EE 2245 Microelectronics Labs

Lab 1: Lab Instruments, DC and AC Circuits (2 Weeks)

實驗室：_____組別：______ Names and ID Numbers: ____

Objectives：

(1) Get familiarized with the instruments in the lab.

(2) Validate the superposition principle.

(3) Validate Thévenin’s theorem and maximum power transfer through experimental measurements.

(4) Validate Norton’s theorem through experimental measurements.

(5) Verify the a.c. responses of a RL circuit and a RLC circuit

Equipment Required:

Resistors: 47 Ω, 91 Ω, 100 Ω, 120 Ω, 130 Ω, 150 Ω, 220 Ω, 270 Ω, 330 Ω, 470 Ω,1 kΩ, 2.2 kΩ ,3.3 kΩ, 5.6 kΩ, 10 kΩ, 910 kΩ, 0 – 1 kΩ potentiometer

Inductor: 10 mH

Capacitor: 0.01 μF

Instruments: Digital multimeter (DMM), digital oscilloscope, function generator, and dc power supply.

Procedure :

Part 1: Resistor

Write down the color codes of the following resistors. You should verify the resistor value using the DMM.

270 Ω : ____ ____ ____

5.6 kΩ : ____ ____ ____

910 kΩ : ____ ____ ____

Part 2: DC Power Supply

(a) Turn on the dc power supply. Set the output voltages to tracked values of +3 V and -3V, and use a DMM to verify them. Similarly, familiarize yourself with assigning the values independently to + 2V and -4 V, and verify them with a DMM.

(b) The dc power supply can also be used as a current source. Prepare the DMM for current measurement, and connect it to the “+” output port of the supply (no current output at this point). Set the output current at 20 mA from the “+” port, and verify the value with the DMM. Similarly, try to get -20 mA from the “-“ port. (Note: In case you do not get the desired current value, you should first check and set the power supply voltage to some value other than zero.)

Part 3: Function Generator and Oscilloscope

(a) Probe Calibration: Connect one end of the oscilloscope probe to Channel 1 and the other to the calibration connections at the lower right corner of the scope (different locations on some scopes). Check if the waveform is satisfactory.

(b) Connect a coaxial cable to the output of the function generator, and connect the measuring probe to CH-1 of the oscilloscope. Set the probe's measuring option to "1x" (make sure that the option is "1x" as well in the scope. Connect the "+" and "–" ends of the two wires.

(c) Set the output of the function generator to a 1-kHz sinusoidal waveform of 1-V amplitude. Set the triggering signal source to CH-1. Adjust the trigger level and the x and y grid sizes to display the waveform on screen. Check if the waveform is correct.
Now change the measuring option to "10x" in the probe and the scope. Check if the waveform magnitude is correct.

(d) Following part (c), apply additionally a 1-V dc offset to the sinusoidal waveform. Use the dc-coupling and the ac-coupling modes in scope, and explain below what you see in difference.
Ans.:

Part 4: Superposition

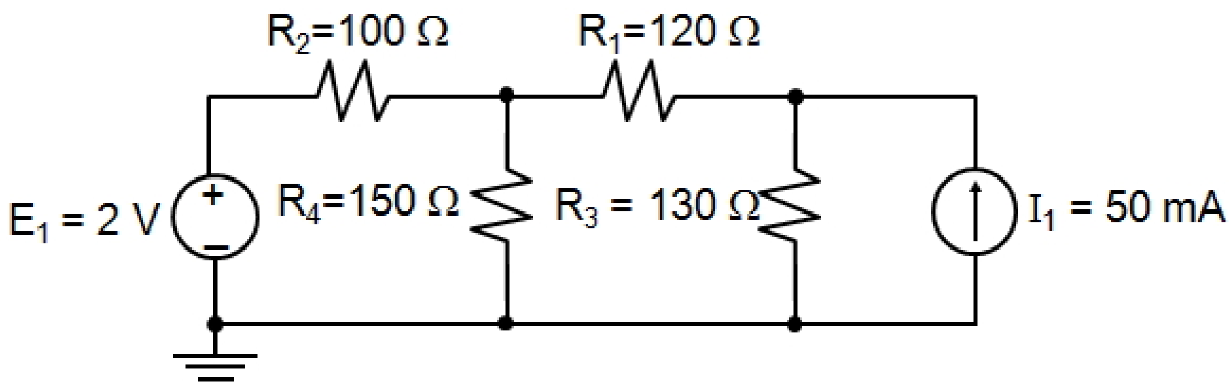


Figure 4-1

(a) The circuit to be analyzed using the superposition principle appears in Fig. 4-1. Measure the individual resistance by a DMM and fill in the values.

R_1 = ___________Ω, R_2 = ___________Ω, R_3 = ___________Ω, and R_4 = ___________Ω

(b) Using the measured values, analyze the voltage V_i across each resistor R_i and the accompanying current I_i and the delivered power P_i .

Your Analysis:

V_1 = ____________V, V_2 = ____________ V, V_3 = _____________ V, and V_4 = _____________ V

I_1 = _____________A, I_2 = _____________A, I_3 = _____________ A, and I_4 = _____________ A

P_1 = ____________W, P_2 = ____________ W, P_3 = _____________W, and P_4 = _____________W

