King Fahd University of Petroleum and Minerals

Department of Electrical Engineering

EE 204

Fundamentals of Electric Circuits

Laboratory Manual

May 2003

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PREFACE

The **EE 204: Fundamentals of Electric Circuits** Lab is intended to teach the basics of Electrical Engineering to undergraduates of other engineering departments. The main aim is to provide hands-on experience to the students so that they are able to put theoretical concepts to practice.

The manual starts off with the basic laws such as Ohm's Law and Kirchhoff's Current and Voltage Laws. The two experiments augment students' understanding of the relations of voltage and current how they are implemented in practical life.

Computer simulation is also stressed upon as it is a key analysis tool of engineering design. PSPICE is used for simulation of electric circuits and is a standard tool at numerous universities and industries of the world. The simulated parameters are then verified through actual experiment. Use of oscilloscopes is also stressed upon as analysis tool.

The important theorems of Thevenin and Norton are also provided along with the frequency domain analysis of circuits. They greatly simplify the complex electrical networks for analysis purposes.

At the end, the students should be able to grasp the concepts thoroughly the electric circuits and able to apply them further in their field of study.

EXPERIMENT NO. 1

RESISTORS AND OHM'S LAW

OBJECTIVE:

1- To determine the value of a selection of resistors using three different methods:
> **a. Using the color codes (to give the nominal value)**
> **b. Using the digital Ohmmeter.**
> **c. Using Ohm's Law.**

2- To determine qualitatively the effect of increased power dissipation on carbon resistor.

Pre-Lab Assignment

For the circuit shown in the Figure below, calculate $v(t)$, $i_1(t)$ and $i_2(t)$:
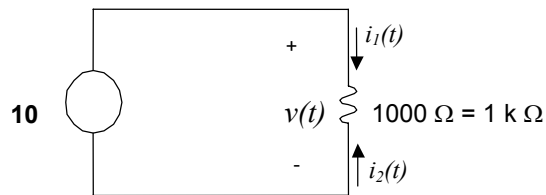
APPARATUS: DC Power Supply
Digital Multimeter
Resistor: 100 Ω , 470 Ω , 1 KΩ, 3.3 KΩ and 10 KΩ

THEORY:

1- The basic relationship between voltage, current, and resistance is determined by Ohm's law:

$$V = I\ R \qquad\qquad (1)$$

> where: V = Voltage across the resistor   (in Volts)
> I = Current through the resistor (in Amperes)
> R = Resistance of the resistor   (in Ohms)

2- Given any resistor, its resistance can be found by one of the four methods:

> a- Using the color codes . This value is called the nominal value, and it is only approximate.
> b- Direct measurement using an Ohmmeter .
> c- Measuring the voltage across the resistor and the current through the resistor, then applying Ohm's law.

3- The product of the voltage across a resistor and the current through the resistor gives power P (in Watts), namely:

$$P = V\,I = I^2\,R = V^2\,/R \qquad\qquad (2)$$

Where equation (1) has been used to express P in terms of I^2 and in terms of V^2.

The power absorbed by the resistor appears in the form of heat. The physical size of the resistor determines the amount of power that it can safely dissipate. This amount is referred to as the power rating. The dissipation of power that exceeds the power rating can damage the resistor physically.

When the resistor gets heated due to excessive power dissipation, its resistance changes .It will either increase or decrease depending on the temperature coefficient. A carbon resistance is expected to decrease as the temperature increases.

Resistance that are operated over the power rating will deviate from the straight line relationship between V and I. The resistor in this case is operating in the non-linear region. In such a case, the resistance is no longer equal the slope of the V versus I graphs. It may however, be calculated using the ratio V/I.

PROCEDURE:

You will be supplied with sets of 5 resistors.

1- Find the nominal value and the tolerance of each resistance using the color codes. Note the relation between the power rating and the physical size of the resistance.
2- Using the digital multimeter as an ohmmeter, measure and record the resistance of each resistor.
3- Connect the circuit as shown in Figure 2 for R = 100 Ω and perform the following :
    a- Set the source voltage V_s to 12 V.
    b- Measure V and I.
    c- Repeat steps 3a and 3b for remaining resistors.
    d- Record your results in Table 1.
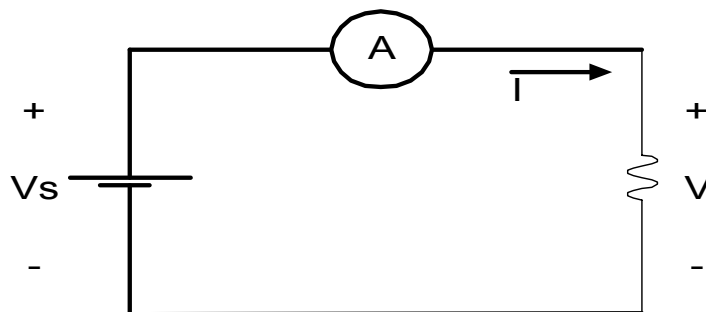

Figure 2

4- Using a 1 W resistor (R = 470 Ω), vary the input voltage from 6 to 24 volts. Measure V and I and calculate the resistance R (by calculating the ratio V/I) and the power dissipated in the

resistance (by calculating the product VI). As the measurement proceeds, touch the resistor from time to time to observe the temperature rise. Record the results in Table 2.

REPORT:

a- For resistance measurements (steps 1,2, and 3), tabulate the nominal and measured values of the resistors. Find the maximum percentage deviation from the nominal values.
b- Plot R versus P from the measured data obtained in step 4. Comment on the value of R as P increases.

QUESTIONS:

1- Does the resistor in step 4 operate in the linear region or non-linear region? Explain by considering the power rating of the resistor.
2- An electric heater takes 1.48 kW from a voltage source of 220 V. Find the resistance of the heater?
3- If the current in a resistor doubles, what happens to the dissipated power? (Assume the resistor operates in the linear region).
4- A 4 Ω resistor is needed to be used in circuit where the voltage across the resistor is 3V .If two 4 Ω resistors with 2 W and 3 W power rating are available, which will you use and why?

