ECE/CoE 0101 – Linear Circuits and Systems
Laboratory # 5 – Power Transfer in Circuits

Objectives:

- Understand how to calculate Thevenin equivalent circuits
- Demonstrate that maximum power transfer is achieved for a given circuit when the load resistance is equivalent to the Thevenin resistance.

Introduction

This laboratory session builds upon the concepts demonstrated in Lab 3 on Thevenin's theorem. In that Lab you learned how the circuit shown in Figure 1, below, could be transformed into a Thevenin equivalent circuit as shown in Figure 2, below ($R_{\square}$ has a different value than that used in Lab 3). Here in Lab 4, we'll see how a Thevenin network, can be used as an equivalent model for the source circuit and how it interacts with a resistive load to deliver the maximum power to the load.

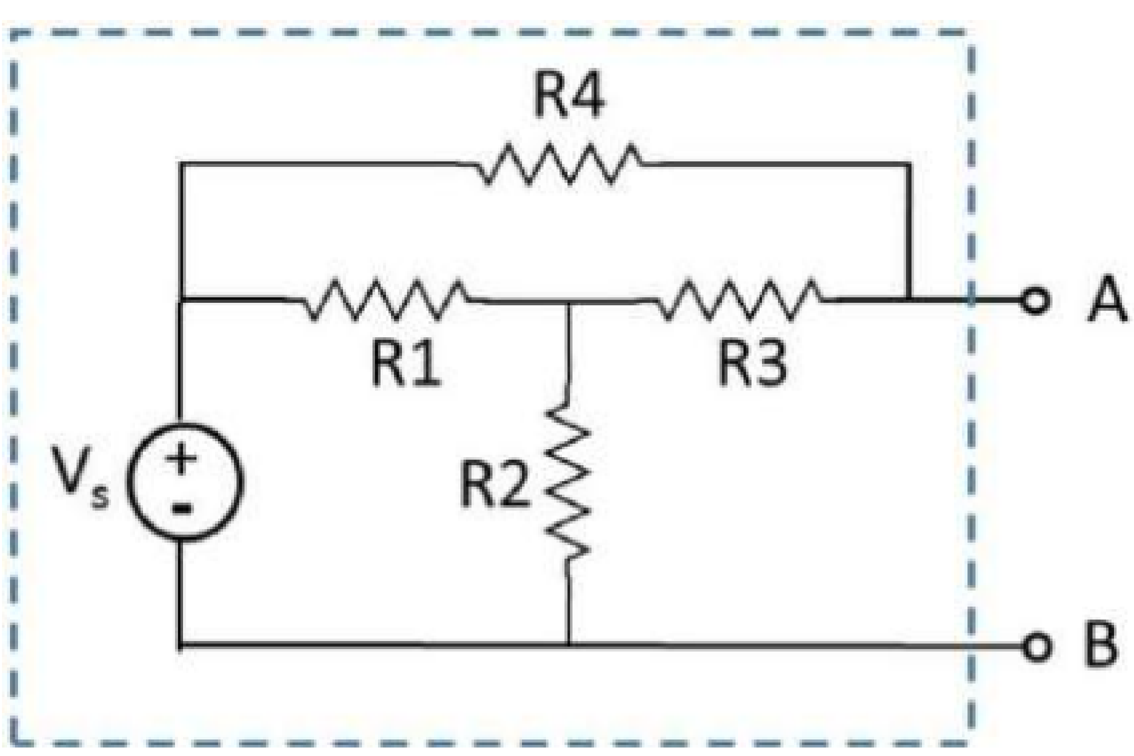


Figure 1 - Source circuit with the following given component values: V_s = 5V, R1 = 600 Ω, R2 = 1.2 kΩ, R3 = 1.8 kΩ, R4 = 3.9 kΩ.

