Experiment No.4

Small Signal BJT Amplifier

Object

The purpose of this experiment is to demonstrate the operation of the small signal common emitter amplifier and investigate the factors influencing the voltage gain as well as to determine the input and output impedances.

Required Parts and Equipment's

1. Electronic Test Board. (M100)
2. Function Generator
3. DC Power Supply.
4. Two-channel Oscilloscope
5. DC Multimeter
6. BC 337 NPN silicon Transistors.
7. Resistors R_L=10KΩ, R_2=4.7KΩ, R_3=39KΩ, R_C= R_5=3.3KΩ, R_{test}=(P_2) P_2=R_{E2}=1KΩ, RE_1=R_4=470Ω,120Ω
8. Capacitors 2.2 µF and 10 µF.C_1=100nf, C_2=C_E=1µf, C_3=100nf

Theory

The common-emitter amplifier is characterized by the application of the input signal to the base lead of the transistor while taking the output from the collector, which always gives 180^o phase shift between the input and output signals. Figure 1 presents a schematic diagram for a typical common-emitter amplifier using the voltage-divider bias configuration.

The DC coupling capacitors C_{in} and C_{out} are used to block the DC current and thus to prevent the source internal resistance and the load resistance R_L from changing the DC bias voltages at the base and collector. Capacitor C_E is a bypass capacitor for the emitter resistor R_E. Resistor R_{E2} is used for bias stability, while R_E is used to minimize the change in the emitter internal AC resistance re due to temperature effects, and thereby to obtain a stable voltage gain.

