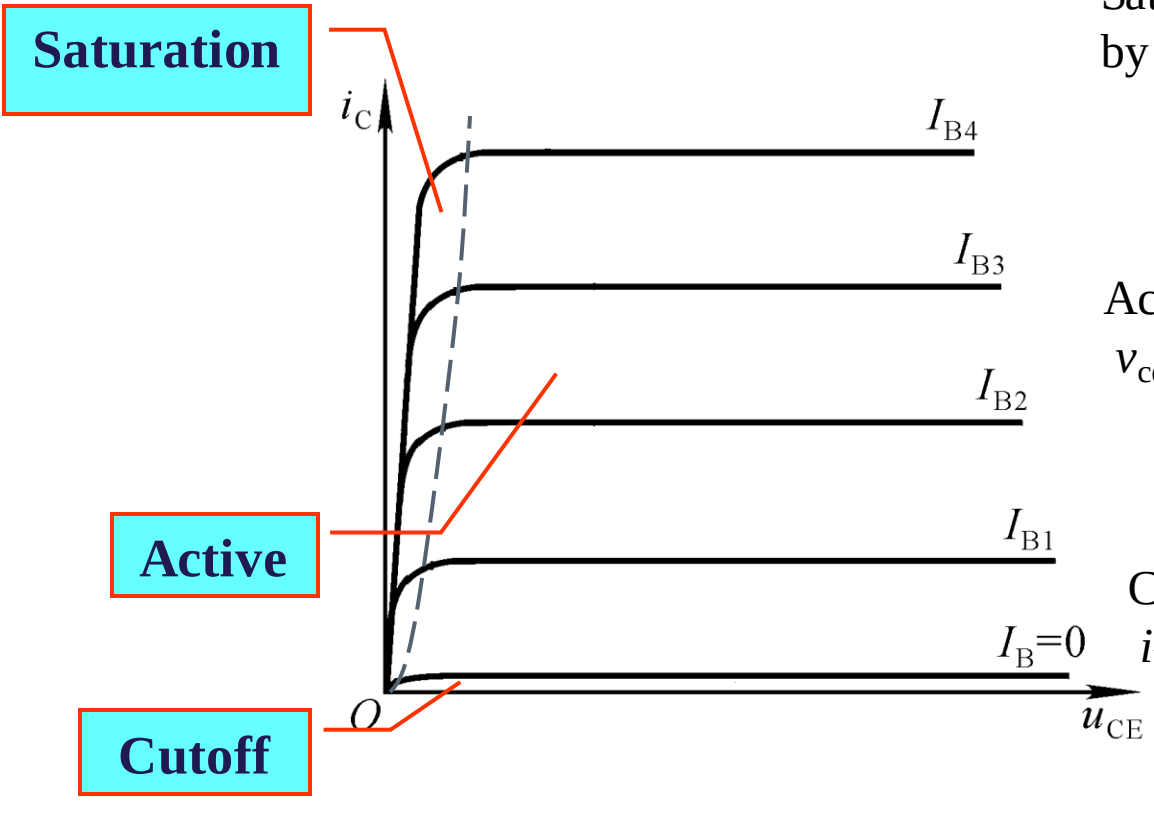
$$i_C = f(u_{CE})\big|_{I_B}$$



Saturation region: i_c is mainly controlled by v_{ce}, $\beta i_b > i_c$

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

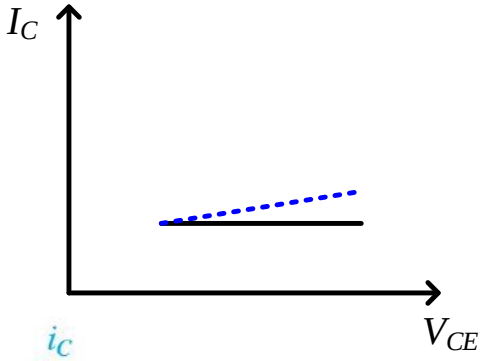
Active region: i_c is basically parallel with v_{ce}, $\beta i_b = i_c$

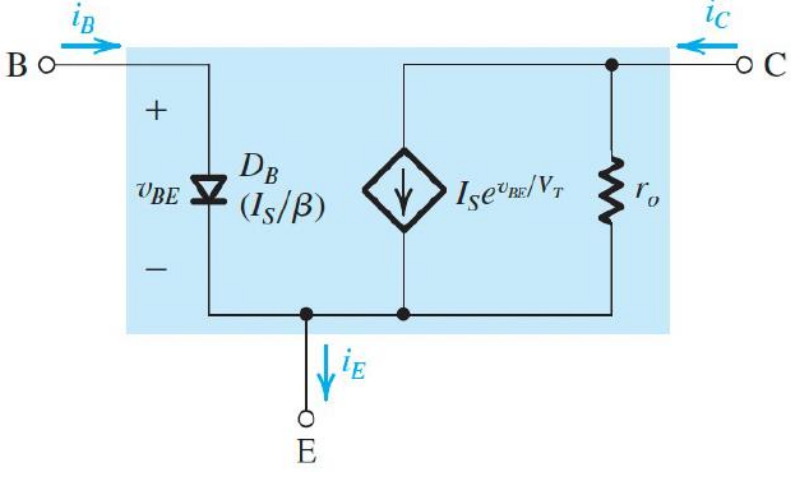
$$\boldsymbol{V_{BE} = 0.7V, V_{CE} > 1V}$$

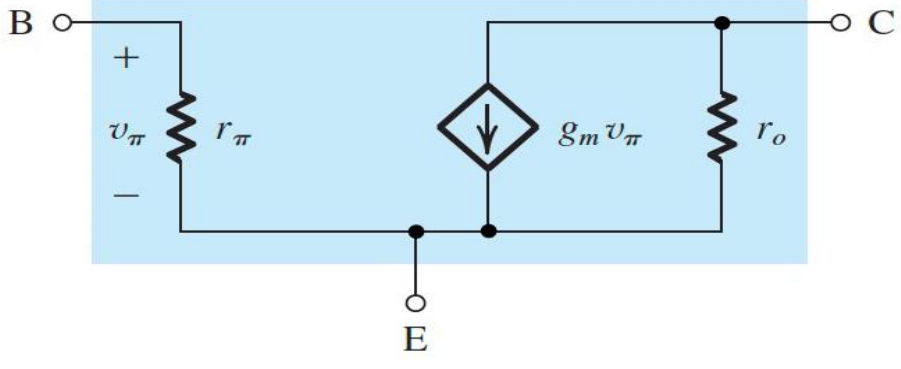
Cutoff region: i_c is approaching to 0, $i_b \approx i_c \approx 0$

$$V_{BE} < 0.5V$$

Early effect:

