Sample Problem from Chapter 10

Consider the small-signal amplifier shown in Figure 1. Assume V_{CC} = 24 V, R_S = 1.5 kΩ, R_1 = 8.6 kΩ, R_2 = 200 kΩ, R_C = 5 kΩ, R_L = 2 kΩ, β = 75, and π = 750 Ω.

- Draw the DC bias circuit and prove that the BJT operates in the active region.
- Draw the small-signal equivalent circuit and find the voltage gain of the amplifier.

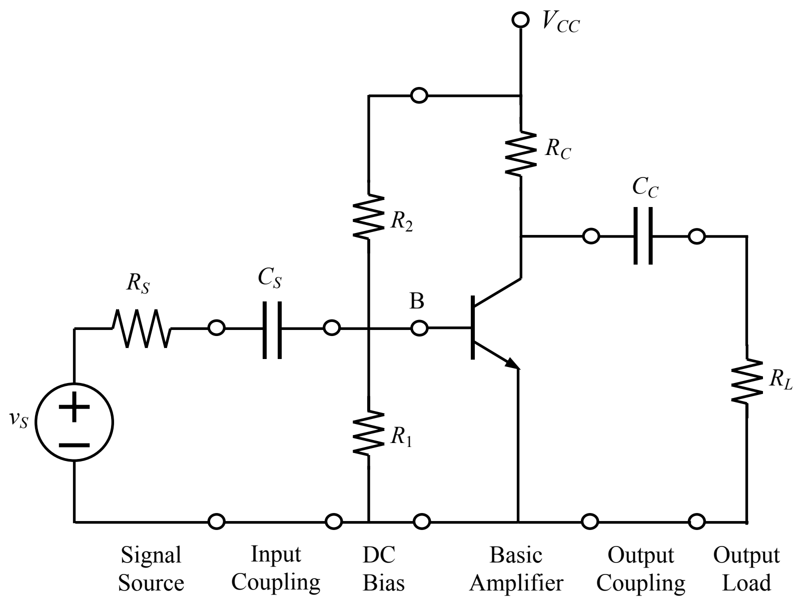

Figure 1 A stage of an amplifier circuit.

Solution: A DC current is supplied to the BJT base by the voltage divider R_1 and R_2. The coupling capacitors act as blocks to the DC current; therefore the equivalent circuit at DC is as shown in Figure 2 (a). Although, practically there is one power supply, the V_{CC} symbol can be replaced with two voltage sources. The circuit in Figure 2 (a) can further be reduced to the circuit shown in Figure 2 (b) by converting the voltage divider to a Thevenin equivalent circuit (Thevenin theorem can be found in your textbook: pp. 102-109). The symbol V_{BB} is used for the open-circuit voltage at the base of the BJT.

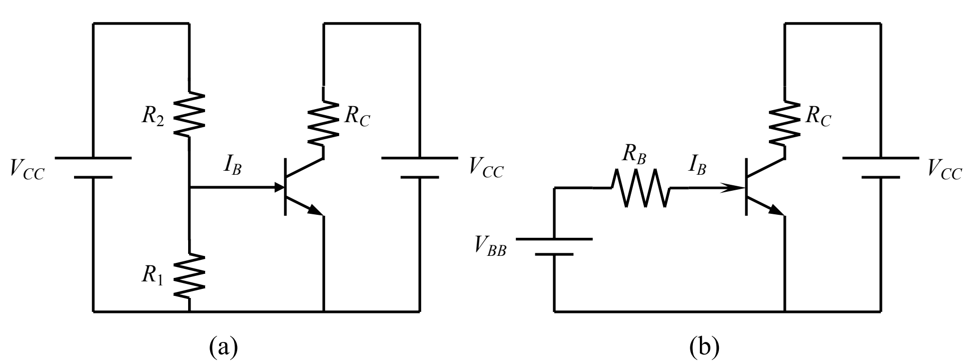

Figure 2 (a) DC bias circuit. (b) Equivalent of the input portion.

