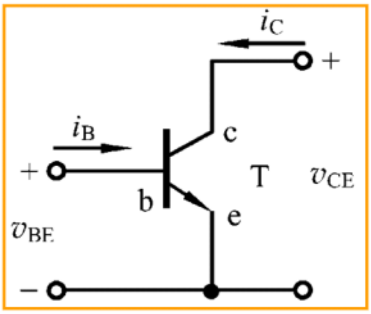
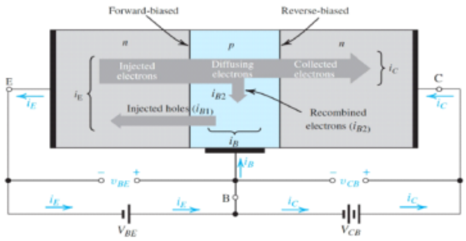
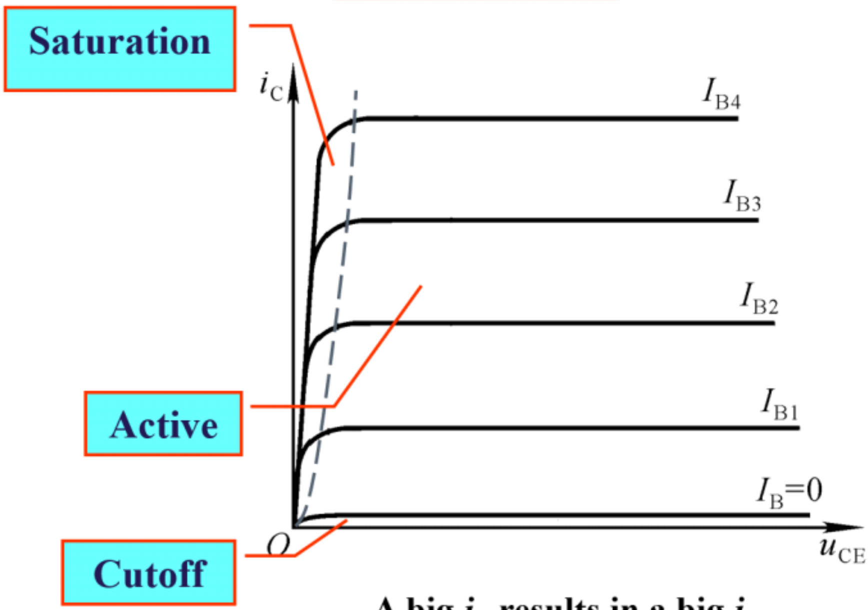
$i_C \sim v_{CE}$ curve:

$$i_C = f(u_{CE})\big|_{I_B}$$







i_C:

Electrons E ⟶ B ⟶ C

A big i_B results in a big i_C.

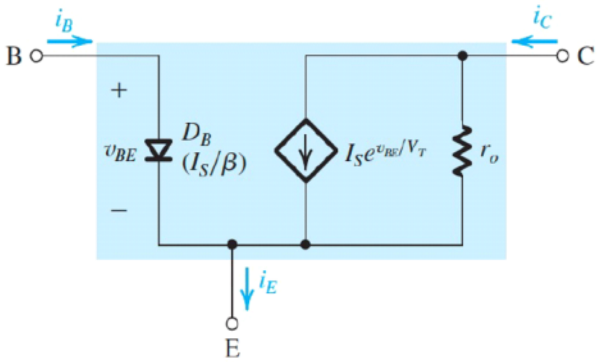
Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

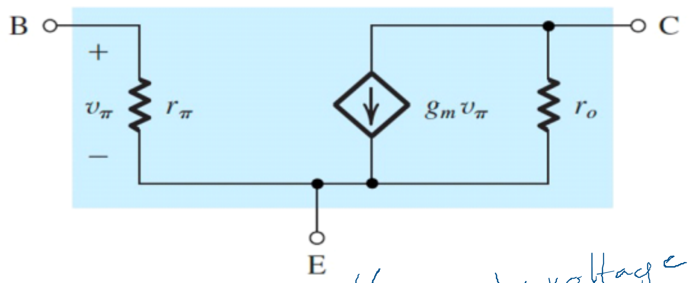
Saturation region: i_c is mainly controlled by v_{ce}, $\beta i_b > i_c$ $\quad$ $\boxed{V_{BE} = 0.7V, V_{CE} < 1V}$