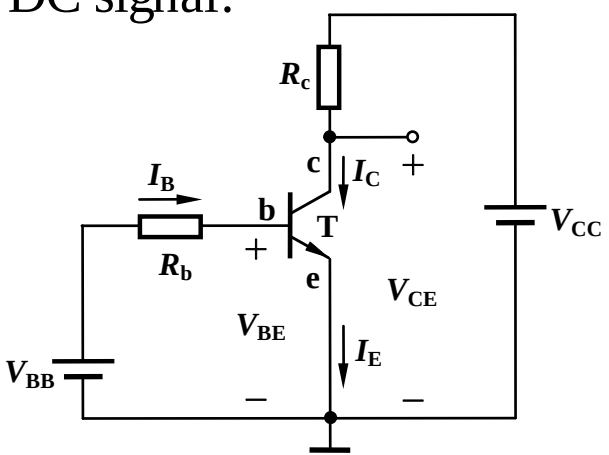




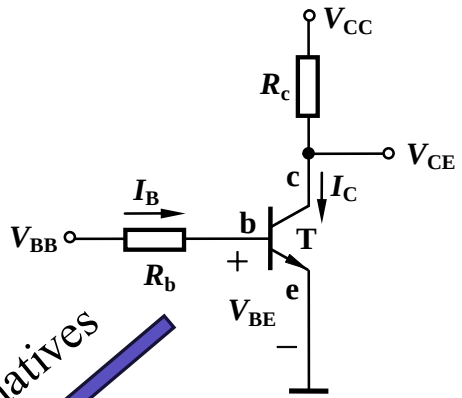


$$r_o = \frac{V_A}{\frac{V_{BE}}{I_S e^{\frac{V_{BE}}{V_T}}}} \approx \frac{V_A}{I_C}$$

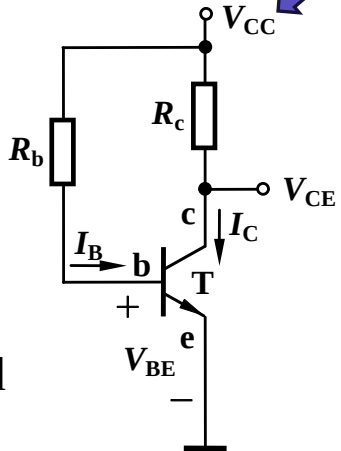
For DC signal:



Simplified



Alternatives



Only one DC power is involved

Q point:

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

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

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

Bipolar Junction Transistors

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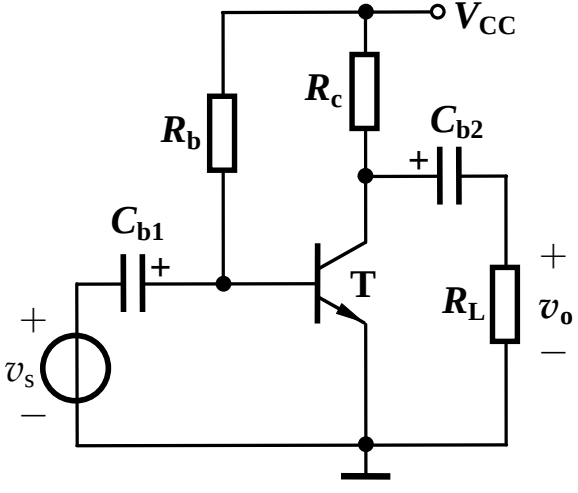
DENMARK

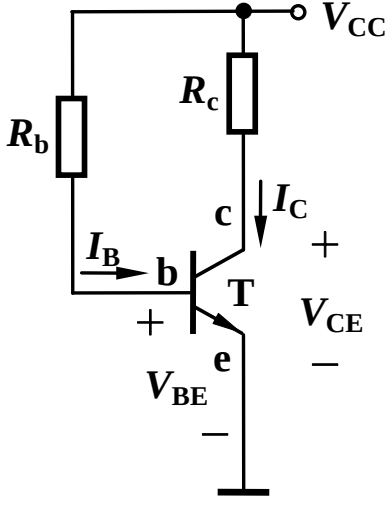
Learning objectives:

- Transistor-based amplifier
- Lab session

Using a diagram to analyze a BJT amplification circuit:



First step: draw the DC circuit



Input $i - v$ curve:

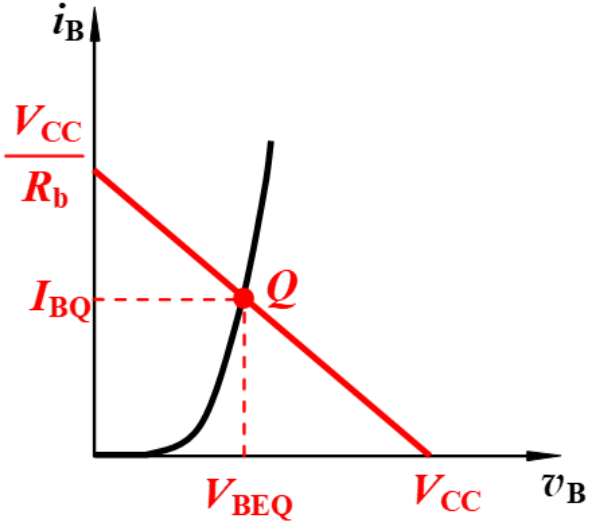
$$v_{BE} = V_{CC} - i_B R_b$$

Output $i - v$ curve:

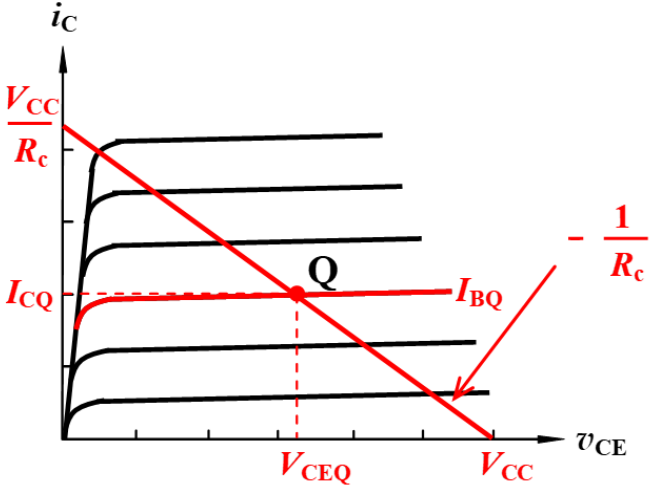
$$v_{CE} = V_{CC} - i_C R_c$$

Diagram analysis of static operating point :

