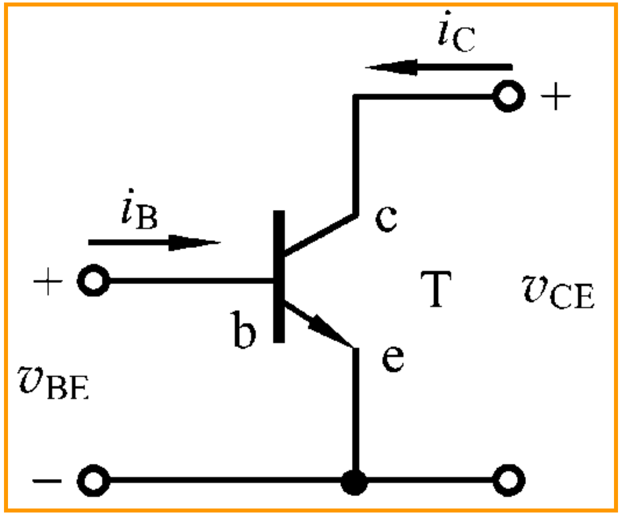
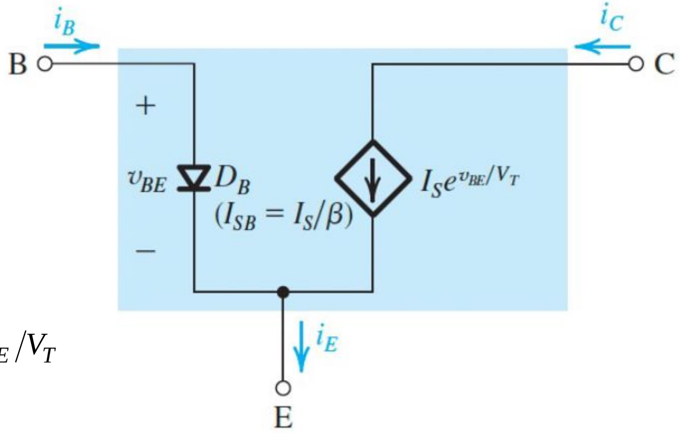
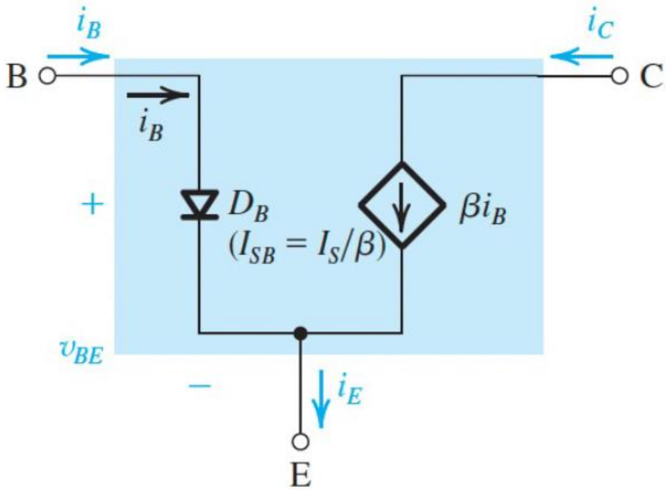
Simple bipolar transistor model

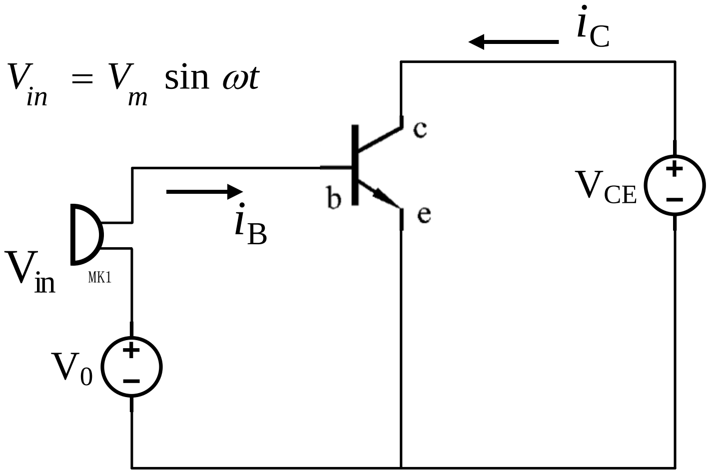


$$i_B = \frac{i_C}{\beta} = \frac{i_S}{\beta} e^{v_{BE}/V_T}$$





$$V_{in} = V_m \sin \omega t$$

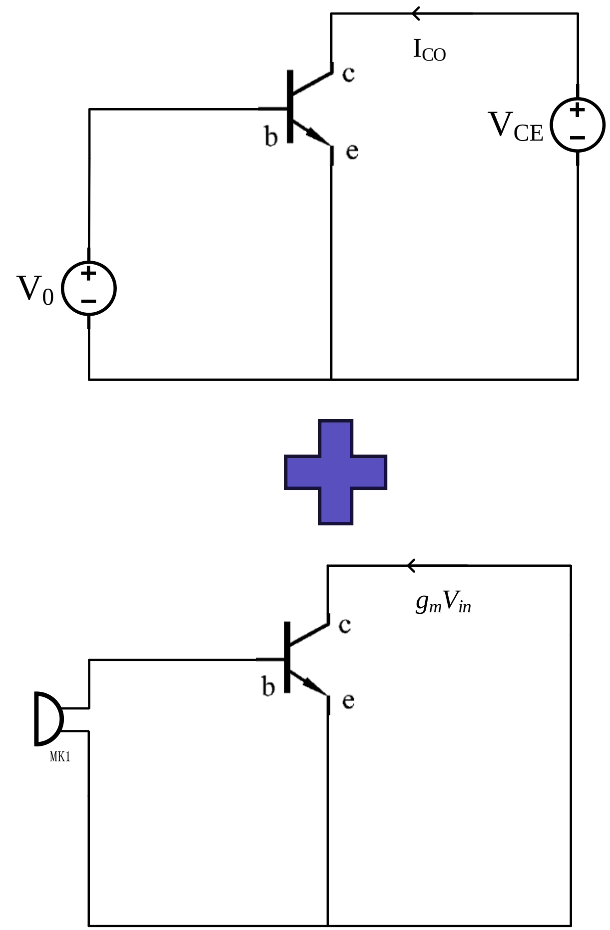


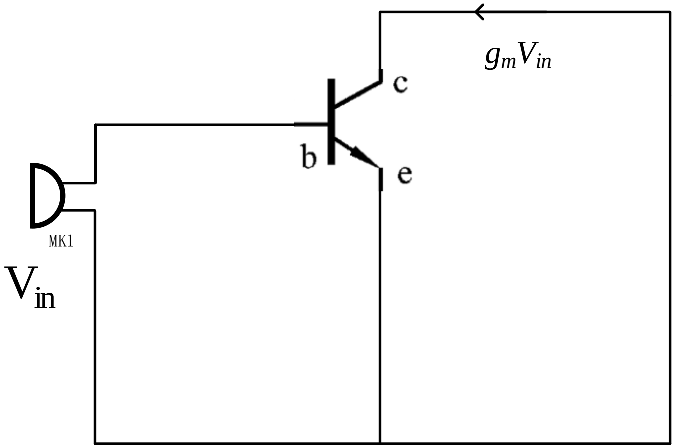
$$i_C = I_S e^{(\frac{V_0 + V_{in}}{V_T})} = I_S e^{(\frac{V_0}{V_T})} \cdot e^{(\frac{V_m \sin \omega t}{V_T})}$$

