Lecture 29

• Last time:
  – Transistor action, large-signal operation

• Today :
  – Ebers-Moll model
  – Small-signal model of the npn bipolar transistor
Transconductance (cont.)

• Forward-active large-signal current:

\[ i_C = I_S e^{v_{BE}/V_{th}} (1 + v_{CE}/V_A) \]

• Differentiating and evaluating at \( Q = (V_{BE}, V_{CE}) \)
Comparison with MOSFET $g_m$

- Bipolar transistor:

- MOSFET:

- Typical bias point: drain/coll. current = 100 $\mu$A; Select $(W/L) = 8/1$, $\mu_n C_{ox} = 100$ $\mu$A/V$^2$
What about the Base Current?

Unlike MOSFET, there is a DC current into the base terminal of a bipolar transistor:

\[ I_B = I_C / \beta_F = (I_S / \beta_F)e^{V_{BE}/V_{th}}(1 + V_{CE}/V_{th}) \]

To find the change in base current due to change in base-emitter voltage:

\[ \frac{\partial i_B}{\partial v_{BE}} \bigg|_Q = \frac{\partial i_B}{\partial i_C} \bigg|_Q \frac{\partial i_C}{\partial v_{BE}} \bigg|_Q = \]
Small-Signal Current Gain $\beta_0$
Input Resistance $r_\pi$

$$(r_\pi)^{-1} = \left. \frac{\partial i_B}{\partial v_{BE}} \right|_Q$$

In practice, the DC current gain $\beta_F$ and the small-signal current gain $\beta_o$ are both highly variable (+/- 25%) 

Typical bias point: DC collector current = 100 $\mu$A
Output Resistance $r_o$

Why does current increase slightly with increasing $v_{CE}$?

Model: math is a mess, so introduce the Early voltage

$$i_C = I_S e^{v_{BE}/V_{th}} (1 + v_{CE}/V_A)$$
Graphical Interpretation of $r_o$

Typical value:
BJT Small-Signal Model
BJT Capacitances

Base-charging capacitance $C_b$: due to minority carrier charge storage (mostly electrons in the base)

$$C_b = g_m \tau_F$$

Base-emitter depletion capacitance: $C_{jE} = 1.4 \ C_{jE_0}$

Total B-E capacitance: $C_\pi = C_{jE} + C_b$
Complete Small-Signal Model
IBM SiGe Heterojunction BJT
SiGe BJT/CMOS vs. RF CMOS

From “IBM and Cadence collaborate to accelerate silicon-accurate design of advanced RF integrated circuits,” IBM Microelectronics Division, March 11, 2005.
$f_T$ vs. $I_C$

**Figure 2**

Cutoff frequency $f_T$ vs. $I_C$ for four lithographic generations of SiGe. The InP curve shows recent production InP results.