Bipolar Junction Transistor Circuits

Voltage and Power Amplifier Circuits

Common Emitter Amplifier

The circuit shown on Figure 1 is called the common emitter amplifier circuit. The important subsystems of this circuit are:

1. The biasing resistor network made up of resistor R_1 and R_2 and the voltage supply V_{CC}.
2. The coupling capacitor C_1.
3. The balance of the circuit with the transistor and collector and emitter resistors.

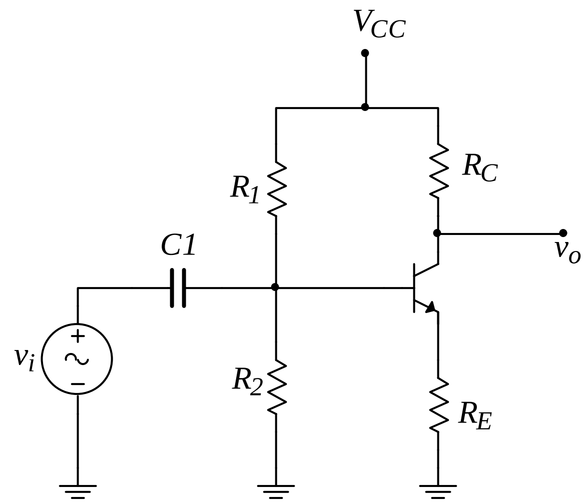

Figure 1. Common Emitter Amplifier Circuit

The common emitter amplifier circuit is the most often used transistor amplifier configuration.

The procedure to follow for the analysis of any amplifier circuit is as follows:

1. Perform the DC analysis and determine the conditions for the desired operating point (the Q-point)

2. Develop the AC analysis of the circuit. Obtain the voltage gain

DC Circuit Analysis

The biasing network (R_1 and R_2) provides the Q-point of the circuit. The DC equivalent circuit is shown on Figure 2.

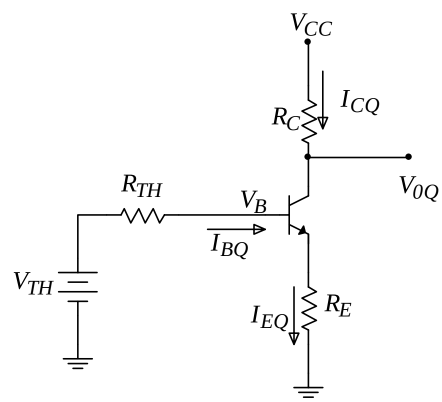

Figure 2. DC equivalent circuit for the common emitter amplifier.

The parameters I_{CQ}, I_{BQ}, I_{EQ} and V_{OQ} correspond to the values at the DC operating point-the Q-point

We may further simplify the circuit representation by considering the BJT model under DC conditions. This is shown on Figure 3. We are assuming that the BJT is properly biased and it is operating in the forward active region. The voltage $V_{BE(on)}$ corresponds to the forward drop of the diode junction, the 0.7 volts.

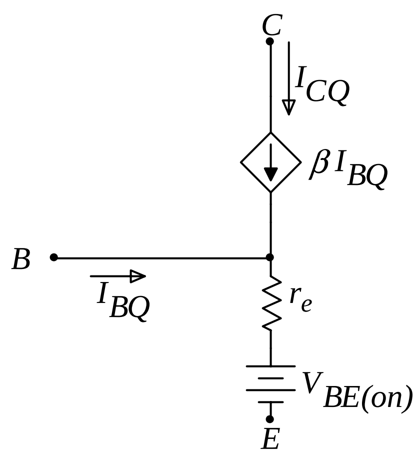

Figure 3. DC model of an npn BJT

For the B-E junction we are using the offset model shown on Figure 4. The resistance r_e is equal to

$$r_e = \frac{V_T}{I_E} \tag{1.1}$$

Where V_T is the thermal voltage, $V_T \equiv \frac{kT}{q}$, which at room temperature is $V_T = 26\text{ mV}$. r_e is in general a small resistance in the range of a few Ohms.