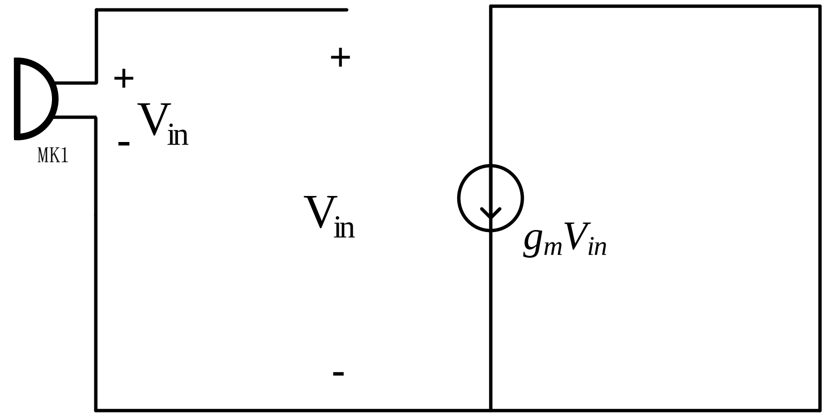
$$= I_{CO} \cdot e^{(\frac{V_m \sin \omega t}{V_T})} = I_{CO} \cdot (1 + \frac{V_m \sin \omega t}{V_T})$$

$$= I_{CO} + \frac{I_{CO}}{V_T} V_m \sin \omega t$$

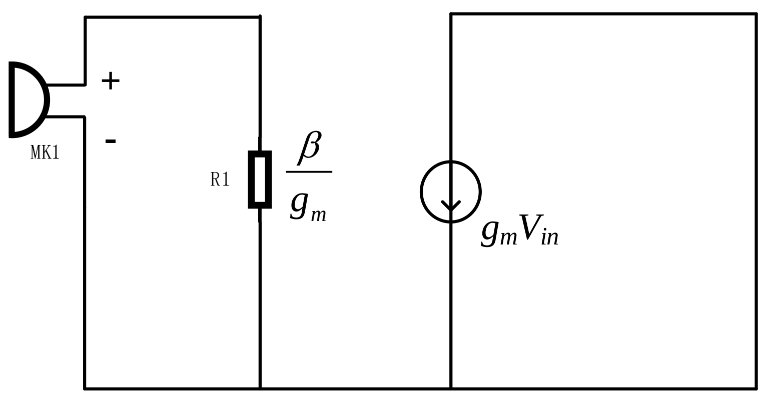
$$= I_{CO} + g_m V_m \sin \omega t$$

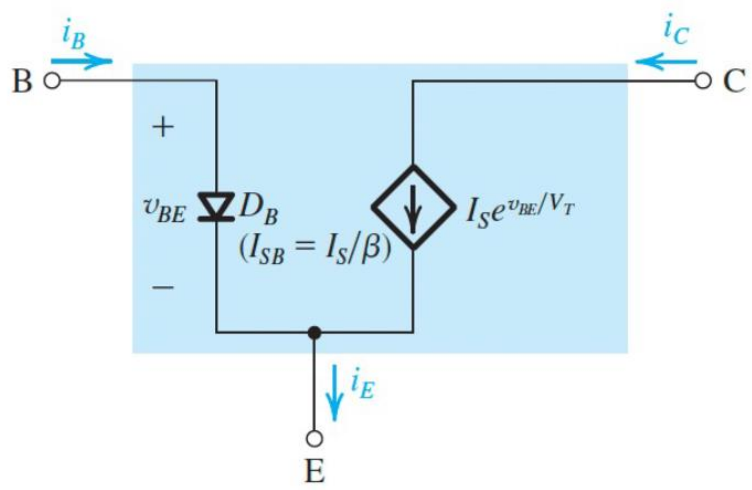




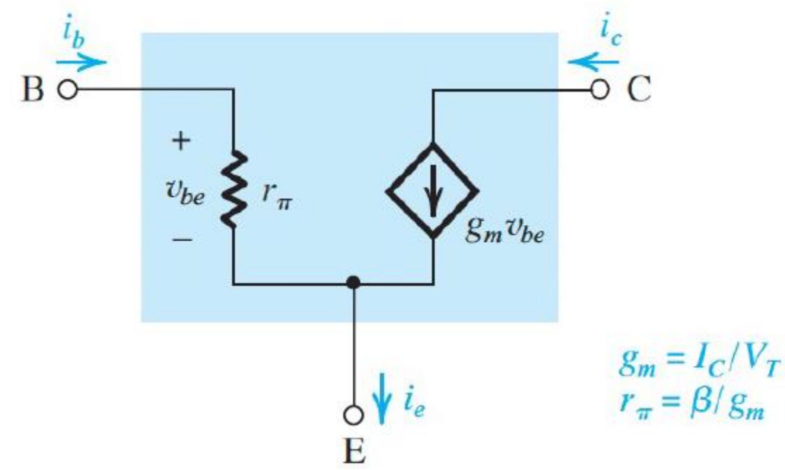


$$i_B = \frac{i_C}{\beta} = \frac{i_{CO}}{\beta} + \frac{g_m V_{in}}{\beta}$$





Large-signal model



Small-signal model

Bipolar Junction Transistors

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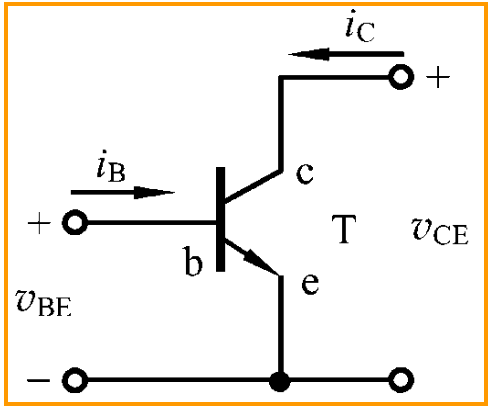
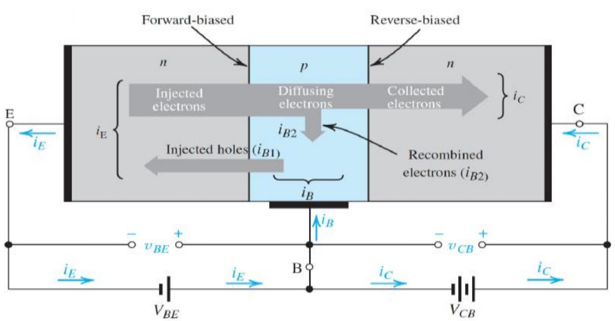
Learning objectives:

- Early effect
- Static operating point in power amplifier design

$i_C \sim \upsilon_{CE}$ curve:





i_C:

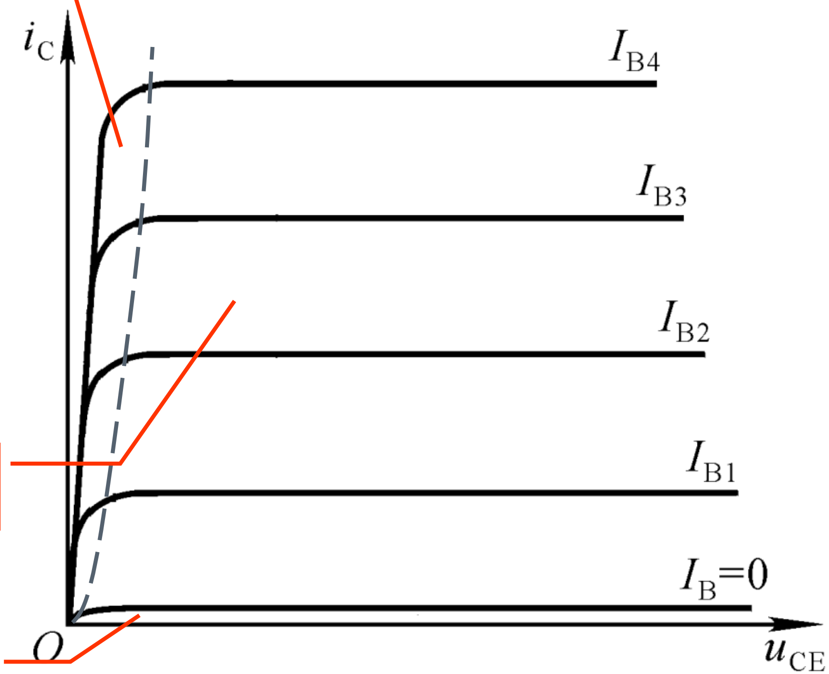
Electrons E ⟶ B ⟶ C

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

Saturation

Active

Cutoff



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}, $\beta i_b > i_c$

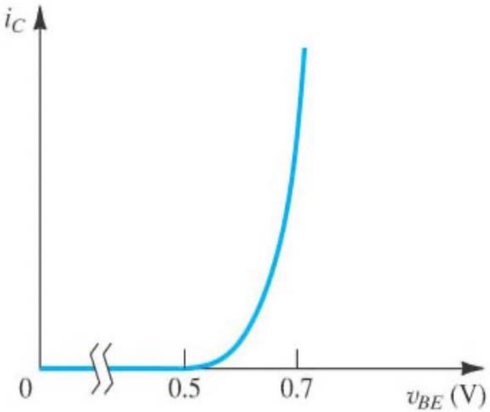
$$\boxed{V_{BE} = 0.7V, V_{CE} < 1V}$$

Active region: i_c is basically parallel with v_{ce}, $\beta i_b = i_c$

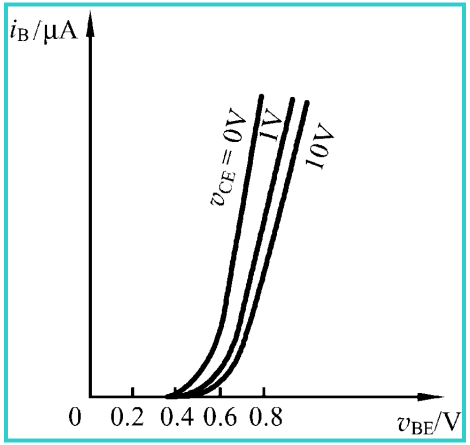
$$\boxed{\boldsymbol{V_{BE} = 0.7V, V_{CE} > 1V}}$$

