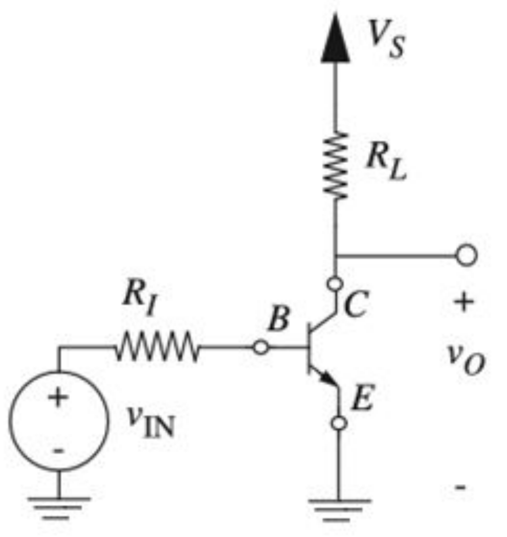
CSE251

BJT Common Emitter Amplifier
Summary & Examples

BJT Common Emitter Amplifier



Cut-off	$v_{IN} \leqslant 0.7v$	$v_O = V_S$
Saturation	$0.7 < v_{IN} < 0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I$	$v_O > 0.2v$
Active	$v_{IN} > 0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I$	$v_O = v_{CE} = 0.2v$

Amplification is done in **Active** mode

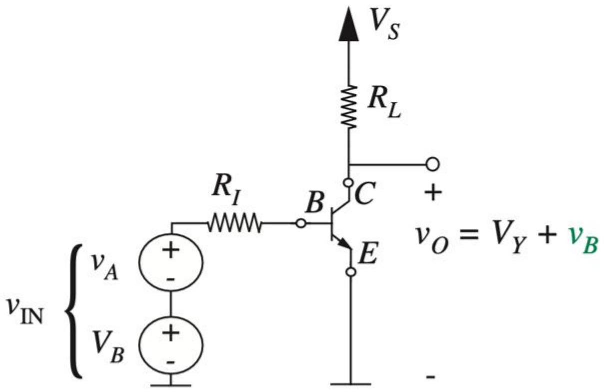
For Small Signal Amplification, Gain, $k = \frac{-\beta R_L}{R_I}$

KVL: $v_O = v_{CE}$

$\rightarrow v_O = V_S - I_C \times R_L$

(True for any mode)

BJT Common Emitter Amplifier

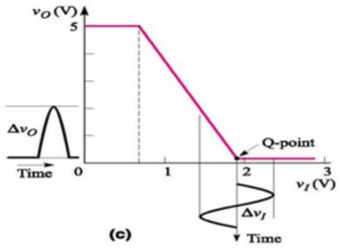


BJT Common Emitter Amplifier

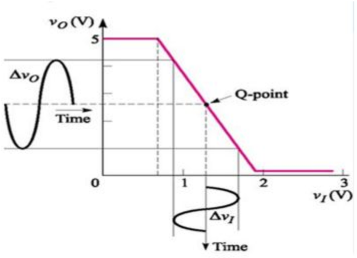
- Input small singnal v_A, output small singnal v_B. Both are AC signals
- $v_B = k \times v_A$, where the gain $k = -\frac{\beta R_L}{R_I}$
- (V_X, V_Y) is called the **Operating point** or **Bias point** or **Q-point**. Both DC Offset
- $V_Y = \left(V_S + \frac{0.7\beta R_L}{R_I}\right) - \frac{\beta R_L}{R_I} V_X$

Valid voltage range The range of input for which the BJT in the circuit operate in the Active region.

If not maintained, output might be distorted



Biased, but ***Valid voltage range*** not maintained



Biased, and ***Valid voltage range*** maintained

- Need to select Q-point or Bias point in such a way that input is within ***Valid voltage range***
- In this case, ***Valid voltage range:*** $0.7 < v_{IN} < 0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I$
- How to select Q-point? Best option: middle of active region, which will give maximum swing (peak-to-peak) for v_A

Example 1

Consider the BJT common emitter circuit with $\beta = 100, R_I = 100k\Omega, \mathrm{R_L} = 10k\Omega$, and $V_S = 10V$

We want to set bias the point in such a way that the DC portion of the input, i.e., $V_X = 1.2V$.

Under small signal approximation, if the input $v_{IN} = V_X + v_i(t)$, the output will be $v_O = V_Y + kv_i(t)$.

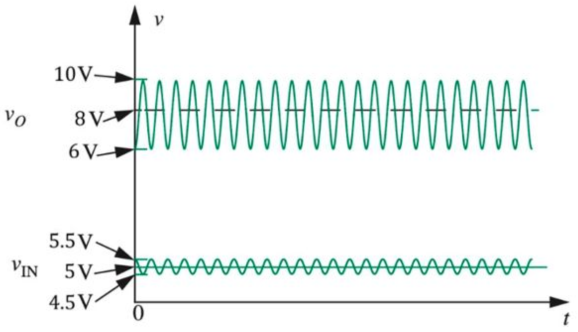
This means the output will be some DC value V_Y plus the amplified version of the small signal $v_i(t)$.