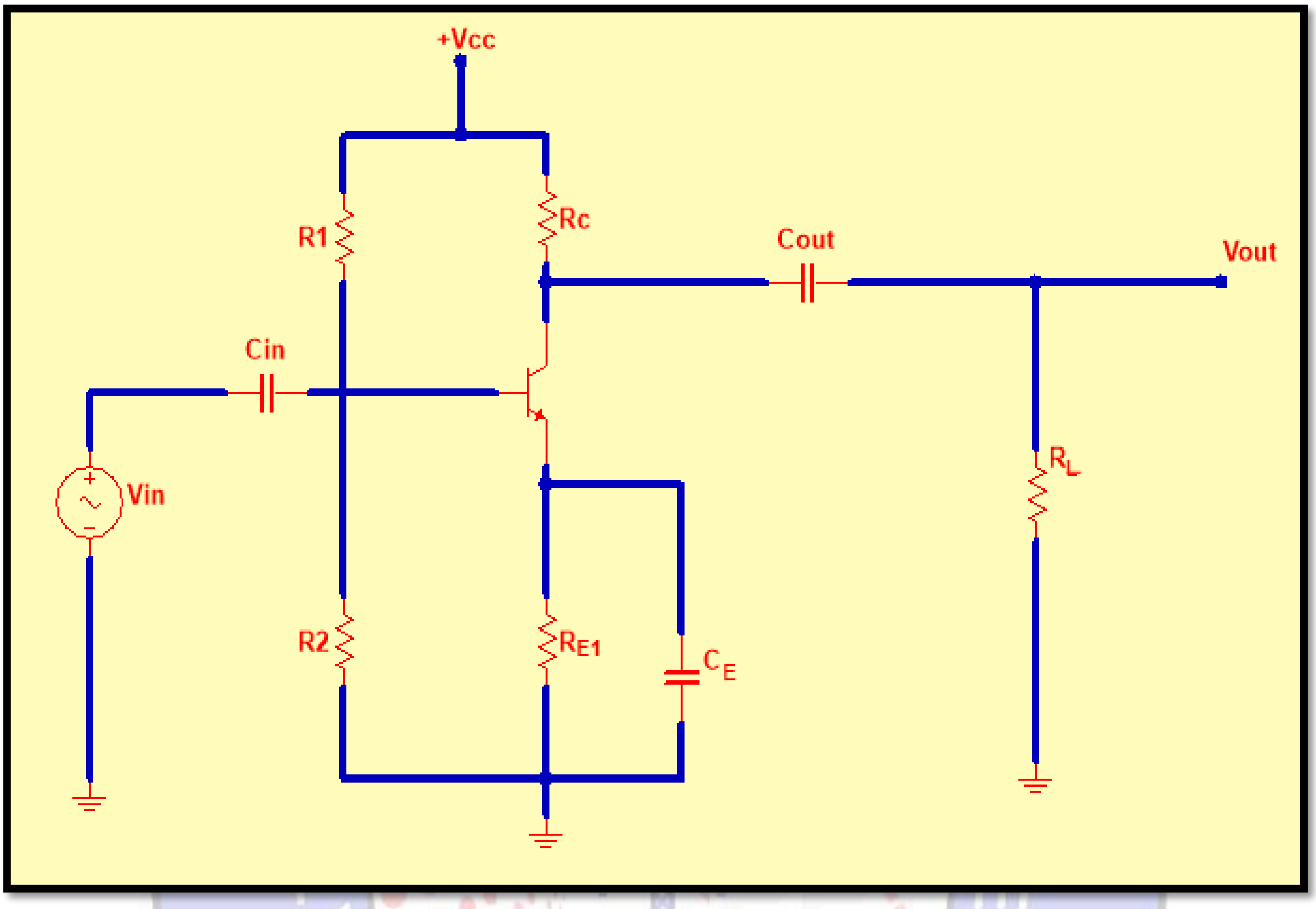

Figure 1: Schematic Diagram for a Typical Common Emitter Amplifier Circuit

The base DC voltage can be calculated approximately from the following equation assuming that $\beta.(R_{E1}) >> R_2$:

$$V_B = \frac{R_2 + V_{CC}}{R_1 + R_2} \tag{1}$$

The emitter DC voltage is therefore:

$$V_E = V_B - V_{BE} \tag{2}$$

The emitter DC bias current can be obtained as:

$$I_{EQ} = \frac{V_E}{R_E} \cong I_{CQ} \tag{3}$$

Transistor AC emitter resistance is obtained from:

$$r_e = \frac{V_R}{I_{EQ}} \tag{4}$$

Where V_T = 26 mV at room temperature.

The quiescent DC collector-emitter voltage is calculated from:

$$V_{CEQ} = V_{CC} - I_{CQ}(R_C + R_E) \qquad (5)$$

- **Voltage Gain Analysis**

Figure 2 presents the AC small-signal equivalent circuit for the common emitter amplifier. From this circuit, the amplifier voltage gain can be found as:

$$A_v = \frac{v_{out}}{v_{in}} = -\frac{R_C \| R_L}{R_E + r_e} \qquad (6)$$

If the load resistor R_L is removed then the voltage gain will become:

$$A_v = -\frac{R_C}{R_E + r_e} \qquad (7)$$

On the other hand, if the bypass capacitor C_E is removed, then the voltage gain will be modified as:

$$A_v = -\frac{R_C \| R_L}{R_E + r_e} \qquad (8)$$

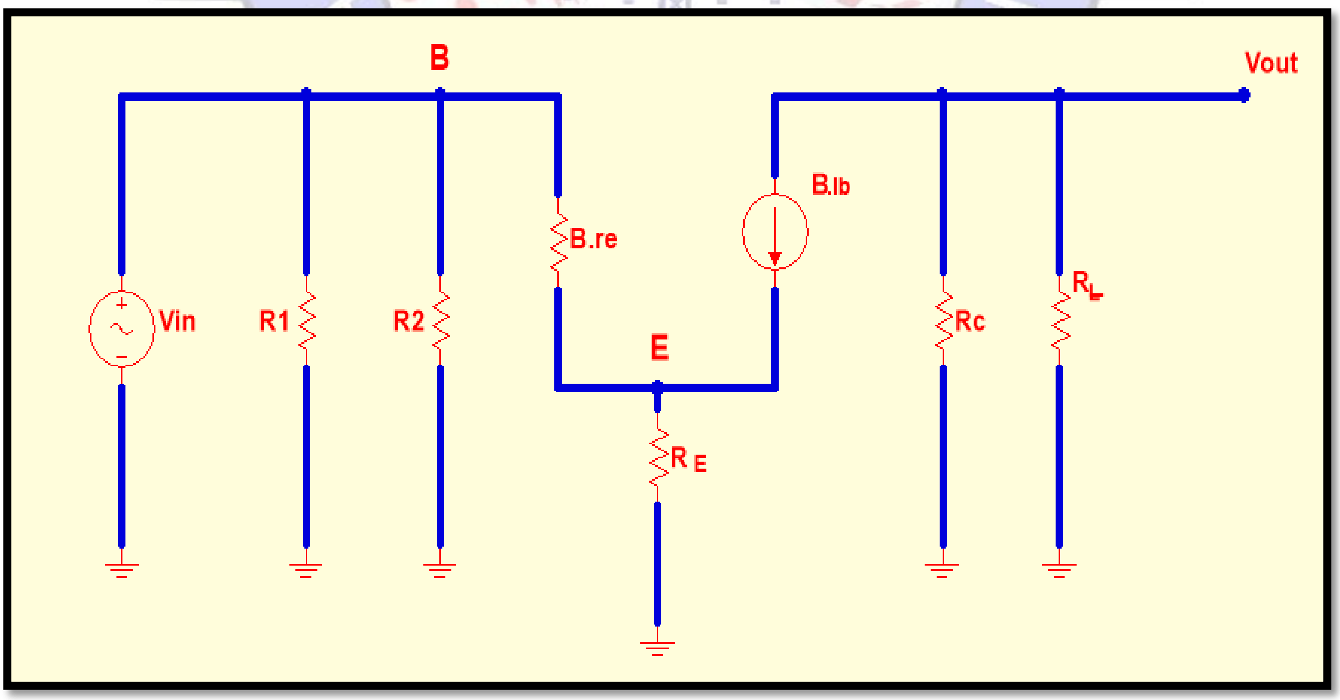

Figure 2: The Small-Signal AC Equivalent Circuit for the Common Emitter Amplifier

- **AC Load Line and Maximum Symmetrical Swing**

The AC load line of the amplifier circuit can be sketched to predict the swing of the output voltage and collector current. Figure 2 shows the AC and DC load lines of the circuit.