TABLE 1

Resistor Values:

Resistor	R1	R2	R3	R4	R5
Nominal value / Tolerance					
Ohmmeter reading					
V / I					
% Deviation from nominal value					
Actual value within tolerance?					

Maximum percent deviation from nominal value =

TABLE 2

Power rating: (R = 470 Ω, 1W)

V (volt)	6	8	10	12	14	16	18	20	22	24
1 (mA)										
R (Ohm) = V/I										
P (Watt)										

The Resistor Color Code table is given at the end of the manual under Appendix

EXPERIMENT # 2

KIRCHHOFF'S LAWS

OBJECTIVE:

To verify Kirchhoff's voltage and current laws experimentally.

Pre-Lab Assignment:

For the circuit shown in Figure 1, calculate:

1- V_{AB} , V_{BC} , V_{AD} , V_{DC} , V_{BD} , and V_{AC}.
2- I_1 , I_2 , I_3 , I_4 and I_5.

APPARATUS: DC Power Supply
Digital Multimeter
Carbon Resistors: 100 Ω, 150 Ω, 220 Ω, and 330 Ω

THEORY:

Kirchhoff's Voltage Law (KVL):

The <u>algebraic</u> sum of all voltages around any closed path is equal to zero.

Kirchhoff's current Law (KCL):

The <u>algebraic</u> sum of all currents at a junction point is equal to zero.

Procedure:

1- Check the values of the resistors, used in the circuit of Figure1, using a multimeter. Record the values in Table 1.
2- Connect the circuit as shown, and have it checked by the instructor. Adjust the supply voltage Vs to 10 V, using a dc voltmeter.
3- Measure the voltages V_{AB}, V_{BC} , V_{AD} , V_{DC} , V_{BD} , and V_{AC}. Record their values (including the signs) in Table 2
4- Measure the currents I_1 , I_2 , I_3 , I_4 and I_5 and record their values (including the signs) in Table

3
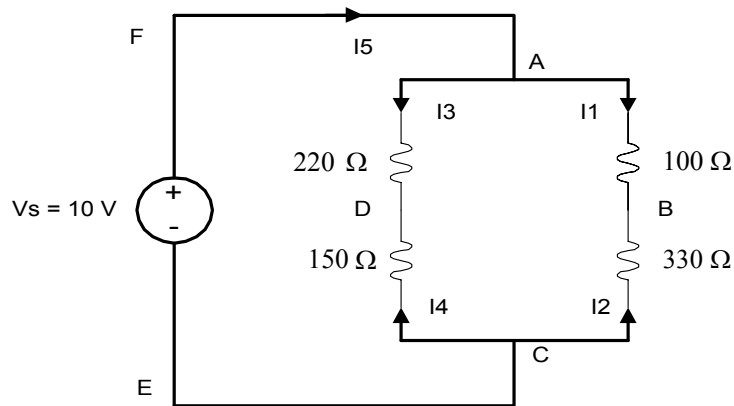
Figure 1

Report:

1- Verify KVL by adding the experimental values of voltages around the loops :

   a) ABCEFA
   b) ABDA
   c) CDAC

2- Verify KCL by adding the <u>experimental values</u> of current at nodes:

   a) A
   b) B
   c) C

QUESTIONS:

1- Do the experimental and theoretical values of voltages and currents agree? Indicate the percentage of differences.
2- Give possible reasons for any discrepancies.

TABLE 1

Resistor Values:

Resistor	R1	R2	R3	R4
Nominal value (Ohm)	100	150	220	330
Ohmmeter reading				

TABLE 2

Voltages:

Voltage	V_{AB}	V_{BC}	V_{AD}	V_{DC}	V_{BD}	V_{AC}
Theory						
Experiment						
% Error						

TABLE 3

Currents:

Current	I_1	I_2	I_3	I_4	I_5
Theory					
Experiment					
% Error					

EXPERIMENT # 3

COMPUTER SIMULATION OF A D.C. CIRCUIT

OBJECTIVE:

        1- To simulate a D.C. circuit on a computer using a Pspice.
        2- To experimentally verify the computer simulation.

Pre- Lab Assignment:

        1-   Find the variables indicated in the circuit of Figure 1.
        2-   Summarize your results in Table 2 & Table 3.

APPARATUS: One Personal Computer with PSPICE installed in it.
                             Digital Multimeter
                             D.C. Power supply (Two)
                             Resistors: 10 KΩ, 22 KΩ, 33 KΩ, and 47 kΩ (Two)

THEORY:

The variables indicated in the circuit of Figure 1 can be solved by using Ohm's Law, KCL and/or KVL. These variables can also be obtained by a computer simulation program known as PSPICE.

Procedure:

1. Simulate the circuit shown in Figure 1 using PSPICE.
2. Summarize your results in table 2.
3. Attach to the report of this experiment a printout of the results you obtained from the PC lab.
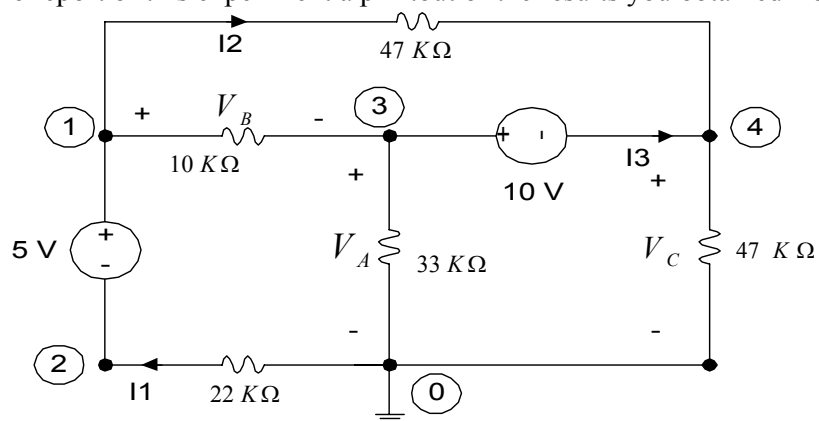

Figure 1

4. Connect the circuit shown in Figure 1.
5. Measure the resistor values with an Ohmmeter. Complete Table 1.
6. Measure all the variables indicated in this circuit. Summarize the results in Table 3.

