Lecture 32

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

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

I-SOURCES
Miller Capacitance $C_M$

Effective input capacitance:

$$Z_{in} = \frac{1}{j\omega C_M} = \left(\frac{1}{1 - A_{vC}}\right) C_M$$

$$C_M = C_m \left(1 - A_{vC}G_P\right)$$

What about the role of $C_x$ when viewed from the output port?
\[ C_{\text{out}} = C_x \left( \frac{1}{1 - \frac{V_{\text{out}}}{V_{\text{in}}} \frac{1}{R}} \right) \]

\[ V_{\text{out}} = \frac{V_{\text{in}}}{3} \]
Some Examples

Common emitter/source amplifier:

\[ A_{VC} = \text{Negative, large number (-100)} \]

Common collector/drain amplifier:

\[ A_{VC} = \frac{C_{m} - (1 - B_{d})}{C_{m} - (1 - B_{d})} \]

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\[ R_{2} = 0 \]

Booster

\[ A_{VC} \]
CE Amplifier using Miller Approx.

Use Miller to transform $C_\mu$

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

Analysis is straightforward now ... single pole!

$V_B / V_A = -g_{m}R'_{out}$
Comparison with "Exact Analysis"

Miller result:

\[ \omega_{p1}^{-1} \approx \text{Re} \omega C_{\text{in}} = \left( R_S \parallel r_\pi \right) \{ C_\pi + (1 + g_m R'_{\text{out}}) C_\mu \} + \left( 1 + g_m R'_{\text{out}} C_{\text{in}} \right) \]

Exact result:

\[ \omega_{p1}^{-1} \approx \left( R_S \parallel r_\pi \right) \{ C_\pi + (1 + g_m R'_{\text{out}}) C_\mu \} + R'_{\text{out}} C_\mu \]
Common-Collector Amplifier

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

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Two-Port CC Model with Capacitors

Find Miller capacitor for $C_\pi$ -- note that the base-emitter capacitor is between the input and output.

$$R_{out} = \frac{1}{g_m} + \frac{1}{g_m R_e} = \frac{1}{g_m}$$

$$A_{vcg} = \frac{R_e}{1 + g_m R_e}$$
Voltage Gain $A_{VC}$ Across $C_T$

$$A_{VC} = \frac{\frac{g_mR_e}{1 + g_mR_e}}{1 - A_{AC}(1 - A_{VC})} = \frac{\frac{g_mR_e}{1 + g_mR_e}}{1 - \frac{g_mR_e}{1 + g_mR_e}} \approx \frac{g_mR_e}{1 + g_mR_e}.$$ 

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

$$C_{in} = C_{\mu} + C_{M} = \frac{C_{\mu}}{1 + g_m R_e} + (1 - A_{VC}) C_{\pi} = C_{\mu} + (1 - A_{VC}) C_{\pi}$$

$$C_{in} = \frac{C_{\mu}}{1 + g_m R_e} + \left(1 - \frac{g_m R_e}{1 + g_m R_e}\right) C_{\pi}$$

$C_{in} = C_{\mu} + \left(1 - \frac{g_m R_e}{1 + g_m R_e}\right) C_{\pi}$
Bandwidth of CC Amplifier

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

\[ \omega_p^{-1} = (R_S \parallel R_n) \left( C_\mu + \frac{C_\pi}{1 + g_m R_L} \right) \]

- Substitute favorable values of \( R_S, R_L \):
  - \( R_S \approx 1/g_m \)
  - \( R_L \gg 1/g_m \)

\[ \omega_p^{-1} \approx \left( \frac{1}{g_m} \right) \left( C_\mu + \frac{C_\pi}{1 + EIG} \right) \approx C_\mu / g_m \]

\[ \omega_p = \frac{g_m}{C_\mu} \approx \omega_p \]

Best case

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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!

Unity gain frequency is on the order of \( \omega_T \) for small \( R_L \).

\[
\omega_p = \frac{1}{\sqrt{C_C R_C}} \quad \omega_L = \frac{1}{\beta R_C} \approx \omega_T
\]
Summary of Single-Stage Amplifier Frequency Response

- CE, CS: suffer from Miller-magnified capacitor for high-gain case
- CC, CD: Miller transformation $\rightarrow$ nulled capacitor $\rightarrow$ "wideband stage"
- CB, CG: no Millerized capacitor $\rightarrow$ wideband stage (for low load resistance)