Lecture 21

Frequency Response of Amplifiers (I)

Common-Emitter Amplifier

Outline

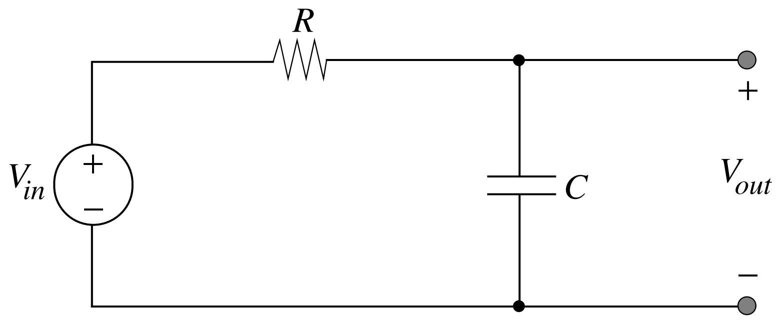
- Review frequency domain analysis
- BJT and MOSFET models for frequency response
- Frequency Response of Intrinsic Common-Emitter Amplifier
- Effect of transistor parameters on f_T

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 / (jωC), we can solve for the ratio of the phasors V_{out}/V_{in}

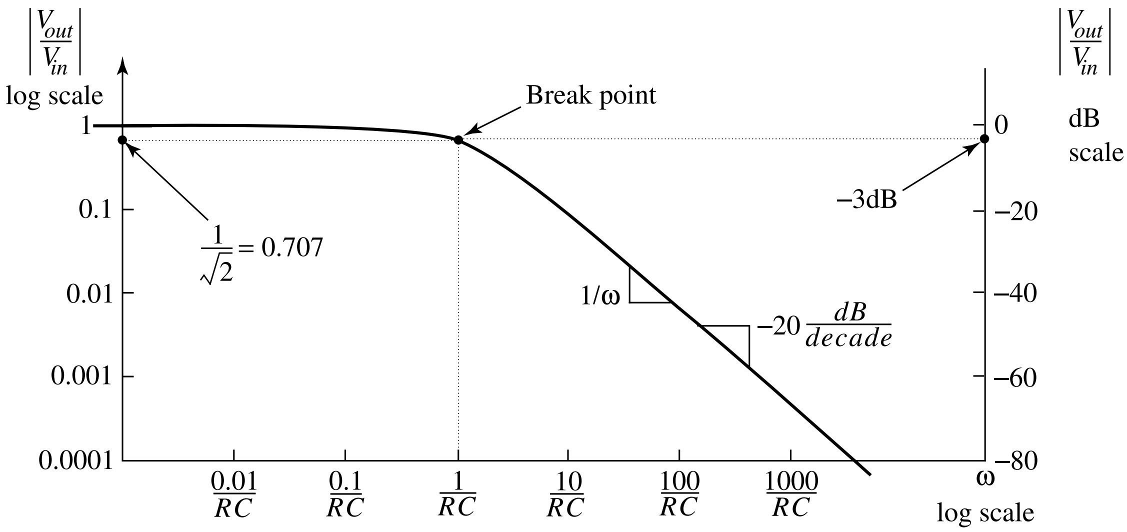
$$\frac{V_{out}}{V_{in}} = \frac{1/j\omega C}{R + 1/j\omega C}$$

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

- $V_{out} \equiv$ Phasor notation

Magnitude Plot of LPF

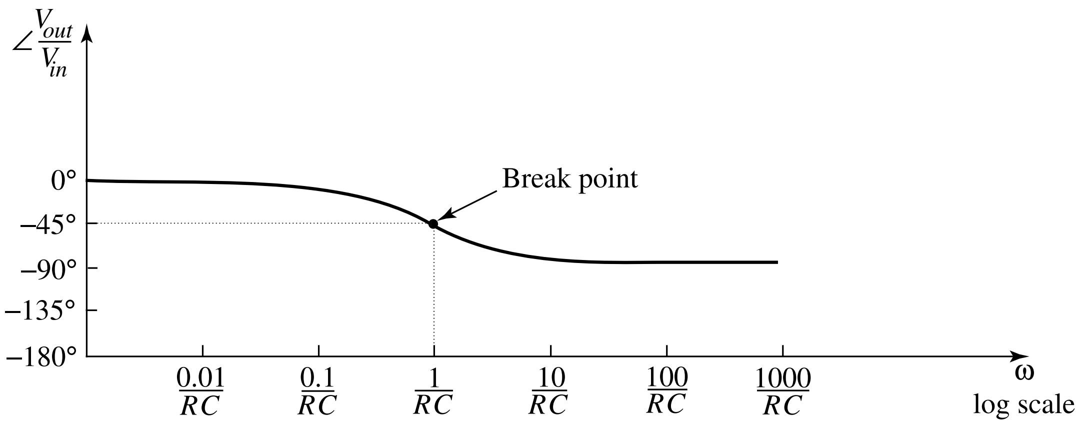
- $\left|V_{out}/V_{in}\right|$ --> 1 for "low" frequencies
- $\left|V_{out}/V_{in}\right|$ --> 0 for "high" frequencies



