Lecture 21
Frequency Response of Amplifiers (I)
Common-Emitter Amplifier

Outline

• Review frequency domain analysis
• BJT and MOSFET models for frequency response
• Frequency Response of Intrinsic Common-Emitter Amplifier
• Effect of transistor parameters on $f_T$

Reading Assignment:
Howe and Sodini, Chapter 10, Sections 10.1-10.4
I. Frequency Response Review

Phasor Analysis of the Low-Pass Filter

- Example:

- Replacing the capacitor by its impedance, \( 1 / (j\omega C) \), we can solve for the ratio of the phasors \( \frac{V_{out}}{V_{in}} \):

\[
\frac{V_{out}}{V_{in}} = \frac{1/j\omega C}{R + 1/j\omega C}
\]

\[
\frac{V_{out}}{V_{in}} = \frac{1}{1 + j\omega RC}
\]

- \( V_{out} \equiv \) Phasor notation
Magnitude Plot of LPF

- \( \left| \frac{V_{out}}{V_{in}} \right| \rightarrow 1 \) for “low” frequencies
- \( \left| \frac{V_{out}}{V_{in}} \right| \rightarrow 0 \) for “high” frequencies

- The “break point” is when the frequency is equal to \( \omega_0 = \frac{1}{RC} \)
- The break frequency defines “low” and “high” frequencies.
- \( \text{dB} \equiv 20 \log x \rightarrow 20\text{dB} = 10, \; 40\text{dB} = 100, \; -40\text{dB} = .01 \)
- At \( \omega_0 \) the ratio of phasors has a magnitude of -3 dB.
Phase Plot of LPF

- Phase \( \frac{V_{out}}{V_{in}} \) = 0° for low frequencies
- Phase \( \frac{V_{out}}{V_{in}} \) = -90° high frequencies.

- Transition region extends from \( \omega_o / 10 \) to 10 \( \omega_o \)
- At \( \omega_o \) Phase = -45°

Review of Frequency Domain Analysis Chap 10.1
II. Small Signal Models for Frequency Response

Bipolar Transistor

![Bipolar Transistor Diagram]

MOS Transistor - VSB = 0

![MOS Transistor Diagram]

- Replace $C_{gs}$ for $C_\pi$
- Replace $C_{gd}$ for $C_\mu$
- Let $r_\pi \longrightarrow \infty$
III. Frequency Response of Intrinsic CE Current Amplifier

$\text{R}_S \longrightarrow \infty \text{ & } \text{R}_L = 0$

Circuit analysis - Short Circuit Current Gain $I_o/I_{in}$

- KCL at the output node:

$$I_o = g_m V_\pi - V_\pi j\omega C_\mu$$

- KCL at the input node:

$$I_{in} = \frac{V_\pi}{Z_\pi} + V_\pi j\omega C_\mu \quad \text{where} \quad Z_\pi = r_\pi \left[ \frac{1}{j\omega C_\pi} \right]$$

- After Algebra

$$\frac{I_o}{I_{in}} = \frac{g_m r_\pi \left( 1 - \frac{j\omega C_\mu}{g_m} \right)}{1 + j\omega r_\pi \left( C_\pi + C_\mu \right)} = \beta_o \frac{1 - \frac{j\omega C_\mu}{g_m}}{1 + j\omega r_\pi \left( C_\pi + C_\mu \right)} = \beta_o \left[ \frac{1 - \frac{j\omega}{\omega_z}}{1 + \frac{j\omega}{\omega_p}} \right]$$

$$\omega_Z = \frac{g_m}{C_\mu} \quad \omega_p = \frac{1}{r_\pi \left( C_\pi + C_\mu \right)}$$
Bode Plot of Short-Circuit Current Gain

- Frequency at which current gain is reduced to 0 dB is defined at $f_T$:

$$f_T = \left( \frac{1}{2\pi} \right) \frac{g_m}{C + C_{\mu}}$$
Gain-Bandwidth Product

- When we increase $\beta_o$ we increase $r_\pi$ BUT we decrease the pole frequency---$\rightarrow$ Unity Gain Frequency remains the same

Examine how transistor parameters affect $\omega_T$

- Recall
  \[ C_\pi = C_{je} + g_m \tau_F \]

- The unity gain frequency is
  \[ \omega_T = \frac{I_C / V_{th}}{(I_C / V_{th}) \tau_F + C_{je} + C_\mu} \]
\[ \omega_T = \frac{I_C / V_{th}}{(I_C / V_{th})\tau_F + C_{je} + C_\mu} \]

- At low collector current, \( f_T \) is dominated by depletion capacitances at the base-emitter and base-collector junctions.
- As the current increases, the diffusion capacitance, \( g_m \tau_F \), becomes dominant.
- Fundamental Limit for the frequency response of a bipolar transistor is set by

\[ \tau_F = \frac{W_B^2}{2Dn, p} \]

**To Increase \( f_T \)**
- High Current - Diffusion capacitance limited - Shrink basewidth.
- Low Current - Depletion capacitance limited - Shrink emitter area and collector area - (geometries)