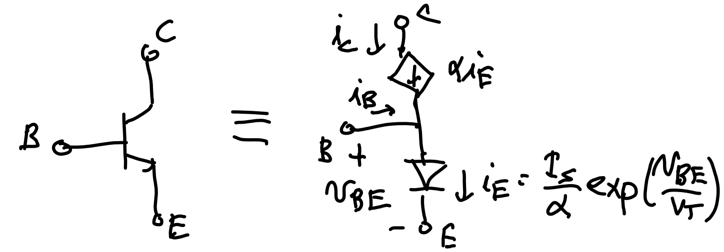
Lecture 18: Bipolar Junction Transistors (BJTs) III

- **Announcements**:
- HW#6 online and due Friday Oct. 12 via Gradescope
- PreLab#4 is online and due next week, as is Lab#3
- Lab#4 (the experimental part) will be online soon
- By popular demand, lab sections run this week
- Midterm 1: Friday, Oct. 5, from 5-6:30 p.m., in 277 Cory
- Midterm Info Sheet online with updates from what we discussed last week
- -----------------------------------
- Lecture Topics:
  - BJT Forward-Active Region
    - —Physics
    - —Large Signal Circuit Model
    - —Operating Pt. Example
  - Reverse Active Region
  - Saturation Region
- -----------------------------------
- **Last Time**:
- Forward-active BJT large signal model
- Now, continue with this

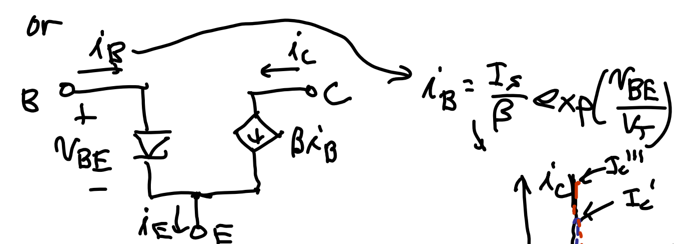
Equiv. Large Signal Ckt. Models for BJT's (in Forward-Active)

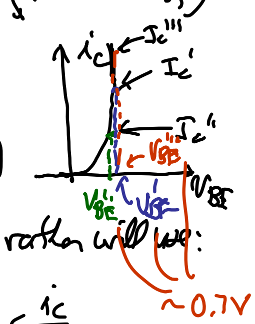
⇒ several of them → two most popular accurate ones:



Common-Base (CCCS)

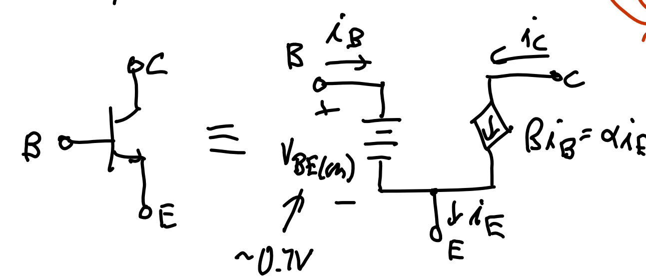
or





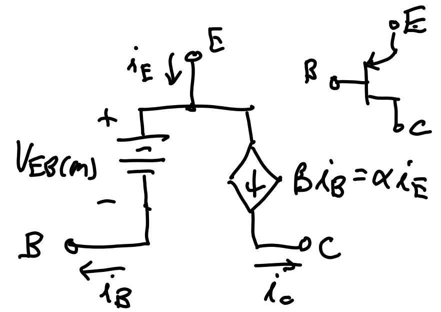
Common-Emitter (CCCS)

↳ usually, won't use the above, but rather will use:



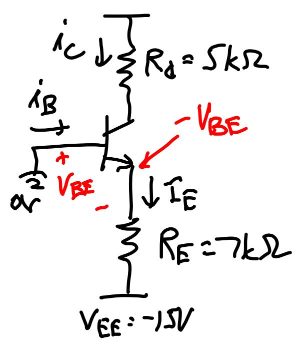
npn

Copyright © 2018 Regents of the University of California



(for pnp)

Example. (exactitude)



Find the DC operating pt.
(i.e., Find the DC voltages at each node and the currents through each branch)

$$I_E = \frac{-V_{BE} - V_{EE}}{R_E}$$

$$I_c = \alpha I_E = \frac{\alpha(-V_{EE} - V_{BE})}{R_E}$$

For npn Xsistor:
$\beta = 100$
$I_S = 2\times10^{-15}A$

$$I_S \exp\left(\frac{V_{BE}}{V_T}\right) = \frac{\beta}{\beta+1}\frac{(-V_{EE} - V_{BE})}{R_E}$$

(V_T = 25mV; $\frac{\beta}{\beta+1} = \alpha$)

(nonlinear equation)

↪ iteration, numerical → painful...

