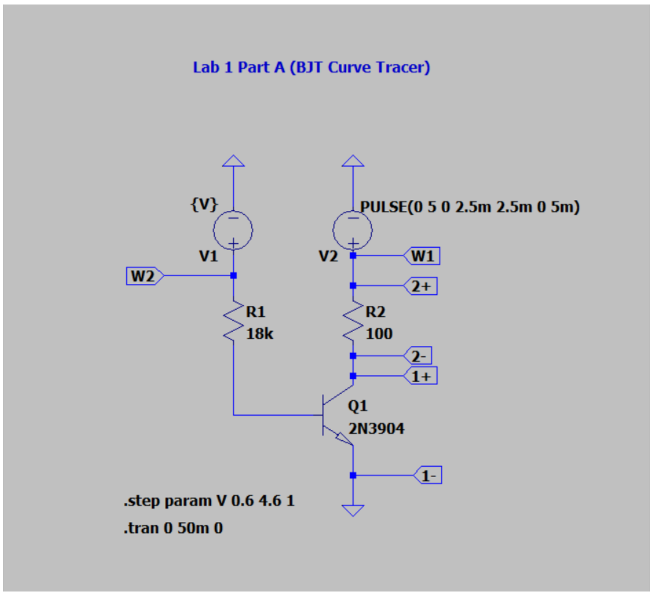
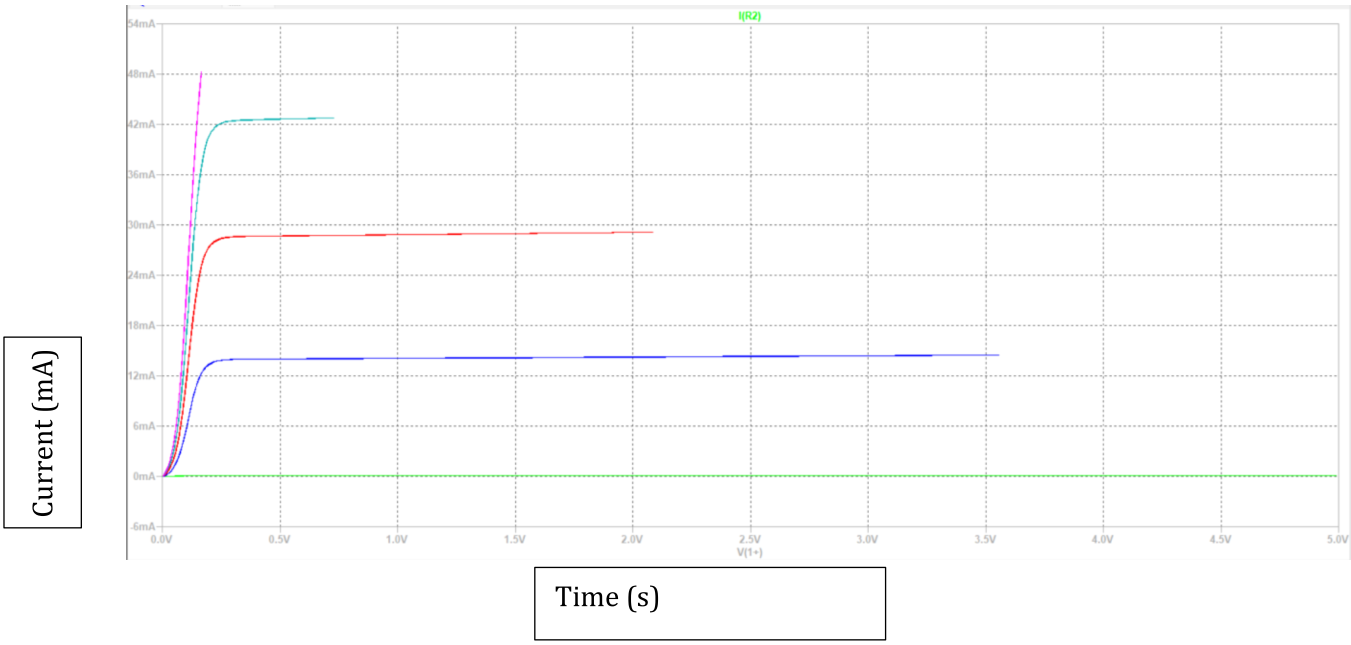
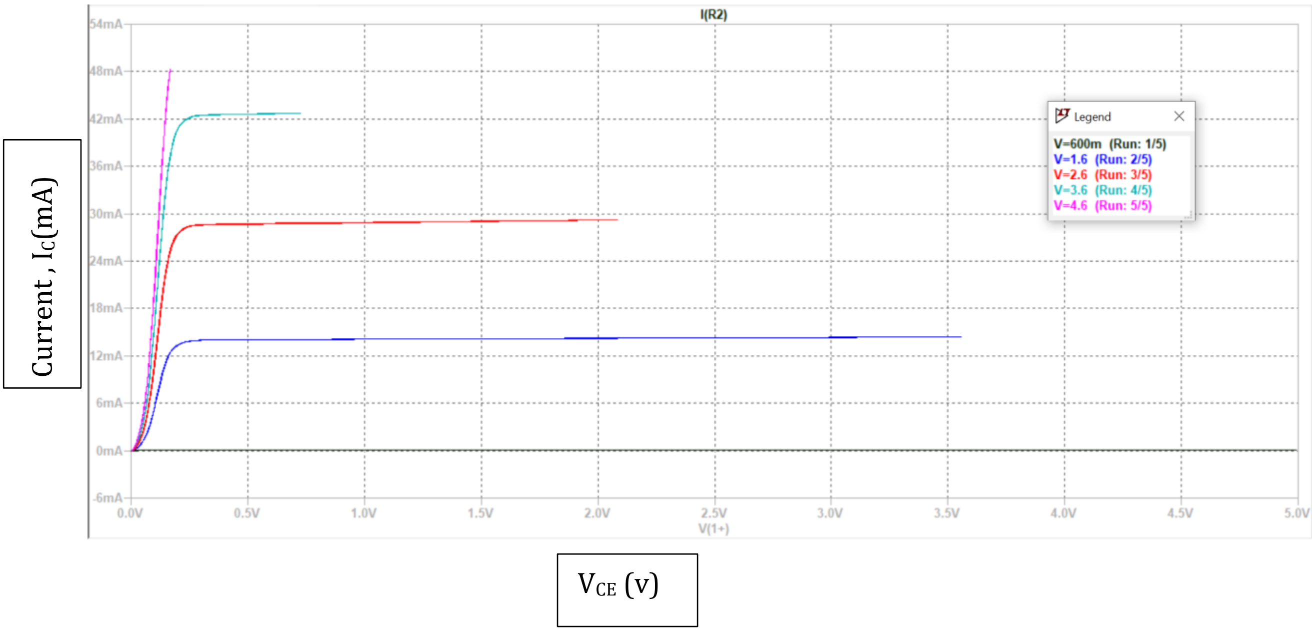
Lab 2 BJT Curve Tracer 1 (Common Emitter)

