EE281 (Introduction to Electrical Engineering II) and EE285 (Electronics I)

Bipolar Junction Transistor (BJT)

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Bipolar Junction Transistor (BJT)

- What is a Transistor?
- History
- Types
- Characteristics
- Applications

What is a transistor ?

- Semiconductors: ability to change from conductor to insulator
- Can either allow current or prohibit current to flow
- Useful as a switch, but also as an amplifier
- Essential part of many technological advances

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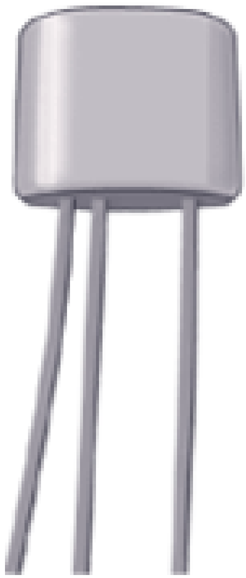
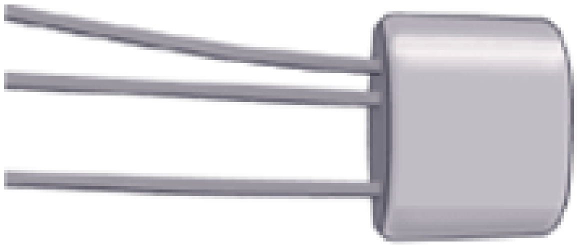


The Transistor is Born

- Bell Labs (1947): Bardeen, Brattain, and Shockley
- Originally made of germanium
- Current transistors made of doped silicon

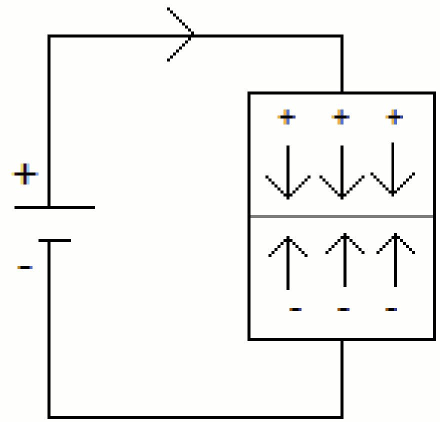


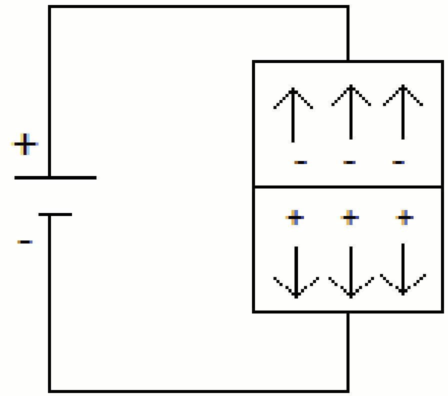
How Transistors Work

- Doping: adding small amounts of other elements to create additional protons or electrons
- P-Type: dopants lack a fourth valence electron (Boron, Aluminum)
- N-Type: dopants have an additional (5^{th}) valence electron (Phosphorus, Arsenic)
- Importance: Current only flows from P to N

Diodes and Bias

- Diode: simple P-N junction.
- Forward Bias: allows current to flow from P to N.
- Reverse Bias: no current allowed to flow from N to P.
- Breakdown Voltage: sufficient N to P voltage of a Zener Diode will allow for current to flow in this direction.