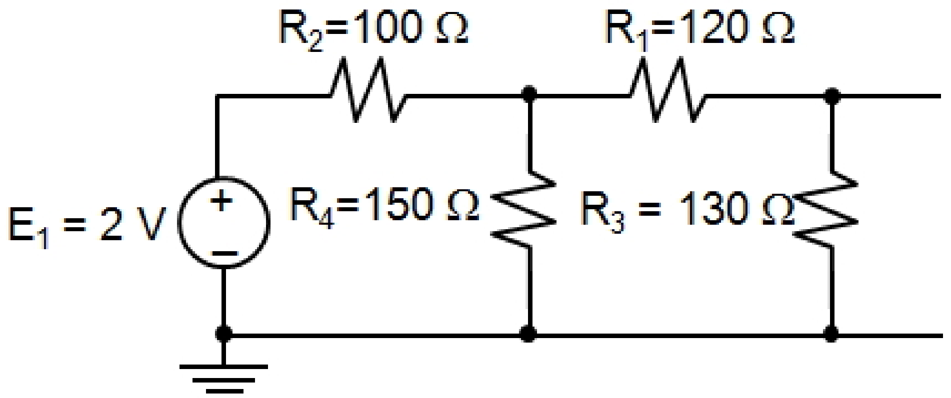


Figure 4-2

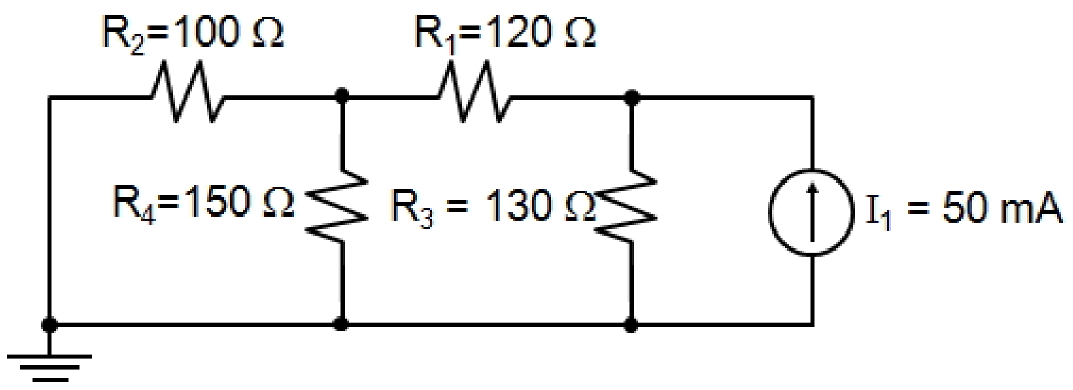


Figure 4-3

(c) Determine the effect of E_1. Construct the network of Fig. 4-2 and measure the voltages V_{i1} across resistors (**Note**: In case you cannot raise the voltage to 2 V, try increase the current limit of the power supply using ISET). Calculate the currents I_{i1} and the delivered power P_{i1} accordingly using the measured resistance values (**Note**: You will get less accurate results by measuring the current directly, because the internal resistance of DMM is not small enough).

V_{11} = ____________ V, V_{21} = ____________ V, V_{31} = ____________ V, and V_{41} = ____________ V
I_{11} = ______________ A, I_{21} = ____________ A, I_{31} = _____________ A, and I_{41} = ____________ A
P_{11} = _____________ W, P_{21} = ____________ W, P_{31} = ____________ W, and P_{41} = ____________ W

(d) Determine the effect of I_1. Construct the network of Fig. 4-3 and measure the voltages V_{i2} across resistors. **Calculate** the currents I_{i2} and P_{i2} accordingly using the measured resistance values.

V_{12} = ____________ V, V_{22} = ____________ V, V_{32} = ____________ V, and V_{42} = ____________ V
I_{12} = _____________ A, I_{22} = ____________ A, I_{32} = _____________ A, and I_{42} = ____________ A
P_{12} = _____________W, P_{22} = ____________ W, P_{32} = ____________ W, and P_{42} = ____________ W

(e) Add up V_{i1} and V_{i2} and fill in the blanks below. Comment on your comparison with respect to results of part 4(b).

$V_{1(total)}$ = ____________ V, $V_{2(total)}$ = ____________ V, $V_{3(total)}$ = ____________ V, and $V_{4(total)}$ = ____________ V

Your Comment:

(f) Add up P_{i1} and P_{i2} and fill in the blanks below. Comment on your comparison with respect to results of part 4(b). Is the superposition applicable to the power effects? Explain.

$P_{1(total)}$ = ____________ W, $P_{2(total)}$ = ____________ W, $P_{3(total)}$ = ____________ W, and $P_{4(total)}$ = ____________ W

Ans.:

Part 5: Thévenin's Theorem

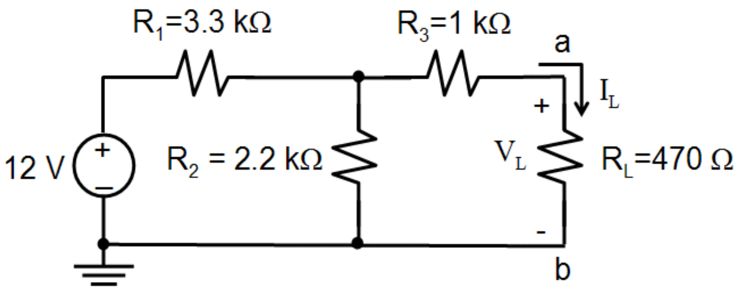


Figure 5-1

(a) Construct the network of Fig. 5.1 (power is off for now). Calculate the Thévenin voltage V_{th} and resistance R_{th} by using the open-circuit voltage and the short-circuit current for the network to the left of the resistor R_L. The calculation should be based on the measured resistances.

$R_{1\ measured}$ = __________Ω, $R_{2\ measured}$ = __________Ω, $R_{3\ measured}$ = __________Ω, $R_{L\ measured}$ = __________Ω

Analysis:

V_{th} = ____________ V, R_{th} = ______________Ω

(b) Using the Thévenin equivalent circuit in Fig. 5-2, calculate the current I_L.

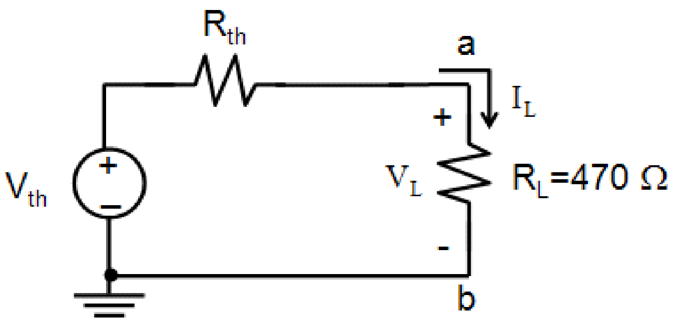


Figure 5-2

Calculation:

I_L = ______________ A

(c) Turn on the power supply in Fig. 5-1 and measure the voltage V_L. Use the measured value of R_L to calculate the current I_L.

