ESc201 : Introduction to Electronics

Transistor Amplifiers

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Forward Active Mode

Base Emitter (BE) junction is forward biased and Base Collector (BC) junction is reverse biased

Current Gain

$$\frac{I_C}{I_B} = \beta_F$$

$$V_{BE} \cong 0.7V$$

Cut off Mode

Both the junctions are reverse biased

$$I_B \cong 0;\ I_C \cong 0;\ I_E \cong 0$$

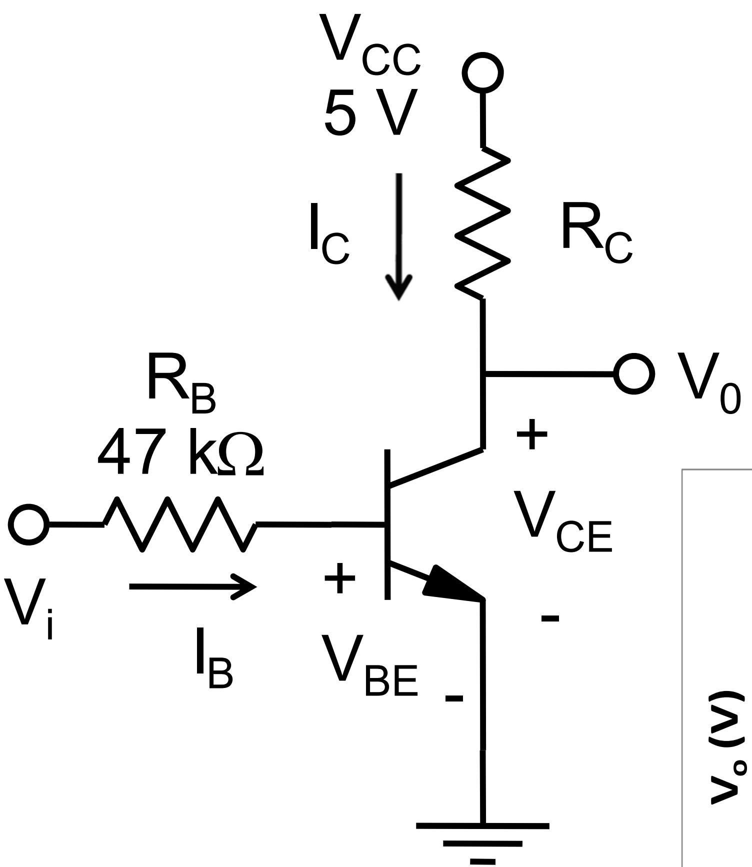
Transistor acts like an open circuit

Saturation Mode

Both the junctions are forward biased

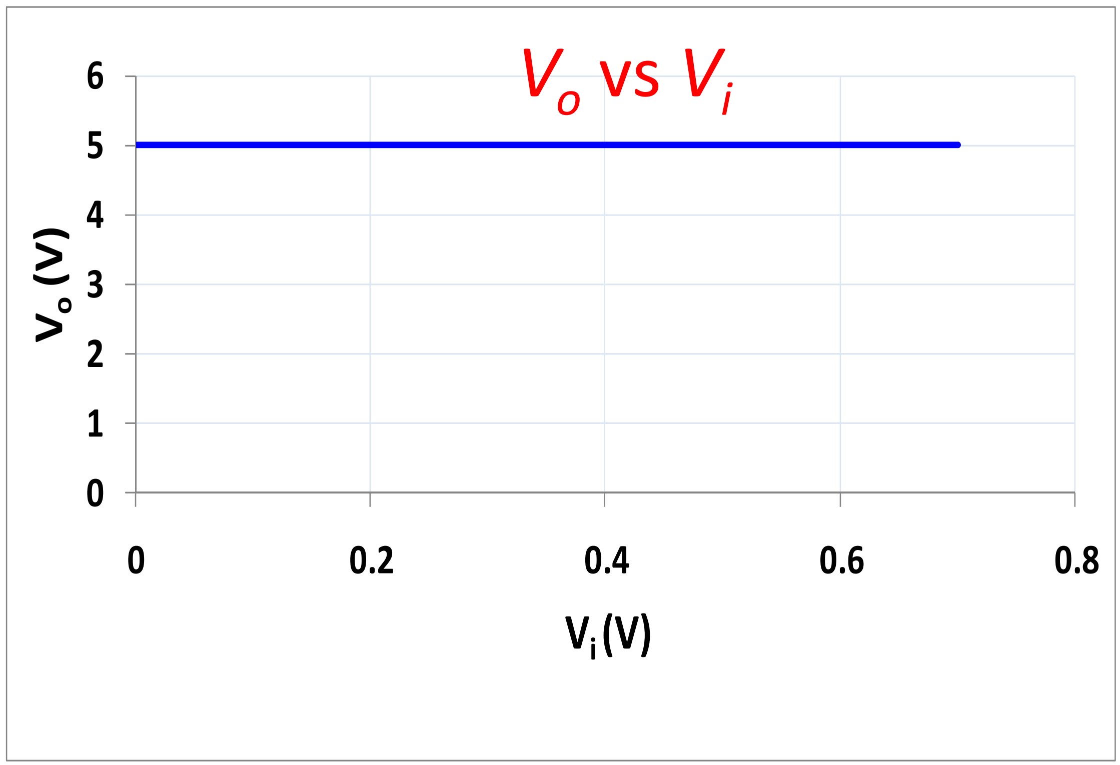
$$V_{BE} \cong 0.7V \qquad V_{BC} \cong 0.5V \qquad V_{BE} - V_{BC} \cong 0.2V$$

Let us analyze this circuit



Choose R_C = 1 kΩ

- $V_i < V_\gamma$
  - Transistor in cut off
  - $I_B=0$; $I_C=0$
  - $V_0=V_{CC}$



$V_i > V_\gamma$

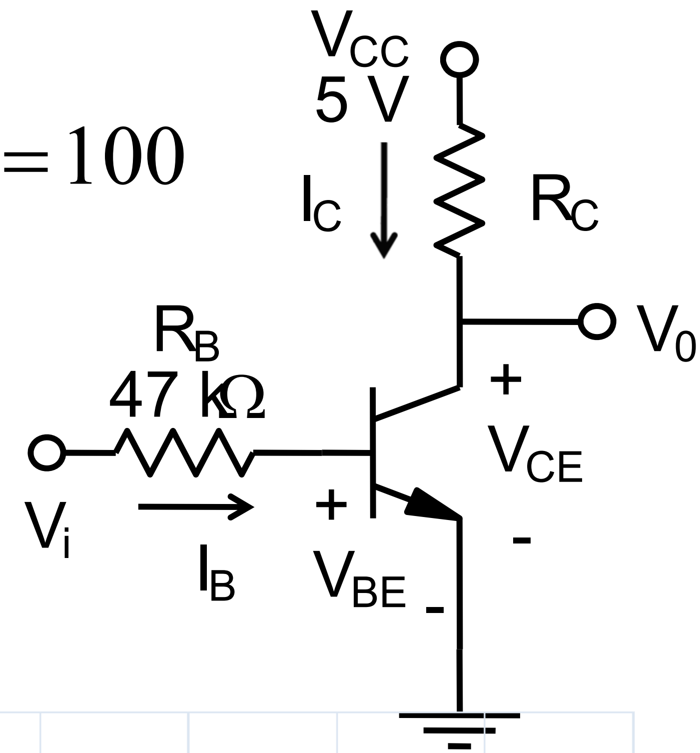
$$V_i = I_B R_B + V_{BE}$$

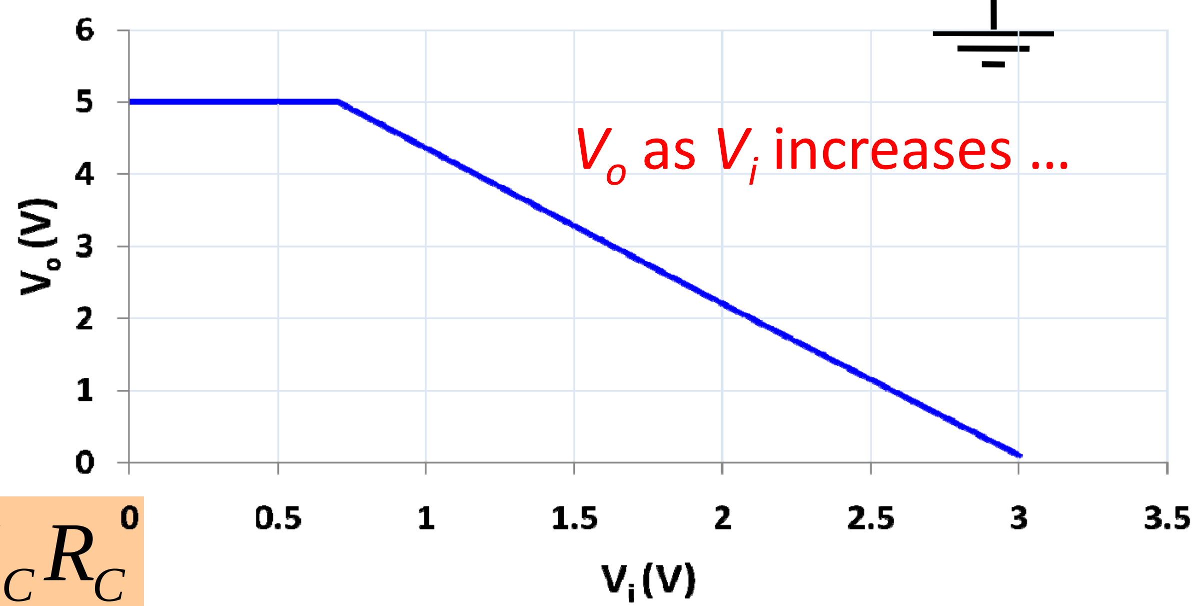
$$I_B = \frac{V_i - V_{BE}}{R_B}$$

$$I_C = \beta I_B$$

$$V_{CC} = I_C R_C + V_{CE}$$

$$\beta = 100$$





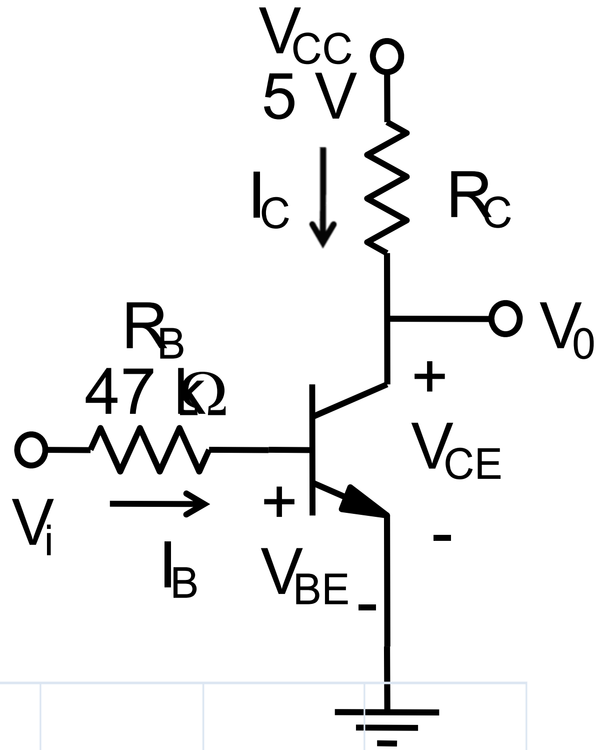
$$V_0 = V_{CE} = V_{CC} - I_C R_C$$

How low can it go?

