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EE 336

Electronic Engineering Lab Manual

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Table of Contents

Experiment

1 Component Identification

Objectives

1. To differentiate different types of electronic components by their size and shape.
2. To separate resistor values by their color codes.
3. To separate capacitor values by their color or numeric codes.
4. To classify other electronic components and electronic hardware.

Equipment

This lab experiment does not require specific components or equipment. It could, in fact, be completed as an assignment. Since every instructional setting likely has different forms of component kits, the instructor may wish to direct the student towards identifying specific available components.

If this lab is to be completed as a laboratory exercise, an assortment of five color-coded resistors and five color-coded capacitors are required, along with three capacitors which are numerically encoded. Five other electronic components such as an inductor, fuse, switch, semiconductor and transformer are also required.

Information

Figure 1-1 illustrates the various shapes of resistors, potentiometers and capacitors to assist in their initial identification. Figure 1-2 illustrates inductors, a transformer and various semiconductors. Figure 1-3 shows an assortment of items often encountered in electronics. Some schematic symbols are also shown in these Figures.

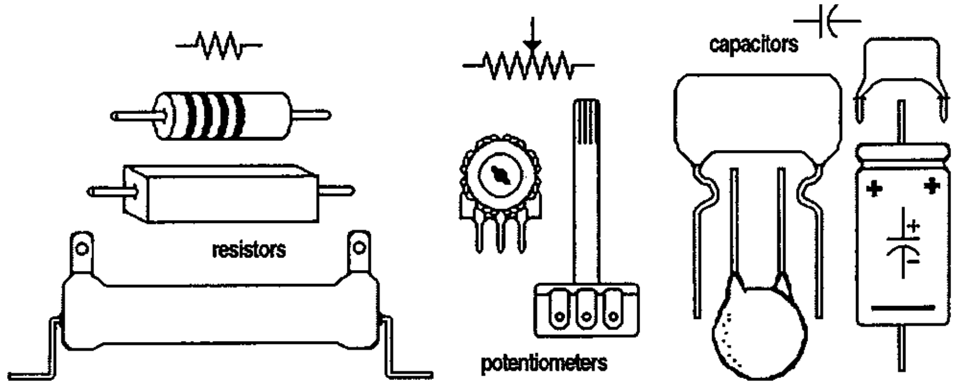


Figure 1-1. Resistors, Potentiometers and Capacitors (scale varies)

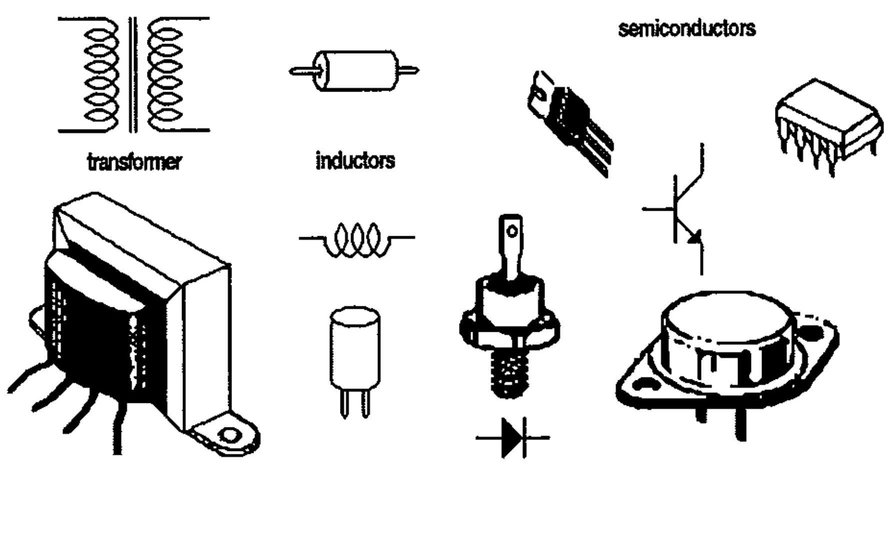


Figure 1-2. Transformers, Inductors and Semiconductors (scale varies)

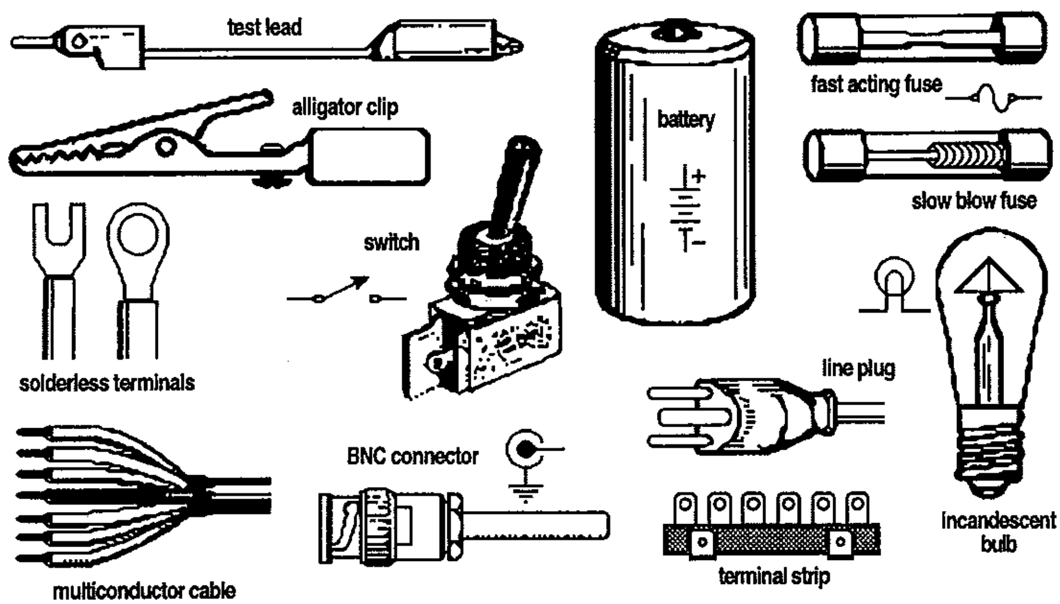


Figure 1-3. Miscellaneous Electronic Items (scale varies)

Notice in Figure 1-1 that resistors are produced in a variety of sizes. The size is not determined by the component's resistance in ohms. That is, a resistor which is 1000 ohms may be exactly the same size as a 1 ohm resistor. The physical size of a resistor is usually related to its wattage rating, or its ability to dissipate power. The larger resistors typically have the ability to dissipate more power than smaller resistors. The larger resistor may be rated at, for example, 10 watts and the smaller one rated at 1 watt.

Figure 1-3 illustrates two types of fuses. It may be important for a student to recognize the differences between these two types of fuses early. A student may be called upon to replace a fuse at any time. The fast-acting fuse is a simple narrowing of a piece of metal. If the current rating of this type of fuse is exceeded, the narrow portion quickly melts and the circuit is opened. The slow blow fuse, usually characterized by an internal spring mechanism, is designed to allow a nominal current overload for a short time before melting and springing apart to open the circuit. The slow blow fuses are used in equipment that needs more current during startup than during normal operation.

Always check the equipment manual before replacing a blown fuse in order to be sure you are replacing it with the correct type. Often, a fuse blows because someone else replaced a previously blown fuse with the wrong type or with the wrong rating.

Figure 1-4 lists the colors which are used to represent numbers in the coding of component values, along with a rhyme which may help the student recall the colors in their proper order. Space has been left in Figure 1-4 for students to write their own rhyme to help recall the color code.

Rhyme	black	beards	rarely	offend	young	girls	but	vulgarity	generally	will
Yours										
Colors	black	brown	red	orange	yellow	green	blue	violet	gray	white
Digits	0	1	2	3	4	5	6	7	8	9
Other colors used for resistor tolerances					gold: ± 5 %		silver: ± 10 %		no color: ± 20 %	
Other colors used for resistor multiplier bands					gold: multiply by 0.1			silver: multiply by 0.01		
	±20 %	Capacitor tolerance		±30 %	±40 %	±5 %				±10 %
Capacitor voltage			200 V	300 V	400 V	500 V	600 V			

Figure 1-4. Resistor and Capacitor Color Codes

Figure 1-5 illustrates the application of the color code to resistors and capacitors. Figure 1-6 shows various forms of numerical coding of capacitors.

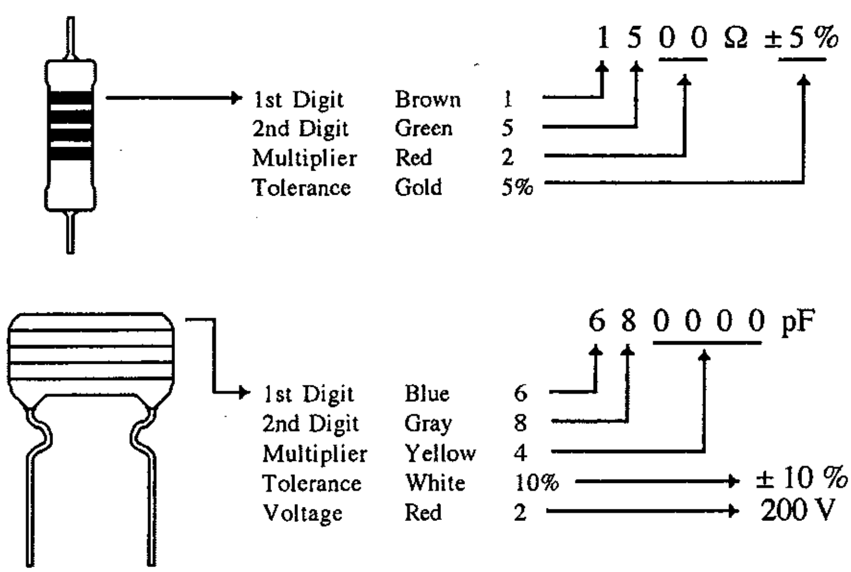


Figure 1-5. Examples of Color Code Use

The resistor color code provides the "nominal" value of the resistor in units of "ohms," which is abbreviated with the symbol, Ω. The tolerance is the range of resistance values for a particular resistor. For the 1500 Ω example in Figure 1-5, the tolerance is ±5 %. This means that the value of the resistor is 1500 Ω ± 5 %, which is 1500 Ω ± 75 Ω. The minimum resistance value is then 1500 Ω - 75 Ω, or 1425 Ω. The maximum resistance value is then 1500 Ω + 75 Ω, or 1575 Ω. Therefore, to be within tolerance, the actual resistance value must be between 1425 Ω and 1575 Ω. Capacitor tolerances are calculated in a similar fashion.

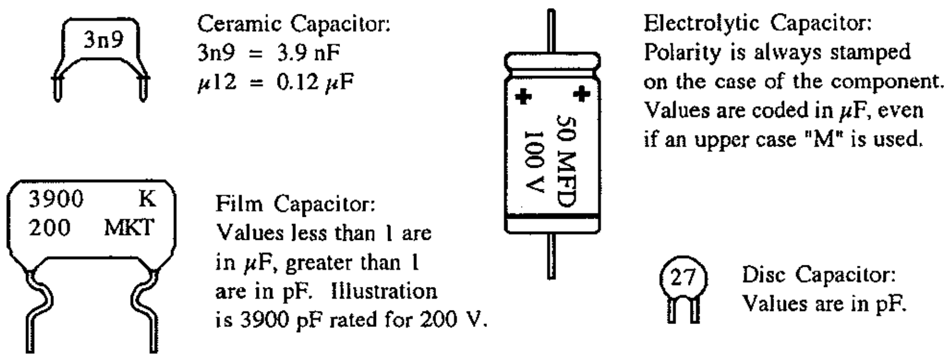


Figure 1-6. Examples of Numerical Coding of Capacitors

Film capacitors tend to the the most confusing for students to identify. As shown in Figure 1-6, decimal values (numbers less than 1), such as 0.033 are coded in μF, whereas a number without a decimal (numbers greater than 1), such as 6800, would be coded in pF. Other forms of numerical coding are also in use, such as "103," which would mean ten, followed by three zeros, or 10000 pF, which is 10 nF or 0.01 μF. Students are exposed to capacitors at this point solely for the purpose of learning their coding methods. The functions of capacitors will be investigated in a later experiment.

Lab Prep

1. Complete Table 1-1 using the given resistor color codes. Determine the coded resistance (Ω), the tolerance (%), the tolerance (Ω), and the permissible range of resistance (Ω). The first line has been completed as an example.

Table 1-1. Resistor Color Codes

first	second	third	fourth	resistance (Ω)	tolerance (%)	tolerance (Ω)	lowest resistance	highest resistance
yellow	violet	orange	gold	47 kΩ	±5 %	±2.35 kΩ	44.65 kΩ	49.35 kΩ
blue	gray	yellow	silver					
brown	black	black	gold					
red	red	green	gold					
orange	white	brown	silver					

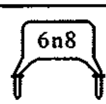
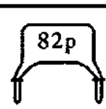
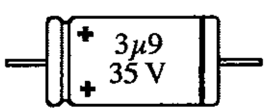
2. Complete Table 1-2 using the given capacitor color codes. Determine the coded capacitance (F), the tolerance (%), the voltage rating (V), and the permissible range of capacitance (F). The first line has been completed as an example.

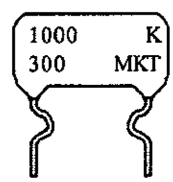
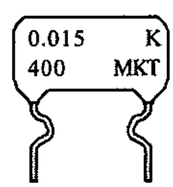
Table 1-2. Capacitor Color Codes

first	second	third	fourth	fifth	capacitance (F)	tolerance (%)	voltage (V)	lowest capacitance	highest capacitance
brown	black	green	white	green	1.0 μF	±10 %	500 V	900 nF	1.10 μF
orange	white	yellow	green	red					
green	blue	orange	black	yellow					
orange	orange	yellow	green	blue					
gray	red	green	white	orange					

3. Complete Table 1-3 using the given capacitor numerical codes. One capacitor has been completed as an example. Determine the coded capacitance (F) and the voltage rating (if available).

Table 1-3. Numerical Color Codes

	0.47 nF or 470 pF
	
	
	
	

4. Copy the data from Tables 1-1, 1-2 and 1-3 into the duplicate tables on the Prep Sheet.

Procedure

1. Pick out five resistors at random from your component kit. Record the colors of these resistors in Table 1-4. Using the coding information from Figure 1-4, determine the values required to complete the remaining portions of Table 1-4.

Table 1-4. Using Resistor Color Codes

first	second	third	fourth	resistance (Ω)	tolerance (%)	tolerance (Ω)	lowest resistance	highest resistance

2. Pick out three color coded capacitors at random from your component kit. Record the colors of these capacitors in Table 1-5. Using the coding information from Figure 1-4, determine the values required to complete Table 1-5.

Table 1-5. Using Capacitor Color Codes

first	second	third	fourth	fifth	capacitance (F)	tolerance (%)	voltage (V)	lowest capacitance	highest capacitance

3. Pick out three numerically coded capacitors at random from your component kit. Record the numbers of these capacitors in Table 1-6. Using the coding information from Figure 1-6, determine the values of the capacitors and record in Table 1-6.

Table 1-6. Using Capacitor Numerical Codes

	Numerical coding	Value of capacitance (and voltage rating if available)
1		
2		
3		

4. Pick out five other components from your kit. Identify these components by any means available to you. Use Table 1-7 to describe the characteristics which provided a positive identification.

Table 1-7. Identifying Other Electronic Components

	Component name	Identifying characteristics
1		
2		
3		
4		
5		

5. Copy the data from Tables 1-4, through 1-7 into the duplicate tables on the Data Sheet.

1 **Prep Sheet** **Name**

1. Complete Table 1-1 below as described in the Lab Prep section of this experiment.

first	second	third	fourth	resistance (Ω)	tolerance (%)	tolerance (Ω)	lowest resistance	highest resistance
yellow	violet	orange	gold	47 kΩ	±5 %	±2.35 kΩ	44.65 kΩ	49.35 kΩ
blue	gray	yellow	silver					
brown	black	black	gold					
red	red	green	gold					
orange	white	brown	silver					

2. Complete Table 1-2 below as described in the Lab Prep section of this experiment.

first	second	third	fourth	fifth	capacitance (F)	tolerance (%)	voltage (V)	lowest capacitance	highest capacitance
brown	black	green	white	green	1.0 μF	±10 %	500 V	900 nF	1.10 μF
orange	white	yellow	green	red					
green	blue	orange	black	yellow					
orange	orange	yellow	green	blue					
gray	red	green	white	orange					

3. Complete Table 1-3 below as described in the Lab Prep section of this experiment.

n47	0.47 nF or 470 pF
6n8	
82p	
+ 3μ9 35 V +	
+10 MFD 50 V +	

1000 K 300 MKT	
0.015 K 400 MKT	
5.6	
330	

 Name ______________________________

1. Complete Table 1-4 below as described in the Procedure section of this experiment.

first	second	third	fourth	resistance (Ω)	tolerance (%)	tolerance (Ω)	lowest resistance	highest resistance

2. Complete Table 1-5 below as described in the Procedure section of this experiment.

first	second	third	fourth	fifth	capacitance (F)	tolerance (%)	voltage (V)	lowest capacitance	highest capacitance

3. Complete Table 1-6 below as described in the Procedure section of this experiment.

	Numerical coding	Value of capacitance (and voltage rating if available)
1		
2		
3		

4. Complete Table 1-7 below as described in the Procedure section of this experiment.

	Component name	Identifying characteristics
1		
2		
3		
4		
5		

Questions

1. How can you determine which end of a color coded resistor is the starting end for purposes of deciphering the coded value?

2. What is the significance of the polarity signs that are printed on some capacitors?

3. Describe the significance of the physical size of resistors.

4. How does a fast acting fuse differ from a slow blow fuse?

5. Describe the significance of the placement of the prefix symbol for a numerically encoded ceramic capacitor.

Experiment

2 Circuit Breadboarding

Objectives

1. To interpolate layout and interconnections of a typical circuit construction breadboard.
2. To construct a breadboard layout from a schematic diagram.
3. To create a schematic diagram of a circuit from a breadboard layout.