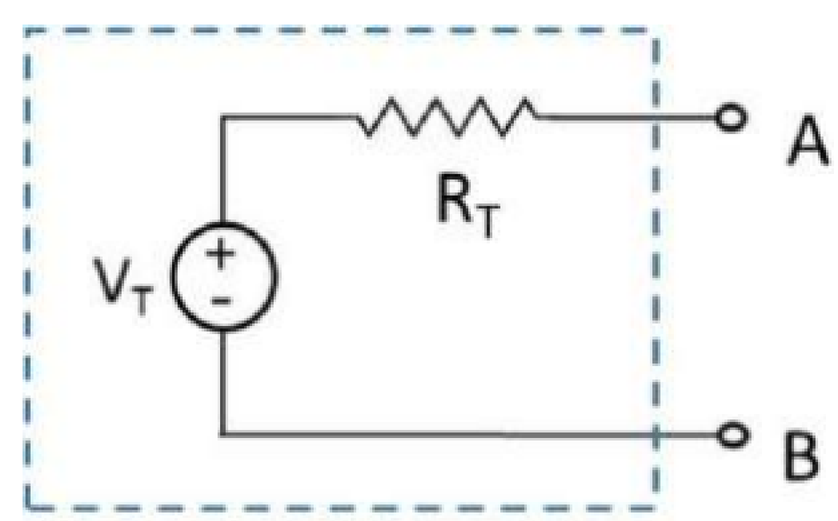


Figure 2 - Thevenin equivalent circuit.

This lab's objective is to determine the necessary source conditions to deliver maximum power to a known specified load. Specifically, we want to determine RX such that the source circuit will deliver the maximum power to the load resistor RL of specified resistance (here $R_T = 2.2\ k\Omega$). The specific circuit of interest is

Figure 3, below, with the power source being the entire circuit within the dotted line box left of terminals A and B.