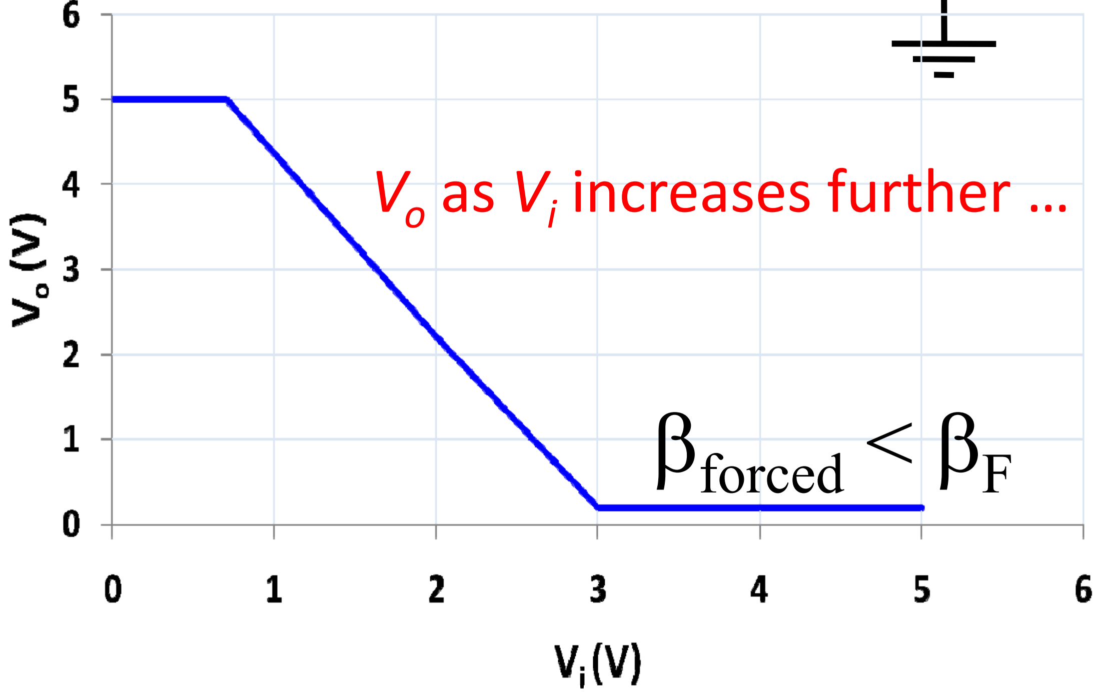
$$V_0 = V_{CE} = -V_{BC} + V_{BE}$$

$$V_{BC} = V_{BE} - V_{CE}$$

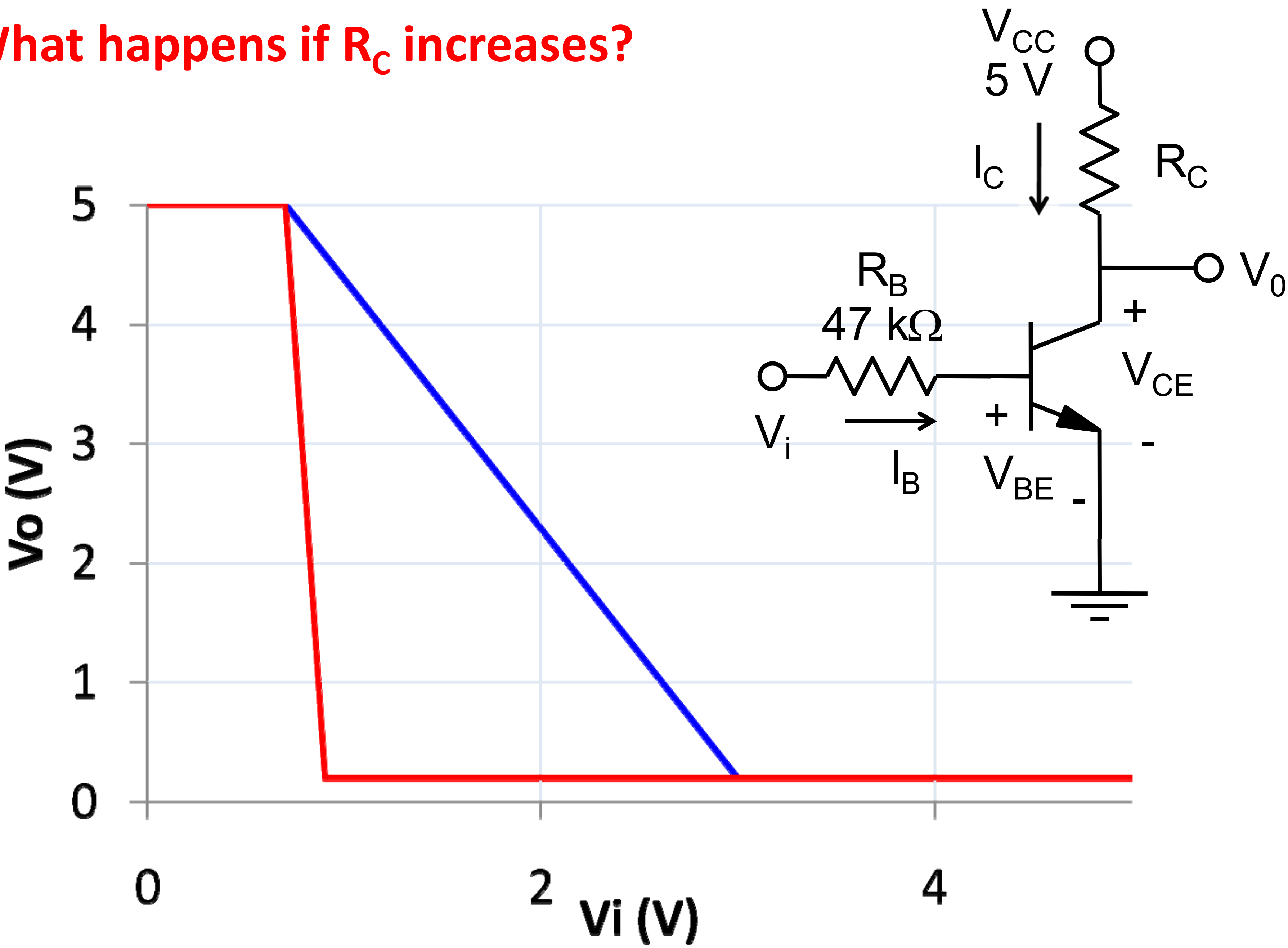
When $V_{CE} \cong 0.2V$ $V_{BC} = 0.5V$



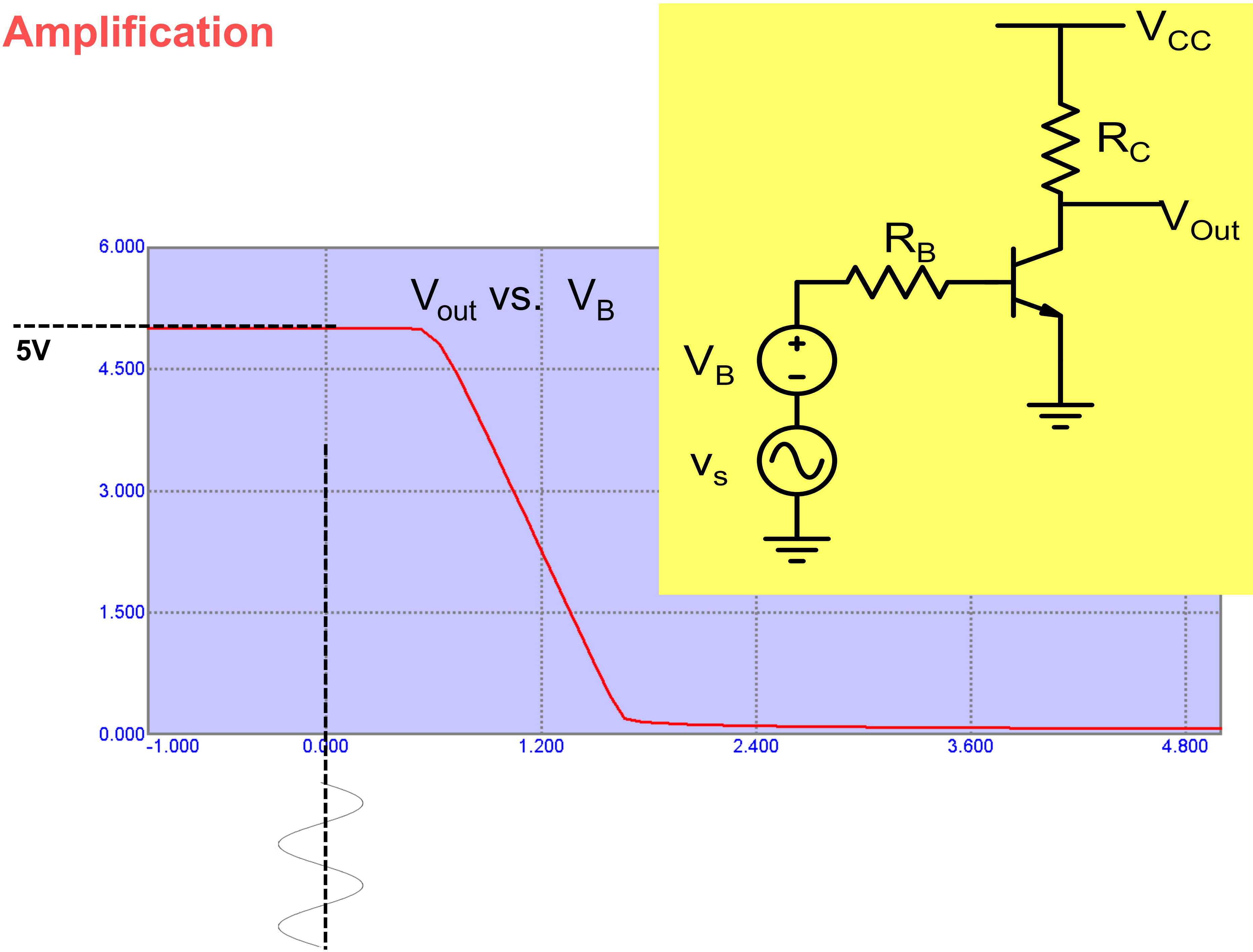
Both CB and BE junctions are forward biased and the transistor enters into saturation



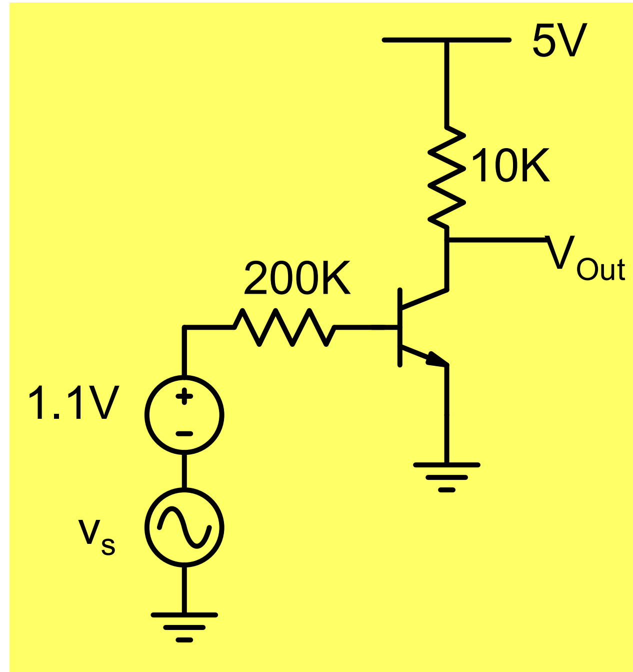
What happens if R_C increases?