Equipment

Circuit construction breadboard

Resistors:	100 Ω	10 kΩ		
	150 Ω	18 kΩ	220 kΩ	(power ratings are not critical)
	560 Ω	33 kΩ	680 kΩ	
	1 kΩ	47 kΩ	1 MΩ	
	8.2 kΩ	100 kΩ		

Capacitors: 100 pF, 10 nF, 150 nF, 10 μF (any voltage rating)

Information

Two views of a typical circuit construction breadboard are shown in Figure 2-1. The board appears as a collection of holes as shown in the left side of Figure 2-1. These are actually sockets which have spring clips inside in order to make electrical contact with any component lead that may be inserted into the socket. The right side of Figure 2-1 illustrates the same breadboard, but shows lines which represent sockets that are connected together underneath the breadboard. The two sets of horizontal sockets at the top and bottom of the board (designated by + and – signs) are commonly called "bus lines," and are used to make connections to common circuit points, usually the top and bottom of the circuit.

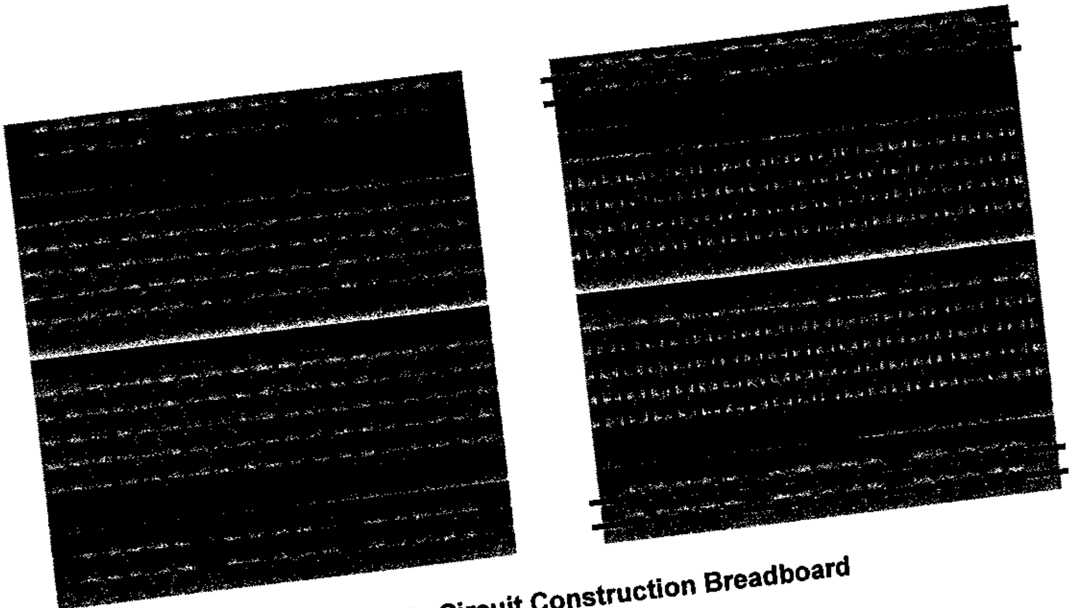


Figure 2-1. Circuit Construction Breadboard

Notice that the socket interconnections for the bus lines run only horizontally. The vertical connections exist only in vertical groups of five sockets between the bus line areas. Notice that there are no connections across the centre of the board. The reason for this is that the centre area is designed to accept integrated circuits and allow easy connections of other components to these circuits. An example is shown in Figure 2-2.

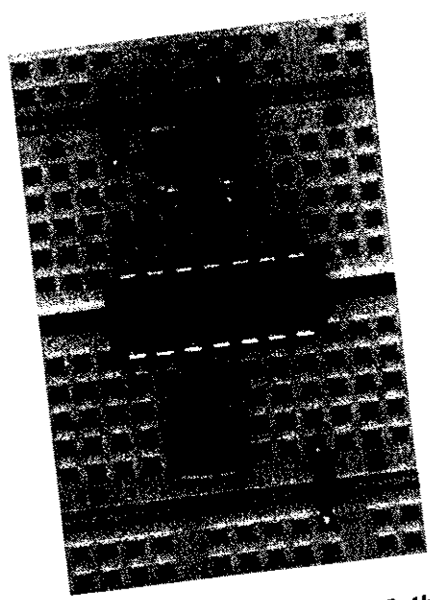


Figure 2-2. IC Connection Method

Lab Prep

1. Study the circuit shown in Figure 2-3 and the equivalent breadboard layout for this circuit shown in Figure 2-4. Note that component leads have been shortened and some components have been laid flat for visual clarity. Do not attempt to make your components lay flat to the board.

2. Number the components on each diagram so that the placement of each component can be verified.

3. Follow the circuit lines of each diagram to verify that all required connections have been made.

4. No Prep Sheet is required for this experiment.

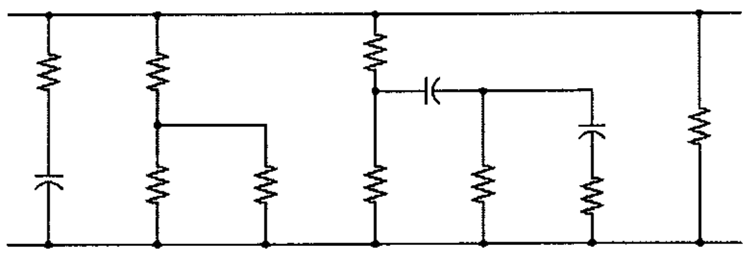


Figure 2-3. Schematic Diagram

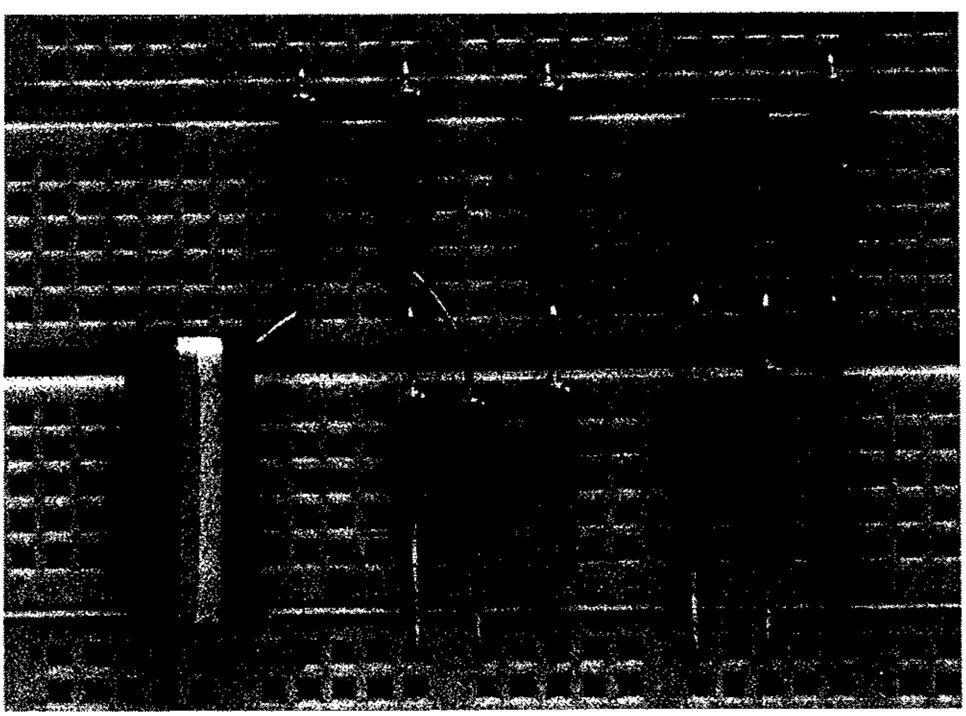


Figure 2-4. Breadboard Layout

Procedure

1. Construct the circuit of Figure 2-5 onto your breadboard. Try to lay out the actual circuit as close as possible to the same placement as appears on the schematic diagram.

2. When the layout has been completed, have your instructor check your breadboard for errors and initial your Data Sheet.

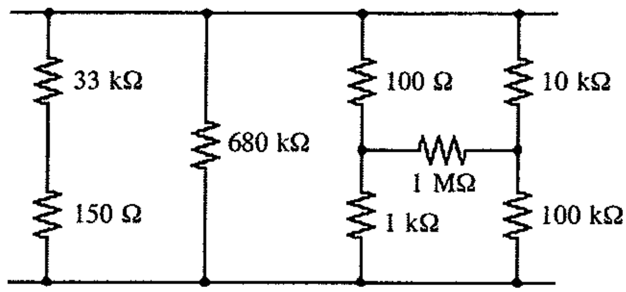


Figure 2-5. Circuit To Be Breadboarded

3. Construct the circuit of Figure 2-6 onto your breadboard. Try to lay out the actual circuit as close as possible to the same placement as appears on the schematic diagram.

4. When the layout has been completed, have your instructor check your breadboard for errors and initial your Data Sheet.

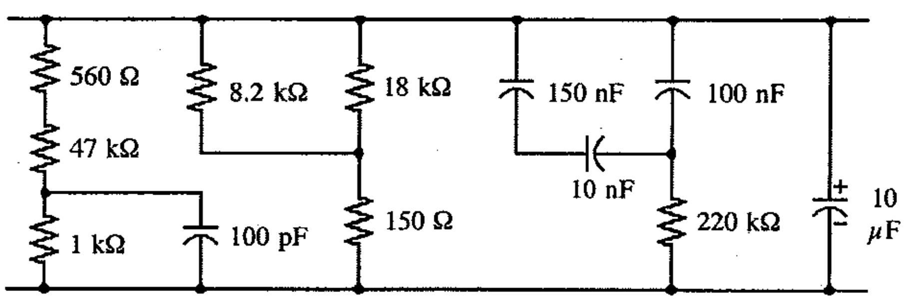


Figure 2-6. Circuit To Be Breadboarded

5. Your instructor may circulate several breadboarded circuits, from which you are expected to draw the schematic diagrams for each.

6. Use the space provided below to draw a rough sketch of the breadboard labeled "Circuit One." Draw your final schematic diagram for Circuit One on the Data Sheet. Include all component values.

7. Use the space provided below to draw a rough sketch of the breadboard labeled "Circuit Two." Draw your final schematic diagram for Circuit Two on the Data Sheet. Include all component values.

8. Use the space provided below to draw a rough sketch of the breadboard labeled "Circuit Three." Draw your final schematic diagram for Circuit Three on the Data Sheet. Include all component values.

1. Obtain your instructor's initials for the breadboarding of Figure 2-5:

Instructor's Initials	Construction Errors	Component Errors

2. Obtain your instructor's initials for the breadboarding of Figure 2-6:

Instructor's Initials	Construction Errors	Component Errors

3. Draw the final schematic diagram for Circuit One in the space provided below. Include all component values.

4. Draw the final schematic diagram for Circuit Two in the space provided below. Include all component values.

5. Draw the final schematic diagram for Circuit Three in the space provided below. Include all component values.

Questions

1. For the circuits of Figures 2-5 and 2-6, is it easiest to orient the breadboard horizontally or vertically? Why?

2. Could the layout of Figure 2-4 have been accomplished without using a jumper wire?

3. What types of wire would be most suitable as jumper wires for breadboards? What types would be unsuitable?

4. Are component lead diameters critical when using circuit breadboards?

5. How many components can be connected to each lead of an integrated circuit using the breadboard illustrated in Figure 2-2?

3 DC Resistance Measurements

Objectives

1. To connect and use an ohmmeter without causing damage to the instrument.
2. To interpret ohmmeter ranges.
3. To evaluate typical ohmmeter accuracy specifications.
4. To determine which situations which may lead to incorrect ohmmeter measurements.

Equipment

One or more ohmmeters

Resistors:	100 Ω,	1/4 W
	1.2 kΩ,	1/4 W
	560 kΩ,	1/4 W
	1 MΩ,	1/4 W

100 kΩ Potentiometer, 3/4 W, Part # 01B15 available from Digi-Key Corporation
Thermistor such as Part # KC001P or KC012N available from Digi-Key Corporation

Information

Ohmmeters differ significantly from voltmeters or ammeters in that ohmmeters use their own power to accomplish a resistance measurement. Both voltmeters and ammeters use power from the circuit under test, thus the circuit must remain energized. A circuit must be de-energized before a resistance measurement can be made. This can be done simply by opening the circuit where it is desired to measure resistance. Care must be taken that the circuit is not closed by the ohmmeter itself.

Scales associated with ohmmeters may be non-linear, linear, or digital readout. Most ohmmeters use a type of range switch in conjunction with the scale or readout. A "VOM," or volt-ohm-milliameter will usually have a non-linear resistance scale. A non-linear scale will have an "Rx" type of range, which is interpreted by multiplying the actual scale reading times the number indicated by the range position, for example, a scale reading of 12.5 while on an Rx10k range results in a measurement of 125 kΩ.

A linear scale, typically found on a "TVM," or transistorized voltmeter, will have a range switch which is marked simply in ohms, such as 100 kΩ. In this case, the user must look for a scale which reads from 0 to 100, or to any other multiple of 100, such as 10 or 1000. The upper end of the scale, called "full-scale deflection," is then interpreted to be 100 kΩ. The position of the needle is then interpreted as being between 0 Ω and 100 kΩ. As an example, a needle pointing at 3.68 on a 0 to 10 scale, on a 100 kΩ range, would indicate a resistance of 36.8 kΩ. A linearly scaled ohmmeter may use several scales so the user must be careful to use whichever scale has a full-scale deflection number which is a multiple of the range position.

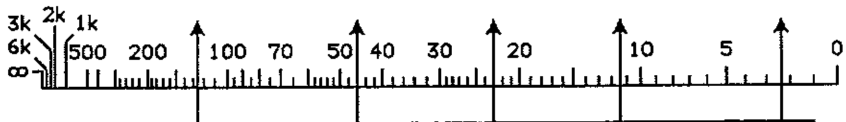
Digital ohmmeters are the easiest to read, since the user typically must only determine if the digital reading is in units of Ω or kΩ. However, the user must always be careful to select a range which provides the greatest number of digits in the display.

Ohmmeter accuracy may be specified a number of ways: ±x degrees of arc, ±x % of reading, ±x % of full-scale deflection, or, with a digital ohmmeter, ±x % of reading +y digits. The first of these methods is extremely difficult to evaluate with any certainty; the others are fairly obvious. A meter that is reading 120 Ω, having an accuracy of ±5 % of reading, should have an accuracy of ±5 % of 120 Ω, or ±6 Ω. The true resistance should be between 114 Ω and 126 Ω. A meter having an accuracy of ±3 % of full-scale deflection, and reading 850 Ω on a 1 kΩ range, has an accuracy of ±3 % of 1 kΩ or ± 30 Ω. The true resistance should be between 820 Ω and 880 Ω. A digital ohmmeter with an accuracy of ±2 % of reading + 1 digit, and reading 18.13 kΩ, has an accuracy of ±2 % of 18.13 kΩ or ±0.36 kΩ, plus 0.01 kΩ, totaling ±0.37 kΩ. The true resistance should be between 17.76 kΩ and 18.50 kΩ.

Precautions in the use of ohmmeters are simple. De-energize the circuit or resistance being measured. Complete any zero adjustments required for a particular instrument. Avoid any paths of resistance which may be beside, or in parallel with, the resistance being measured.

Lab Prep

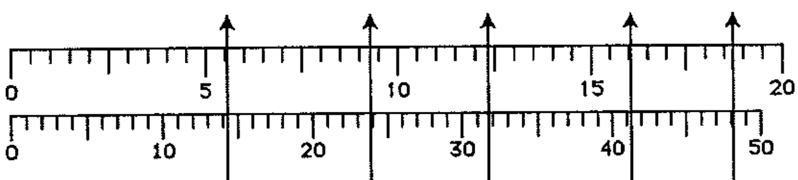
1. Determine the resistance readings for the different needle positions and ranges in the non-linear ohmmeter of Figure 3-1. The first reading has been completed as a guide.



Range	R x 1 k	R x 10	R x 10 k	R x 1	R x 100
Scale Reading	127				
Resistance	127 kΩ				

Figure 3-1. Non-Linear Ohmmeter

2. Determine the resistance readings for the different needle positions and ranges in the linear ohmmeter of Figure 3-2. The first reading has been completed as a guide.



Range	2 kΩ	200 Ω	50 kΩ	200 kΩ	500 Ω
Scale Reading	5.55				
Resistance	555 Ω				

Figure 3-2. Linear Ohmmeter

3. Copy the resistance readings (not scale readings) from Figures 3-1 and 3-2 into Table 3-1 on the Prep Sheet.

4. Complete the accuracy calculations required for Table 3-2 on the Prep Sheet.

Procedure

For the first three steps of this experiment, sufficient space has been allowed for the use of up to three different ohmmeters. Use as many ohmmeters as are available to you. The remainder of the experiment may be performed with any ohmmeter.

1. Record, in Table 3-3, the name and model number of each ohmmeter available at your lab station.

2. Consult the operator's manual for each instrument to determine the ohmmeter's accuracy specifications and record these in Table 3-3.

Table 3-3. Ohmmeter Specifications

Name and Model of Ohmmeter	Ohmmeter 1	Ohmmeter 2	Ohmmeter 3
Accuracy Specifications			

3. Measure the resistors specified in Table 3-4 using available ohmmeters. Record also, the resistor tolerances and the ohmmeter ranges used.

Table 3-4. Resistor Measurements

Coded Resistance		100 Ω	1.2 kΩ	560 kΩ	1 MΩ
Resistor Tolerance		± 5%	± 5	± 5%	± 5%
Meter 1	Oh meter Range Used	200Ω	2kΩkΩ	2mΩ	2mΩ
	Measured R	99.2	1.84	0.552mΩ	0.974mΩ
Meter 2	Multimeter Range Used	100Ω	1.2kΩ	560kΩ	1MΩ
	Measured R	98.92Ω	1.18kΩ	0.557mΩ	0.982mΩ
Meter 3	Range Used				
	Measured R				

4. With dry hands, grasp the ohmmeter leads and measure the resulting body resistance from one hand to the other. Record in Table 3-5.