Cutoff region: i_c is approaching to 0, $i_b \approx i_c \approx 0$

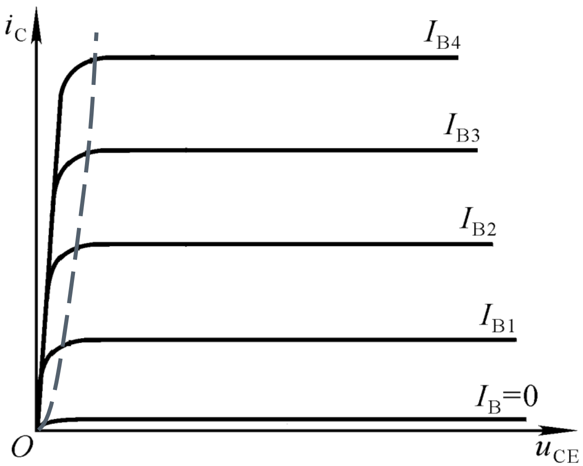
$$\boxed{V_{BE} < 0.5V}$$



u_{BE} - i_{C}

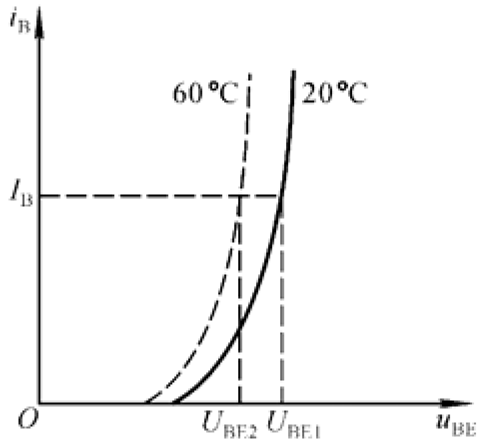


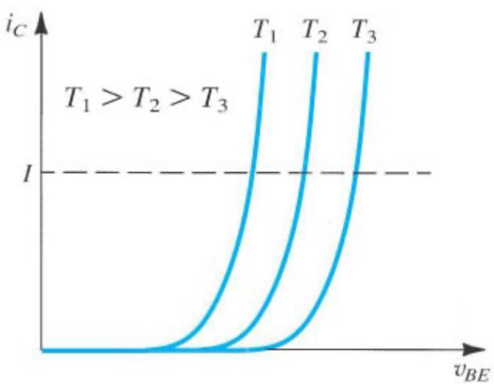
u_{BE} - i_{B}

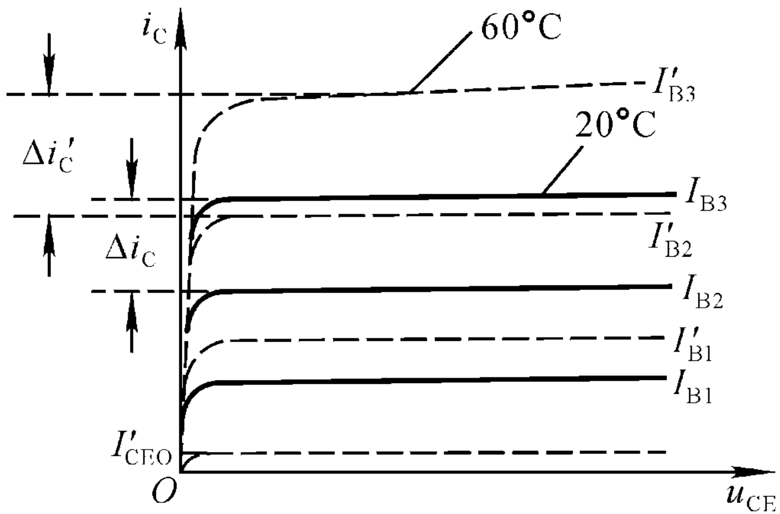


u_{CE} - i_{C}

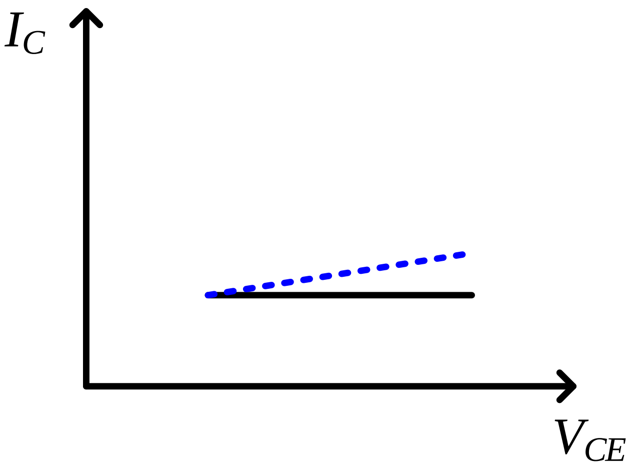
Effects of temperature:







Early effects:



The effects of early voltage on transconductance:

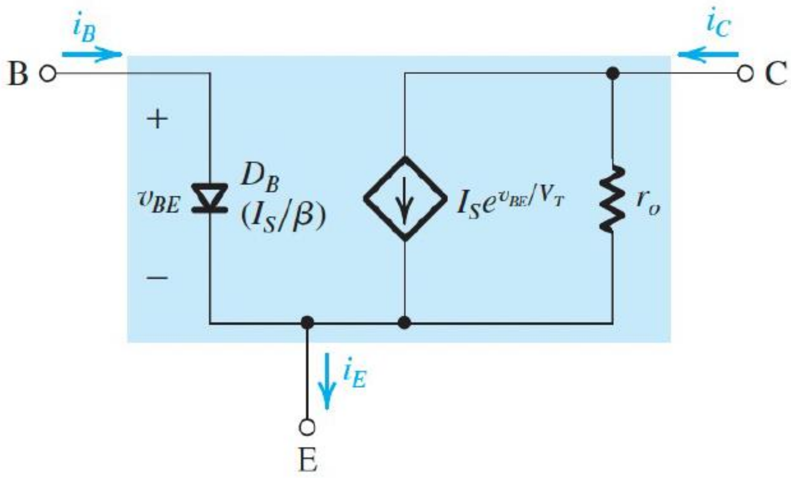
$$g_m = \frac{dI_C}{dV_{BE}} = \frac{I_S}{V_T} e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CE}}{V_A}\right) = \frac{I_C}{V_T}$$

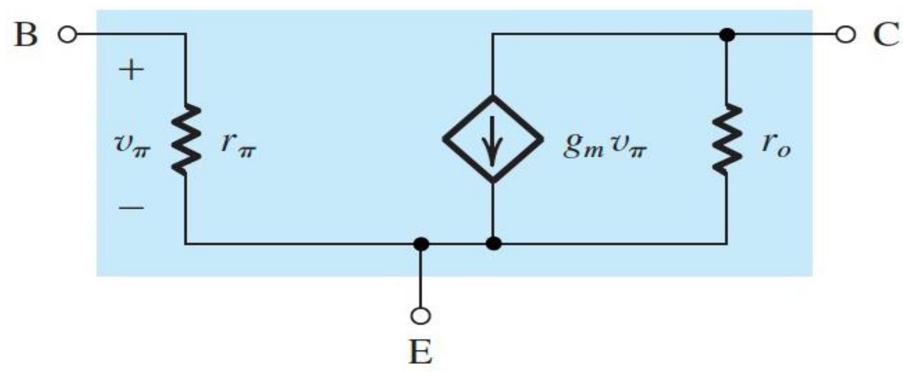
Not change

$$I_C = I_S e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CE}}{V_A}\right)$$

V_A is early voltage

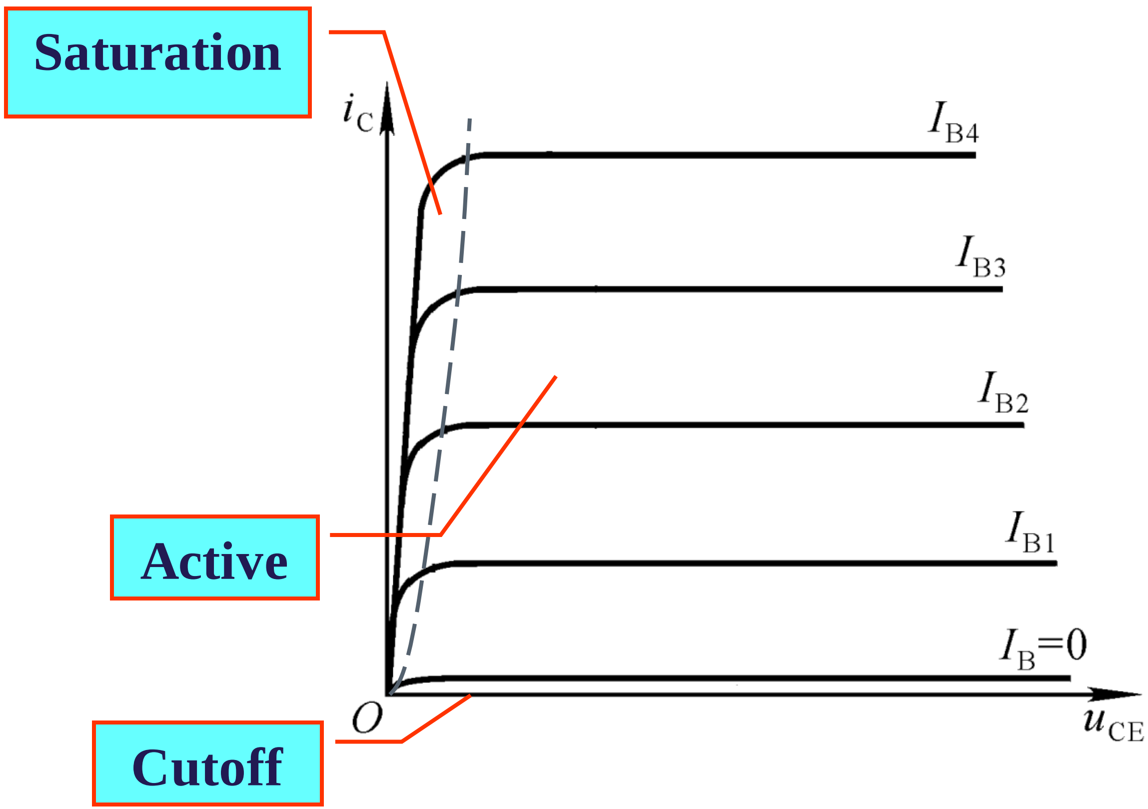
Inclusion of early effect in large-signal and small-signal models:





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

Power amplifier:



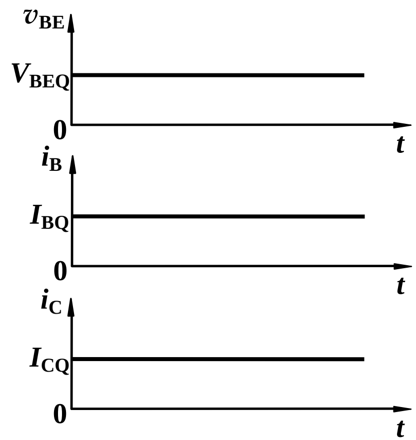
DC biasing (Static operating point (Q point)):

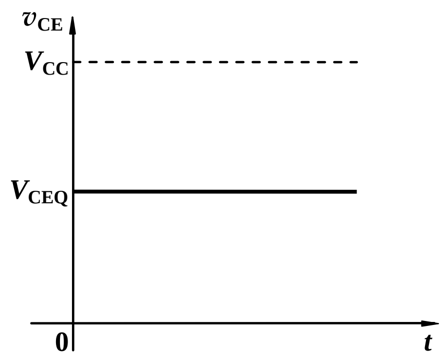
$$I_{BQ} = \frac{V_{BB} - V_{BEQ}}{R_b}$$

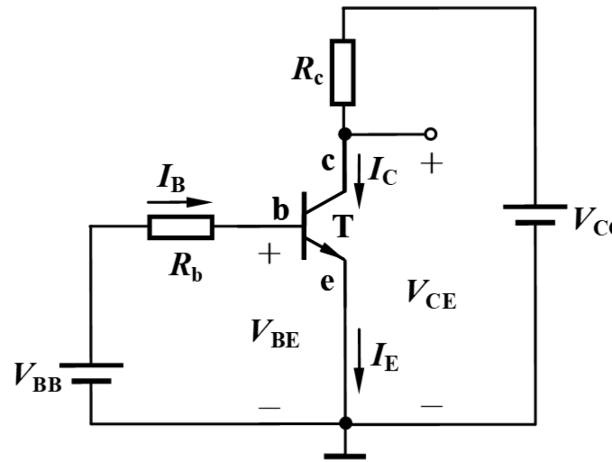
$$I_{CQ} \approx \beta \cdot I_{BQ}$$

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

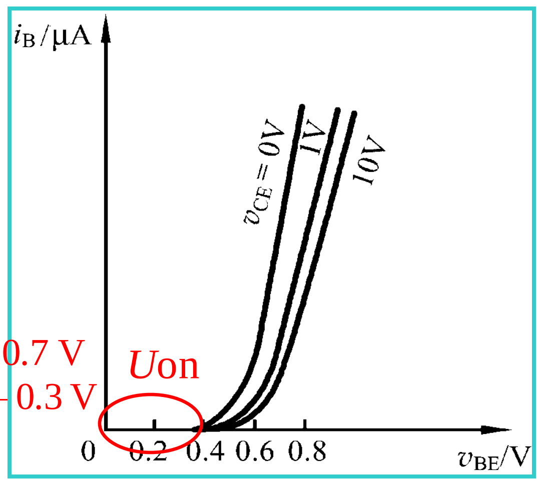
Q (I_{BQ}, I_{CQ}, V_{CEQ})



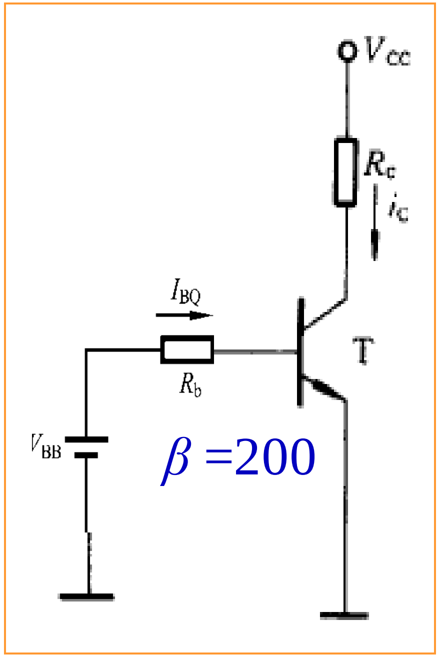




Si: 0.5 – 0.7 V
Ge: 0.1 – 0.3 V



Calculate Q point:



V_{CC}=15V, R_C=1.5kΩ, i_B=20μA

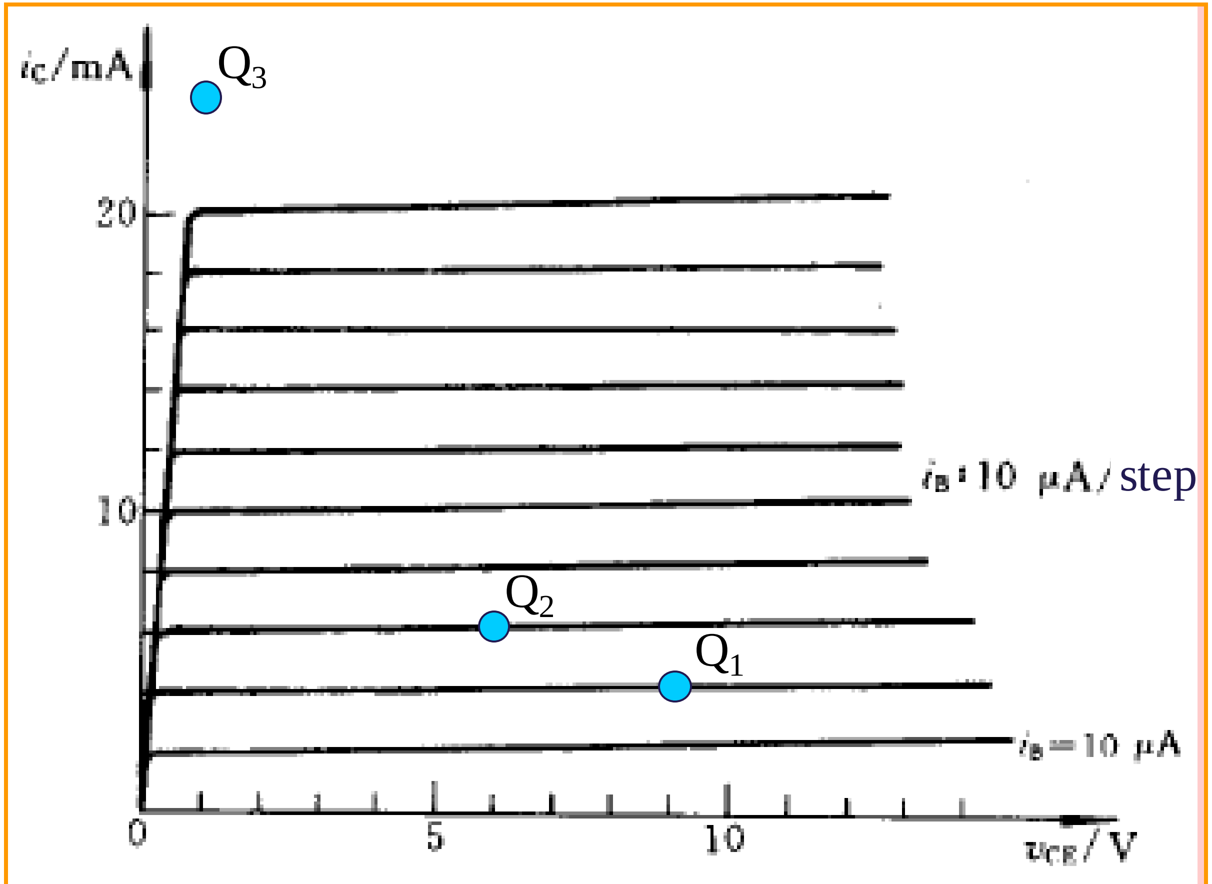
Q(20μA, 4mA, 9V)

