National Aviation University

Department of Electronics, Robotics, Monitoring and IoT Technologies

Course: “Fundamentals of Analog Electronics”

Experiment 4

“Common Collector Amplifier”

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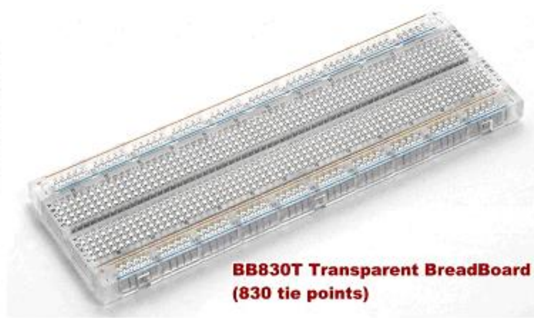
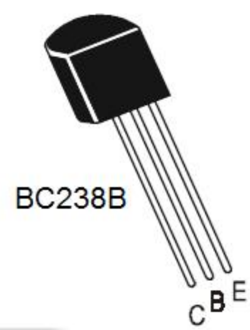
OBJECTIVES

1. To measure the voltage and current gains of the CC amplifier.
2. To measure the input impedance of the CC amplifier.
3. To simulate the CC amplifier using MULTISIM software.

EQUIPMENT

1. Digital multimeter: Agilent 34401A
2. Solderless breadboard: BB830T
3. Oscilloscope: HAMEG HMO1024
4. Sinusoidal generator
5. Power Supply: 12V
6. BJT: BC238B
7. Resistors: 2 × 8.2 kΩ, 2 ×1.2 kΩ
8. Potentiometer: 100 kΩ
9. Capacitor: 2 × 10μF





Theory

The circuit of a common-collector (CC) amplifier is shown in Fig. 1.

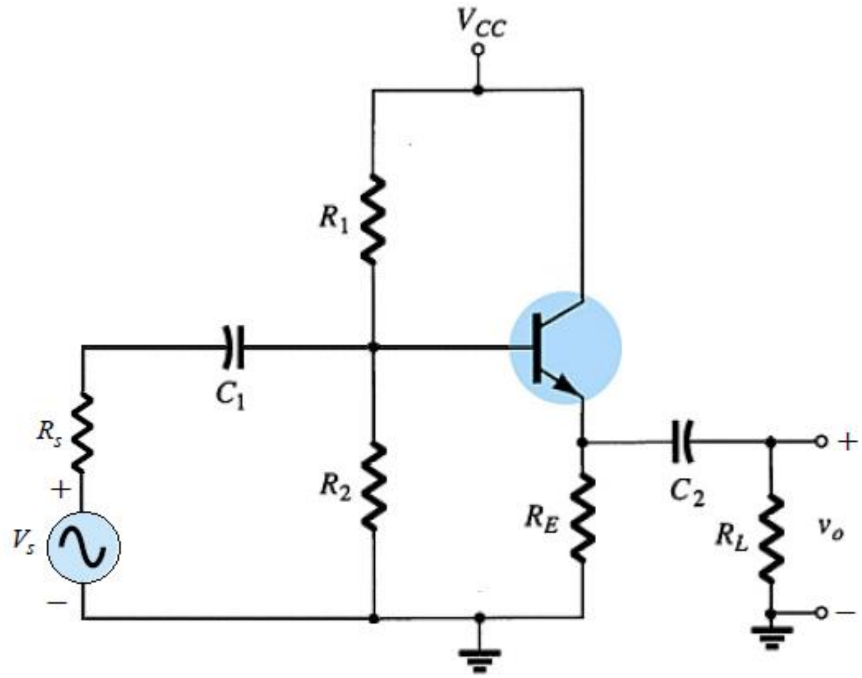


Fig. 1 Common-collector amplifier circuit

The ac equivalent circuit of the CC amplifier is shown in Fig. 2. For converting the equivalent circuit of Fig. 2 into an equivalent electrical circuit, the transistor must be replaced by its small-signal model as shown in Fig. 3.