5. Repeat the measurement of step 4, with moist hands this time. Record in Table 3-5.

6. Measure the cold resistance of the thermistor. Avoid touching the component with your hands. Record your measurement in Table 3-5.

7. Warm the thermistor for about one minute with your hands, and measure the resulting resistance. Again, record your measurement in Table 3-5.

Table 3-5. Resistance Measurements

Body Resistance		Thermistor Resistance	
Dry Hands	Moist Hands	Cold	Warm
0.06 mΩ	0.046 mΩ		

8. Connect an ohmmeter from the centre, or wiper, lead of a 100 kΩ potentiometer to one of the outside leads. As the potentiometer control is rotated clockwise, as viewed from the end, describe in Table 3-6 if the resistance increases, decreases, or stays the same.

9. Move the ohmmeter test lead from the outside potentiometer lead to the other outside lead and again describe the effect upon resistance as the control is rotated clockwise.

10. Connect the ohmmeter test leads to both of the outside leads of the potentiometer and again describe the effect upon resistance as the control is rotated clockwise.

Table 3-6. Potentiometer Resistances

	Effect on Resistance
Potentiometer resistance: centre to outside lead	
Potentiometer resistance: centre to other outside lead	
Potentiometer resistance: across both outside leads	

11. Copy the data from Tables 3-3 through 3-6 into the duplicate tables on the Data Sheet.

 Name

1. Complete the data required for Table 3-1 as described in the Lab Prep section of this experiment.

Prep, Step 1	127 kΩ				
Prep, Step 2	555 Ω				

2. Complete the accuracy calculations required for Table 3-2. One column has been completed as a guide.

	±3 % of Range	±5 % of Range	±6 % of Reading	±2 % of Reading Plus 2 Digits
Range	100 kΩ	1 kΩ		
Resistance Reading	67.8 kΩ	236 Ω	1.35 kΩ	103.4 kΩ
Accuracy in Ohms	±3.0 kΩ			
Lower Limit of Reading	64.8 kΩ			
Higher Limit of Reading	70.8 kΩ			

5

3 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 3-3 below.

	Ohmmeter 1	Ohmmeter 2	Ohmmeter 3
Name and Model of Ohmmeter	ohmeter		
Accuracy Specifications	± 1.5%	6 1/2 digits	

2. Complete the data required for Table 3-4 below.

Coded Resistance		100 Ω	1.2 kΩ	560 kΩ	1 MΩ
Resistor Tolerance		± 5%	± 5%	± 5%	± 5%
Meter 1	Range Used	200Ω	2kΩ	2mΩ	2mΩ
	Measured R	99.2 Ω	1.84kΩ	0.552mΩ	0.974mΩ
Meter 2	Range Used	100Ω	1.2 kΩ	560kΩ	1 MΩ
	Measured R	98.92Ω	1.18 kΩ	0.557mΩ	0.982mΩ
Meter 3	Range Used				
	Measured R				

3. Complete the data required for Table 3-5 below.

Body Resistance		Thermistor Resistance	
Dry Hands	Moist Hands	Cold	Warm
0.06mΩ	0.046mΩ		

Complete the data required for Table 3-6 below.

	Effect on Resistance
Potentiometer resistance: centre to outside lead	
Potentiometer resistance: centre to other outside lead	
Potentiometer resistance: across both outside leads	

Questions

1. Using the data from Table 3-5, calculate the expected measured resistance if a 330 kΩ resistor were held at both ends while being measured, with dry hands. If you have not yet studied parallel resistance, use the formula:

   $R_{expected} = (R_{dry} \times 330\ k\Omega) / (R_{dry} + 330\ k\Omega)$

   $R = \frac{60k\Omega \times 330k\Omega}{60k\Omega + 330k\Omega} = 50.77\ k\Omega$ = R expected

2. Use the accuracy specifications for ohmmeter 1 from Table 3-3 to calculate the possible range of measured resistance for the 560 kΩ resistor in Table 3-4. Is this range within the tolerance range of the resistor?

   $\pm 1.5\%$ $\pm 8.4k\Omega$

   $(560k\Omega)(0.015) = 8.4k\Omega$

   $560k\Omega \pm 8.4k\Omega = 551.6k\Omega$ through $568.4\ k\Omega$

   Our data shows a 552 kΩ resistance on a 560kΩ resistor so yes, it is within 1.5% tolerance range of the resistor.

3. Is your body more susceptible to electric shock with dry hands or with moist hands? Why?

   Resistance through wet hands is less than with dry hands. Therefore, if your hands are wet, you maybe the path of less resistance rather when you would have dry hands. So having wet hands makes you more susceptible to electric shock.

4. The resistance of a thermistor with a positive temperature coefficient will increase when heated. Does your thermistor have a negative or positive temperature coefficient?

4 DC Voltage Measurements

Objectives

1. To correctly connect a voltmeter to a circuit.
2. To interpret voltmeter ranges.
3. To evaluate typical voltmeter specifications.
4. To utilize single and double subscripted voltage notation.

Equipment

DC voltage supply
One or more voltmeters

Resistors:	1 kΩ, 1/4 W	18 kΩ, 1/4 W	39 kΩ, 1/4 W
	10 kΩ, 1/4 W	22 kΩ, 1/4 W	47 kΩ, 1/4 W
	12 kΩ, 1/4 W	33 kΩ, 1/4 W	68 kΩ, 1/4 W

Batteries: one each: D cell, C cell and 9 V
Solar cell such as Part # P246 available from Digi-Key Corporation

Information

Voltages exist as a potential difference between or across two points of an energized circuit. To correctly measure a voltage, a voltmeter must be connected between or across the two points of interest. The positive, or red test lead is connected to whichever point is closest in potential to the positive side of the energy source. The negative, or black test lead connects to the other point.

Voltmeter ranges refer to the full-scale deflection end of the scales. A voltmeter with a 0 to 10 volt scale, while on a 100 volt range, would require a potential of 100 volts to cause full-scale deflection of the meter movement. A pointer reading of 6.34 on the scale would be interpreted as 63.4 volts.

Voltmeter accuracy is typically expressed as ±x % of reading, ±x % of full-scale deflection, or, with a digital voltmeter, ±x % of reading +y digits. Refer to other experiments for examples of the use of accuracy specifications.

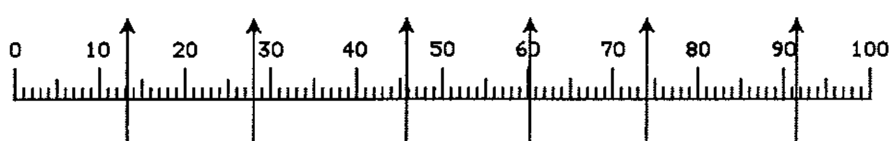
A single subscripted voltage, such as V_E, refers to the potential from point "E" to a ground or circuit common reference point. To measure this voltage, the positive test lead is connected to point E while the negative is connected to ground or circuit common. An upscale deflection is recorded as a positive voltage, although a plus sign is not required. If deflection is downwards, the meter leads must be reversed, and the resulting measurement must be recorded as a negative voltage. Some voltmeters will automatically correct for reversed polarity and provide a separate indicator of correct polarity.

Double subscripted voltages, such as V_{CD}, refer to the potential from point "C" to point "D." The positive lead must be connected to point C, the negative to point D. Again, an upscale reading is a positive voltage, while a reversed deflection must be recorded as a negative voltage. Correct polarity must always be expressed in a single or double subscripted voltage, whereas the notation "V_{R3}" does not imply any polarity and simply means "the voltage across the resistor R3."

A general precaution to observe when taking voltage measurements is to start on a high voltage range and successively reduce the range to obtain the maximum deflection without causing the needle to exceed maximum deflection.

Lab Prep

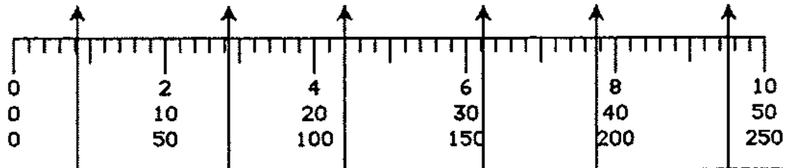
1. Determine the voltage readings for the different needle positions and ranges of the voltmeter of Figure 4-1. The first column has been done as an example.



Range	10 V	100 mV	1 V	1 kV	100 V	10 V
Scale Reading	13.2	28	45.9	60.1	74	91.5
Voltage	1.32 V	0.028V	4.59V	60.1	74V	9.15V

Figure 4-1. Single Scale Voltmeter

2. Determine the voltage readings for the different needle positions, scales, and ranges of the voltmeter of Figure 4-2. The first column has been done as an example.



Range	500 V	100 mV	2.5 V	5 V	100 V	25 V
Scale Reading	4.10	14.2	22	31.1	38.8	47.6
Voltage	41.0 V	0.014V	1.1 V	3.11 V	77.6V	23.75V

Range	250 mV	50 V	1 V	250 V	50 mV	1 kV
Scale Reading	20.5	14.2	22	31.1	38.8	47.6
Voltage	20.5 mV	14.2 V	0.44V	155.5 V	0.0388 V	950 V

Figure 4-2. Multiple Scale Voltmeter

3. Copy the voltage readings from Figures 4-1 and 4-2 into Table 4-1 on the Prep Sheet.

Procedure

1. For your future reference, record in Table 4-2, the accuracy specifications for all voltmeters which are available for your use.

Table 4-2. Voltmeter Specifications

Name and Model of Voltmeter	Voltmeter 1	Voltmeter 2	Voltmeter 3
Accuracy Specifications			

2. Connect the circuit of Figure 4-3. You are not expected to be able to analyze this circuit at this time. Note that this circuit may also be used for the next experiment, so you may wish to leave it connected.

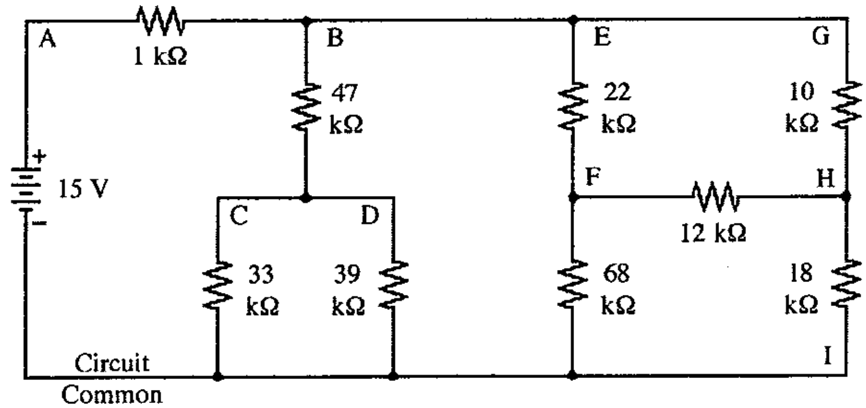


Figure 4-3. Voltage Measurement Circuit

3. Double check each connection and each resistor color code before continuing, since a single error will result in incorrect measurements throughout Table 4-3.

4. Measure voltages across the resistors of Figure 4-3, as well as the single and double subscripted voltages required to complete Table 4-3.

Table 4-3. Voltmeter Measurements

Voltage Designations	Measured Voltage	Voltage Designations	Measured Voltage	Voltage Designations	Measured Voltage
Across 1 kΩ	0.226	V_A	15 V	V_{AB}	0.225 V
Across 47 kΩ	10.67	V_B	14.78V	V_{DB}	-10.67V
Across 33 kΩ	4 V	V_C	4.08V	V_{HF}	-0.14V
Across 39 kΩ	4V	V_D	4.08V	V_{DF}	-6.4V
Across 22 kΩ	4.5 V	V_E	15 V	V_{EH}	5.05V
Across 68 kΩ	10.5V	V_F	10.5V	V_{AD}	10.9V
Across 12 kΩ	0.56V	V_G	15V	V_{GH}	5.0V
Across 10 kΩ	5 V	V_H	9.94	V_{IB}	-14.7V
Across 18 kΩ	9.9V	V_I	0.04V	V_{CH}	-5.83V

5. Measure the voltages of each of the batteries listed in Table 4-4. Additional space is allowed for any additional battery types that may be available.

Table 4-4. Cell Measurements

	D Cell	C Cell	9 V	Other	Other
Measured Voltages					
Solar Cell Voltages	Illuminated			Shielded	

6. Measure the voltage across the solar cell under normal room lighting conditions, then measure its voltage with the cell somewhat shielded from the light. Record these measurements in Table 4-4.

6

4 Prep Sheet

Name Oleksandr Vladyka

1. Record your meter interpretations from Figures 4-1 and 4-2 in Table 4-1 below.

Preparation, Step 1	1.32 V	0,028V	0.495 V	601V	74 V	9.15 V
Preparation, Step 2	41.0 V	0.0071V	1.1V	3.11 V	77.6V	23.75V
Preparation, Step 2	20.5 mV	14.2 V	0.44V	155.5V	0.0388V	950 V

Nice Unit conversions!

515

4 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 4-2 below.

	Voltmeter 1	Voltmeter 2	Voltmeter 3
Name and Model of Voltmeter	Volt Meter		
Accuracy Specifications	6 1/2 digits		

2. Complete the data required for Table 4-3 below.

Voltage Designations	Measured Voltage	Voltage Designations	Measured Voltage	Voltage Designations	Measured Voltage
Across 1 kΩ	0.226	V_A	15 V	V_{AB}	0.225 V
Across 47 kΩ	10.67	V_B	14.78 V	V_{DB}	-10.67 V
Across 33 kΩ	4 V	V_C	4.08 V	V_{HF}	-0.14 V
Across 39 kΩ	4 V	V_D	4.08 V	V_{DF}	-6.4 V
Across 22 kΩ	4.5 V	V_E	15 V	V_{EH}	5.05 V
Across 68 kΩ	10.5 V	V_F	10.5 V	V_{AD}	10.9 V
Across 12 kΩ	0.56 V	V_G	15 V	V_{GH}	5.0 V
Across 10 kΩ	5 V	V_H	9.94 V	V_{IB}	-14.77 V
Across 18 kΩ	9.9 V	V_I	0.04 V	V_{CH}	-5.83 V

3. Complete the data required for Table 4-4 below.

	D Cell	C Cell	9 V	Other	Other
Measured Voltages					
Solar Cell Voltages	Illuminated			Shielded	

Questions

1. Refer to Table 4-3. Calculate the sum of the measured voltages across the 1 kΩ, 10 kΩ, 12 kΩ, and 68 kΩ resistors.

   $0.226 + 5 + 0.56 + 10.5 = 16.29\ V$

2. Refer to Table 4-3. Is the measured voltage across the 18 kΩ resistor the same as the measured voltage V_H? Should they be the same?

   Yes, they are the same.

3. Refer to Table 4-3. Are the measured voltages V_{IB} and V_B the same? Should they be identical?

   No, they are not the same and shouldn't

4. Refer to Table 4-3. If the voltage V_{HC} were measured, how would it differ from the measured V_{CH}?

   The measurment would be positive.
   sign flipped

5. Refer to Table 4-3. Why are the measurements of V_{EH} and V_{GH} the same?

6. Refer to Table 4-3. The measured voltage V_{AD} represents the sum of the measured voltages across which two resistors?

5 DC Current Measurements

Objectives

1. To connect ammeters correctly into a circuit.
2. To interpret ammeter ranges.
3. To evaluate typical ammeter accuracy specifications.
4. To explain actions which could damage ammeters.

Equipment

DC voltage supply
One or more ammeters

Resistors:	1 kΩ,	1/4 W	18 kΩ,	1/4 W	39 kΩ,	1/4 W
	10 kΩ,	1/4 W	22 kΩ,	1/4 W	47 kΩ,	1/4 W
	12 kΩ,	1/4 W	33 kΩ,	1/4 W	68 kΩ,	1/4 W

Information

The flow of current in a circuit is much like the flow of water through a pipe. For this reason, the circuit must be physically broken before a current measurement can be accomplished. The easiest way to remember how to do this is as follows. When a circuit is broken at a location, it leaves a hole with two wire ends available. The ammeter must be connected to each of these wire ends, thus completing the circuit again. The positive lead of the ammeter should be connected to the wire end nearest to the positive side of the energy source. The current which originally flowed through the point of interest must now flow through the ammeter, which is now located at the point of interest.

Ammeter ranges are interpreted in the same manner as voltage ranges. Students usually experience some difficulty connecting ammeters so as to measure currents entering and leaving a node or junction of several resistors. Figure 5-1 illustrates a circuit having such a node, as well as the circuit board implementation of the circuit.

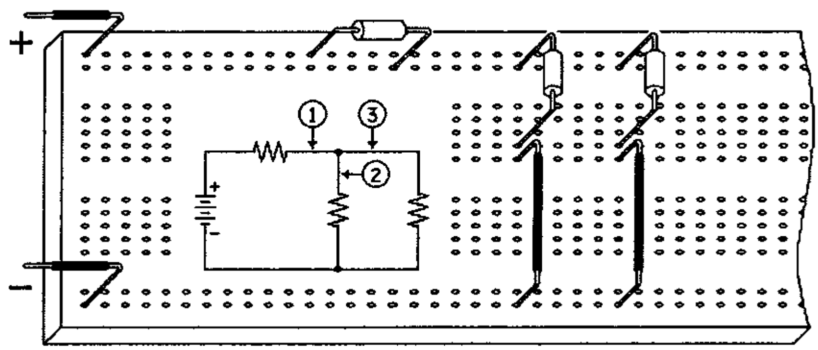


Figure 5-1. A Typical Node Connection

Figure 5-2 illustrates how ammeters could be connected to measure all three currents depicted in Figure 5-1. Try marking the actual current paths in Figure 5-2 to verify to yourself that they are correct.