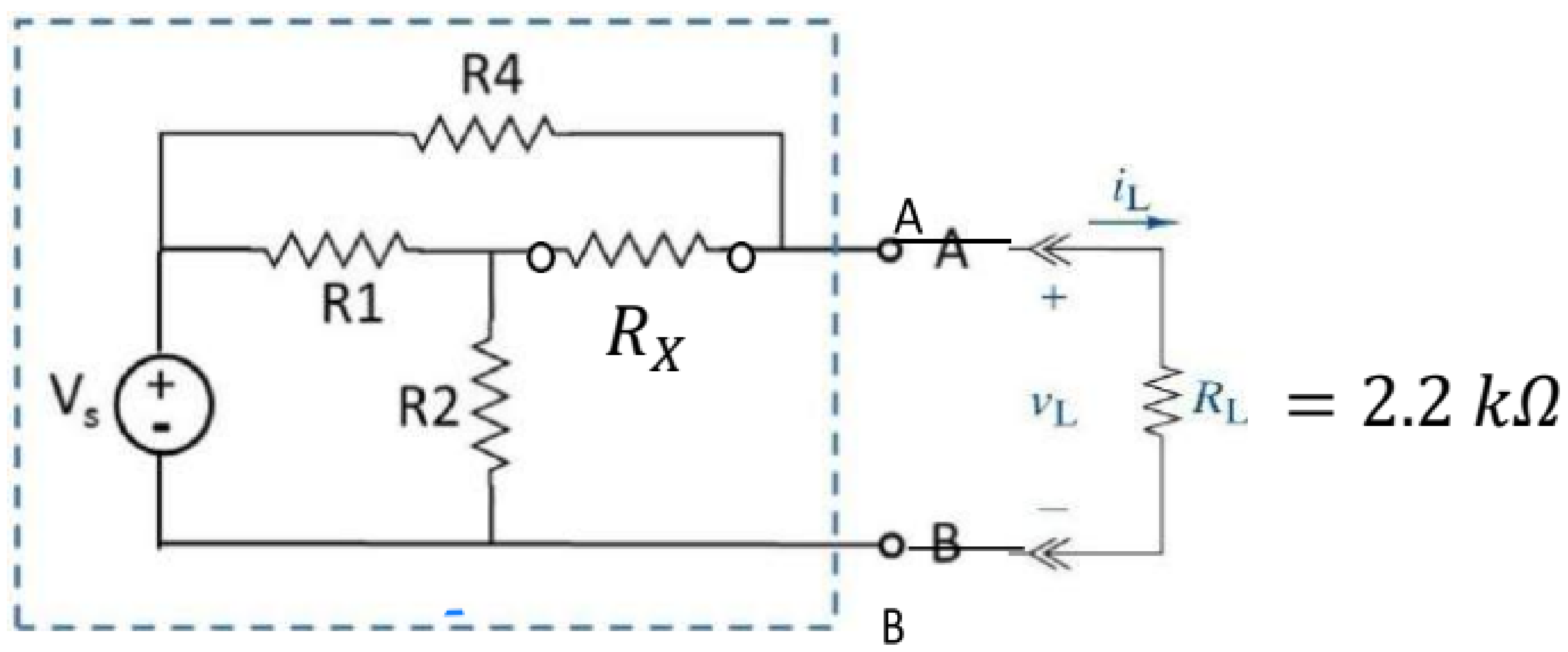
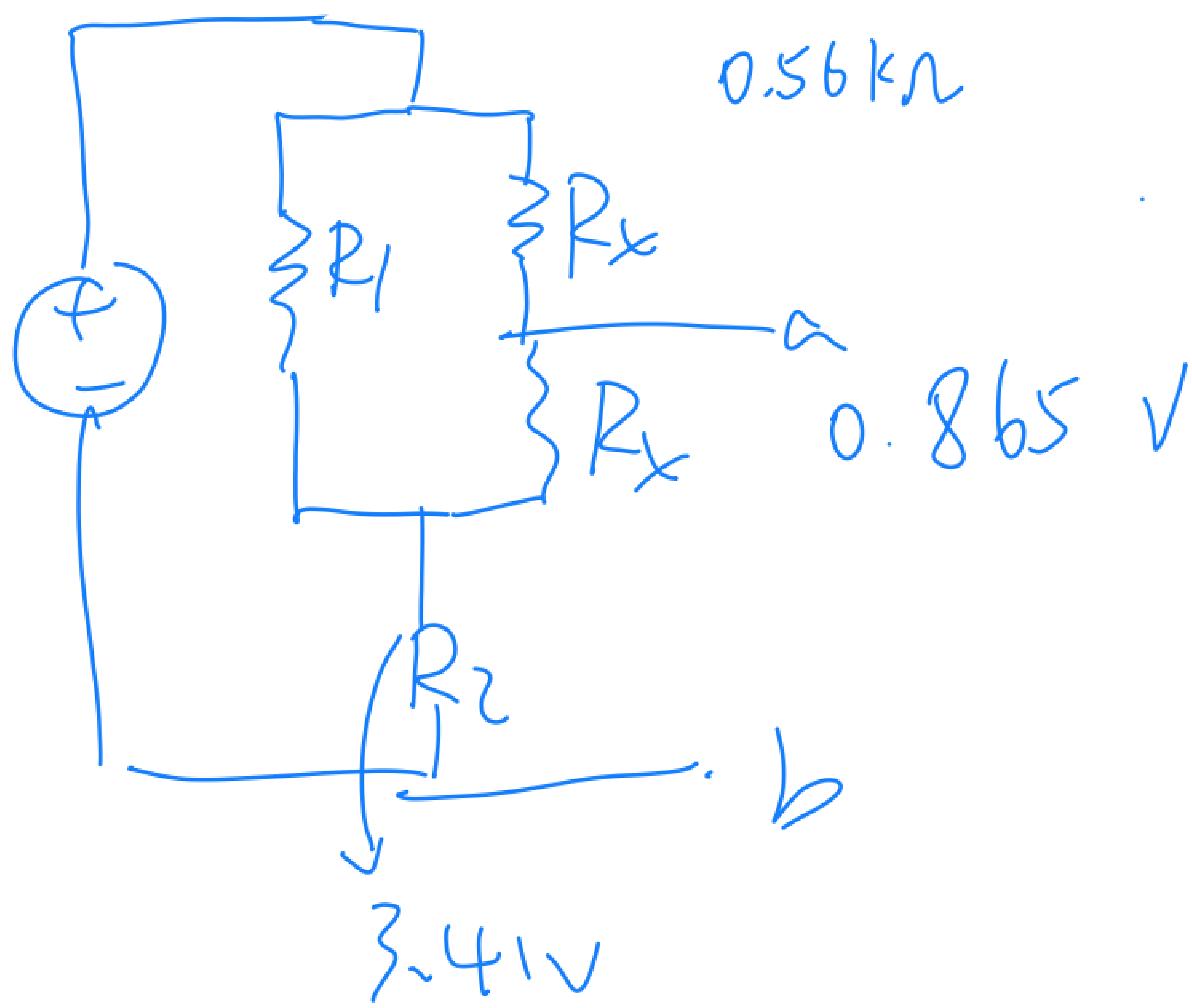


Figure 3 - Source circuit (left of terminals) and load resistor (right of terminals A-B) for homework analysis and lab measurement. Use the values for V_S, R1, R2, and R4 given in Fig. 1.