$V_{L\ measured}$ = ____________ V, $I_{L\ measured}$ = _______________ A

How does the measured value of I_L compare with the calculated value in part (b)?

Your Comment:

(d) Determine R_{th} by constructing the network of Fig. 5-3 and measuring the resistance between points a-b with R_L removed.

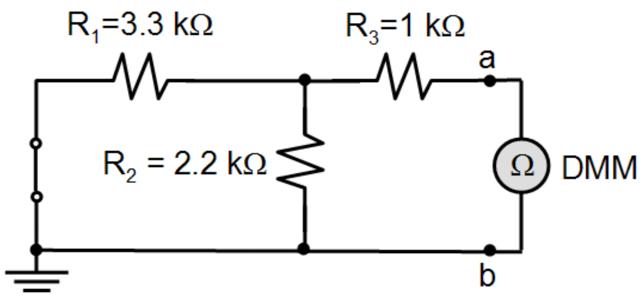


Figure 5-3

$R_{th\ measured}$ = ______________ Ω

How does the measured value compare with the calculated value in part (a)?

Your Comment:

(e) Determine V_{th} by constructing the network of Fig. 5-4 and measuring between points with R_L removed.

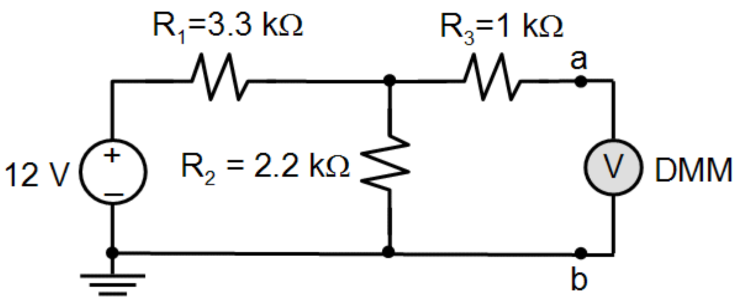


Figure 5-4

$V_{th\ measured}$ = _______________ V

How does the measured value compare with the calculated value in part (a)?

Your Comment:

Part 6: Maximum Power Transfer

(a) Construct the network of Fig. 6-1. Insert measured values of each resistor.

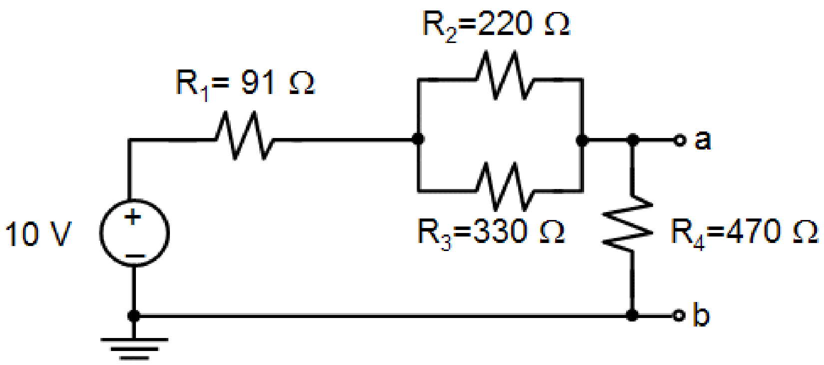


Figure 6-1

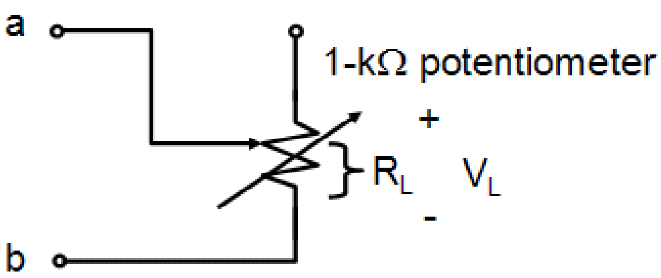


Figure 6-2

R_1 measured = ____________, *R_2 measured* = ____________, *R_3 measured* = ____________, *R_4 measured* = ___________

(b) The Thévenin equivalent circuit will now be determined for the network to the left of the terminals a-b without disturbing the structure of the network. All the measurements will be made at the terminal a-b.
Determine E_{Th} by turning on the supply and measuring the open-circuit voltage V_{ab}.

$E_{Th} = V_{ab} =$ ____________

Introduce the 1-kΩ potentiometer to the terminals a-b as shown in Fig. 6-2. Turn on the supply and adjust the potentiometer until the voltage V_L is $E_{th}/2$, a condition that must exist if $R_L = R_{Th}$. Then turn off the supply and remove the potentiometer from the network carefully. Measure the resistance between the two terminals connected to a-b and record as R_{Th}.

$R_{Th} = R_L =$ _______________

(c) Now we need to check our measured results against a theoretic solution. Calculate R_{Th} and E_{Th} for the network to the left of terminals a-b of Fig. 6-1. Use measured resistor values.
Calculation:

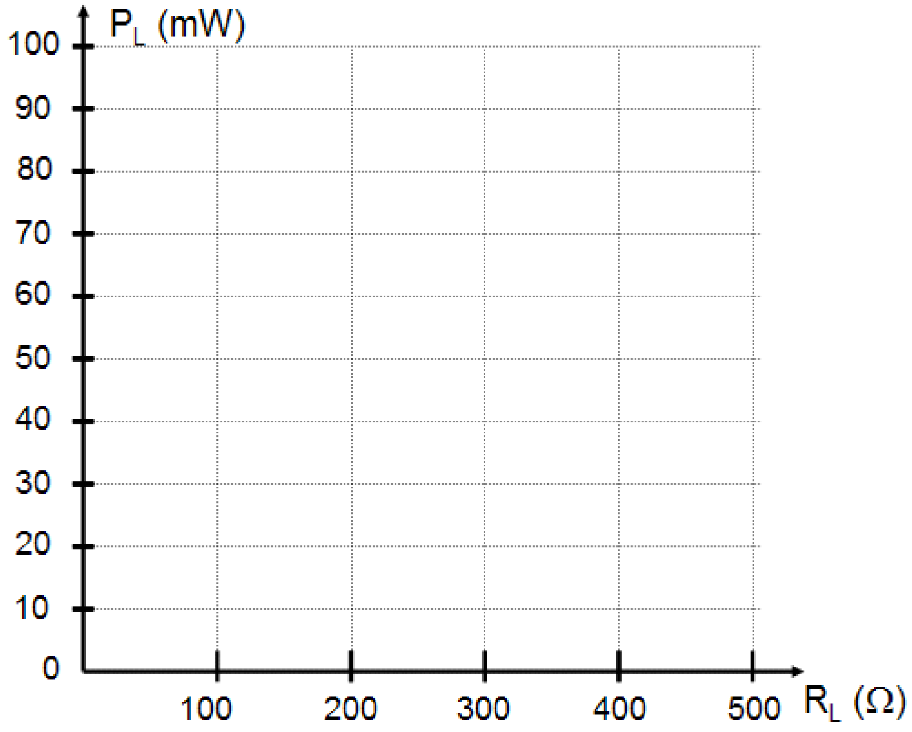
$R_{Th} =$ _______________, $E_{Th} =$ _______________

How do the calculated and measured values compare?
Comment:

(d) Let us now plot P_L versus R_L to confirm the condition for maximum power transfer. Leave the potentiometer as connected in Fig. 6-2 and measure V_L for all the values R_L appearing in Table 6-1. (Note: Be sure to remove the potentiometer from the network when setting each value of R_L. At the very least, disconnect one side of the potentiometer when making the setting.) Then calculate the resulting power to the load and complete the table. Finally, plot P_L vs. R_L on Graph 6-1. Please comment on if the drawn curve matches your expectation.
Comment:

Table 6-1

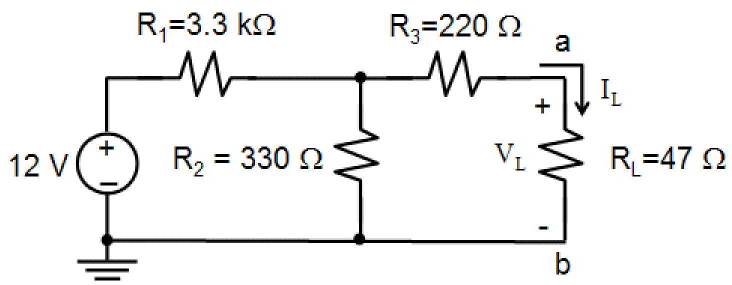
R_L (Ω)	V_L (measured)	$P_L = V_L^2/R_L$ (mW)
0	0	0
25		
50		
100		
150		
200		
250		
300		
350		
400		
450		
500		



Graph 6-1

Part 7: Norton's Theorem

(a) Construct the network of Fig. 7-1(a) (power is off for now). Fill in the measured resistance values.



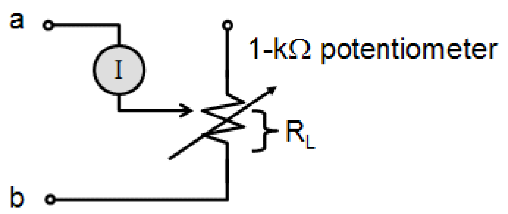


Figure 7-1 (a) **Figure 7-1(b)**

$R_{1\ measured}$ = __________Ω, $R_{2\ measured}$ = __________Ω, $R_{3\ measured}$ = __________Ω, $R_{L\ measured}$ = _________Ω

(b) Using the measured resistance values, calculate the Norton current ($I_N = V_{th}/R_{th}$) and the Norton resistance ($R_N = R_{th}$) for the network to the left of the 47-Ω resistor. See Fig. 7-3(a).

Calculation:

R_N = ______________Ω, I_N = _______________ A

(c) Using the Norton equivalent circuit in Fig. 7-3(a), calculate the current I_L for a load of 47 Ω.

Calculation:

I_L = _______________ A

(d) Now return to Fig. 7-1(a). Turn on the supply and measure the voltage V_{ab}. Then calculate the current I_L using the measured resistor value.

V_{ab} = _____________ V

$I_{L\ measured}$ = ______________ A

Calculation:

How do the I_L values in (c) and (d) compare?

Your comment:

(e) The following procedure will show you how to measure the Norton current and resistance when the circuit schematic is assumed unknown. The value of I_N can be determined by replacing the 47-Ω resistor by a short circuit and measuring the short-circuit current. You can accomplish this by removing the 47-Ω resistor and replacing it by the ammeter section of the DMM. Please fill in the value.

$I_{N\ measured}$ = ______________A

How do the I_N values in (b) and (e) compare?

Your comment:

(f) R_N is now experimentally determined by first calculating $I_N/2$ using the measured value from part (e). For the Norton equivalent circuit with $R_L = R_N$, we get $I_L = I_N/2$.

$\frac{I_N}{2}$ = _______________ A

As shown in Fig. 7-1(b), remove the 47Ω resistor and connect the 1-kΩ potentiometer and ammeter in a series configuration between points a-b. Turn on the supply and vary the potentiometer until the ammeter reading is $I_N/2$. Then remove the potentiometer and measure its value, which should be equal to R_N.

$R_{N\ measured}$ = _____________Ω

Note: Since the internal resistance of the ammeter in our lab is relatively larger than expected, you would notice some difference in the R_N values measured in (b) and (f).

(g) We will now construct the Norton equivalent circuit defined by the calculated values of R_N and I_N from part (b). First construct the network of Fig. 7-2.