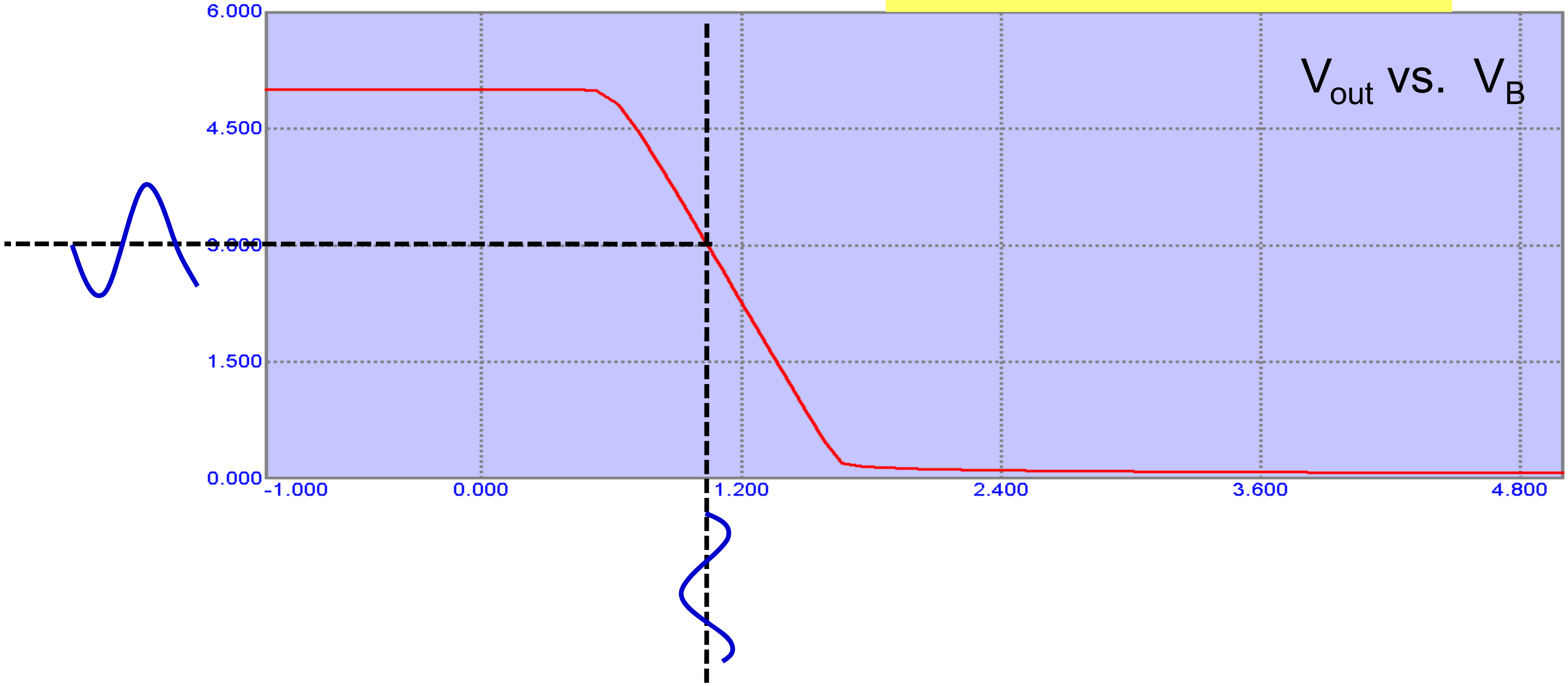


Amplification

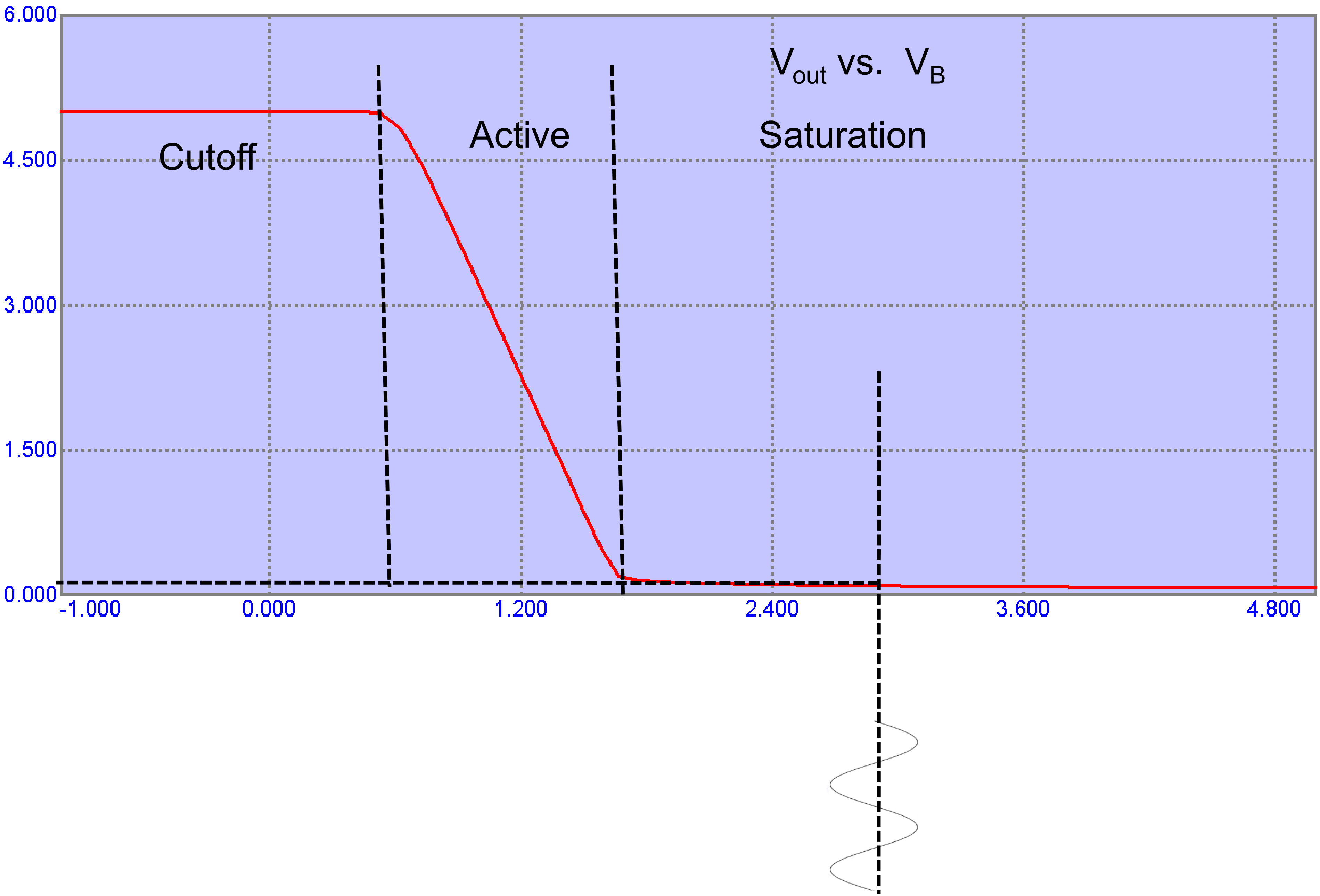


How do we amplify the weak signal?

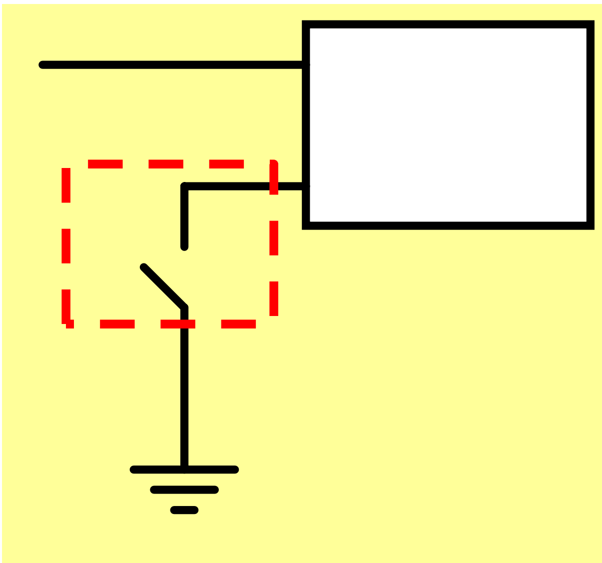


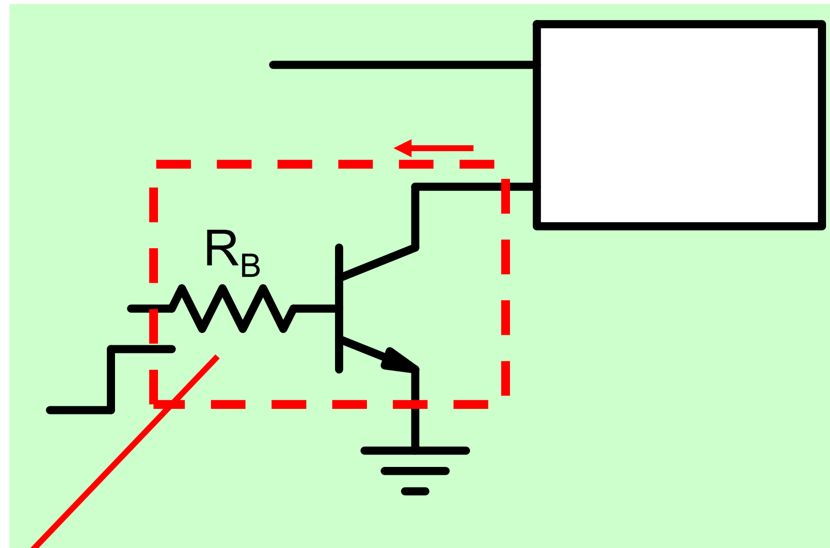


Transistor biased in saturation also does not result in Amplification



Transistor as a Switch



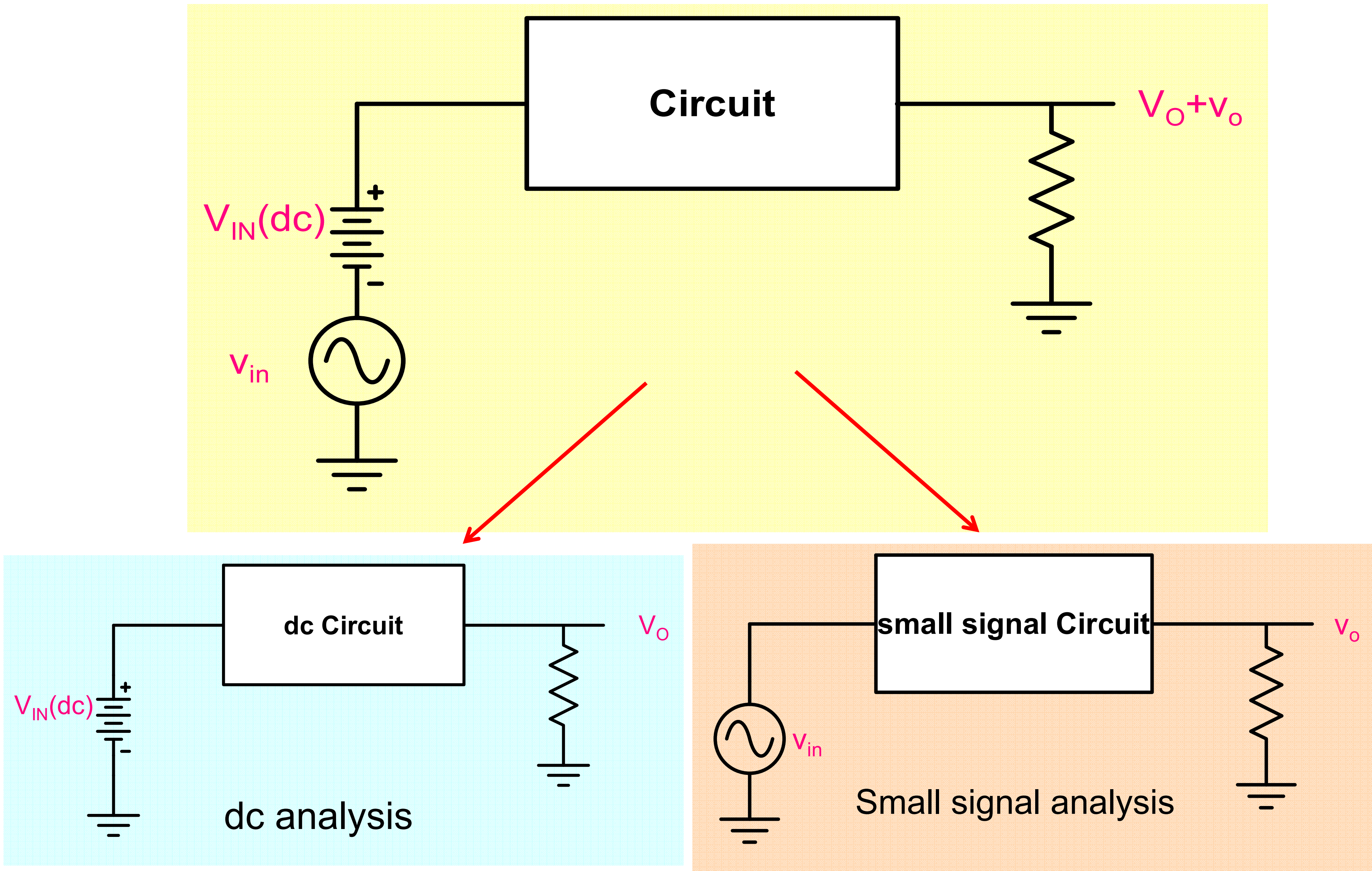


Choose value of R_B such that, the transistor is driven into saturation when it is on

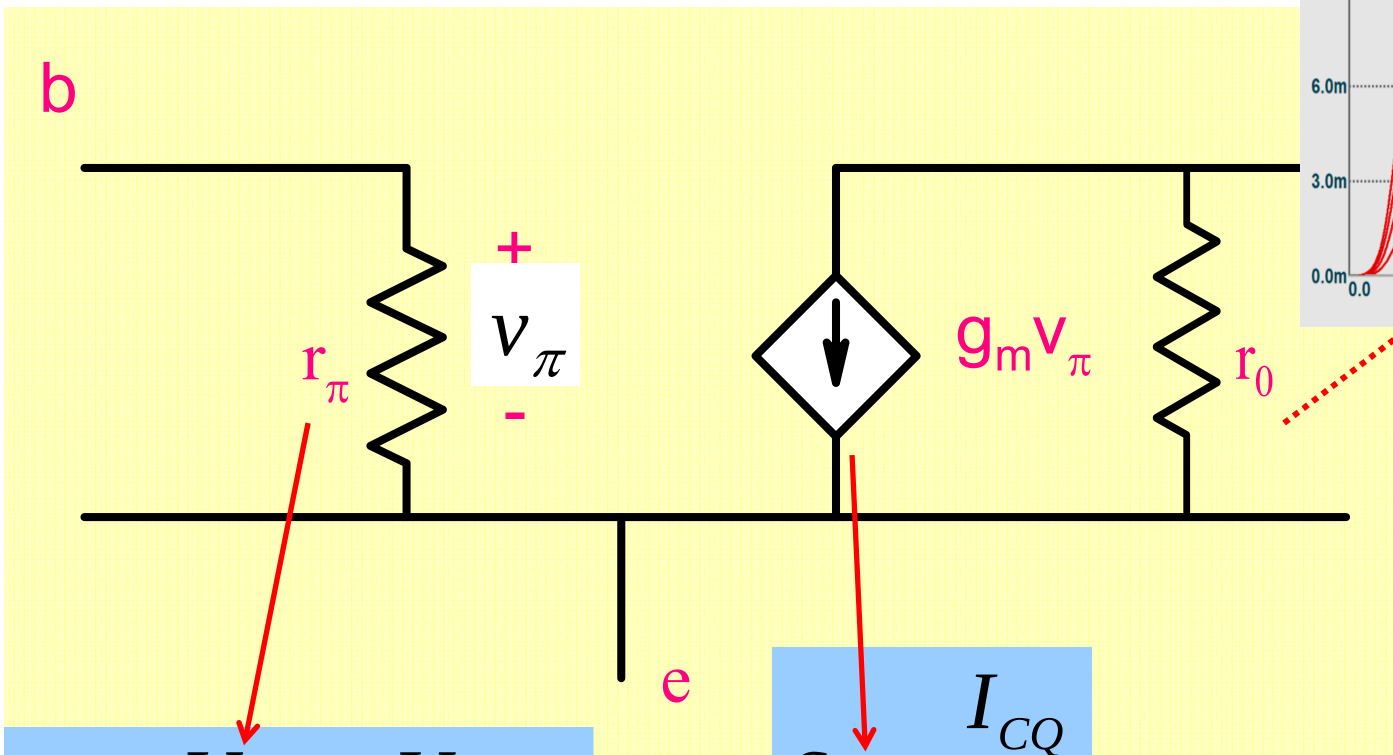
$$\frac{I_C}{I_B} = \beta_{forced} < \beta_F$$

