第 7 講: BJT 電晶體共集(Common Collector)放大電路

參考文獻與網頁:

[1]蕭敏學，大學電子學實習(一):電子電路分析篇，台科大圖書，2013

[2]Common Collector Amplifire,
https://www.electronics-tutorials.ws/amplifier/common-collector-amplifier.html

[3]Basic BJT Amplifier,
http://cdcpc.ce.ncu.edu.tw/classes/EEShortversion/Elect/Ch6%20Basic%20BJT%20Amplifiers.pdf

一、電路分析，請參考[1]~[3]

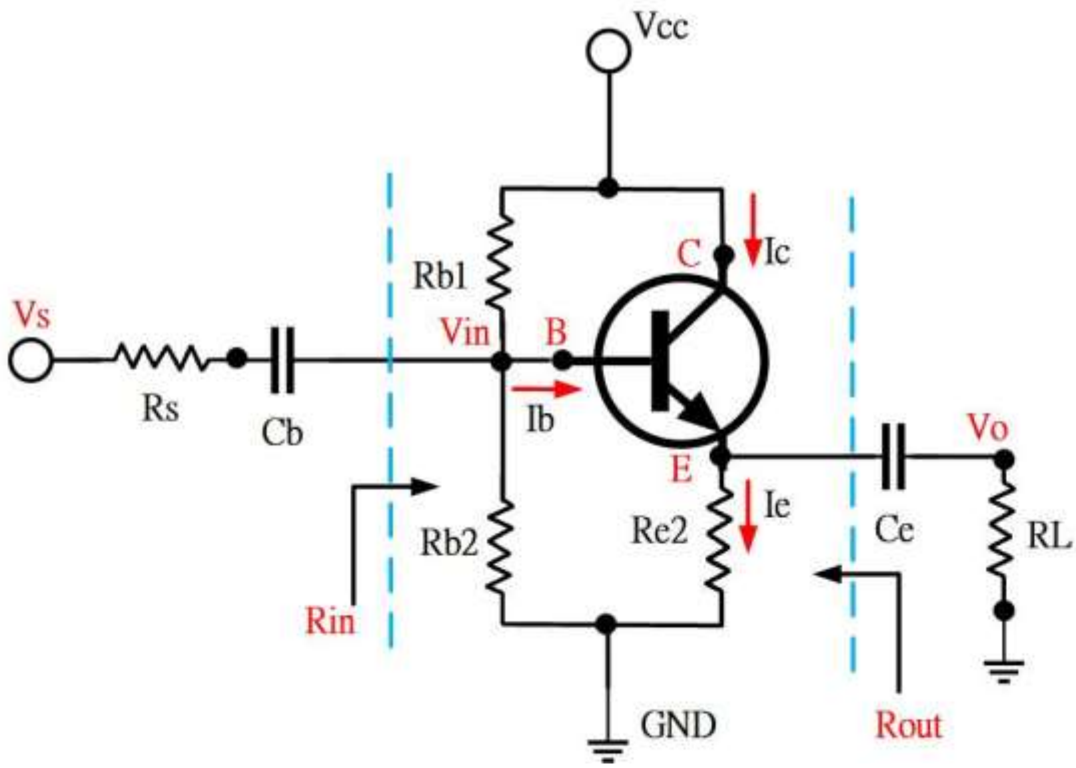


圖 7-1　BJT 電晶體共集電路[2]

- 電壓放大率:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{(1+\beta)(R_{e2}//R_L)}{R_{b1}//R_{b2}//(r_\pi+(1+\beta)(R_{e2}//R_L))} = \frac{(1+\beta)(R_{e2}//R_L)}{r_\pi+(1+\beta)(R_{e2}//R_L)} \cong 1 \quad (7.1)$$

- 電流放大率:

$$A_i = \frac{I_e}{I_b} = (1+\beta)\text{，}\quad \beta = \frac{I_{CQ}}{I_{BQ}} \tag{7.2}$$

