Lecture 21: MOS Model and Common Emitter Amp

- Announcements:
  - HW#7 online and due Friday via Gradescope
  - Lab#5 online (this is your first project)
    - Due Tuesday, Nov. 12, 5 p.m.
  - Graded Midterm coming back today

- Lecture Topics:
  - T Model
  - Pnp Transistor Hybrid-π Model
  - Saturated NMOS Hybrid-π Model
  - Example: Common Emitter Amplifier

- Last Time:
  - Derived the BJT Hybrid-π Model
  - Now, continue with models ...

### Hybrid-π Model Summary (for npn BJT)

- $r_T = \beta/g_m = V_T/I_B$
- $g_m = I_C/V_T$
- $r_o = V_T/I_F$

- Remarks:
  - $g_m$ is independent of device specifics, i.e., $\beta, I_s$
  - Depends only on temperature (via $V_T$) and biasing ($I_C$)
  - Small-signal model valid for $v_{be} << V_T$

What about emitter resistance?

- $r_e = \frac{N_{be}}{I_C}$
- $r_e = \frac{V_T}{g_m I_C}$
- $r_e = \frac{V_T}{g_m I_E}$

Why is this not included in the hybrid-π model? So well... it is!
To explicitly show the emitter resistance in the small-signal model, use the T-model:

$$i_X = \frac{V_X}{r_{T}} - g_m V_{be}$$

$$V_x = V_X(r_{T} + g_m)$$

$$r_e = \frac{V_x}{i_X} = \frac{1}{r_{T}} + g_m = \frac{r_{T}}{1 + g_m r_{T}} = \frac{r_{T}}{1 + g_m} = \frac{1}{g_m(1 + \beta)}$$

$$r_e = \frac{a}{g_m}$$

- To explicitly show the emitter resistance in the small-signal model, use the T-model:

**T-Model** (Common Base Model)

Where (as before): $g_m = \frac{I_e}{V_T}$

$$r_e = \frac{V_T}{I_e} = \frac{1}{g_m}$$

**Small-Signal Models for Forward-Active pnp Xistor**

- For pnp transistors, use the same small-signal models as npn with NO change in polarities

**Hybrid-T Model** (Same as npn model, just upside down)
• Note that in the above small-signal models, the current directions are the same as used for npn, i.e., no change in polarities
• Large signal directions, however, are as before

\[
\begin{align*}
\frac{I_c}{V_T} & = I_f \exp\left(\frac{V_{BE}}{V_T}\right) \\
\frac{I_C}{I_f} & = \frac{I_f}{I_f} \exp\left(\frac{V_{BE}}{V_T}\right) = I_f \exp\left(-\frac{V_{BE}}{V_T}\right)
\end{align*}
\]

[2 terms of Taylor expansion] \Rightarrow \frac{I_c}{V_T} = I_f (1 - \frac{V_{BE}}{V_T}) = I_f - \frac{I_f}{V_T} \frac{V_{BE}}{V_T}

\[
\frac{I_c}{V_T} = \frac{I_f}{V_T} V_{BE} \quad \text{(as with npn, and with the same directions as npn)}
\]
Procedure for Small-Signal Analysis

(Common Emitter Example)

Threshold Voltage \( V_t = f(N_{BS}) \):

\[ V_t = V_{SB} + \frac{V_t}{\beta} \]

Source (Input) Amplifier Output Load

(Thermin Equivalent)

For \( Q : \beta = 100, V_A = 100V \)

Find the voltage gain, \( \frac{V_o}{V_i} \).

Draw the collector voltage waveform for

\( V_c = (0.014) \cos \omega t + 4V \)

Ac small-signal De component
Graphically, here's what we're looking to do:

Apply an input here

Determine the resulting output here

\[ V_T = V_{th} + N_f = 1V + (0.014) \cos \omega t \]

\[ V_s (DC) \]

1V

\[ V_s (AC, 5.5) \]

0.04V

Contains the info to be processed

\[ V_{21} = V_{d1} + N_{v1} \]

\[ \frac{V_{21}}{\text{total}} \text{ DC} = \frac{5.5 \text{ AC}}{	ext{total signal}} \]

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