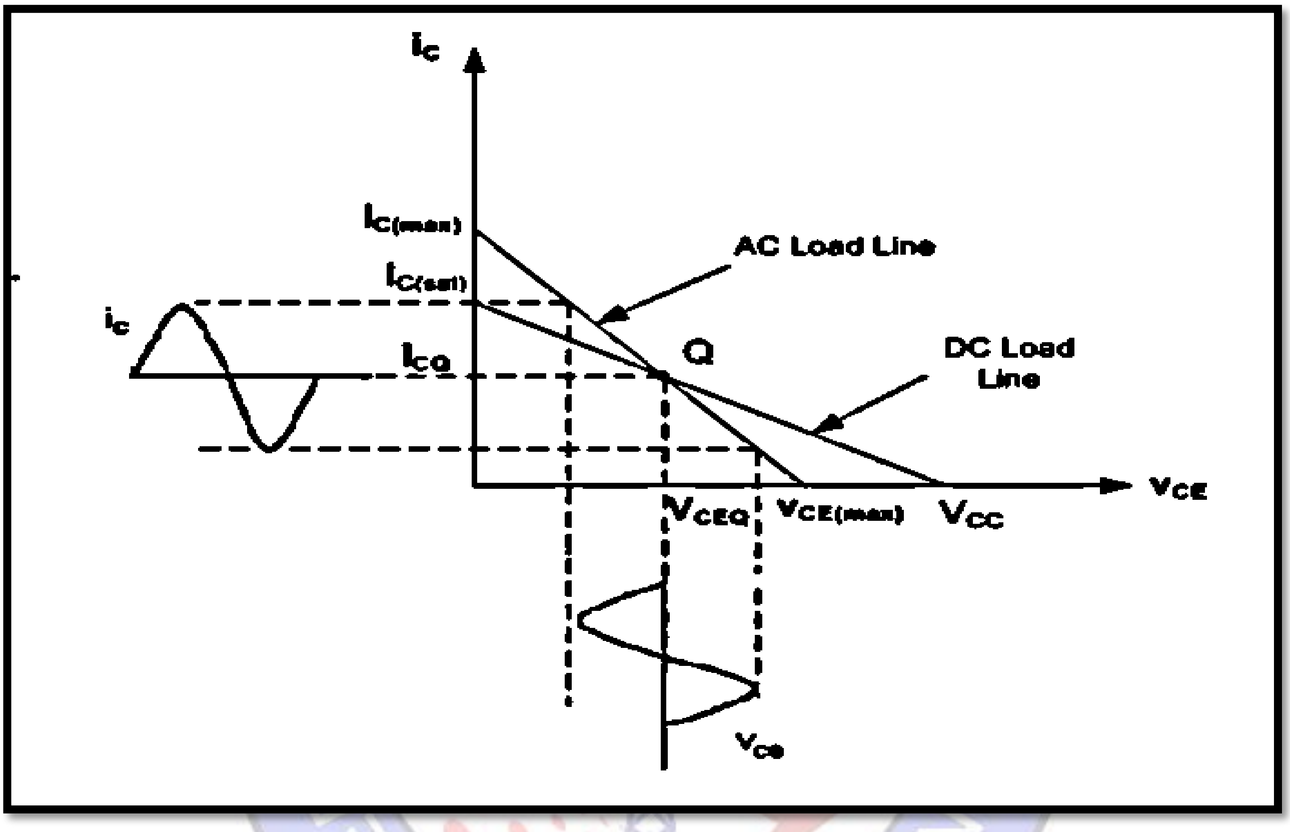

Figure 3: DC and AC Load Lines and Collector Current and Voltage Swing

As shown in Fig.2, both load lines intersect at the Q-point of the transistor. The slope of the AC load line is equal to $-1/R_{ac}$, where R_{ac} is the AC equivalent resistance seen between the collector and emitter terminals. R_{ac} can be obtained from the amplifier's small signal equivalent circuit of Fig.2. The total collector current and voltage can be expressed as the sum of the quiescent values and the AC signal quantities as shown below:

$$i_C = I_{CQ} + i_c \qquad (9)$$

$$v_{ce} = V_{CEQ} + v_{ce} \qquad (10)$$

It can be shown that $i_{C(max)}$ and $v_{CE(max)}$ in Fig.3 are given by:

$$i_{C(\max)} = I_{CQ} + \frac{V_{CEQ}}{R_{ac}} \tag{11}$$

$$v_{CE(\max)} = V_{CEQ} + I_{CQ}.R_{ac} \tag{12}$$

Where:

$$R_{ac} = R_E + R_C \parallel R_L \tag{13}$$

Maximum symmetrical swing in the output signal can be obtained if the Q-point bisects the AC load line. The AC load line concept can be used to predict the maximum amplitude in the output signal before clipping.