1 LTspice Simulations (Pre-lab)

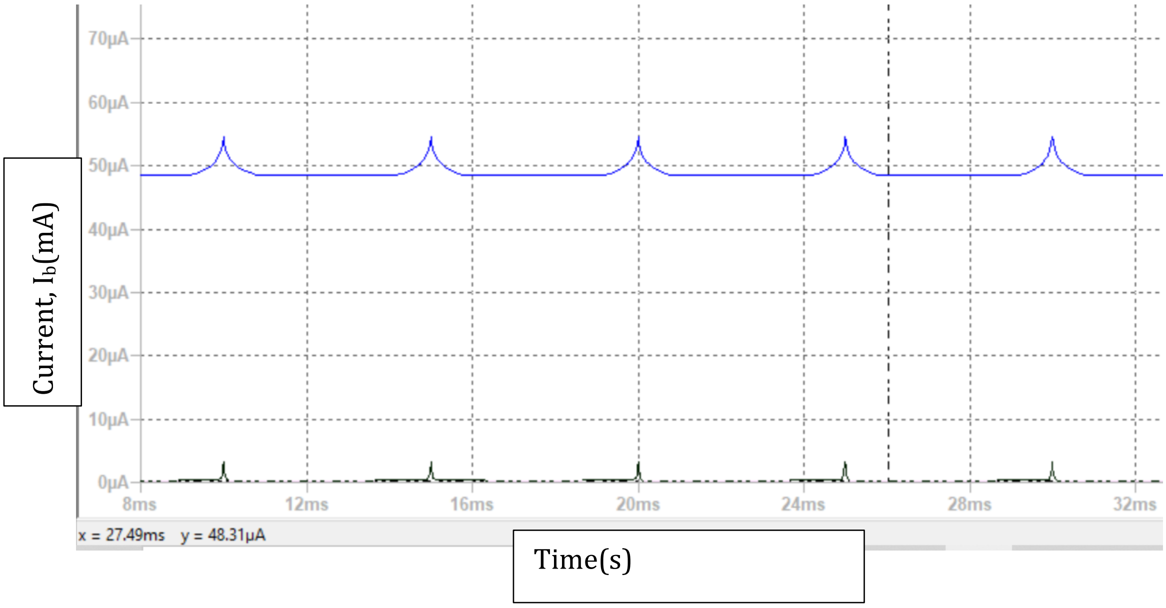
(a) Plot I_C vs V_{CE} using X-Y plot and export the plot to be included in your lab report. In your XY plot, X-Axis should be VCE and Y-Axis should be IC. Include the circuit schematic in the report. **(1 mark)**







A zoom-in measurement of I_c-V_{CE} graph for the 2nd line



(b) From the plot, calculate the (forward) **large-signal current gain** at a chosen current, Beta ($\beta = I_C/I_B$). **(1 mark)**

$$\beta = \frac{I_C}{I_B}$$

Compare your calculated gain to that of the value (hFE) in 2N3904 datasheet. **(1 mark)**

$$I_B = 48.31\ \mu A$$

$$I_C = 14.00\ mA$$

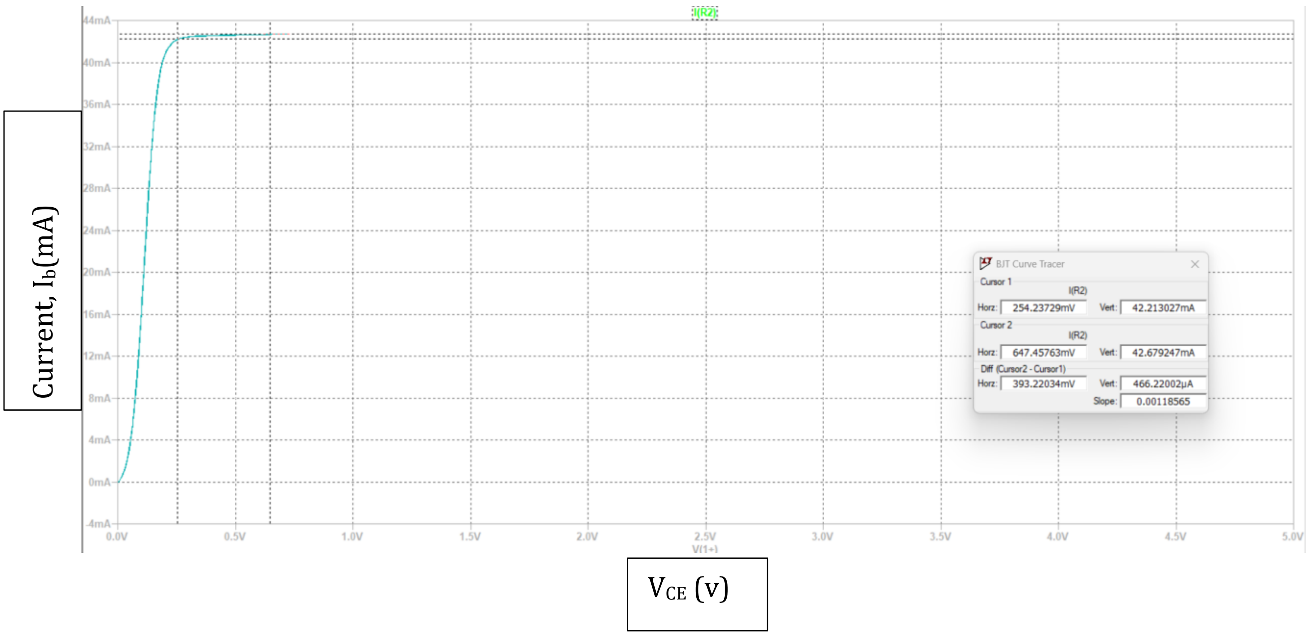
$$\beta = \frac{I_C}{I_B} = \frac{14.00\ mA}{48.31\ \mu A} = 289.80$$

Based on the datasheet, the value of β is approximately 300.

$$300 - 289.80 = 10.2$$

There is a slight difference between the data sheet and the theoretical value due to the systematic error caused during the reading of the graph.