Here assume that $v_i = 0.1 \cos \omega t$.

- What is the value of DC part of the output, i.e., V_Y? $V_X = 1.2$, therefore $V_Y = \left(V_S + \frac{0.7\beta R_L}{R_I}\right) - \frac{\beta R_L}{R_I} V_X = 5$
- What will be the value of gain k under small signal approximation? $k = -\frac{\beta R_L}{R_I} = -10$
- What is amplitude (peak-to-peak) of the input small signal waveform $v_i(t)$?
  max = 0.1V, min = -0.1V. Therefore, peak-to-peak amplitude = 0.2V
- What is amplitude (peak-to-peak) of the output small signal waveform?
  Amplitude of output = $|k|$ ×Amplitude of input $\Rightarrow 10 \times 0.2 = 2V$

Example 2

The input voltage of a common source amplifier is given as $v_{IN} = V_X + v_i(t)$ and the output voltage is given $v_O = V_Y + kv_i(t)$. Here, $v_i(t)$ is a sinusoidal voltage with amplitude a, V_X is the input DC offset voltage, V_Y is the output DC offset voltage. The input and output waveforms are given below. Notice the output small signal is inverted compared to input small signal. Hence, the small signal gain "k" will be negative.



- What is the amplitude of the input small signal $vi(t)$? 0.5 V
- What is the amplitude of the output small signal? 2 V
- Hence, what is the small signal gain k? $k = -\frac{2}{0.5} = -4$
- From the above graph, what is the value of input DC voltage V_X and the output DC voltage V_Y? $V_X = 5, V_Y = 8$
- Design the circuit, i.e., find the value of V_S, R_I, and R_L to achieve given input-output voltage relation. Given $\beta = 100$.

$$k = -4 = -\frac{\beta R_L}{R_I} \Rightarrow \frac{\beta R_L}{R_I} = 4 \Rightarrow R_L = 0.04R_I$$

Let $R_I = 100k\Omega \Rightarrow R_L = 4k\Omega$

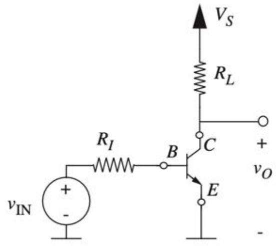
$$V_Y = \left(V_S + \frac{0.7\beta R_L}{R_I}\right) - \frac{\beta R_L}{R_I}V_X \Rightarrow 8 = (V_S + 0.7 \times 4) - 4 \times 5$$

$$\Rightarrow V_S = 8 + 20 - 2.8 = 25.2\ V$$

Example 3

Choose an operating point for the amplifier below to maximize the input voltage swing.

Here $R_I = 100\ k\Omega, R_L = 10\ k\Omega, \beta = 100, V_S = 10\ V$



Solution: BJT will be active for the ***valid input range:*** $0.7 < v_{IN} < 0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I$

Here, $0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I = 0.7 + \left(\frac{10 - 0.2}{100 \times 10}\right) = 0.7 + 0.98 = 1.68\ \text{V}$

Therefore, ***valid input range:*** $0.7V < v_{IN} < 1.68\ V$

For maximum input swing, V_X should be midway between the ***valid input range***

Hence, $V_X = \frac{0.7 + 1.68}{2} = 1.19\ V$

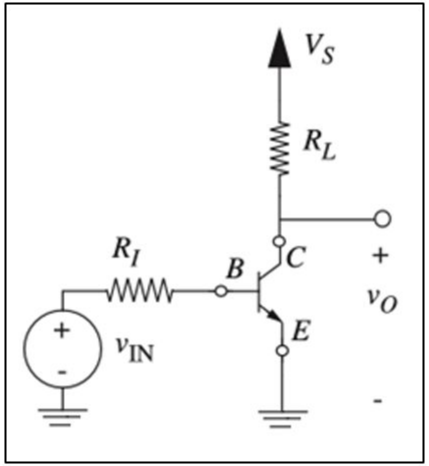
Therefore, $V_Y = \left(V_S + \frac{0.7\beta R_L}{R_I}\right) - \frac{\beta R_L}{R_I} V_X = \left(10 + \frac{0.7 \times 100 \times 10}{100}\right) - \frac{100 \times 10}{100} \times 1.19 = 5.1$

Therefore, maximum peak-to-peak input swing $= (1.19 - 0.7) = (1.68 - 1.19) = \mathbf{0.49\ V}$

Note: $V_Y = 5.1$ is midway between the ***valid output range:*** $0.2 \leq v_o < 10$

Example 4

Consider the BJT common emitter circuit with, $\beta = 100, \quad R_I = 85\ \mathrm{k\Omega}, V_S = 15\mathrm{v}, V_X = 1.3\ v$
The amplifier's operating point is set in such a way that it maximizes the input voltage swing. Find **R_L**



Solution

BJT will be active for the ***valid input range:*** $0.7 < v_{IN} < 0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I$

