Name: 赵雅萱 SID: 11811336 Experiment date: 2019.10.8

## Laboratory 2

# Common-emitter BJT Amplifiers

## I. Objectives

- Grasp the analysis techniques of the common-emitter BJT amplifier circuits and get deep understanding of the amplifier performances;
- To learn the adjusting method of the Q-point and get familiar with the influences of the Q-point to the dynamic performances of the amplifiers;
- To learn how to measure the dynamic performance parameters of the amplifiers including voltage gain, input and output resistances and dynamic range.

## II. Principals

The common-emitter (CE) configuration of BJT amplifiers can amplify both voltage and current, it is usually used to amplify small signals. The voltage gain of the amplifier can be changed by adjusting the Q-point, this configuration has mediate input resistance, large voltage gain and relatively large output resistance, so it is usually used as the middle stage in the whole multi-stage amplifiers.

A voltage-divider biased common-emitter BJT amplifier circuit is shown in figure 1, resistors $R_{B1}$ and $R_{B2}$ are used to stabilize the base voltage $V_B$, resistors $R_{E1}$ and $R_{E2}$ can also make the Q-point stable by negative feedback mechanism in the circuit when the parameters may be changed with temperature. DC equivalent circuit is composed of

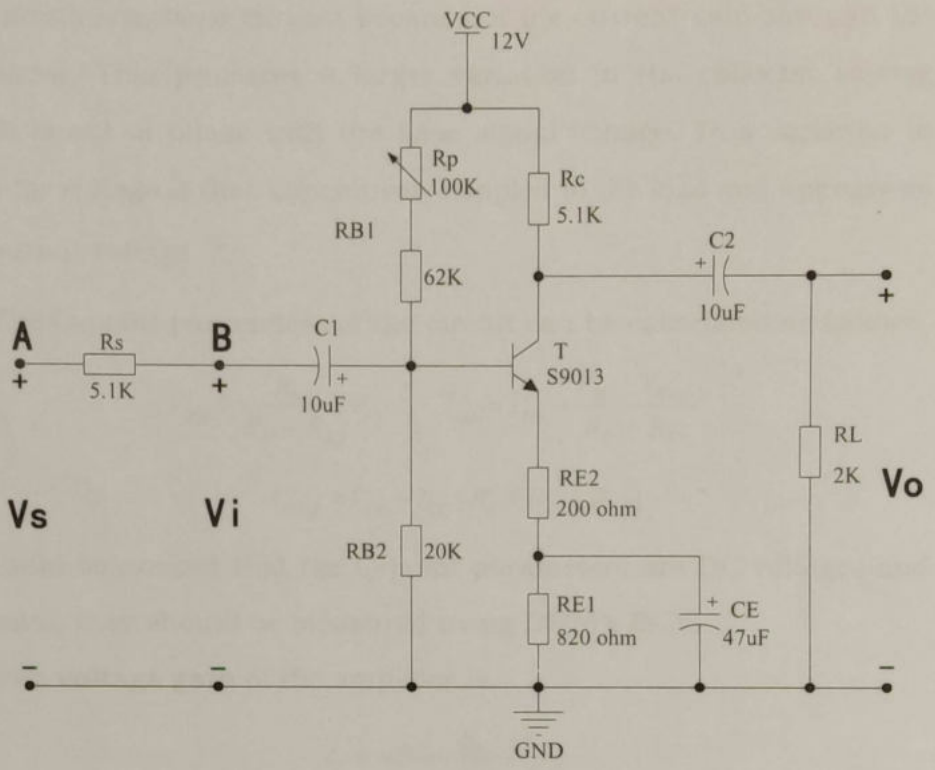



**Figure 1**

$T$、$R_{B1}$、$R_{B2}$、$R_C$、$R_{E1}$ and $R_{E2}$. The AC signal is brought into and out of the amplifier through series capacitors ($C_1$ and $C_2$) called **coupling capacitors**. The coupling capacitors can pass the AC signal while simultaneously blocking the DC voltage, making the Q-point separate from the source stage and load. The capacitor $C_E$ is different, it is connected in parallel with one of the emitters resistors $R_{E1}$. This causes the AC signal to bypass $R_{E1}$; thus, it is called a **bypass capacitor**. The purpose of the bypass capacitor is to increase the gain of the amplifier. The input signal $V_i$ is capacitively coupled to the base through $C_1$, causing the base current to vary above and below its DC bias value. This variation in base current produces a corresponding variation in collector current. The variation in collector current is much larger than

the variation in base current because of the current gain through the transistor. This produces a larger variation in the collector voltage which is out of phase with the base signal voltage. This variation in collector voltage is then capacitively coupled to the load and appears as the output voltage $V_o$.