(c) Using the curve for the 3.6V step, estimate the **Early voltage**, V_A. **(1 mark)**



We can determine the long forward active portion of the graph. From here, we will take out the value of the two points. From these two points, we can calculate the gradient of the graph. LTSpice will automatically calculate the gradient of the graph

$$
\begin{aligned}
m &= 0.00118565 \\
Y &= mX + C \\
42.679247mA &= 0.00118565 * (647.45763mV) + C \\
C &= 0.0415
\end{aligned}
$$

The early voltage can be obtained by finding the x-intercept of the linear line

$$-Va = -\frac{0.0415}{0.00118585} = 35.0\,V$$

(d) Calculate the **small-signal output resistance** at this current, $r_o = V_A/I_C$. **(1 mark)**

Measured from the graph, I_c= 42.65mA when V_{w2}=3.6 V

$$r_o = \frac{35V}{42.65\,mA} = 820.63\Omega$$

2 Experimental Work (pre-lab and in-lab)

PART A: CREATE A SET OF I_C VS. V_{CE} CURVES

Report (you may have to refer to lecture note or wiki for definitions):

a. Using the XY plot function in Scopy to plot I_C *vs.* V_{CE}, and export the plot to be included in your lab report. In your XY plot, X-Axis should be CH 1, Y-Axis should be CH 2.

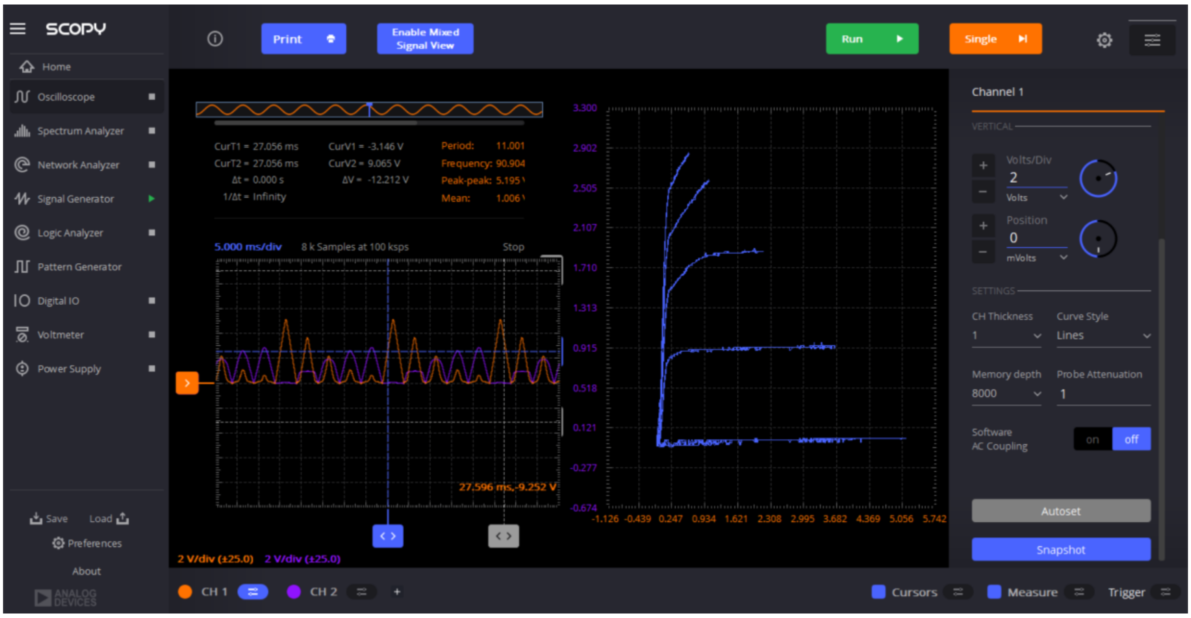


Fig. 1. I_c-V_{CE} graph (Right), y-axis is I_c and x-axis is V_{CE}

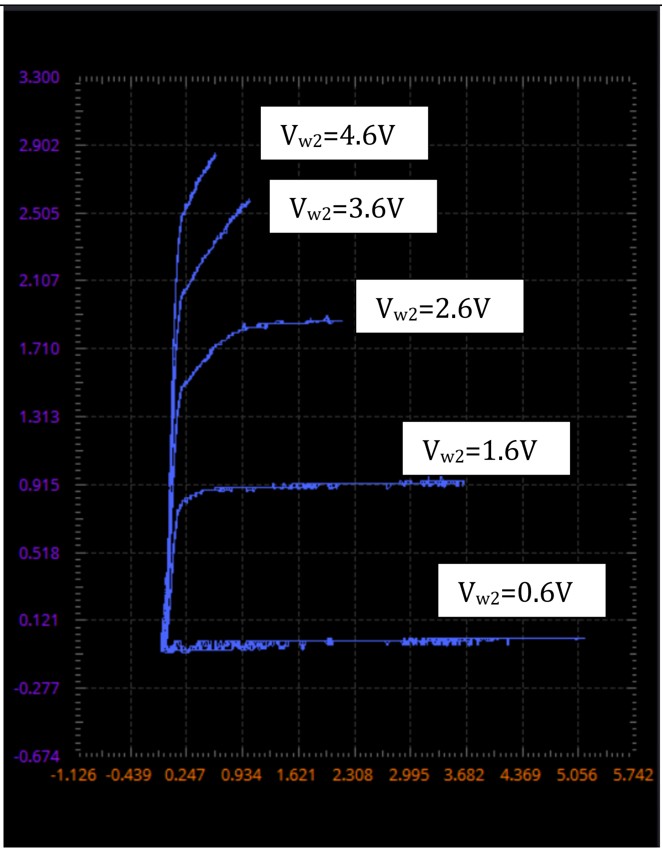


Fig. 2. I_c-V_{CE} graph, y-axis is I_c and x-axis is V_{CE}

Fig 1. Ic-Vce graph

b. From the measured data calculate the (forward) **large-signal current gain** at a chosen current, Beta ($\beta = I_C/I_B$).