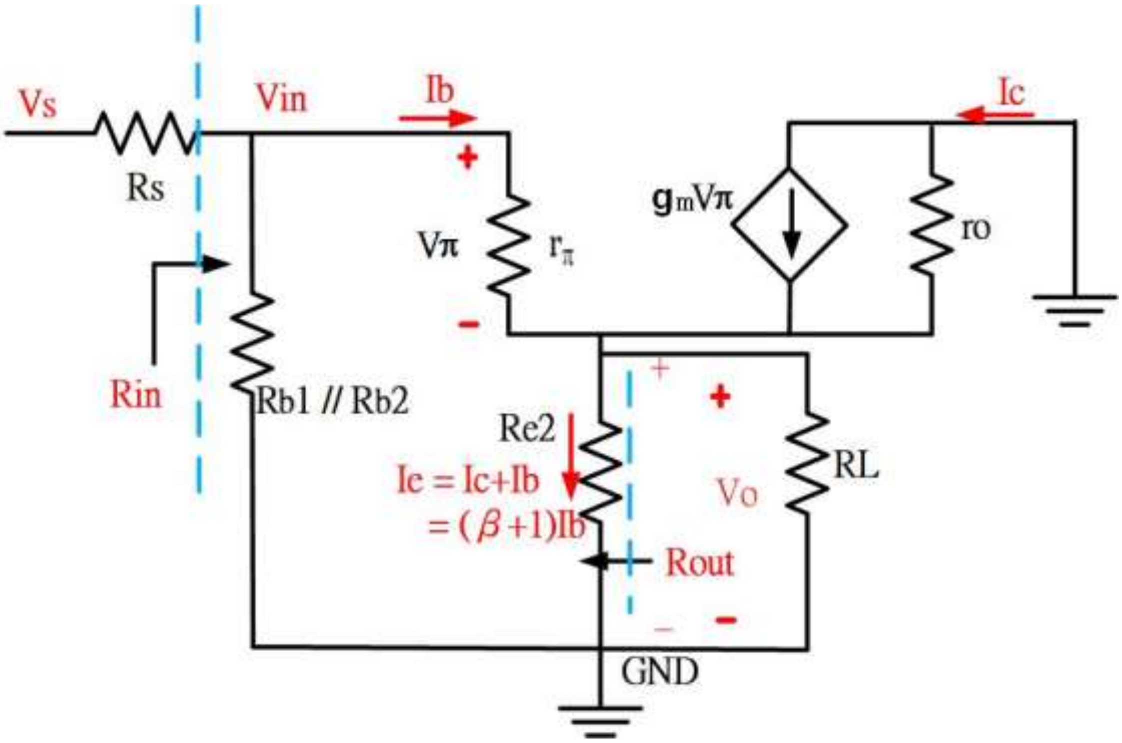


圖 7-2　BJT 電晶體共集電路小訊號模型[3]

- 輸入電阻:

$$\begin{aligned} R_{in} = &\ R_{b1}//R_{b2}//(r_\pi + (1+\beta)(r_o//R_{e2}//R_L)) \\ &\le R_{b1}//R_{b2}//(r_\pi + (1+\beta)(R_{e2}//R_L)) \end{aligned} \tag{7.3}$$

$$\mathrm{r}_\pi = \frac{\beta V_T}{I_{CQ}} \tag{7.4}$$

熱電壓(Thermal Voltage):

$$V_T = 25 \times 10^{-3}\ V\ \ (室溫)$$

- 輸出電阻:

$$R_{out} = \left(\frac{R_S//R_{b1}//R_{b2} + r_\pi}{1+\beta}\right)//r_o//R_{e2}$$

$$\le \left(\frac{R_S//R_{b1}//R_{b2}+r_\pi}{1+\beta}\right)//R_{e2} \tag{7.5}$$

- **BJT 電晶體共集電路小訊號等效電路範例 1[3]**

Example 4.10 **Objective:** Calculate the small-signal voltage gain of an emitter-follower circuit.

For the circuit shown in Figure 4.44, assume the transistor parameters are: $\beta = 100$, $V_{BE}(\text{on}) = 0.7\text{ V}$, and $V_A = 80\text{ V}$.

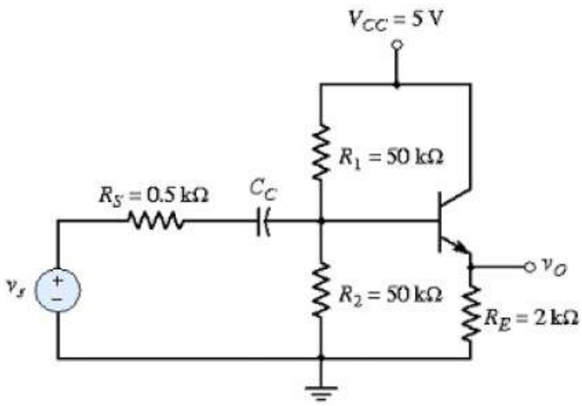
Solution: The dc analysis shows that $I_{CQ} = 0.793\text{ mA}$ and $V_{CEQ} = 3.4\text{ V}$. The small-signal hybrid-π parameters are determined to be

$$r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.026)(100)}{0.793} = 3.28\text{ k}\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.793}{0.026} = 30.5\text{ mA/V}$$

and

$$r_o = \frac{V_A}{I_{CQ}} = \frac{80}{0.793} \cong 100\text{ k}\Omega$$



We may note that

$$R_{ib} = 3.28 + (101)(100\|2) = 201\text{ k}\Omega$$

and

$$R_i = 50\|50\|201 = 22.2\text{ k}\Omega$$

The small-signal voltage gain is then

$$A_v = \frac{(101)(100\|2)}{3.28 + (101)(100\|2)} \cdot \left(\frac{22.2}{22.2 + 0.5}\right)$$

or

$$A_v = +0.962$$

例題 2: 參考圖 7-3-1 共集放大電路模擬圖:

- 找出 Q-point 的 V_{CEQ} 、 I_{BQ} 與 I_{CQ}，β = I_{CQ} / I_{BQ} = ?
- 計算輸出入電阻 Rin , Rout，並修改該電路模擬圖 7-3-1 驗證該輸出入電阻計算值是否相近。
- 計算 Av = ? 比較理論值與模擬電路輸出入 Vp-p 波形比率值。

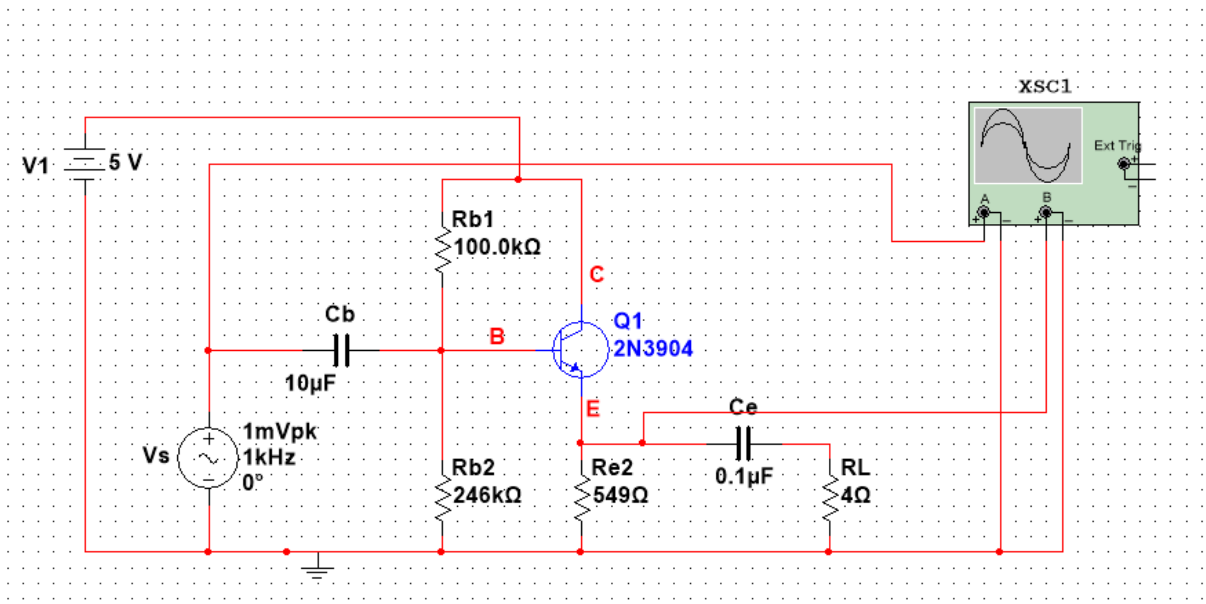


