Transistors.

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Week 6

Transistors

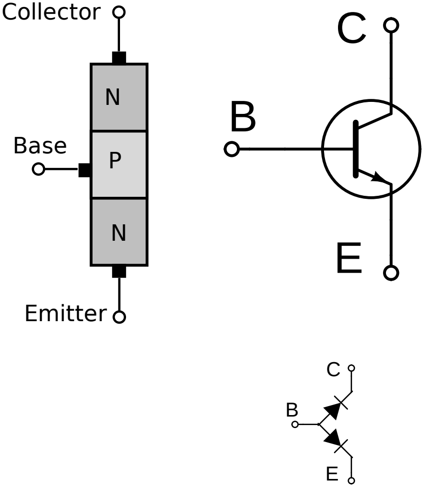
- invented in 1947
- amplify current
- lower power consumption
- cheap for mass production
- robust to vibration
- long working time (decades) when properly used
- replaced vacuum tube
- building block of modern electronics

Some areas where vacuum tube are still good

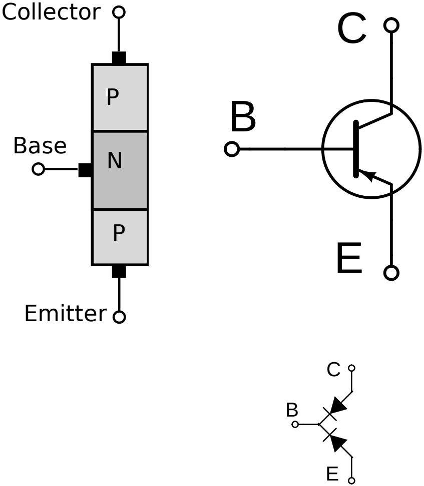
- ultra high voltage applications (more then 1000 V)
- radiation prone locations

Bipolar junction Transistor (BJT)

NPN-transistor

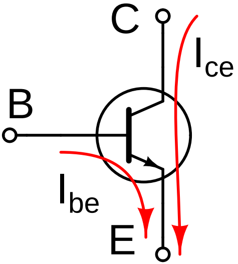


PNP-transistor



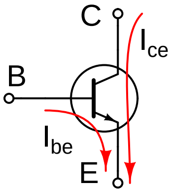
Notation

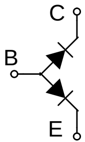
- Base-emitter current (I_{be})
- Collector-emitter current (I_{ce})
- Base-emitter voltage difference ($V_{be} = V_b - V_e$)
- Collector-emitter voltage difference ($V_{ce} = V_c - V_e$)



Simple NPN-transistor rules

To support shown currents direction





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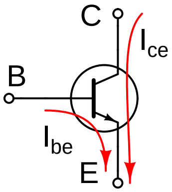
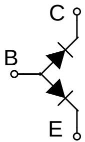
- $V_{ce} > 0$





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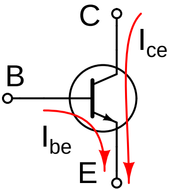
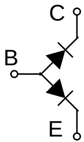
- $V_{be} > 0$
  - since, it is forward biased diode $V_{be} \approx 0.6$ V





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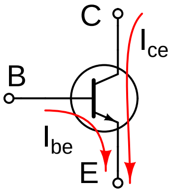

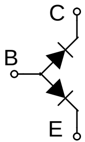

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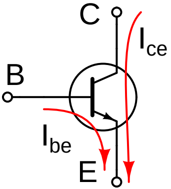

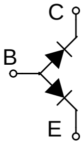

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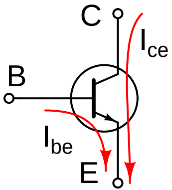

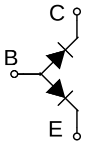

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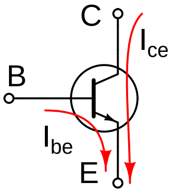

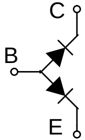

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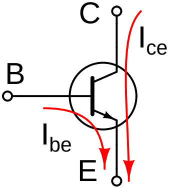

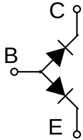

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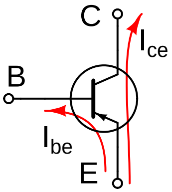
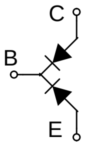
- $I_{ce} = \beta I_{be}$ thus a BJT is a current amplifier
- *the static forward current transfer ratio* β (or sometimes h_{fe}) $\approx 100 \ldots 200$
- $I_e = I_{be} + I_{ce} = (\beta + 1) I_{be} \approx \beta I_{be}$

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.





Design considerations for β

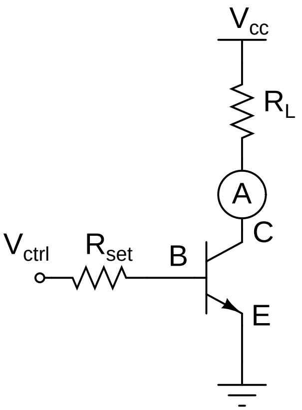
Remember β is not a constant!
It depends on many parameters

- temperature
- collector current
- varies from device to device even in the same batch

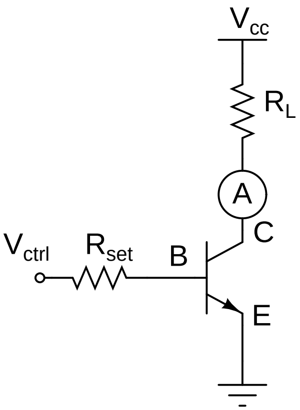
Good design should not depend on β value.