In order to calculate beta, β, we would need to calculate I_B and I_C.
Assuming V_{BE} = 0.7V, and the resistor used is 18kΩ, and the choice of V_{W2} = 1.6V

I_B can be calculated using the following formula

$$I_B = \frac{V_{W2} - V_{BE}}{18\ k\Omega} = \frac{1.6\ V - 0.7\ V}{18\ k\Omega} = 0.05\ mA$$

I_C can be calculated by taking the voltage across resistor R2 and divide the value with the resistance value of R2. The voltage value is taken from the graph below.

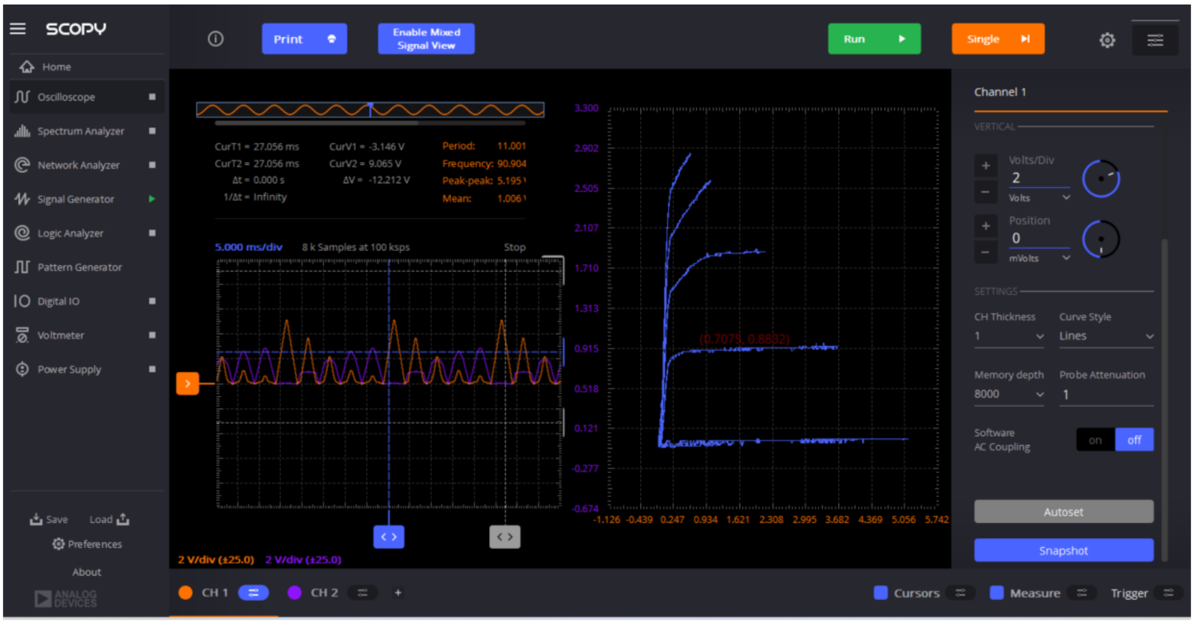


Fig. 3. I_c-V_{CE} graph (Right), y-axis is I_c and x-axis is V_{CE}

$$I_C = \frac{V_{100\Omega}}{100\ \Omega} = \frac{0.8832\ V}{100\ \Omega} = 8.832\ mA$$

With both of the values, we can then calculate our β value using the following formula

$$\beta = \frac{I_C}{I_B}$$

We will obtain

$$\beta = \frac{8.832\ mA}{0.05\ mA} = 176.64$$

c. Identify the Forward-Active regions in the curves. Use the highest-current curve that has a reasonably long forward-active portion to avoid the knees of the curves, and estimate the **Early voltage**, V_A.

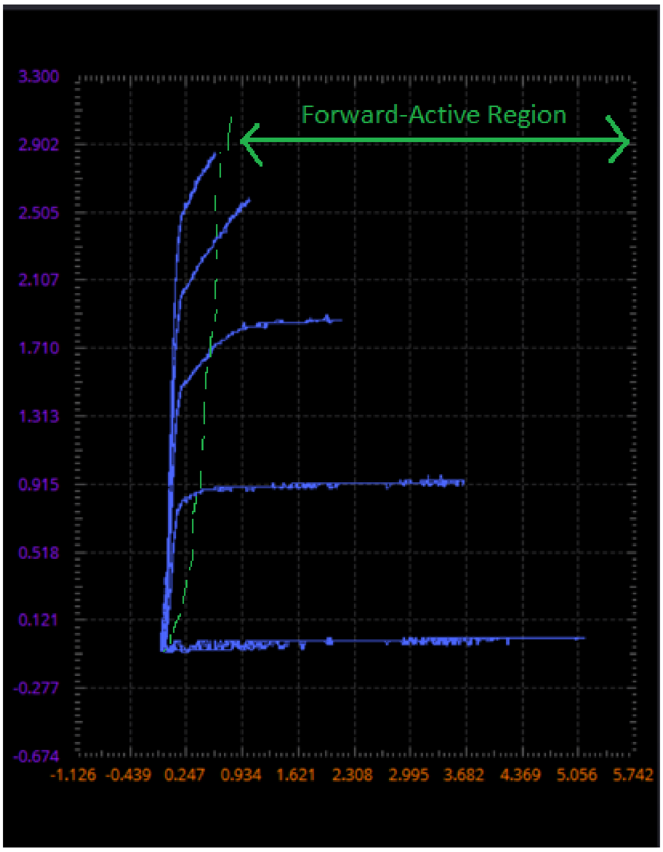


Fig. 4. I_c-V_{CE} graph, y-axis is I_c and x-axis is V_{CE}, and the label forward-active region