圖 7-3-1 共集放大電路模擬圖

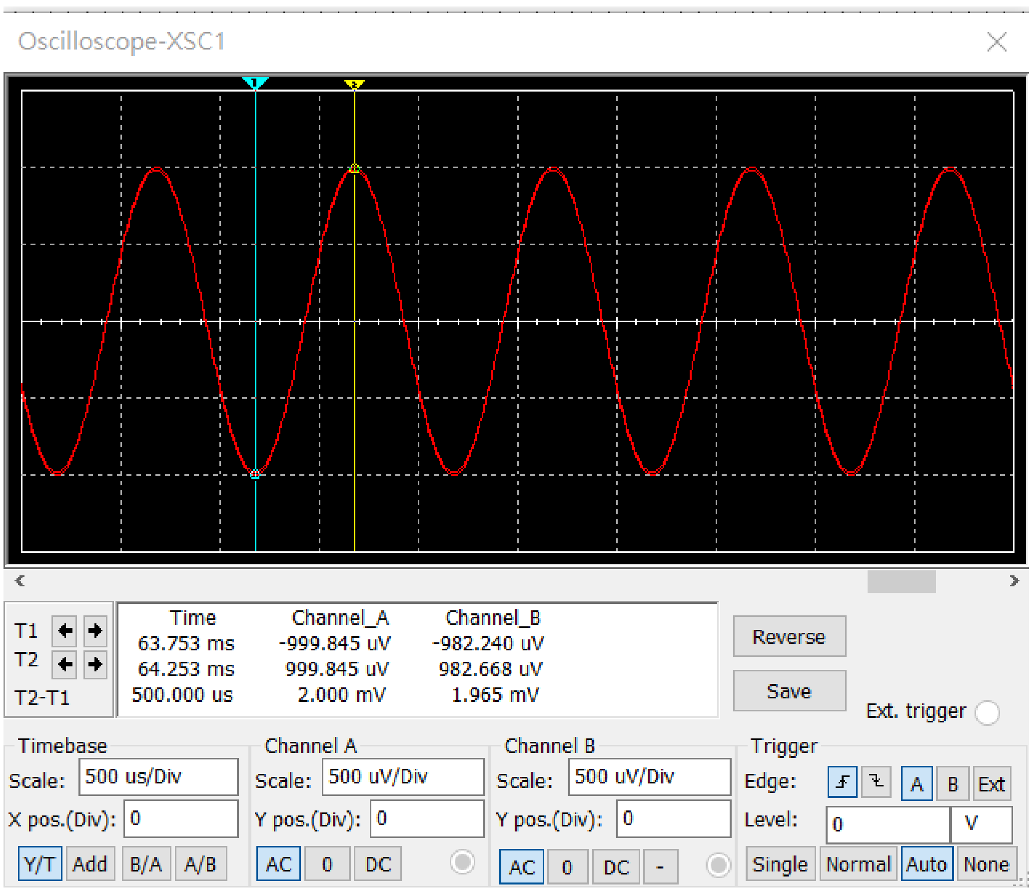


圖 7-3-2　輸入端 Vs 輸入波形與電阻 Re2 端輸出波形(因兩者同相位，波形重疊), Av = 1.965/2 = 0.9825

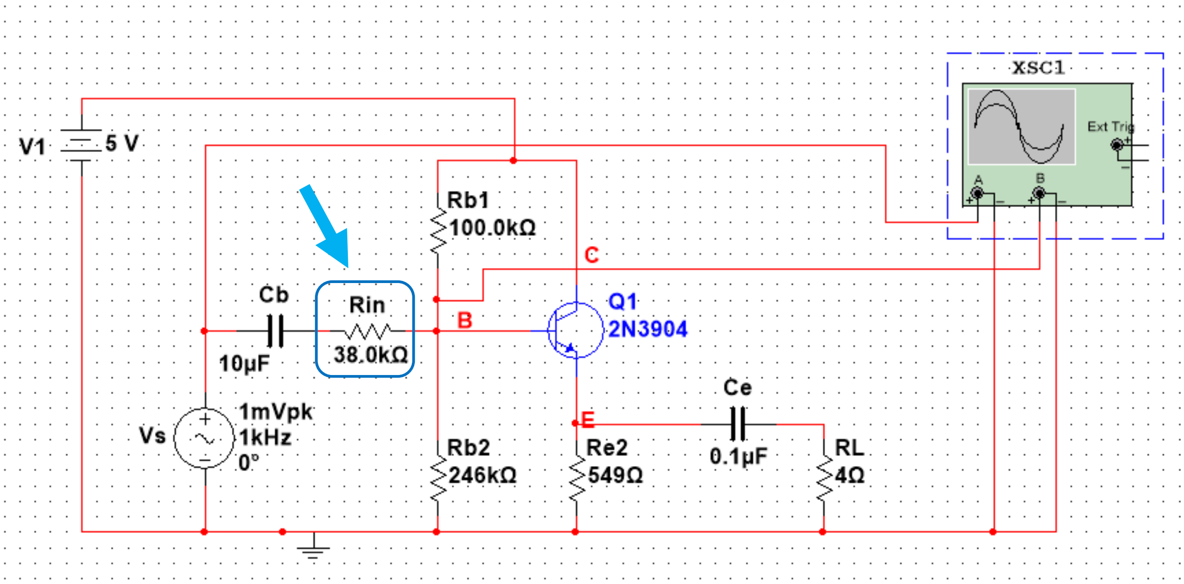


圖 7-3-3 輸入電阻 Rin = 38.0 KΩ