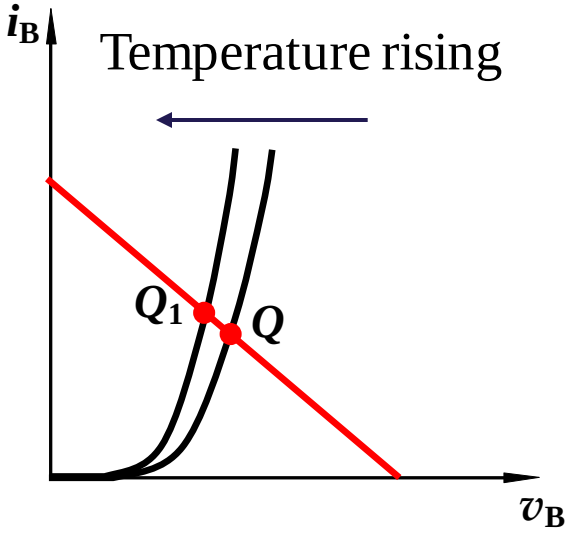
$v_{BE} = V_{CC} - i_B R_b$

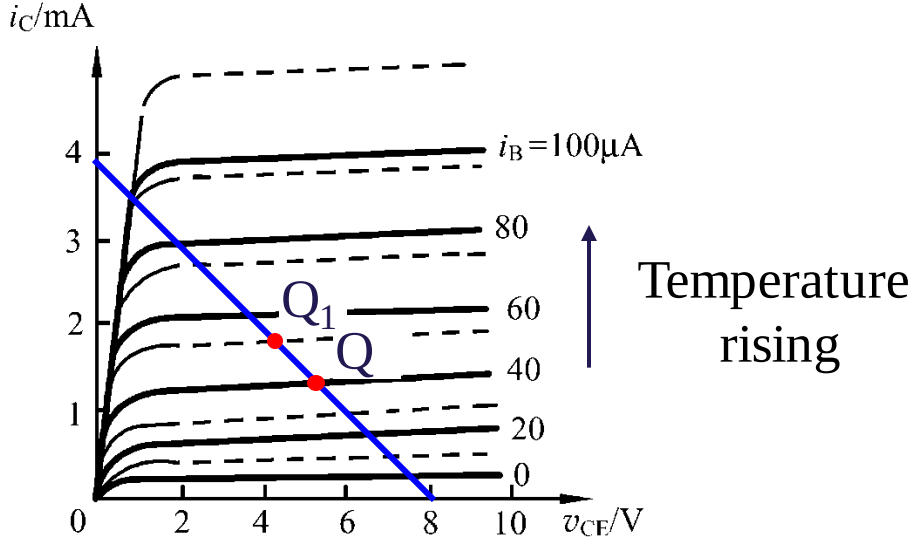


$v_{CE} = V_{CC} - i_C R_c$

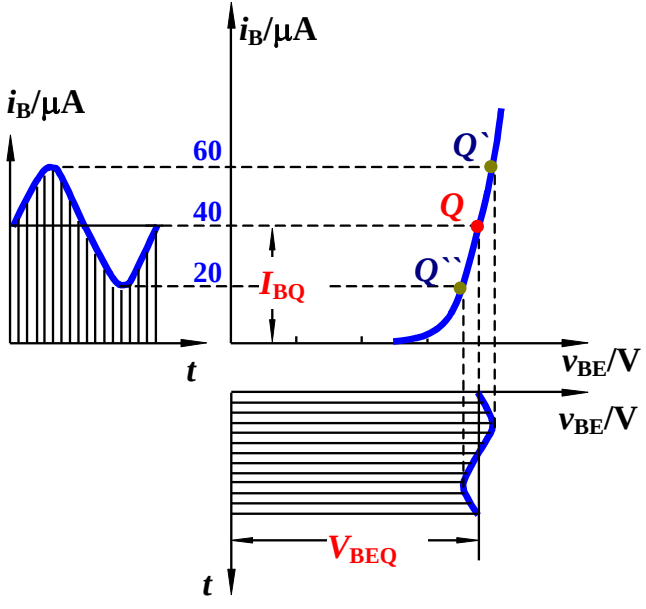


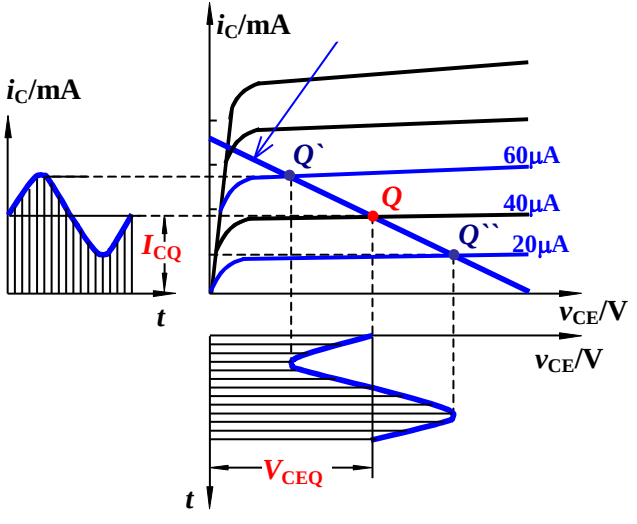
Effects of temperature on Q point :



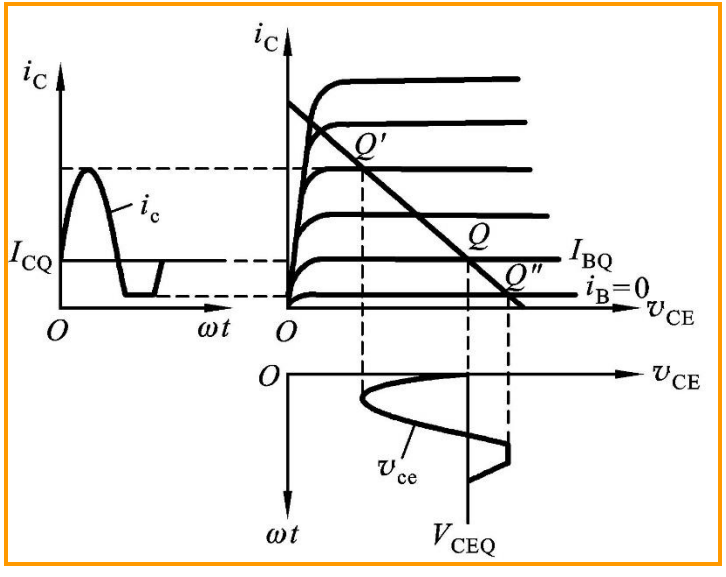


The effects of Q point on waveform distortion:

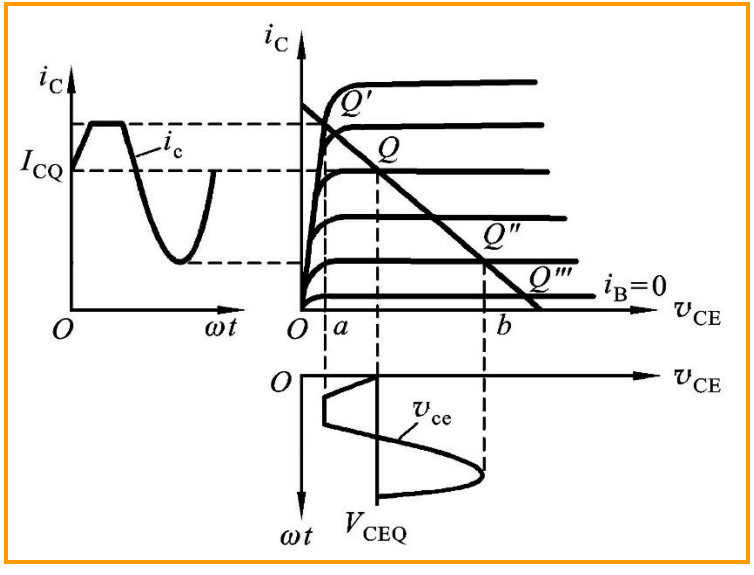




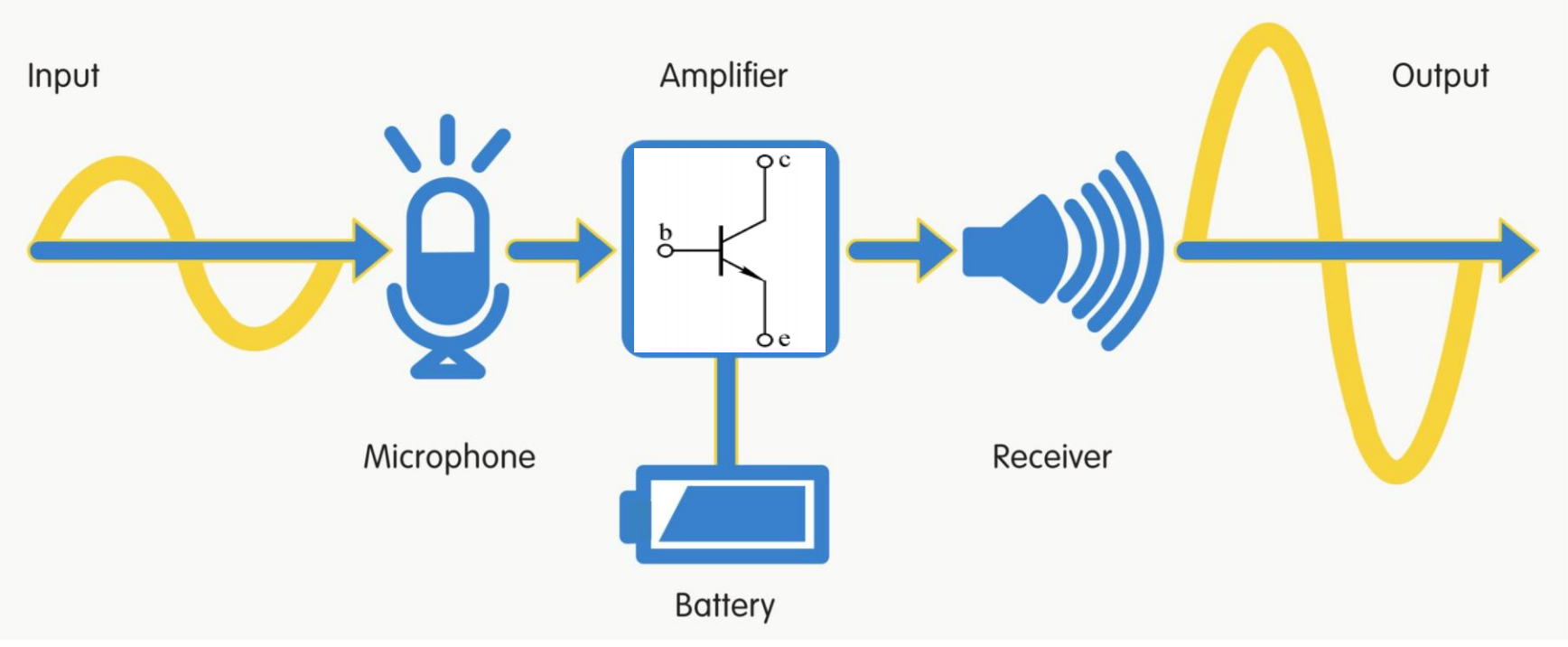
The effects of Q point on waveform distortion:



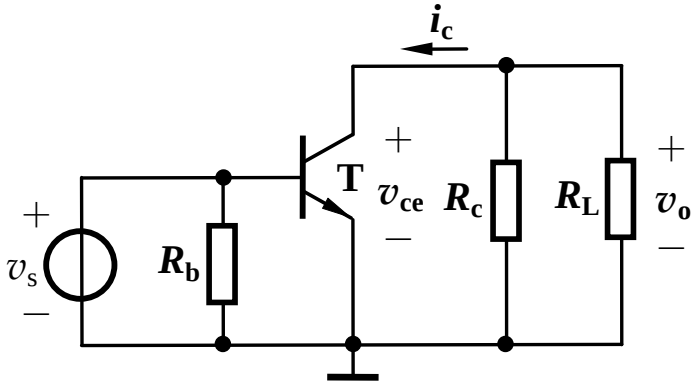
Cutoff distortion

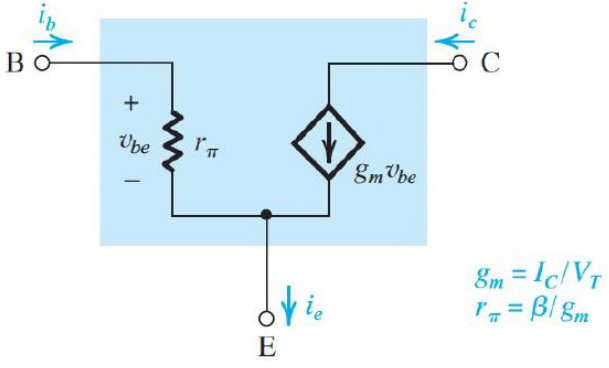


Saturation distortion

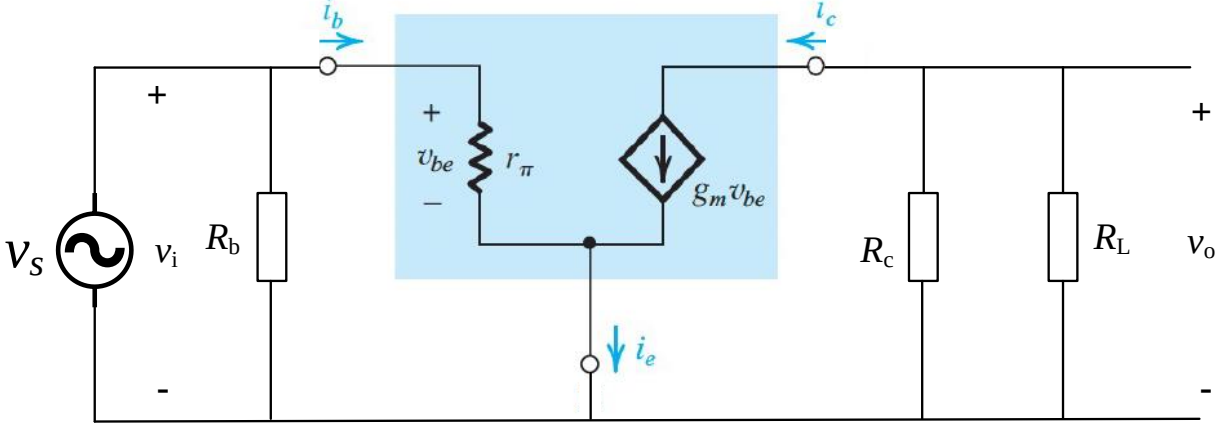

Input
Amplifier
Output
c
b
e
Microphone
Receiver
Battery

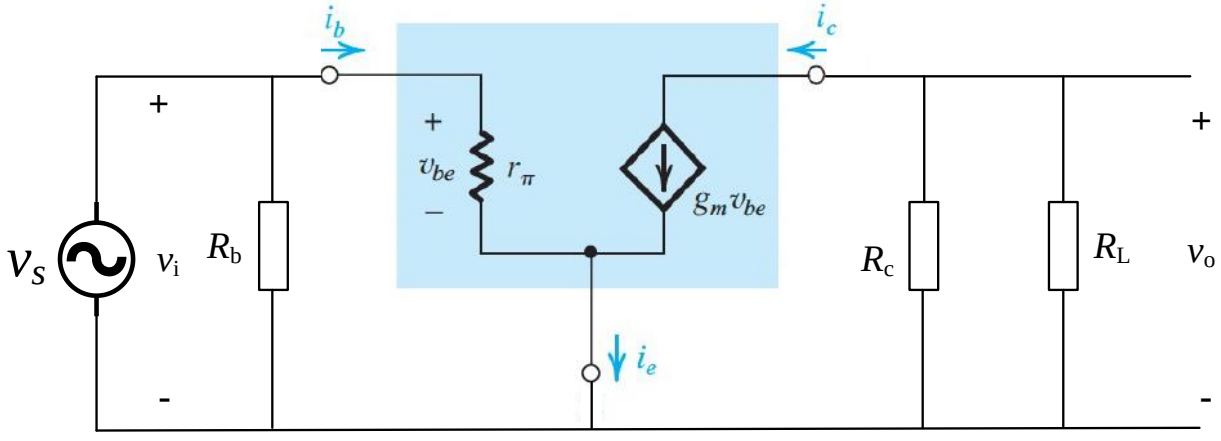
For the AC signal diagram:

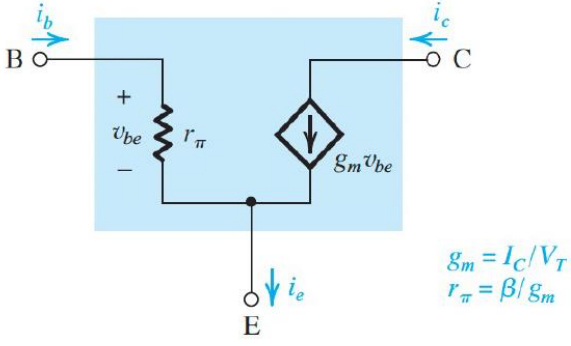




Small-signal model of a BJT







$$v_i = v_{be} = i_b r_\pi$$

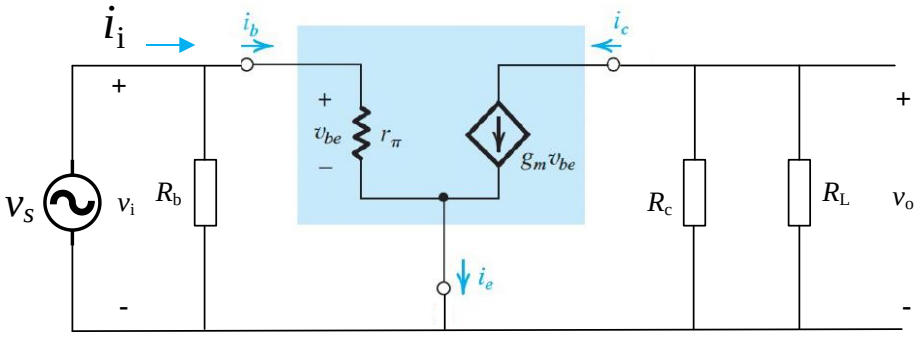
$$v_o = -i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)$$

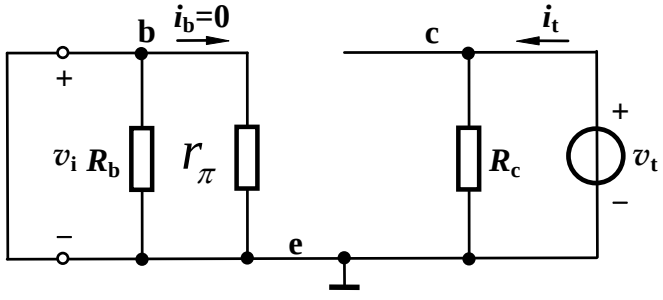
$$i_c = g_m v_{be} = g_m i_b r_\pi = g_m i_b \, \beta / g_m$$
$$= \beta i_b$$

AC small-signal amplification coefficient:

$$A_V = \frac{v_o}{v_i} = \frac{-i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)}{i_b r_\pi} = -\frac{\beta \cdot R_c R_L}{r_\pi (R_c + R_L)}$$

Input and output impedances:





Input impedance:

$$R_i = \frac{v_i}{i_i} = \frac{R_b r_\pi}{R_b + r_\pi}$$

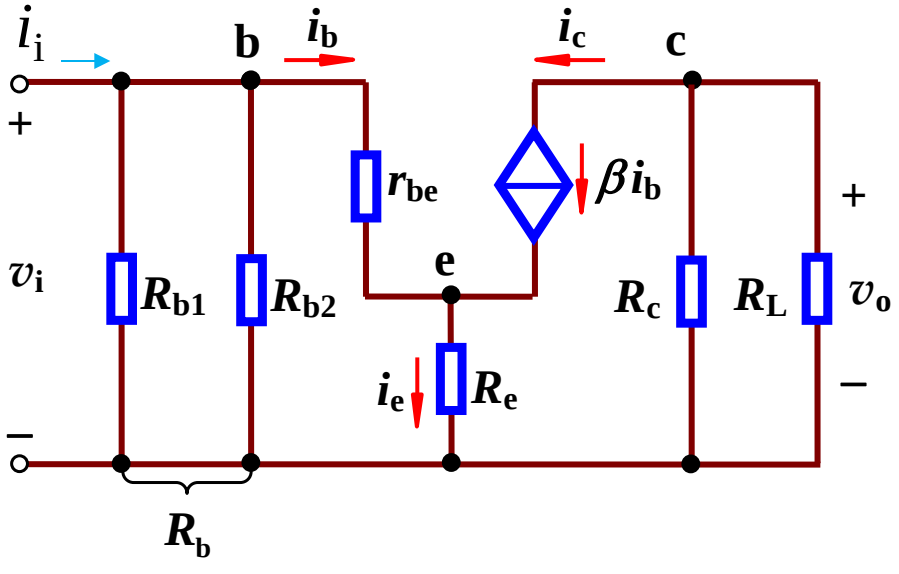
Output impedance:

$$R_o = \left.\frac{v_t}{i_t}\right|_{v_s=0, R_L=\infty} = R_c$$

R_L is replaced with a voltage source (v_t):

Input source is short:

For a more complicated circuit:



Input impedance:

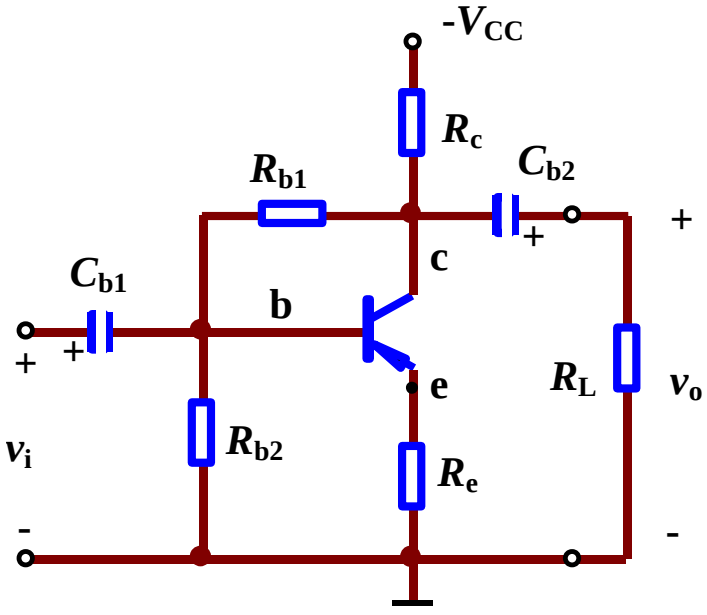
$$R_i = \frac{v_i}{i_i}$$

$$\boldsymbol{R_i = R_{b1} \parallel R_{b2} \parallel [r_{be} + (1+\beta)R_e]}$$

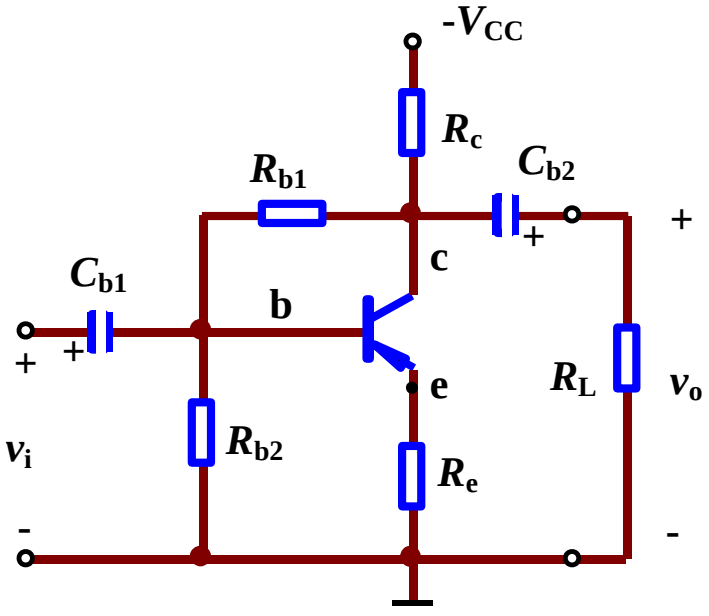
Output impedance:

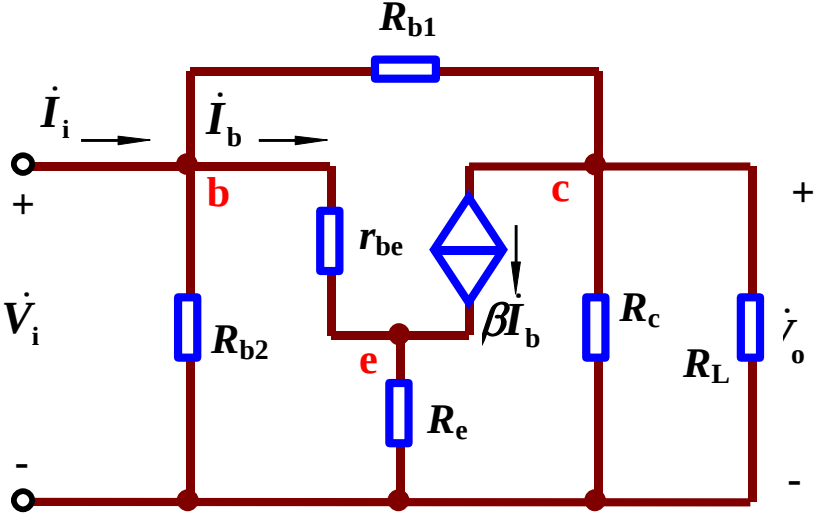
$$R_o = \left.\frac{v_t}{i_t}\right|_{v_s=0, R_L=\infty} \approx R_c$$

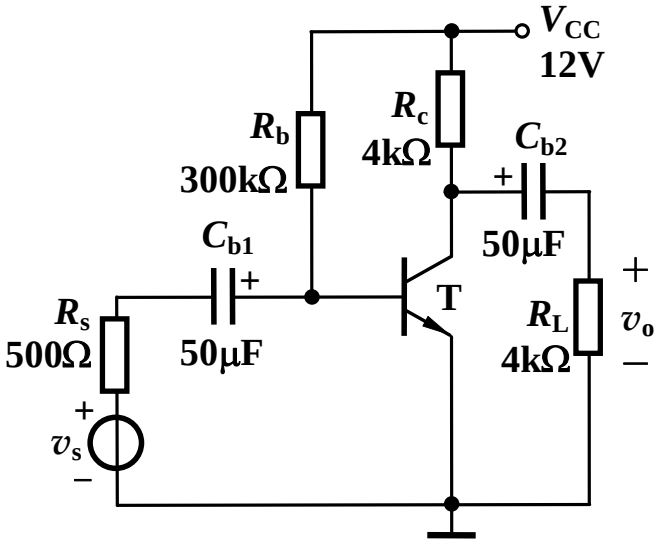
Please draw the corresponding small-signal equivalent circuit:



Please draw the corresponding small-signal equivalent circuit:





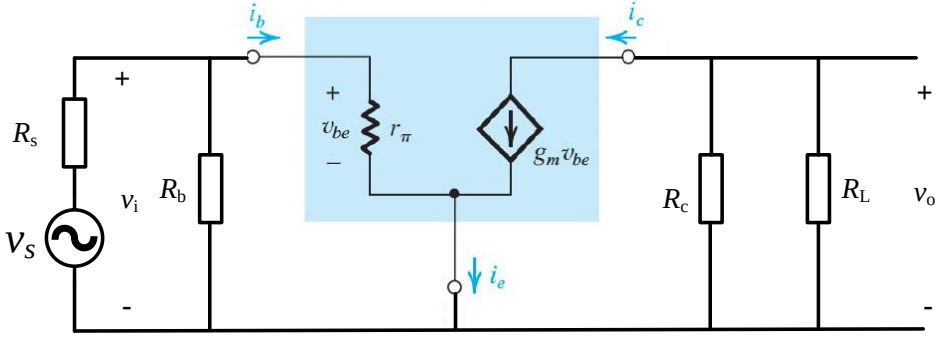


β = 50

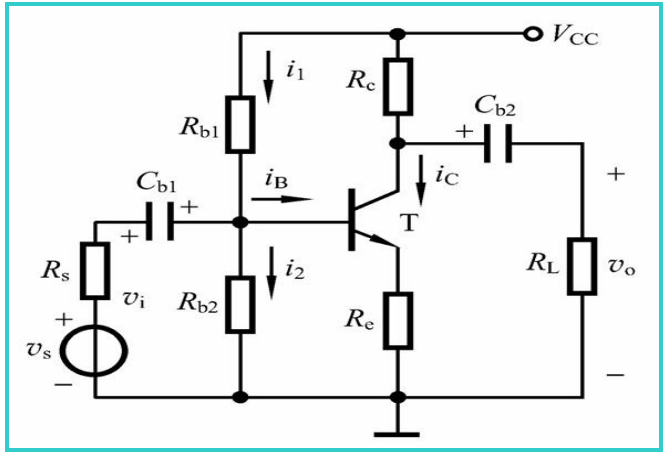
a. Calculate Q point ?