The identified curve is the 2nd curve

Fig. 5. I_c-V_{CE} graph (Right), y-axis is I_c and x-axis is V_{CE}, label point 1

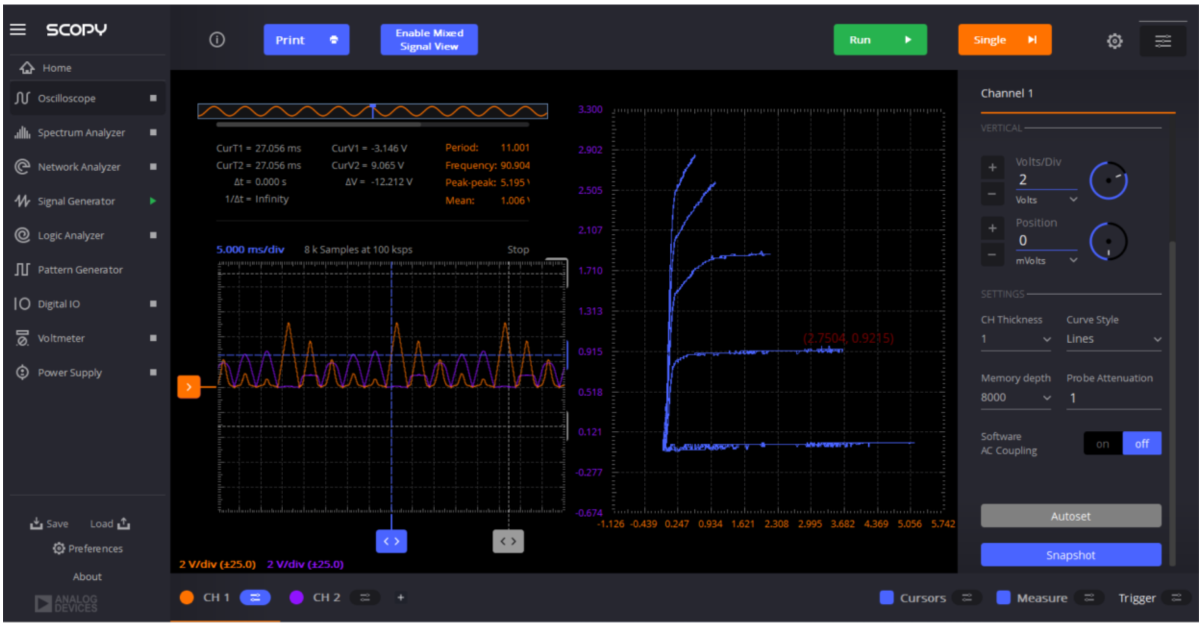


Fig. 6. I_c-V_{CE} graph (Right), y-axis is I_c and x-axis is V_{CE}, label point 2

Fig. 6. I_c-V_{CE} graph (Right), y-axis is I_c and x-axis is V_{CE}, label point 3

At here,we can take two points from one of the highest-current curve that has a reasonably long forward-active portion. In this case, it would be when V_{W2} = 1.6V. The two points obtained is shown on the graph above.

The two points are as follows:
Point 1 (0.6015, 0.8832)
Point 2 (3.682, 0.9215)

From here, we will need to calculate the gradient from the two measured points

$$m = \frac{\frac{0.9215-0.8832}{100}}{3.682-0.6015} = 0.000124$$

Now, we will need to obtain the y-intercept from the formula y = mx + c. We can just substitute one of the points into our equation and the gradient calculated from above.

$$\frac{0.9215}{100} = 0.000124\ (3.682) + c$$

We will obtain c to be

$$c = 0.008758$$

Now, we can obtain the Early Voltage by finding the x-intercept of the line, $I_C = 0\ mA$

$$I_C = 0.000124\ V_{CE} + 0.008758$$

$$Va = 70.629\ V$$

d. Calculate the **small-signal output resistance** at this current, $r_o = V_A/I_C$. Does this fit with the slope of the curve?

$$r_o = \frac{V_A}{I_C} = \frac{70.629}{8.832\ mA} = 7996.94\ \Omega$$

$$gradient\ from\ r_o\ = \frac{1}{7996.94}\ =\ 1.250\ \times\ 10^{-4}$$

The computed value from r_o is very similar to the value of gradient found from the graph.

$$|1.250\ \times\ 10^{-4} - 0.000124| = 1 \times 10^{-6}$$

Percentage of error is

$$\frac{1 \times 10^{-6}}{1.25 \times 10^{-4}} * 100\% = 0.8\%$$

The error is almost negligible, and it might be contributed from the systematic error of reading the graph. Yes, this fit with the slope of the curve.

e. Where possible, compare your results with the manufacturer's specifications in the datasheet.

h_{FE}*	DC Current Gain	I_C = 0.1 mA I_C = 1 mA I_C = 10 mA I_C = 50 mA I_C = 100 mA	V_{CE} = 1 V V_{CE} = 1 V V_{CE} = 1 V V_{CE} = 1 V V_{CE} = 1 V	60 80 100 60 30		300	

Output Admittance (I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{oe}	1.0	40	μmhos

Fig. 7. Datasheet values for 2N3904 Transistor

As we can see from the datasheet, the stated range for the β value is between 100 to 300. As our measure value is 176.64, the value lies in between the specified range. The measured value is acceptable.

For the small-signal output resistance, we can compute it from the output admittance,

$$\frac{1}{40\mu\mho} = 25k\Omega \leq r_o \leq \frac{1}{1\mu\mho} = 1M\Omega$$

The small-signal output resistance that we measured, 7996.94 Ω falls outside of the range stated by the datasheet. The measured value is not acceptable.

PART B: A MORE ACCURATE APPROACH TO CREATE I_B

Report (you may have to refer to the lecture notes or Wiki):

a. Using the XY plot function in Scopy to plot I_C *vs.* V_{CE}, and export the plot to be included in your lab report. In your XY plot, X-Axis should be CH 1, Y-Axis should be CH 2.

Click the Hyperlink Scopy Oscilloscope if you are not sure about how to draw an XY plot.