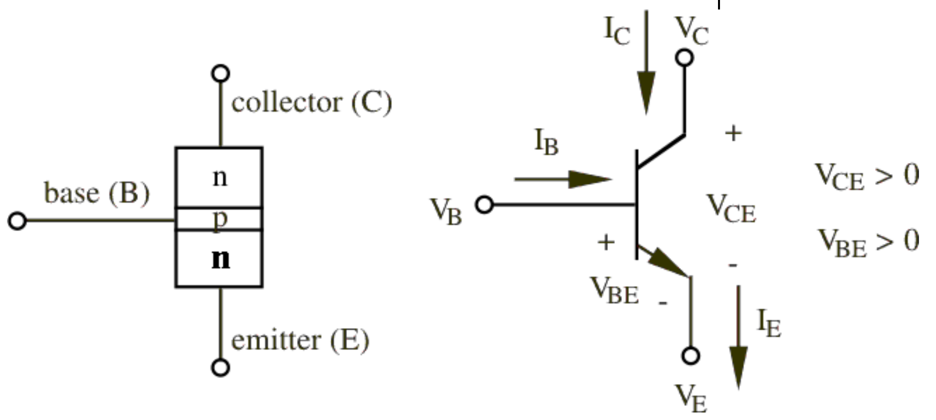




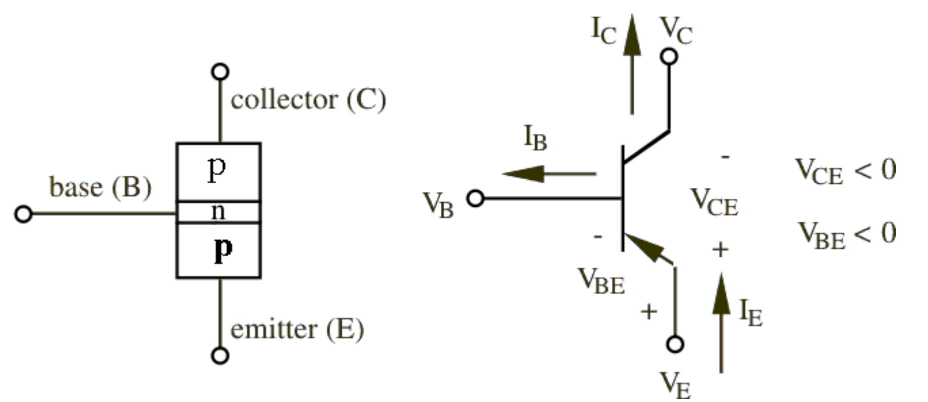
Bipolar Junction Transistor (BJT)

- 3 adjacent regions of doped Si (each connected to a lead):
  - Base. (thin layer,less doped).
  - Collector.
  - Emitter.
- 2 types of BJT:
  - npn.
  - pnp.
- Most common: npn (focus on it).

Developed by Shockley (1949)



npn bipolar junction transistor



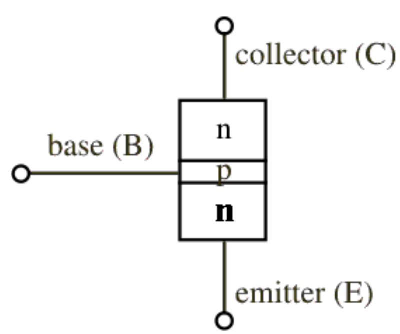
pnp bipolar junction transistor

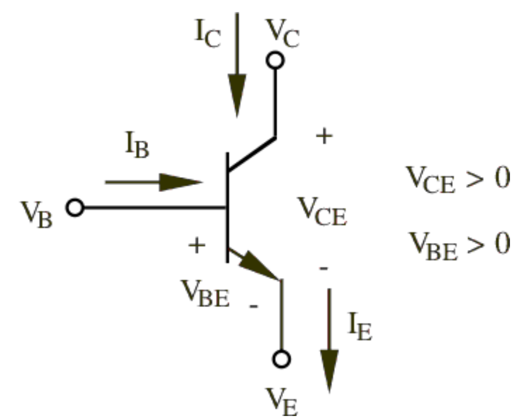
BJT npn Transistor

- 1 thin layer of p-type, sandwiched between 2 layers of n-type.
- N-type of emitter: more heavily doped than collector.
- With $V_C > V_B > V_E$:
  - Base-Emitter junction forward biased, Base-Collector reverse biased.
  - Electrons diffuse from Emitter to Base (from n to p).
  - There's a depletion layer on the Base-Collector junction → no flow of e^- allowed.
  - **BUT** the Base is thin and Emitter region is n^+ (heavily doped) → electrons have enough momentum to cross the Base into the Collector.
  - The small base current I_B controls a large current I_C

$$V_C > V_B > V_E$$

$$\begin{aligned} I_E &= I_C + I_B \\ V_{BE} &= V_B - V_E \\ V_{CE} &= V_C - V_E \\ I_C &= \beta I_B \end{aligned}$$





BJT characteristics

- Current Gain:
  - α is the fraction of electrons that diffuse across the narrow Base region
  - 1- α is the fraction of electrons that recombine with holes in the Base region to create base current
- The current Gain is expressed in terms of the **β** (beta) of the transistor (often called h_{fe} by manufacturers).
- β (beta) is Temperature and Voltage dependent.
- It can vary a lot among transistors (common values for signal BJT: 20 - 200).