Report:

Compare the computer results and the experimental results. Calculate the percentage error.

Questions:

1- Which method is better and why?
2- Does a computer simulation represent actual circuit behavior? Discuses the point by referring to the results you obtained in this experiment.

TABLE 1

Resistors Values:

Resistor	R1	R2	R3	R4	R5
Nominal value (Ohm)	10 KΩ	22 KΩ	33 KΩ	47 KΩ	47 KΩ
Ohmmeter reading					

TABLE 2

Results For Circuit Of Figure 1 Using PSPICE:

Variable	I_1	I_2	I_3	V_A	V_B	V_C
Calculation						
Computer Simulation						
% Error						

TABLE 3

Results For Circuit Of Figure 1 Experimentally:

Variable	I_1	I_2	I_3	V_A	V_B	V_C
Calculation						
Experimental Results						
% Error						

EXPERIMENT # 4

CURRENT AND VOLTAGE DIVIDER RULES

OBJECTIVE:

To experimentally verify the current divider rule (CDR) for parallel circuits and the voltage divider rule for series circuits.

Pre-Lab Assignment

For the circuit shown in Figure 2a and Figure 2b, calculate:
- 1- The unknown voltages and currents shown. Vs=10V.
- 2- The equivalent resistance seen by V_s.

Hint: Read through this experiment.

APPARATUS: DC Power Supply
Digital Multimeter
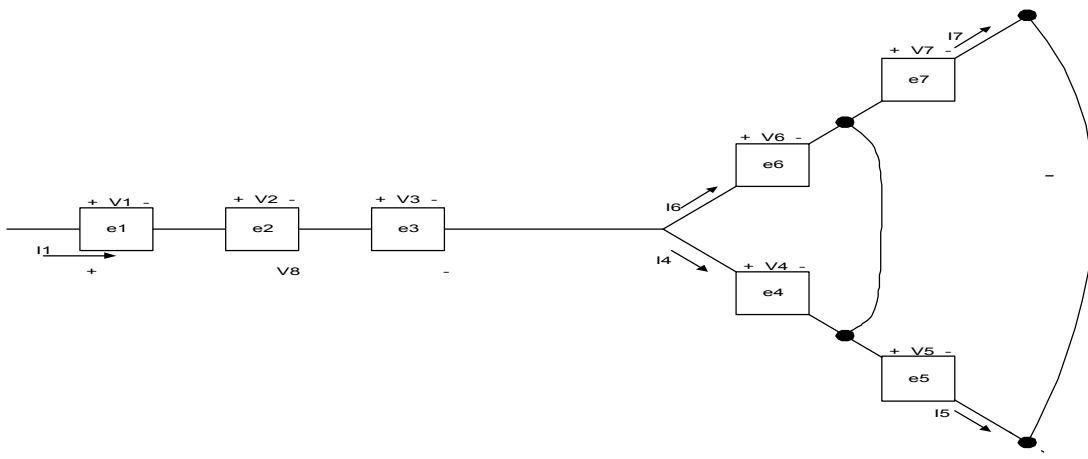Carbon Resistors: 100 Ω , 250 Ω ,220 Ω and 330 Ω .

THEORY:
-
Series Connections:

By definition, a series connection between any two electrical elements is such that the same current passes through both elements. For example element e1, e2, and e3 in Figure 1 are in series since the same current I1 passes through them.

Figure 1

Parallel Connections:

By definition, a parallel connection between any two electrical elements is such that the voltage is the same across both the elements. For example, elements e4 and e6 in Figure 1 are in parallel, since the same voltage $(V_4 = V_6)$ is across both of them. Also, element e5 and e7 are in parallel for a similar reason.

Voltage Divider Rule (VDR) :

For a discussion of VDR, refer to your textbook. As an example of VDR, in Figure 1, if e1 =R1, e2 = R2, and e3 =R3, then:

$$V_1 = \frac{R_1}{R_1 + R_2 + R_3}V_s \qquad (1)$$

$$V_2 = \frac{R_2}{R_1 + R_2 + R_3}V_s \qquad (2)$$

Current Divider Rule (CDR):

For a discussion of CDR, refer to your textbook. As an example of CDR in Figure 1,
If e4=R4 and e6 = R6, then:

$$I_4 = \frac{R_6}{R_4 + R_6}I_1 \qquad (3)$$

For I5 and I7, CDR can be applied as

$$I_5 = \frac{R_7}{R_5 + R_7}(I_4 + I_6) \qquad (4)$$

$$I_7 = \frac{R_5}{R_5 + R_7}(I_4 + I_6) \qquad (5)$$

This is valid, since I4 + I6 is the total current passing though the parallel combination in this case.

Procedure:
1- Check the values of resistors used in the circuit of Figure 2, using the multimeter. Record the values in Table 1.
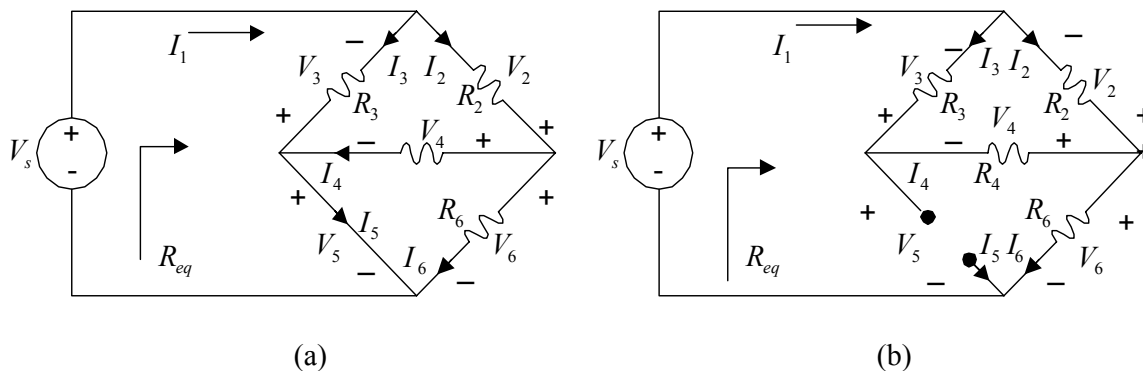