⇒ Get $V_{BE} = 0.717V$

⇒ $I_E = \frac{15 - 0.717}{7k} = 2.04mA$

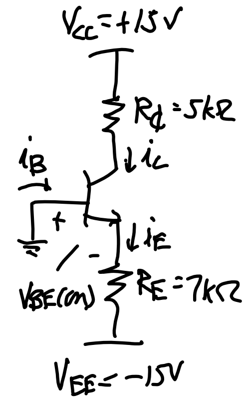
⇒ $I_c = \alpha I_E = \left(\frac{100}{101}\right) I_E = 2.02mA$

⇒ $I_B = \frac{I_c}{\beta} = 0.02\ mA$

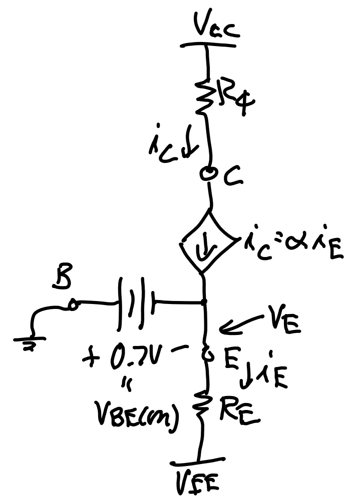
$V_B = 0V$
$V_E = -0.717V$
$V_c = 15 - I_c(5k) = 4.9V$

⇒ What if we don't know β & I_S accurately? → No need to be so accurate!

⇒ Do the problem again using approximations.
↪ esp. the model.



≡



⇒ no exponential
⇒ easy to solve!

$V_B = 0V$, $V_E = -0.7V = -V_{BE(on)}$

$$I_E = \frac{-0.7 - (-15)}{7k} = 2.04mA$$

$$I_c = \alpha I_E \cong I_E = 2.04mA$$

$$I_B = \frac{I_c}{\beta} = 0.02mA$$

$$V_c = 15 - (2.04m)(5k) = 4.8V$$

($m = 10^{-3}$, $k = 10^3$)

③ **Reverse-Active Region:**

BEJ reverse-biased
BCJ forward-biased

⇒ similar to forward-active region w/ one important difference:

$$\beta_R \propto \frac{N_{dC} W_a D_p}{N_{aB} W_B D_n} \leftarrow N_{dC} < N_{aB} \text{ (collector is n-)}$$

↑ reverse

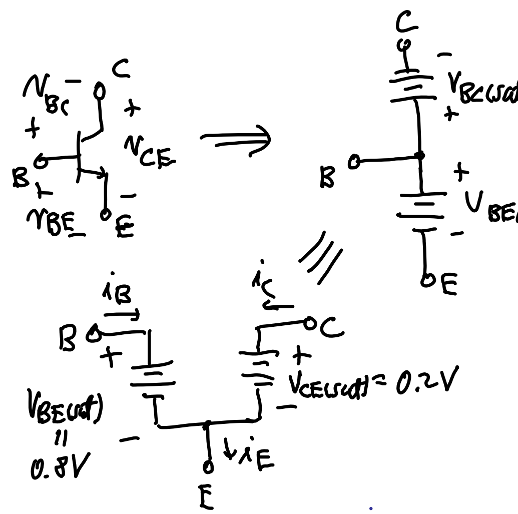
$\therefore \beta_R \ll \beta_F$ ← forward

Thus, avoid using the device in reverse-active!

④ **Saturation Region:**

higher than 0.7V in saturation

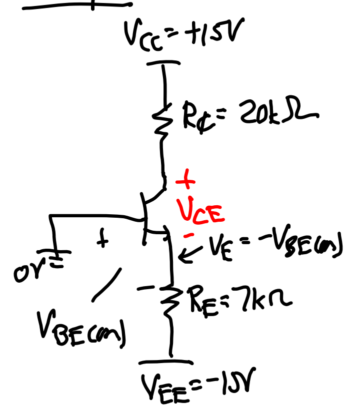
BEJ forward-biased → $V_{BE(on)} \sim 0.8V$
BCJ forward-biased → $V_{BC(on)} \sim 0.6V$



(All for npn; come up w/ pnp model)

- When determining DC operating point:
  1. First, assume forward-active, then check for cut-off, i.e., is there enough V_{BE}?
  2. Assume forward-active, then determine V_{CE}.
  3. If $V_{CE} > V_{CE(sat)}$, then okay … otherwise, must do analysis using the device saturation model.

Example.



① $i_E = \frac{15 - 0.7}{7K} = 2.04mA$
⇒ enough voltage to turn on BEJ ✓

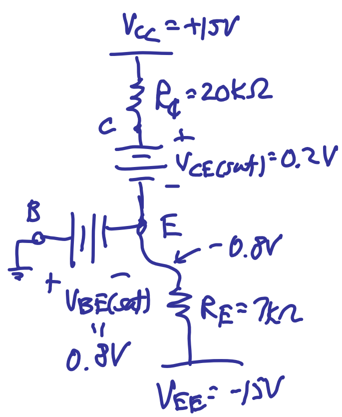
② Assume forward-active

$V_C = 15 - (2.04m)(20k) = -25.8V$

$\therefore V_{CE} = V_C - V_E = -25.8 - (-0.7) = -25.1V < 0.2V = V_{CE(sat)}$

∴ saturated BJT

③ Analyze assuming saturation:



$V_B = 0V$, $V_E = -0.8V$

$I_E = \frac{-0.8 + 15}{7K} = 2.03mA$

$I_C = \frac{15 - (-0.8) - 0.2}{20K} = 0.78mA$

$I_B = I_E - I_C = 1.25mA$

(Note: no longer $I_B = \frac{I_C}{\beta}$.)

$V_C = 15 - (0.78m)(20K) = -0.6V$

Copyright © 2018 Regents of the University of California