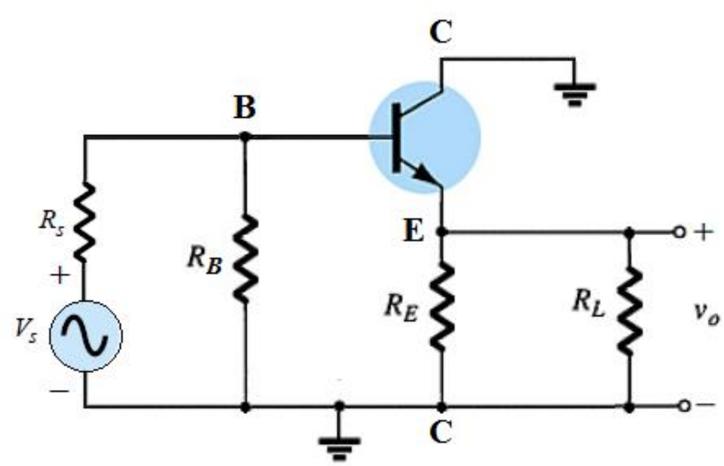


Fig. 2 AC equivalent circuit of a CC amplifier

The complete CC small-signal model of the BJT with CE h-parameters has been substituted and the final network redrawn as shown in Fig. 4.