Homework

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(30 points) Knowing now (after Lab No. 3) how to calculate the equivalent Thevenin circuit for a source, use this to calculate the value of resistor R_X that will enable the source circuit (all left of terminals A & B) to deliver the maximum power to the 2.2 kΩ load resistor RL (right of terminals A & B). Also calculate the value for V_T. Then calculate the maximum power transfer expected, pmax. Neatly show your calculation and the resultant values for R_X, V_T, and P_{max} in the following space:

$$R_L = (R_1 \| R_2 + R_X) \| R_4 = 2.2\,k\Omega$$

$$\frac{(0.4+R_X)3.9}{0.4+R_X+3.9} = 2.2 \Rightarrow R_X = 4.647\,k\Omega$$

$$R_{14X} = R_1 \| (R_4 + R_X) = \frac{0.6 \times (3.9+4.647)}{0.6+3.9+4.647} = 0.56\,k\Omega$$

$$Req = R_{14X} + R_2 = 1.76\,k\Omega$$

$$I = \frac{V}{Req} = \frac{5V}{1.76\,k\Omega} = 2.841 \times 10^{-3} A$$

$$V_T = I \cdot R_2 + I \cdot R_{14X} \cdot \frac{R_X}{R_X+R_4} = 3.41V + 2.841 \times 10^{-3} A \times 0.56\,k\Omega \times \frac{4.647}{4.647+3.9} = 4.275V$$

$$P_{max} = \frac{V_T^2}{4R_X} = 2.077 \times 10^{-3} W$$

$R_X =$ 4.647 kΩ

$V_T =$ 4.275 V

$P_{max} =$ 2.077×10⁻³ W

Laboratory Procedure

1. Build the circuit shown in Figure 3 using the value for R_X that you determined above.

2. Measure the following operating parameters in the assembled circuit:

   a. (6 points) Maximum open circuit source voltage at terminals AB V_{OC}= 4.277V

   b. (6 points) Max. short circuit source current between terminals AB I_{RL}= 1.935mA

   c. (18 points) Actual power delivered to the 2.2 kΩ load resistor (i.e. P = VI for this resistor).

   V_{RL} (measured) = 2.133 V

   I_{RL} (measured) = 0.970 mA

   P_{RL} (calculated from measurements) 2.069 $\times 10^{-3}$ W

3. (10 points) Calculate the maximum power transfer expected from 2a and 2b – see the following equation. Compare this with the power measured/calculated in 2c.

$$p_{max} = \frac{(V_T)^2}{4R_T} = \left(\frac{V_T}{2}\right)\left(\frac{V_T}{2R_T}\right) = \left(\frac{V_{OC}}{2}\right)\left(\frac{I_{SC}}{2}\right) = 2.068 \times 10^{-3} \text{ W}$$

<u>Comments on Comparison:</u>

The difference between P_{RL} and P_{max} less than 0.1%, and it is acceptable, two results are identical.

4. (15 points) Replace R_X with resistors of the following values: 680Ω, 5.6kΩ. Re-measure the power delivered to R_L for each condition. For each data point, calculate the ratios $\frac{R_L}{R_T}$ and $\frac{p}{p_{max}}$.

$R_L = \frac{(0.4+R_x)\times 3.9}{4.3+R_x}$

680Ω

$V = 2.67$ V

$I = 1.215$ mA

$\frac{R_L}{R_T} = \frac{2200}{846} = 2.6$

$\frac{P}{P_{max}} = 1.568$

5.6kΩ

$V = 2.09$V

$I = 0.950$ mA

$\frac{R_L}{R_T} = \frac{2200}{2364} = 0.93$

$\frac{P}{P_{max}} = 0.96$

5. (15 points) Plot your measured results from Q4 on the semi-log graph given below. Are your measurements consistent with the expected theoretical graph?