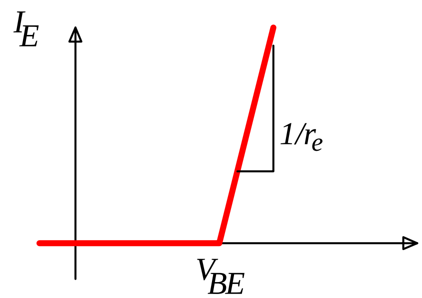

Figure 4

By incorporating the BJT DC model (Figure 3) the DC equivalent circuit of the common emitter amplifier becomes

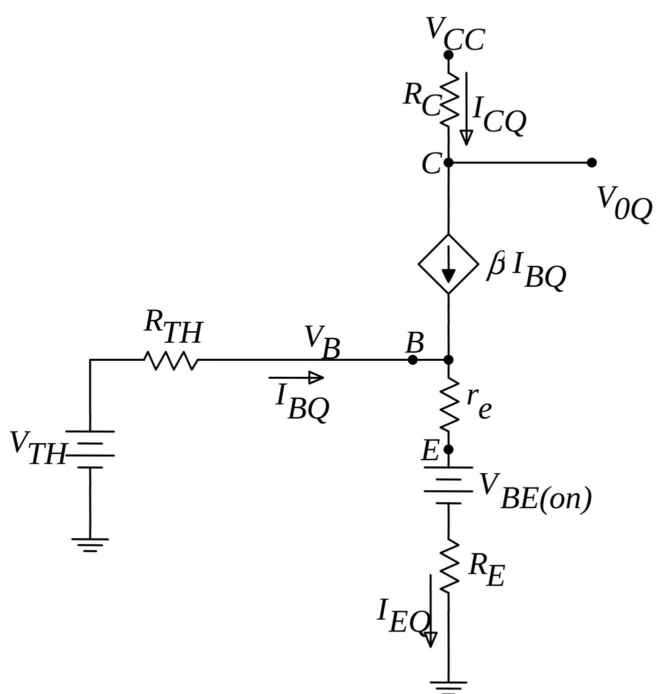

Figure 5

Recall that the transistor operates in the active (linear) region and the Q-point is determined by applying KVL to the B-E and C-E loops. The resulting expressions are:

$$\text{B-E Loop:} \Rightarrow \quad V_{TH} = I_{BQ} R_{TH} + V_{BE(on)} + I_{EQ} R_E \tag{1.2}$$

$$\text{C-E Loop:} \Rightarrow \quad V_{CEQ} = V_{CC} - I_{CQ} R_C - I_{EQ} R_E \tag{1.3}$$

Equations (1.2) and (1.3) define the Q-point

<u>AC Circuit Analysis</u>

If a small signal *vi* is superimposed on the input of the circuit the output signal is now a superposition of the Q-point and the signal due to *vi* as shown on Figure 6.

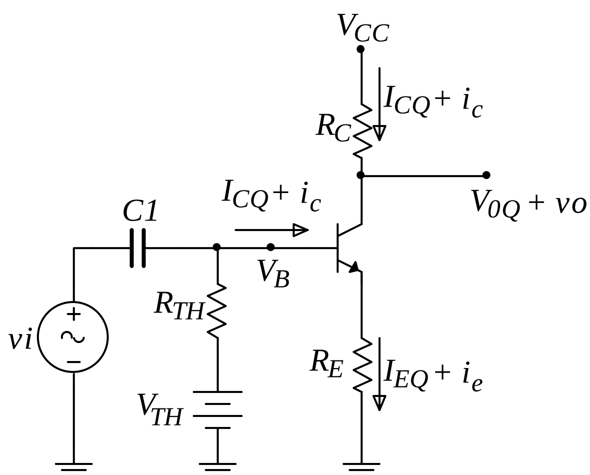

Figure 6

Using superposition, the voltage V_B is found by:

1. Set $V_{TH} = 0$ and calculate the contribution due to *vi* (V_{B1}). In this case the capacitor *C1* along with resistor R_{TH} form a high pass filter and for a very high value of *C1* the filter will pass all values of *vi* and $V_{B1} = vi$

2. Set *vi=0* and calculate the contribution due to V_{TH} (V_{B2}). In this case the $V_{B2} = V_{TH}$

And therefore superposition gives

$$V_B = vi + V_{TH} \tag{1.4}$$

The AC equivalent circuit may now be obtained by setting all DC voltage sources to zero. The resulting circuit is shown on Figure 7 (a) and (b). Next by considering the AC model of the BJT (Figure 8), the AC equivalent circuit of the common emitter amplifier is shown on Figure 9.