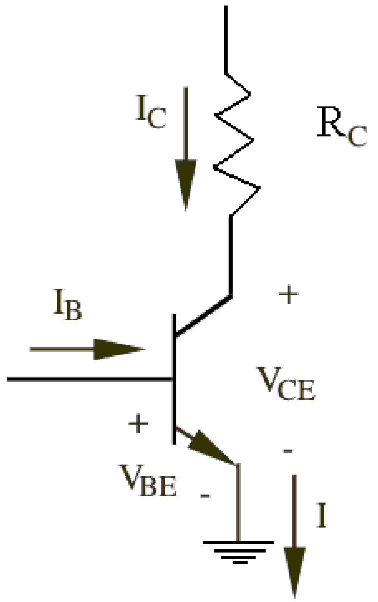
$$I_C = \alpha I_E$$

$$I_B = (1-\alpha) I_E$$

$$\beta = \frac{I_C}{I_B} = \frac{\alpha}{1-\alpha}$$

npn Common Emitter circuit

- Emitter is grounded.
- Base-Emitter starts to conduct with V_{BE}=0.6V,I_C flows and it's $I_C=\beta * I_B$.
- Increasing I_B, V_{BE} slowly increases to 0.7V but I_C rises exponentially.
- As I_C rises ,voltage drop across R_C increases and V_{CE} drops toward ground. (transistor in saturation, no more linear relation between I_C and I_B)



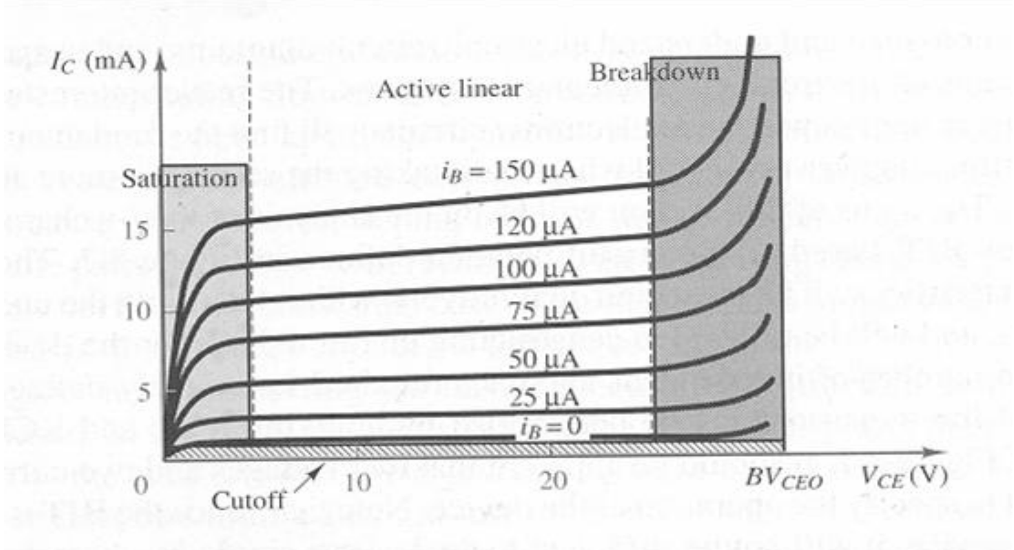


Figure 8.9(b) The collector-emitter output characteristics of a BJT

Common Emitter characteristics

Collector current controlled by the collector circuit. (Switch behavior)

In full saturation V_{CE}=0.2V.