When the resistor has a value of 10K

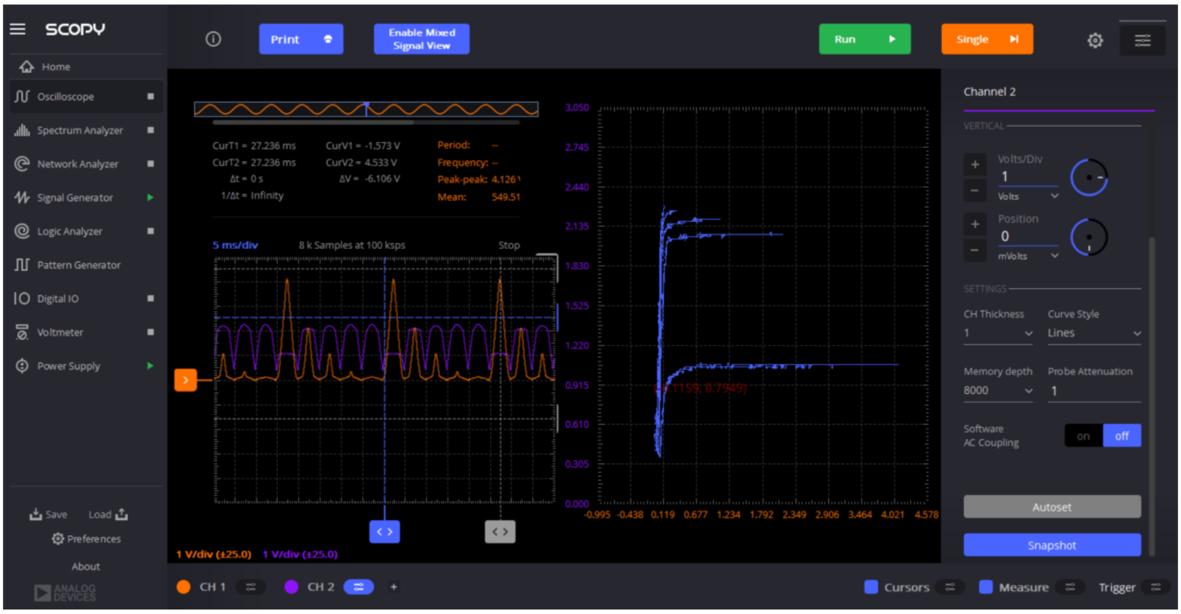


Fig. 8. I_c-V_{CE} graph (Right), y-axis is I_c and x-axis is V_{CE}, using 10kΩ resistor

When the resistor has a value of 24K

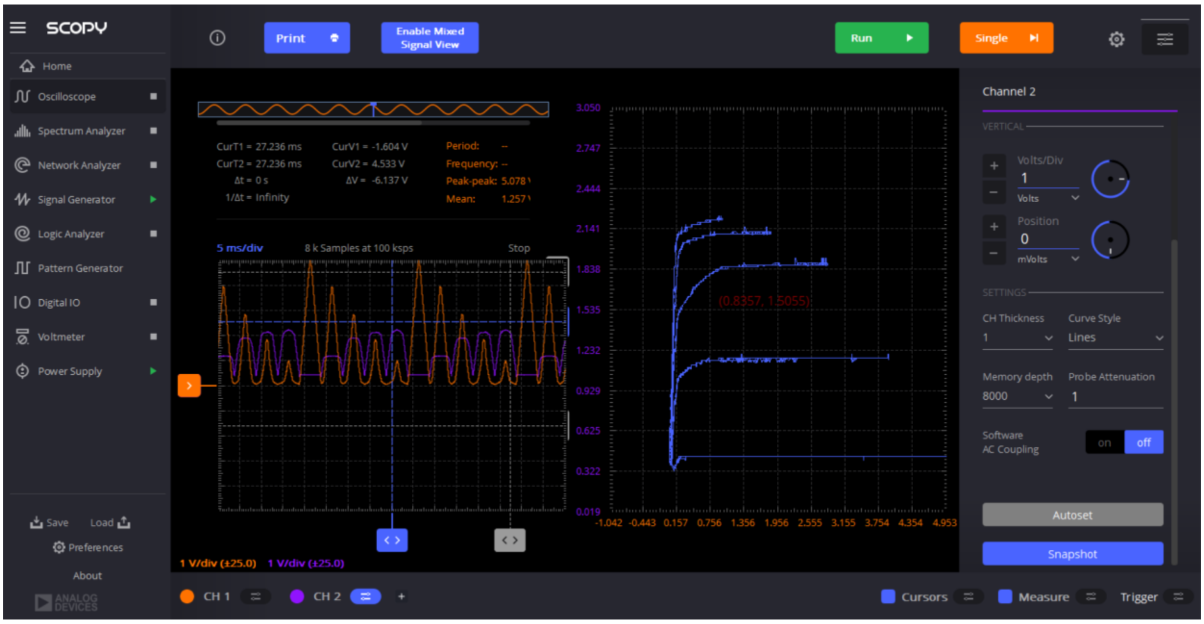


Fig. 9. I_c-V_{CE} graph (Right), y-axis is I_c and x-axis is V_{CE}, using 24kΩ resistor

b. Calculate the large-signal current gain **Beta** ($\beta = I_C/I_B$) from the measured data.

Assuming V_{w2}=2.6 and V_{be}=0.7V, using a 24kΩ resistor for a longer forward active region,

$$I_B = \frac{V_{W2} - V_{BE}}{24\ k\Omega} = \frac{2.6\ V - 0.7\ V}{24\ k\Omega} = 79.167\ \mu A$$

I_C can be calculated by taking the voltage across resistor R2 and divide the value with the resistance value of R2. The voltage value is taken from the graph below.