- **Input and Output Impedances**

The input and output impedances of the amplifier can be found theoretically as the Thevenin equivalent impedances at the input and output terminals respectively. For the equivalent circuit of Fig.2, the input impedance (Z_{in}) of the amplifier seen by the source is:

$$Z_{in} = R_1 \parallel R_2 \parallel \beta(r_e + R_E) \tag{14}$$

Similarly, the output impedance (Z_{out}) seen from the output terminals is:

$$Z_{out} = R_C$$

The amplifier circuit can be represented as a two-port network as illustrated in Fig.4. In this figure, A_{vo} represents the no-load voltage gain of the amplifier, Z_{in} is the amplifier's input impedance, and Z_{out} is the amplifier's output impedance. Resistor R_S is the internal resistance of the signal source, while R_L is the load resistance.

The overall voltage gains of the amplifier taking the effects of R_S and R_L into account can be expressed as:

$$A_v = \frac{v_{in}}{v_s}.\frac{v_{out}}{v_{in}}$$

$$A_v = \frac{Z_{in}}{Z_{in}+R_S}.\frac{A_{vo}.R_L}{R_L+Z_{out}} \tag{16}$$

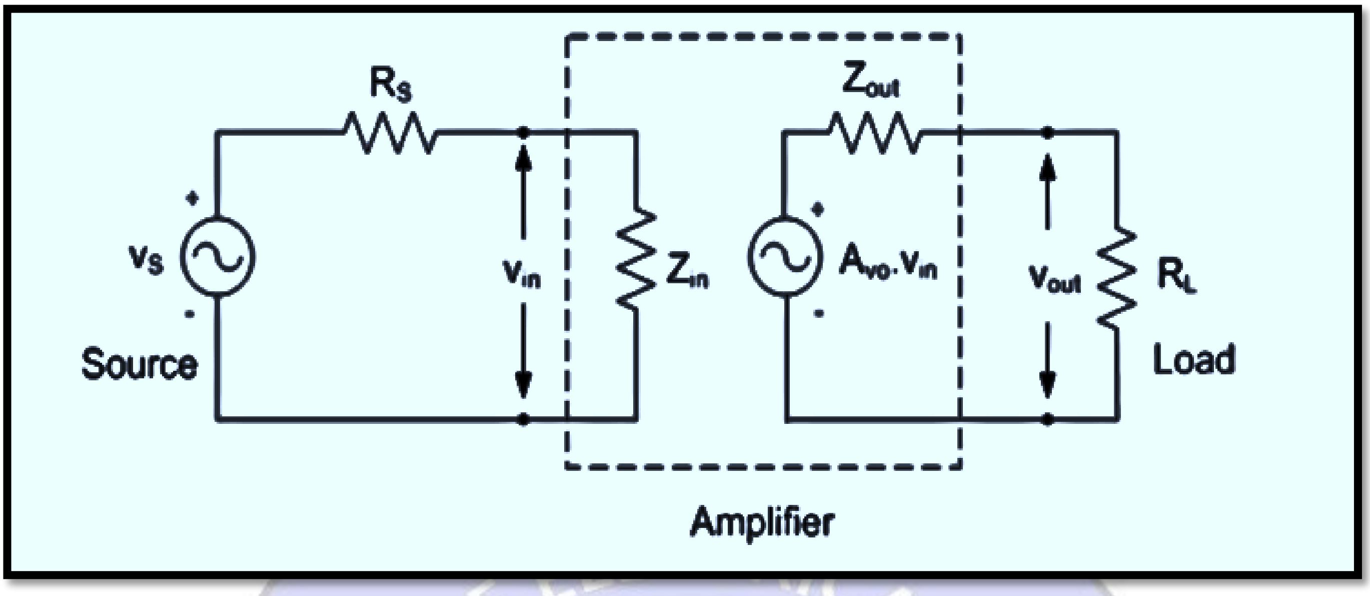

Figure 4: The Amplifier as a Two-Port Network

For the input port, when $R_S = Z_{in}$, we have:

$$v_{in} = \frac{Z_{in}}{Z_{in}+R_S} v_s = \frac{1}{2} v_s$$

Assuming that the amplifier is connected with no-load, we have:

$$A_v = \frac{v_{in}}{v_s} . \frac{v_{out}}{v_{in}} = \frac{1}{2} A_{vo}$$

Thus, the input impedance can be estimated practically by inserting a variable source resistor R_S in series with the source and varying it until the voltage gain of the amplifier equals half the no-load gain A_{vo}. This value of R_S represents the input impedance Z_{in}.

