(1 + j\omega/\omega_{p2}\right)}$$

$\frac{\omega}{\omega_z}$ SMALL

2 POLES ⇐ 2 ENERGY STORAGE ELEMENTS

Low-frequency gain:

MAX. ω FOR OUR MODELS.

$$\text{Zero: } \omega_z > \omega_T = \frac{g_m}{C_\pi + C_\mu}$$

REALLY HIGH

NOT EXACT

Poles

$$\omega_{p1} \not\approx \cong \frac{1}{(R_S \parallel r_\pi)\{C_\pi + (1 + g_m R'_{out})C_\mu\} + R'_{out}C_\mu}$$

$$\omega_{p2} \not\approx \cong \frac{R'_{out}/(R_S \parallel r_\pi)}{(R_S \parallel r_\pi)\{C_\pi + (1 + g_m R'_{out})C_\mu\} + R'_{out}C_\mu}$$

$$\frac{R_{out}'}{R_S \parallel r_\pi} = \frac{r_o \parallel r_{oc} \parallel R_L}{R_S \parallel r_\pi} >> 1$$

(R_S SMALL

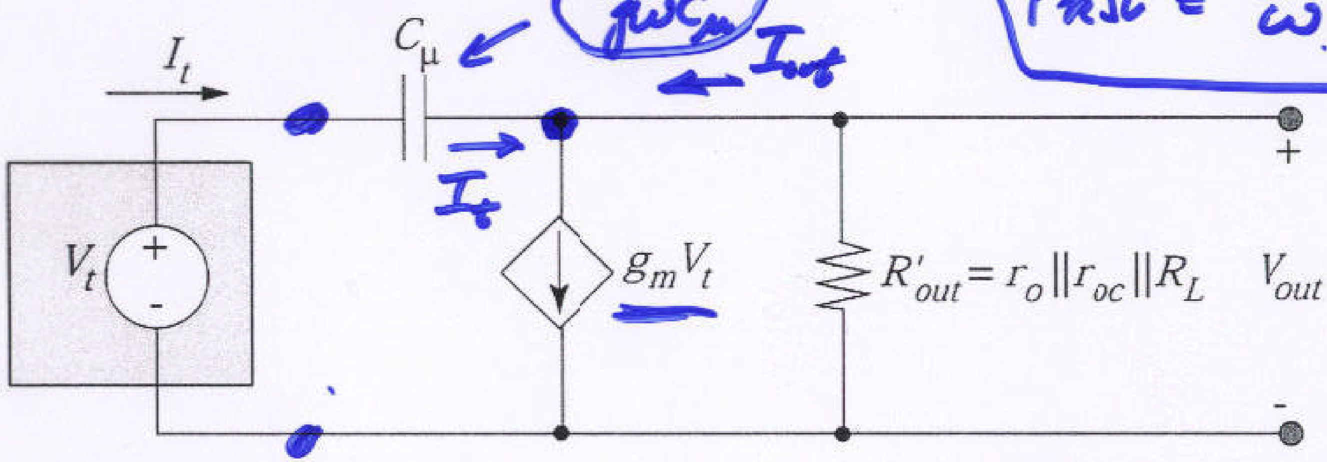
BETTER WAY.

Decoupling Input and Output: the Miller Approximation

Results of complete analysis: not exact and little insight if any

Look at how Z_μ affects the transfer function: find Z_{in}

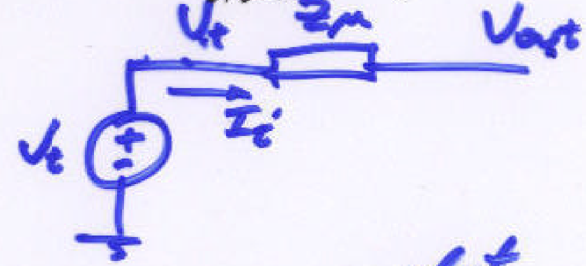
$1\,k\Omega = \frac{1}{\omega C_\mu}$ ← $\omega \approx$ Grads^{-1}



Z_{eff} from input ....

$\frac{V_t}{I_t} \equiv Z_{eff}$

Input Impedance $Z_{in}(j\omega)$



$$I_t = (V_t - V_{out}) / Z_\mu$$

At output node:

$-I_{out} \cdot R_{out}' \rightarrow 0$

$$V_{out} = (\underbrace{-g_m V_t - I_t}_{KCL}) R_{out}' \approx \boxed{-g_m V_t R_{out}'}$$

neglect I_t ...Why?

$$I_t = (V_t - A_{vC_\mu} V_t) / Z_\mu$$

$g_m \cong 1\ mS.$

$A_v \quad \frac{1}{g_m} = 1k\Omega.$

$$\boxed{Z_{in} = \underline{V_t / I_t} = \frac{Z_\mu}{1 - A_{vC_\mu}}}$$

A_{vC_μ} = voltage gain across C_μ $= -g_m R_{out}'$