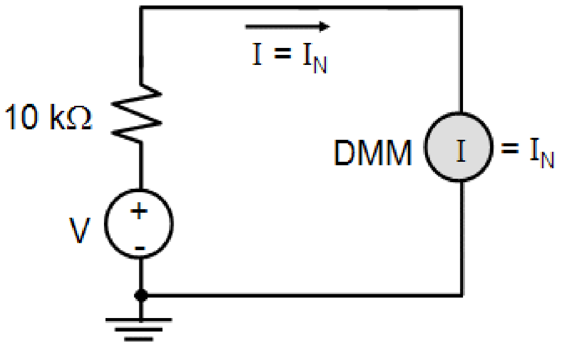


Figure 7-2

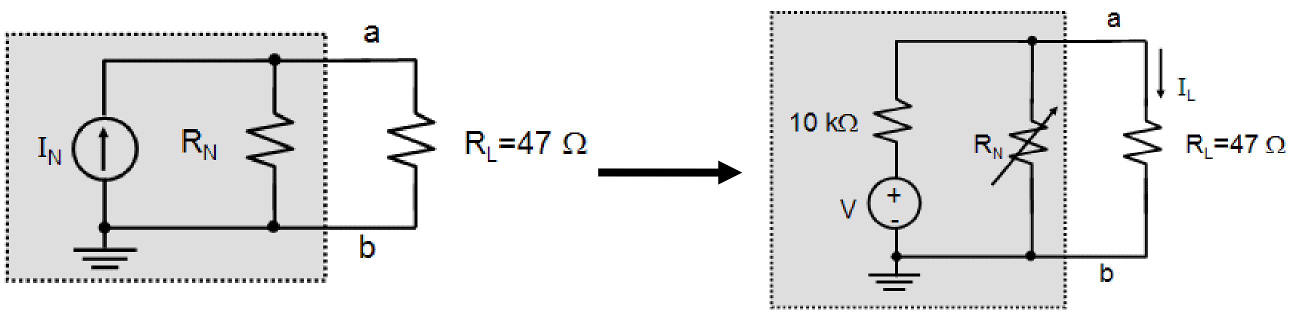
Then vary the dc supply voltage until the DMM indicates the value of I_N from part (b). Record the values of V and I_N.

V = ______________ V, I_N = _______________ A

Next remove the DMM and, using it as an ohmmeter, set the 0-1-kΩ potentiometer to the value of R_N from part (b). Now insert the potentiometer in the circuit of Fig. 7-3(b)

R_N = _____________Ω

The network of Fig. 7-3(b) is the Norton equivalent circuit. The 0-1-kΩ potentiometer is equivalent to R_N, and the 10-kΩ resistor in series with the dc source is the equivalent current source. The 10-kΩ resistor is chosen to ensure minimum sensitivity on I_N to the smaller resistor value connected in parallel in Fig. 7-3(b).



(a) (b)

Figure 7-3

Measure the voltage V_{ab} and compute I_L using the measured resistor value.

V_{ab} = ______________ V, I_L = ________________ A

How does the I_L value here compare with the calculated level from part (c)? Has the Norton equivalent circuit been verified with respect to Fig. 7-1?

<u>Ans.</u>:

Part 8: 1st-order *R-L* circuit

Part 8-1: V_L, V_R, and I versus Frequency

(a) Construct the network as shown in Fig. 8-1. Insert the measured resistance value. For the frequency range of interest, we will ignore the effects of the internal resistance of the inductor.

(b) Please first connect the output of the function generator to the oscilloscope to make sure that you get 4 V (p-p) before connect to the RL circuit. Record the voltage $V_{L(\text{p-p})}$ for the frequencies appearing in Table 8-1. DO NOT MEASURE THE VOLTAGE V_R AT THIS POINT! The grounds of the supply and the scope are connected together and thus will short out the effect of the inductor when you measure V_R directly. And doing so may result in damage to the equipment.

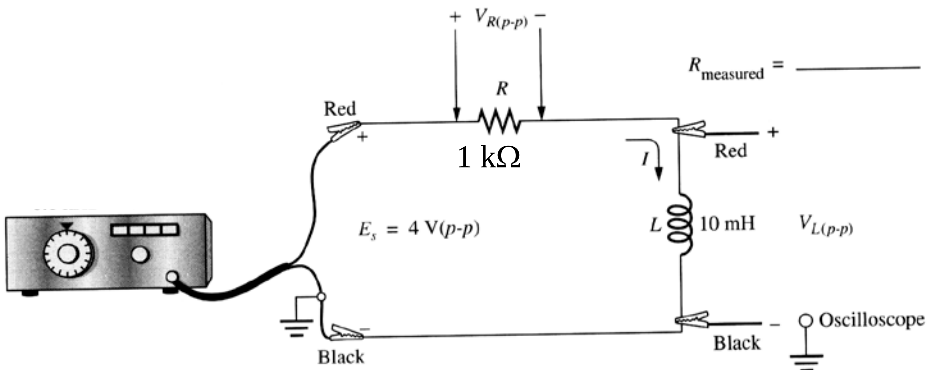


Figure 8-1

(c) Turn off the supply and interchange the positions of *R* and *L* in Fig. 8-1 (VERY IMPORTANT!) and measure $V_{R(p\text{-}p)}$ for the same frequencies. Write down the measurements in Table 8-1.

(d) Calculate $I_{p-p} = V_{R(p-p)} / R_{measured}$ and insert the values in Table 8-1.

(e) Calculate the reactance X_L ($=V_{L(\text{p-p})}/ I_{(\text{p-p})}$, magnitude only) at each frequency and insert the values in Table 8-1. Also, calculate the reactance ($X_{L(\text{calculated})} = 2\pi fL$) at each frequency using the inductance value (10 mH) and complete the table.

Table 8-1

Frequency (kHz)	$V_{L(\text{p-p})}$ (V)	$V_{R(\text{p-p})}$ (V)	$I_{(\text{p-p})}$ (A)	$X_{L(\text{measured})} = V_{L(\text{p-p})}/ I_{(\text{p-p})}$	$X_{L(\text{calculated})} = 2\pi fL$
1					
5					
10					

13					
16					
20					
30					
40					
60					
80					
100					

(f) How do the measured and calculated values of X_L compare?

Comment:

(g) Plot the measured value of X_L versus frequency on Graph 8-1. Is the resulting plot a straight line? Should it be? Why?