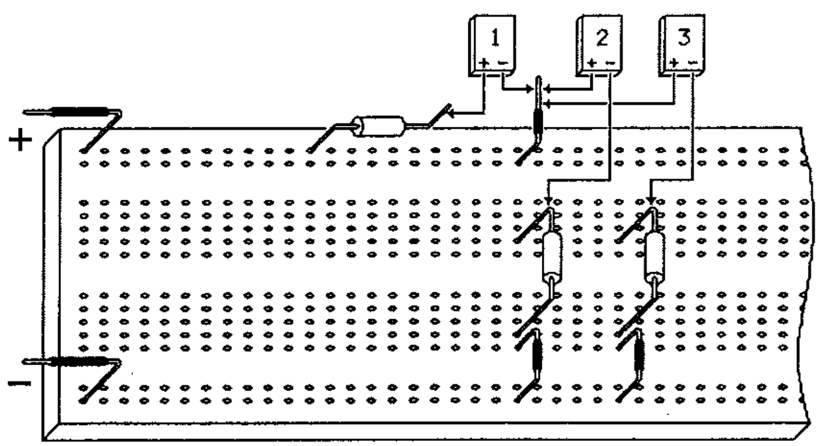
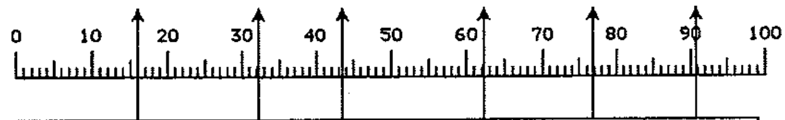


Figure 5-2. Ammeter Connections

Precautions to be observed in the use of the ammeter are as follows. Be sure to break the circuit and insert the ammeter in the resulting hole. As with a voltmeter, start on a high range and successively reduce ranges until a reasonably high deflection is obtained. Be extremely careful to connect the ammeter in series with the line in which a measurement is required; never connect an ammeter "across" a component. Some meters require that one or more test leads be plugged into different sockets from those used for voltage measurement, consequently care must be taken when switching back and forth between current and voltage measurements.

Lab Prep

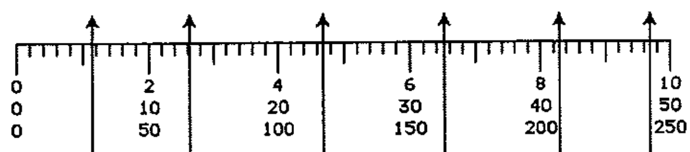
1. Determine the current readings for the different needle positions and ranges of the ammeter of Figure 5-3. The first column has been done as an example.



Range	10 mA	100 μA	1 A	1 mA	100 mA	10 mA
Scale Reading	16.0					
Current	1.60 mA					

Figure 5-3. Single Scale Ammeter

2. Determine the current readings for the different needle positions, scales, and ranges of the ammeter of Figure 5-4. The first column has been done as an example.



Range	1 mA	5 mA	25 mA	1 A	500 mA	250 μA
Scale Reading	1.15					
Current	115 μA					

Range	2.5 mA	100 μA	50 mA	25 μA	10 mA	500 μA
Scale Reading	28.0					
Current	280 μA					

Figure 5-4. Multiple Scale Ammeter

3. Copy the current readings from Figures 5-3 and 5-4 into Table 5-1 on the Prep Sheet.

Procedure

1. For your future reference, record in Table 5-2, the accuracy specifications for all ammeters which are available for your use.

Table 5-2. Ammeter Specifications

Name and Model of Ammeter	Ammeter 1	Ammeter 2	Ammeter 3
Accuracy Specifications			

2. Connect the circuit of Figure 5-5. You are not expected to be able to analyze this circuit at this time. This is the same circuit as was used in Experiment 5.

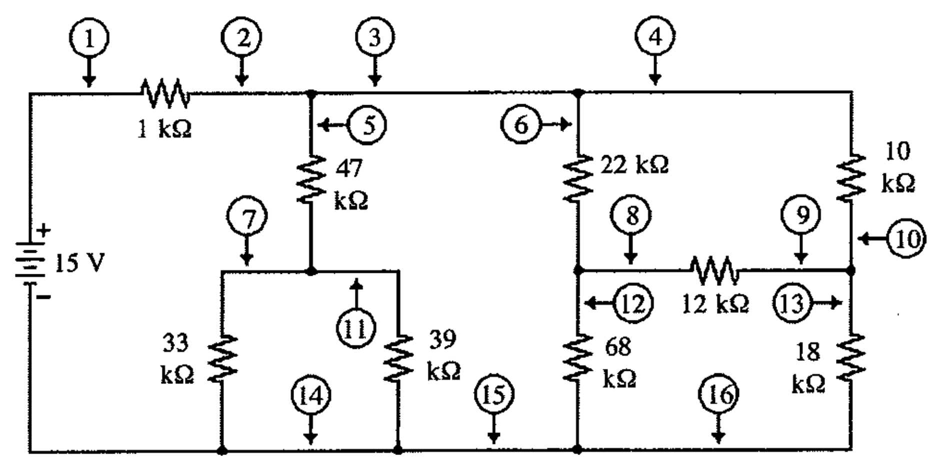


Figure 5-5. Ammeter Measurement Circuit

3. Double check each connection and each resistor color code before continuing, since a single error will result in incorrect measurements throughout Table 5-3.

4. Measure the currents at the various points specified in Table 5-3.

Table 5-3. Ammeter Measurements

Measurement Location	Measured Current	Measurement Location	Measured Current
1	0.01mA	9	
2	0.23mA	10	
3		11	
4		12	
5		13	
6		14	
7		15	
8		16	

5. Leave your ammeter connected at measurement location 16. Use your voltmeter to measure the voltage across the ammeter while the ammeter is measuring the current at location 16. Record this voltage in the space below. Record also, the range presently being used for the ammeter.

Voltage across the ammeter = ______________ Ammeter range = ______________

6. Remove the ammeter from the circuit, and use your ohmmeter to measure the resistance of the ammeter while on the same range as was used for the measurement of the current at location 16. Record below.

Ammeter resistance = ______________

7. Remove the voltmeter from the circuit. Use your ohmmeter to measure the resistance of your voltmeter while on the same range as was used for the voltage measurement of step 5. Record below. Record also, the voltmeter range which was used in step 5.

Voltmeter resistance = ______________ Voltmeter range = ______________

 Name

1. Record your meter interpretations from Figures 5-3 and 5-4 in Table 5-1 below.

Table 5-1. Ammeter Scale Interpretations

Preparation, Step 1	1.60 mA					
Preparation, Step 2	115 μA					
Preparation, Step 2	280 μA					

5 Data Sheet Name

1. Complete the data required for Table 5-2 below.

	Ammeter 1	Ammeter 2	Ammeter 3
Name and Model of Ammeter	Agilent		
Accuracy Specifications	6 $\frac{1}{2}$ digits		

2. Complete the data required for Table 5-3 below.

Measurement Location	Measured Current	Measurement Location	Measured Current
1	—	9	0.044mA
2	0.892mA	10	0.48mA
3	0.672mA	11	—
4	0.48mA	12	—
5	0.22mA	13	0.975mA
6	0.192mA	14	—
7	—	15	—
8	—	16	—

Questions

1. Refer to Table 5-3. Were the currents measured at locations 1 and 2 the same? Should these two measurements be the same?

$$0.672\,mA + 0.22\,mA = 0.892\,mA$$

It is correct

2. Refer to Table 5-3. Were the currents measured at locations 4 and 10 the same? Should these two measurements be the same?

$$0.48\,mA + 0.192\,mA = 0.672\,mA$$

It is correct.

3. Refer to Table 5-3. Were the currents measured at locations 13 and 16 the same? Should these two measurements be the same?

$$0.044\,mA + 0.48\,mA = 0.524\,mA$$

It is correct.

4. Refer to Table 5-3. Were the currents measured at locations 7 and 11 the same? Should these two measurements be the same?

No, signs are flipped

We didn't get this far

5. Refer to the measurement of procedure step 5. Using this measurement and the measurement of current at location 16 from Table 5-3, calculate the resistance of your ammeter.

6. Compare your calculated resistance in question 5 with your measured resistance in procedure step 6.

7. What conclusions can be made from the measured resistances in procedure steps 6 and 7?

6 Ohm's Law

Objectives

1. To verify Ohm's Law, which is the fundamental premise of electronics.
2. To evaluate the effect upon current of changing the resistance in a circuit.
3. To evaluate the effect upon current of changing the voltage in a circuit.
4. To assess the effects which a potentiometer can cause in a circuit.
5. To create characteristic curves for linear and nonlinear resistance components.

Equipment

DC voltage supply
A voltmeter, an ammeter, and an ohmmeter
Multiturn 10 kΩ potentiometer, part # 01B14, available from Digi-Key Corporation

Resistors:	15 kΩ, 1/4 W	27 kΩ, 1/4 W
	22 kΩ, 1/4 W	39 kΩ, 1/4 W

12 V LED with bias resistance

Information

Ohm's Law states that voltage is equal to the product of current times resistance. If resistance in a circuit increases, while voltage is held constant, circuit current will decrease. This, and other similar effects, will be investigated in this experiment.

A characteristic curve is a graphical representation of how current through a component varies with the voltage applied to that component. A characteristic curve is a graph which tells the observer something about the component; in other words, it is a graph of the component's properties, usually its resistive properties. Most characteristic curves present current on the vertical axis and voltage on the horizontal axis.

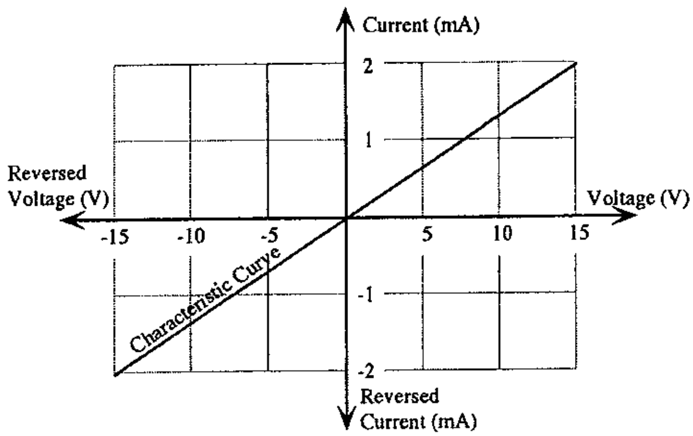


Figure 6-1. A Characteristic Curve of a Resistor

A component which has a fixed (or linear) resistance, such as a resistor, will display a characteristic curve which is a straight line such as the example in Figure 6-1. Figure 6-2 shows a similar characteristic curve, but for a nonlinear resistance.

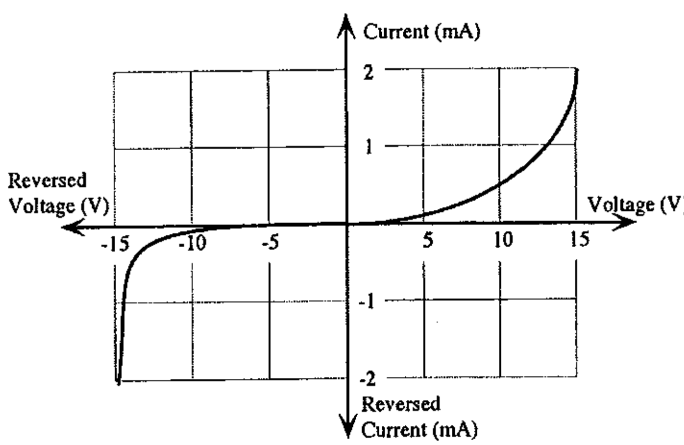


Figure 6-2. Characteristic Curve of a Nonlinear Resistance

The slope of a characteristic curve defines the conductance of the component. The reciprocal of the slope is the resistance of the component. For Figure 6-1, the slope equals the rise divided by the run, or 2 mA / 15 V, which is 133 µS. The reciprocal of the slope is 15 V / 2 mA, or 7.50 kΩ. The nonlinear characteristic of Figure 6-2 shows that the resistance depends upon the applied voltage, and that the resistance is constantly changing.

Lab Prep

1. Determine the expected theoretical currents for the circuit of Figure 6-3 and procedure steps 1 through 4, using conventional calculation techniques or by using circuit simulation software. Enter these currents in Table 6-1 below and in the same table on the Prep Sheet.

Table 6-1. Theoretical Ohm's Law Currents

Resistor Voltage	Theoretical Currents for Various Values of R		
	15 kΩ	27 kΩ	39 kΩ
2 V			
4 V			
6 V			
8 V			
10 V			
12 V			
14 V			

Procedure

Ohm's Law Measurements

1. Construct the circuit of Figure 6-3.

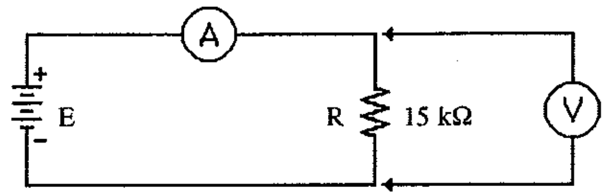


Figure 6-3. Ohm's Law Circuit

2. Adjust E until the voltage across the 15 kΩ resistor is 2 V. Record the measured current, as indicated on the ammeter, in Table 6-2.

3. Readjust E to set the voltage across the 15 kΩ resistor to each voltage required in Table 6-2, and record the current through the resistor for each case.

4. Repeat steps 2 and 3 using a 27 kΩ resistor, and again using a 39 kΩ resistor.

Table 6-2. Ohm's Law Measurements

Resistor Voltage	Measured Currents for Various Values of R		
	15 kΩ	27 kΩ	39 kΩ
2 V	0.133 mA	0.074 mA	0.051 mA
4 V	0.267 mA	0.149 mA	0.103 mA
6 V	0.401 mA	0.224 mA	0.155 mA
8 V	0.535 mA	0.299 mA	0.207 A
10 V	0.669 mA	0.374 mA	0.258 mA
12 V	0.803 mA	0.449 mA	0.310 mA
14 V	0.937 mA	0.523 mA	0.362 mA

5. Compare your measurements in Table 6-2 with the calculated values in Table 6-1 in the Lab Prep section of this experiment. If any measurements differ by more than 10%, repeat the measurements before continuing with the experiment.

Potentiometer Effects

6. Figure 6-4 shows a top view of one style of 10 kΩ multiturn potentiometer. Terminals A, B, and C represent the actual pins exiting the bottom of the component. Your potentiometer may be different from the one shown, so spend enough time to familiarize yourself with the potentiometer you will be using.

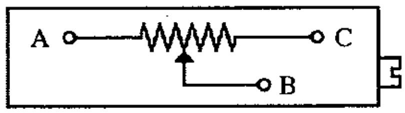
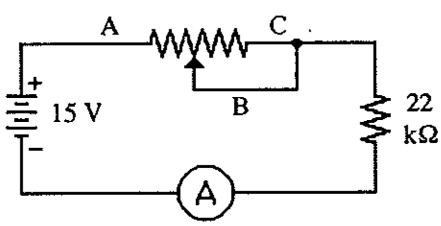


Figure 6-4. Multiturn Potentiometer

7. Use your ohmmeter to set the resistance from A to B at 5.00 kΩ, then connect the circuit of Figure 6-5 using this potentiometer. Part of this circuit is shown breadboarded to the right of Figure 6-5. At this point the potentiometer could be set by connecting an ohmmeter to the wire on the left and to the top of the 22 kΩ resistor. Note that if you connect the rest of the circuit before setting the potentiometer, you may have an additional resistance path which will cause an error when setting the potentiometer.



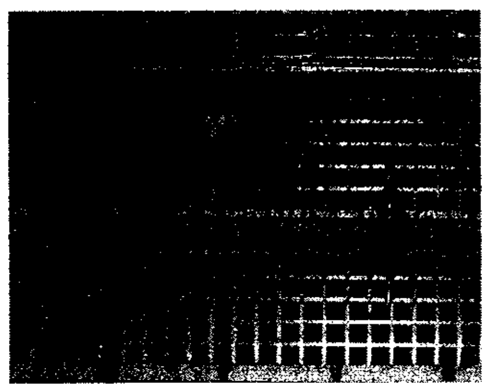


Figure 6-5. Potentiometer Circuit

8. Without adjusting the potentiometer, record the circuit current in Table 6-3.

9. As the potentiometer shaft is turned clockwise, as viewed from the shaft end, the circuit resistance should increase, thus reducing the current. Record, in Table 6-3, the lowest current obtained when the shaft is fully clockwise. Then, record the highest current obtained when the shaft is fully counterclockwise.

Table 6-3. Potentiometer Measurements

Current with pot set at 5 kΩ	Current with pot set fully clockwise	Current with pot set fully counterclockwise

Nonlinear Resistance Measurements

This part of the experiment will use the light-emitting diode (LED) as the nonlinear resistance component. This component differs from most LEDs because it has a built-in biasing resistance and can be connected to a 12 V supply just like an incandescent bulb, except that polarity must be observed. If it is connected backwards, no harm will occur, it will just not emit light.

10. Figure 6-6 illustrates the basing diagram for the LED as well as the circuit to be used. Set the power supply voltage to 4 V and connect the circuit. Note that the longer lead on the LED connects to the positive side of the power supply.

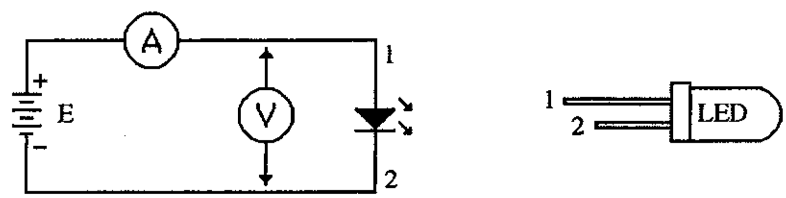


Figure 6-6. LED Circuit

11. If your LED lights up, you may continue with the experiment. If it does not light, you have connected it backwards, or the LED is faulty, or there is an open somewhere in your circuit.

