Today:

- Basic Single transistor gain stages
- Intro to analysis by inspection

Quick Review:

- Large signal
  - For DC analysis:
    - $V_A \gg V_{BE}$ (usually)
    - $I_c = I_e \left( e^{V_{BE}/V_T} - 1 \right)$
    - $I_c \approx I_e e^{V_{BE}/V_T}$ in F.A.R.
  - Point: Know $V_{BE}$ → Find $I_c$
  - Know $I_c$ → Find $V_{BE}$

Model for DC analysis (F.A.R.):

- $I_c \approx \beta_f I_B$
  - Assume $V_{BE} = 0.7V$

$G_T =$ s.s. input conductance

$$G_T = \frac{\Delta I_c}{\Delta V_{BE}} |_{Q} = \frac{1}{\beta_f} \frac{\Delta I_c}{\Delta V_{BE}} |_{Q} = \frac{1}{\beta_f} \frac{\Delta V_{BE}}{\Delta I_c} |_{Q}$$

$$G_T = \frac{I_c}{\beta_f V_T} = \frac{G_m}{\beta_f}$$

$$G_T = \frac{1}{\beta_f G_m}$$

$G_O =$ s.s. output conductance

$$G_O = \frac{\Delta I_c}{\Delta V_T} |_{Q} = \frac{I_c}{V_T + V_{BE}} = \frac{I_c}{V_T}$$

$\beta_f G_m$
Small-signal model: (including some capacitors)

Terminal resistances: (use for intuitive Design/Analysis)

Signal ground via small-signal but arbitrary DC

Note: $V_{be} = -V_{test}$

KCL: $i_C + g_m V_{be} + i_o + i_{test} = 0$

$g_T (\alpha - V_{test}) + g_m (\alpha - V_{test}) + g_o (\alpha - V_{test}) + i_{test} = 0$

$g_{in.e} = \frac{g_m + g_T + g_o}{g_m}$

$\therefore \frac{1}{g_{in.e}} = \frac{1}{g_m}$
Typical Values: \( I_c = 100 \mu A, \ V_A = 100 V, \ \beta_f = 100 \)
\( V_T = 25 \text{ mV at } T = 300^\circ \text{ K} \)
\[ G_m = \frac{I_c}{V_T} = \frac{100 \mu A}{25 \text{ mV}} = 4.0 \text{ mS} \]
\( V_T = \beta_f \frac{I_c}{G_m} = (100)(250 \Omega) = 25 \text{ k}\Omega \)
\[ V_o = \frac{V_A}{I_c} = \frac{100V}{100 \mu A} = 1 \text{ M}\Omega \]

How do we use this? Recall basic voltage gain:

\[ A_v = \frac{V_o}{V_i} = \frac{G_m R}{R} \]

Want: large \( G_m \) and large \( R \)

Note also:

\[ A_v(s) = \frac{G_m C}{s + \frac{1}{RC}} \]

Generally:

C "High Impedance" \( \Rightarrow \) High Gain Low Freq.
B "Moderate Impedance" \( \Rightarrow \) Mod. Gain Mod. Freq.
E "Low Impedance" \( \Rightarrow \) Low Gain High Bandwidth
Basic BJT Single Transistor Stages:

(A) Common-Emitter Stage:

\[ V_{cc} = 10V \]

Signal path:

\[ R \]

\[ V_i \]

\[ C \]

\[ c_i \]

\[ V_o \]

\[ R \]

\[ I_c \]

\[ V_{be} \]

\[ I_B \]

\[ I_C \]

\[ V_{ce} \]

\[ V_{be} \]

\[ I_C \]

\[ V_{be} \]

\[ I_B \]

DC Analysis:

\[ \frac{E_{out}}{I_{E}} = \frac{R}{R} \]

Solution: Assume, e.g., \[ V_o = \frac{V_{cc}}{2} \]

\[ \Rightarrow I_c = \frac{V_{cc} - V_o}{R} = \frac{V_{cc}}{2R} \]

Now, we can calculate \( g_m, r_i \) and \( V_o \) as needed.