Comment:

(h) Use the measured X_L on Graph 8-1 to calculate a reasonable value for L from $L = X_L/2\pi f$.

$L_{(measured)}$ = ______________H

Graph 8-1

(i) Plot the curve of $V_{L(p\text{-}p)}$ vs. frequency on Graph 8-2 and label the name of the curve.

(j) Plot the curve of $V_{R(p\text{-}p)}$ vs. frequency on Graph 8-2 and label the name of the curve.

(k) As the frequency increases, describe in a few sentences what happens to the voltages across the inductor and the resistor. Explain why.

<u>Comment</u>:

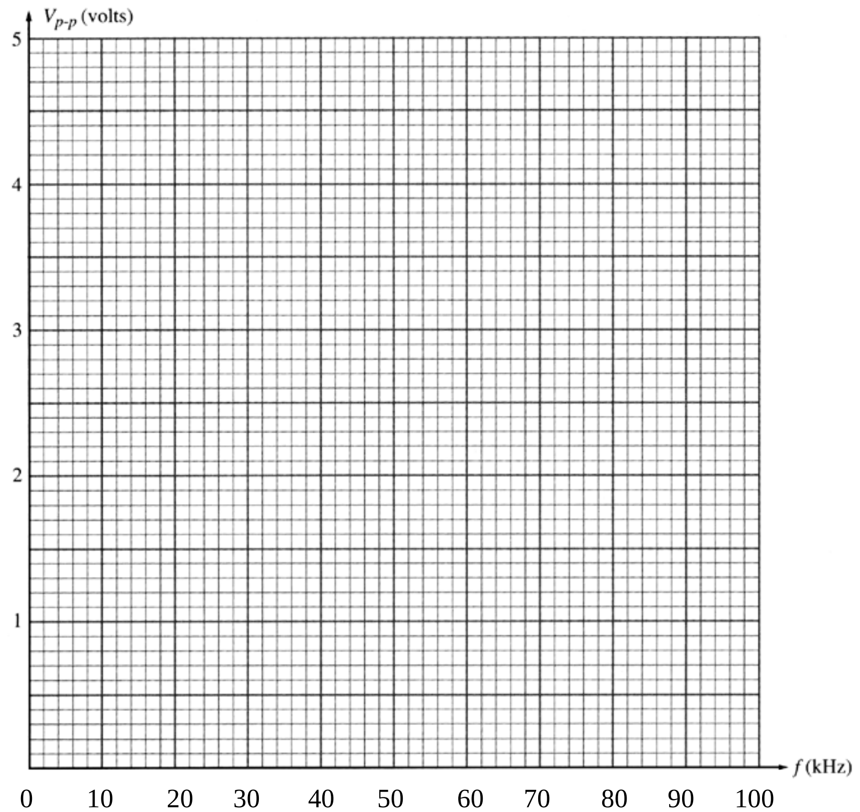
(l) At the point where $V_L = V_R$, does the reactance $X_L = R$? Should they be equal? Why? Record the level of voltages and the impedance of each element below.

<u>Comment</u>:

$V_L = V_R =$ ________________ V

$X_L =$ ________________Ω

$R =$ ________________Ω



Graph 8-2

(m) Determine $V_{L(p\text{-}p)}$ and $V_{R(p\text{-}p)}$ at some random frequency such as 50 kHz from the curves.

$V_{L(p\text{-}p)}$ = ______________ V, $V_{R(p\text{-}p)}$ = ________________ V

Are the magnitudes such that $V_{L(p\text{-}p)} + V_{R(p\text{-}p)} = E_{(p\text{-}p)}$? If not, why not? Please explain.

Comment:

(n) Plot the curve of $I_{(p\text{-}p)}$ vs. frequency on Graph 8-3.

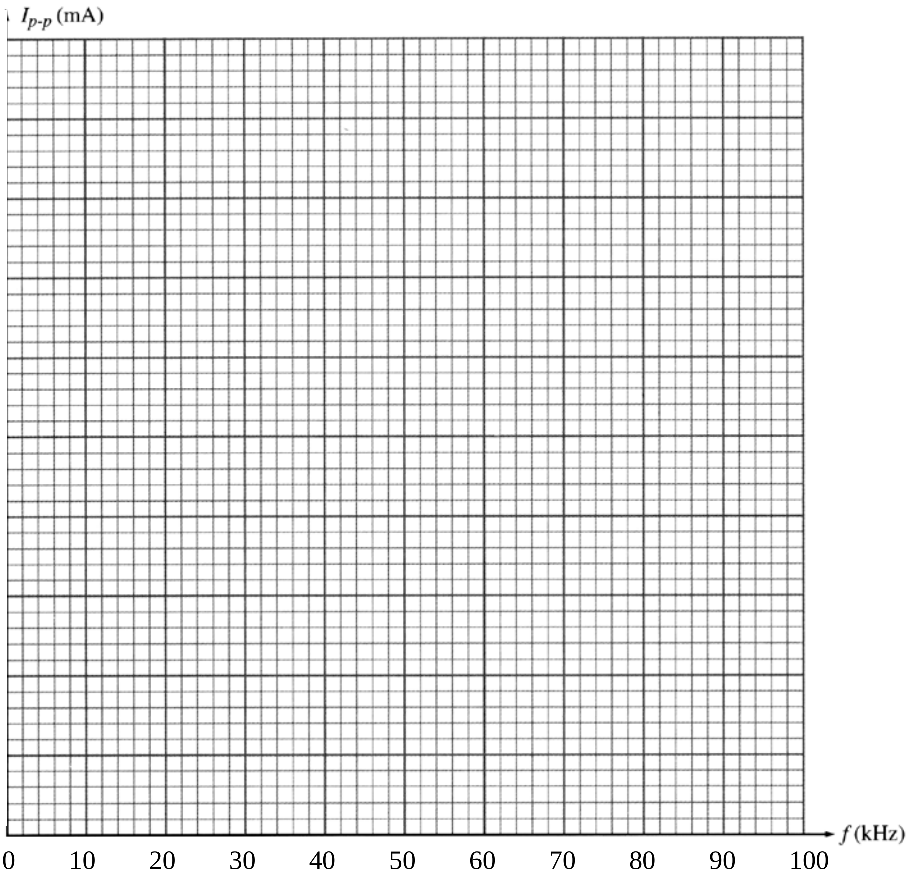
(o) How does the curve of $I_{p\text{-}p}$ vs. frequency compare to the curve of $V_{R(p\text{-}p)}$ vs. frequency? Explain why they compare as they do.