- The "break point" is when the frequency is equal to ω_o = 1 / RC
- The break frequency defines "low" and "high" frequencies.
- dB $\equiv$ 20 log x ----> 20dB = 10, 40dB = 100, -40dB = .01
- At ω_o the ratio of phasors has a magnitude of - 3 dB.

Phase Plot of LPF

- Phase (V_{out} / V_{in}) = 0^o for low frequencies
- Phase (V_{out} / V_{in}) = -90^o high frequencies.

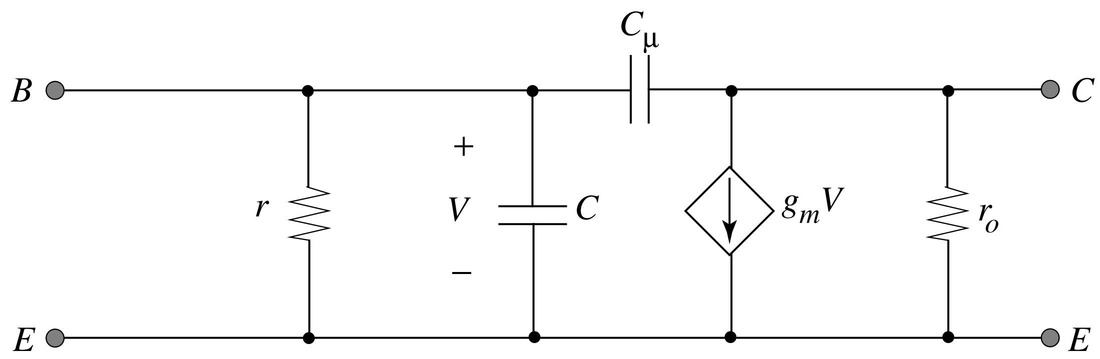


- Transition region extends from ω_o / 10 to 10 ω_o
- At ω_o Phase = -45^o

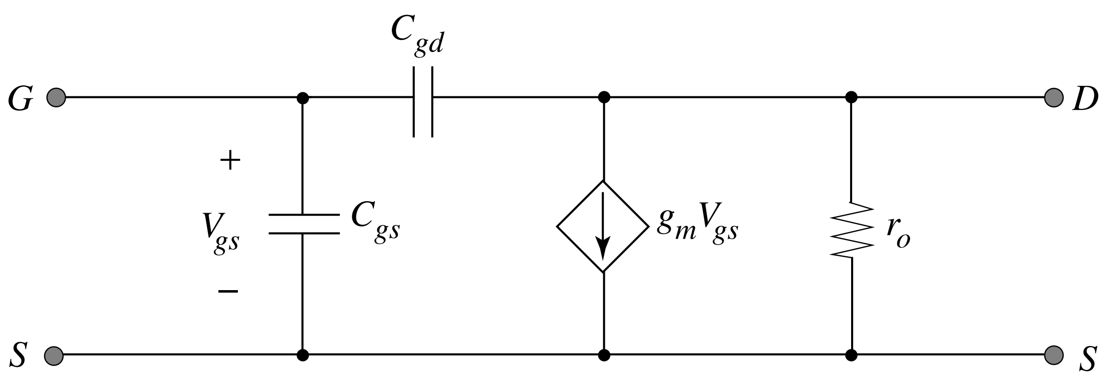
Review of Frequency Domain Analysis Chap 10.1