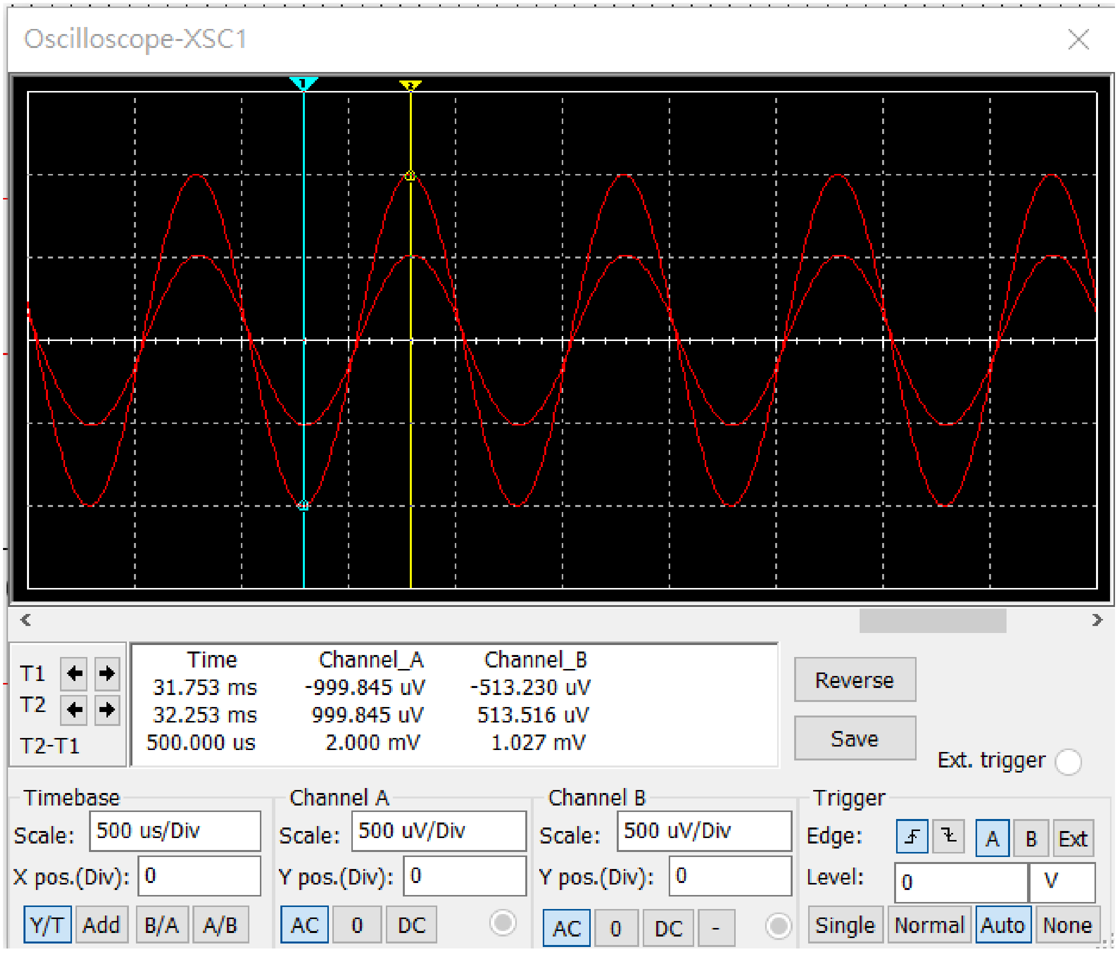


圖 7-3-4 VB 端電壓波形為輸入波形 Vs 的半值

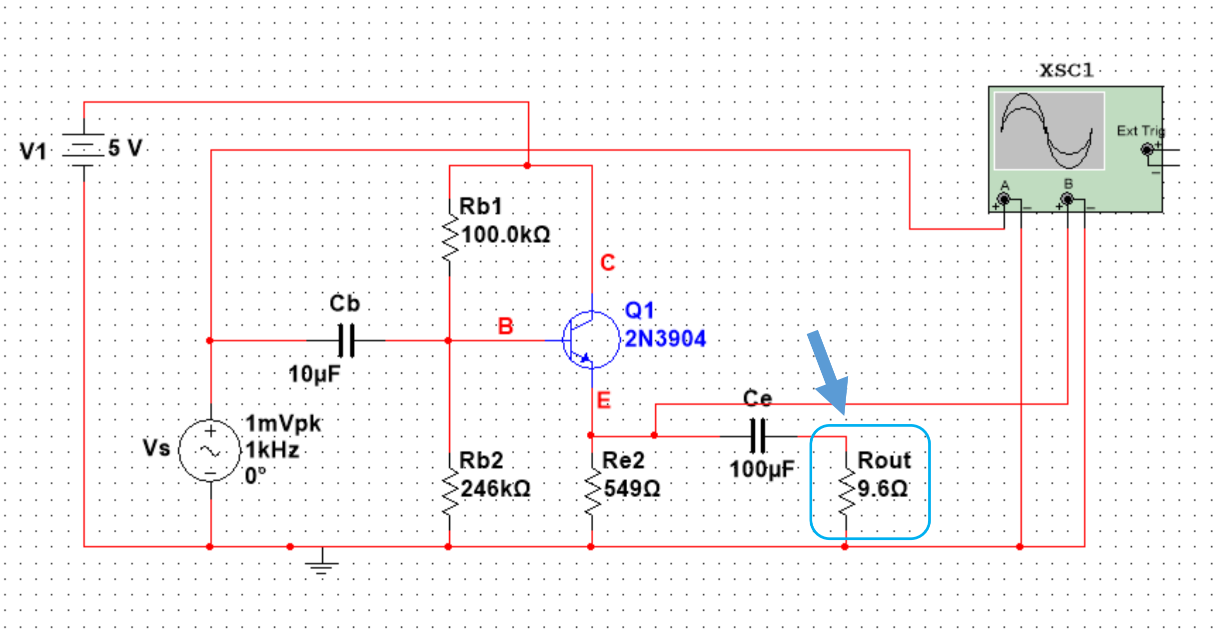


圖 7-3-5　輸出電阻 Rout = 9.6 Ω

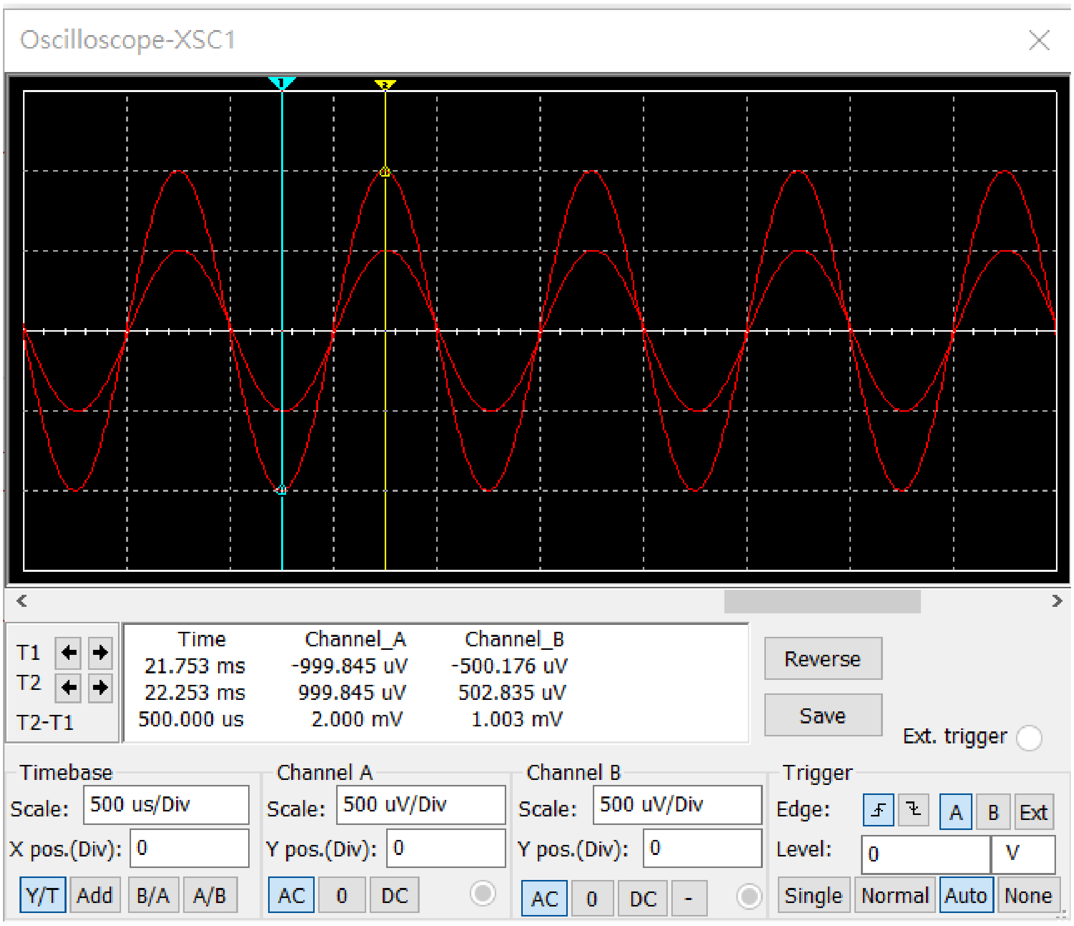
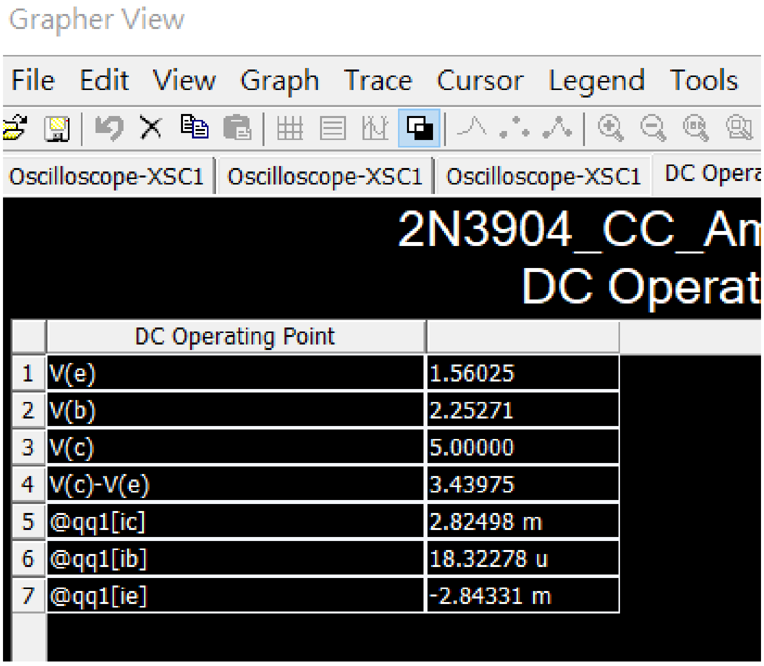


圖 7-3-6　電阻 Re2 端電壓波形為輸入波形 Vs 的半值



	DC Operating Point	
1	V(e)	1.56025
2	V(b)	2.25271
3	V(c)	5.00000
4	V(c)-V(e)	3.43975
5	@qq1[ic]	2.82498 m
6	@qq1[ib]	18.32278 u
7	@qq1[ie]	-2.84331 m