Comment:

(p) Calculate the voltage $V_{L(p\text{-}p)}$ at a frequency of 40 kHz using the measured L (from (h)) and R, and compare with the measured result of Table 8-1.

Calculation:

$V_{L(\text{p-p})}$ (calculated) = ______________ V, $V_{L(\text{p-p})}$ (measured) = ______________ V



Graph 8-3

(q) At low frequencies the inductor approaches a low-impedance short-circuit equivalent and at high frequencies a high-impedance open-circuit equivalent. Do the data of Table 8-1 and Graph 8-2 and 8-3 verify the above statement? Comment accordingly.

Comment:

Part 8-2: The Total Impedance Z_T versus Frequency

(a) Transfer the results of I_{p-p} from Table 8-1 to Table 8-2 for each frequency.

Table 8-2

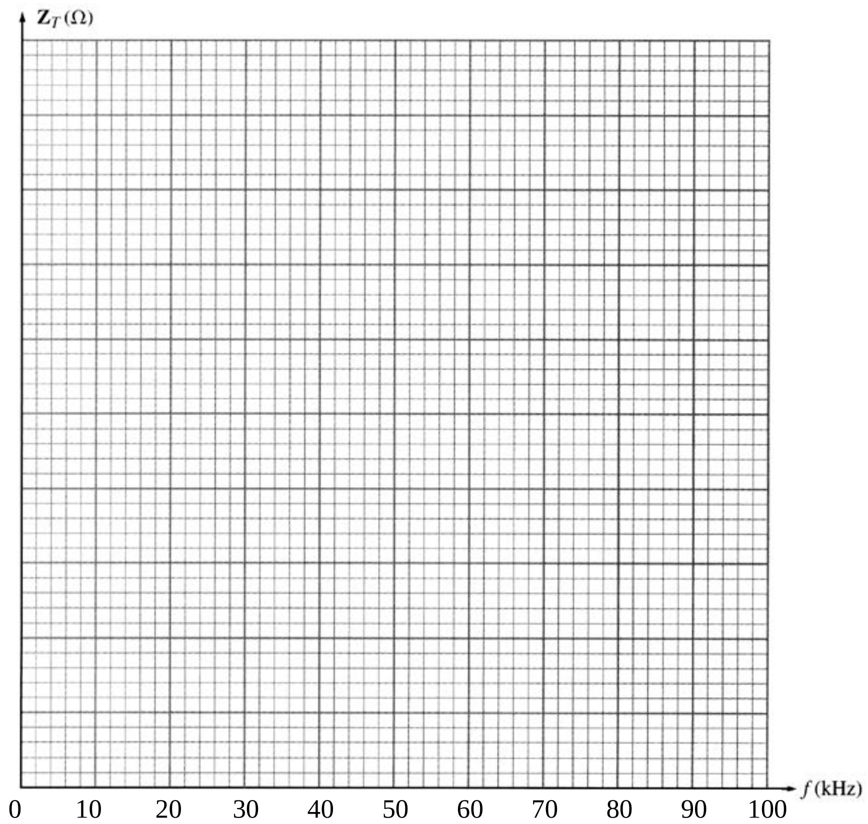
Frequency (kHz)	E_{p-p} (V)	I_{p-p} (mA)	$Z_T = E_{p-p} / I_{p-p}$	$Z_T = \sqrt{R^2 + X_L^2}$
1	4			
5	4			
10	4			

13	4			
16	4			
20	4			
30	4			
40	4			
60	4			
80	4			
100	4			

(b) At each frequency, calculate the magnitude of the total impedance using the equation $Z_T = E_{p-p} / I_{p-p}$ in Table 8-2.

(c) Plot the curve of measured Z_T vs. frequency on Graph 8-4 and label the curve.

(d) For each frequency calculate the total impedance using the equation $Z_T = \sqrt{R^2 + X_L^2}$ and the measured values of R and X_L. Insert the results in Table 8-2.



Graph 8-4

(e) How do the magnitudes of Z_T compare for the last two columns of Table 8-2?

Comment:

(f) On Graph 8-4, plot measured R vs. frequency. Label the curve.

(g) On Graph 8-4, plot measured X_L vs. frequency. Label the curve.

(h) At which frequency does $X_L = R$ based on the measured values? At which frequency does $X_L = R$ based on the nameplate values of L and R?

f = ____________Hz (from graph), f = ______________Hz (from nameplate values)

(i) For frequencies less than the frequency calculated in part 8-2(h), is the network primarily resistive or inductive?

(j) The phase angle by which the applied voltage leads the same current is determined by $\theta = tan^{-1}(X_L / R)$. Calculate the phase angle using the measured R and X_L for each of the frequencies in Table 8-3.

Table 8-3

Frequency (kHz)	R (measured) (Ω)	X_L (Ω)	$\theta = \tan^{-1}(X_L/R)$ (degree)
1			
10			
20			
40			
60			
80			
100			

(k) At a frequency of 1 kHz, does the phase angle suggest a primarily resistive or inductive network? Explain why.