For the output port, when RL = Zout, and assuming that RS = 0, then we have:

$$A_v = \frac{v_{out}}{v_{in}} = \frac{A_{vo}. R_L}{R_L + Z_{out}} = \frac{1}{2} A_{vo}$$

So that the output impedance can be estimated practically by connecting a variable load resistor R_L and varying it until the voltage gain becomes equal to half the value of the no-load gain with $R_S = 0$. This value of R_L represents the output impedance Z_{out}.

Procedure

1. Connect the circuit shown in Fig.5 and measure the DC voltages V_B, V_E, and V_C. Try to measure the DC current gain of the BC337 transistor h_{FE} using a multi-meter. Tabulate your results as illustrated in Table-1.

Table-1: Measured Quantities for the DC Bias Circuit

Parameter	β	V_B	V_E	V_C	I_{CQ}	V_{CEQ}	V_{BEQ}	r_e
Value								

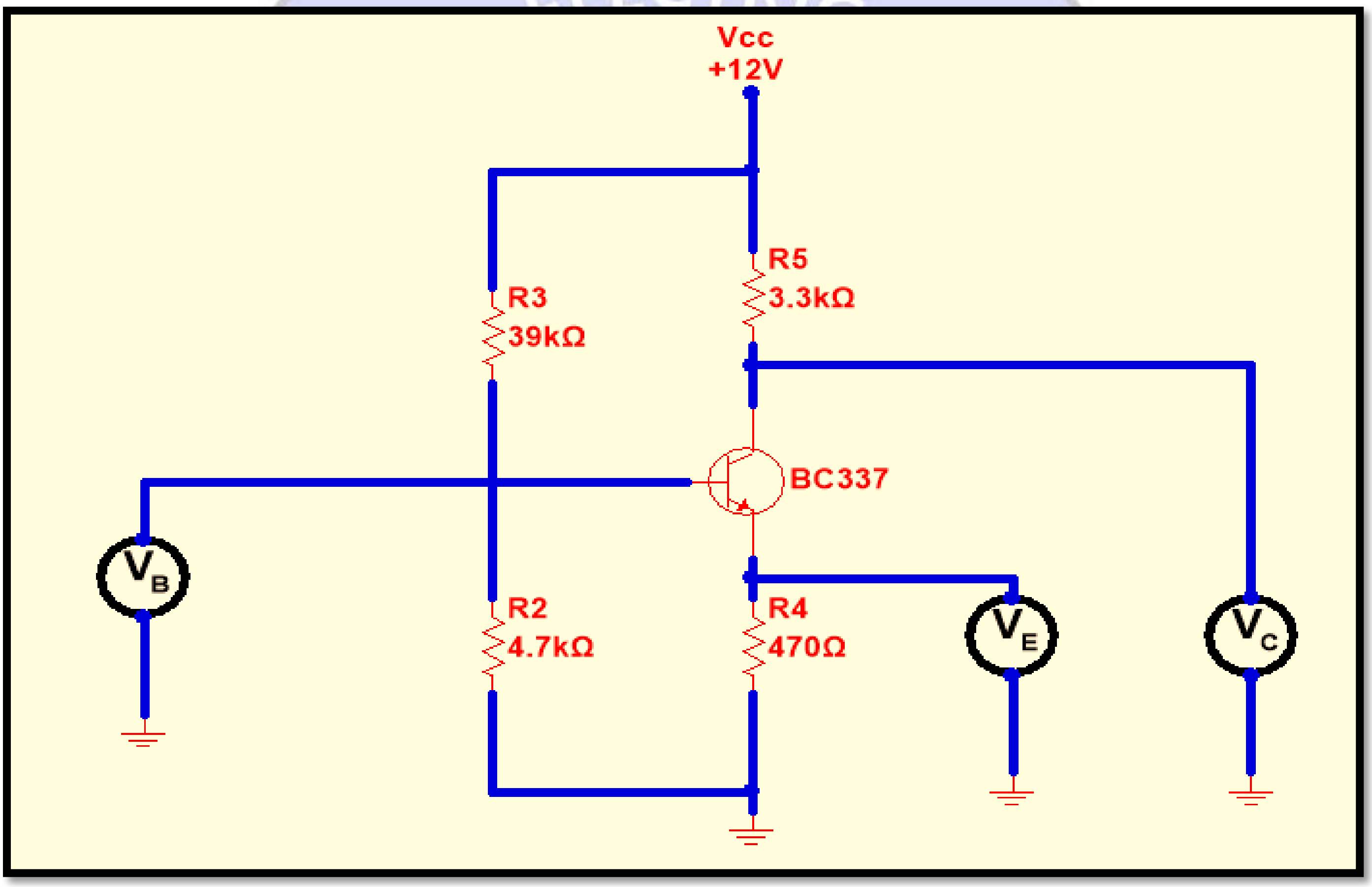

Figure 5: The DC Bias Circuit of the Common Emitter Amplifier

2. Connect the amplifier circuit shown in Fig.6, and apply a sinusoidal source signal with peak amplitude of 0.1V and frequency of 10 KHz. Display both the input (source) and output (load) signals on the oscilloscope. Try to measure the voltage gain Av, where Av = Vout/Vs.

