ECE-345: VLSI
Chapter 1: Frequency Response Model

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January 21, 2022

1 Preliminary Concepts

1.1 Bipolar Amplifiers

1.1.1 Large Signal Model

Collector current: $I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$
Collector, Base, Emitter current relations:

$$I_C = \beta I_B = \frac{\beta}{\beta+1} I_E$$
$$I_E = I_C + I_B = I_C\left(1 + \frac{1}{\beta}\right)$$
$$\therefore$$
$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$
$$I_B = \frac{1}{\beta} I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$
$$I_E = \frac{\beta+1}{\beta} I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$

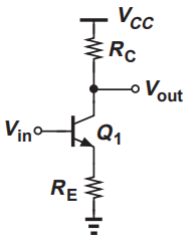
1.1.2 Small Signal Model

Transconductance: $g_m = \frac{I_C}{V_T}$
Base-Emitter resistance: $r_\pi = \frac{\beta}{g_m}$
Introducing **Early Effect**:

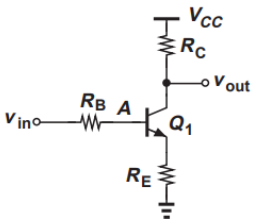
$$I_C = \left(I_S \exp\left(\frac{V_{BE}}{V_T}\right)\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$
$$r_O = \frac{V_A}{I_C}$$

1.1.3 Amplifier Topologies

Common-Emitter Topology (w/ Emitter Degeneration):



$$R_{in} = r_\pi + (\beta + 1)R_E$$
$$R_{out} = R_C \parallel r_O$$
$$A_v = -\frac{R_C}{\frac{1}{g_m} + R_E}$$



$$R_{in} = R_B + r_\pi + (\beta + 1)R_E$$
$$R_{out} = (1 + g_m R_E)\, r_O$$
$$A_v = -\frac{R_C \parallel r_O}{\frac{1}{g_m} + R_E}$$

1.2 CMOS Amplifiers