No current flows

Collector current proportional to Base current

The avalanche multiplication of current through collector junction occurs: to be avoided

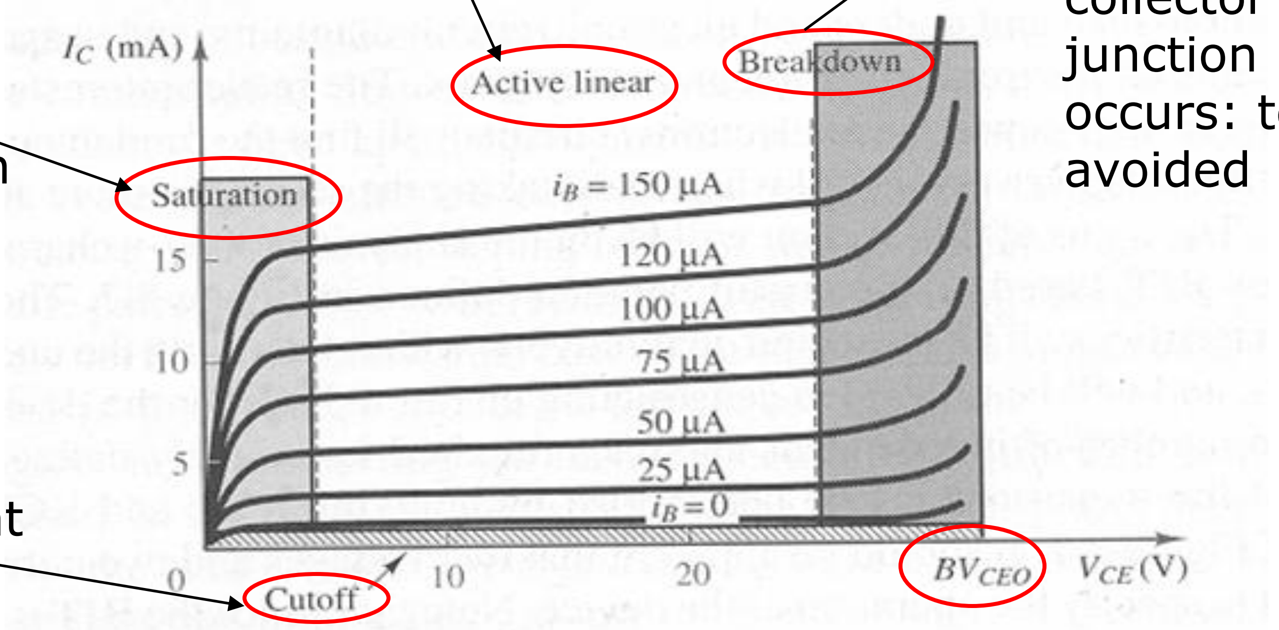
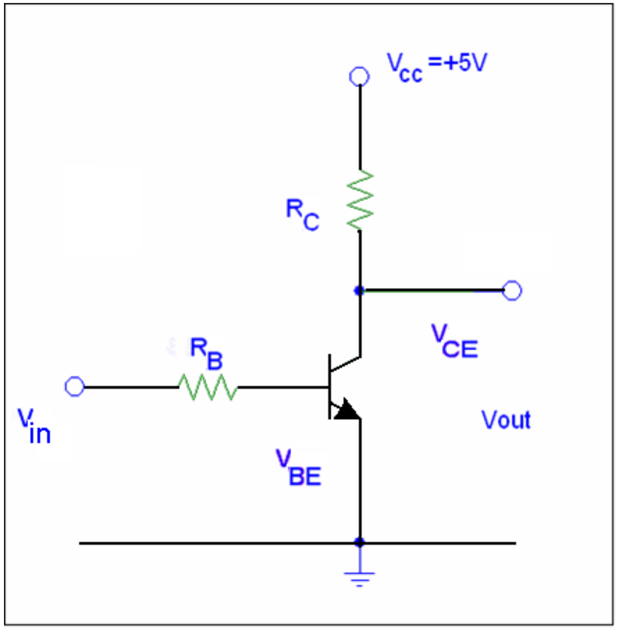
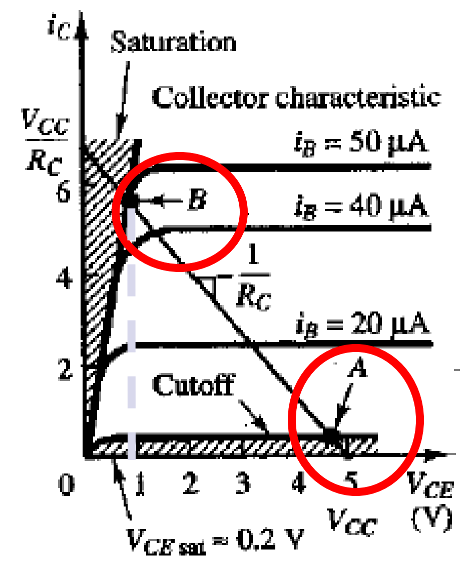