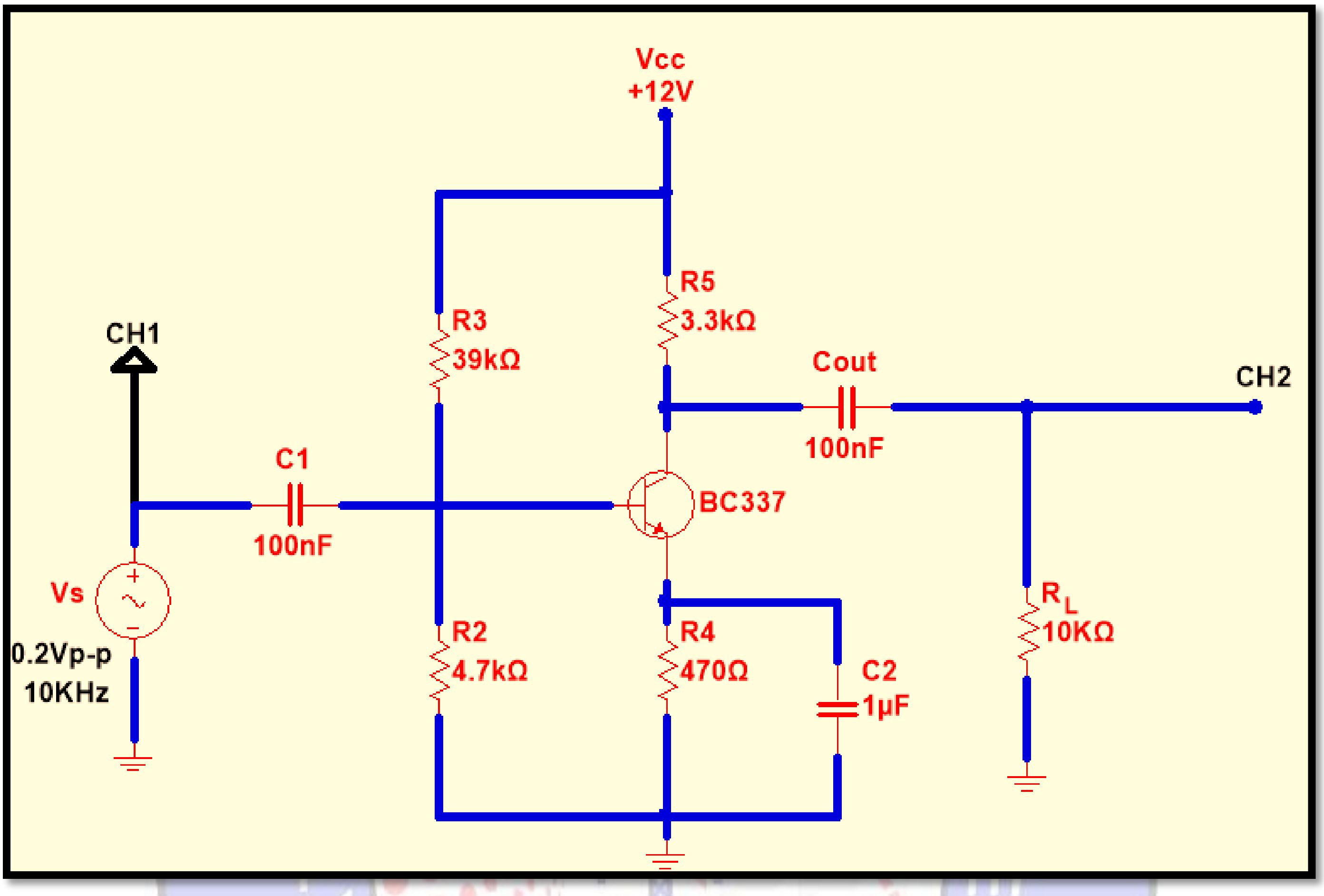

Figure 6: The Practical Common Emitter Amplifier Circuit

3. Remove load resistor R_L and re-measure the voltage gain.
4. Remove the bypass capacitor C_E and measure the voltage gain with the load resistor R_L connected at the output. Tabulate your results as shown in Table-2.

Table-2: Voltage Gain for Different Cases

Case	Voltage Gain
Normal (R_L=10KΩ)	
No-Load ($R_L = \infty$)	
No Bypass Capacitor	

5. Increase the amplitude of the source input signal gradually until clipping occurs in the output signal. Find the maximum peak amplitude for v_{out} and vs at the edge of clipping for the three cases illustrated in Table-3.