(a)   (b)

Figure2

1. Connect the circuit of Figure 2a and adjust the supply voltage Vs to 10 V, using the DC voltmeter.
2. Measure the entire unknown voltages and currents shown. Record their values in Table 2.
3. Measure R_{eq} using an Ohmmeter and record its values in Table 2.
4. Connect the circuit of Figure 2b and adjust the supply voltage Vs to 10 V, using the DC voltmeter.
5. Measure the entire unknown voltages and currents shown. Record their values in Table3 (recall that when measuring current by an ammeter, the ammeter should be placed in series with the element in which the current passes. Keep this fact in mind when measuring I5.
6. Measure R_{eq}. and record its value in Table 3.

Report:

1- Compare the theoretical and experimental values of voltages and currents and the equivalent resistance of both circuits. Calculate the percent errors.
2- Give reasons for any discrepancies.

Questions:

Referring to the circuit of Figure 2a:

1- Are R4 and R6 in parallel or in series?
2- Are R3 and R4 in parallel or in series?
3- Are Vs and R6 in series or in parallel?
4- Is VDR applicable for applicable for R3 and R4?
5- Is CDR applicable for R4 and R6?
6- Is the parallel combination of R4 and R6 in series or in parallel with R2?

Justify your answer in each case by referring to the experimental results.

TABLE 1

Resistor Values:

Resistor	R2	R3	R4	R6
Nominal Value (Ohm)	100	220	150	330
Ohmmeter reading				

TABLE 2

Circuit of Figure 2a:

Unknown	I_1	I_2	I_3	I_4	I_5	I_6	V_2	V_3	V_4	V_5	V_6	R_{eq}
Theory												
Experiment												
% Error												

TABLE 3

Circuit of Figure 2b

Unknown	I_1	I_2	I_3	I_4	I_5	I_6	V_2	V_3	V_4	V_5	V_6	R_{eq}
Theory												
Experiment												
% Error												

EXPERIMENT # 5

SUPERPOSITION & THEVENIN / NORTON THEOREMS

OBJECTIVE:

1- To experimentally verify the superposition.
2- To experimentally verify the Thevenin and Norton Theorems.
3- To experimentally verify the Maximum Power Transfer Theorem for resistive circuits.

Pre- Lab Assignment:

For the circuit shown Figure 1:

1- Find the V_L and I_L using superposition.
2- Find the Thevenin's equivalent circuit between A and B (i.e. as seen by R_L)
3- Find the Norton's equivalent circuit as seen by R_L.
4- Vary R_L from 2.5 K to 10.5 K in steps of 1 K Ohms. Calculate V_L in each case. For (this purpose, use the Thevenin's equivalent circuit you obtained).
5- Calculate the power P_L absorbed by R_L in each case of steps 4.
6- Find the value of R_L for maximum power transfer and the value of the maximum power.

Summarize your results in Tables 2, 3 and 4.

APPARATUS: HF 6216 A, 0-3-V, Power Supply (Two)
Triplet Multimeter, Type 630.
Carbon Resistors: 10 kΩ, 22 kΩ, 33 kΩ, 47 kΩ, and 1 kΩ.
Decade Resistors.

THEORY:

- **Superposition Theorem**:
The voltage and current responses in a network from two or more sources acting simultaneously can be obtained as the sum of the responses from each source acting alone with other sources deactivated. A deactivated current source is an open circuit. A deactivated voltage source is a short circuit.

- **Thevenin's Theorem:**
A two–terminal network can be replaced by a voltage source with the value equal the open circuit voltage across its terminals, in series with a resistor with the value equal to the equivalent resistance of the network.

Norton's Theorem:

A two terminal network can be replaced by a current source with the value equal to the short–circuit current at its terminal, in parallel with a resistor with the value equal to the equivalent resistance

of the network. The equivalent resistance of a two–terminal network is equal to the open circuit voltage divided by the short circuit current.

Maximum Power Transfer Theorem:

In a resistive circuit, a resistive load receives maximum power when the load resistance is equal to the Thevenin's equivalent resistance of the circuit (i.e. RL = R_{TH}). The maximum power can be calculated using the expression:

$$p = \frac{V_{OC}^2}{4R_{TH}}$$

Where V_{OC} is the open circuit voltage.

Procedure:

1- Check the values of the resistors using the multimeter. Record the values in Table 1.
2- Connect the circuit of Figure 1 and measure V_L and I_L.
3- Deactivate the 10 V source and measure V_L' and I_L'.
4- Reactive the 10 V sources and deactivate the 5 V source. Measure V_L'' and I_L''
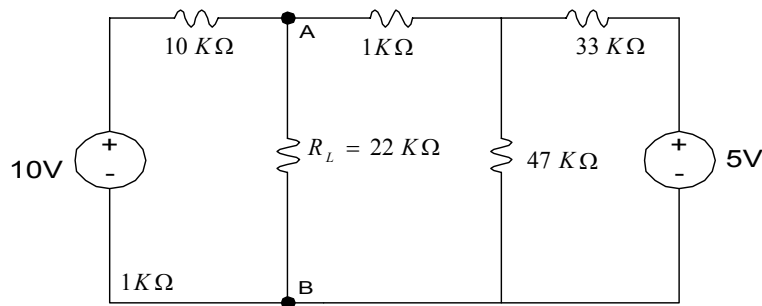5- Record the results in Table 2.

