Last time: Common Emitter Amplifier with resistive bias ("classic" bias)

Inverting amplifier with relatively low input impedance;
$R_E$ – feedback resistor, improves input impedance but reduces voltage gain
Common Emitter Amplifier biased by current source.

\[
\begin{align*}
I_E & \rightarrow I_0^Q = \alpha \cdot I_E \rightarrow g_m, r_h, v_o \\
\text{Bias} & \\
* \text{But make sure that BJT is in FA, i.e. } V_{CE}^Q > 0.2-0.3V
\end{align*}
\]

Equivalent circuit based on Hybrid-\(\pi\) model, caps are short circuits for signals.
Common Emitter Amplifier biased by current source.

Voltage gains

\[ AV = \frac{V_{out}}{V_{in}} = \left( -\frac{g_m}{r_{BE}} \right) \left( r_{o} || r_c || r_L \right) = -g_m \left( r_{o} || r_c || r_L \right) \]

\[ A_{V0} = -g_m \left( r_o || r_c \right) \]

\[ A_{V0}^{\text{MAX}} = -g_m \cdot r_o \]

Finite output resistance puts upper limit on amplifier voltage gain.
Common Emitter Amplifier biased by current source.

Input/output impedances

\[ R_{in} = \frac{V_{in}}{i_{in}} = \frac{V_{BE}}{I_{B} + I_{C}} = \frac{1}{\frac{1}{I_{B}} + \frac{1}{I_{C}}} = \left( \frac{2}{I_{B}} \parallel \frac{1}{I_{C}} \right) \approx \frac{1}{I_{C}} \]

\[ R_{out} = \frac{V_{out}}{i_{out}} \bigg|_{V_{s} = 0} = (R_{C} \parallel V_{o}) \approx R_{C} \]

Net voltage gain

\[ G_{V} = A_{v} \cdot \frac{R_{in}}{R_{in} + R_{S}} \approx \frac{\beta}{R_{S}} \cdot \left( \frac{R_{C} \parallel V_{o}}{R_{S}} \right) \cdot \frac{R_{in}}{R_{S} + R_{S}} \]

\[ G_{V} \approx \beta \cdot \frac{R_{C} \parallel V_{o}}{R_{S}} \quad \text{for} \quad R_{S} \gg R_{S} \]

Not high enough - problem

Depends on \( \beta \), hence unstable
Common Emitter Amplifier biased by current source.

**Short circuit current gain**

\[ \tilde{I}_{\text{out}} = g_m V_{BE} \]

\[ \tilde{I}_{\text{in}} = g_m V_{BE}/r_{\text{in}} \]

\[ A_{\text{sh.c.}} = \frac{g_m \cdot V_{BE}}{r_{BE}/r_{\text{in}}} = g_m \cdot I_{\text{in}} \approx g_m \cdot r_{\text{in}} \equiv \beta \]

For \( R_B \gg r_h \)

**Common emitter current gain**
Example

nPN - BJT with \( \beta = 100 \) and \( V_A = 100V \).

Bias current \( I_E = 1mA, \ V_{CC} = -V_{EE} = 10V \)
\( R_B = 100k, \ R_C = 8k, \ R_S = 5k, \ R_L = 5k \)

1. Check if BJT is in FA regime

\[
I_B = \frac{I_E}{\beta + 1} = \frac{1mA}{101} \approx 10\mu A
\]

\[
V_B = -10\mu A \cdot 100k = -1V \rightarrow V_E = -1V - 0.7V = -1.7V > -10V.
\]

\[
V_C \approx 10V - 1mA \cdot 8k = 2V \rightarrow V_{CE} \approx 2V - (-1.7V) = 3.7V > 0.3V
\]

2. Calculate small signal parameters

\[
g_m = \frac{I_C^Q}{V_{th}} \approx \frac{1mA}{25mV} = 40 \frac{mA}{V}
\]

\[
r_\pi = \frac{\beta}{g_m} = \frac{100}{40mA/V} = 2.5k\Omega
\]

\[
R_o = \frac{V_A}{I_C^Q} \approx \frac{100V}{1mA} = 100k\Omega
\]

3. Find voltage gain

\[
G_V = \frac{R_{in}}{R_{in} + R_S} \cdot A_{V0} \cdot \frac{R_L}{R_L + R_{out}}
\]

\[
A_{V0} = -g_m \cdot (R_C \parallel r_o) \approx -296 \frac{V}{V}
\]

\[
R_{in} = (R_B \parallel r_\pi) \approx 2.4k, \ R_{out} = (R_C \parallel r_o) \approx 7.4k
\]

\[
G_V \approx 0.32 \cdot \left(-296 \frac{V}{V}\right) \cdot 0.4 \approx -38 \frac{V}{V}
\]

30mV p-p signal corresponds to about 10mV p-p variation of \( V_{BE} \).
This produces about 1.2V p-p across load.
Example – output voltage swing

Maximum amplitude of the undistorted sine wave at the output is limited by maximum negative voltage swing, i.e. by 3.5 V.

For 1mA bias current what could we do to increase the maximum output voltage amplitude?

What is the maximum value of this amplitude?
CE amp biased by current source and with $R_E$.

Case 1
$R_E = 0$
$R_{in} = (R_B \parallel r_\pi) \approx r_\pi$
$A_{V0} = -g_m \cdot (R_C \parallel r_O)$

Case 2 (neglect $r_O$)
$R_E \neq 0$
$R_{in} = (R_B \parallel (r_\pi + R_E \cdot [\beta+1])) > r_\pi$
$A_{V0} = -\frac{\beta \cdot R_C}{r_\pi + R_E \cdot [\beta+1]}$

Negative feedback resistor $R_E$ improves input impedance for the expense of gain