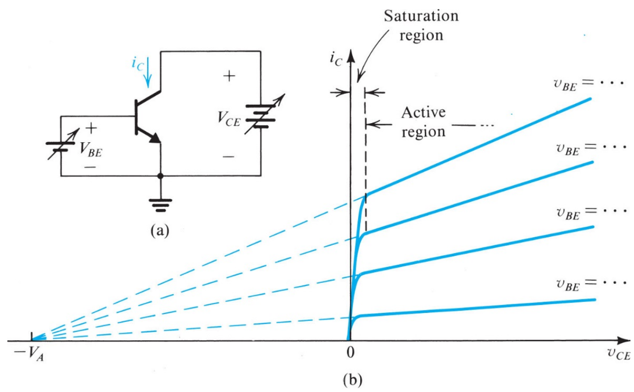
EE105 – Fall 2015
Microelectronic Devices and Circuits

Prof. Ming C. Wu

wu@eecs.berkeley.edu

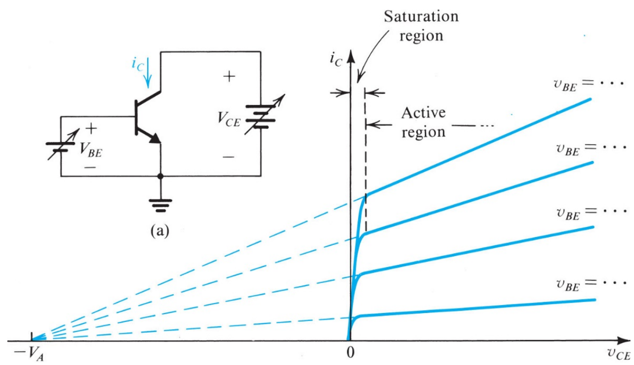
511 Sutardja Dai Hall (SDH)

I-V Characteristics of BJT



- **The I-V looks similar to MOSFET's I-V, though the physical equations governing the saturation (triode for MOSFET) and active (saturation for MOSFET) are different**
- **i_C has a finite slope in the active region, due to base width modulation (called Early Effect).**
  - **Similar to channel length modulation in MOSFET**

Early Effect



Recall that $i_C = I_S e^{\frac{v_{BE}}{V_T}}$, where $I_S = \frac{A_E q D_n n_i^2}{N_A W}$

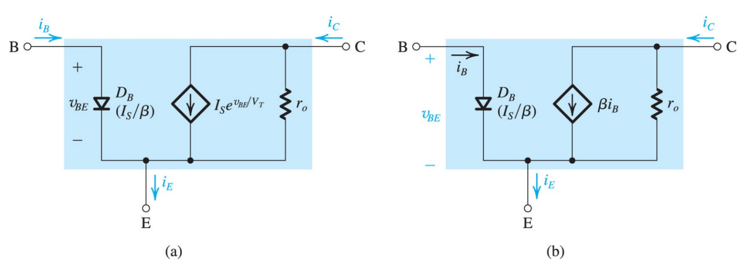
$v_{CE} = v_{CB} + v_{BE} \approx v_{CB} + 0.7V$

As v_{CE} increase, the base-collector junction becomes more reverse-biased

As a result, the neutral base width, W, decrease, leading to increase in I_S.

This is modeled by: $i_C = I_S e^{\frac{v_{BE}}{V_T}} \left(1 + \frac{v_{CE}}{V_A}\right)$, V_A is called "Early voltage"

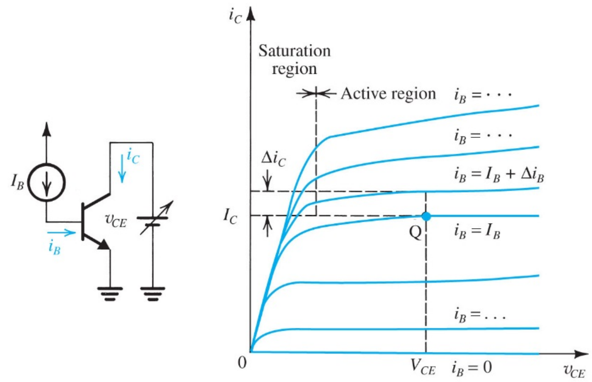
Large-Signal Model of BJT in Active Mode



Output resistance account for the finite slope of i_C-vs-v_{CE} :

$$r_o = \left(\frac{\partial i_C}{\partial v_{CE}}\right)^{-1} = \left(\left(I_S e^{\frac{v_{BE}}{V_T}}\right)\left(\frac{1}{V_A}\right)\right)^{-1} \approx \left(\frac{I_C}{V_A}\right)^{-1} = \frac{V_A}{I_C}$$

BJT I-V using Base Current as Parameter



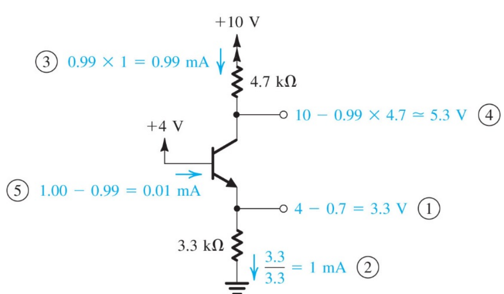
Usually the I-V curves are plotted with i_B as parameter rather than v_{BE} so the family of curves are roughly equally spaced.