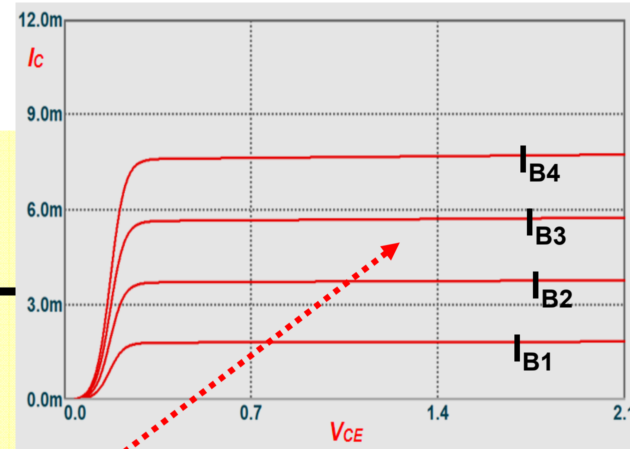
$$\frac{I_C}{\beta_F I_B} < 1$$

Transistor Circuit Analysis



Small Signal Model or ac Model





$$r_\pi = \frac{V_T}{I_{BQ}} = \frac{V_T}{I_{CQ}}\beta$$

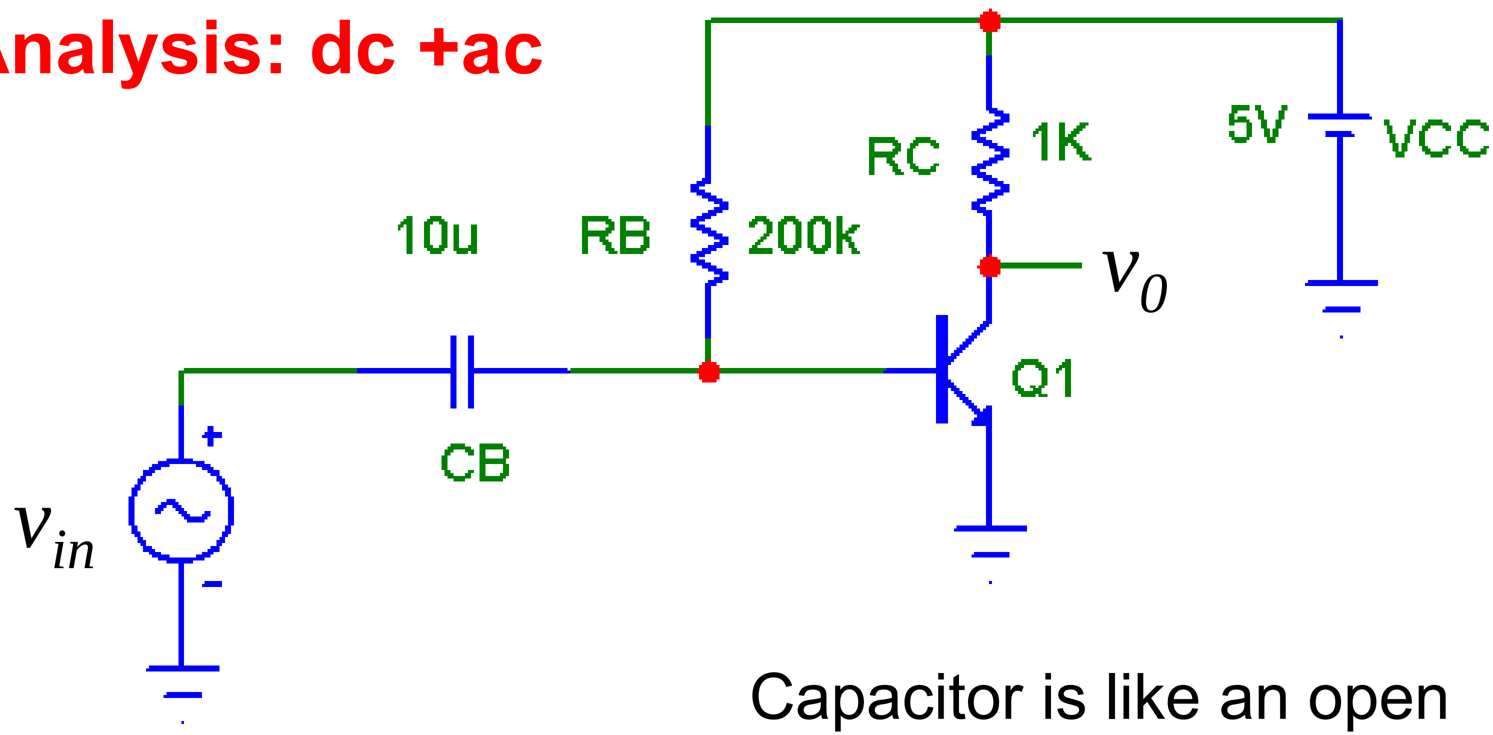
$$g_m = \frac{I_{CQ}}{V_T}$$

The small signal model is valid only when

$$v_\pi << V_T = \frac{kT}{q} = 26mV\ at\ 300K$$

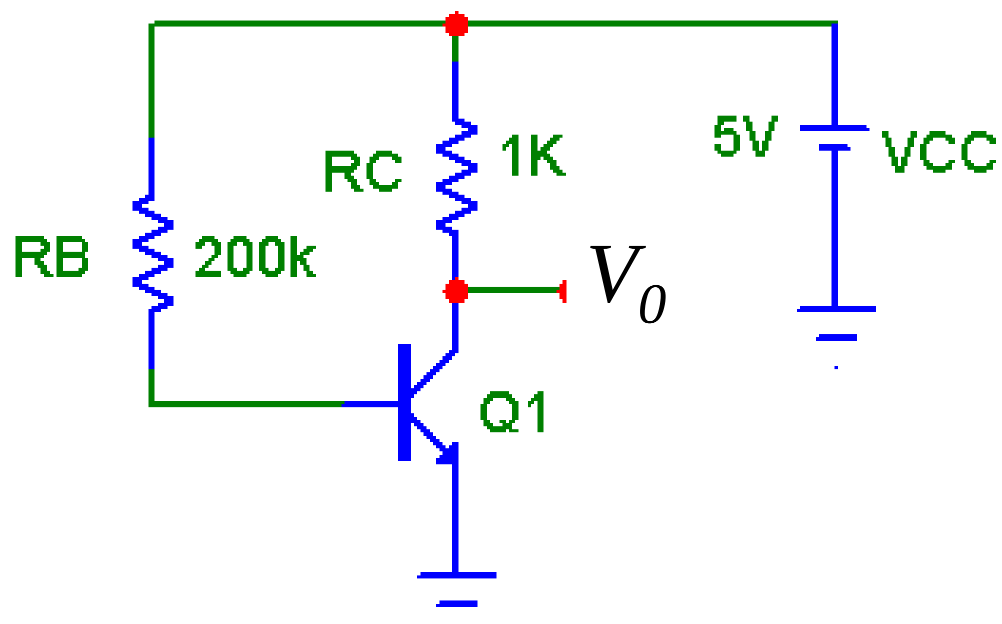
This model is valid for both npn and pnp transistors