Figure 1

Thevenin and Norton Theorems:

6- Remove R_L from the original circuit and measure the open circuit voltage Voc.
7- Measure the short circuit current I_{sc}. This is accomplished by placing an Ammeter between A and B. In this manner, <u>the Ammeter will act as a short circuit</u>.
8- Replace the voltage sources with short circuits. With R_L removed from the circuit, measure R_{th} using a multimeter.
9- Record the results in Table 3.

Maximum Power Transfer:

10- Reconnect the circuit as shown in Figure 1, but replace the 22 KΩ resistor between A and B and by a variable resistor (i.e. R_L in this case is the variable resistor).
11- Vary RL from 2.5 KΩ to 10.5 KΩ in steps of 1 KΩ and measure V_L in each case.
12- Record the results in Table 4.

Report:

1- Compare the theoretical and experimental values of the voltages and currents obtained using superposition. Calculate the percentage error.
2- Draw the Thevenin's and Norton's equivalent circuit obtained experimentally.
3- Compare step 2 with theoretical Thevenin and Norton's equivalent circuits obtained in pre-lab.
4- Calculate P_L from step 11 above and record the results in Table 5.
5- Plot the theoretical and experimental values of P_L versus R_L (on the same graph).
6- Compare the two graphs of step 5.
7- Discuss the reasons for any discrepancies between the theoretical and experimental values for all cases.

Questions:

1- Thevernin's and Norton's Theorem are very useful. List at least two reasons for it
2- Is the Maximum Power Theorem verified experimentally? Explain.

TABLE 1

Resistor Values:

Resistor	R1	R2	R3	R4	R5
Nominal value (Ohm)	10K	22K	1K	47K	33K
Ohmmeter Reading					

TABLE 2

Superposition Theorem:

	$V_L(V)$	V'_L (V)	V''_L (V)	I_L (mA)	I'_L (mA)	I''_L (mA)
Theory						
Experiment						
% Error						

TABLE 3

Thevenin's and Norton's Equivalent Circuits:

	V_{oc} (V)	I_{sc} (mA)	R_{TH} (K Ohm)
Theory			
Experiment			
Error			

THEVENIN'S EQUIVALENT CIRCUIT	NORTON'S EQUIVALENT CIRCUIT

TABLE 4

Load Voltage Results:

R_L (K Ohm)	2.5	3.5	4,5	5.5	6.5	7.5	8.5	9.5	10.5
V_L (Theoretical)									
V_L (Experimental)									

TABLE 5

Maximum Power Transfer Results:

R_L (K Ohm)	2.5	3.5	4,5	5.5	6.5	7.5	8.5	9.5	10.5
P_L (Theoretical)									
P_L (Experimental)									
% Error									

EXPERIMENT # 6

FREQUENCY DOMAIN ANALYSIS

OBJECTIVE:
1. To experimentally verify frequency domain calculations using the phasor method.
2. Experimentally measure the phase difference between two sinusoidal signals.

Pre-Lab Assignment:

For the circuit shown in Figure 2:

       1- Assume that the inductor has an internal resistance of 51 Ohms.
       2- Add 1 K Ohm resistor with the inductor.
       3- Let the source voltage V_s have a peak amplitude of 10 V and frequency $f = 20$ kHz. Assume that V_s has a zero phase angle.
       4- Use phasor method to calculate all voltages and currents shown.

Enter your results in Table 2.

APPARATUS: Signal Generator.
                  Digital Multimeter.
                  Oscilloscope.
                  Capacitor 0.022 μF.
                  Inductor 8.2 mH
                  Resistor: 100 Ω, 1 KΩ, and 1.5 KΩ.

THEORY:
       In the frequency domain (phasor domain), the currents and voltages are represented by complex numbers whose magnitudes are equal to the maximum values of the sinusoidal time-domain quantities, and whose angles are equal to the phase angles of the time-domain functions expressed as cosines.

       In terms of voltage and current phasors and the complex impedance $\bar{Z}$, Ohm's law becomes:
$$\bar{V} = \bar{I}\,\bar{Z} \qquad\qquad\qquad (1)$$

Where $\bar{Z} = R$ for a resistance
                       $= jL$ for an inductance
$$= \frac{1}{j\omega C} \qquad \text{for a capacitance}$$

where $\omega = 2\pi f$ is the angular frequency of the source . The bar indicates a complex quantity.

In general, for $\bar{V} = V\angle\alpha$ and $\bar{I} = I\angle\beta$, the impedance $\bar{Z} = \dfrac{V}{I}\angle\alpha - \beta$

Analytically, frequency-domain circuits are treated by the same method as used in DC circuits, except that the algebra of complex numbers is used.

Experimentally, the frequency-domain phasors can be measured on the oscilloscope. The magnitudes can be measured by means of calibrated vertical scales. Phase difference can be measured by using the dual traces and measuring the time difference between two waveforms, as illustrated in Figure 2.

IMPORTANT NOTE: When measuring the phase difference between two signals, make sure that the control knobs in the oscilloscope are set properly such that the signals are not relatively inverted.
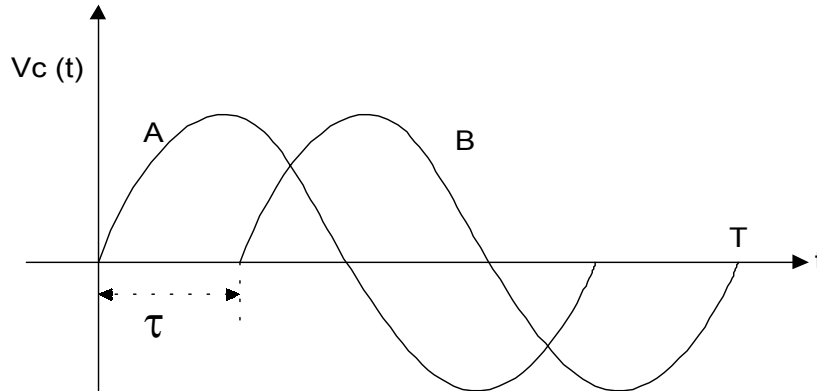
Time shift $= \tau$