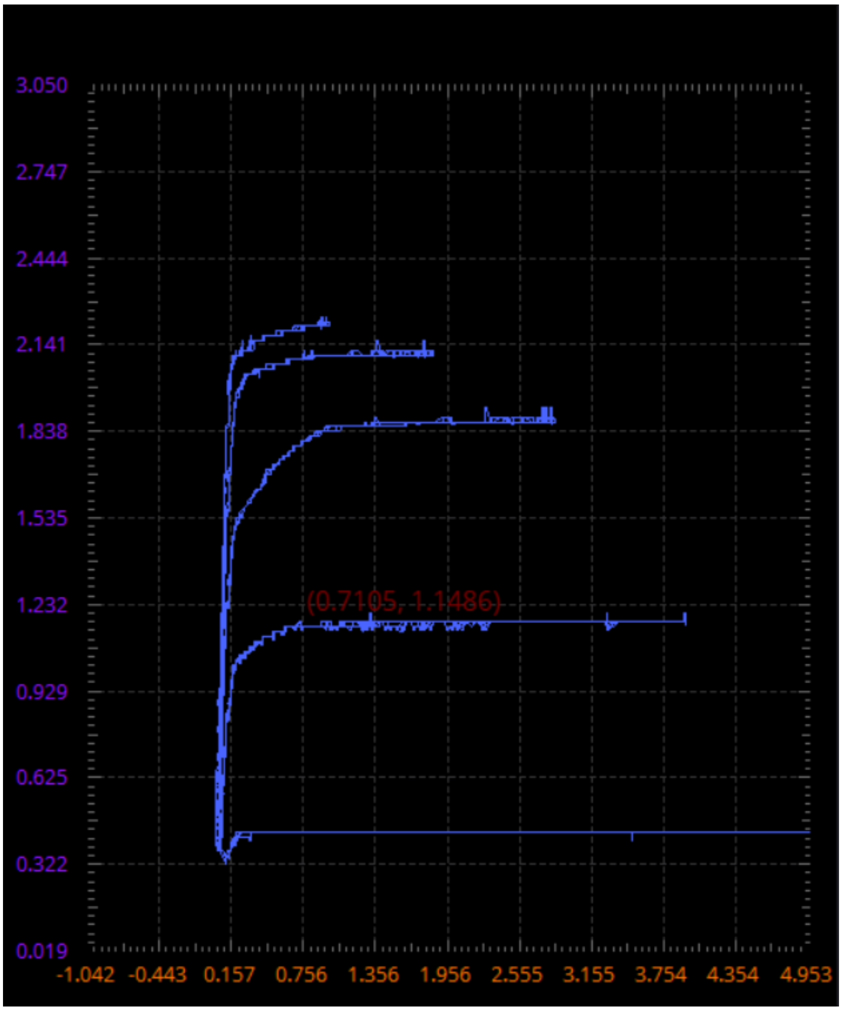


Fig. 10. I_c-V_{CE} graph, y-axis is I_c and x-axis is V_{CE}, label point 1

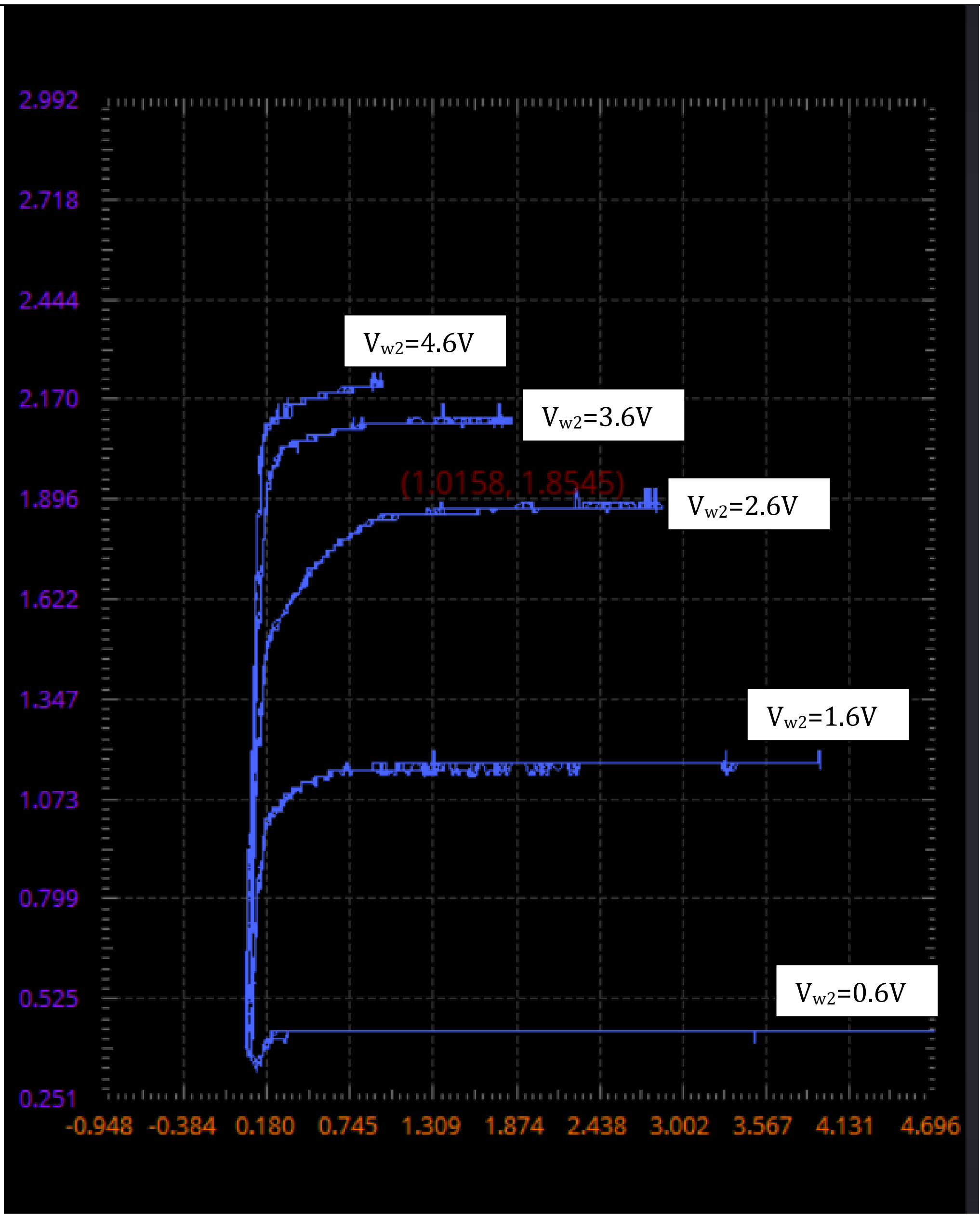


Fig. 11. I_c-V_{CE} graph, y-axis is I_c and x-axis is V_{CE}, label point 2

$$I_C = \frac{V_{100\,\Omega}}{100\,\Omega} = \frac{1.8545\ V}{100\,\Omega} = 0.018545\ A$$

With both of the values, we can then calculate our β value using the following formula

$$\beta = \frac{I_C}{I_B}$$

We will obtain

$$\beta = \frac{0.018545\ A}{79.167\ \mu A} = 234.25$$

c. Calculate the **Early voltage** from the I_C *vs.* V_{CE} curve.

