Few more details on transistors and useful transistor circuits.

Something fishy about the amplifier circuit?

\[ V_{out} = -\frac{R}{r} V_{in} + C \]

\[ i = 0 \quad 0.6 < V_c = 0.6 + V_E < 0.6 + \frac{r}{R+r} V_c \]

\[ V_{out} = V_c \quad V_{out} = \frac{r}{R+r} V_c \]

- Note the limited range of operation
- Our calculation is based on an ideal transistor model.
What is the largest gain one can get? What if \(r=0\)? Do we have infinite gain? What is wrong with our model?

\[
\begin{align*}
\text{ideal diode} & \quad \text{real diode} \\
i_b & \uparrow \quad i_b & \uparrow \quad 0.6V \\
\Rightarrow V_{be} & \Rightarrow 0.6V
\end{align*}
\]

\[
i_b = i_o \left[ e^{\frac{qV}{KT}} - 1 \right] = i_o \left( e^{\frac{V}{25\,mV}} - 1 \right)
\]

Ebers-Moll eqn.

So we can define an effective resistance \(R_e\):

\[
\text{Gain} = \frac{R}{R_e(V_{in})}
\]

\(\Rightarrow\) higher \(V_{in}\) \(\Rightarrow\) lower \(R_e\) \(\Rightarrow\) higher gain.

Safer to have an emitter resistor \(R \gg R_e\), so the total gain

\[
G = \frac{R}{r + R_e} \text{ source of distortion.}
\]

Let's use PNP this time
NPN not good, why?

Feedback control
when $I \uparrow V_{eb} \downarrow$
thus regulate $I$

$\begin{align*}
\text{1st transistor} \\
\text{current} = 1mA \\
\text{2nd transistor} \\
\end{align*}$

Unfortunately $I_e$ depends on temperature, a matched pair of transistors is typically needed.

It suffers from the Early effect too.
Second effect of transistor: Early effect

Result: When used in a switch, current can depend on both $V_b$ and $V_c$, namely

$$i_c = \beta [e^{V_{be}/0.05\text{meV}} - 1] + \frac{V_{ce}}{R}$$

$$= \beta [e^{(V_{be} + \alpha V_{ce})/0.05\text{meV}} - 1]$$

Early effect: if we wish to keep $i_c = 0$

$V_{be}$ should be reduced by

$$\Delta V_{be} = -\alpha V_{ce}, \ \alpha \text{ is typically } 10^{-4}$$
Transistor circuits:

**Push-Pull**

![Push-Pull circuit diagram](image)

**Differential amplifier**

![Differential amplifier circuit diagram](image)