Figure 8.9(b) The collector-emitter output characteristics of a BJT

BJT as Switch



- $\underline{V_{in}}$(Low) < 0.7 V
  - BE junction <u>not</u> forward biased
  - Cutoff region
  - No current flows
  - $V_{out} = V_{CE} = V_{cc}$
- <u>V_{out} = High</u>

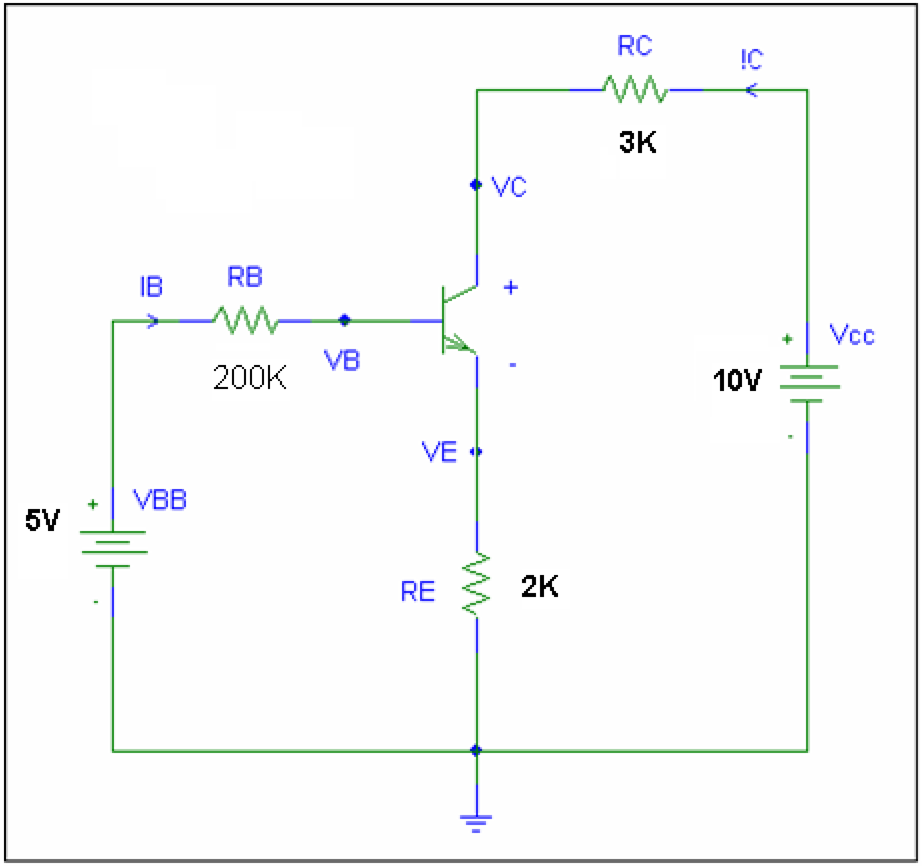


- $\underline{V_{in}}$(High)
  - BE junction <u>forward biased</u> (V_{BE}=0.7V)
  - Saturation region
  - V_{CE} small (~0.2 V for saturated BJT)
  - V_{out} = small
  - $I_C = (V_{cc}-V_{CE})/R_C$

BJT as Switch 2

- Basis of digital logic circuits
- Input to transistor gate can be analog or digital
- Building blocks for TTL – Transistor Transistor Logic
- Guidelines for designing a transistor switch:
  - $V_C > V_B > V_E$
  - $V_{BE} = 0.7$ V
  - I_C independent from I_B (in saturation).
  - Min. I_B estimated from by ($I_{Bmin} \approx I_C/\beta$).
  - Input resistance→ such that I_B > 5-10 times I_{Bmin} because β varies among components, with temperature and voltage and R_B may change when current flows.
  - Calculate the max I_C and I_B not to overcome device specifications.