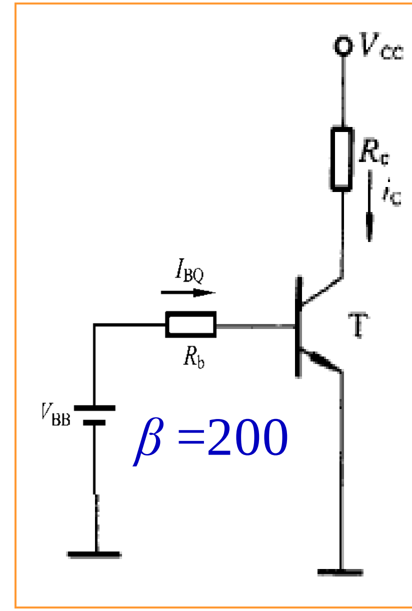
V_{CC}=12V, R_C=1kΩ, V_{BB}=2.2V, R_b=50kΩ, V_{BEQ}=0.7V

Q(30μA, 6mA, 6V)

V_{CC}=6V, R_C=200Ω, V_{BB}=3.2V, R_b=20kΩ, V_{BEQ}=0.7V

Q(125μA, 25mA, $\boxed{1\text{V}}$)



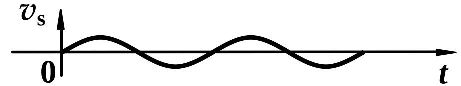


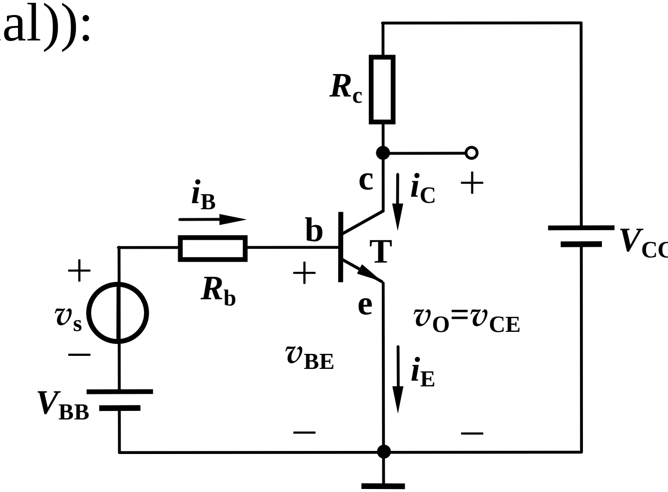
Q_1(20μA,4m A ,9 V)

Q_2(30μA,6m A ,6 V)

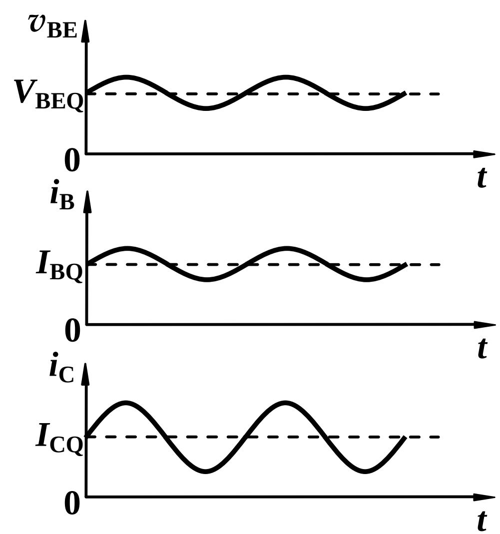
Q_3(125μA,25m A ,1 V)

With a perturbation (a sinusoidal signal (alternating signal)):

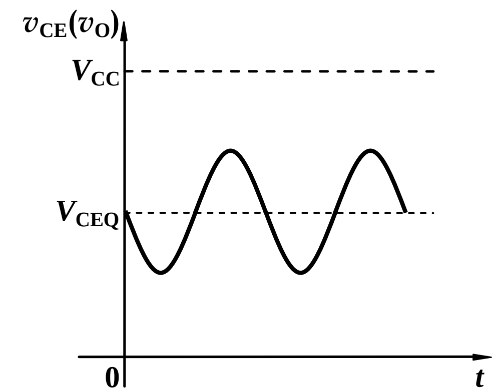




$$i_B = \frac{\boldsymbol{V}_{BB} + v_s - \boldsymbol{V}_{BEQ}}{\boldsymbol{R}_b}$$



$$i_C = \beta \cdot i_B$$

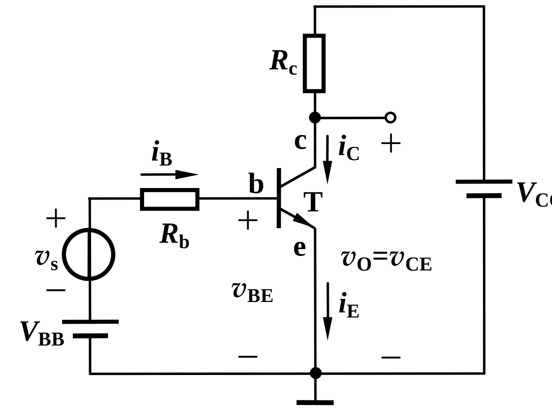


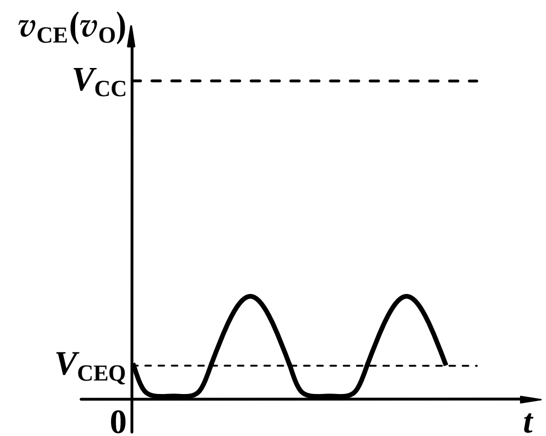
$$v_{CE} = \boldsymbol{V}_{CC} - i_C \boldsymbol{R}_c$$