Complete Analysis: dc +ac



1. DC analysis

Capacitor is like an open circuit under dc

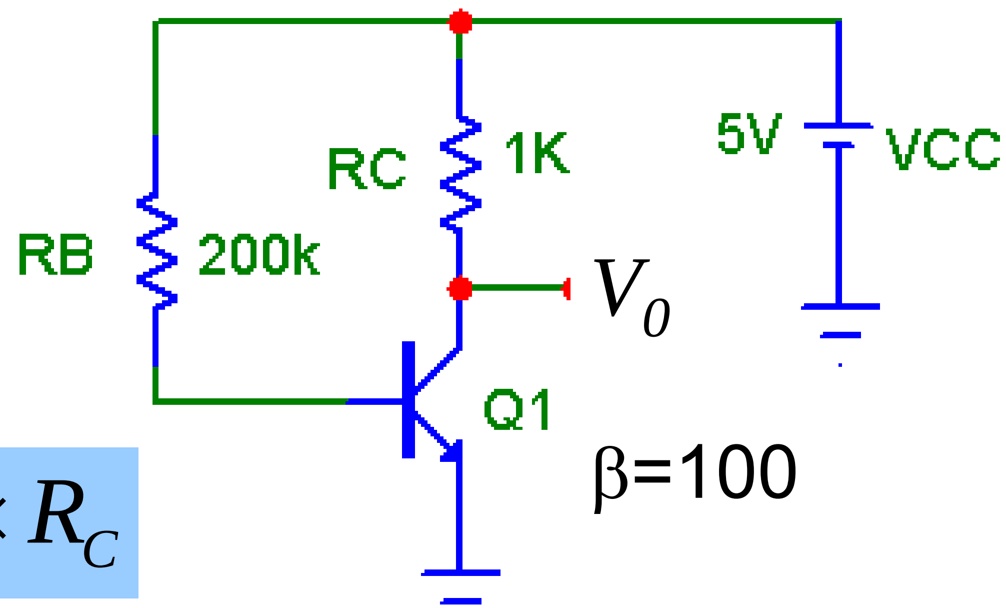


1. DC analysis

$$I_{BQ} = \frac{V_{CC} - 0.7}{R_B}$$

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

$$V_O(dc) = V_{CC} - I_{CQ} \times R_C$$



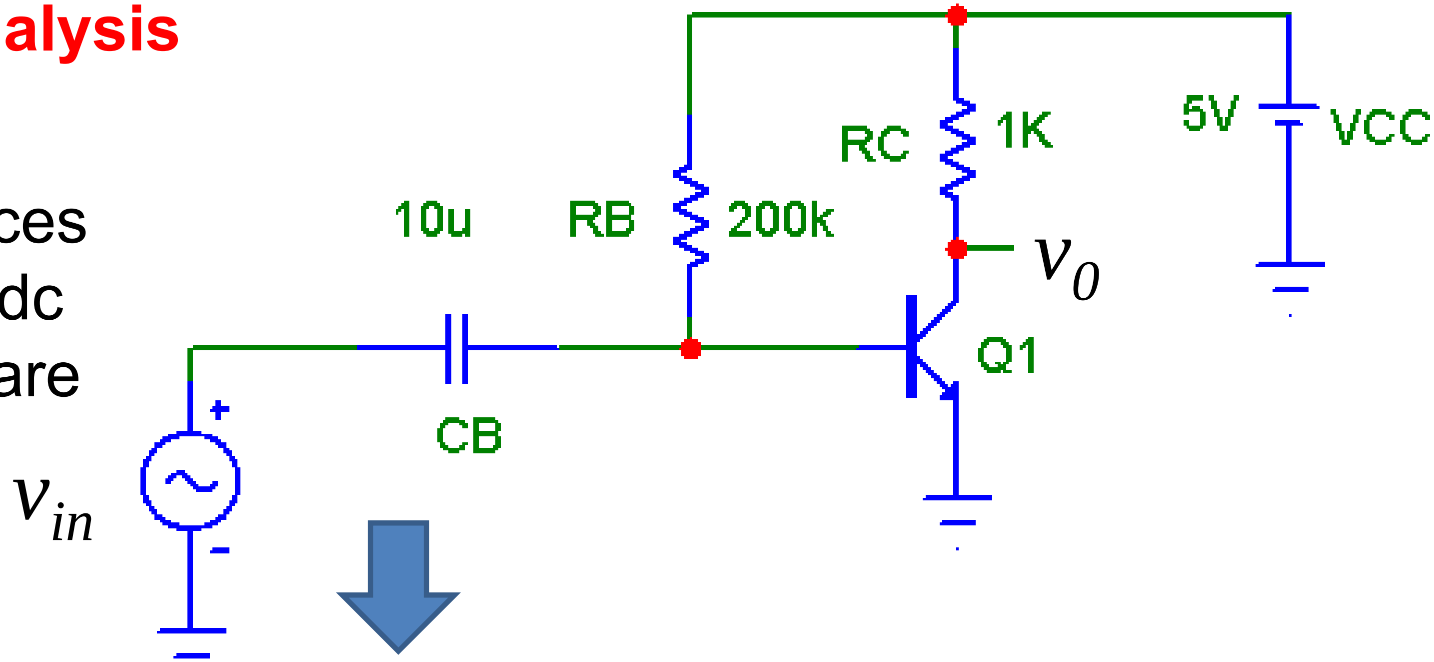
$$I_{BQ} = 0.0215mA$$

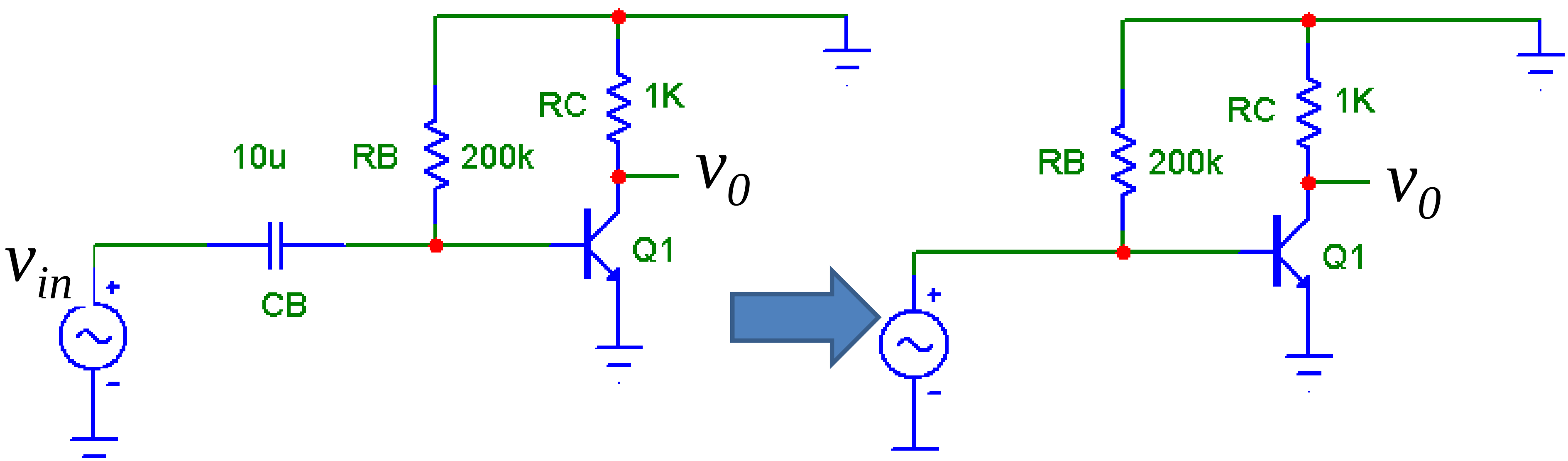
$$I_{CQ} = 2.15mA$$

$$V_0 = 2.85V$$

Small signal Analysis

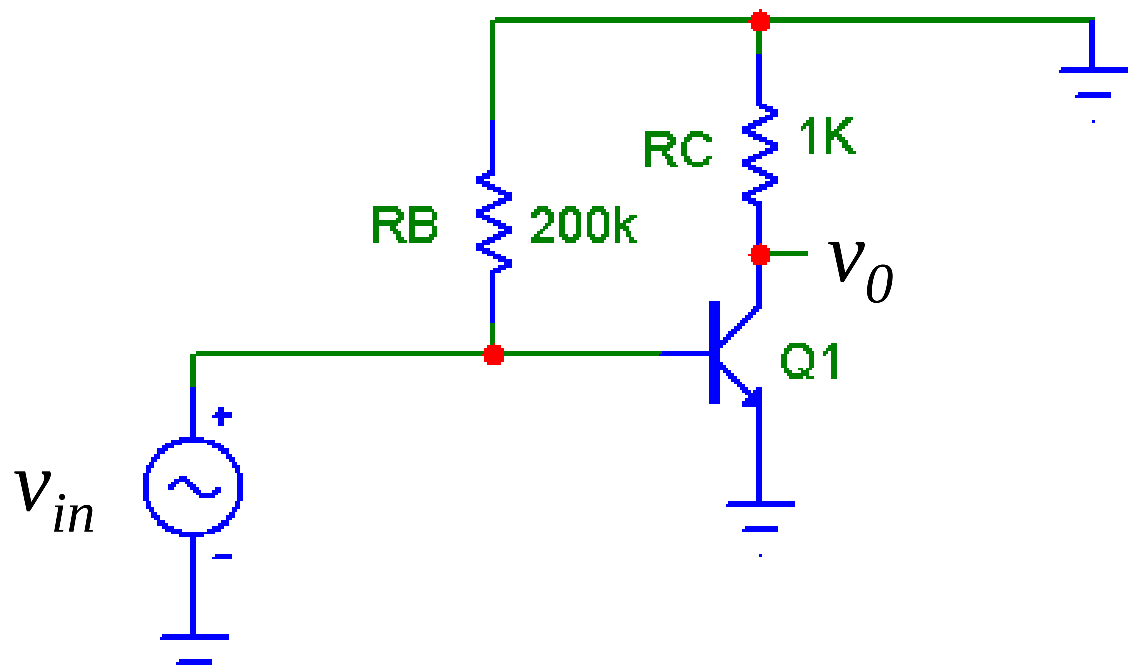
DC voltage sources are shorted and dc current sources are open circuited



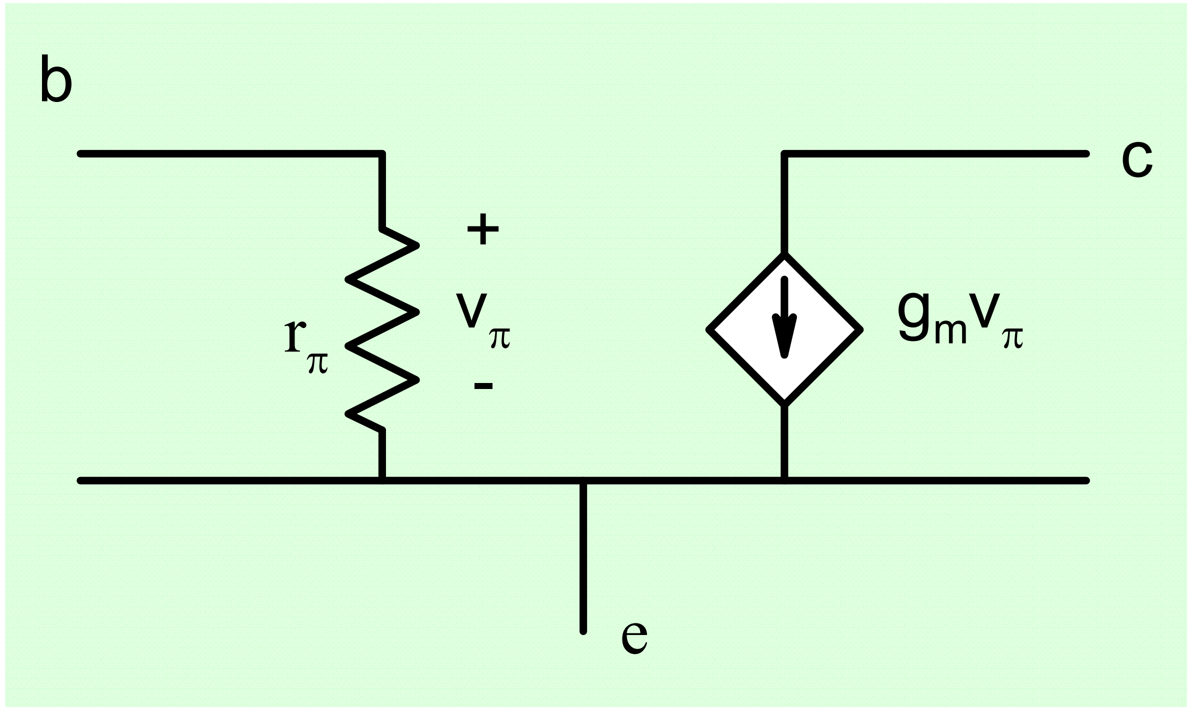


Analysis is done at frequencies for which impedance due to capacitor is small so that capacitor can be considered as short.

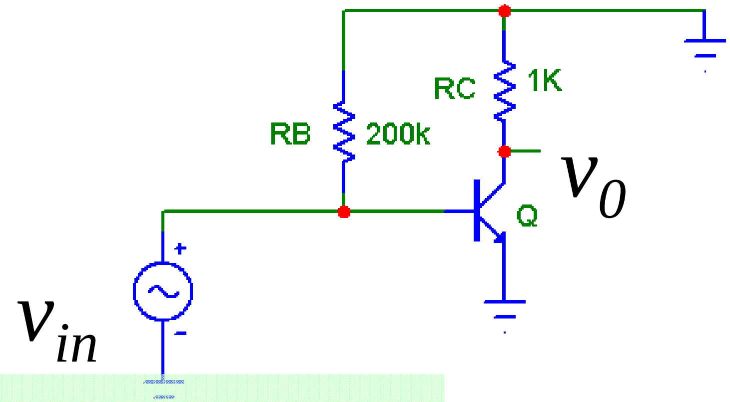
Small signal Analysis

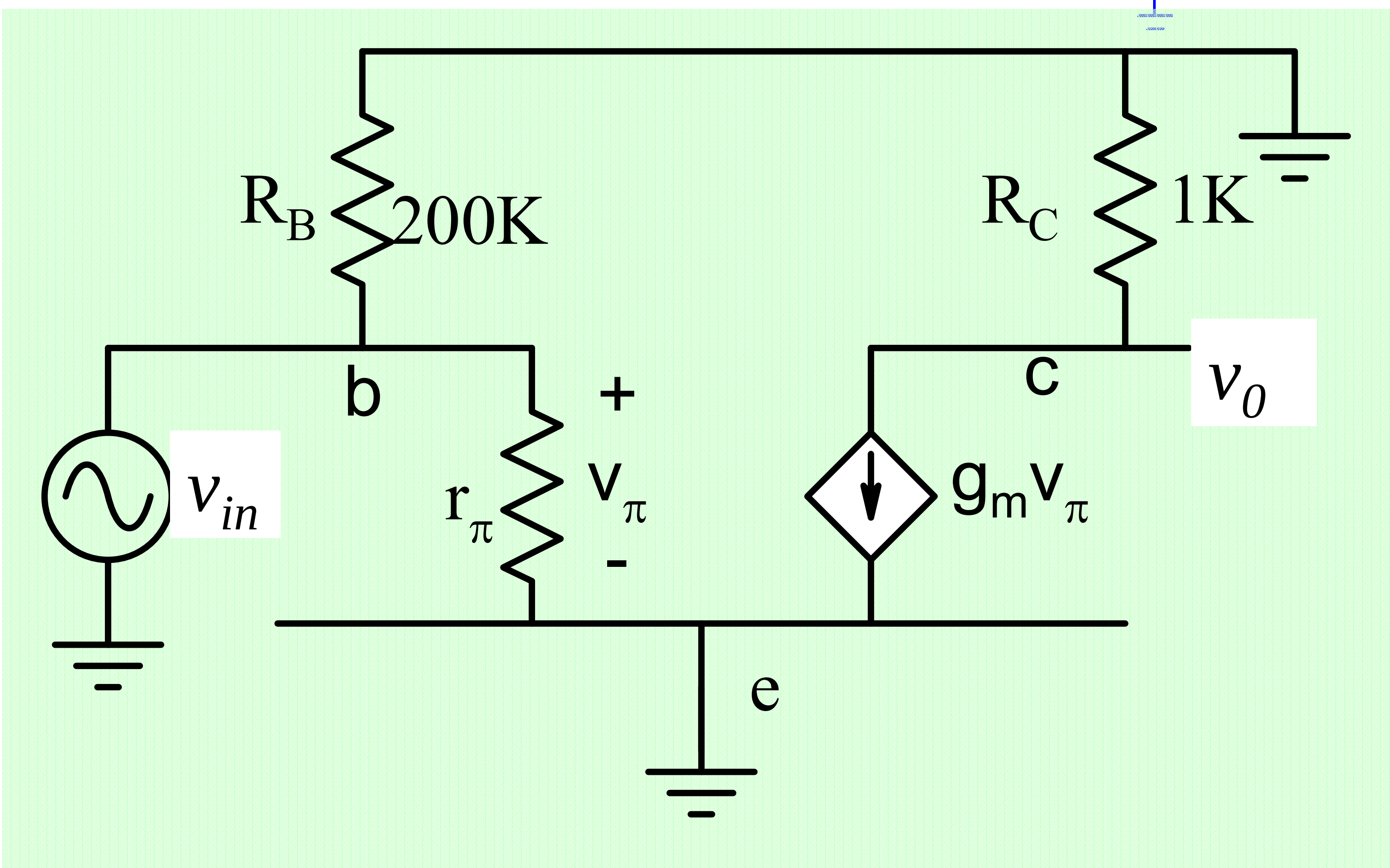


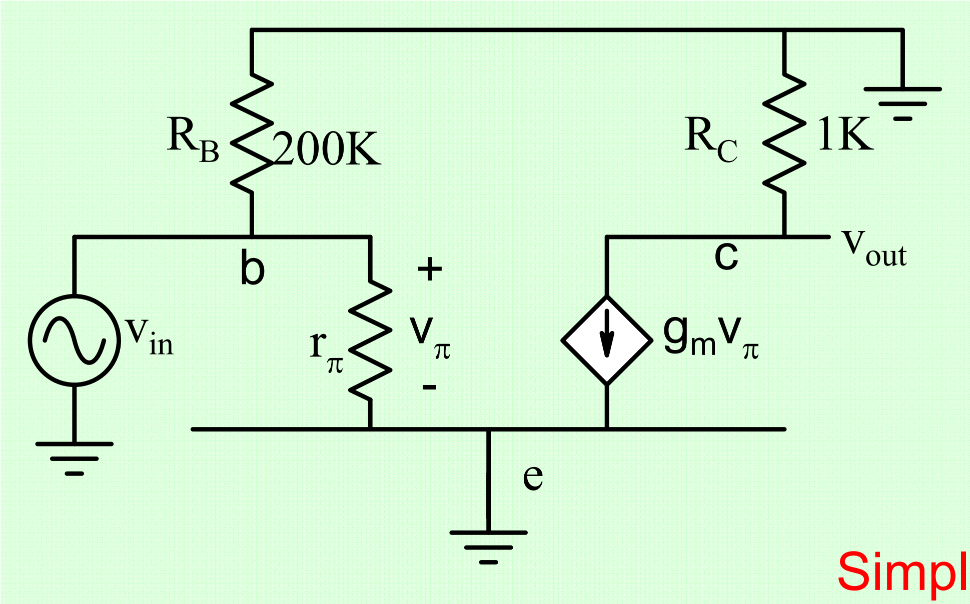
Next, the transistor is replaced by its small signal model