BJT as Amplifier

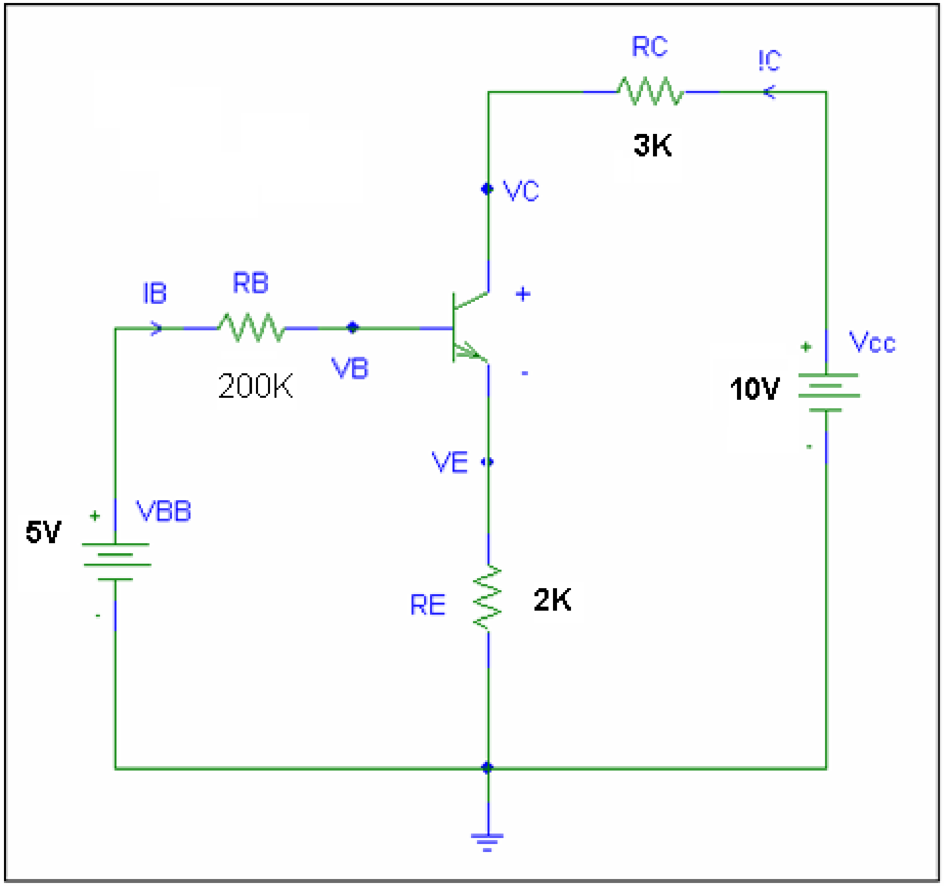


- Common emitter mode
- Linear Active Region
- Significant current Gain

Example:

- Let Gain, $\beta = 100$
- Assume to be in active region -> $V_{BE}=0.7V$
- Find if it's in active region

BJT as Amplifier



$$V_{BE} = 0.7V$$

$$I_E = I_B + I_C = (\beta + 1) I_B$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B + R_E * 101} = \frac{5 - 0.7}{402} = 0.0107 mA$$

$$I_C = \beta * I_B = 100 * 0.0107 = 1.07 mA$$

$$V_{CB} = V_{CC} - I_C * R_C - I_E * R_E - V_{BE} =$$

$$= 10 - (3)(1.07) - (2)(101 * 0.0107) - 0.7 =$$

$$= 3.93V$$

$V_{CB} > 0$ so the BJT is in active region