Active region: i_c is basically parallel with v_{ce}, $\beta i_b = i_c$ $\quad$ $\boxed{V_{BE} = 0.7V, V_{CE} > 1V}$

Cutoff region: i_c is approaching to 0, $i_b \approx i_c \approx 0$ $\quad$ $\boxed{V_{BE} < 0.5V}$

Inclusion of early effect in large-signal and small-signal models:





V_A = early voltage

$15 > V_A > 200$

$$r_o = \frac{V_A}{I_S e^{\frac{V_{BE}}{V_T}}} \approx \frac{V_A}{I_C}$$

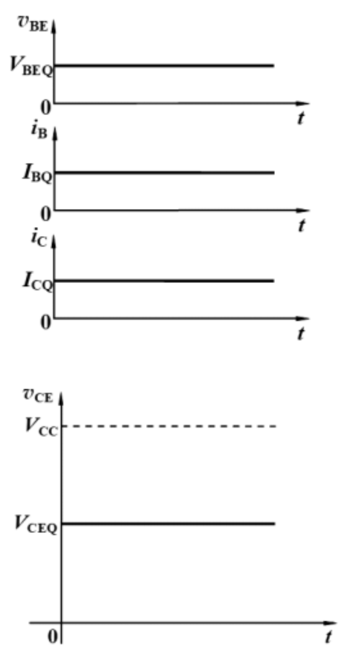
DC biasing (Static operating point (Q point)):

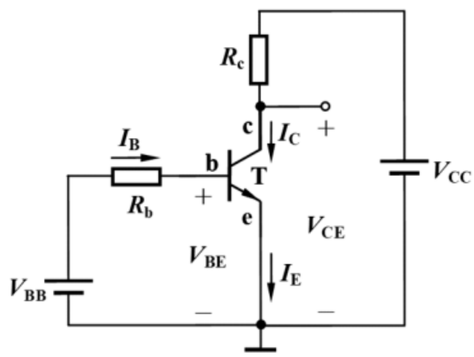
$$I_{BQ} = \frac{V_{BB} - V_{BEQ}}{R_b}$$

$$I_{CQ} \approx \beta \cdot I_{BQ}$$

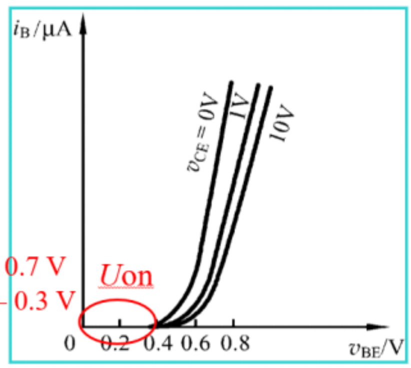
$$V_{CEQ} = V_{CC} - I_{CQ} R_c$$

Q (I_{BQ}, I_{CQ}, V_{CEQ})

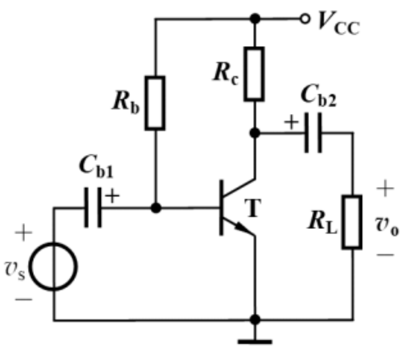


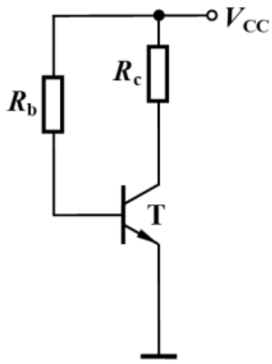


Si: 0.5 – 0.7 V
Ge: 0.1 – 0.3 V

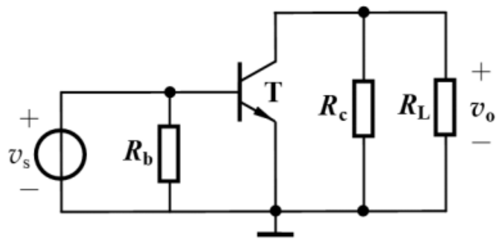


DC circuit and AC circuit:





DC circuit



AC circuit

DC circuit: capacitor is open, AC source is open;

AC circuit: capacitor is short, DC source is short;

Blackboard Notes for lecture - 3

slide 8:

A theoretical relationship between i_c and V_{CE} is that i_c is parallel with V_{CE}. when V_{CE} reaches a certain value, but in practical product, when you measure a NPN transistor, the i_c is not parallel with V_{CE} anymore, we call it early effects.