The Q-point parameters of the circuit can be calculated as follows,

$$V_{BQ} \doteq \frac{R_{B2}}{R_{B1}+R_{B2}}V_{CC} \quad , \quad I_{CQ} \approx I_{EQ} = \frac{V_{BQ}-V_{BEQ}}{R_{E1}+R_{E2}}$$

$$V_{CEQ} \approx V_{CC} - I_{CQ}\left(R_C + R_{E1} + R_{E2}\right).$$

It should be noticed that the Q-point parameters are DC voltages and currents, they should be measured using DMM's DCV.

The **voltage gain** of the amplifier is,

$$A_V = -\beta \frac{R_C // R_L}{r_{be} + (1+\beta)R_{E2}},$$

where $r_{be} \approx 300 + \beta \frac{26(mV)}{I_{EQ}(mA)}$ is the dynamic emitter resistance.

The **input resistance** for an amplifier is an AC parameter that acts like a load in series with the source resistance. As long as the input resistance is high compared to the source resistance, most of the voltage will appear at the input and loading effect is small. If the input resistance is small compared to the source resistance, most of the source voltage will drop across its own series resistance, leaving little for the amplifier to amplify. The input resistance of the amplifier shown in figure 1 is

$$R_i = R_{B1} // R_{B2} // \left[r_{be} + (1+\beta)R_{E2}\right].$$

One of the problems with the CE amplifier is that the input resistance is dependent on $\beta$ , a highly variable parameter. So you cannot calculate

input resistance exactly for a given amplifier without knowing $\beta$. Despite this, you can minimize the effect of $\beta$ and increase the total input resistance by adding a swamping resistor to the emitter circuit, as done in figure 1.

The **output resistance** of the CE amplifier is

$$R_O = R_C .$$

### A. Q-point Adjustment and DC Parameters Measurement

Connect the input $V_i$ to the ground ( $V_i = 0$ ), take measurements of $V_B$ , $V_C$ and $V_E$ using DMM's DCV. The biasing collector current can be calculated by $I_C \approx I_E = \dfrac{V_E}{R_{E1} + R_{E2}}$ or $I_C = \dfrac{V_{CC} - V_C}{R_C}$.

The collector characteristic curve of a transistor is shown in figure 2, four different Q-points with different DC parameters are plotted in the figure. From this figure, we can analyze the influence of the Q-point to the dynamic performances of the amplifiers.

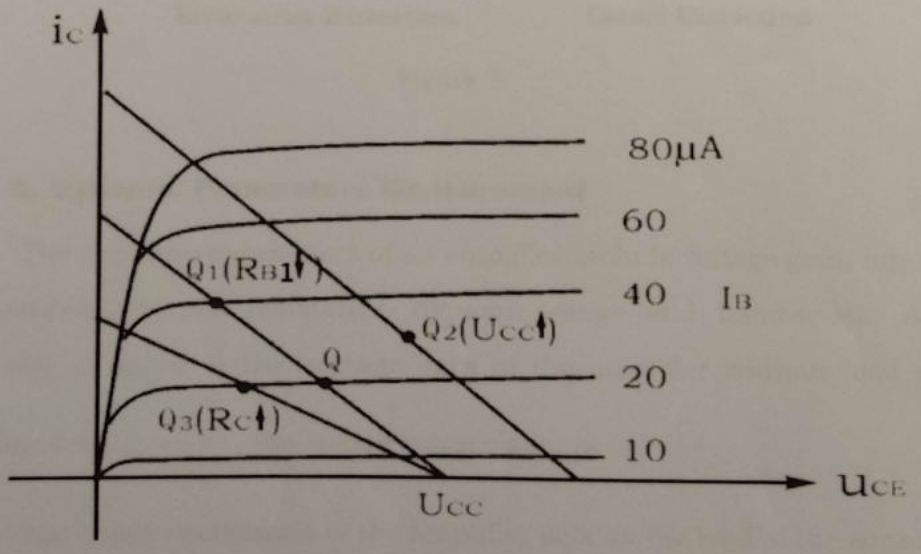



**Figure 2**

The DC biasing is critical to the dynamic performance of the

amplifier. If the Q-point on the load line is too high, then the transistor will step into **saturation**, if it is too low, the transistor will step into **cutoff**. This will cause distortion, other than linear amplification. The statements "too high" or "too low" are related to the input signal's amplitude, if the input amplitude is very small, the output will have no distortion even if the Q-point is "relatively too high" or "relatively too low". In other words, the distortion occurs when the Q-point is not well matched with the input amplitude. If the amplifier is required to amplify input signals with relatively big amplitude, then the Q-point should be set to the middle point of the AC load line.