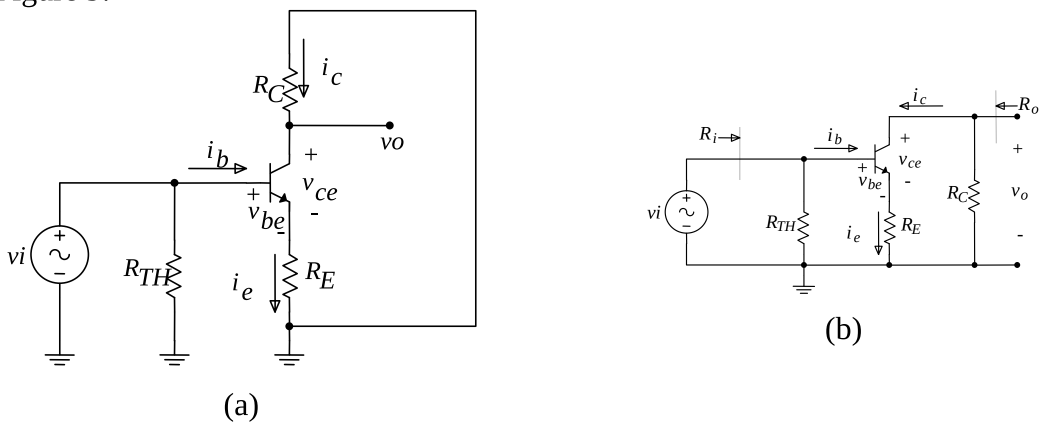

Figure 7. AC equivalent circuit of common emitter amplifier

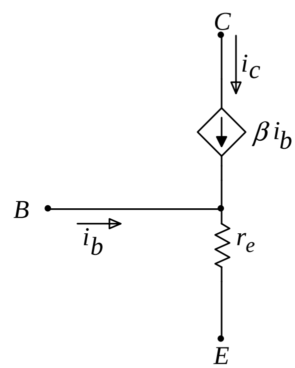

Figure 8. AC model of a npn BJT (the T model)

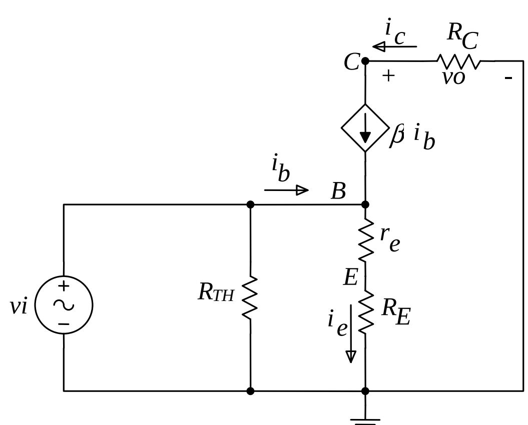

Figure 9. AC equivalent circuit model of common emitter amplifier using the npn BJT AC model

The gain of the amplifier of the circuit on Figure 9 is

$$A_v = \frac{vo}{vi} = \frac{-i_c R_C}{i_e (r_e + R_E)} = \frac{-\beta i_b R_C}{(1+\beta) i_b (r_e + R_E)} = -\frac{\beta}{\beta+1} \frac{R_C}{r_e + R_E} \tag{1.5}$$

For $\beta >> 1$ and $r_e << R_E$ the gain reduces to

$$A_v \cong -\frac{R_C}{R_E} \tag{1.6}$$

Let's now consider the effect of removing the emitter resistor R_E. First we see that the gain will dramatically increase since in general r_e is small (a few Ohms). This might appear to be advantageous until we realize the importance of R_E in generating a stable Q-point. By eliminating R_E the Q-point is dependent solely on the small resistance r_e which fluctuates with temperature resulting in an imprecise DC operating point. It is possible with a simple circuit modification to address both of these issues: increase the AC gain of the amplifier by eliminating R_E in AC and stabilize the Q-point by incorporating R_E when under DC conditions. This solution is implemented by adding capacitor *C2* as shown on the circuit of Figure 10. Capacitor *C2* is called a bypass capacitor.