Small signal Analysis

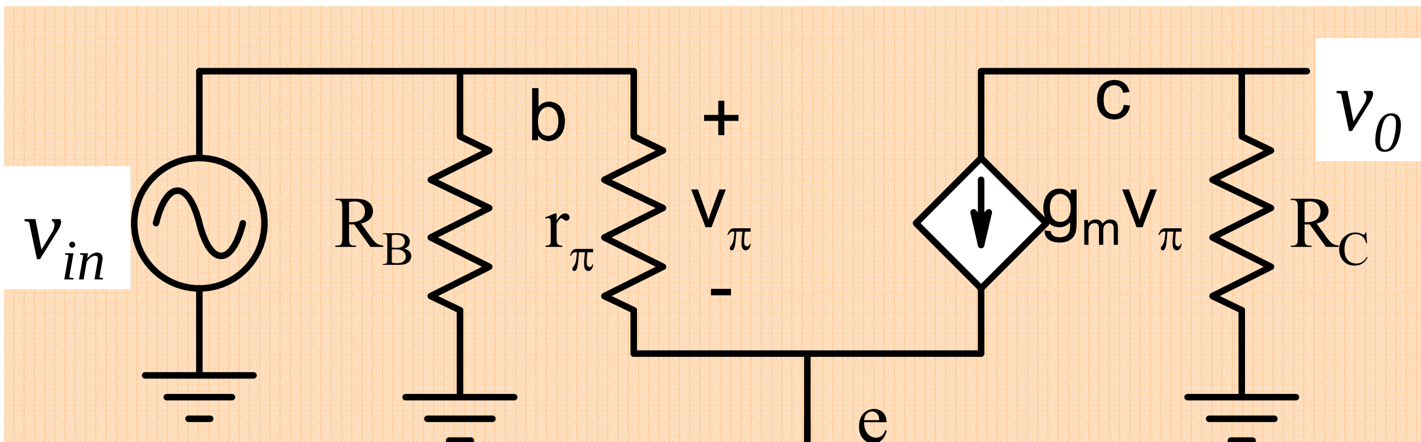






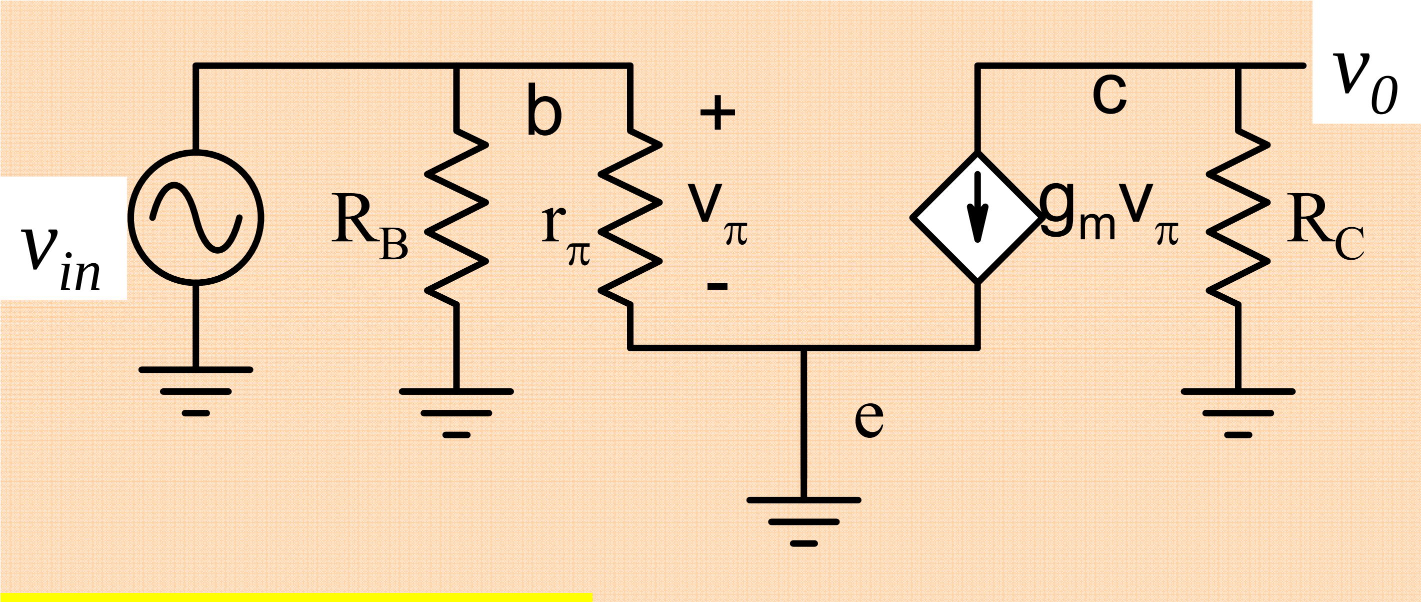
Simplify

$$v_o = -g_m v_\pi \times R_C$$



$$v_\pi = v_{in}$$

$$\frac{v_o}{v_{in}} = -\,g_m R_C$$



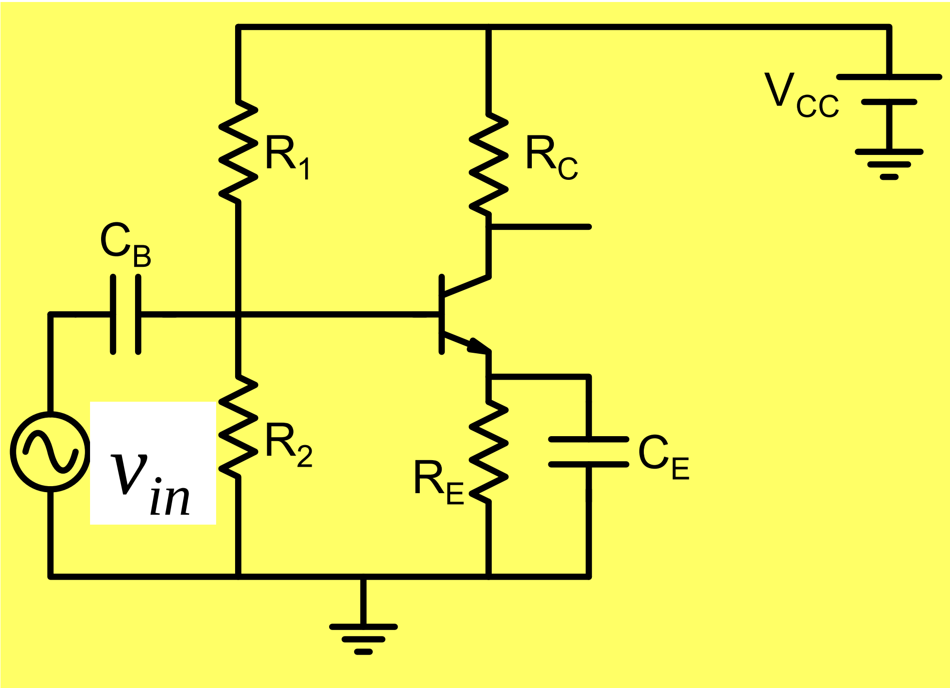
$$\frac{v_o}{v_{in}} = -g_m R_C$$

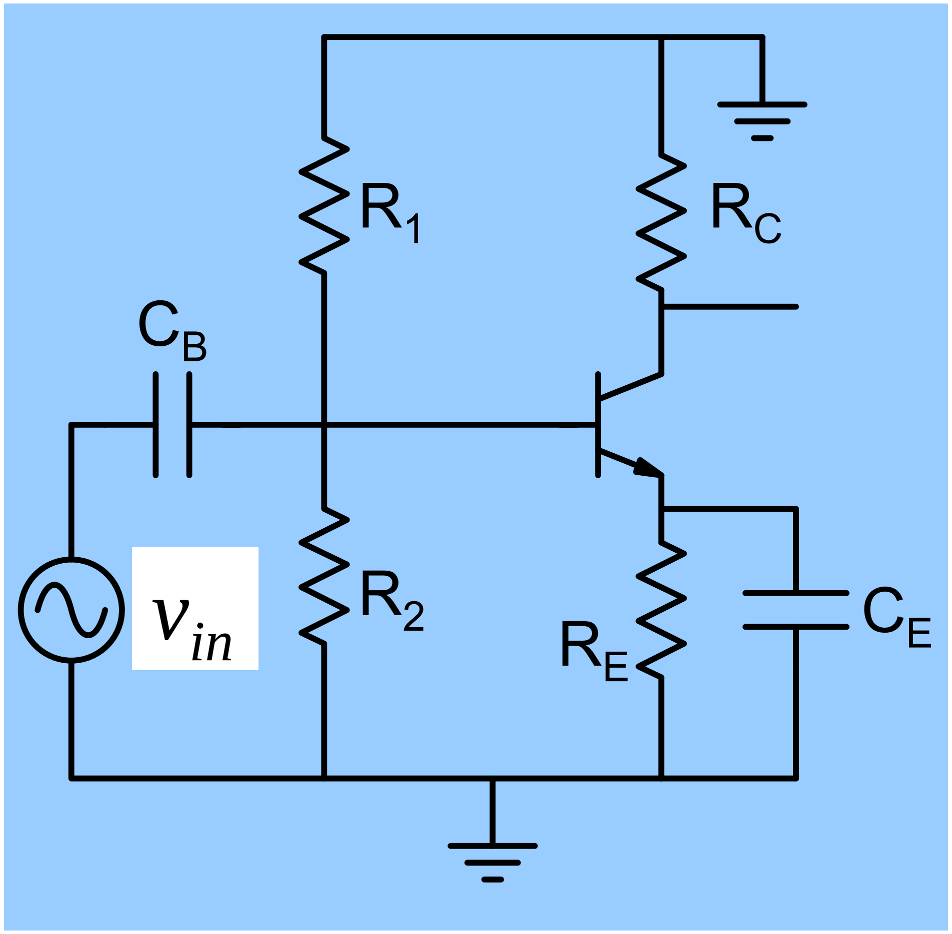
$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.15mA}{25mV} = 0.086\ S$$

$$\frac{v_0}{v_{in}} = -g_m R_C = -0.086 \times 1000 = -86$$

Small Signal (or ac) Analysis

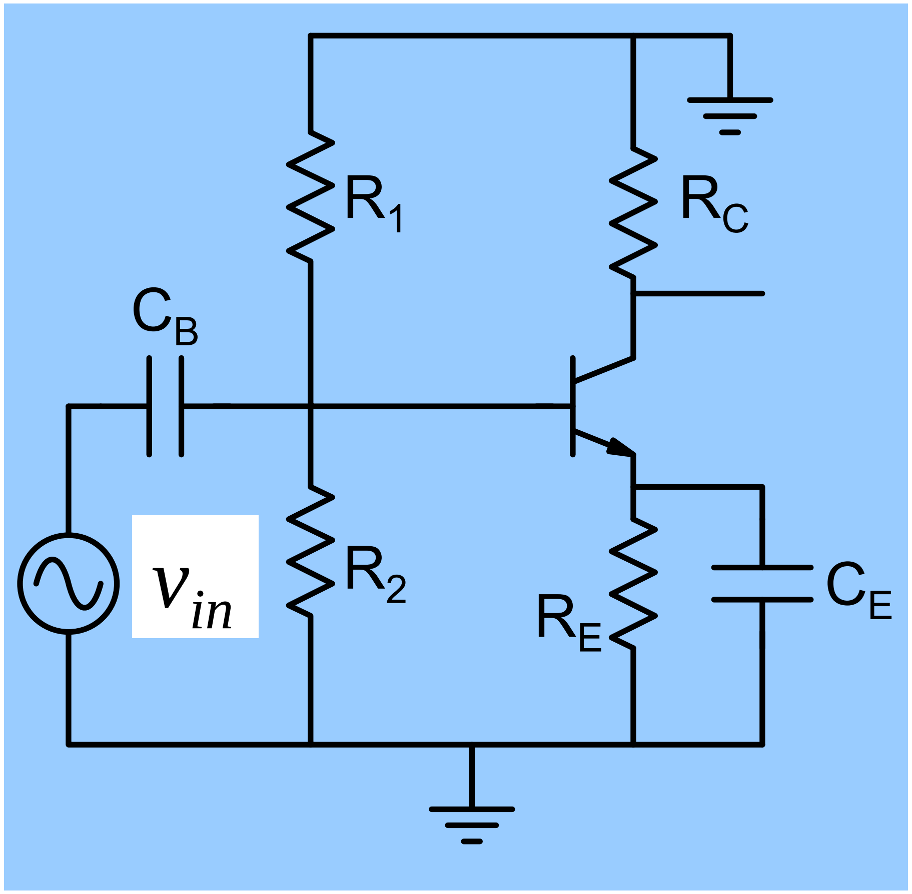
Step-1. Short dc voltage source and open circuit dc current source