12. Adjust the power supply until the voltmeter registers 1 V across the LED. Record the resulting current in Table 6-4.

13. Repeat step 12 for each voltage listed in Table 6-4, recording the current each time.

Table 6-4. LED Measurements

LED Voltage	LED Current	LED Voltage	LED Current
1.0 V		5.0 V	
1.5 V		6.0 V	
2.0 V		8.0 V	
3.0 V		10 V	
4.0 V		12 V	

5/5

6 Prep Sheet

Name Olehsandr Vladyka

1. Complete the data required for Table 6-1 below.

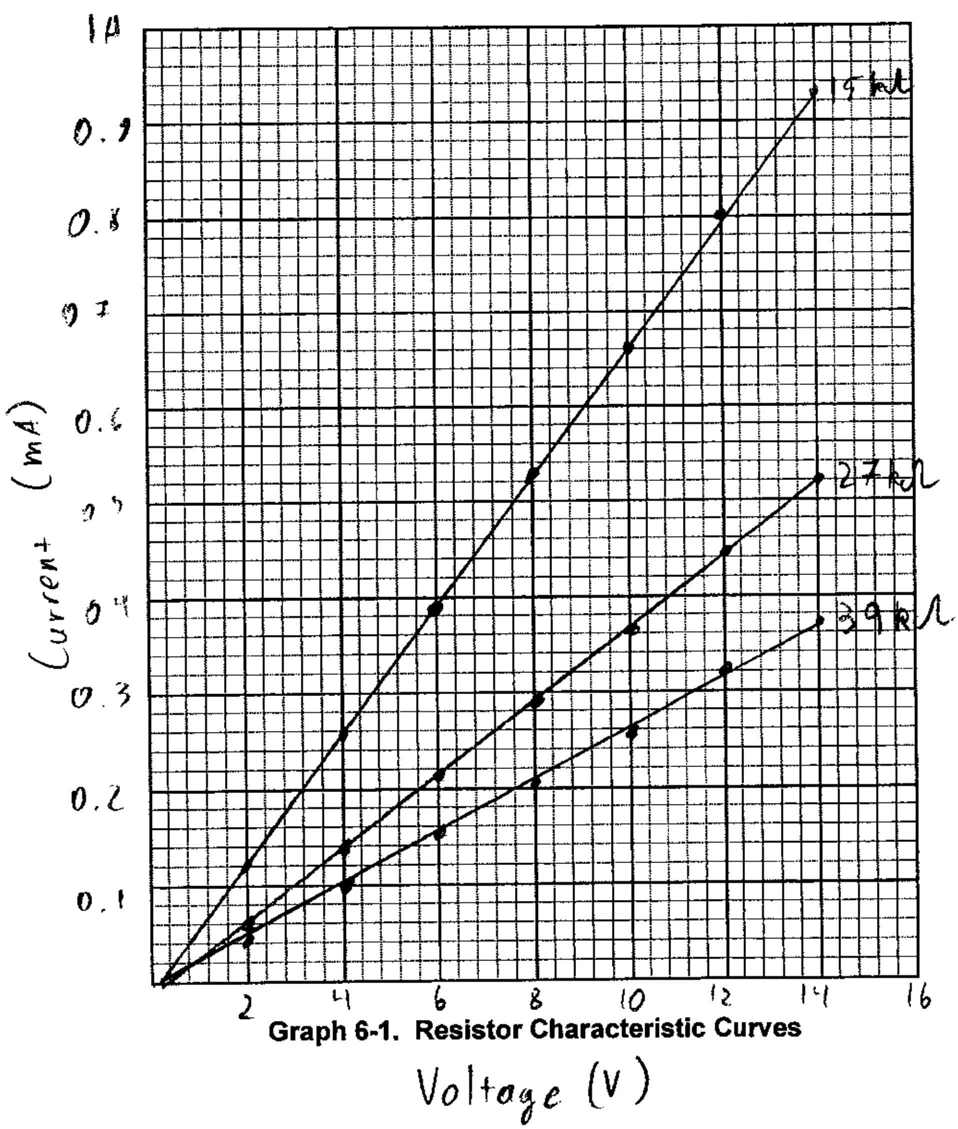
Resistor Voltage	Theoretical Currents for Various Values of R		
	15 kΩ	27 kΩ	39 kΩ
2 V	0.133 mA	0.074 mA	0.051 mA
4 V	0.267 mA	0.148 mA	0.103 mA
6 V	0.400 mA	0.222 mA	0.154 mA
8 V	0.533 mA	0.296 mA	0.205 mA
10 V	0.667 mA	0.370 mA	0.256 mA
12 V	0.800 mA	0.444 mA	0.308 mA
14 V	0.933 mA	0.519 mA	0.359 mA

5/5

6 Data Sheet

Name Oleksandr Vladyka

1. Use the data recorded in Table 6-2 to draw the characteristic curves for the three resistors used in Figure 6-3. Using the graph provided below, show current on the vertical axis and voltage on the horizontal axis. Pick scales so as to present as large a graph as possible. Label axes, scales, and each characteristic curve.

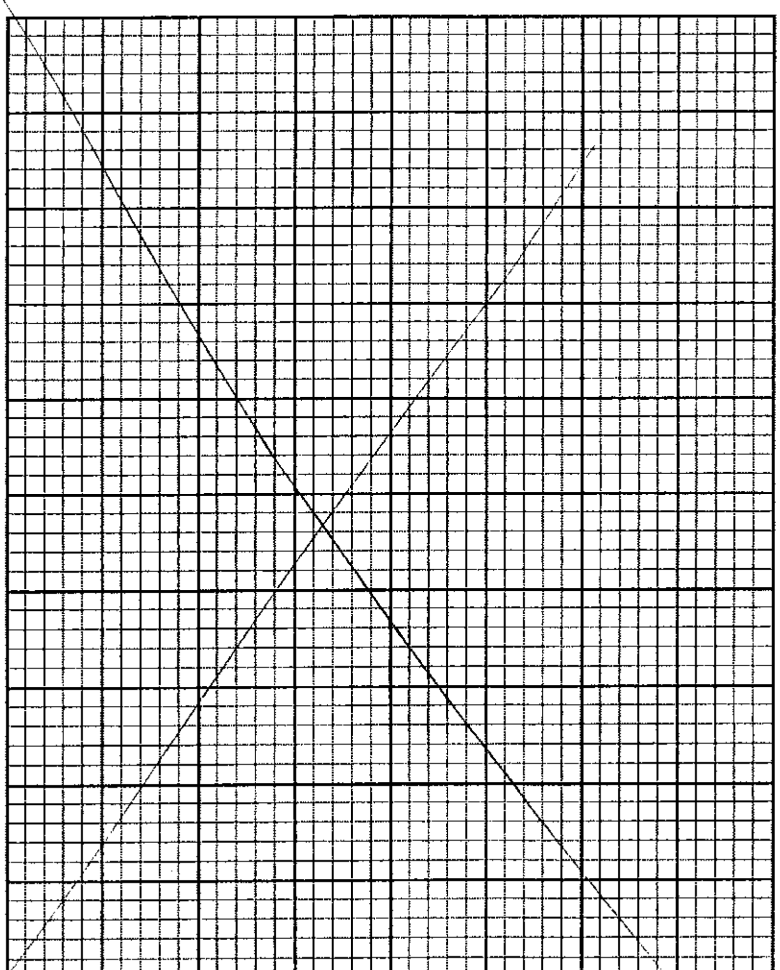


Graph 6-1. Resistor Characteristic Curves

2. Complete the data required for Table 6-3 below.

Current with pot set at 5 kΩ	Current with pot set fully clockwise	Current with pot set fully counterclockwise

3. Use the data recorded in Table 6-4 to draw the characteristic curve for the LED. Using the graph provided below, show current on the vertical axis and voltage on the horizontal axis. Pick scales so as to present as large a graph as possible. Label axes and scales.



Graph 6-2. LED Characteristic Curve

Questions

1. Refer to Graph 6-1 and Table 6-2. Calculate the inverse slope of the characteristic curve for the 15 kΩ resistor.

$$\frac{V_2 - V_1}{I_2 - I_1} \qquad \frac{14-0}{0.93-0} = 15.1\,k\Omega = \frac{V}{mAmp}$$

2. Refer to Graph 6-1 and Table 6-2. Calculate the inverse slope of the characteristic curve for the 27 kΩ resistor.

$$\frac{V_2 - V_1}{I_2 - I_1} \qquad \frac{14-0}{0.52-0} = 26.9\,k\Omega = \frac{V}{mAmp}$$

3. Refer to Graph 6-1 and Table 6-2. Calculate the inverse slope of the characteristic curve for the 39 kΩ resistor.

$$\frac{V_2 - V_1}{I_2 - I} \qquad \frac{14-0}{0.37-0} = 37.8\,k\Omega = \frac{V}{mAmp}$$

4. Refer to Graph 6-1. Describe the expected characteristic curve for a resistance of zero ohms.

Verticle line, infanite voltage

5. Refer to Graph 6-1. Describe the expected characteristic curve for an infinite resistance.

6. Refer to Table 6-2. If voltage is increased across a 39 kΩ resistance while the resistance is held constant, what happens to the circuit current? Does this verify Ohm's Law?

7. Refer to Table 6-2. If voltage is held constant while the resistance is decreased, what happens to the circuit current? Does this verify Ohm's Law?

8. Refer to Figure 6-5. Describe why the potentiometer's wiper lead (point B) has been connected to one end of the potentiometer.

9. Refer to Graph 6-2 and Table 6-4. Calculate the inverse slope of the linear portion of the characteristic curve of the LED.

10. Refer to Graph 6-2. The initial portion of the LED characteristic curve, between 0 V and 1.5 V, has a significantly different slope from the portion between 8 V and 10 V. What is the approximate resistance of the LED below 1.5 V?

7 Series-Parallel DC Circuits

Objectives

1. To apply series circuit principles and parallel circuit principles to circuits which are a combination of both series and parallel circuits.
2. To demonstrate methods of determining the resistance of portions of combination series-parallel circuits.
3. To integrate Ohm's Law and Kirchhoff's Laws into the understanding of combination series-parallel circuits.
4. To evaluate the distribution of power within combination series-parallel circuits.

Equipment

DC voltage supply
Voltmeter, ammeter, ohmmeter

Resistors:	10 kΩ, 1/4 W	18 kΩ, 1/4 W	22 kΩ, 1/4 W
	33 kΩ, 1/4 W	56 kΩ, 1/4 W	68 kΩ, 1/4 W
	82 kΩ, 1/4 W		

Information

The most efficient method of solving complex series-parallel circuits is to reduce the circuit by successive re-drawings until the circuit is reduced to one energy source and one total resistance. Circuit reduction can begin anywhere in the complex circuit. It is a common misconception that circuit reduction begins at a point opposite the energy source and proceeds towards the source.

Wherever two resistors are found to be in series, they can be replaced by one resistor. The important task of the student is to learn how to recognize that two resistors are in series. If it can be shown that the same current must flow through two resistors, then they are in series. Wherever two resistors are found to be in parallel, they can be replaced by one resistor. The student must recognize when two resistors are in parallel. If it can be shown that the voltage across the two resistors is the same, then they are in parallel.

If the above principles are practiced carefully, circuit reduction is simplified. Initially, the student must draw several equivalent circuits until reduction is completed. Solutions of various voltages and currents are then carried back from the equivalent circuit to the original circuit, until all voltages and currents are known. As the student gains experience, fewer re-drawings are required, but there is no substitute method to gain that experience.

A commonly-used method of designating resistances in a circuit is as shown in Figure 7-1. This form of notation indicates the total resistance seen looking in the direction of the arrow, from the vertical line attached to the arrow. For the example shown, any resistance to the left of the vertical line is not considered, so $R_E = (22\ k\Omega + 33\ k\Omega)//15\ k\Omega$, or $11.8\ k\Omega$. This method of designating resistances is often used to indicate input and output resistance in transistor amplifier circuits.

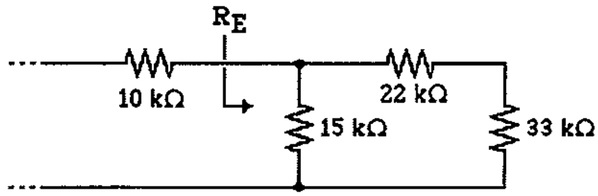


Figure 7-1. Designating Resistance

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Calculate the voltage across, the current through, and the power dissipated by each resistor in the schematic diagram of Figure 7-2. Record your results in Table 7-1 in the Procedure and in the equivalent table on the Prep Sheet.

Procedure

1. Connect the circuit of Figure 7-2, then set the voltage supply to 12 V.
2. Use the techniques learned in Experiments 5 and 6 to measure the voltage across and the current through each resistor of Figure 7-2. Record your results in Table 7-1.
3. Use the measured values of voltage and current to calculate the power dissipated by each resistor. Record this in the calculated power column of Table 7-1.
4. Transfer your measurements to the table on the Data Sheet.

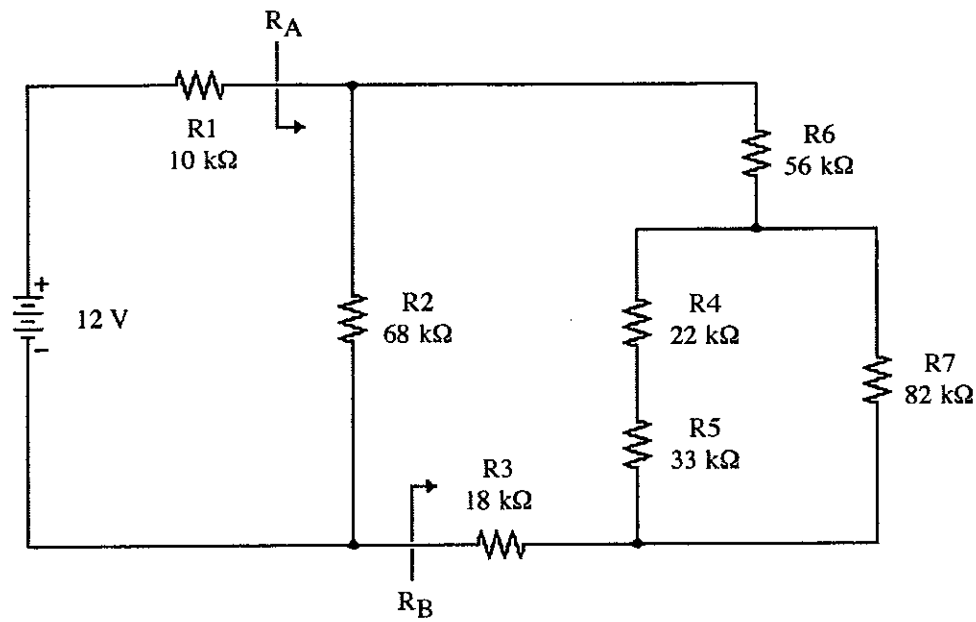


Figure 7-2. Series-Parallel Circuit

Table 7-1. Series-Parallel Measurements

	Voltages		Currents		Powers	
	Theoretical	Measured	Theoretical	Measured	Theoretical	Calculated
R1	2.33 V	2.36 V	0.233 mA	0.238 mA	0.543 W	
R2	9.67 V	9.62 V	0.142 mA	0.154 mA	1.37 W	
R3	1.64 V	1.61 V	0.091 mA	0.09 mA	0.149 W	
R4	1.19 V	1.19 V	0.054 mA	0.076 mA	0.064 W	
R5	1.78 V	1.76 V	0.054 mA	0.054 mA	0.096 W	
R6	5.1 V	5.04 V	0.091 mA	0.103 mA	0.464 W	
R7	2.95 V	2.95 V	0.036 mA	0.063 mA	0.106 W	

5. Disconnect power from the circuit and break any other connections necessary in order to measure the resistances designated as R_A and R_B on the schematic diagram of Figure 7-2.

R_A = 51.9 kΩ

R_B = 77.3 kΩ

7 Prep Sheet

Name Oleksandr Vladyka

1. Complete the theoretical calculations required for Table 7-1 below.

	Voltages		Currents		Powers	
	Theoretical	Measured	Theoretical	Measured	Theoretical	Calculated
R1	2.33 V		0.233mA		0.543W	
R2	9.67 V		0.142mA		1.37 W	
R3	1.64 V		0.091mA		0.149W	
R4	1.19V		0.051mA		0.064 W	
R5	1.78 V		0.051mA		0.096 W	
R6	5.1 V		0.091mA		0.464W	
R7	2.95 V		0.036mA		0.106W	

 Name Oleksandr Vladyka

1. Complete the data required for Table 7-1 below.

	Voltages		Currents		Powers	
	Theoretical	Measured	Theoretical	Measured	Theoretical	Calculated
R1	2.33V	2.36V	0.233mA	0.238mA	0.543W	0.562W
R2	9.67V	9.62V	0.142mA	0.154mA	1.37W	1.48W
R3	1.64V	1.61V	0.091mA	0.09mA	0.149W	0.145W
R4	1.19V	1.19V	0.054mA	0.054mA	0.064W	0.064W
R5	1.78V	1.76V	0.054mA	0.054mA	0.096W	0.095W
R6	5.1V	5.04V	0.091mA	0.091mA	0.464W	0.459W
R7	2.95V	2.95V	0.036mA	0.036mA	0.106W	0.106W

2. Record the measured resistances from Procedure step 5 below.

R_A = 41.2 kΩ

R_B = 106.4 kΩ

Questions

1. Use the data from Table 7-1 to illustrate two verifications of Kirchhoff's Voltage Law.

$V_1 + V_2 - 12V = 0$

$\boxed{2.33V + 9.67V - 12V = 0}$

$V_1 + V_6 + V_7 + V_3 - 12V = 0$

$\boxed{2.33 + 5.1V + 2.95V + 1.64V - 12V = 0}$

2. Use the data from Table 7-1 to illustrate two verifications of Kirchhoff's Current Law.

$$I - I_1 - I_2 = 0$$

$$0.233mA - 0.091mA - 0.142mA = 0$$

$$I_1 - I_7 - I_4 = 0 \Rightarrow 0.091mA - 0.036mA - 0.054mA = 0$$

3. Show how the resistance R_A is calculated.

$$\frac{(R_2)(R_B)}{R_2 + R_B} = R_A$$

4. Show how the resistance R_B is calculated.

$$\frac{(R_4 + R_5) R_7}{(R_4 + R_5) + R_7} + R_6 + R_3 = R_B$$

5. Using arrows (↑ = increases, ↓ = decreases, → = stays the same), describe the effect upon total circuit resistance if the following changes were made, one at a time, to the circuit of Figure 7-2.