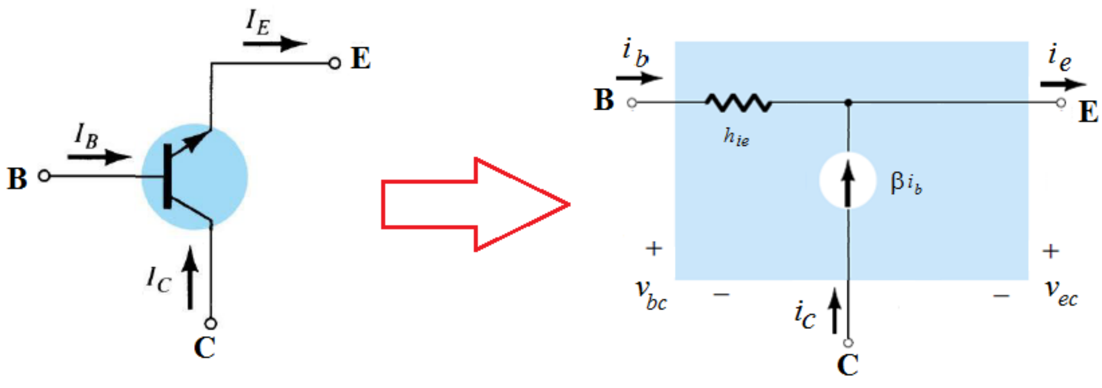


Fig. 3 Replacement of transistor with a simplified small-signal model

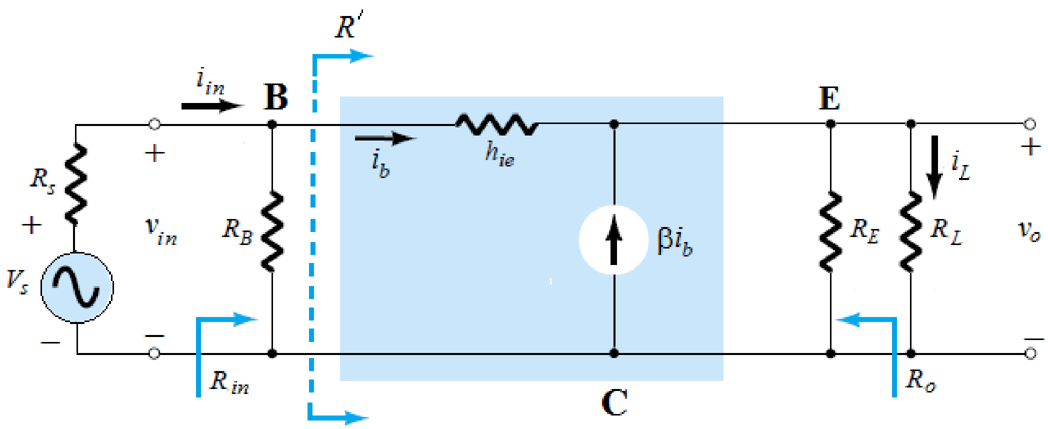


Fig. 4 Small-signal model of the CC amplifier in mid frequency range

Input Resistance, R_{in}

Let us begin by finding the resistance to the right of the dashed line in Fig. 4

$$R' = \frac{v_{in}}{i_B}$$

where

$$v_{in} = i_B h_{ie} + (1+\beta) i_B (R_E \| R_L)$$

Now assuming that β is large $(\beta + 1 \approx \beta)$, we have

$$v_{in} = i_B (h_{ie} + \beta (R_E \| R_L))$$

Thus,

$$R' = h_{ie} + \beta\left(R_E \| R_L\right)$$

Now solving for R_{in} we have

$$R_{in} = R_B \| R' = R_B \| \left[\beta h_{ib} + \beta\left(R_E \| R_L\right)\right] = \frac{R_B\left[h_{ib} + \left(R_E \| R_L\right)\right]}{R_B/\beta + h_{ib} + \left(R_E \| R_L\right)}$$

If $h_{ib} << R_E \| R_L$, then h_{ib} can be neglected and

$$R_{in} = R_B \| \left[\beta\left(R_E \| R_L\right)\right]$$

Current Gain, A_i

The current gain is defined as

$$A_i = \frac{i_L}{i_{in}}$$

where

$$i_B = i_{in} \frac{R_B}{R_B + h_{ie} + \beta\left(R_E \| R_L\right)}$$

$$i_L = \beta i_B \frac{R_E}{R_E + R_L}$$

and

$$i_{in} = i_B \frac{R_B + h_{ie} + \beta\left(R_E \| R_L\right)}{R_B}$$

Substituting i_L and i_{in} into equation for A_i, gives

$$A_i = \beta i_B \frac{R_E}{R_E + R_L} \Big/ i_B \frac{R_B + h_{ie} + \beta\left(R_E \| R_L\right)}{R_B} = \frac{\beta R_E R_B}{\left(R_E + R_L\right)\left(R_B + h_{ie} + \beta\left(R_E \| R_L\right)\right)}$$

and finally

$$A_i = \frac{R_E R_B}{(R_E + R_L)\left[R_B/\beta + h_{ib} + (R_E \| R_L)\right]} \qquad (1)$$

Equation (1) is the general expression for current gain. If $h_{ib} << R_E \| R_L$, then

$$A_i = \frac{\beta R_E R_B}{(R_E + R_L)\left[R_B + \beta(R_E \| R_L)\right]}$$

If $R_B << \beta(R_E \| R_L)$, then

$$A_i \approx \frac{\beta R_E R_B}{(R_E + R_L)(\beta(R_E \| R_L))} = \frac{\beta R_E R_B (R_E + R_L)}{(R_E + R_L)\beta R_E R_L} = \frac{R_B}{R_L}$$

Note that the current gain is positive for the CC amplifier, since i_{in} is in phase with i_L.

Voltage Gain, A_V

We find the voltage gain from the gain impedance formula, input resistance, and the current gain:

$$A_V = A_i \frac{R_L}{R_{in}} \qquad (2)$$

$$R_{in} = \frac{R_B (h_{iB} + R_E \| R_L)}{R_B/\beta + h_{ib} + R_E \| R_L}$$

(3)

$$A_i == \frac{\beta R_E R_B}{(R_E + R_L)(R_B + h_{ie} + \beta(R_E \| R_L))} \qquad (4)$$

Substituting (3) and (4) into 2 gives

$$A_V = \frac{R_E R_B R_L}{(R_E + R_L)\left[R_B/\beta + h_{ib} + (R_E \| R_L)\right]} \times \frac{\left[R_B/\beta + h_{ib} + (R_E \| R_L)\right]}{R_B\left[h_{ib} + (R_E \| R_L)\right]}$$

and finally

$$A_V = \frac{R_E \| R_L}{h_{ib} + (R_E \| R_L)}$$

Since h_{ib} is usually small compared to $R_E || R_L$, we can approximate the voltage gain as

$$A_V \approx 1$$

Output Resistance, R_O

For finding R_O we shall use the CC equivalent circuit of the BJT with the CB *h*-parameter h_{ib} as shown in Fig. 5.