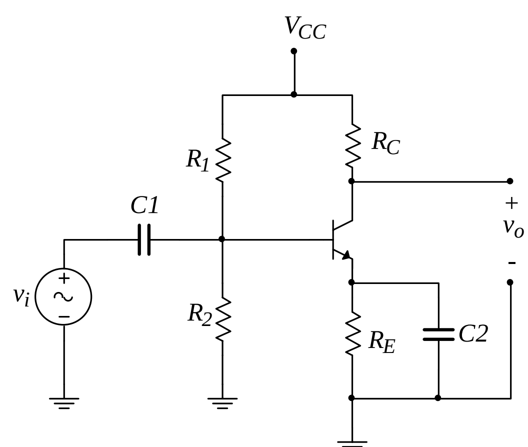

Figure 10. Common-emitter amplifier with bypass capacitor C2

Under DC conditions, capacitor *C2* acts as an open circuit and thus it does not affect the DC analysis and behavior of the circuit. Under AC conditions and for large values of *C2*, its effective resistance to AC signals is negligible and thus it presents a short to ground. This condition implies that the impedance magnitude of *C2* is much less than the resistance r_e for all frequencies of interest.

$$\frac{1}{\omega C2} << r_e \tag{1.7}$$

Input Impedance

Besides the gain, the input, R_i, and the output, R_o, impedance seen by the source and the load respectively are the other two important parameters characterizing an amplifier. The general two port amplifier model is shown on Figure 11.

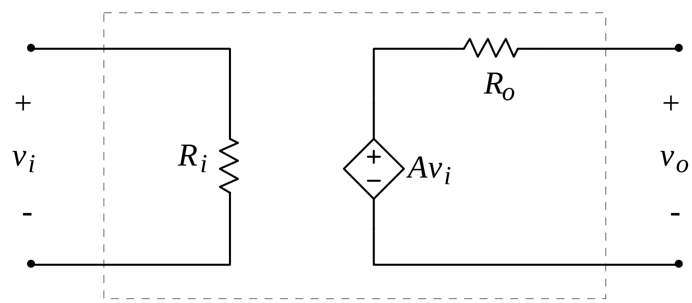

Figure 11. General two port model of an amplifier

For the common emitter amplifier the input impedance is calculated by calculating the ratio

$$R_i = \frac{v_i}{i_i} \tag{1.8}$$

Where the relevant parameters are shown on Figure 12 .

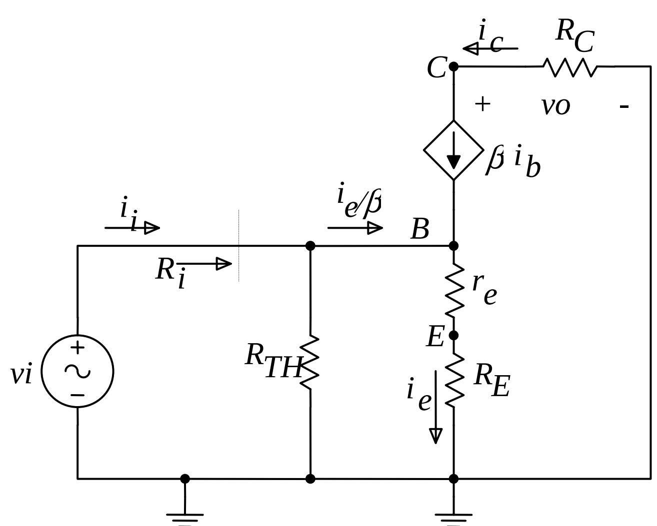

Figure 12

The input resistance is given by the parallel combination of R_{TH} and the resistance seen at the base of the BJT which is equal to $(1+\beta)(r_e + R_E)$

$$R_i = R_{TH} // (1+\beta)(r_e + R_E) \tag{1.9}$$

Output Impedance

It is trivial to see that the output impedance of the amplifier is

$$R_o = R_C \tag{1.10}$$

Common Collector Amplifier: (Emitter Follower)

The common collector amplifier circuit is shown on Figure 13. Here the output is taken at the emitter node and it is measured between it and ground.