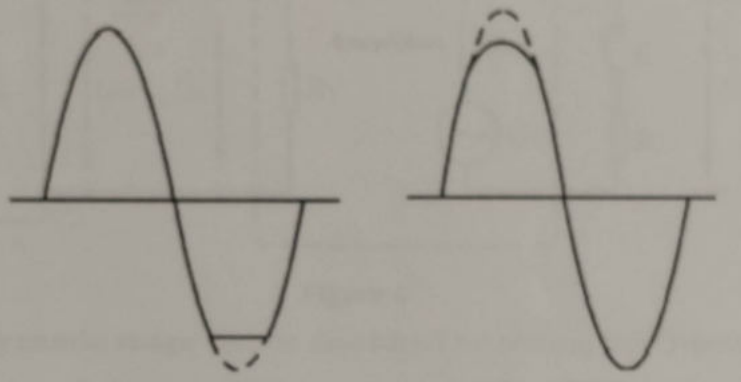



Figure 3

### B. Dynamic Parameters Measurement

The dynamic parameters of an amplifier include voltage gain, input resistance, output resistance, dynamic range and band-width. As shown in figure 4, the **voltage gain** of the amplifier without load is defined as $A_v = \frac{U_o}{U_i}$ , the loaded voltage gain is $A_L = \frac{U_L}{U_i}$.

The **input resistance** of the amplifier acts as the load of the source input, it can be measured by serially connecting a resistor $R_s$ to the

input $U_i$ . It is defined as

$$R_i = \frac{U_i}{U_s - U_i} R_S .$$

The **output resistance** of an amplifier indicates the capability of driving output loads. It can be calculated by the unloaded output voltage and the loaded voltage.

$$R_o = \frac{U_o - U_L}{U_L} R_L = \left( \frac{U_o}{U_L} - 1 \right) R_L$$

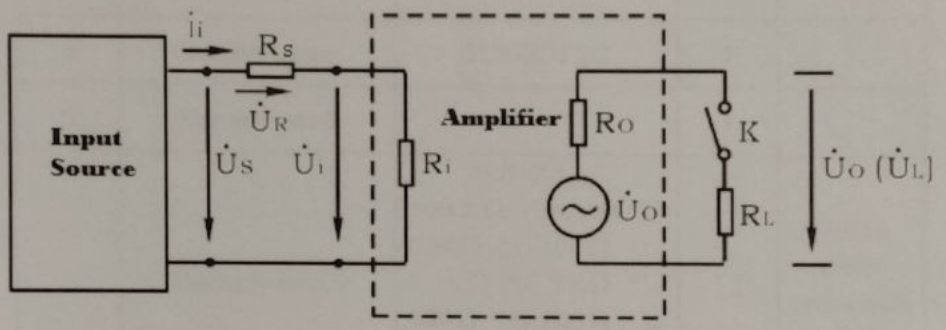



**Figure 4**

The **dynamic range** can be measured by setting the Q-point to the middle point of the AC load line. This point can be found by the following way: when the amplifier is working without distortion, increase the input magnitude, then you may see distortion of the output waveform on the oscilloscope, if it is cutoff, move the Q-point up, if it is saturation, move the Q-point down on the AC load line by tuning the variable resistor until the distortion disappears, then increase the input magnitude again, move the Q-point and get rid of the distortion once again until when you increase the input magnitude a little bit, the cutoff and saturation will occur simultaneously on the output. At this moment, you find the **best Q-point** (the middle point of the AC load line), measure the DC parameters of this point using DMM's DCV and measure the **Maximum undistorted output voltage** by DMM's ACV

(effective value $V_{O\max}$)or oscilloscope (peak-to-peak value $V_{Op-p}$).