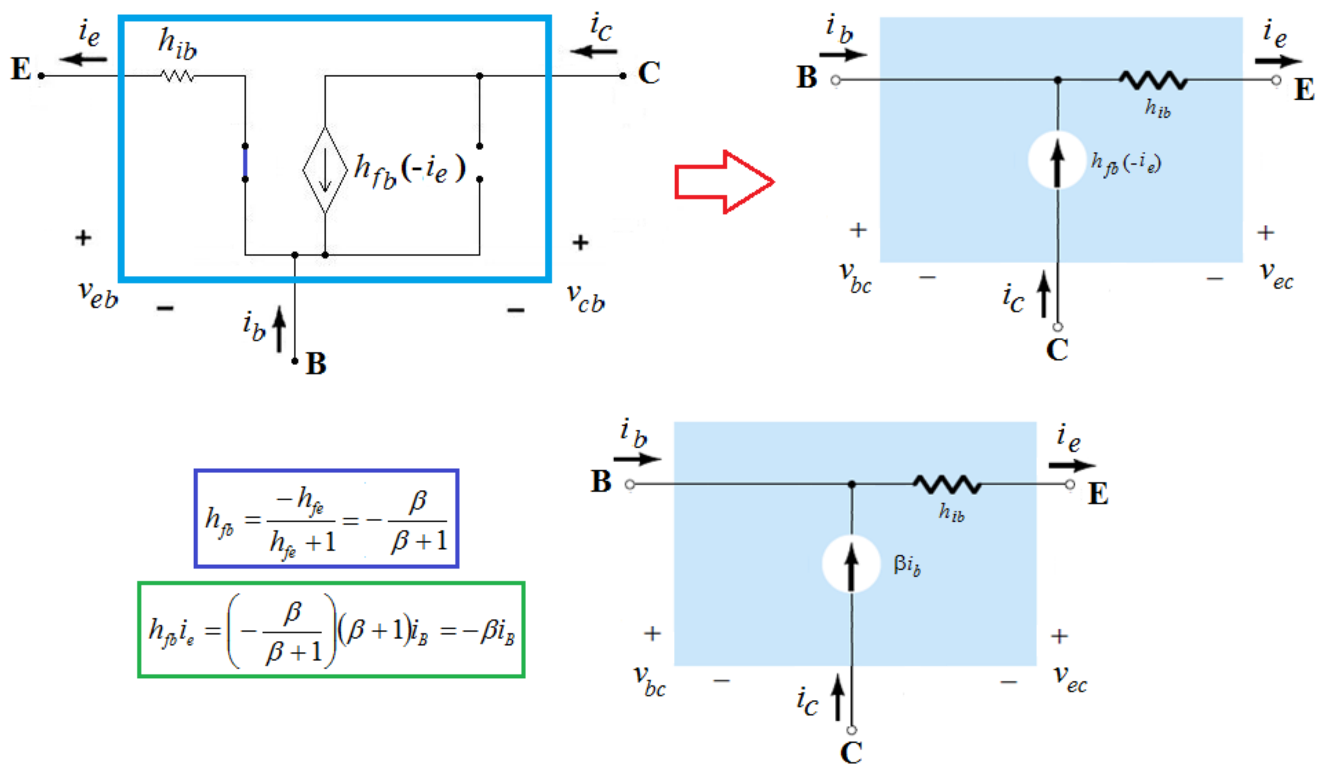


Fig. 5 CC small-signal model of a BJT with CB small-signal parameter h_{ib}

The small-signal equivalent circuit of the CC amplifier is shown in Fig. 6.

