Transistors

- invented in 1947
- **amplify current**
- lower power consumption
- cheap for mass production
- robust to vibration
- long working time (decades) when properly used
- replaced vacuum tube
- building block of modern electronics

Some areas where vacuum tube are still good
- ultra high voltage applications (more than 1000 V)
- radiation prone locations
Bipolar junction Transistor (BJT)

NPN-transistor

Collecter
Base
Emitter

PNP-transistor

Collector
Base
Emitter

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Electronics 1
 Lecture 06
Notation

- Base-emitter current ($I_{be}$)
- Collector-emitter current ($I_{ce}$)
- Base-emitter voltage difference ($V_{be} = V_b - V_e$)
- Collector-emitter voltage difference ($V_{ce} = V_c - V_e$)
Simple NPN-transistor rules

To support shown currents direction

\[ V_{ce} > 0 \]

since, it is forward biased diode

\[ V_{be} \approx 0.6 \text{ V} \]

\[ V_{cb} > 0 \]

since, it is reversed biased diode, no current goes from collector to base, all collector current is directed to emitter

If \[ V_{cb} < 0 \] transistor goes to saturation and cannot be described by the following simple rule.

If above holds true then

\[ I_{ce} = \beta I_{be} \]

thus a BJT is a current amplifier

the static forward current transfer ratio

\[ \beta \text{ or } h_{fe} \approx 100 \ldots 200 \]

\[ I_{e} = I_{be} + I_{ce} = (\beta + 1)I_{be} \approx \beta I_{be} \]
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![NPN transistor diagram]
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The static forward current transfer ratio $\beta$ (or sometimes $h_{fe}$) $\approx 100$ to $200$...

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Simple PNP-transistor rules

Apply the same rules as before for NPN BJT but multiply currents and voltages by -1.

Hints

- the arrow indicates the direction in which current is supposed to flow.
- the arrow always connects the base and emitter.
Remember $\beta$ is not a constant!
It depends on many parameters
- temperature
- collector current
- varies from device to device even in the same batch

Good design should not depend on $\beta$ value.
Current through the load resistor does not depend on the load resistance.

\[ I_L = I_c = \beta I_{be} = \beta \frac{V_{ctrl} - 0.6V}{R_{set}} \]
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\[ V_c = V_{cc} - R_L I_L \]

remember that \( V_c \) must be \( > V_b \) thus current cannot be bigger than the saturation current

\[ I_{sat} = \max(I_L) \leq \frac{V_{cc} - V_b}{R_L} \approx \frac{V_{cc}}{R_L} \]
From $V_{cc}$ point of view, left schematic is equivalent to the right one.

$$R_{trans} = \frac{V_C}{I_L} = \frac{V_{cc} - I_L R_L}{I_L}$$

**Transistor**

Trans(sform)-(re)sistor
Constant current source. Power dissipation.

Transistor power dissipation

\[ P_{\text{trans}} = P_{\text{be}} + P_{\text{ce}} = V_{\text{be}}I_{\text{be}} + V_{\text{ce}}I_{\text{ce}} \]

Since

\[ V_{\text{be}} \leq V_{\text{ce}}, \quad I_{\text{be}} = I_{\text{ce}}/\beta \ll I_{\text{ce}}, \quad \text{and} \quad I_{\text{ce}} = I_L \]

\[ P_{\text{trans}} \approx V_{\text{ce}}I_{\text{ce}} = R_{\text{trans}}I_L^2 \]
Transistor power dissipation

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Maximum power dissipation in transistor
Transistor power dissipation

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Maximum power dissipation in transistor is when \(R_{\text{trans}} = R_L\)
Constant current source. Power dissipation.

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\[ \text{max}(P_{\text{trans}}) = \frac{V_{\text{cc}}^2}{4R_L}, \quad \text{when} \quad I_L = \frac{V_{\text{cc}}}{2R_L} \]
Voltage controlled switch

When properly designed outcome does not depend on reasonable variations of $\beta$

Recall that typically $\beta = 100 \ldots 200$
We will assume the worst case scenario $\beta = 10$
Notice that $R_L$ limits collector current

\[
I_L = \frac{V_{cc}}{R_L}
\]

\[
I_{be} = \frac{V_{ctrl} - .6V}{R_b} = \frac{I_L}{\beta}
\]

\[
R_b \leq \frac{V_{ctrl} - .6V}{V_{cc}} \beta R_L
\]
Emitter follower

\[ V_{out} = V_{in} - 0.6V \]

Gain. What gain?

We achieved the input impedance increase.

As a result our \( V_{in} \) source is not overloaded and our load receive all required current (as long as the collector power supply can support it).

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\[ R_{input} = \frac{V_{in}}{I_{be}} \approx R_L(\beta + 1) \]

As a result our \( V_{in} \) source is not overloaded and our load receive all required current (as long as the collector power supply can support it).