To model the effects:

$$I_c = I_S \exp^{\frac{V_{BE}}{V_T}} \left(1+\frac{V_{CE}}{V_A}\right).$$ V_A is early voltage.

slide 9:

if we have a small perturbation (ΔV) on V_{CE}, then $V_{CE}+\Delta V \to V_{CE}$

$$I_c = I_S \exp^{\frac{V_{BE}}{V_T}} \left(1+\frac{V_{CE}+\Delta V}{V_A}\right)$$

$$= I_S \exp^{\frac{V_{BE}}{V_T}} \left(1+\frac{V_{CE}}{V_A}+\frac{\Delta V}{V_A}\right)$$

$$= \underbrace{I_S \exp^{\frac{V_{BE}}{V_T}} \left(1+\frac{V_{CE}}{V_A}\right)} + I_S \exp^{\frac{V_{BE}}{V_T}} \cdot \frac{\Delta V}{V_A}$$

$$= I_{co} + \underbrace{I_S \exp^{\frac{V_{BE}}{V_T}} \cdot \frac{\Delta V}{V_A}}$$

it means with the inclusion of early effects, there is one more current ($I_S \exp^{\frac{V_{BE}}{V_T}} \cdot \frac{\Delta V}{V_A}$) in the collector lead.

and the current is

$$\Delta I = I_S \exp^{\frac{V_{BE}}{V_T}} \cdot \frac{\Delta V}{V_A} \Rightarrow \frac{\Delta V}{\Delta I} = \frac{V_A}{I_S \exp^{\frac{V_{BE}}{V_T}}} \approx \frac{V_A}{I_c}$$

then can be modeled with a resistor(r_o)

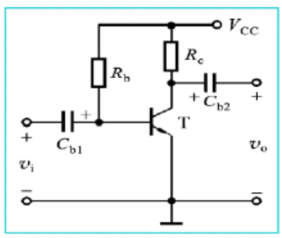
slide 18:

when $V_S = 0$, Base and Emitter will be short,

the transistor will operate at cutoff state.

Answers to practical exercise of lecture - 3

① the transistor is working at the cutoff region.



possible reasons:

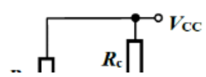
(1). R_b is open

R_b is open $\Rightarrow I_B = 0 \Rightarrow I_c = 0 \Rightarrow V_{CE} = V_{CC} - I_c R_c = V_{CC}$

(2). C_{b1} is short

C_{b1} is short $\Rightarrow V_{BE} = 0 \Rightarrow I_B = 0 \Rightarrow I_c \Rightarrow 0 \Rightarrow V_{CE} = V_{CC} - I_c R_c = V_{CC}$

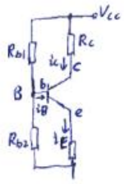
②

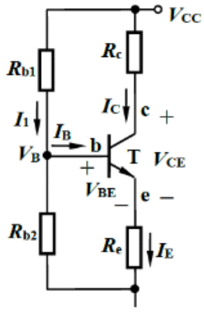


C_{b1} is short ⇒ $v_{BE}=0$ → $i_B=0$ → $i_C \approx 0$ → $v_{CE} = V_{CC} - i_C R_c = V_{CC}$

②

$$V_{BQ} \approx \frac{R_{b1}}{R_{b1}+R_{b2}} \cdot V_{cc}$$



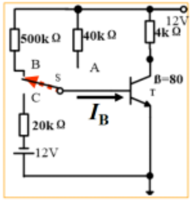


$$I_{CQ} \approx I_{EQ} \approx \frac{V_{BQ} - V_{BEQ}}{R_e}$$

$$V_{CEQ} = V_{cc} - I_{CQ} R_c - I_{EQ} \cdot R_e = V_{cc} - I_{CQ} \cdot (R_e + R_c)$$

