Effective emitter resistance

Ebers-Moll \( \Rightarrow V_{BE} \equiv V_T \ln \frac{I_C}{I_S} = V_T \left[ \ln I_C - \ln I_S \right] \)

\[ \Rightarrow r_e \equiv \frac{dV_{BE}}{dI_C} = \frac{V_T}{I_C} \]

\( V_T \approx 25 \text{ mV at } RT \)

Resistance built into the transistor:

\[ r_e = \frac{25}{I_c} \text{ (I_cm mA)} \]

Push-Pull Buffer

NPN-based emitter follower doesn't work well for \( V_{IN} < 0.6V \):

Emitter can't sink current.

\( \Rightarrow \) for \( V_{IN} < 0.6V \),

\[ Z_{out} = R_e \]

Solution:

For \( V_{IN} > 0.6V \), NPN can source lots of current, giving low \( Z_{out} \).

For \( V_{IN} < -0.6V \), PNP can sink lots of current, giving low \( Z_{out} \).

One problem: for \(-0.6 < V_{IN} < 0.6\), neither transistor is active \( \Rightarrow V_{out} = 0 \). 😞
Op amps

\[ V_{out} = A(V_+ - V_-) \]

\[ A = \text{open loop gain} \approx 10^6 \text{ at DC} \]

Golden Rules

1) No current flows into inputs
   \[ (Z_{in} \text{ typically } > 100 \text{ M}\Omega \text{ at DC}) \]

\[ V_{out} \text{ is between } \pm 15V \]
\[ \Rightarrow (V_+ - V_-) \text{ is between } \pm 15mV \approx 0 \]

2) \[ V_+ \approx V_- \]

Example: buffer

By 2), \[ V_- = V_{in} \]
because of the wire from \( V_{out} \) to \( V_- \),
\[ V_{out} = V_- \]
\[ \Rightarrow V_{out} = V_{in}, \text{ as desired for a buffer} \]

Why is \( Z_{out} \) of the buffer so low? feedback!

Low \( Z_{out} \) \( \Rightarrow \) \( V_{out} \) should be constant

If \( V_{out} \downarrow \), \( V_- \downarrow \). Then, since \( V_{out} = A(V_+ - V_-) \),
the op amp brings \( V_{out} \) back up!