II. Small Signal Models for Frequency Response

Bipolar Transistor



MOS Transistor - VSB = 0

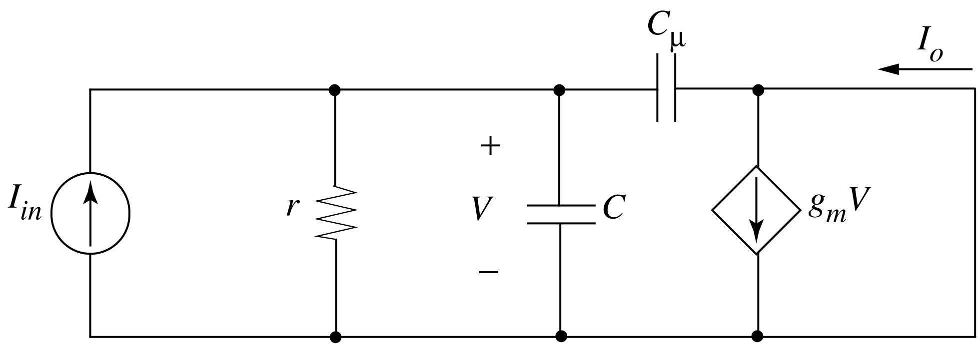


- Replace C_{gs} for C_π
- Replace C_{gd} for C_μ
- Let r_π ---> ∞

III. Frequency Response of Intrinsic CE Current Amplifier

R_S ---> ∞ & 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:

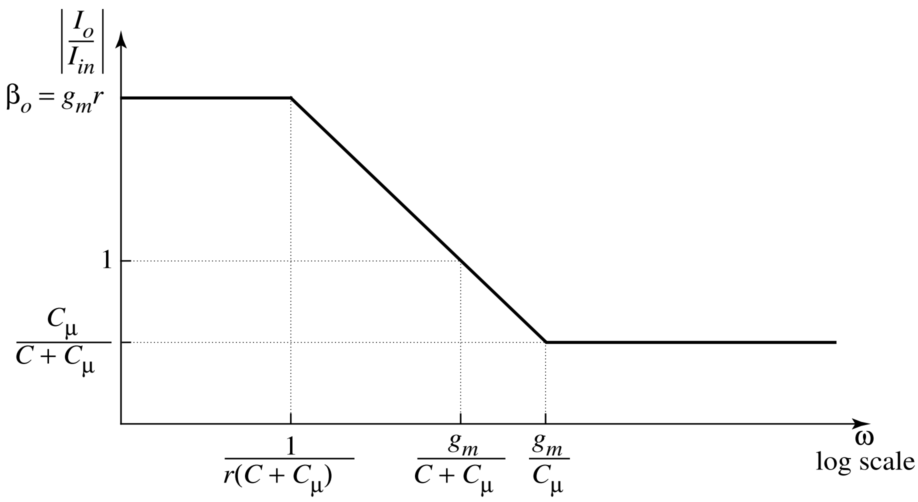
$$I_{in} = \frac{V_\pi}{Z_\pi} + V_\pi j\omega C_\mu \qquad \text{where} \qquad Z_\pi = r_\pi \parallel \left(\frac{1}{j\omega C_\pi}\right)$$

- After Algebra

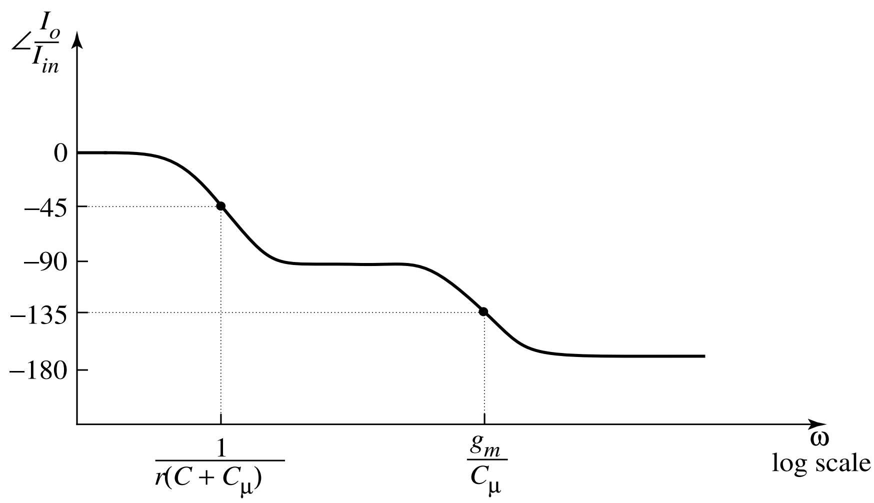
$$\frac{I_o}{I_{in}} = \frac{g_m r_\pi \left(1 - \frac{j\omega C_\mu}{g_m}\right)}{1 + j\omega r_\pi (C_\pi + C_\mu)} = \frac{\beta_o \left(1 - \frac{j\omega C_\mu}{g_m}\right)}{1 + j\omega r_\pi (C_\pi + C_\mu)} = \beta_o \left[\frac{1 - j\frac{\omega}{\omega_z}}{1 + j\frac{\omega}{\omega_p}}\right]$$