圖 7-3-7 VCEQ = Vc – Ve = 3.44V, $\beta = I_{CQ} / I_{BQ}$ = 2.824m/18.32u = 154.14

- 輸入電阻:

熱電壓(Thermal Voltage): $V_T = 25 \times 10^{-3}\ V$ (室溫)

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{154 * 0.026}{2.824 * 10^{-3}} = 1.417\ \text{K}\Omega$$

$$\begin{aligned} R_{in} = \ & R_{b1}//R_{b2}//(r_\pi + (1+\beta)(r_o//R_{e2}//R_L)) \\ & \le R_{b1}//R_{b2}//(r_\pi + (1+\beta)(R_{e2}//R_L)) \\ & = 100\text{K}//246\text{K}//(1.417\text{K} + (1+154)(549//4)) = 1{,}976\ \ \Omega \end{aligned}$$

(此答案與圖 7-3-3 輸入電阻 Rin = 38.0 KΩ 落差明顯)

若考量 Ce = 0.1uF 電容效應(即容抗 1/jwc),則上面公式需修改為

$$\begin{aligned} R_{in} = \ & R_{b1}//R_{b2}//(r_\pi + (1+\beta)(r_o//R_{e2}//(R_L\ + 1/jwc)) \\ & \le R_{b1}//R_{b2}//(r_\pi + (1+\beta)(R_{e2}//(R_L\ + 1/jwc))) \\ & = 100\text{K}//246\text{K}//(1.417\text{K} + (1+154)(549//(4 \\ & \qquad + \frac{1}{j * 1000 * 2\pi * 0.1 * 10^{-6}}))) \\ & = 100\text{K}//246\text{K}//(1.417\text{K} + (1+154)(549//(4 - 1.59 * 10^3 j) \\ & = 38.52\text{K}\ \angle -8.69^\circ\ \ \Omega \end{aligned}$$

(此答案與圖 7-3-3 輸入電阻 Rin = 38.0 KΩ 相差甚小)

- 輸出電阻:

$$R_{out} = (\frac{R_S//R_{b1}//R_{b2} + r_\pi}{1+\beta})//r_o//R_{e2}$$

$$\leq (\frac{R_S//R_{b1}//R_{b2}+r_\pi}{1+\beta})//R_{e2}$$

$$= \frac{0+1417}{155} \ // \ 549 \ \ = 9.0 \ \ \Omega$$

(此答案與 圖 7-3-5 輸出電阻 Rout = 9.6 Ω 相差不遠)

- 電壓放大率:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{(1+\beta)(R_{e2}//R_L)}{R_{b1}//R_{b2}//(r_\pi+(1+\beta)(R_{e2}//R_L))} = \frac{(1+\beta)(R_{e2}//R_L)}{R_{in}} = \frac{(1+\beta)(R_{e2}//R_L)}{r_\pi+(1+\beta)(R_{e2}//R_L)} \cong 1$$

若不考量 Ce =0.1uF 電容效應(即容抗 1/*jwc*)，電壓放大率遠小於 1，如下計算:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{(1+\beta)(R_{e2}//R_L)}{r_\pi+(1+\beta)(R_{e2}//R_L)} = \frac{(1+154)*(549//9.6)}{2032} = 0.3028$$

若考量 Ce = 0.1uF 與 Cb =10uf 電容效應，電壓放大率接近於 1，如下計算:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{(1+\beta)(R_{e2}//(R_L + 1/jwc_e)}{r_\pi + (1+\beta)(R_{e2}//(R_L + 1/jwc_e) + 1/jwc_b}$$

$$= \frac{(1+154)(549//(4-1.59*10^3 j)}{1417 + (1+154)(549//(4-1.59*10^3 j) - 15.91j}$$

$$= 0.9835\angle -0.3131°$$

(此理論值與圖 7-3-2 Av = 0.9825 非常接近)

二、作業:

作業 7-1: 共集電路模擬圖如圖 7-4 ，

- 找出 Q-point 的 V_{CEQ} 、 I_{BQ} 與 I_{CQ}，$\beta = I_{CQ} / I_{BQ}$ = ?
- 計算輸出入電阻 Rin , Rout，並修改該電路模擬圖 7-4 驗證該輸出入電阻與理論值是否相近。
- 計算 Av = ? 比較理論值與模擬電路輸出入 Vp-p 波形比率值。