The effects of static operating point on output voltage

- $I_{BQ}\uparrow \longrightarrow I_{CQ}\uparrow \longrightarrow$ the voltage on $R_c\uparrow$ $\longrightarrow V_{CEQ}\downarrow$

- $R_c\uparrow \longrightarrow$ the voltage on $R_c\uparrow \longrightarrow V_{CEQ}\downarrow$

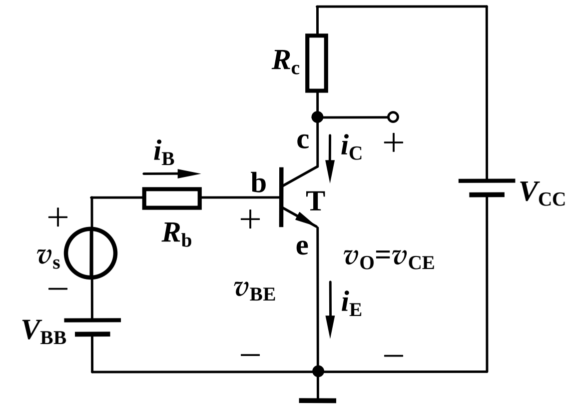




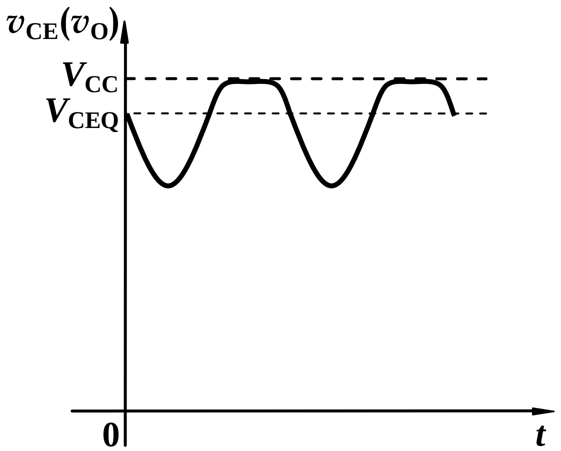
The effects of static operating point on amplification

- $I_{BQ} \downarrow \longrightarrow I_{CQ} \downarrow \longrightarrow$ the voltage on $R_c \downarrow$

  $\longrightarrow V_{CEQ} \uparrow$

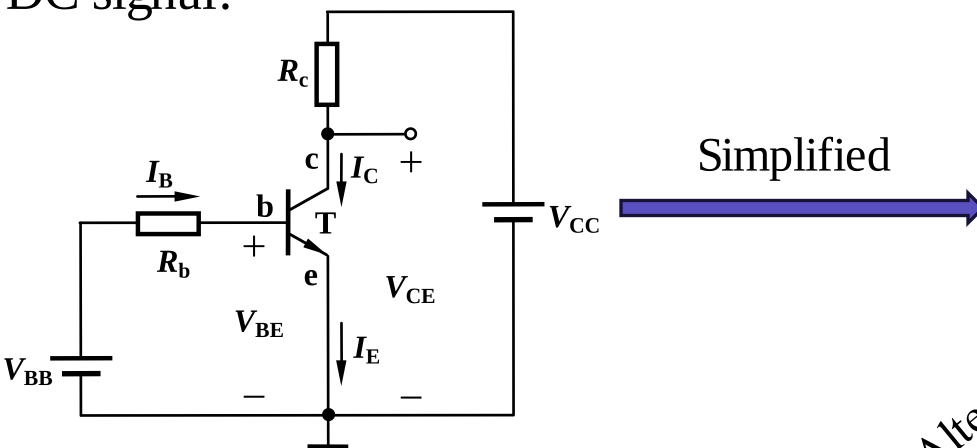


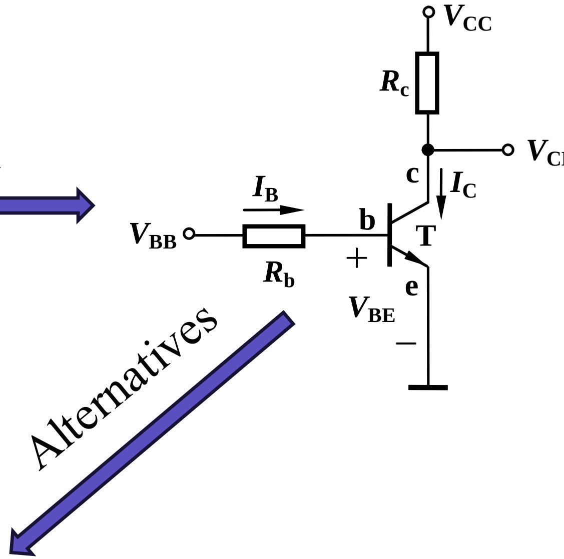
A proper static operating point should be provided to make the transistor operate at the active mode (amplification region).

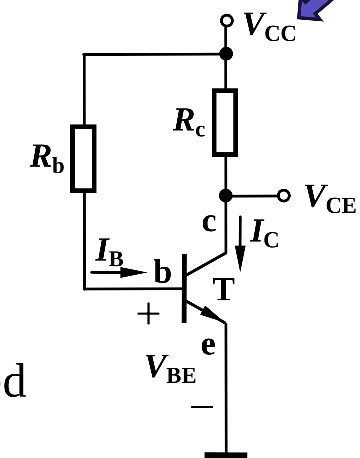


The amplitude of output signal is limited by V_{CC}.

For DC signal:







Only one DC power is involved

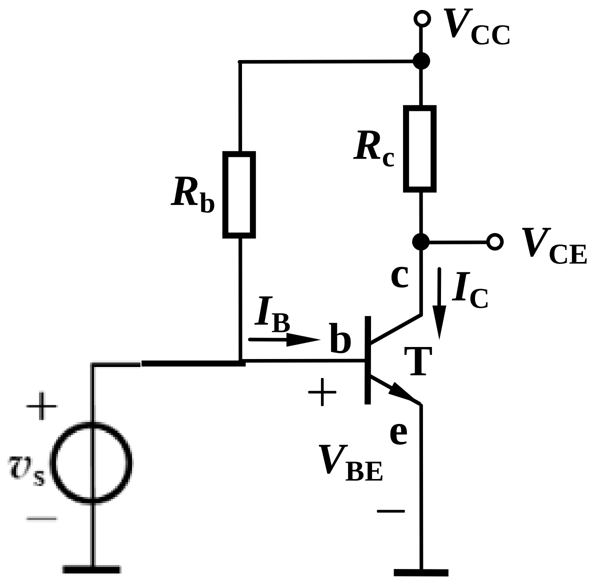
Q point:

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

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

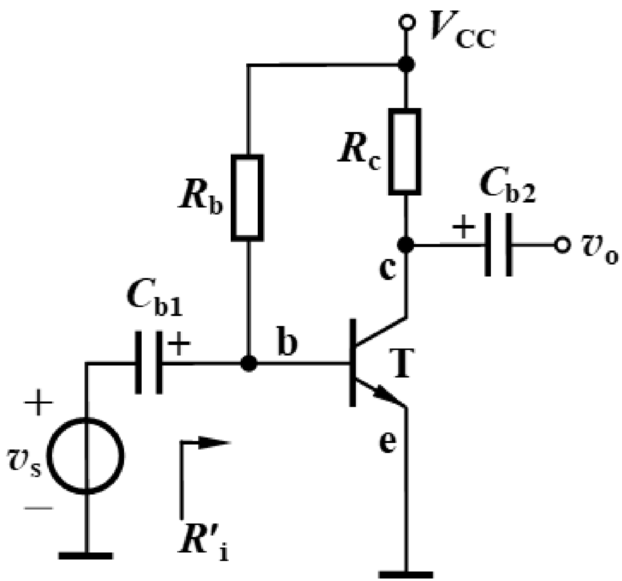
$$V_{CEQ} = V_{CC} - I_{CQ} R_c$$

When AC signal is added directly:



What will happen when $v_s = 0$?