Constant current source

Current through the load resistor does not depend on the load resistance.



$$I_L = I_c = \beta I_{be} = \beta \frac{V_{ctrl} - .6V}{R_{set}}$$



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This is actually a sample of bad design since the current through the load depends on β.

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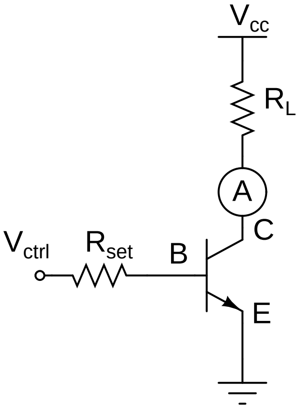

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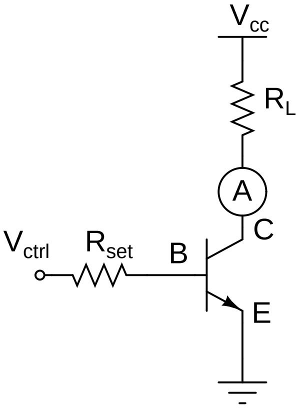

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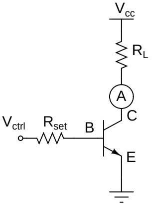
$$V_c = V_{cc} - R_L I_L$$

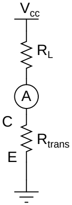
remember that V_c must be $>$ V_b thus current cannot be bigger then the saturation current

$$I_{sat} = max(I_L) \leq \frac{V_{cc} - V_b}{R_L} \approx \frac{V_{cc}}{R_L}$$

From V_{cc} point of view, left schematic is equivalent to the right one.



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



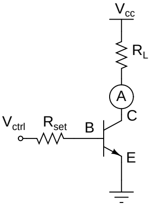
Transistor

Tran(sform)-(re)**sistor**

Constant current source. Power dissipation.

Transistor power dissipation

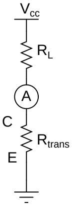
$$P_{trans} = P_{be} + P_{ce} = V_{be} I_{be} + V_{ce} I_{ce}$$



Since

$V_{be} \leq V_{ce}$, $I_{be} = I_{ce}/\beta \ll I_{ce}$, and $I_{ce} = I_L$

$$P_{trans} \approx V_{ce} I_{ce} = R_{trans} I_L^2$$



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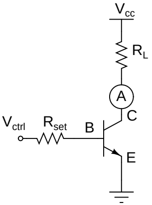

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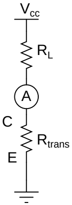
Maximum power dissipation in transistor



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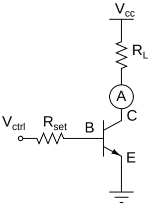

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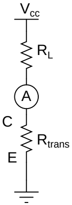

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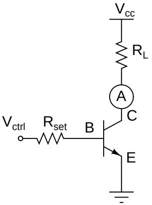

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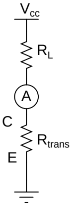
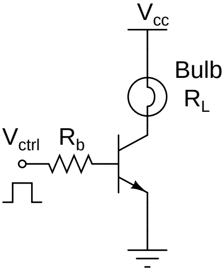


$$max(P_{trans}) = \frac{V_{cc}^2}{4R_L}, \text{ when } I_L = \frac{V_{cc}}{2R_L}$$

Voltage controlled switch

When properly designed outcome does not depend on reasonable variations of β



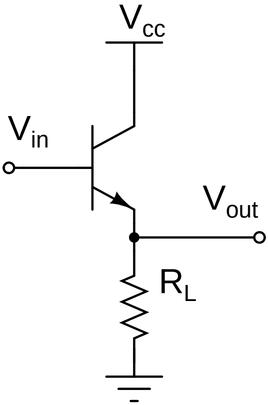
Recall that typically $\beta = 100 \ldots 200$
We will assume the worst case scenario $\beta = 10$
Notice that R_L limits collector current

$$I_L = \frac{V_{cc}}{R_L}$$

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

$$R_b \leq \frac{V_{ctrl} - .6V}{V_{cc}} \beta R_L$$

Emitter follower



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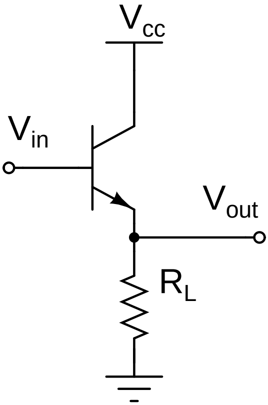

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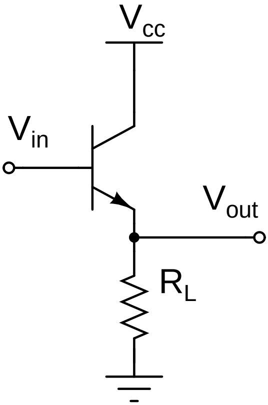
Gain. What gain?



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Gain. What gain?
We achieved the input impedance increase.

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

As 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).