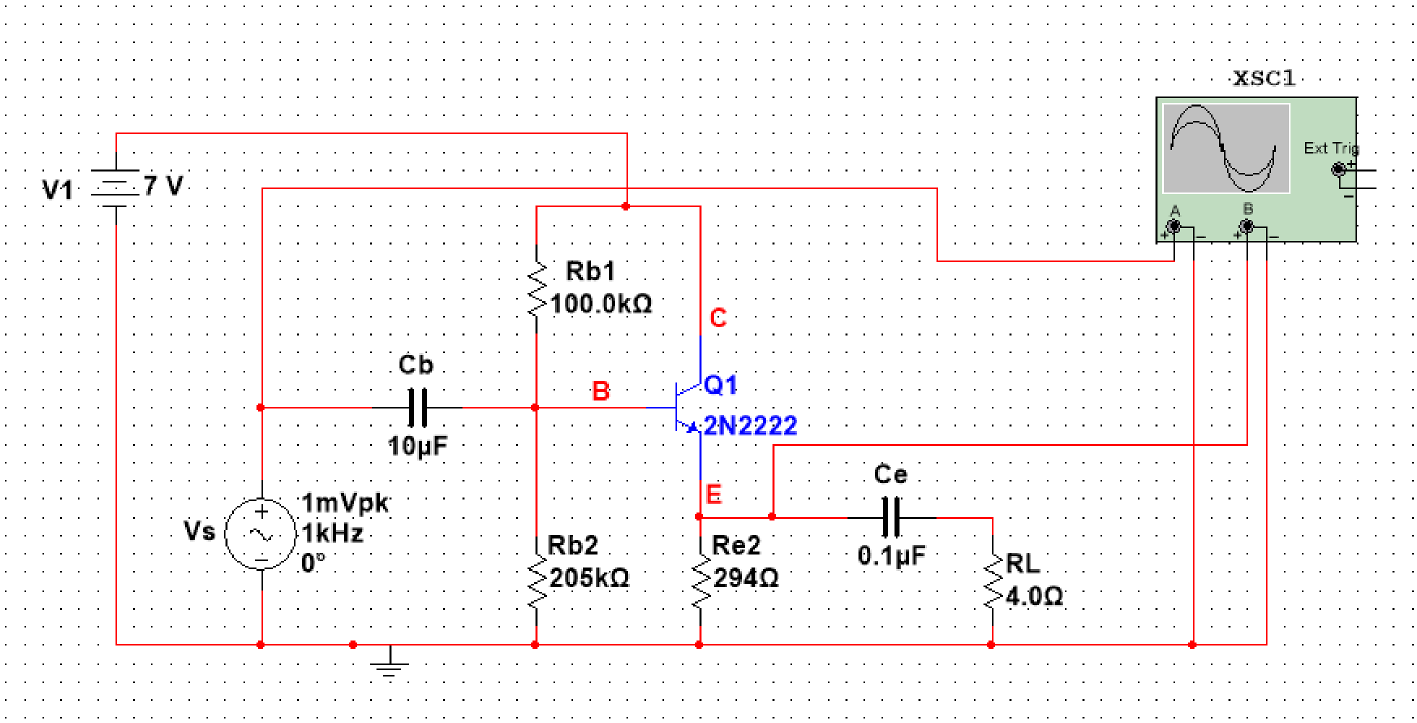


圖 7-4 作業 7-1 共集電路模擬圖

作業 7-2: 續上題，

- 計算輸出入電阻 Rin , Rout，與電路模擬圖 7-4 有極大的差異，請問該如何修改。
- 在模擬圖 7-3-5 驗證 Rout = 9.6Ω，為何 Ce = 0.1uf 改為 Ce = 100uf ? 請說明。

附錄: 計算 Rin 與 Av 的 Matlab 程式

```
function result = calpara(a, b)
 result =  a*b/(a + b);
end
```

```
% 計算 Rin

Rb1 = 100e3;
Rb2 = 246e3;
Ce = 0.1e-6;
f = 1000;
beta = 154;
Re2 = 549;
RL = 4;
rpi = 1417;

%不考量Ce容抗之Rin計算
a = rpi + (1+beta)*calpara(Re2, RL);
b = calpara(Rb1, Rb2);
Rin_1 = calpara(a, b)

%考量Ce容抗之Rin計算
a =  rpi + (1+beta)*calpara(Re2, RL-i/(2*pi*f*Ce))
Rin_2 = calpara(a, b)
abs(Rin_2)
angle(Rin_2)*360/(2*pi)
```

```
% 計算 Av
Rb1 = 100e3;
Rb2 = 246e3;
Ce = 0.1e-6;
f = 1000;
beta = 154;
Re2 = 549;
RL = 4;
rpi = 1417;
```

```
Cb = 10e-6;

%不考量Cb,Ce容抗之Av計算
a = rpi + (1+beta)*calpara(Re2, RL);
Rbb = calpara(Rb1, Rb2);
Rin_1 = a
Av_1 =  (1+beta)*calpara(Re2, RL)/Rin_1

%考量Cb,Ce容抗之Av計算
a2 =  rpi+ (1+beta)*calpara(Re2, RL-i/(2*pi*f*Ce))
Rin_2 = a2 -i/(2*pi*f*Cb)
Av_2 =  (1+beta)*calpara(Re2, RL-i/(2*pi*f*Ce))/Rin_2
abs(Av_2)
angle(Av_2)*360/(2*pi)
```