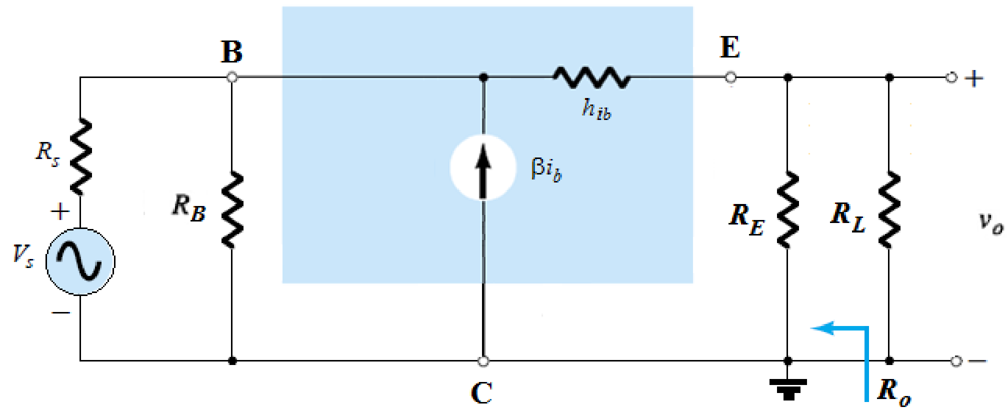


Fig. 6 CC amplifier small-signal equivalent circuit

The output resistance is determined with assumption that $R_L = \infty$. In this case we can represent output current by an ideal current source, i_o, with infinity internal resistance. The input ac source must be set to 0. The corresponding small-signal model is shown in Fig. 7.

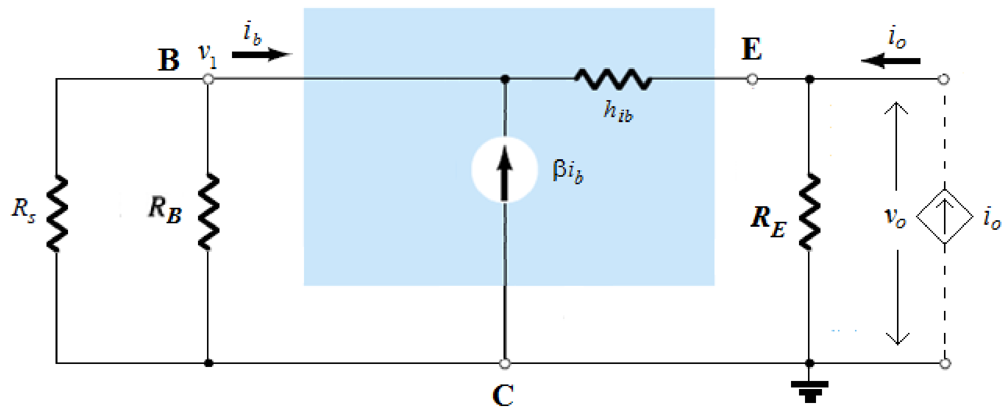


Fig. 7 Small-signal model for finding output resistance of the CC amplifier

We write the following equations for the circuit:

$$i_b = \frac{0 - v_1}{R_S \| R_B} = -\frac{v_1}{R_S \| R_B} \tag{5}$$

$$v_1 - v_o = (1 + \beta) h_{ib} i_b \tag{6}$$

$$i_o = \frac{v_o}{R_E} + \frac{v_o - v_1}{h_{ib}} \tag{7}$$

From Eq. (5) and Eq. (6) we find v_o

$$v_1 = -i_b\left(R_s \| R_B\right)$$
$$v_o = v_1 - (1+\beta)i_b h_{ib} = -i_b\left(R_s \| R_B\right) - (1+\beta)i_b h_{ib}$$

$$v_o = -i_b\left[\left(R_s \| R_b\right) + (1+\beta)h_{ib}\right] \tag{8}$$

Substituting $v_1 - v_o$ and v_o from Eq. (6) and Eq. (8) into Eq. (7), gives

$$i_0 = -\frac{i_b}{R_E}\left[\left(R_s \| R_B\right) + (1+\beta)h_{ib}\right] - \frac{(1+\beta)i_b h_{ib}}{h_{ib}} = -i_B\left\{\frac{1}{R_E}\left[\left(R_s \| R_B\right) + (1+\beta)h_{ib}\right] + 1 + \beta\right\} \tag{9}$$

The output resistance of the CC configuration is

$$R_0 = \frac{v_o}{i_o} = \frac{-i_b\left[\left(R_S \| R_b\right) + (1+\beta)h_{ib}\right]}{-i_b\left\{\frac{1}{R_E}\left[\left(R_s \| R_B\right) + (1+\beta)h_{ib}\right] + 1 + \beta\right\}} = \frac{R_E\left[\left(R_s \| R_b\right) + (1+\beta)h_{ib}\right]}{\left(R_s \| R_B\right) + (1+\beta)h_{ib} + (1+\beta)R_E} = \frac{R_E\left[h_{ib} + \frac{\left(R_s \| R_b\right)}{\beta+1}\right]}{R_E + h_{ib} + \frac{R_S \| R_b}{\beta+1}}$$