R1 increased	____	R2 decreased	____	R3 opened	____
R4 shorted	____	~~R5 increased~~	____	R6 shorted	____
R7 decreased	____	12 V increased	____	R2 opened	____

6. Compare the total power dissipation of the circuit by adding all of the calculated resistor powers from Table 7-1, and comparing that sum to the product of 12 V times the measured current through R1.

7. Using the data from Table 7-1, show three ways of determining the power dissipated by R3.

Nick

8 Voltage Divider Circuits

Objectives

1. To critique the operation of fixed voltage dividers.
2. To evaluate the operation of variable voltage dividers.
3. To illustrate the operation of variable bipolar voltage dividers.

Equipment

Variable DC voltage supply
Voltmeter

Resistors:	1.8 kΩ, 1/4 W	2.2 kΩ, 1/4 W	3.3 kΩ, 1/4 W
	3.9 kΩ, 1/4 W	5.6 kΩ, 1/4 W	2 -10 kΩ, 1/2 W

10 kΩ Potentiometer, 3/4 W, Part # 01B14 available from Digi-Key Corporation

Information

One of the primary functions of resistors is to divide voltages into desired amounts which can then perform specific functions. A typical example is the fixed voltage divider shown in Figure 8-1. The numbered terminals are used to tap off the desired voltage to be used. If nothing is connected to the terminals, the divider is said to be unloaded. If a resistor is connected to the terminals, the divider is loaded.

Variable voltage dividers, such as those shown in Figure 8-2, are used to obtain a voltage which can be adjusted to a desired amount. Variable dividers are generally of three types: those adjustable from 0 V up to the value of the supply voltage, those adjustable between two predetermined levels within the range of the power supply, and those which are variable in amount and in polarity, known as bipolar dividers.

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Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Refer to the fixed voltage divider of Figure 8-1. For each resistor, calculate the percentage that it represents of the total resistance of the circuit. Also, calculate the voltage drop across each resistor.

2. Refer to the variable voltage dividers of Figure 8-2 through Figure 8-4. For each circuit, calculate the range of the variable voltage V_{AB}.

3. Enter the data from Table 8-1 and Table 8-2 into the duplicate tables on the Prep and Data Sheets.

Procedure

1. Connect the circuit of Figure 8-1. Measure the voltage drops across each resistor and record this data in Table 8-1.

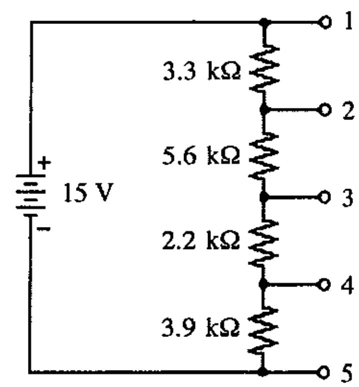


Figure 8-1. Fixed Voltage Divider Circuit

2. For each voltage drop, calculate the percentage that it represents of the total voltage of the circuit. Record these percentages in Table 8-1.

Table 8-1. Fixed Voltage Divider Measurements

Resistor	Percentage of R_T	Calculated Voltage	Measured Voltage	Percentage of 15 V
3.3 kΩ	22%	3.3V	3.3V	
5.6 kΩ	37.2%	5.6V	5.57V	
2.2 kΩ	14.2%	2.2V	2.2 V	
3.9 kΩ	26%	3.9V	3.89V	

3. Connect the circuits of Figure 8-2 and Figure 8-3, one at a time, and measure the range of the voltage V_{AB} which is available for each circuit. Record in Table 8-2.

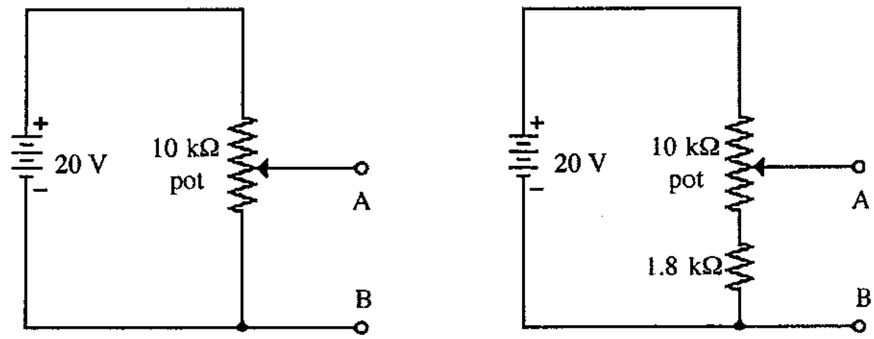


Figure 8-2. Variable Voltage Divider Circuits

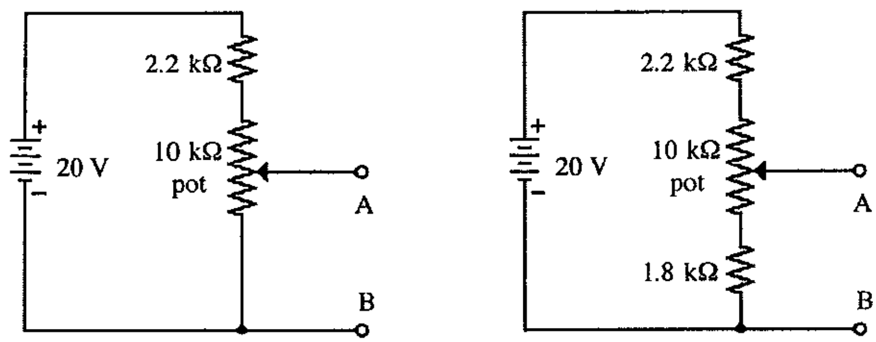


Figure 8-3. Variable Voltage Divider Circuits

Table 8-2. Variable Voltage Divider Measurements

	Calculated Range Of Voltage V_{AB}	Measured Range Of Voltage V_{AB}
Figure 8-2 (left)	0 - 20 V	19.98 V
Figure 8-2 (right)	0.3025 - 20V	2.98V - 19.98V
Figure 8-3 (left)	0 - 16.4V	0.057V - 16.93V
Figure 8-3 (right)	2.7 - 16.9V	2.51V - 16.87V
Figure 8-4	~~10V~~ - 10V	

4. Connect the circuit of Figure 8-4. Note that the polarity of the output voltage changes for this circuit as the potentiometer is varied. Measure the range of the voltage V_{AB} and record in Table 8-2.

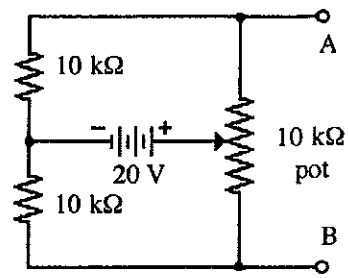


Figure 8-4. Variable Voltage Divider Circuit

5/5

8 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 8-1 below.

Resistor	Percentage of R_T	Calculated Voltage	Measured Voltage	Percentage of 15 V
3.3 kΩ	22 %	3.3 V		
5.6 kΩ	37.2%	5.6 V		
2.2 kΩ	14.2%	2.2 V		
3.9 kΩ	26 %	3.9 V		

2. Complete the data required for Table 8-2 below.

	Calculated Range Of Voltage V_{AB}	Measured Range Of Voltage V_{AB}
Figure 8-2 (left)	0 – 20 V	
Figure 8-2 (right)	0.3025V – 20V	
Figure 8-3 (left)	0 – 16.4V	
Figure 8-3 (right)	2.7 – 16.9V	
Figure 8-4	–10V – 10V	

515

8 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 8-1 below.

Resistor	Percentage of R_T	Calculated Voltage	Measured Voltage	Percentage of 15 V
3.3 kΩ	22 %	3.3 V	3.3 V	22%
5.6 kΩ	37.2 %	5.6 V	5.57V	37.2%
2.2 kΩ	14.2 %	2.2 V	2.2 V	14.7%
3.9 kΩ	26 %	3.9 V	3.89 V	26%

2. Complete the data required for Table 8-2 below.

	Calculated Range Of Voltage V_{AB}	Measured Range Of Voltage V_{AB}
Figure 8-2 (left)	0 - 20 V	19.98 V
Figure 8-2 (right)	0.[illegible]25 - 20V	2.98 - 19.98V
Figure 8-3 (left)	0 - 16.4 V	0.057 - 16.43V
Figure 8-3 (right)	2.7 - 16.9V	2.51 - 16.87V
Figure 8-4		

Questions

1. Refer to Table 8-1. Did the percentage data support the contention that voltage divides in proportion to resistance?

Yes, the percentage data does support the contention that voltage divides in proportion to resistance.

2. Refer to Figure 8-2 (left side). Describe what happens to the current in this circuit as the potentiometer wiper is varied from the top to the bottom.

The current does not change in this situation.

3. Refer to Figures 8-2 and 8-3. Which circuit allows the greatest range of adjustable voltage? Which circuit provides the smallest (or finest) range of adjustable voltage?

greatest: fig 8-2 Left

smallest: fig 8-3 Right

4. Refer to the circuits of Figures 8-2 and 8-3. Describe the advantage of the circuit of Figure 8-3 (right side) over the other three circuits.

It has the smallest voltage range over the other three circuits.

5. Refer to Figure 8-3 (right side). Calculate the upper and lower resistor values required, using a 50 kΩ potentiometer and a 30 V supply, to obtain a V_{AB} of 15 V to 25 V.

6. Refer to Figure 8-4. Calculate the range of V_{AB} for this circuit if the potentiometer were 50 kΩ.

9 Thévenin's Theorem

Objectives

1. To formulate the Thévenin Voltage and the Thévenin Resistance for an experimental circuit.
2. To generate load voltage and current calculations using a Thévenin equivalent circuit in place of an experimental circuit.
3. To measure the Thévenin Voltage and the Thévenin Resistance for an experimental circuit.
4. To prove through measurement that a Thévenin equivalent circuit will behave identically to the original experimental circuit.

Equipment

Variable dc voltage supply
Voltmeter, ammeter and ohmmeter

1/4 W Resistors:	1 kΩ	6.8 kΩ	8.2 kΩ	10 kΩ	12 kΩ
	15 kΩ	18 kΩ	22 kΩ	39 kΩ	56 kΩ

Information

Thévenin's Theorem can save significant amounts of time when a technologist is confronted with doing repetitive calculations upon one circuit. A typical example is a circuit which must be evaluated several times to determine the optimum value of one component. This might involve a great deal of work to solve the entire circuit each time, whereas the solution of the Thévenin equivalent circuit for each case would be much easier. Thévenin's Theorem also provides a technologist with a tool whereby a complex circuit can be replaced with a much simpler circuit.

For handy reference, the steps required to Thévenize a circuit are listed below. The student should actually follow the steps very carefully until the process becomes familiar. After a short time, the process will become simple.

1. Remove the portion of the circuit which is identified as the load, leaving an open circuit.
2. Either solve or measure the voltage across the open-circuited load terminals. This is called the Thévenin voltage, often abbreviated as V_{Th}.
3. Disconnect all power sources and replace them with their equivalent resistances. Voltage sources are replaced with short circuits, current sources are replaced with open circuits.
4. Either solve or measure the resistance seen looking into the open-circuited load terminals. This is called the Thévenin resistance, often abbreviated as R_{Th}.
5. Either draw or construct the Thévenin equivalent circuit by connecting the Thévenin voltage in series with the Thévenin resistance.
6. The original load may now be connected to the Thévenin equivalent circuit.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Determine the Thévenin voltage and the Thévenin resistance for the circuit of Figure 9-1. Record the values into Table 9-1 and also on the Prep Sheet.

Table 9-1. Calculated Thévenin Values

	V_{Th}	R_{Th}
Thévenin Values	7.15V	8.22kΩ

2. Apply the loads specified in Table 9-2 to the Thévenin equivalent circuit and, for each case, calculate the load voltage and current. Record the values into Table 9-2 and also on the Prep Sheet.

Table 9-2. Calculated Load Conditions

Load	Calculated Load Voltage	Calculated Load Current
12 kΩ		
22 kΩ		
39 kΩ		
56 kΩ		

$-20 + I_1 + 6.8I_1 + 15I_1 - 15I_2 = 0$

$22.8I_1 - 15I_2 = 20$

Procedure

$15I_2 - 15I_1 + 18I_2 + 10I_2 = 0$

$43I_2 - 15I_1 = 0$

$43I_2 = 15I_1$

$2.86I_2 = I_1$

$I_2 = 0.397A$

$I_1 = 1.14\ A$

1. Connect the circuit of Figure 9-1.

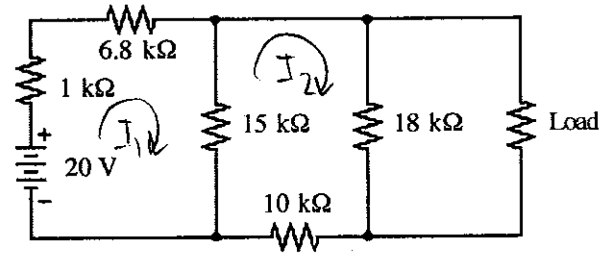


Figure 9-1. Experimental Circuit to Test Thévenin's Theorem

2. Apply the rules of Thévenin's Theorem to the circuit of Figure 9-1 so as to measure the Thévenin voltage and the Thévenin resistance. Record the measured V_{Th} and R_{Th} in Table 9-3.

Table 9-3. Measured Thévenin Values

	V_{Th}	R_{Th}
Thévenin Values	7.15V	8.22kΩ

3. Rebuild the circuit of Figure 9-1 using a 12 kΩ resistor as the load and measure the load voltage and load current. Record in Table 9-4.

4. Repeat step 3 for the other load values specified in Table 9-4.

Table 9-4. Measured Load Conditions

Load	Measured on Original Circuit		Measured on Equivalent Circuit	
	Load Voltage	Load Current	Load Voltage	Load Current
12 kΩ	4.23V	0.359 mA	4.14 V	0.35 mA
22 kΩ	5.2 V	0.238 mA	5.1 V	0.232 mA
39 kΩ	5.9 V	0.153 mA	5.78 V	0.149 mA
56 kΩ	6.25V	0.113 mA	6.1 V	0.11 mA

5. Connect the circuit of Figure 9-2, which is the Thévenin equivalent of the circuit of Figure 9-1. Use a 12 kΩ resistor as the load.

6. Set the supply to the Thévenin voltage which you recorded in Table 9-3 and select a resistor for the Thévenin resistance which is close to that which you recorded in Table 9-3.

7. If step 6 did not result in a voltage close to 7.15 V along with an 8.2 kΩ resistor, you have made an error and should repeat steps 1 and 2 of the procedure.

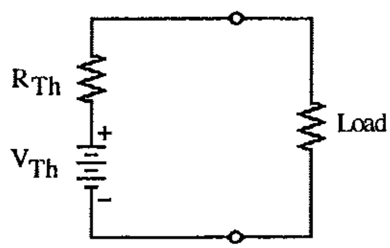


Figure 9-2. Thévenin Equivalent Circuit

8. Measure the load voltage and the load current obtained with the Thévenin equivalent circuit and record these values into Table 9-4. Repeat for the other load resistances.

9. Transfer the data from Tables 9-3 and 9-4 into the same tables on the Data Sheet.

5|5

9 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 9-1 below.

	V_{Th}	R_{Th}
Thévenin Values	7.15V	8.22kΩ

2. Complete the data required for Table 9-2 below.

Load	Calculated Load Voltage	Calculated Load Current
12 kΩ		
22 kΩ		
39 kΩ		
56 kΩ		

5/5

9 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 9-3 below.

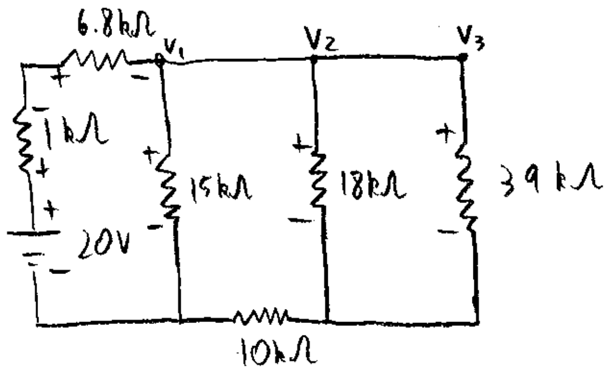
	V_{Th}	R_{Th}
Thévenin Values	7.15V	8.22kΩ

2. Complete the data required for Table 9-4 below.

Load	Measured on Original Circuit		Measured on Equivalent Circuit	
	Load Voltage	Load Current	Load Voltage	Load Current
12 kΩ	4.23 V	0.359mA	4.14 V	0.35mA
22 kΩ	5.2 V	0.238mA	5.1 V	0.232mA
39 kΩ	5.9 V	0.153mA	5.78 V	0.149mA
56 kΩ	6.25 V	0.113mA	6.1 V	0.11 mA

Questions

1. For the circuit of Figure 9-1, with 39 kΩ as the load, solve the circuit for the load voltage and current using conventional circuit reduction theory. Show all work below.



