Lecture 20

• Last time:
  – the npn bipolar junction transistor (BJT)

• Today:
  – Large-signal model under forward bias
  – Ebers-Moll model

Collector Current

Diffusion of electrons across base results in

\[ J_n^{\text{diff}} = qD_n \frac{dn_p}{dx} = \]

\[ I_C = I_S e^{V_{BE}/V_{th}} \]
Base Current

Diffusion of holes across emitter results in

\[ J_{p}^{\text{diff}} = -qD_{p} \frac{dp_{nE}}{dx} = \]

\[ I_B = \]

Current Gain \( \beta_F \)

\[ \beta_F = \frac{I_C}{I_B} = \left( \frac{qD_{n}n_{pBoA_E}}{W_B} \right) = \left( \frac{qD_{p}p_{nEoA_E}}{W_E} \right) \]

Parameter sensitivities:
Ebers-Moll Equations

Exp. 6: measure E-M parameters
Derivation: write emitter and collector currents in terms of internal currents at two junctions

\[ I_E = -I_{ES}\left(e^{V_{BE}/V_{th}} - 1\right) + \alpha_R I_{CS}\left(e^{V_{BC}/V_{th}} - 1\right) \]

\[ I_C = \alpha_F I_{ES}\left(e^{V_{BE}/V_{th}} - 1\right) - I_{CS}\left(e^{V_{BC}/V_{th}} - 1\right) \]

\[ \alpha_F I_{ES} = \alpha_R I_{CS} \]

Ebers-Moll Equivalent Circuit

Building blocks: diodes and \( I \)-controlled \( I \) sources
Forward-Active Model

B-C junction is not forward-biased $\Rightarrow I_R$ is very small

Simplified Ebers-Moll (Cont.)

Forward-Active Case

Saturation: both diodes are forward-biased $\Rightarrow$ batteries
Small-Signal Model

Analogy from MOSFET s.s. model:

\[
\begin{align*}
    i_D &= f(v_{GS}, v_{DS}, v_{BS}) \\
    i_C &= f(v_{BE}, v_{CE})
\end{align*}
\]

Transconductance $g_m$