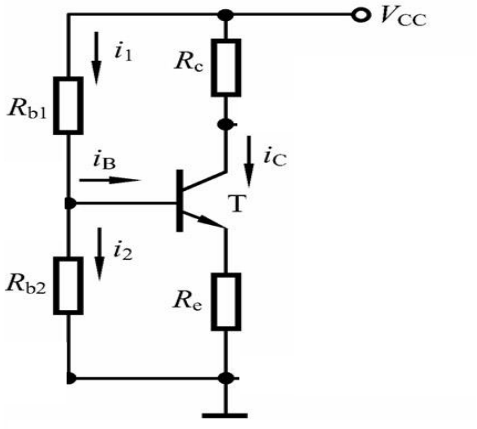
b. Calculate AC small-signal amplification coefficient ?

Draw the small-signal equivalent circuit



For a more complicated BJT circuit:





DC circuit

Q point:

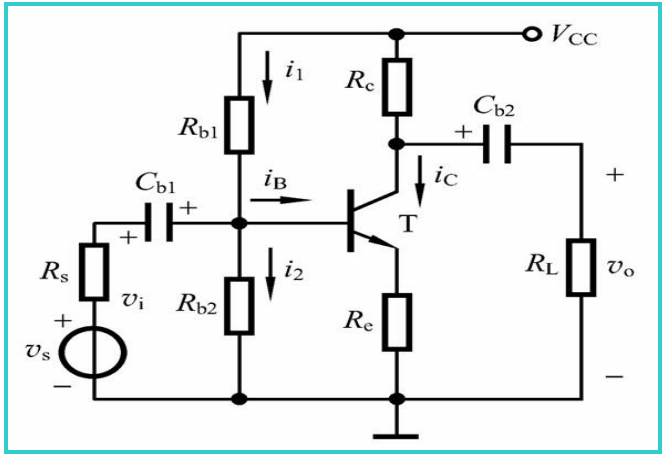
$$V_{BQ} \approx \frac{R_{b2}}{R_{b1}+R_{b2}} \cdot V_{CC}$$

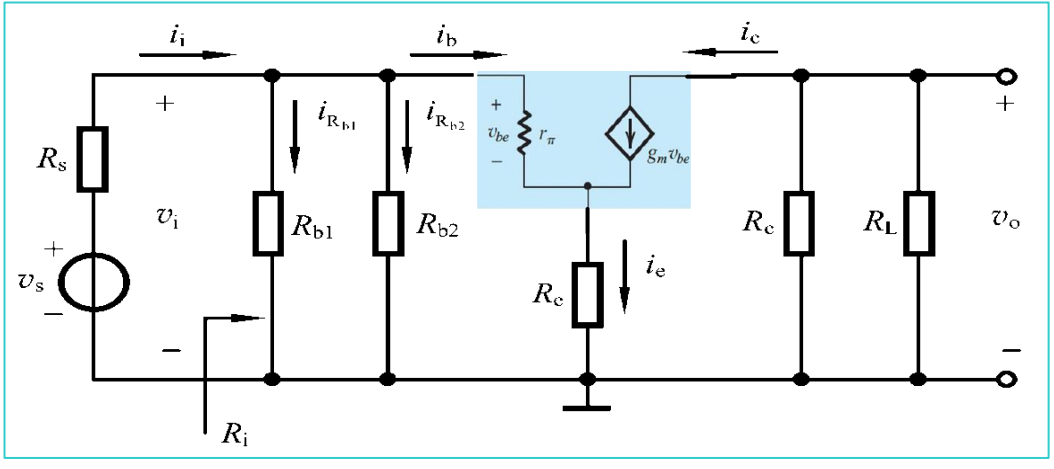
$$I_{CQ} \approx I_{EQ} = \frac{V_B - V_{BEQ}}{R_e}$$

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

$$V_{CEQ} \approx V_{CC} - I_{CQ}(R_c + R_e)$$

For a more complicated BJT circuit:





AC circuit

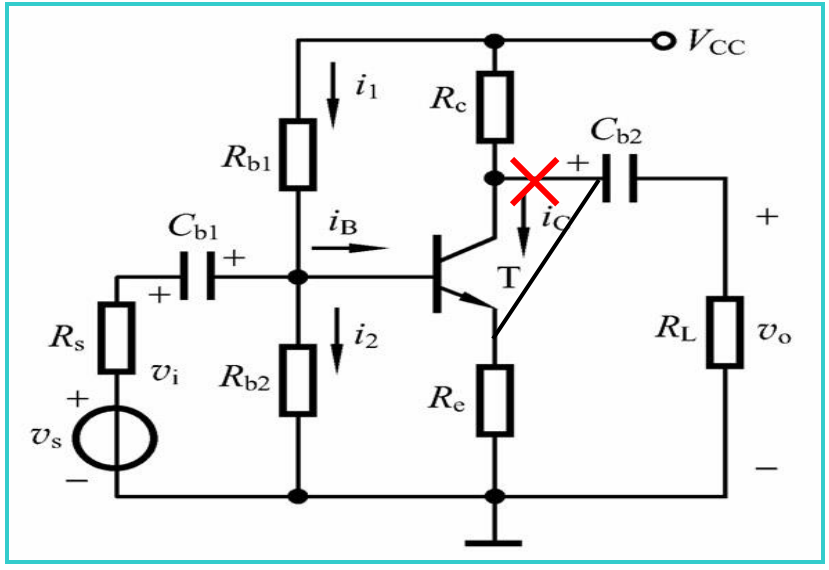
$$v_i = v_{be} + i_e R_e = i_b r_\pi + i_e R_e = i_b r_\pi + (1+\beta) i_b R_e$$

$$i_c = g_m v_{be} = g_m i_b r_\pi = g_m i_b \, \beta / g_m = \beta i_b$$

$$v_o = -i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)$$

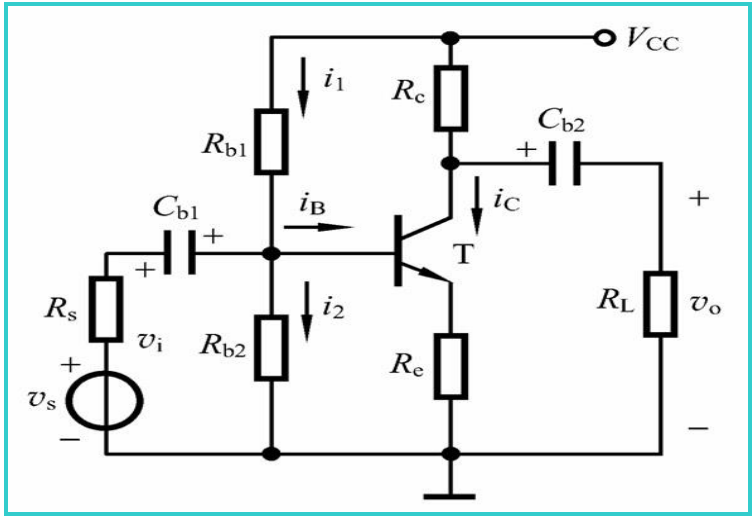
$$A_V = \frac{v_o}{v_i} = \frac{-i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)}{i_b r_\pi + (1+\beta) i_b R_e} = -\frac{\beta \cdot R_c R_L}{(r_\pi + (1+\beta) R_e)(R_c + R_L)}$$