Phase shift $= 360 \, (\dfrac{\tau}{T})$ degrees

Figure 1

Signal B lags signal A.
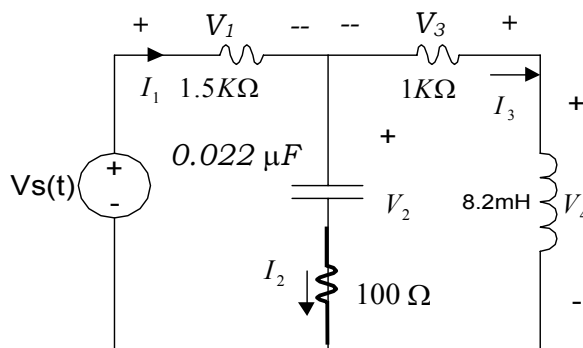
Figure 2

PROCEDURE:

1. Measure the resistor values and the internal resistance of the inductor, using an Ohmmeter.

2. Connect the circuit of Figure 2. Adjust the source voltage to 10 V peak at 20 kHz, while it is connected to the circuit.

3. Use the oscilloscope to measure the magnitudes and phases of all voltages and currents and record the values in Table 2.

IMPORTANT NOTE:

1. When measuring the phase difference between two signals, make sure that the control knob of the oscilloscope are set properly such that the signals are not relatively inverted.

2. Whenever two signals are to be displayed simultaneously on the oscilloscope, they should have one common node as a reference. Therefore, you may have to change the position of some elements to be able to measure two signals simultaneously.

3. To find I_2, measure the voltage on the 100 Ω resistor.

REPORT:

1. Draw the circuit of Figure 2 in the frequency domain (in the phasor representation).
2. Record the theoretical and experimental values in Table 2.
3. Draw the phasor diagram, showing all the voltages and currents, based on the experimental values.
4. Discuss the sources of discrepancies between the theoretical and experimental values.

QUESTIONS:

1. For a resistance and capacitance in series with a voltage source, show that it is possible to draw a phasor diagram for the current and all voltages from magnitude measurement of these quantities only. Illustrate your answer graphically

2. The equivalent impedance of a capacitor in series with an inductor is equivalent to a short circuit (i.e. equal to zero) at a certain frequency. Derive an expression for this frequency.

3. The equivalent impedance of a capacitor in parallel with an inductor is equivalent to an open circuit (i.e. equal to infinity) at a certain frequency. Derive an expression for this frequency.

TABLE 1

Resistor	R1	R2	R3
Nominal Value (Ohm)	100	1k	1.5k
Ohmmeter Reading			

Internal resistance of the inductor =   Ohms

TABLE 2

		V_1	V_2	V_3	V_4	I_1	I_2	I_3
Theoretical Values	Magnitude (Volts)							
	Phase Shift (Degree)							
Experimental Values	Magnitude (Volts)							
	Phase Shift (degrees)							
% Error	Magnitude (Volts)							
	Phase Shift (degrees)							

CIRCUIT IN FREQUENCY DOMAIN

PHASOR DIAGRAM

EXPERIMENT # 7

MAXIMUM POWER TRANSFER

OBJECTIVE:

1. To obtain maximum output power from a sinusoidal source with an internal impedance
2. To experimentally verify the theory of maximum power transfer.

Pre- Lab Assignment:

For the circuit shown Figure 1:

1. Assume that the inductor has an internal resistance of 51 ohms accounts for this resistance in this calculation
2. Find the value of R_L and C_L for maximum power transfer, and
3. Calculate the maximum power transferred to this load
4. Summarize your results in Table 4.
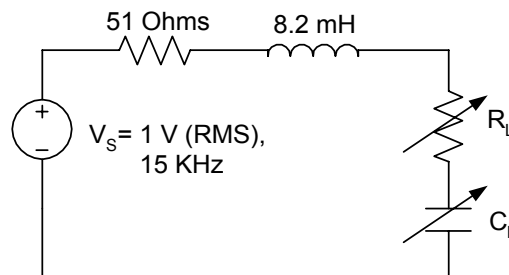
Figure 1

APPARATUS:

- Signal Generator
- Digital Multimeter
- Cornell Dubillier Decade Resistance Boxes RDB and RDA
- Cornell Dubillier Decade Capacitance Box CDA (Two boxes)
- Inductor (8.2 mH)
- Resistance (51 ohms)

THEORY:

Consider Figure 1. If the source impedance has a resistive and reactive parts, the maximum power is transferred to the load (actually to the resistive part of the load) when the load resistance equal the source resistance and the load reactance is opposite to the source reactance. Namely

$$Z_L = Z_S^* \qquad (1)$$

Equation (1) implies that if the source impedance is inductive the load impedance must be capacitive and vice versa. In order to compute the value of a capacitance, one can use the following relation

$$C = \frac{1}{\omega x_c} = \frac{1}{2\Pi f x_c} \qquad (2)$$

where x_c is a capacitive reactance.

Note that since $Z_L = Z_S$, V_S sees a combined load with impedance $Z_L + Z_S = Z_S + Z_S = 2R_S$ which is purely resistive. This means, under this condition (the condition of maximum power transfer), V_S becomes in phase with the current through the load and thus V_S becomes <u>in phase</u> with the voltage across the load resistance.

The maximum power transferred to the load in this is

$$P_{max} = \frac{V_s^2}{4R_s} \qquad (3)$$

PROCEDURE:

1. Consider the 8.2 mH inductor in the circuit of Fig. 1. as part of the source impedance. Measure its internal resistance R_i. Add 51 Ohm in addition to this resistance. This means $R_S = R_i + 51$. Set the source voltage to a sinusoid of 1 V r.m.s and frequency of 15 KHz.

2. With R_L set the value of R_S, vary C from 0.01 F to 0.02 F in steps of 0.001 F (use two decade capacitors in parallel). Measure the voltage across R_L in each case, <u>maintaining an input voltage of 1 V r.m.s.</u> Record the values in table 2.