## III. Hardware Requirements

| Items | Name | Type Specification | Units | Notes |
|---|---|---|---|---|
| 1 | DC Power Supply | DP1308A | 1 | |
| 2 | Digital Multi-meter | DM3051 | 1 | |
| 3 | Signal Generator | DG1022 | 1 | |
| 4 | Oscilloscope | TDS2012C | 1 | |
| 5 | Breadboard | | 1 | |
| 6 | Components | S9013 *1, 100 KΩ rheostat *1, 62KΩ *1, 20KΩ *1, 5.1KΩ *2, 2KΩ *1, 820Ω *1, 200Ω *1, 10 $\mu F$ *2, 47 $\mu F$ *1 | 12 | S9013 (NPN transistor) |

## IV. Experiment Procedures

***Notice:*** *please write down the theoretical value in the following table 1 & 2 as pre-lab exercises.*

### A. Q-point Measurement

Build the circuit in figure 1 on the breadboard, tune the rheostat to the maximum value, set the output of the signal generator to zero (or you can short the input terminal $V_i$ to the ground) before you turn on the power supply output, then turn on the power supply to provide 12V DC voltage, adjust the rheostat to an appropriate value such that $I_{CQ} = 1mA$ (DO NOT measure the current directly, measure voltage

through a resistor instead, here, it is equivalent to let $V_c = 6.9V$ ), measure $V_{CQ}$、$V_{BQ}$、$V_{EQ}$ using DMM's DCV and calculate $I_{EQ}$, write down the measured value into table 1. (*All of the blanks marked yellow in the tables of this lab are measured values, others are calculated ones.*)

**Table 1**

| | $V_{CQ}/V$ | $V_{BQ}/V$ | $V_{EQ}/V$ | $I_{EQ}/mA$ |
|---|---|---|---|---|
| Theoretical value | 6.9 | 1.72 | 1.02 | 1 |
| Measured Value | 6.9 | 1.63 | 1.02 | 1 |

### B. Voltage Gain Measurement

Maintain the Q-point set in part A, turn on the signal generator to provide **Vi** ( NOT Vs ) a sinusoidal signal with frequency setting to 1KHz, and the magnitude $V_{ip-p}$ (peak to peak value) as 300mV, then connect the oscilloscope to see the output waveform in two circumstances, loaded and unloaded, and finally measure the output voltages using DMM's ACV separately in these two circumstances, write down the measured values $V_O$ and $V_{OL}$ in table 2 and calculate the voltage gains $A_{VO}$ and $A_{VL}$ in the table (pay attention the relationship between the effective value and peak-to-peak value, $V_i = V_{ip-p}/2\sqrt{2}$ ). You can also see the phase difference by connecting the input and output signals to two channels of the oscilloscope.

**Table 2**

| | $V_O/mV$ | $A_{VO}$ | $V_{OL}/mV$ | $A_{VL}$ |
|---|---|---|---|---|
| Theoretical value | 2329.11 | 22 | 656.1 | 6.186 |
| Measured Value | 2321 | 21.88 | 654 | 6.166 |

### C. Q-point Adjustment and Distortion

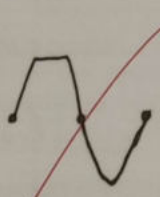
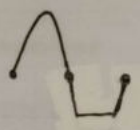
As we know, the Q-point can be changed by tuning the rheostat, now we tune the rheostat to the maximum (connect the rheostat's two end terminals to the circuit, not the middle terminal) and minimum (short circuit the rheostat) value respectively to make the transistor step into cutoff and saturation distortions. Turn on the signal generator to provide **Vi** ( NOT Vs ) a sinusoidal signal with frequency setting to 1KHz, and the magnitude $V_{ip-p}$ (peak to peak value) as 600mV, then connect the oscilloscope to see the output waveform (**Loaded**). Copy this waveform into table 3. Then measure the Q-point parameters $V_{CQ}$ and $V_{EQ}$ in these two circumstances using DMM's DCV, calculate other parameters and write down them into the upper part of table 3.

### D. Maximum Undistorted Output Voltage Measurement

Start from any Q-point, increase the input (1KHz sinusoidal signal) magnitude gradually, connect the oscilloscope to the **loaded output** to see the output waveform, if the transistor steps into saturation, then increase the rheostat's value to lower down the Q-point until the distortion is suppressed, if the transistor step into cutoff, then decrease the rheostat's value to move up the Q-point until the distortion is suppressed. Do this repeatedly until when you increase the input magnitude a little bit, the cutoff and saturation will occur simultaneously on the output. If the two types of distortion occur in the output, please decrease the input magnitude a little bit to make them disappeared. At this moment, you find the best Q-point! **And keep this best Q-point in the following experiment procedures**. Please measure the peak-to-peak value of the output by oscilloscope and measure the effective value of the Maximum Undistorted Output

Voltage using DMM's ACV. Then shut down the signal generator, measure the Q-point parameters $V_{CQ}$ and $V_{EQ}$ using DMM's DCV and fill in the blanks in the lower part of table 3.