When AC signal is added with capacitors:

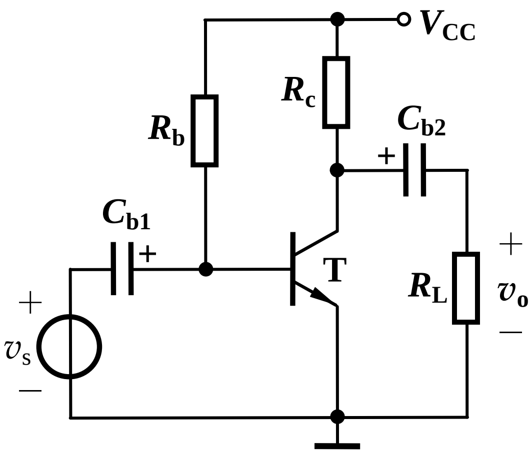


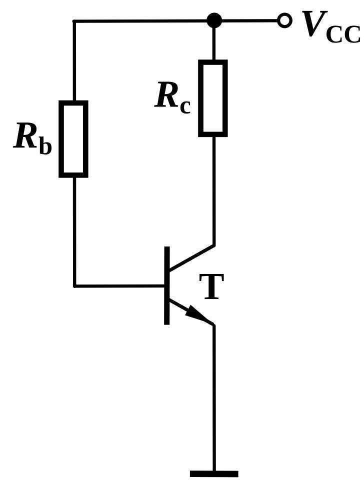
Two capacitors are added at input and output ends to isolate DC and AC signals.

The involvements of v_s and v_o do not affect the Q point of the circuit.

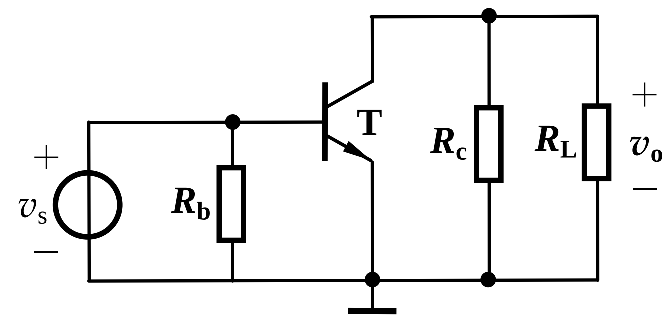
The frequency of v_s can not be too small.

DC circuit and AC circuit:





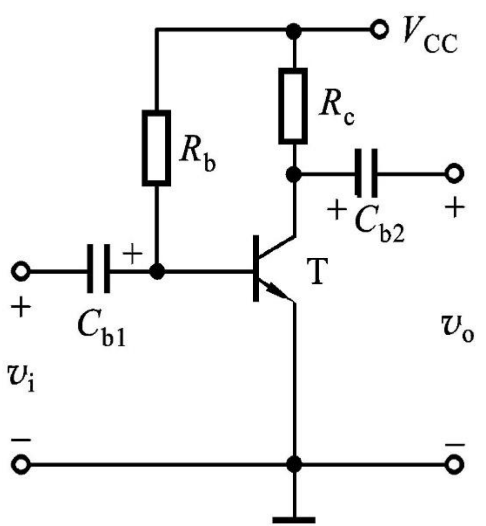
DC circuit



AC circuit

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

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



$\beta = 80$, $R_b = 300k\Omega$, $R_c = 2k\Omega$， $V_{CC} = +12V$

V_{BEQ} is assumed to be 0

Calculate Q point, which region does the BJT operate?

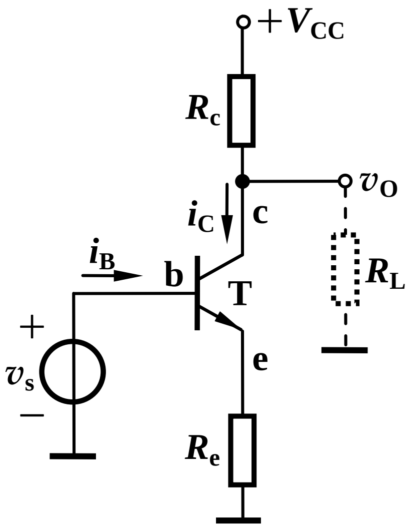
Q (40μA，3.2mA，5.6V)　Active region

If R_b=100kΩ,

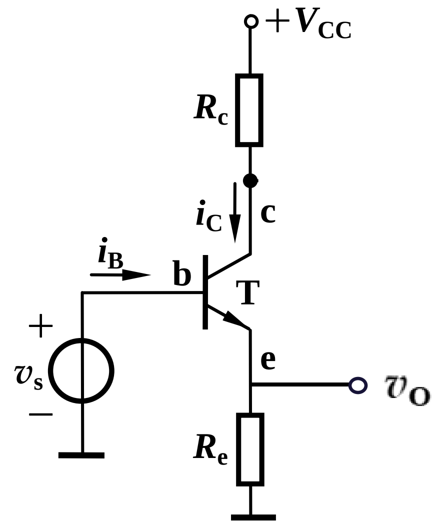
Q (120μA，6.0mA，0V)　Saturation region

If R_b = 300kΩ, R_c = 5kΩ

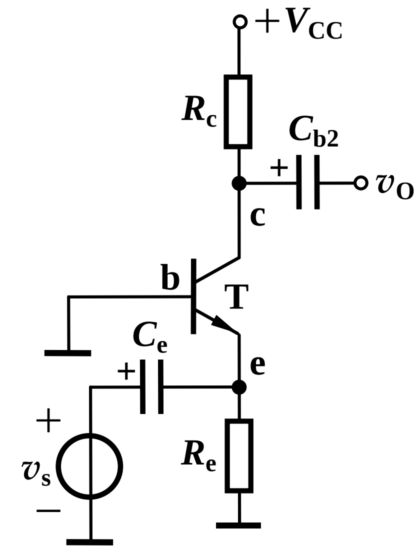
Q (40μA，2.4mA，0V)　Saturation region



Common emitter



Common collector



Common base

Common emitter: signal is input from the base, and output from the collector;

Common collector: signal is input from the base, and output from the emitter;

Common base: signal is input from the emitter, and output from the collector;

Thanks