Formulate the voltage amplification coefficient:



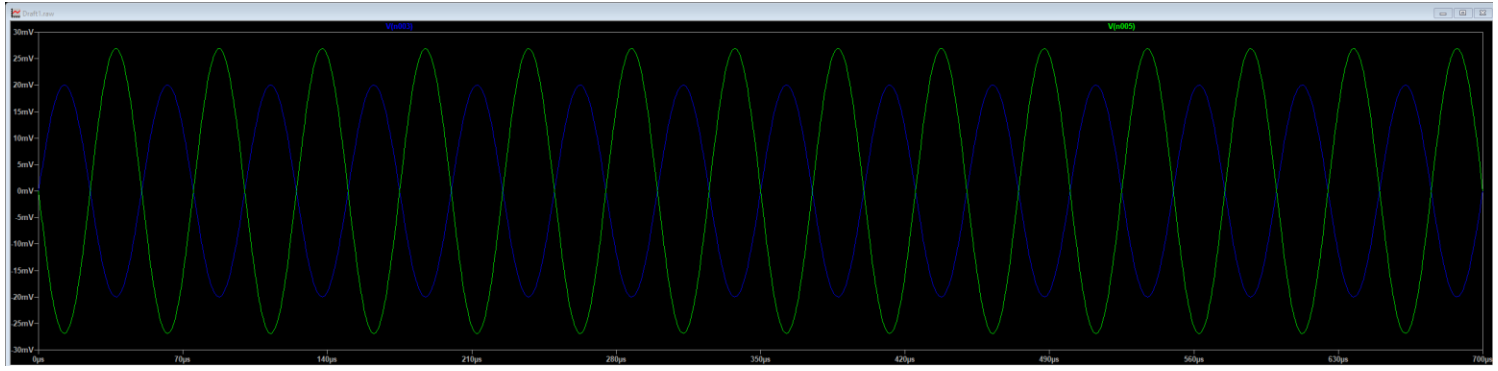
Interesting results found here!

Lab session:

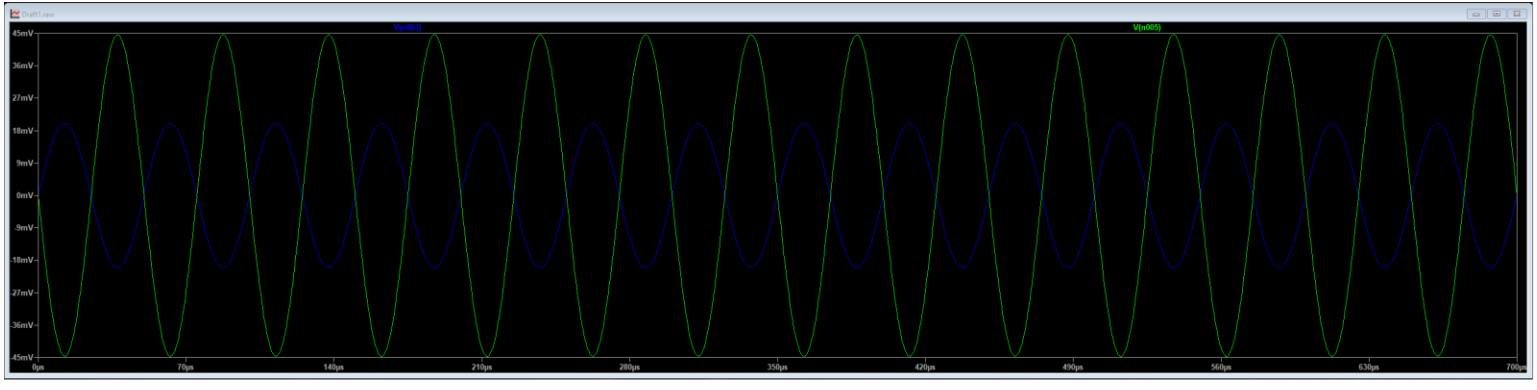


V_{CC}= 15 V, R_{b1} = 309 kΩ, R_{b2} = 110 kΩ, Re = 3.01 kΩ, Rc = 6.98 kΩ, C_{b1} = 1 uF, C_{b2} = 1 uF, R_L = 10 kΩ.

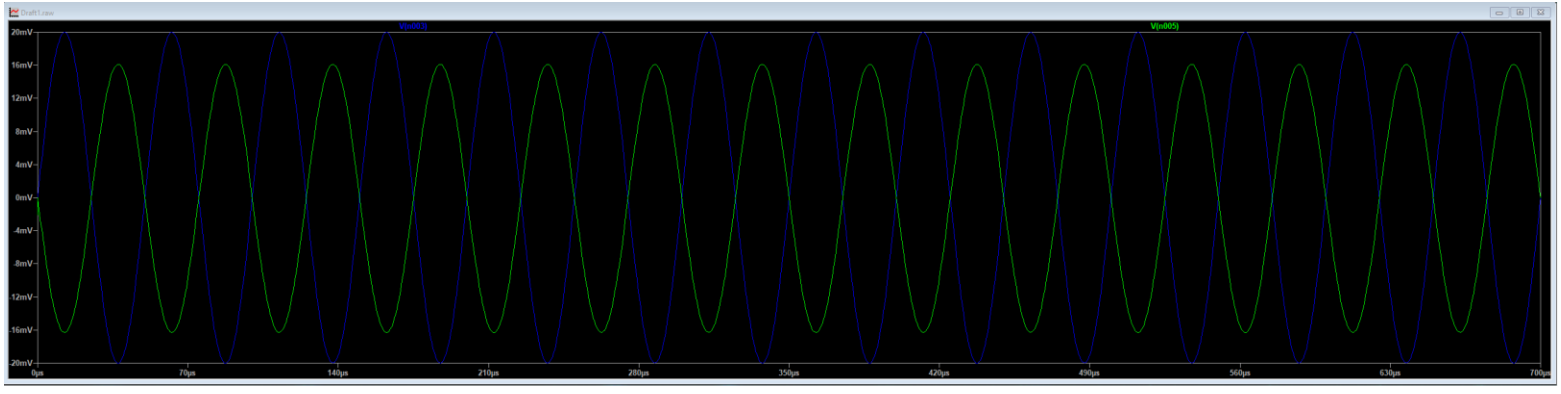
If $v_s = 20\sin(2\pi f)$ mv, $f = 20$ kHz, please measure v_i and v_o, and calculate the amplitude amplification coefficient A_v.



If R_L = 300 kΩ, please please measure v_i and v_o, and calculate the amplitude amplification coefficient A_v.



If Re = 5 kΩ, please measure v_i and v_o, and calculate the amplitude amplification coefficient A_v.



Thanks