**Table 3**

| | $V_{CQ}/V$ | $I_{CQ}/mA$ | $V_{EQ}/V$ | $V_{CEQ}/V$ | Output waveform (sketch) | Type of Distortion |
|---|---|---|---|---|---|---|
| **Q-point Adjustment and Two Types of Distortion** | 8.669 | 0.653 | 0.665 | 8.004 |  | 截止失真 |
| | 2.178 | 1.93 | 1.991 | 0.187 |  | 饱和失真 |
| **The Best Q-point and Maximum Undistorted Output Voltage** | 4.23 | 1.52 | 1.55 | 2.68 | Maximum Undistorted Output Voltage<br>$V_{O\max} = 1.56$ V<br>$V_{Op-p} = 4.40$ V | |

### E. Input Resistance and Output Resistance Measurement

In order to measure the output resistance of the amplifier, **maintain the best Q-point found in the previous steps**, adjust the signal generator to provide **Vi** ( NOT Vs )a sinusoidal signal with frequency setting to 1KHz, and the magnitude $V_{ip-p}$ (peak to peak value) to 200mV. Take the measurements $U_L$ and $U_O$ when the output

is loaded and unloaded using DMM's ACV and write down them into table 4.

In order to measure the input resistance of the amplifier, **maintain the best Q-point found in the previous steps**, connect the signal generator to provide **Vs** ( NOT Vi )a sinusoidal signal with frequency setting to 1KHz, and the magnitude $V_{ip-p}$ (peak to peak value) to 200mV. Take the measurements $U_S$ and $U_i$ using DMM's ACV and write down them into table 4 and finish the calculations.

**Table 4**

| | $U_O$ / V | $U_L$ / V | $R_O$ / kΩ | $U_S$ / mV | $U_i$ / mV | $R_i$ / kΩ |
|---|---|---|---|---|---|---|
| Measured Values | 1.617 | 0.457 | 5.077 | 70.28 | 54.0 | 16.92 |

### F. Frequency Response of the CM Amplifier

**Maintain the best Q-point found in the previous steps**, Adjust the signal generator to provide **Vi** ( NOT Vs )a sinusoidal signal with magnitude $V_{ip-p}$ = 600mV and frequency setting to the values in the table 5, measure the effective value of the **loaded** output using DMM's ACV, and finally find the upper and lower frequencies of the amplifier by the method of trails and errors.

**Table 5**

| $f$ / Hz | 20 | 25 | 50 | 100 | 200 | 500 | 1k | 10k |
|---|---|---|---|---|---|---|---|---|
| $V_o$ / V | 0.941 | 1.037 | 1.231 | 1.305 | 1.329 | 1.339 | 1.342 | 1.342 |
| $f$ / Hz | 100k | 200k | 300k | 400k | 500k | 800k | 820k | 1M |
| $V_o$ / V | 1.320 | 1.303 | 1.279 | 1.240 | 1.186 | 0.989 | 0.973 | 0.854 |

Upper Frequency: 90kHz Lower Frequency: 22 Hz

### G. Influence of the Bypass Capacitor on Voltage Gain

Do the experiments under conditions in table 6, take the measurements of the output using DMM's ACV and calculate the **unloaded** voltage gains. Write observations and conclusions you can find from this experiment.

**Table 6**

| Test conditions | | $V_o$ / V | $A_{VO}$ |
|---|---|---|---|
| **Maintain the best Q-point**, $R_L = \infty$ (**unloaded**), $R_S = 0$ (**Input from B**), $V_{ip-p} = 200mV$, $f = 1kHz$ | $C_E = 47\mu F$ | 1.618 | 22.88 |
| | **without** $C_E$ | 0.748 | 4.92 |

The Bypass Capacitor can increase the voltage ~~gain~~ gain by increasing $V_o$.

Because it can provide circuit for PC signal which is blocked by resistor $R_E$, to preserve the signal and increase the grain of amplifier.

## V. Questions

1. Why the rheostat in the circuit should be connected serially with a 62KΩ resistor, other than being connected independently?

To stabilize the base voltage $V_B$. Otherwise, if the rheostat is adjusted to too small carelessly, then the $V_B$ will be very high to harm the circuit.

2. If we change the transistor type from NPN to PNP, then what should be changed for the Vcc power supply and the capacitors?

The Vcc power supply should be changed to -12V.

The anode and cathode of the capacitors should be exchanged.