$$\omega_Z = \frac{g_m}{C_\mu} \qquad \omega_p = \frac{1}{r_\pi (C_\pi + C_\mu)}$$

Bode Plot of Short-Circuit Current Gain



(a)



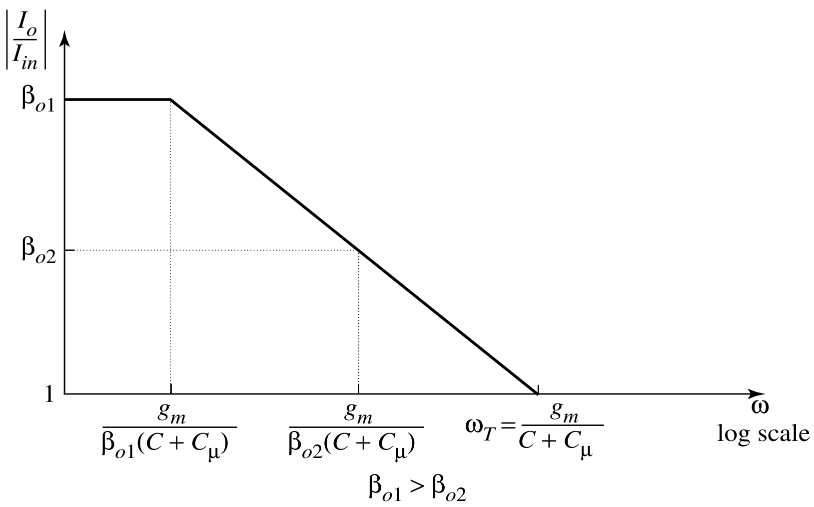
(b)

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

$$f_T = \left(\frac{1}{2\pi}\right)\frac{g_m}{(C_\pi + C_\mu)}$$

Gain-Bandwidth Product

- When we increase β_o we increase r_π BUT we decrease the pole frequency---> Unity Gain Frequency remains the same



Examine how transistor parameters affect ω_T

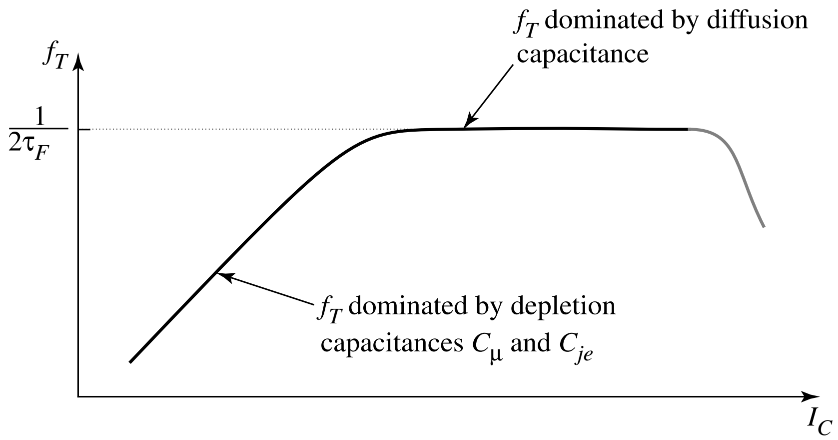
- Recall

$$C_\pi = C_{je} + g_m \tau_F$$

- 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

$$\tau_F = \frac{W_B{}^2}{2\,D_{n,p}}$$

To Increase f_T

- High Current - Diffusion capacitance limited - Shrink basewidth
- Low Current - Depletion capacitance limited - Shrink emitter area and collector area - (geometries)