Table-3: Peak Input and Output Voltages before Clipping

Case	$V_{s(max)}$	$V_{out(max)}$
Normal		
No-Load		
No Bypass Capacitor		

6. Connect the circuit shown in Fig.7, where R_{test} is a variable resistor box. This circuit is used to measure the input impedance of the amplifier.

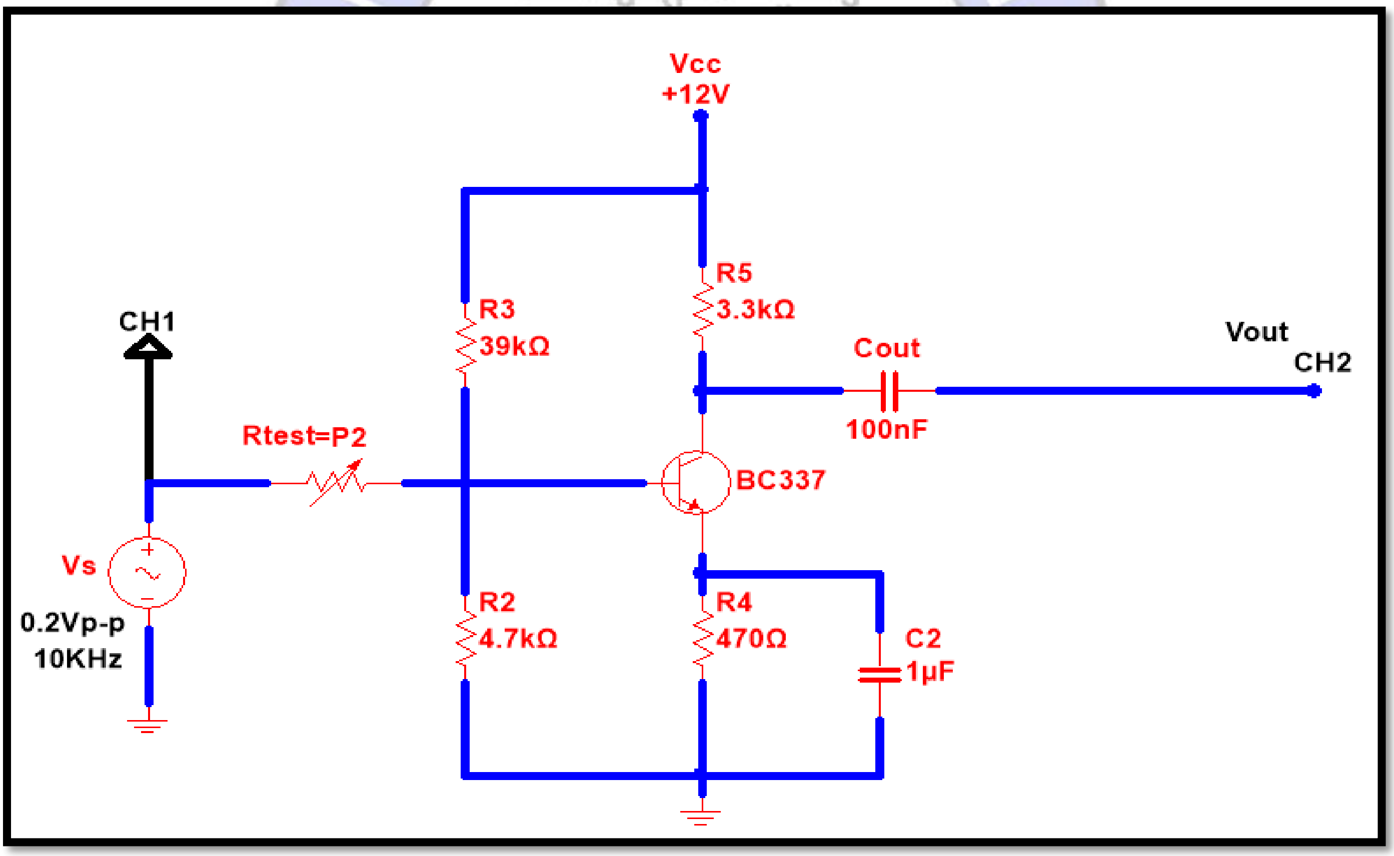

Figure 7: Test Circuit to Measure the Input Impedance of the Amplifier

7. Set R_{test} = 0 Ω initially, and measure the no-load voltage gain A_{vo}.
8. Increase R_{test} in steps until the voltage gain becomes equal to half the no-load gain. Record this value of R_{test} as Z_{in}.
9. Connect the circuit shown in Fig.8 to measure the output impedance of the amplifier. Resistor R_{test} is inserted at the output terminals instead of R_L.