Step One: The DC analysis

The open-circuit base DC bias voltage is

$$V_{BB} = 24 \times \frac{8.6}{8.6 + 200} = 0.99 \text{ V}$$

The DC output impedance of the bias network is

$$R_B = 8.6//200 = 8.25 \text{ k}\Omega$$

A silicon transistor requires a threshold voltage of V_{BE} = 0.7 V to turn ON the base-emitter junction, therefore

$$I_\text{B} = \frac{V_{BB} - 0.7}{R_B} = \frac{0.99 - 0.7}{8.25 \text{ k}\Omega} = 35.1\ \mu\text{A}$$

$$I_C = \beta I_\text{B} = 75 \times 35.1 \times 10^{-6} = 2.63 \text{ mA}$$

Now consider the closed loop path in the output circuit of the amplifier and apply KVL in order to find the collector-emitter voltage V_{CE}.

$$-V_{CC} + I_C R_C + V_{CE} = 0$$

$$V_{CE} = 24 - 5 \times 2.63 = 10.8 \text{ V}$$

Therefore, the BJT is operating in the active region.

Step Two: AC Analysis
All capacitors are replaced by short circuit. The voltage source v_S and its internal resistance R_S are replaced by a current source (v_S/R_S) according to Source Transformation theorem (see page 112 of the textbook)

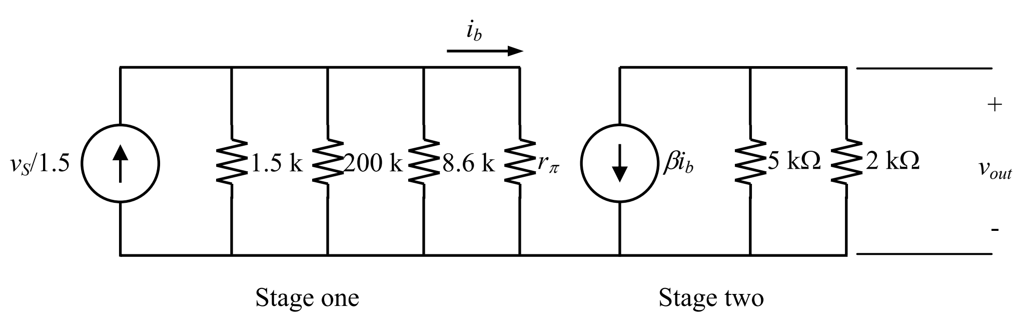

Figure 3: Small-signal circuit of the BJT amplifier.

Consider the circuit in stage one, first.

- Let us find the equivalent resistance of the four resistors: 1.5, 200, 8.6, and 0.75

$$\frac{1}{R_T} = \frac{1}{1.5} + \frac{1}{200} + \frac{1}{8.6} + \frac{1}{0.75}$$
$$R_T = 0.472\ \text{k}\Omega$$

Stage one circuit will turn into the following circuit

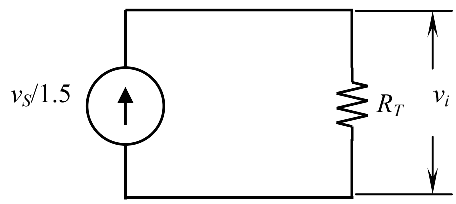

Figure 4: Equivalent circuit of stage-one circuit.

$$v_i = \frac{v_S}{1.5} \times R_T = 0.314\, v_S$$

This value of v_i is same across each element in the circuit of Figure 3. Now, apply ohm's law to find i_b

$$i_b = \frac{v_i}{r_\pi} = \frac{0.314\, v_S}{0.75} = 0.416\, v_S$$

Now, consider stage two circuit

$$v_{out} = -75\ i_b \times (2//5) = -75 \times 0.416\, v_S \times 1.42 = -44.6\, v_S$$

Accordingly, the gain is $v_{out} / v_S = -44.6$. The (-) sign is an indication for the counterclockwise direction of current in stage-two circuit.