Using approximation $\beta + 1 \approx \beta$, we have

$$R_o = \frac{R_E\left(h_{ib} + \frac{R_s \| R_B}{\beta}\right)}{R_E + h_{ib} + \frac{R_s \| R_B}{\beta}} = R_E \left\| \left(h_{ib} + \frac{R_s \| R_B}{\beta}\right)\right.$$

PROCEDURE

1. Construct the CC amplifier circuit (see Fig. 8) on the solderless breadboard.
2. Turn on 12 V power supply.
3. Adjust the FREQUENCY control of signal generator so the output is 1 kHz sinusoidal waveform.
4. Adjust the 100 kΩ potentiometer (R_s) fully counterclockwise (thus making it 0).
5. Adjust the amplitude of the generator output voltage so that the amplifier output voltage amplitude V_O is 1 V.
6. Measure the voltage amplitude going from the generator into the amplifier (V_i). Record the voltage measurement.

7. Use the formula $A_V = V_O/V_i$ to calculate the voltage gain. Record the voltage gain calculation.
8. Measure the rms current flowing from the generator into the amplifier ($I_{i,rms}$). Record the input current measurement.
9. Measure the rms current flowing through the 1-kΩ load resistor ($I_{L,rms}$). Record the load current measurement.
10. Use the formula $A_I = I_{L,rms}/I_{i,rms}$ to calculate the current gain. Record the current gain calculation.
11. Readjust the 100 kΩ potentiometer (R_s) so the amplifier output voltage amplitude is 0.5 V.
12. Turn off the power supply, and measure the resistance between terminals 1 and 2 of the 100 kΩ potentiometer (R_s). Record this resistance value. It is equal to the amplifier input resistance R_{in}.
13. Use the formula $I_{L,rms} = V_O/(\sqrt{2}R_L)$, and the values of V_O (1 V) and R_L (1 kΩ) to calculate the output current. Record your current calculation
14. Using the formula $I_{i,rms} = V_i/(\sqrt{2}R_{in})$, and the values of V_i (step 6) and R_{in} (step 12) that you recorded earlier to calculate the input rms current. Record the input current calculation.
15. Use the formula $A_P = A_V A_I$ to calculate the powert gain of the amplifier. Record the power gain calculation.

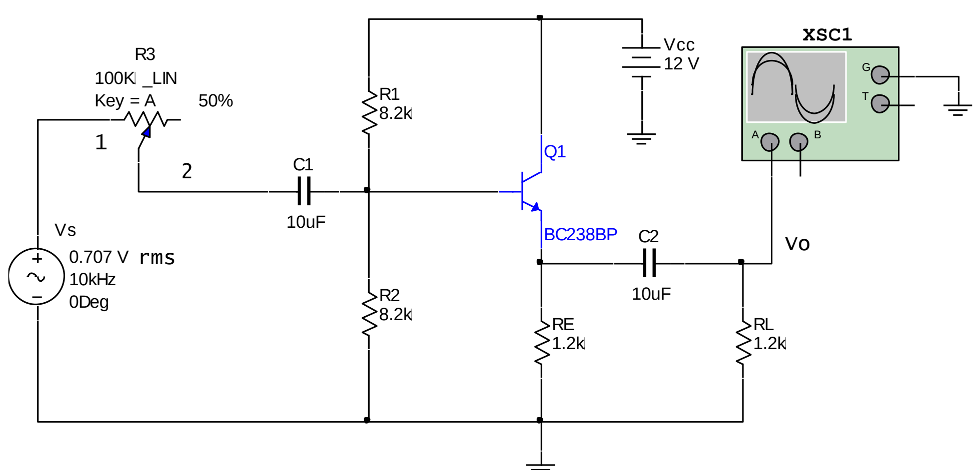


Fig. 8 Experimental CC amplifier circuit diagram

Reference

1. A.S. Sedra and K.S. Smith, “Microelectronic circuits”, 5th ed., New York: Oxford University Press, 2004, 1283 p.