$$I_{BQ} = \frac{I_{CQ}}{\beta}$$

③

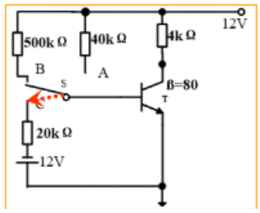


$$I_{BQ} = \frac{V_{cc} - V_{BEQ}}{500\,k\Omega} = \frac{(12-0.6)V}{500\,k\Omega} \approx 23\mu A$$

$$I_{CQ} = \beta \cdot I_{BQ} = 80 \times 23\mu A = 1.84mA$$

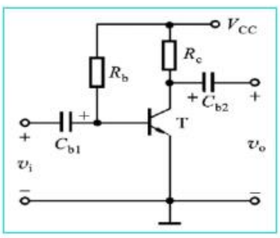
$$V_{CEQ} = V_{cc} - I_{CQ} R_c = 4.64V. \quad Q\,(23\mu A,\ 1.84mA,\ 4.64V)$$

④ Due to Base and Emitter Junction is reversed, the transistor is working at the cutoff region.



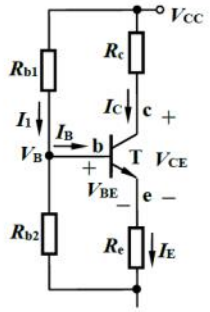
CAN WE CALCULATE

1. For a BJT-based amplification circuit, we measure the voltage of V_{CE}, and find its value approximately equal to V_{CC}, please evaluate the operating state of the circuit and also list the possible reasons resulting in the phenomenon.



1. First reason is that VCC is to ground and therefor we measure the extact same.
2. Rc is so FUCKING small, that we ignore it instead/Rb is open and ALL runs through Rc
3. Cb1 is short and there is no voltage generator.

2. Give the formulae to calculate the Q point of the following circuit? ($I_1 >> I_B$)



Q point $(I_{BQ}, I_{CQ}, V_{CEQ})$

$$I_{BQ} = \frac{V_{BQ} - V_{BEQ}}{R_B} \approx \frac{I_{CQ}}{\beta}$$

$I_{CQ} \approx \beta \cdot I_{BQ}$; V_{BEQ}: $0.6 < V_{BEQ} < 0.8$

; $R_B = R_{b1} \parallel R_{b2}$

$V_{CEQ} = V_{CC} - I_{CQ} \cdot R_C$; $V_{BQ} = \frac{R_{b1}}{R_{b1} + R_{b2}} V_{CC}$

$I_{CQ} \approx I_{EQ}$ as I_{BQ} is very small for $\frac{I_{CQ}}{\beta}$ and that it will be very large

③ find V_{CEQ}

Per KVL we know:

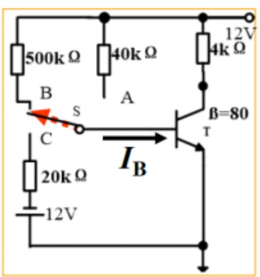
$V_{CC} = V_C + V_{CE} + V_E \Rightarrow V_{CE} = V_{CC} - V_C - V_E$

$V_C = R_C \cdot I_{CQ}$ and $V_E = I_{EQ} \cdot R_e$ so:

$V_{CE} = V_{CC} - I_{CQ} \cdot R_C - I_{EQ} \cdot R_e$, But $I_{CQ} \approx I_{EQ}$:

$V_{CE} = V_{CC} - I_{CQ} \cdot (R_C + R_e)$

3. Calculate the Q point of the following circuit and also evaluate what region does the transistor operate? ($V_{BEQ} = 0.6$ V)



$Q = (I_{BQ}, I_{CQ}, V_{CEQ})$ $V_{BEQ} = 0.6$ V

$$I_{BQ} = \frac{V_{bb} - V_{BEQ}}{} = \frac{12V - 0.6V}{} = 23\mu \text{ [A]}$$

$$I_{BQ} = \frac{U_{bb} - U_{BEQ}}{R_b} = \frac{12V - 0.6V}{500k\Omega} = 23\mu\ [A]$$

$$I_{CQ} = \beta \cdot I_{BQ} = 80 \cdot 23\mu = 1.84m\ [A]$$

$$U_{CEQ} = V_{CC} - I_{CQ} \cdot R_C = 12 - 1.8mA \cdot 4k[\Omega] = 4.64\ [V]$$

$$Q \quad \text{point}(23\mu[A],\ 1.84m[A],\ 4.64\ [V])$$