For maximum input swing, V_X should be midway between the ***valid input range***

Let, $v_{IN,max} = 0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I$

So, $V_X = \frac{0.7 + v_{IN,max}}{2} = 1.3\ v \ \text{---}\!\!\rightarrow v_{IN,max} = 1.9\ v$

So, $0.7 + \left(\frac{V_S - 0.2}{\beta R_L}\right) R_I = 1.9$

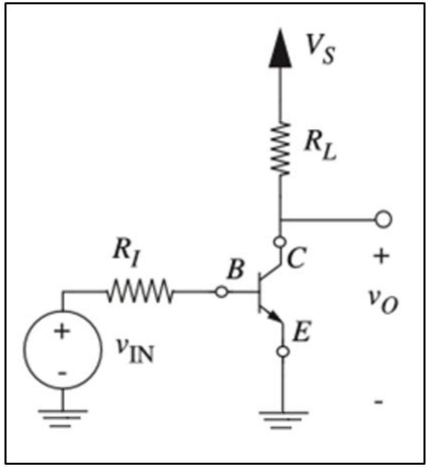
$-\!\!\rightarrow 0.7 + \left(\frac{15 - 0.2}{100 * R_L}\right) * 85 * 10^3 = 1.9$

$-\!\!\rightarrow R_L = 10.483\ \mathrm{k\Omega}$

Example 5

Consider the BJT common emitter circuit with $\beta = 105, R_I = 95k\Omega, \mathrm{R_L} = 12k\Omega, V_S = 12V,\ V_X = 1.1V$.

$v_i = 0.12 \cos \omega t$.



(1) What is the value of DC part of the output, i.e. V_Y?

(2) What will be the value of gain k under small signal approximation?

(3) What is amplitude (peak-to-peak) of the input small signal waveform $v_i(t)$?

(4) What is amplitude (peak-to-peak) of the output small signal waveform?

Do it yourself

Answer

(1) 6.6947 v

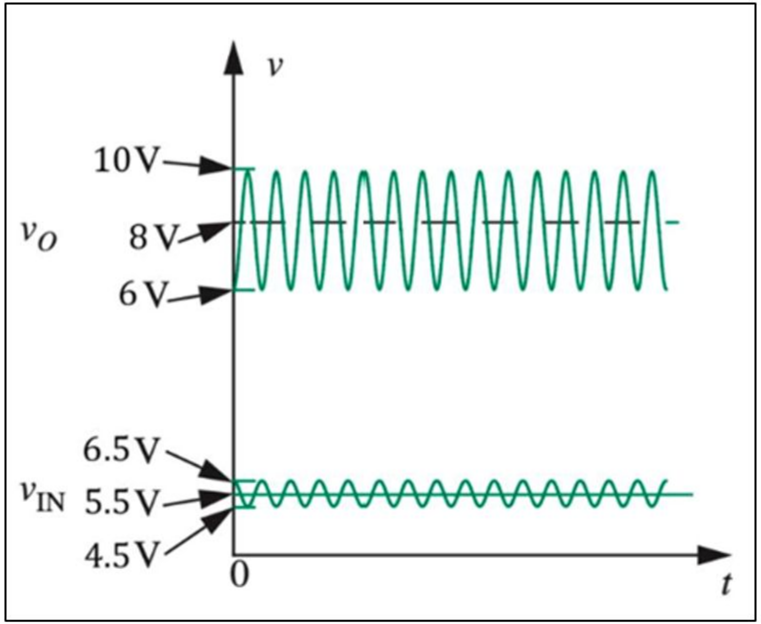
(2) -13.263

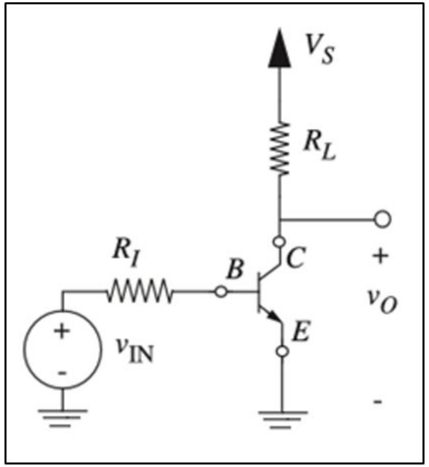
(3) 0.24 v

(4) 3.18312 v

Example 6

(1) What is the amplitude of the input small signal $v_{IN}(t)$?
(2) What is the amplitude of the output small signal?
(3) What is the small signal gain k?
(4) From the above graph, what is the value of input DC voltage V_X and the output DC voltage V_Y?
(5) Design the circuit, i.e., find the value of V_S, R_I, and R_L to achieve given input-output voltage relation. Given $\beta = 120$.





Do it yourself

<u>Answer</u>
(1) 1 v
(2) 2 v
(3) k = -2
(4) V_X = 5.5 v, V_Y = 8 v
(5) R_I = 100 kΩ, R_L = 1.67 kΩ, V_S = 17.6192 v