(2.6, 1.57)

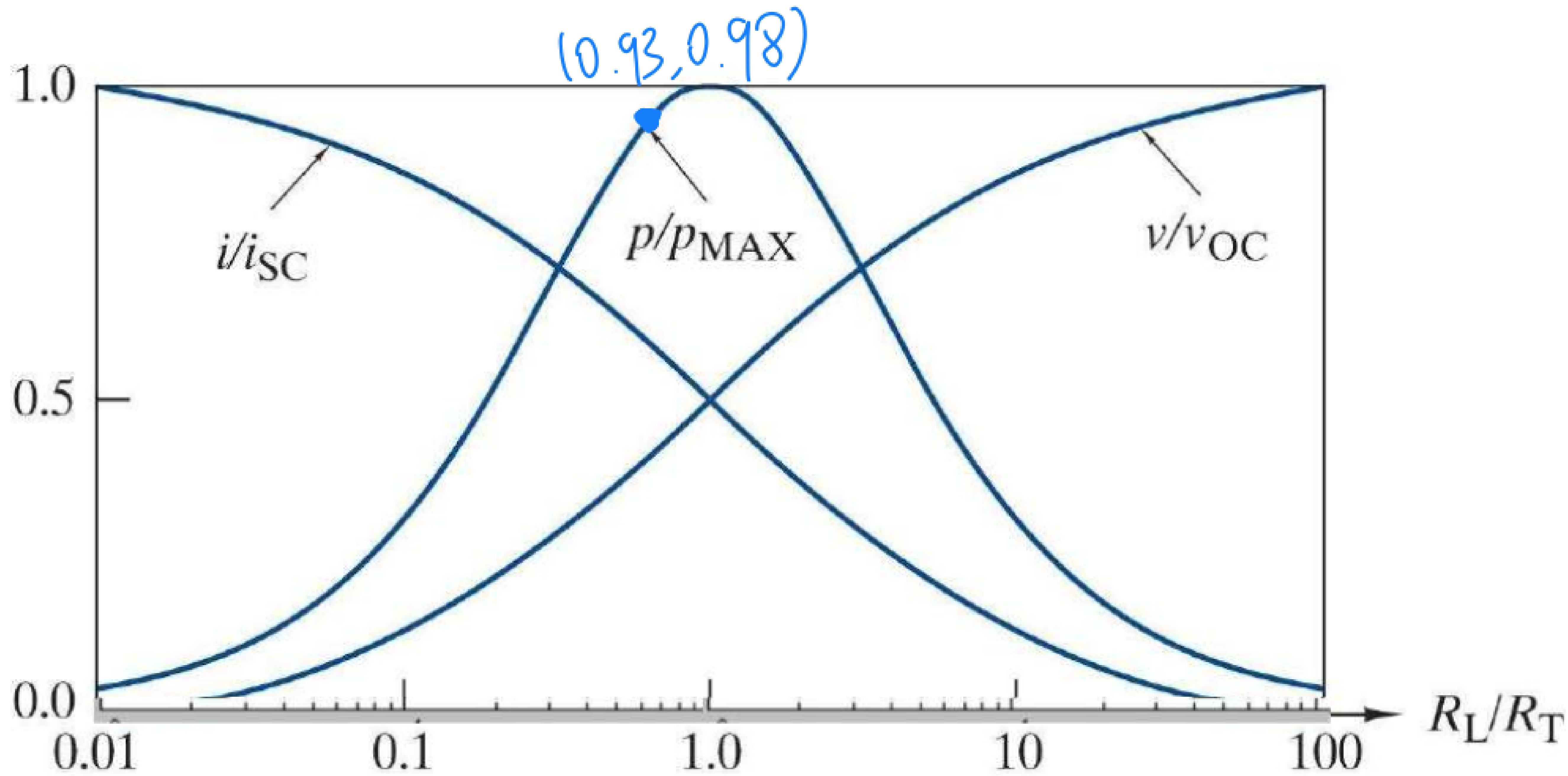

Figure 3-58

① $R_x = 5.6k\Omega$ messurments consistent with the expected theoretical graph

② $R_x = 680\Omega$, it isn't consistent with the expected theoretical graph