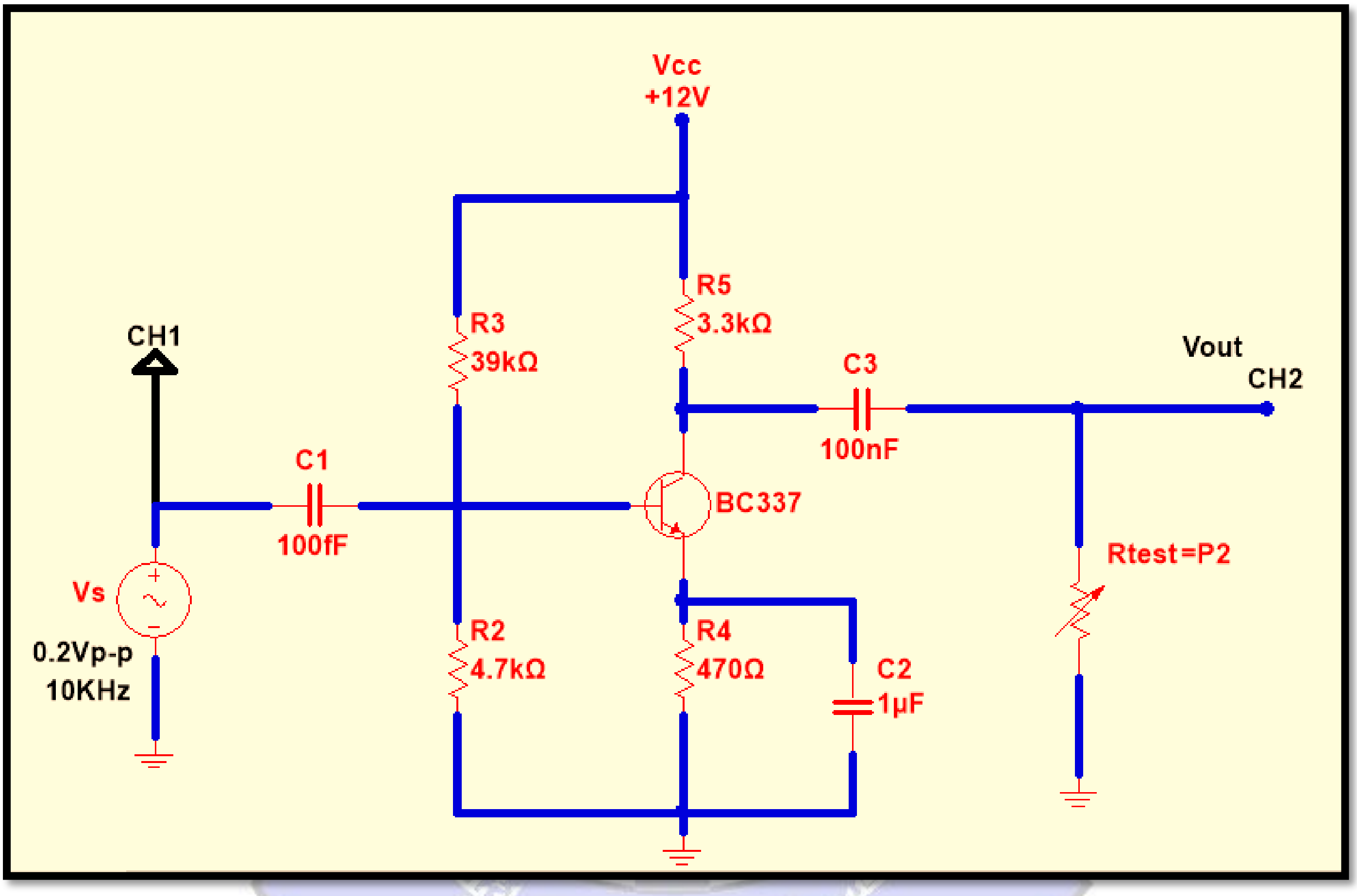

Figure 8: Test Circuit for Measuring the Output Impedance of the Amplifier

10. Vary R_{test} in steps until the voltage gain becomes equal to half the no-load gain. Record this value of R_{test} as Z_{out}.

Discussion

1. Calculate the theoretical DC voltages and currents for the transistor bias circuit and compare them with the practically measured values.
2. Calculate the theoretical values of the voltage gain for the three cases and compare them with the measured quantities.
3. Sketch the AC load line for the amplifier circuit and find the theoretical maximum symmetrical swing in collector voltage v_{ce} before clipping when $R_L = 10\ K\Omega$. Determine $V_{out(max)}$ before clipping and compare it with the measured value.
4. Determine the theoretical value of the input impedance and compare it with the measured value.
5. Calculate the theoretical value of the output impedance and compare it with the measured value.
6. If resistor R_2 is opened (or removed) in the circuit of Fig.5, what is its effect on the transistor circuit? Determine the collector current I_C and voltage V_{CE} in this case.
7. Calculate the current gain A_i of the amplifier circuit of Fig.6.