3. Display the source voltage and the voltage across R_L simultaneously on the oscilloscope. Vary C and notice the phase shift between the two signals. Record the value of C that makes the two signals in phase.

4. With C set at the value found in step 3, vary R_L from 10-200 and measure the voltage across R_L in each case, again <u>maintaining an input voltage of 1 V r.m.s.</u> Record the values in Table 4.

IMPORTANT NOTES:

1. Your results are based on having an ideal voltage source (one whose terminal voltage is independent of the current and frequency). You convert your physical signal generator in to an ideal voltage source by changing the gain setting for each measurement so that the terminal voltage remains constant.

2. Whenever two signals are to be displayed simultaneously on the oscilloscope, they should have one common node as a reference. Therefore, you may have to change the position of some elements to be able to measure two signals simultaneously.

REPORT:

1. Complete the tables in your report sheets

2. Plot the load power vs. C and the load power vs. R_L. Determine from the graphs the value of Z_L for maximum power transfer, and compare it with the theoretical value.

3. Compare the theoretical and experimental values of the maximum power transferred to the laod.

4. Comment on the causes of errors between the measure and calculated values.

TABLE 1

Resistive value

Resistor	R1
Nominal Value (Ohm)	51
Ohmmeter Reading	

Internal Resistance of the inductance $R_i =$

TABLE 2

Results for C

C (nF)	10	11	12	13	14	15	16	17	18	19	20
V_L (V)											
P_L (W)											

TABLE 3

Results for R_L

R_L (Ohm)	10	50	90	100	102	103	104	105	110	150	200
V_L (V)											
P_L (W)											

TABLE 4

Comparison at Maximum Power Transfer

	R_L	C	P_{max}
Theory			
Experiment			
% Error			

QUESTIONS:

1. Comment on the sharpness of the maximum of the power curves. Is it necessary to match with great care to achieve maximum power transfer?

2. What is the phase difference between the current and the voltage source when maximum power transfer is achieved?

3. If the frequency of the source is doubled, what change should be done to maintain maximum power transfer to the load? How does this change affect the value of the maximum power? Explain.

4. The term <u>available power</u> is used to describe a source in many communication applications. It is the maximum possible power which the source can deliver to an external load. What is the available power of a source of voltage V and internal resistance R?

EXPERIMENT # 8

AVERAGE AND RMS VALUES

OBJECTIVE:

    1- To measure the average and root mean square (r.m.s) values of some electrical signals.

    2- To compare the calculated and experimental values.

Pre-Lab Assignment

  1- For the periodic signals shown in Figure 1, find:

      a) The average value of each signal.

      b) The r.m.s. value of each signal.

  2- For the periodic signals shown in Figure 2, find the average value of each signal.

APPARATUS: Oscilloscope

                  Signal Generator

                  Digital Multimeter (DMM)

THEORY:

1- Average Value:

The average value of a periodic signal $f(t)$ is defined as:

$$f_{avg} = \frac{1}{T}\int_0^T f(t)dt = \frac{area \quad under \quad one \quad period}{period} \qquad (1)$$

2- The Root Mean Square value:

The r.m.s. value of a periodic signal $f(t)$ is defined as :

$$f_{rms} = \sqrt{\frac{1}{T}\int_0^T f^2(t)dt} = \text{Square root of the average of } f^2 \text{ (t).} \qquad (2)$$

For a general sinusoidal signal $f(t) = A\cos(\omega t + \phi)$., it is easy to show that

$$f_{avg} = 0 \qquad\qquad\qquad\qquad (3)$$

$$f_{max} = \frac{A}{\sqrt{2}} \qquad\qquad\qquad\qquad (4)$$

For a signal that consists of a DC and AC parts such as, $f(t) = B + A\cos(\omega t + \phi)$
where, B = constant, it is equally easy to show that the average value is equal to the DC
part only, namely:

$$f_{avg} = B \qquad\qquad\qquad\qquad (5)$$

Procedure:

1- Set the oscilloscope controls as follows:

Time / Div.	0.2 ms	Volts / Div.	0.5 V
Vertical Display	A	Coupling	D.C.

2- Connect the output of the signal generator to channel A of the oscilloscope.
3- Set the signal generator to a sinusoid of 2000 Hz and a peak to peak voltage $V_{p-p} = 2$ V.
4- Adjust the DC offset of the signal generator to zero, so that the signal you obtain on the
   oscilloscope has no DC value (similar to the signals of Figure 1). This is done by first setting
   the oscilloscope control to ground then moving ground level to the middle of the screen).
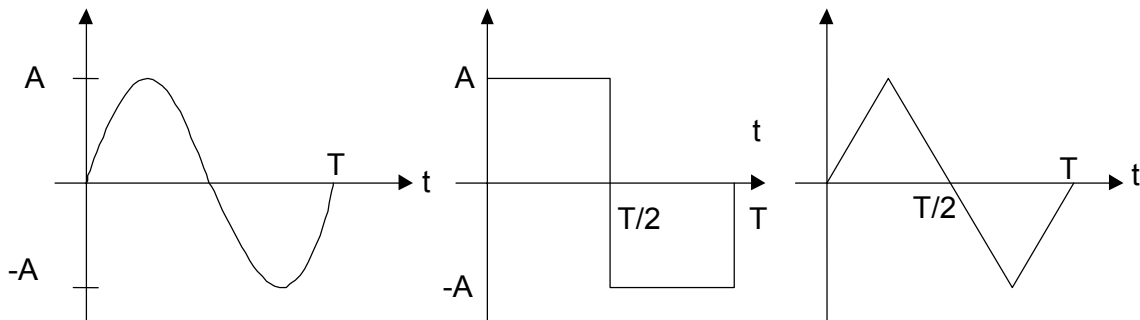

Figure 1

5- Measure :

   a) The average value of the signal with a DMM (set the voltmeter to D.C.).
   b) The r.m.s. value of the signal with a DMM (set the voltmeter to AC).
   c) The period of the signal from the oscilloscope. Then calculate the corresponding
   frequency from the relation f = 1/T.