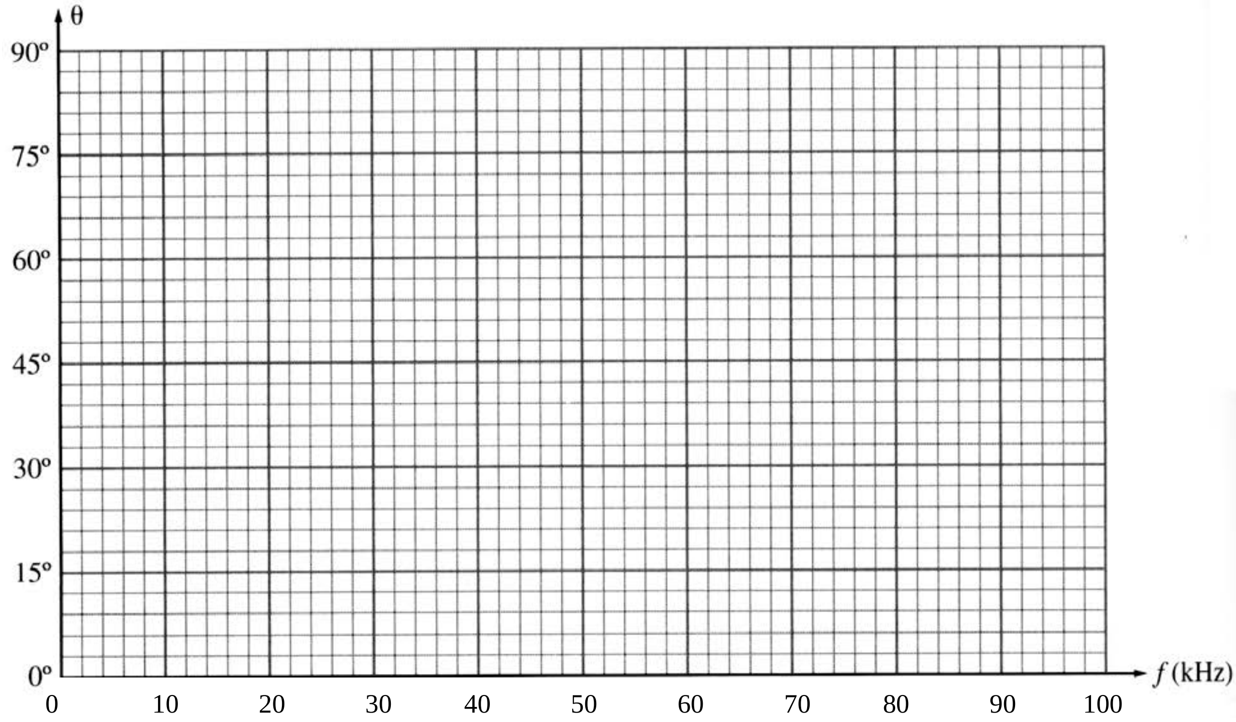
Comment:

(l) At a frequency greater than 80 kHz, does the phase angle suggest a primarily resistive or inductive network? Explain why.

Comment:

(m) Plot θ versus frequency for the frequency range 1 kHz to 100 kHz on Graph 8-5. At what frequency is the phase angle equal to 45°? At 45°, what is the relationship between X_L and R?

f (measured θ = 45°) = ________________Hz



Graph 8-5

Part 9: Series *R*-*L*-*C* circuit

(a) Construct the network of Fig. 9-1. Insert the measured resistance value. Ignore the effect of inductor resistance in the following analysis.

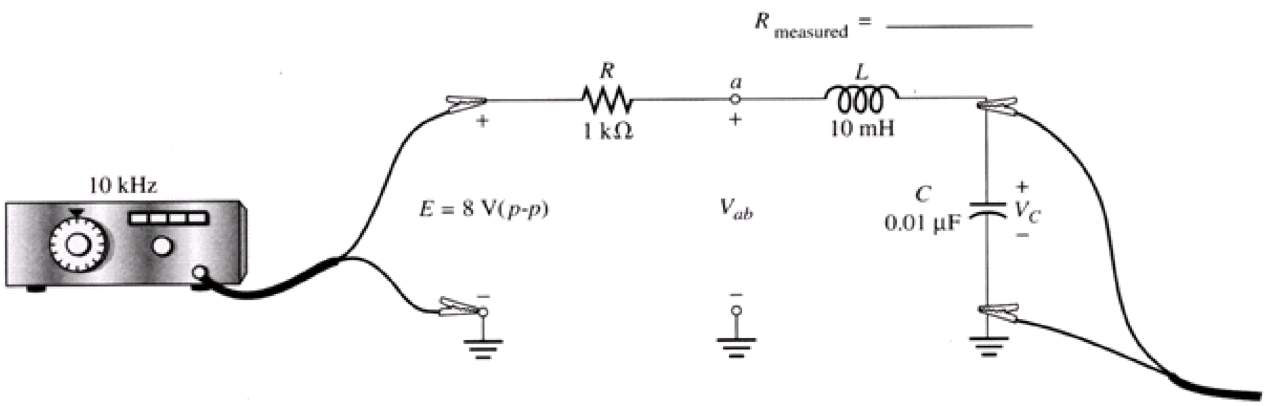


Figure 9-1

(b) Measure all the component voltages with E = 8 V(p-p) at 10 kHz. Make sure the element is placed in the position of the capacitor C as in previous experiments.

$V_{R(p\text{-}p)}$ = ________________ V, $V_{L(p\text{-}p)}$ = ________________ V, $V_{C(p\text{-}p)}$ = ________________ V

Comment: Is the measured value of $V_{c(p\text{-}p)}$ reasonable? Please explain.

(c) Determine $I_{p\text{-}p}$ from $I_{p\text{-}p} = V_{R(p\text{-}p)}/R_{measured}$.

$I_{p\text{-}p}$ = _______________ A

(d) Calculate Z_T from $Z_T = E_{p\text{-}p}/I_{p\text{-}p}$.

Z_T = _______________Ω

(e) Using the nameplate values for L and C and the measured value for R, calculate Z_T and compare to the result of (d).

Z_T(calculated) = ____________Ω

(f) Please explain why $E_{p-p} = \sqrt{V_{R(p-p)}^2 + \left(V_{L(p-p)} - V_{C(p-p)}\right)^2}$, and check with your measured values.

(g) Use the voltage divider rule to calculate the voltage $V_{ab(p-p)}$.

$V_{ab(p-p)}$ (calculated) = ______________V

(h) Measure the voltage $V_{ab(p-p)}$ and compare to the result of (g).

$V_{ab(p-p)}$ (measured) = _______________V