$R_{eq} = 16.77\,k\Omega$

$i = 1.19$

Load current : $\boxed{i = 0.151\,A}$

$V = (0.206\,A)(39\,k\Omega) = \boxed{5.88\,V}$

2. Compare the results of question 1 with the measured results in Table 9-4 for the 39 kΩ load.

$i = 0.151\,A \approx 0.149\,A$

$V = 5.88V \approx 5.78\,V$

3. Did your Thévenin equivalent circuit behave the same as the original circuit, within experimental error? Support your answer by calculating percentage errors between measured load voltages.

10 Norton's Theorem

Objectives

1. To formulate the Norton Current and the Norton Resistance for an experimental circuit.
2. To generate load voltage and current calculations using a Norton equivalent circuit in place of an experimental circuit.
3. To measure the Norton Voltage and the Norton Resistance for an experimental circuit.
4. To prove through measurement that a Norton equivalent circuit will behave identically to the original experimental circuit.

Equipment

Variable dc voltage supply
Voltmeter, ammeter and ohmmeter

1/4 W Resistors:	1 kΩ	6.8 kΩ	8.2 kΩ	10 kΩ	12 kΩ
	15 kΩ	18 kΩ	22 kΩ	39 kΩ	56 kΩ

Information

As with Thévenin's Theorem, Norton's Theorem can save significant amounts of time when a technologist is confronted with doing repetitive calculations upon one circuit. A typical example is a circuit which must be evaluated several times to determine the optimum value of one component. This might involve a great deal of work to solve the entire circuit each time, whereas the solution of the Norton equivalent circuit for each case would be much easier. Norton's Theorem also provides a technologist with a tool whereby a complex circuit can be replaced with a much simpler circuit.

For handy reference, the steps required to Nortonize a circuit are listed below. The student should actually follow the steps very carefully until the process becomes familiar. After a short time, the process will become simple.

1. Remove the portion of the circuit which is identified as the load, and replace it with a short circuit.
2. Either solve or measure the current through the short-circuited load terminals. This is called the Norton current, often abbreviated as I_N.
3. Remove the short circuit from the load terminals.
4. Disconnect all power sources and replace them with their equivalent resistances. Voltage sources are replaced with short circuits, current sources are replaced with open circuits.
5. Either solve or measure the resistance seen looking into the open-circuited load terminals. This is called the Norton resistance, often abbreviated as R_N. Note that R_N is exactly the same as R_{Th}.
6. Either draw or construct the Norton equivalent circuit by connecting the Norton current in parallel with the Norton resistance.
7. The original load may now be connected to the Norton equivalent circuit.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Determine the Norton current and the Norton resistance for the circuit of Figure 10-1. Record the values into Table 10-1 and also on the Prep Sheet.

Table 10-1. Calculated Norton Values

	I_N	R_N
Norton Values	0.87 mA	8.22 kΩ

2. Apply the loads specified in Table 10-2 to the Norton equivalent circuit and, for each case, calculate the load voltage and current. Record the values into Table 10-2 and also on the Prep Sheet.

Table 10-2. Calculated Load Conditions

Load	Calculated Load Voltage	Calculated Load Current
12 kΩ		
22 kΩ		
39 kΩ		
56 kΩ		

Procedure

1. Connect the circuit of Figure 10-1.

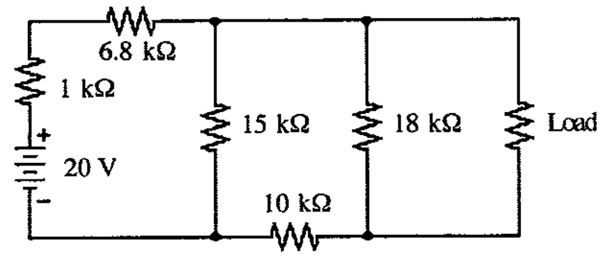


Figure 10-1. Experimental Circuit to Test Norton's Theorem

2. Apply the rules of Norton's Theorem to the circuit of Figure 10-1 so as to measure the Norton current and the Norton resistance. Record the measured I_N and R_N in Table 10-3.

Table 10-3. Measured Norton Values

	I_N	R_N
Norton Values	0.887 mA	8.13 kΩ

3. Rebuild the circuit of Figure 10-1 using a 12 kΩ resistor as the load and measure the load voltage and load current. Record in Table 10-4.

4. Repeat step 3 for the other load values specified in Table 10-4.

Table 10-4. Measured Load Conditions

Load	Measured on Original Circuit		Measured on Equivalent Circuit	
	Load Voltage	Load Current	Load Voltage	Load Current
12 kΩ				
22 kΩ				
39 kΩ				
56 kΩ				

5. Figure 10-2 represents a Norton equivalent circuit. On the schematic diagram of Figure 10-2, label the values for the Norton current and the Norton resistance which you measured in Table 10-3.

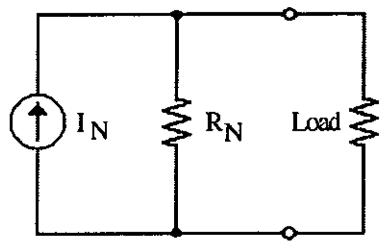


Figure 10-2. Norton Equivalent Circuit

6. **NOTE**: Since dc current sources are relatively uncommon, the circuit of Figure 10-2 cannot usually be connected with equipment available to students. The circuit of Figure 10-3 will be used to simulate a Norton equivalent circuit, although it should be realized that this circuit is not entirely equivalent to the circuit of Figure 10-2. It will, however, work correctly for the purposes of this experiment.

7. Connect the circuit of Figure 10-3, which will function as the Norton equivalent of the circuit of Figure 10-1. Use a 12 kΩ resistor as the load.

8. Select a resistor for the Norton resistance which is close to that which you recorded in Table 10-3 and adjust the power supply until the ammeter reads the Norton current which you recorded in Table 10-3.

9. If step 8 did not result in a current close to 870 μA along with an 8.2 kΩ resistor, you have made an error and should repeat steps 1 and 2 of the procedure.

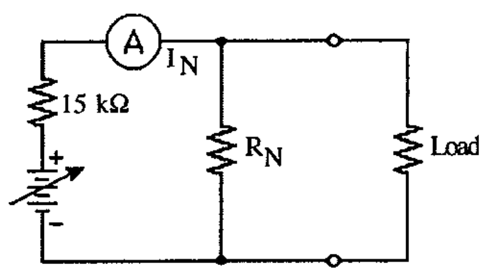


Figure 10-3. Simulated Norton Equivalent Circuit

10. Measure the load voltage and the load current obtained with the Norton equivalent circuit and record these values into Table 10-4.

11. For each remaining load resistance values in Table 10-4, connect the load then adjust the power supply until the ammeter reads the Norton current, then measure the load voltage and the load current and record these values into Table 10-4.

12. Transfer the data from Tables 10-3 and 10-4 into the same tables on the Data Sheet.

5/5

10 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 10-1 below.

	I_N	R_N
Norton Values	0.87 mA	8.22 kΩ

2. Complete the data required for Table 10-2 below.

Load	Calculated Load Voltage	Calculated Load Current
12 kΩ		
22 kΩ		
39 kΩ		
56 kΩ		

5/5

10 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 10-3 below.

	I_N	R_N
Norton Values	0,887mA	8.13V

2. Complete the data required for Table 10-4 below.

Load	Measured on Original Circuit		Measured on Equivalent Circuit	
	Load Voltage	Load Current	Load Voltage	Load Current
12 kΩ				
22 kΩ				
39 kΩ				
56 kΩ				

Questions

1. The circuit of Figure 10-1 is the same circuit as was used in a Thévenin's Theorem Experiment. If you completed that experiment, apply Norton's Theorem to the Thévenin equivalent circuit obtained in that Experiment. Show all work below.

$V_{TH} = 7.15\text{ V}$, $R_{TH} = 8.2\text{ k}\Omega$

$$I_N = \frac{V_{TH}}{R_{TH}} = \frac{7.15\text{ V}}{8.2\text{ k}\Omega} = 0.872\text{ mA}$$

$$I_N = 0.872\text{mA}$$

2. Compare the results of question 1 with the Norton equivalent circuit calculated for this experiment.

The I_N we calculated was slightly lower but still very close.

3. Did your Norton equivalent circuit behave the same as the original circuit, within experimental error? Support your answer by calculating percentage errors between measured load voltages.

11 Superposition Theorem

Objectives

1. To experimentally evaluate the voltages and currents caused by each source of a multi-source circuit.
2. To prove that the separate effects caused by each source of a multi-source circuit can be superimposed to produce the same effect as the original multi-source circuit.

Equipment

Two dc power supplies
Voltmeter, ammeter
1/4 W Resistors: 10 kΩ 12 kΩ 15 kΩ 18 kΩ 22 kΩ

Information

The superposition theorem allows the student to simplify networks which have any number of voltage or current sources present. The concept involves solving the circuit once for each source, that is, all other sources except the one being solved are replaced by their equivalent resistances. Each time the circuit is solved, a record is kept of the current through and the voltage across each resistor, along with the current direction and voltage polarity. When each circuit-source combination has been solved, the currents through and the voltages across each resistor are summed, observing voltage polarity and current direction. The summations will provide the correct answers which would exist with all sources simultaneously connected.

As a reference, the steps required to perform superposition are outlined in detail below.

1. Remove all sources except one from the circuit.
2. Replace the removed sources with their equivalent resistances: a short if a voltage source, an open if a current source.
3. Solve the single-source circuit for the voltage across and/or the current through any or all resistors of interest.
4. Note the voltages and polarities as well as the currents and directions for each resistor.
5. Rebuild the original circuit and repeat steps 1 through 4 for every other source in the circuit.
6. Sum the results to obtain the the correct answers which would exist with all sources simultaneously connected.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Apply superposition theorem to the circuit of Figure 11-1. Solve for the voltage across and the current through each resistor due to the 10 V source, then repeat for the 20 V source. Record your calculated values, along with polarities and current directions in Table 11-1.

Table 11-1. Calculated Superposition Values

	Solutions due to 10 V source		Solutions due to 20 V source	
	Voltage and Polarity	Current and Direction	Voltage and Polarity	Current and Direction
12 kΩ				
15 kΩ				
10 kΩ				
18 kΩ				
22 kΩ				

2. Sum the results from Table 11-1 for each resistor. Enter the summations, polarities and directions into Table 11-2. Transfer values from Tables 11-1 and 11-2 to the Prep Sheet.

Table 11-2. Summation of Superposition Values

Mark polarity and current direction →	12 kΩ	15 kΩ	10 kΩ	18 kΩ	22 kΩ
Summation of voltages					
Summation of currents					

Procedure

1. Connect the circuit of Figure 11-1.

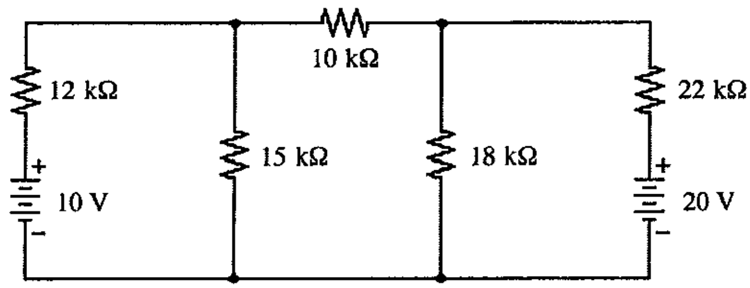


Figure 11-1. Superposition Circuit

2. Completely disconnect the 20 V power supply from the circuit, and connect a short circuit in its place.

3. Measure the voltage across and the current through each resistor, along with the polarity and current direction. Record in Table 11-3.

Table 11-3. Superposition Measurements

	Measurements due to 10 V source		Measurements due to 20 V source	
	Voltage and Polarity	Current and Direction	Voltage and Polarity	Current and Direction
12 kΩ				
15 kΩ				
10 kΩ				
18 kΩ				
22 kΩ				

4. Remove the short circuit at the 20 V power supply location, and replace the 20 V supply.

5. Completely disconnect the 10 V power supply from the circuit, and connect a short circuit in its place.

6. Measure the voltage across and the current through each resistor, along with the polarity and current direction. Record in Table 11-3.

7. Remove the short circuit at the 10 V power supply location, and replace the 10 V supply.

8. With both power supplies now operational, measure the voltage across and the current through each resistor, along with the polarity and current direction. Record in Table 11-4.

Table 11-4. Original Circuit Values

Mark polarity and current direction →	12 kΩ	15 kΩ	10 kΩ	18 kΩ	22 kΩ
Measured voltages					
Measured currents					

9. Transfer the data from Tables 11-3 and 11-4 to the Data Sheet.

11 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 11-1 below.

	Solutions due to 10 V source		Solutions due to 20 V source	
	Voltage and Polarity	Current and Direction	Voltage and Polarity	Current and Direction
12 kΩ	− 5.84V +	0.486mA ↑	+ 2.26 V −	0.188mA ↓
15 kΩ	+ 4.16V −	0.277mA ↓	+ 2.27V −	0.151mA ↓
10 kΩ	+ 2.09V −	0.209mA →	3.39V − +	0.339mA ←
18 kΩ	+ 2.07V −	0.115mA ↓	+ 5.63 V −	0.313mA ↓
22 kΩ	+ 2.07V −	0.094mA ↓	− 14.34 V +	0.652mA ↑

2. Complete the data required for Table 11-2 below.

Mark polarity and current direction →	12 kΩ	15 kΩ	10 kΩ	18 kΩ	22 kΩ
Summation of voltages					
Summation of currents					

11 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 11-3 below.

	Measurements due to 10 V source		Measurements due to 20 V source	
	Voltage and Polarity	Current and Direction	Voltage and Polarity	Current and Direction
12 kΩ	− 5.8V +	↑.491mA	+ 2.3V −	↓.191mA
15 kΩ	+ -4.2V −	↓.278mA	+ 2.3V −	↓.15mA
10 kΩ	+ 2.1V −	→ .212mA	− 3.4V +	← .34mA
18 kΩ	+ 2.1V −	↓.118 mA	+ 5.6V −	↓.315mA
22 kΩ	+ 2.1V −	↓.95mA	− 14.4V +	↑ .655mA

2. Complete the data required for Table 11-4 below.

Mark polarity and current direction →	↑ + 12 kΩ −	↓ + 15 kΩ −	− + 10 kΩ ←	↓ + 18 kΩ −	↑ − 22 kΩ +
Measured voltages	3.55V	6.44V	1.25V	7.69 V	12.28 V
Measured currents	0.301mA	0.428mA	0.127mA	0.432mA	0.559mA

Questions

1. Use the data obtained in Table 11-4 to prove Kirchhoff's Voltage Law for each of the three "windows" in the circuit of Figure 11-1.

(1) $-10V + 3.55 + 6.44 = 0 \approx 0$

(2) $-6.44 - 1.25 + 7.96 = 0 \approx 0$

(3) $-7.96 - 12.28 + 20V = 0 \approx 0$

2. Use the data obtained in Table 11-4 to prove Kirchhoff's Current Law for any two node points or junctions in the circuit of Figure 11-1.

(1) 301 mA − 428 mA + 127 mA = 0 equal 0

(2) 559 mA − 432 mA − 127 mA = 0 equal 0

3. Compare your theoretical superposition values (Table 11-1) for the 18 kΩ resistor with the measured superposition values (Table 11-3) for the 18 kΩ resistor.

12 Mesh Analysis

Objectives

1. To experimentally prove the mesh currents for a multi-source circuit.
2. To explain how mesh currents can be used to determine any desired circuit quantity.

Equipment

Two dc power supplies
Voltmeter, ammeter
1/4 W Resistors: 10 kΩ 12 kΩ 15 kΩ 18 kΩ 22 kΩ

Information

Mesh analysis is one of the most universally used methods of circuit analysis. This method requires the solution of simultaneous equations, which was once considered a disadvantage, but now is an easy task with modern calculators. Most technical calculators will solve simultaneous equations, either directly, or by the use of matrices. Writing simultaneous equations is a very straightforward task requiring the student to follow a simple set of rules which are quickly mastered. A knowledge of Kirchhoff's Voltage Law is essential because each equation to be written is simply a Kirchhoff voltage loop.

As a reference, the steps required to perform mesh analysis are outlined in detail below.

1. Identify the number of windows in the circuit. This will be the number of equations required. Some components will appear in more than one window.

2. Draw and label a current loop in each window, and show its direction. This is most commonly done as shown in the partial schematic of Figure 12-1.

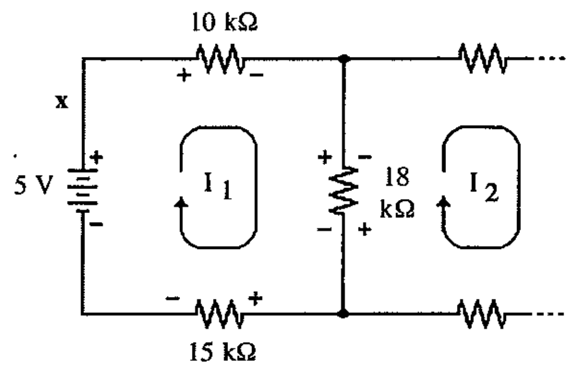


Figure 12-1. Partial Schematic Diagram

3. Within each window, mark the polarities of the voltages which would be produced by that window's current. Note that resistors which border two windows, such as the 18 kΩ resistor of Figure 12-1, will have two voltage polarities.

4. Start at any point in the first window and write a Kirchhoff's Voltage Law equation for that complete window, using the polarity of the first side of every component encountered. Each resistor voltage is written as the product of the current times the resistance; voltage sources are just pure voltages. In the case of the 18 kΩ resistor, two voltages exist, one caused by each current. When you have returned to the start point, the sum of all voltages is equated to zero. As an example, the first window in Figure 12-1 is written as follows, starting at point **x**:

$$+ 10\,\text{k}\Omega\, I_1 + 18\,\text{k}\Omega\, I_1 - 18\,\text{k}\Omega\, I_2 + 15\,\text{k}\Omega\, I_1 - 5 = 0$$

5. The terms of the equation are then rearranged into standard form as shown below for this equation:

$$+ 43\,\text{k}\Omega\, I_1 - 18\,\text{k}\Omega\, I_2 = 5$$

6. Repeat steps 4 and 5 for each window and solve the simultaneous equations for the unknown currents.

The circuit used in this experiment was also investigated in a previous experiment using the superposition theorem. Students may wish to compare the results of calculations and measurements for both experiments to verify that both techniques yield correct results.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Apply mesh analysis to the circuit of Figure 12-2. Solve for the three indicated currents and find their true directions. Record your calculated values in Table 12-1.