6- Repeat steps 3-5 for a square signal with the same V_{p-p} and frequency.
7- Repeat steps 3-5 for a triangular signal with the same V_{p-p} and frequency.
8- Repeat the measurement of the <u>average value</u> for the same signals as in previous steps with the following changes:

   a) Adjust the ground level to the bottom of the screen.
   b) Adjust the D.C. offset of the signal generator, so that the signals start from zero and reach a peak value of 2 V as shown in Figure 2.
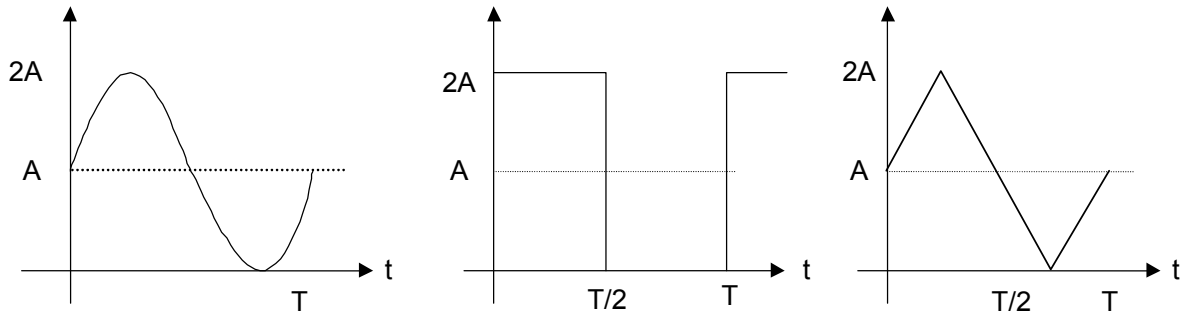

Figure 2

Report:

1- Complete the Tables in your report sheets.

2- Comment on the causes of errors between the measured and calculate values.

Question:

1- The frequency of the voltage in your house is 60 Hz. How much time is required for the waveform to complete three cycles?

2- What is the difference between AC and DC coupling of the oscilloscope? Explain how to use them to measure the average value of any periodic signal.

3- Some meters are calibrated to read r.m.s. Value of sinusoidal waveforms from the basic unit that responds to the peak value of the waveform. In terms of the peak value, V_p , the meter will read $\dfrac{V_p}{\sqrt{2}}$, which is the correct r.m.s value for a sinusoidal signal. Can this meter be used to read the correct rms value for other waveforms like square, triangular, etc? Comment.

TABLE 1

	Sinusoidal	Square	Triangular
T (ms)			
f (Hz)			
Average Value (Calculated)			
Average Value (Experimental)			
% Error			
R.M.S. Value (Calculated)			
R.M.S. Value (Experimental)			
% Error			

TABLE 2

	Sinusoidal	Square	Triangular
Average Value (Calculated)			
Average value (Experimental)			
% Error			

APPENDIX I

Resistor Color Code

Resistor Color Code

A B C D

A: FIRST BAND	B: SECOND BAND	C: THIRD BAND	D: FOURTH BAND
1ST SIGNIFICANT FIGURE	2ST SIGNIFICANT FIGURE	MULTIPLIER	TOLERANCE

COLOR	DIGIT
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

COLOR	DIGIT
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

COLOR	DIGIT
SILVER	-2
GOLD	-1
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

COLOR	DIGIT
WITHOUT	20 %
SILVER	10 %
GOLD	5 %
RED	2 %
BROWN	1 %

EXAMPLES

YELLOW	VIOLET	BROWN	SILVER		BROWN	RED	ORANGE	GOLD	
4	7	0	10 %	=470, 10%	1	2	000	5 %	=12KΩ, 5%

APPENDIX II

LABORATORY REGULATIONS AND SAFETY RULES

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS
ELECTRICAL ENGINEERING DEPARTMENT

LABORATORY REGULATIONS AND SAFETY RULES

The following Regulations and Safety Rules must be observed in all concerned laboratory location.

1. **It is the duty of all concerned who use any electrical laboratory to take all reasonable steps to safeguard the HEALTH and SAFETY of themselves and all other users and visitors.**
2. **Be sure that all equipment are properly working before using them for laboratory exercises. Any defective equipment must be reported immediately to the Lab. Instructors or Lab. Technical Staff.**
3. **Students are allowed to use only the equipment provided in the experiment manual or equipment used for senior project laboratory.**
4. **Power supply terminals connected to any circuit are only energized with the presence of the Instructor or Lab. Staff.**
5. **Students should keep a safety distance from the circuit breakers, electric circuits or any moving parts during the experiment.**
6. **Avoid any part of your body to be connected to the energized circuit and ground.**
7. **Switch off the equipment and disconnect the power supplies from the circuit before leaving the laboratory.**
8. **Observe cleanliness and proper laboratory house keeping of the equipment and other related accessories.**
9. **Wear the proper clothes and safety gloves or goggles required in working areas that involves fabrications of printed circuit boards, chemicals process control system , antenna communication equipment and laser facility laboratories.**
10. **Double check your circuit connections specifically in handling electrical power machines, AC motors and generators before switching "ON" the power supply.**
11. **Make sure that the last connection to be made in your circuit is the power supply and first thing to be disconnected is also the power supply.**
12. **Equipment should not be removed, transferred to any location without permission from the laboratory staff.**
13. **Software installation in any computer laboratory are not allowed without the permission from the Laboratory Staff.**
14. **Computer games are strictly prohibited in the computer laboratory.**
15. **Students are not allowed to use any equipment without proper orientation and actual hands on equipment operation.**
16. **Smoking and drinking in the laboratory are not permitted.**

All these rules and regulations are necessary precaution in Electrical Laboratory to safeguard the students, laboratory staff, the equipment and other laboratory users.