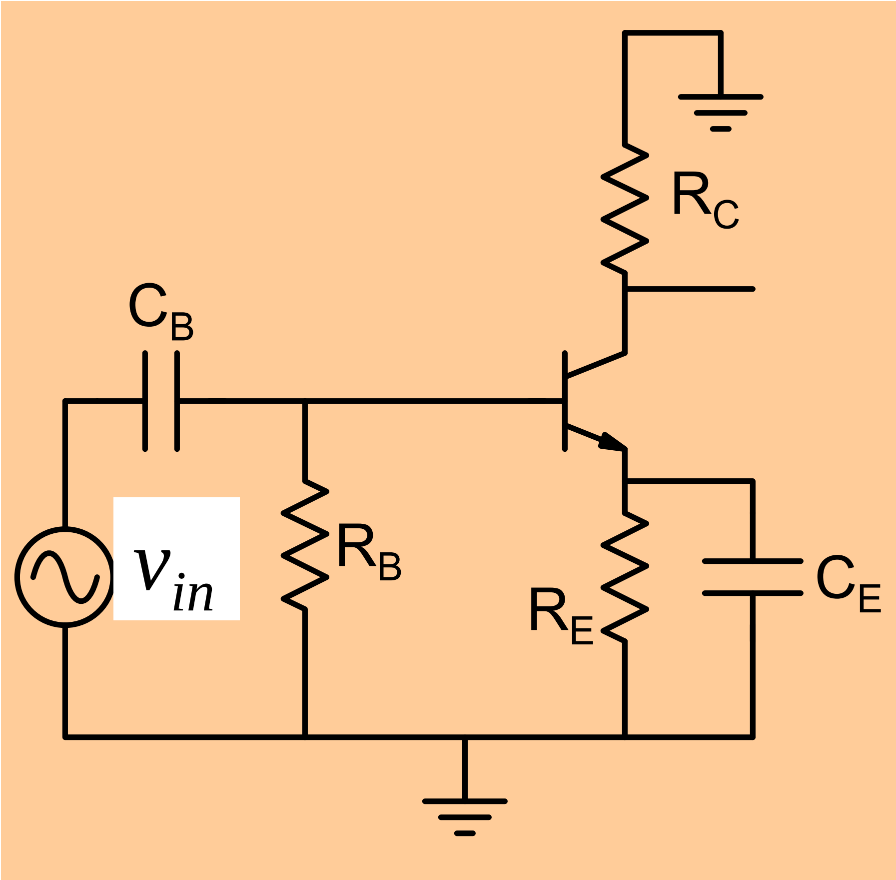




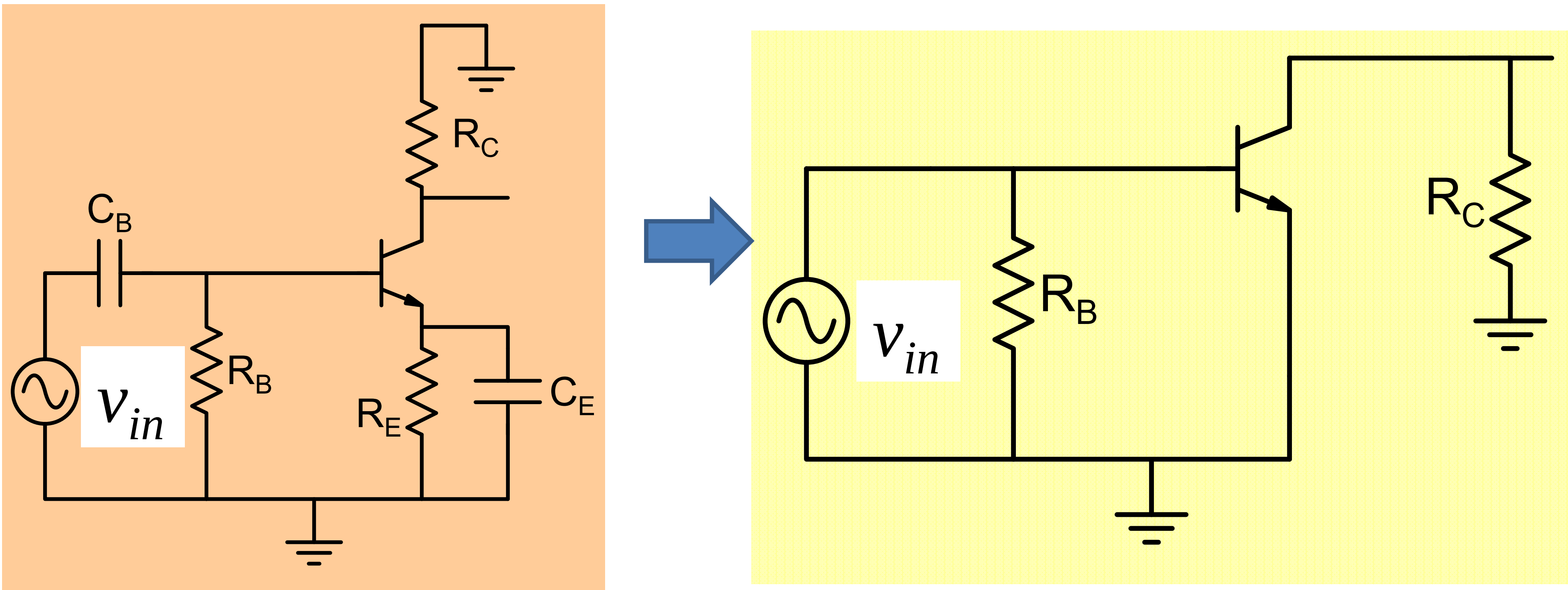
Small Signal Analysis

Step2- Redraw the circuit and Simplify

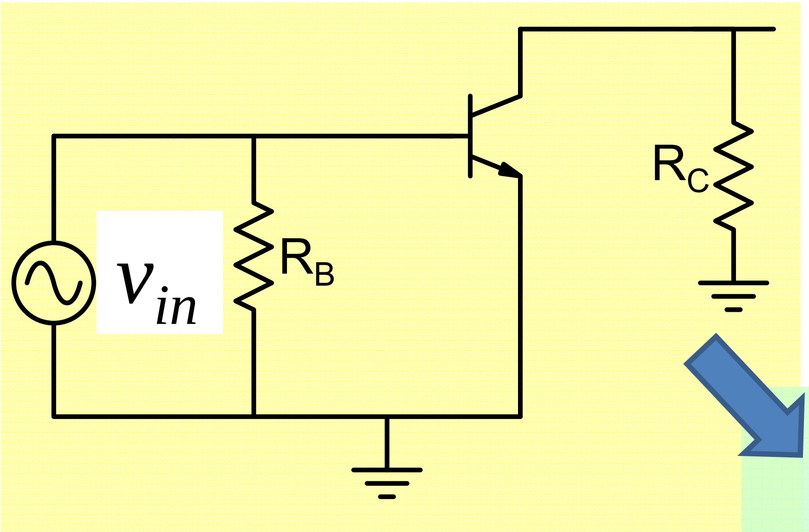




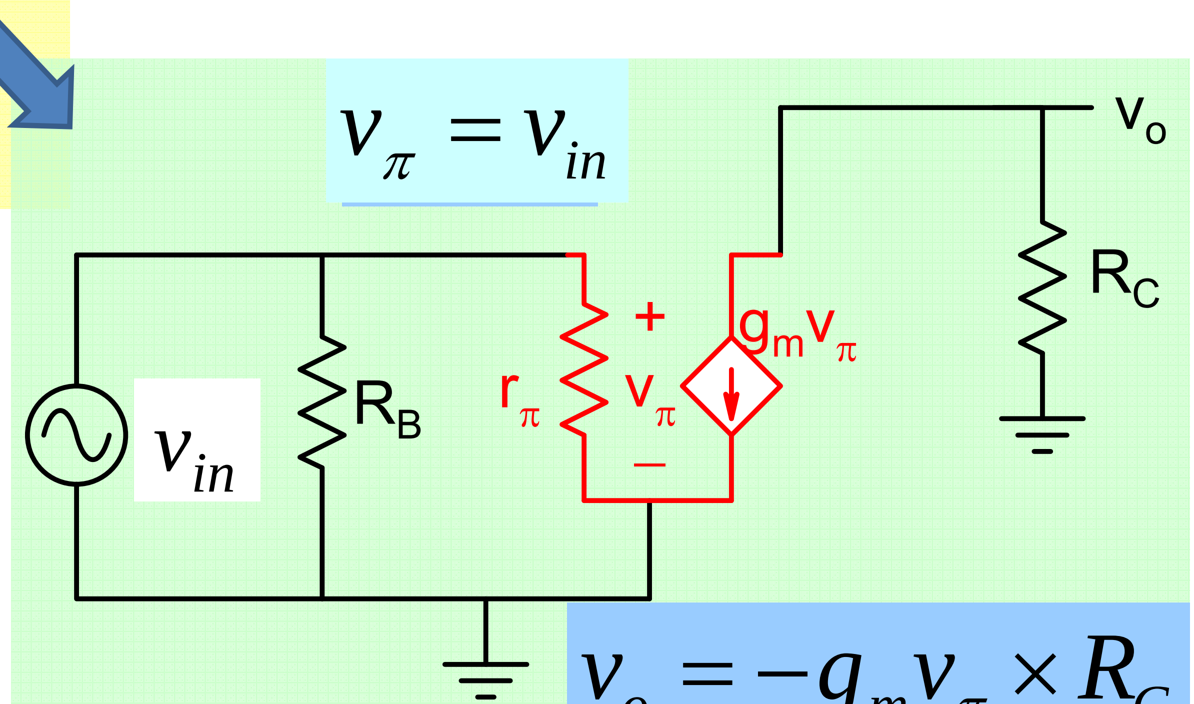
Step-3. For analysis at sufficiently high frequencies, the capacitors can be considered as short.



Step-4. The transistor is replaced by its hybrid-pi small signal mode



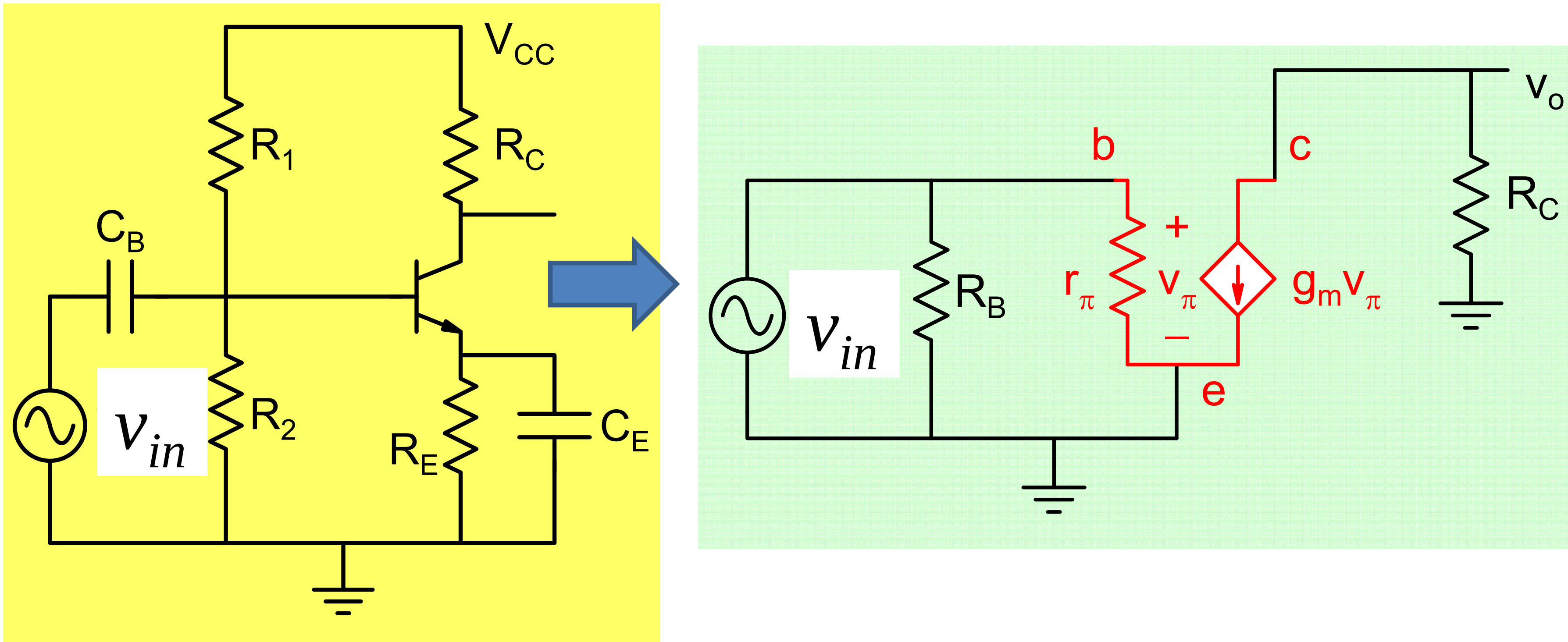
$$v_\pi = v_{in}$$



$$v_o = -g_m v_\pi \times R_C$$

$$A_v = \frac{v_0}{v_{in}} = -g_m R_C$$

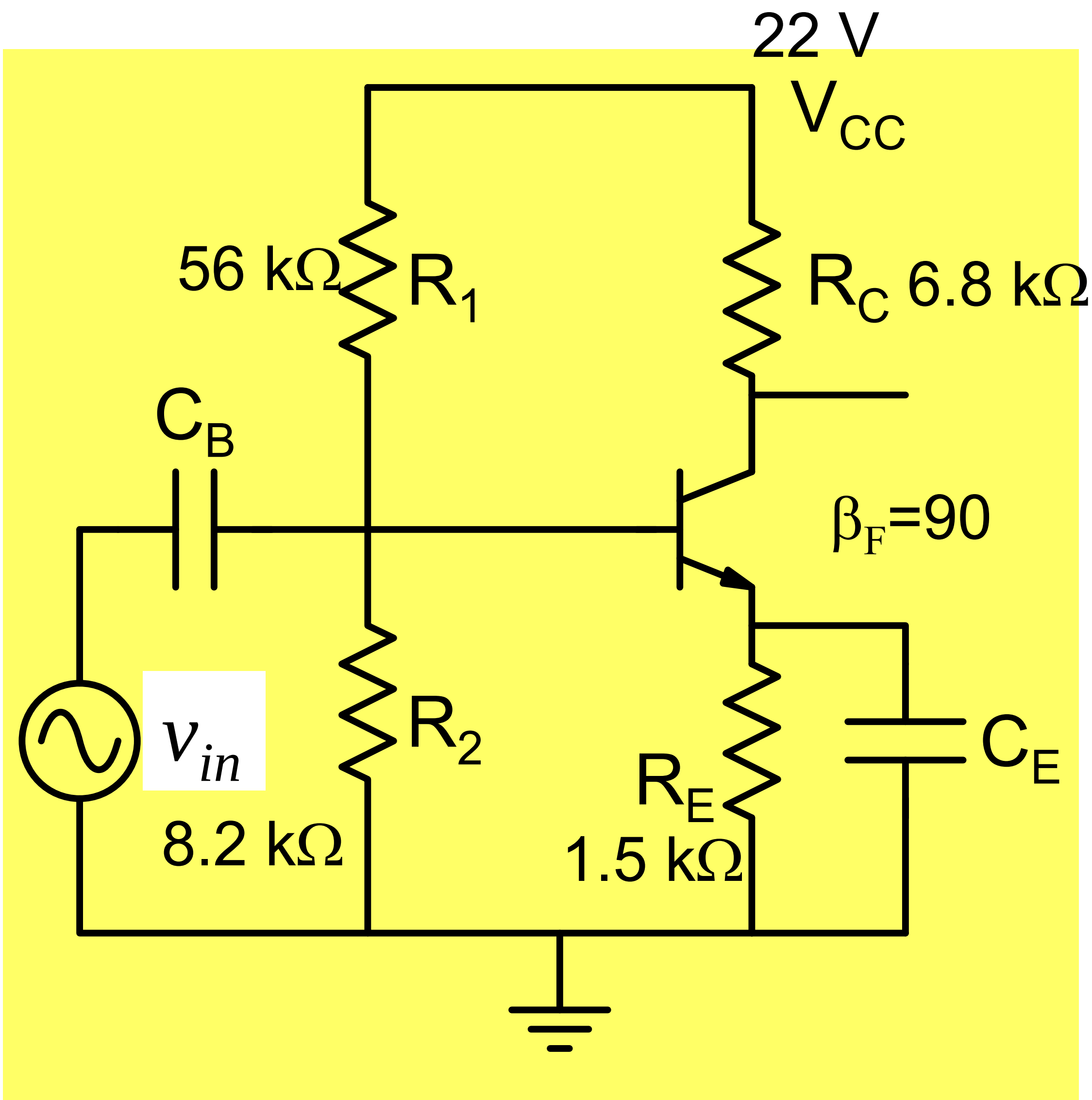
Common Emitter (CE) Amplifier



Emitter is the **common terminal** between input and output ports !