S-S Analysis:

(Complete analysis first)

\[ V_i = \text{ideal source} \]

\[ V_i = V_{be} \text{ for } V_i \text{, ideal source} \]

\[ V_o = \text{inverting stage} \]

Apply KCL at \( V_o \):

\[ S C_m V_o - V_i + g_m V_i + g_o V_o + S C_m V_o + S C_L V_o = 0 \]

\[ A(s) = \frac{V_o}{V_i} = -g_m \left( \frac{1 - S C_m/g_m}{1 + S (C_u + C_c + C_L) g_o g_m} \right) \]

S-plane:

\[ \text{Inverting Stage} \]

\[ \text{Gain} \]

\[ \text{Inverting Stage} \]

\[ \text{Intuition: Cap in signal path between inverting nodes give RHP zero and vice-versa} \]
Observations: \( G_m \) determined between input and output nodes. \( G_m = G_m \) in CE stage.

\( G_{out} = \text{total conductance at output node} \)
\( C_{out} = \text{total capacitance at output node} \)

In this example, \( G_{out} = G_0 + g_o \)
\( C_{out} = C_u + C_c + C_L \)
\( C_u = \frac{G_m}{\omega} \) RHP zero since inverting around it.

Let's extend to a bigger circuit:

\( V_{B2} = 9.3 \text{ V} \)
\( V_A \)
\( Q_2 \)
\( Q_3 \)
\( V_A \)
\( Q_3 \)  \( Q_2 \)
\( V_A \)
\( Q_3 \)

\( V_i \)  \( Q_1 \)  \( \)  \( Q_1 \)

Clearly, the transconductance from \( V_i \) to \( Q_1 \) is \( g_m \): In general, \( \text{AV}_A = \frac{-g_m}{g_A} \) What is \( g_A \)?

By inspection:
\( g_A = g_1 + g_2 + g_3 \)
\( = g_{01} + g_{02} + g_{03} \)

\( \therefore \) \( \text{AV}_A = \frac{-g_m}{g_A} = \frac{-g_m}{g_{01} + g_{02} + g_{03}} \)

Question: What is total capacitance at \( Q_1 \) which sets \( W_{PA} \)?
(B) Common-Collector Stage (Emitter Follower):

\[ V_{CC} = 10V \]

\[ V_i \rightarrow V_{BE} \rightarrow V_o \]

DC Model:

\[ I_E = \frac{V_B - 0.7}{R_E} \]

\[ I_C = \frac{B E}{I_E} \approx I_E \]

Again, apply small-signal model first:

Apply KCL at \( V_o \) and factor:

\[ A_v = \frac{V_o}{V_i} = \frac{g_m + g_t}{g_m + g_t + g_0 + g_E} \]

\[ \approx \frac{g_m}{g_{out}} \]

Let's simplify with \( g_m \gg g_t \) (in numerator):

Bottom line: We can use same form as for CE stage!!
(C) Common-base stage:

\[
\begin{align*}
\text{CE stage:} & \quad \text{\( V_{be} = V_i - \delta \)} \\
\text{CB stage:} & \quad \text{\( V_{be} = 0 - V_i \)}
\end{align*}
\]

Basically, just a sign difference.

Again, apply small-signal model first:

\[
\begin{align*}
\text{KCL at \( V_o \) and \( V_i \):} \\
\frac{V_o}{V_i}(s) = \frac{\beta_m + \beta_o}{\beta_o + s} \frac{1}{1 + s(\beta_m + \beta_o + C_L s)}
\end{align*}
\]

Now, again assume \( \beta_m \gg \beta_o \) in numerator:

\[
\begin{align*}
\Rightarrow \quad \frac{V_o}{V_i}(s) = \frac{\beta_m}{\beta_o \text{out}} \frac{1}{1 + s\text{out}/\text{gain}}
\end{align*}
\]

Bottom line: We can use same form as CE and CC stages.