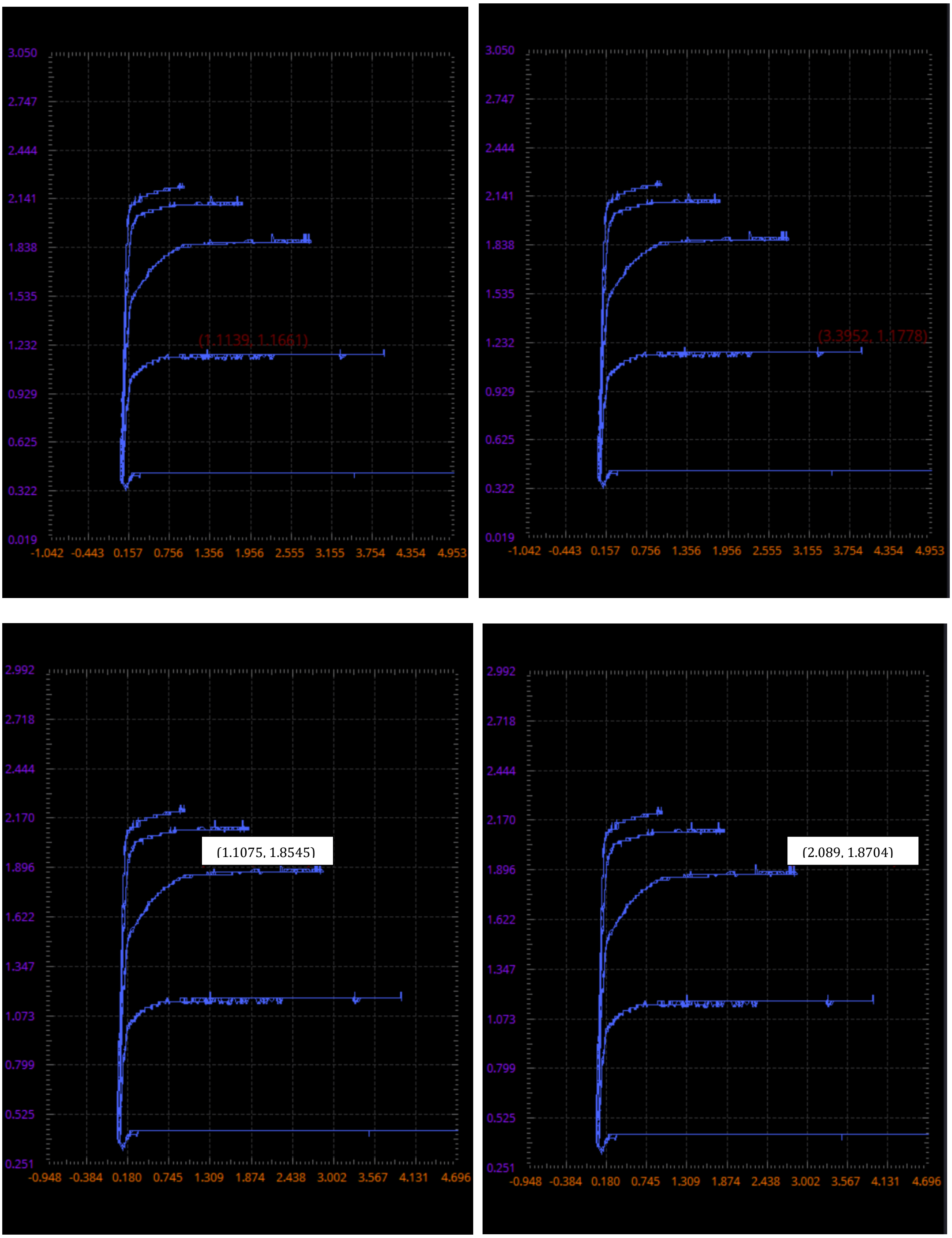


Fig. 12. I_c-V_{CE} graph, y-axis is I_c and x-axis is V_{CE}, label points

At here,we can take two points from one of the highest-current curve that has a reasonably long forward-active portion. In this case, it would be when V_{W2} = 2.6V. The two points obtained is shown on the graph above.

The two points are as follows:
Point 1 (1.1075, 1.8545)
Point 2 (2.089, 1.8704)

From here, we will need to calculate the gradient from the two measured points

$$m = \frac{\frac{1.8704 - 1.8545}{100}}{2.089 - 1.1075} = 0.000162$$

Now, we will need to obtain the y-intercept from the formula y = mx + c. We can just substitute one of the points into our equation and the gradient calculated from above.

$$\frac{1.8545}{100} = 0.000162\ (1.1075) + c$$

We will obtain c to be

$$c = 0.01837$$

Now, we can obtain the Early Voltage by finding the x-intercept of the line

$$I_C = 0.000162\ V_{CE} + 0.01837$$

$$Va = 113.4\ V$$

Acknowledgement

This labsheet is based on the Educational Programme of Analog Devices Inc. The original source can be found at https://wiki.analog.com/university/courses/electronics/electronics-lab-4. Please browse their educational pages for supporting material on ADALM2000, Scopy and the devices used in this lab.

For extra information, please go to https://wiki.analog.com/university/tools/adalm2000/users .

ASSESSMENT

Student Statement:

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Student signature: Tan Jin Chun, Izaac Chong Yen Juin Date: 16/3/2023

TOTAL: _______ (/10)

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All components must be kept by you, for future use (including the miniproject).