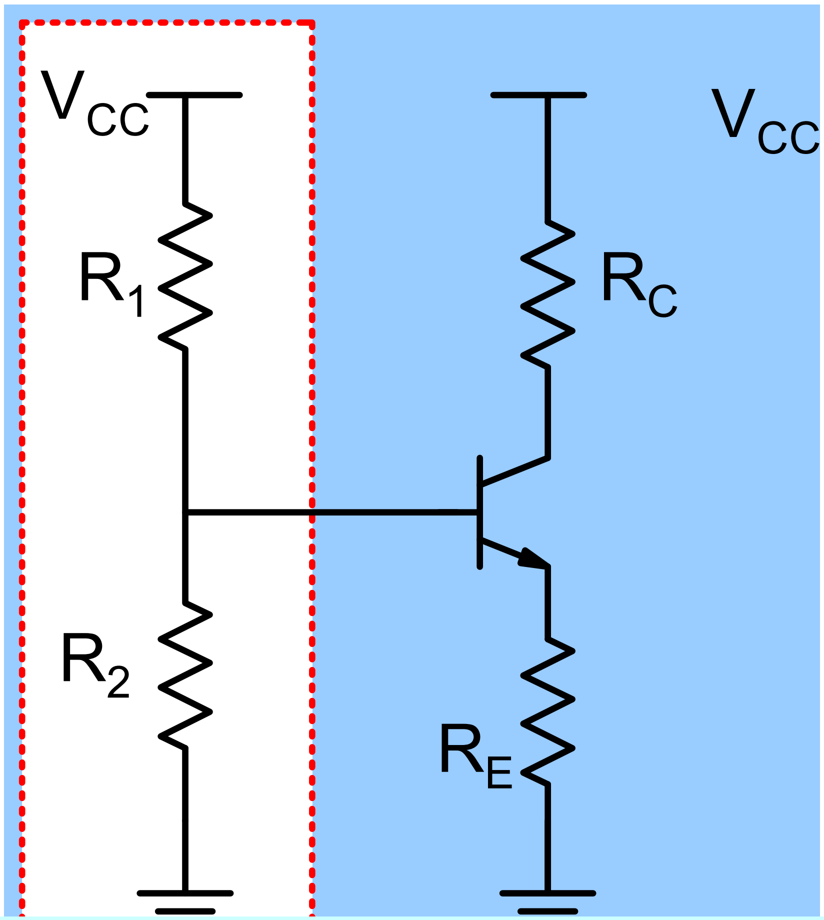
Common Emitter (CE) Amplifier

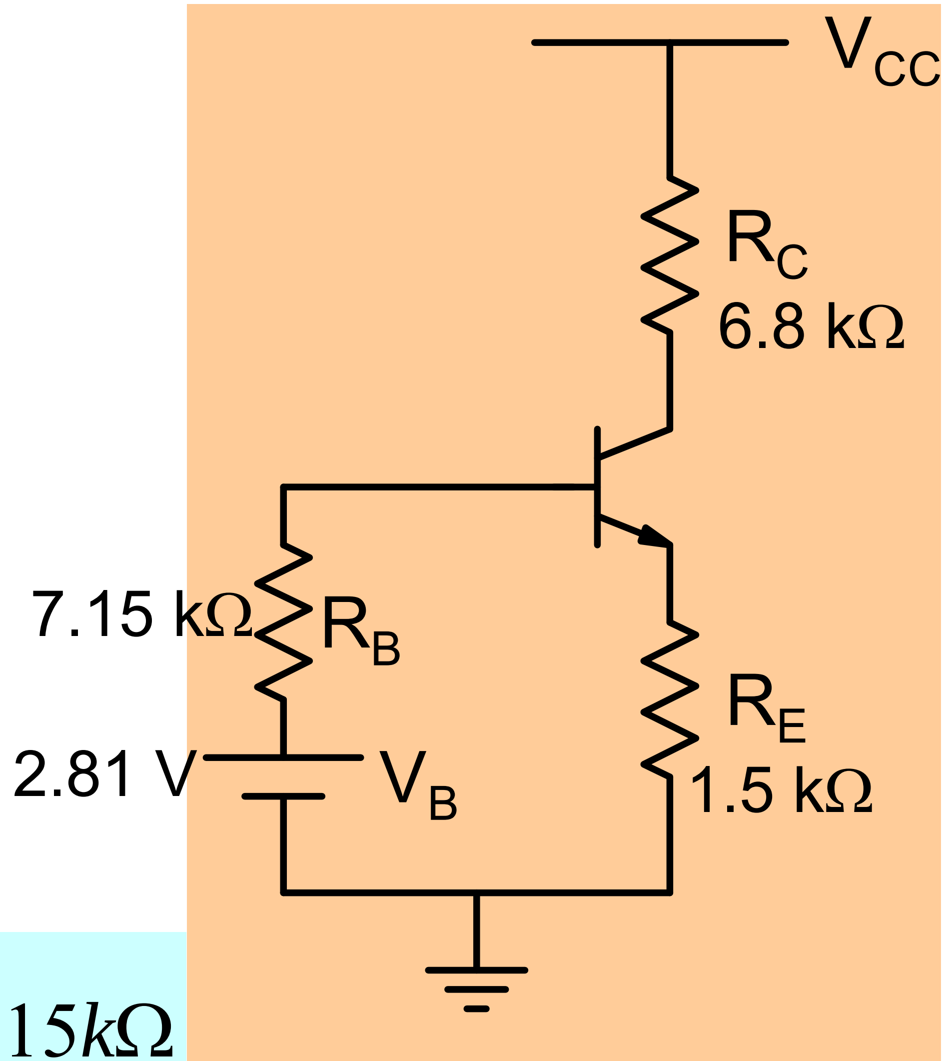
Example



DC Analysis

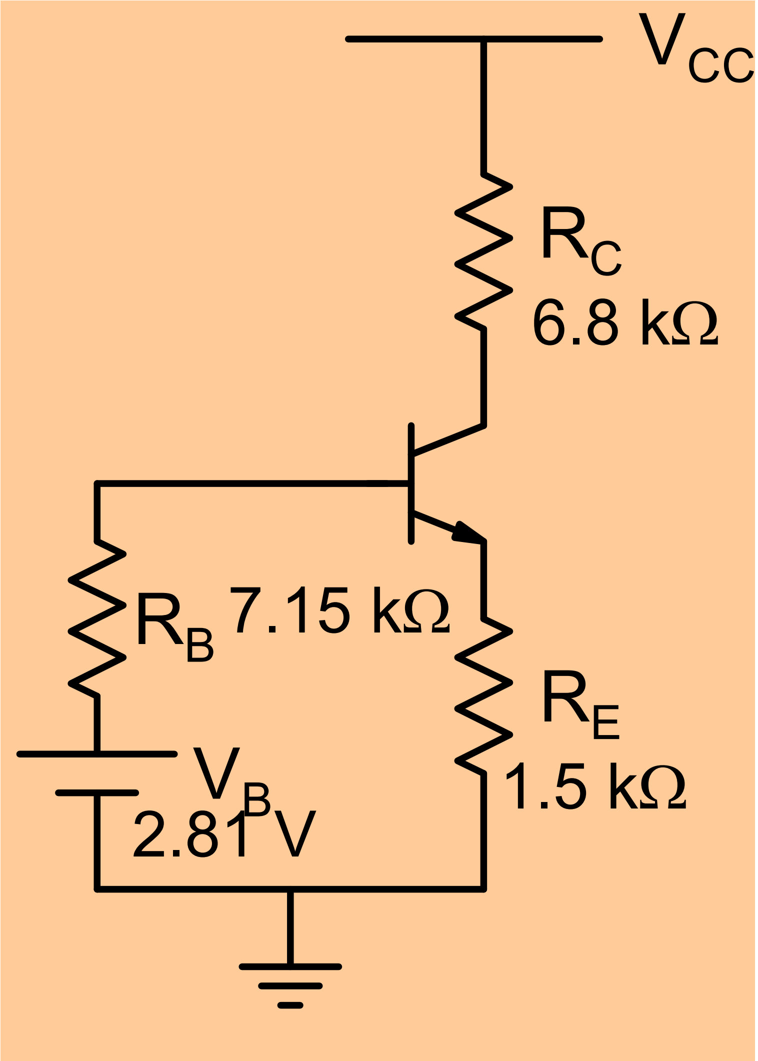
Apply Thevenin's theorem





$$R_B = R_1 \| R_2 = \frac{56k \times 8.2k}{56k + 8.2k} = 7.15k\Omega$$

$$V_B = V_{CC} \times \frac{R_2}{R_1 + R_2} = 22 \frac{8.2}{64.2} = 2.81V$$



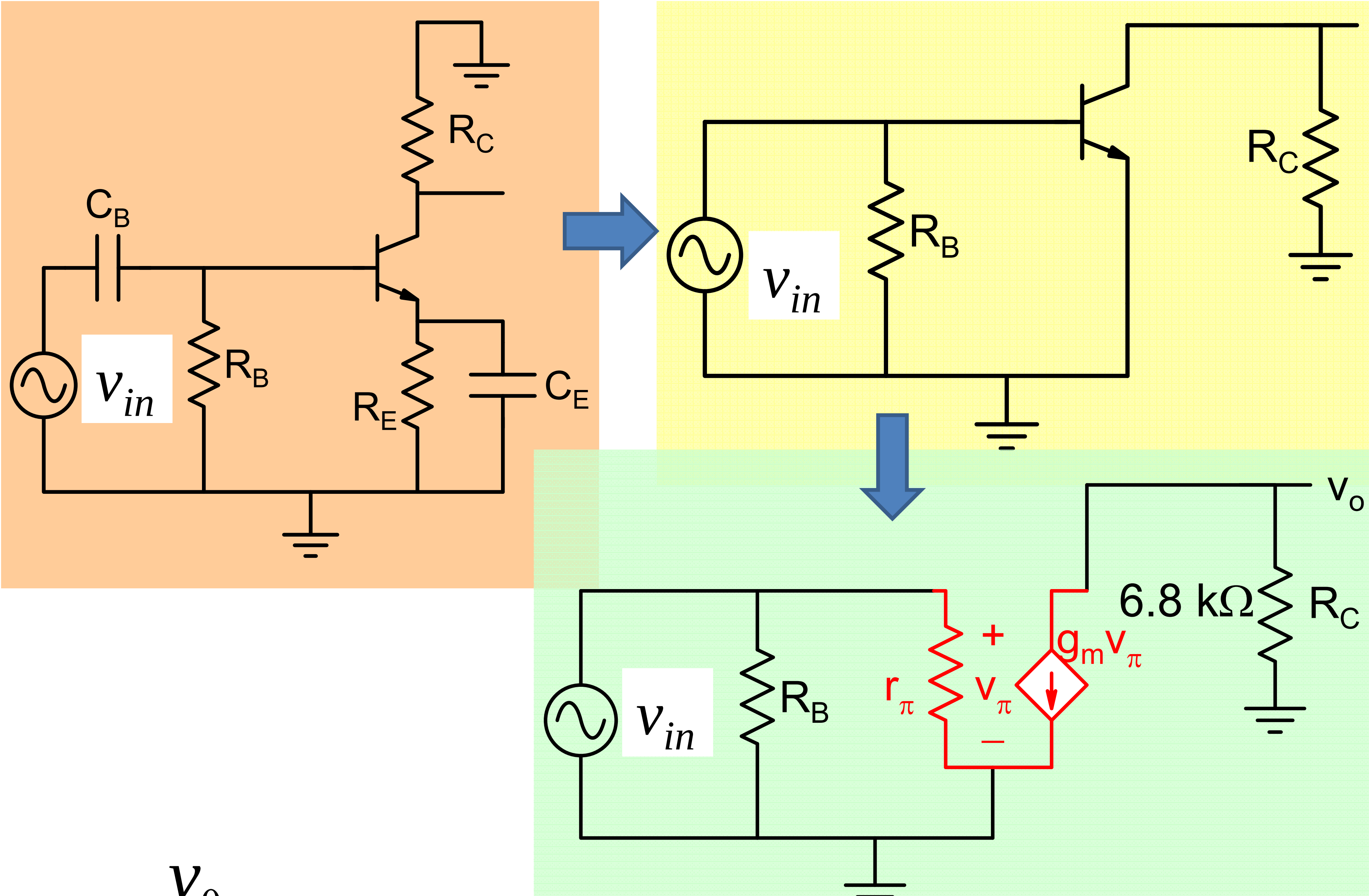
$$2.81 = I_{BQ}7.15k + 0.7 + I_{EQ}1.5k$$

$$I_{BQ} = \frac{I_{CQ}}{\beta_F};\ I_{EQ} = I_{CQ}(1+\frac{1}{\beta_F})$$

$$2.11 = I_{CQ}\frac{7.15k}{90} + I_{CQ}\left(1+\frac{1}{90}\right)1.5k$$

$$I_{CQ} = 1.32mA$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.32mA}{25mV} = 0.0528\ S$$



$$A_v = \frac{v_0}{v_{in}} = -g_m R_C = -0.0528 \times 6800 = -359$$