The current gain can be simply measured by

$$\beta = \frac{\Delta i_C}{\Delta i_B}$$

Example: BJT Bias Point

β=100, Find the bias point of the BJT circuit (i.e., i_C and all nodal voltages)



(c)

Usually it is not necessary to consider Early effect in DC analysis.

Assume $V_{BE} = 0.7V$

$$V_E = 4 - V_{BE} = 3.3V$$

$$I_E = \frac{3.3V}{3.3k\Omega} = 1mA$$

$$I_B = \frac{I_C}{\beta} \approx \frac{I_E}{\beta} = 0.01mA$$

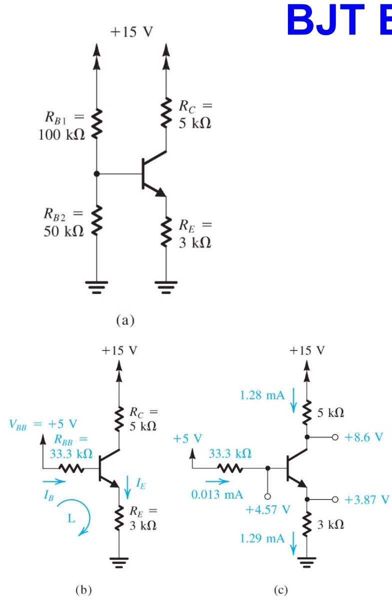
$$I_C = I_E - I_B = 0.99mA$$

$$V_C = 10 - R_C I_C = 5.3V$$

We have assumed the BJT is in active mode. It is important to verify that after we solve the bias point. Here, $V_{CE} = V_C - V_E = 2V$, which is > $V_{CE,sat} \approx 0.2V$.

Note: in DC analysis, we can usually approximate $I_C \approx I_E$

BJT Bias Example



β=100, find the bias point.

Assume BJT in active mode.

(1) Find Thevenin equivalent circuit of R_{B1} and R_{B2}

$$V_{BB} = V_{CC}\frac{R_{B2}}{R_{B1}+R_{B2}} = 5V$$

$$R_{BB} = R_{B1} \| R_{B2} = 33.3k\Omega$$

(2) Apply KVL to the loop with R_{BB}, V_{BE}, and R_E

$$V_{BB} = I_B R_{BB} + V_{BE} + I_E R_E \approx \frac{I_C}{\beta} R_{BB} + 0.7 + I_C R_E$$

$I_C = 1.29mA$

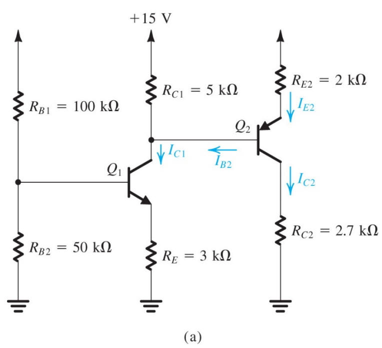
(3) $V_E = I_C R_E = 3.87V$

(4) $V_C = 15 - I_C R_C = 8.55V$

(5) $V_{CE} = V_C - V_E = 4.68V > 0.2V$

BJT is indeed in active mode

BJT Bias Example



Assume both Q1 and Q2 are in active mode.

Quick analysis: assume I_{B2} is small and does not change I_{E1}

(1) Q1 bias has been solved previously.

$I_{C1} = 1.29mA$

$V_{C1} = 8.55V = V_{B2}$

(2) $V_{E2} = V_{B2} + 0.7 = 9.25V$

(3) $I_{E2} = \frac{V_{CC} - V_{E2}}{R_{E2}} = 2.86mA \approx I_{C2}$

(4) $V_{CE2} = V_{CC} - I_{C2}(R_{E2} + R_{C2}) = 1.56V$ --> OK

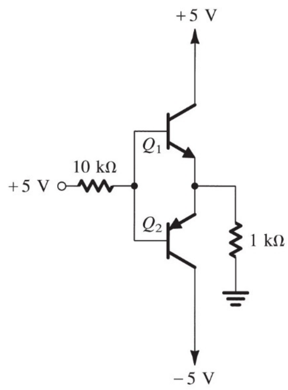
The solution is very close to more detailed analysis considering I_{B2} flowing into Q1 (see textbook):

$I_{C2} = 2.75mA$ (4% error)

$V_{E2} = 9.44V$ (2% error)

Usually good enough for hand analysis

"Digital" Circuit Example



(a)

Since the Bases and Emitters of Q1 and Q2 are tied together, and one is npn and the other is pnp, one of them will be in the cut-off mode.

Assume Q1 is OFF, all currents from 1kΩ load resistor flow through Q2. Therefore V_E will be between 0 and -5V. In this case, $V_{BE1} > 0$, so the assumption is incorrect.

Assume Q2 is OFF, now we need to find whether Q1 is in Active or Saturation mode.

(1) Assume Q1 in Active. $V_{BE} = 0.7V$.

Apply KVL:

$5 = I_{B1} \cdot 10k\Omega + 0.7V + \beta I_{B1} \cdot 1k\Omega$

$I_{B1} = 0.039mA, \quad I_{C1} = 3.9mA$

$V_E = I_{C1} \cdot 1k\Omega = 3.9V$

$V_B = 5 - I_{B1} \cdot 10k\Omega = 4.61V$

Q2 is indeed cut-off, and Q1 in Active