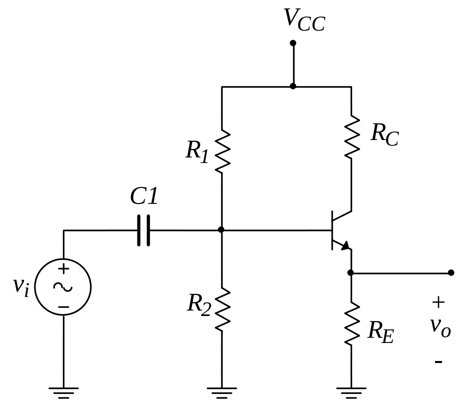

Figure 13. Emitter Follower amplifier circuit

Everything in this circuit is the same as the one we used in the analysis of the common emitter amplifier (Figure 1) except that in this case the output is sampled at the emitter.

The DC Q-point analysis is the same as developed for the common emitter configuration.

The AC model is shown on Figure 14. The output voltage is given by

$$v_o = v_i \frac{R_E}{R_E + r_e} \tag{1.11}$$

And the gain becomes

$$A_v = \frac{v_o}{v_i} = \frac{R_E}{R_E + r_e} \cong 1 \tag{1.12}$$

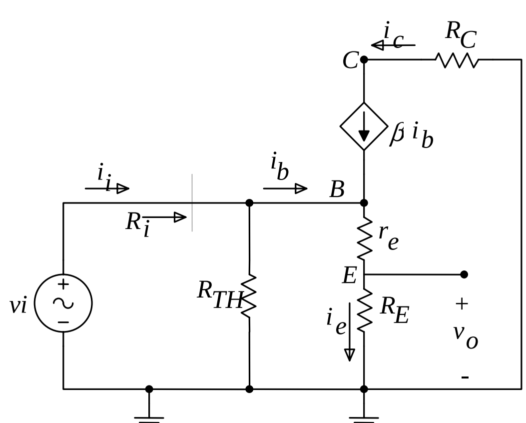

Figure 14

The importance of this configuration is not the trivial voltage gain result obtained above but rather the input impedance characteristics of the device.

The impedance looking at the base of the transistor is

$$R_{ib} = (1+\beta)(r_e + R_E) \quad (1.13)$$

And the input impedance seen by the source is again the parallel combination of R_{TH} and R_{ib}

$$R_i = R_{TH} // (1+\beta)(r_e + R_E) \quad (1.14)$$

The output impedance may also be calculated by considering the circuit shown on Figure 15.

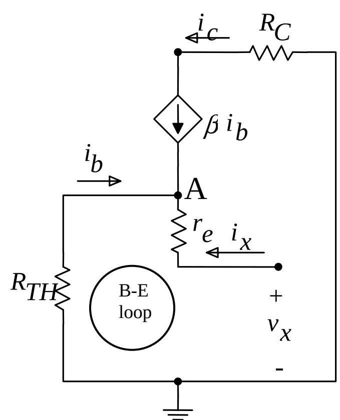

Figure 15

We have simplified the analysis by removing the emitter resistor R_E in the circuit of Figure 15. So first we will calculate the impedance R_x seen by R_E and then the total output resistance will be the parallel combination of R_E and R_x.
R_x is given by

$$R_x = \frac{v_x}{i_x} \quad (1.15)$$

KCL at the node *A* gives

$$i_x = -i_b(1+\beta) \quad (1.16)$$

And KVL around the B-E loop gives

$$i_b R_{TH} - i_x r_e + v_x = 0 \quad (1.17)$$

And by combining Equations (1.15), (1.16) and (1.17) R_x becomes

$$R_x = \frac{v_x}{i_x} = r_e + \frac{R_{TH}}{\beta + 1} \tag{1.18}$$

The total output impedance seen across resistor R_E is

$$R_o = R_{TH} // \left(r_e + \frac{R_{TH}}{\beta + 1} \right) \tag{1.19}$$