Table 12-1. Calculated Mesh Values

	Current 1	Current 2	Current 3
Assumed Direction	clockwise	clockwise	clockwise
Mesh Current Solution	0.298 mA	-0.13 mA	-0.558 mA
True Current Direction	CW	CW	CCW

2. Use the results from Table 12-1 to calculate the current through each resistor in Figure 12-2, as well as the correct direction of each current. Transfer values from Tables 12-1 and 12-2 to the Prep Sheet.

Table 12-2. Calculated Resistor Currents

	12 kΩ	15 kΩ	10 kΩ	18 kΩ	22 kΩ
Current Direction	Positive	Positive	Negative	Positive	Negative
Calculated Current	0.3 mA	0.429 mA	0.13 mA	0.43 mA	0.56 mA

Procedure

1. Connect the circuit of Figure 12-2.

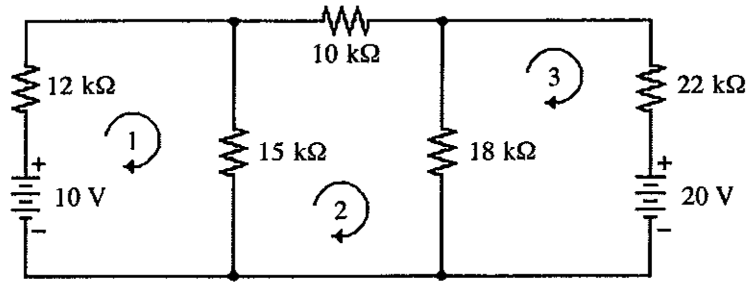


Figure 12-2. Mesh Circuit

2. Measure each of the mesh currents by inserting an ammeter into the top edge of each of the mesh windows in the circuit of Figure 12-2. Record in Table 12-3.

3. Determine the direction of current flow for each of the mesh currents. Record in Table 12-3 by using arrows to indicate direction.

Table 12-3. Mesh Current Measurements

	Current 1	Current 2	Current 3
Measured Current	0.3 mA	0.022 mA	-0.49 mA
Current Direction	CW	CCW	CCW

4. Use the ammeter to measure the current through each resistor, and to determine the direction of current flow through each resistor. Record in Table 12-4.

Table 12-4. Measured Resistor Currents

	12 kΩ	15 kΩ	10 kΩ	18 kΩ	22 kΩ
Current Direction	↑	↑	←	↓	↑
Measured Current	0.302	0.432	0.13	0.434	0.505

5. Transfer the data from Tables 12-3 and 12-4 to the Data Sheet.

 Name Oleksandr Vlodyka

1. Complete the data required for Table 12-1 below.

	Current 1	Current 2	Current 3
Assumed Direction	clockwise	clockwise	clockwise
Mesh Current Solution	0.298 mA	-0.13 mA	-0.558 mA
True Current Direction	CW	CCW	CCW

2. Complete the data required for Table 12-2 below.

	12 kΩ	15 kΩ	10 kΩ	18 kΩ	22 kΩ
Current Direction	Positive	Positive	Negative	Positive	Negative
Calculated Current	0.3 mA	0.429 mA	0.13 mA	0.43 mA	0.56 mA

12 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 12-3 below.

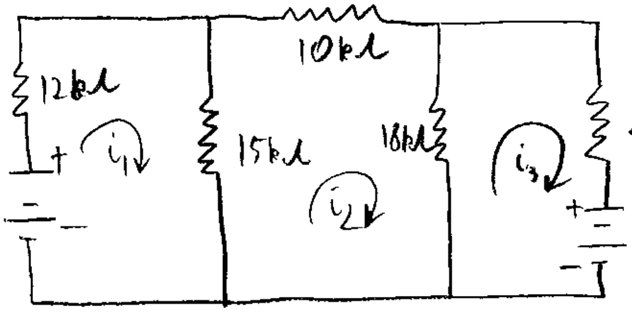
	Current 1	Current 2	Current 3
Measured Current	0.3 mA	0.022 mA	-0.49 mA
Current Direction	CW	CCW	CCW

2. Complete the data required for Table 12-4 below.

	12 kΩ	15 kΩ	10 kΩ	18 kΩ	22 kΩ
Current Direction	↑	↑	←	↓	↑
Measured Current	0.302 mA	0.432 mA	0.13 mA	0.434 mA	0.505 mA

Questions

1. Use the data obtained in Table 12-3 to show how the mesh currents I_1 and I_2 are used to determine the current magnitude and direction through the 15 kΩ resistor.



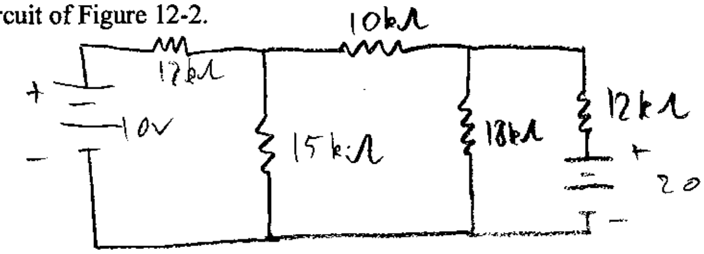
$I_1 = 0.302\,mA$ CW

$I_2 = 0.13\,mA$ CCW

$I_1 + I_2 = I_{15\Omega}$

$I_{15\Omega} = 0.432\,mA$ ↓ down

2. Use the data obtained in Table 12-4 to prove Kirchhoff's Current Law for any two node points or junctions in the circuit of Figure 12-2.



① $i_1 = I_{15\Omega} = I_{10\Omega} + I_{12\Omega}$

$0.432\,mA = 0.302 + 0.129$

$0.432\,mA \approx 0.431\,mA$

② $i_2 = I_{18\Omega} = I_{22\Omega} - I_{10\Omega}$

$0.432 = 0.562 - 0.129$

$\boxed{0.432\,mA \approx 0.433\,mA}$

3. Compare your calculated mesh current value for the middle window (Table 12-1) with the measured mesh current value (Table 12-4) for the 10 kΩ resistor.

Table 12.1 = 0.216 mA   Table 12.4 = 0.129 mA

Difference = 0.087 mA

4. Compare the measured resistor currents from Table 12-4 with the calculated currents obtained using superposition in an earlier Experiment if it was completed.

13 Maximum Power Transfer Theorem

Objectives

1. To experimentally prove that maximum power transfer from a source to a load occurs when the load resistance is equal to the internal resistance of the source.
2. To illustrate that the circuit efficiency will be 50% when the load resistance is equal to the internal resistance of the source.
3. To summarize the characteristics of maximum power transfer and circuit efficiency versus load resistance.
4. To evaluate the characteristics of maximum voltage transfer.
5. To develop familiarity with semi-log graphical plotting.

Equipment

DC power supply, voltmeter, ammeter

1/4 W Resistors:	10 Ω	39 Ω	100 Ω	390 Ω	1.0 kΩ
	3.9 kΩ	6.8 kΩ	2 -10 kΩ	18 kΩ	39 kΩ
	100 kΩ	390 kΩ	1.0 MΩ		

Information

The concepts of maximum power transfer, maximum voltage transfer and maximum current transfer are closely related. If you wish, for example, to transfer a maximum amount of power from a battery to a load, it will be necessary to make the load resistance equal to the internal resistance of the battery. Maximum voltage transfer from a source to a load occurs when the load resistance is much greater than the source resistance, ideally ∞ Ω. Maximum current transfer from a source to a load occurs when the load resistance is much smaller than the source resistance, ideally 0 Ω.

Maximum voltage transfer is used in the early stages of an audio amplifier. The ac voltage signal from a tape or CD player is very small and must be enlarged by the amplifier. Power is not the concern at this time; what is needed is to transfer as much voltage as possible from one amplification stage to another, thus maximum voltage transfer is required.

The concepts of maximum power transfer, maximum voltage transfer and maximum current transfer may be equally applied to dc or ac circuits. This experiment will achieve its objectives through the use of dc circuits since the student is already familiar with such circuits.

Ideal voltage or current sources would deliver all their power or voltage to a load, but since there are no ideal sources, some power or voltage is always distributed internally to the source. Be it a voltage source or a current source, maximum power transfer from a source to a load will occur when the load resistance is equal to the internal resistance of the source. Any other load resistance value will result in less power delivered to the load. Maximum voltage transfer will occur when the load resistance is much larger than the internal resistance of the source, in fact, when the load resistance is infinite. For practical purposes, if the load resistance is 100 times greater than the internal source resistance, 99% of the voltage will be transferred from the source to the load. Similarly, maximum current transfer will occur when the load resistance is much smaller than the internal resistance of the source. For practical purposes, if the load resistance is just 1% of the internal source resistance, 99% of the current will be transferred from the source to the load.

In this experiment, and many others to follow, semi-log graph scales will be used extensively. Semi-log graphs have one axis with a linear scale (usually the vertical axis) and the other logarithmic, such as the example shown in Figure 13-1.

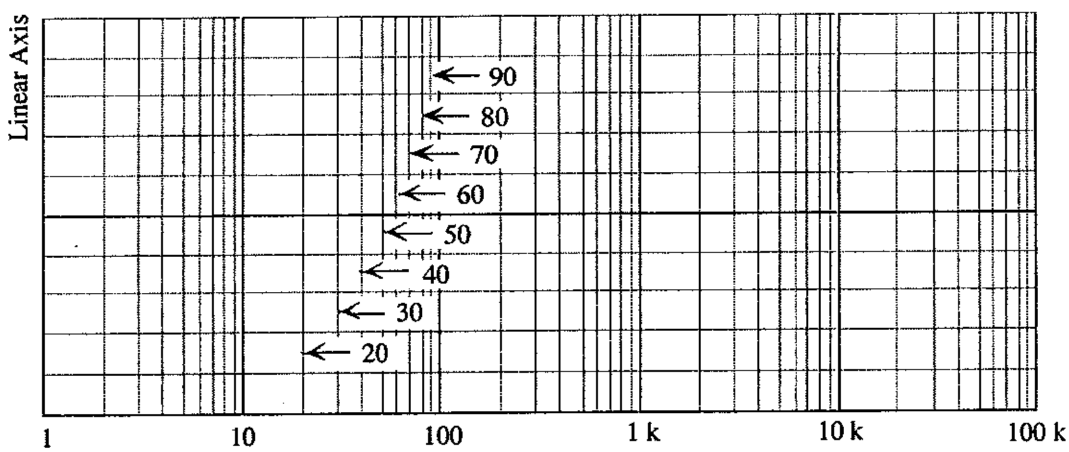


Figure 13-1. Semi-log Graph Scales

This type of graph scale is very useful to compress data having a large dynamic range. In electronics, semi-log graphs are most frequently used to represent resistance or frequency on the horizontal axis, both of which often have a large range of values. In Figure 13-1, notice that major horizontal divisions are multiples of 1, and that a value of 0 cannot be plotted on this graph. The values for the divisions between 10 and 100 are marked on Figure 13-1 to illustrate how values are determined on a log scale.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Refer to the circuit of Figure 13-2. For each value of load resistance listed in Table 13-1, calculate the circuit current, the load voltage, the total power dissipated in the circuit, the power dissipated by the load resistor, and the circuit efficiency (load power divided by total power times 100%). Enter your calculations in Table 13-1.

Table 13-1. Theoretical Calculations

Load Resistance	Circuit Current	Load Voltage	Total Power	Load Power	Circuit Efficiency
10 Ω					
39 Ω					
100 Ω					
390 Ω					
1.0 kΩ					
3.9 kΩ					
6.8 kΩ					
10 kΩ					
18 kΩ					
39 kΩ					
100 kΩ					
390 kΩ					
1.0 MΩ					

2. Use the theoretical data from Table 13-1 to plot graphs of load power and efficiency versus load resistance on Graphs 13-1 and 13-2 provided on the Prep Sheet.

Procedure

1. Connect the circuit of Figure 13-2, using a 10 Ω resistor as the load.

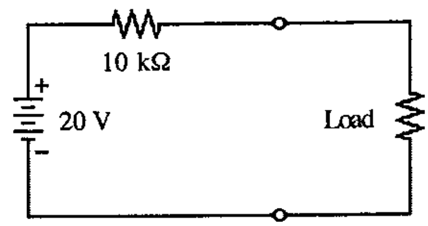


Figure 13-2. Test Circuit

2. Adjust the power supply to 20 V, then measure the circuit current and the load voltage. Record these measurements in Table 13-2.

3. Using the measurements of step 2, calculate the total power supplied by the 20 V source, the power delivered to the load, and the circuit efficiency (load power divided by total power times 100%). Record these calculations in Table 13-2.

4. Repeat steps 2 and 3 for each load resistance value in Table 13-1.

Table 13-2. Measured Values

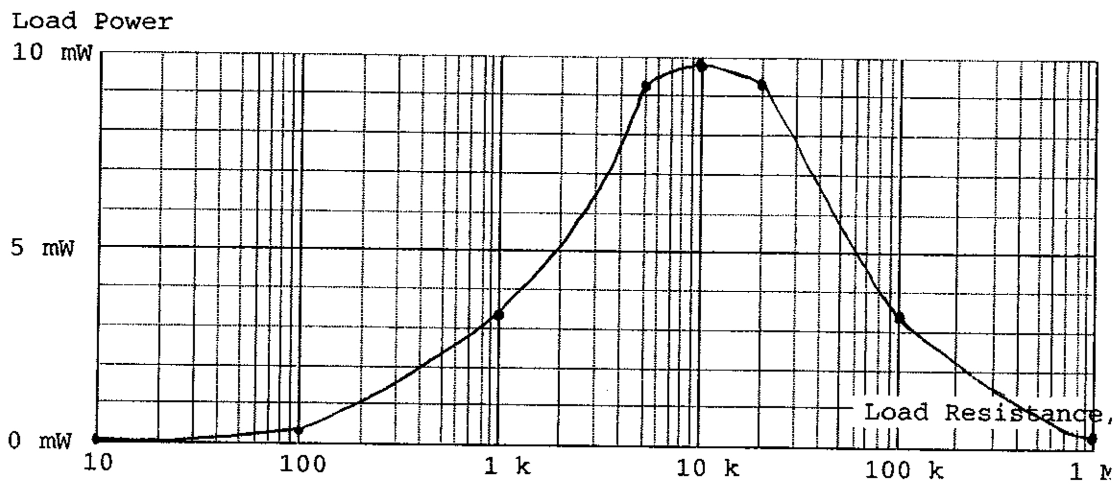
20V · I L_V · I   ($L_P \div T_P$)100

Load Resistance	Circuit Current	Load Voltage	Total Power	Load Power	Circuit Efficiency
10 Ω	2.02mA	0.02 V	40.4W	0.0404w	0.1%
39 Ω	1.94mA	0.075	38.8W	0.1455w	0.38%
100 Ω	2.00mA	0.19V	40.0W	0.38 w	0.95%
390 Ω	1.94mA	0.749V	38.8W	1.45 w	3.74%
1.0 kΩ	1.83mA	1.82 V	36.6W	3.33w	9.1 %
3.9 kΩ	1.45mA	5.59 V	29.0W	8.11 w	27.9%
6.8 kΩ	1.2mA	8.07V	24.0W	9.68 w	40.3%
10 kΩ	1.01mA	9.96V	20.2 W	10.06 w	49.8%
18 kΩ	0.72mA	12.82V	14.4W	9.23w	64.1%
39 kΩ	0.41mA	15.91 V	8.20W	6.52w	79.5%
100 kΩ	0.184mA	18.15V	3.68W	3.34 w	90.76%
390 kΩ	0.05mA	19.48V	1.00 W	0.97 W	97 %
1.0 MΩ	0.02mA	19.78V	0.4 W	0.40 W	100%

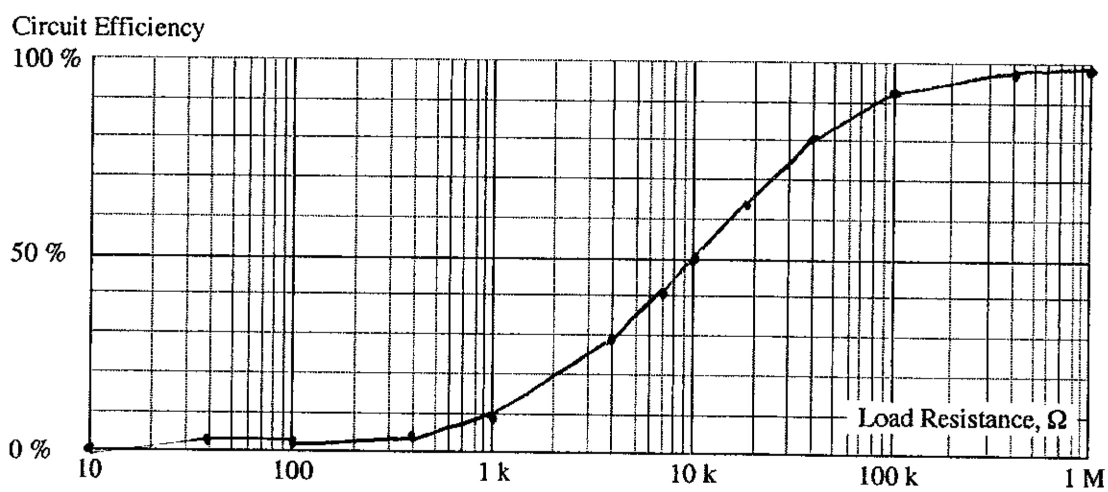
13 Prep Sheet

Name Oleksandr Vladyka

1. Use the data from Table 13-1 to complete the graphs given below.



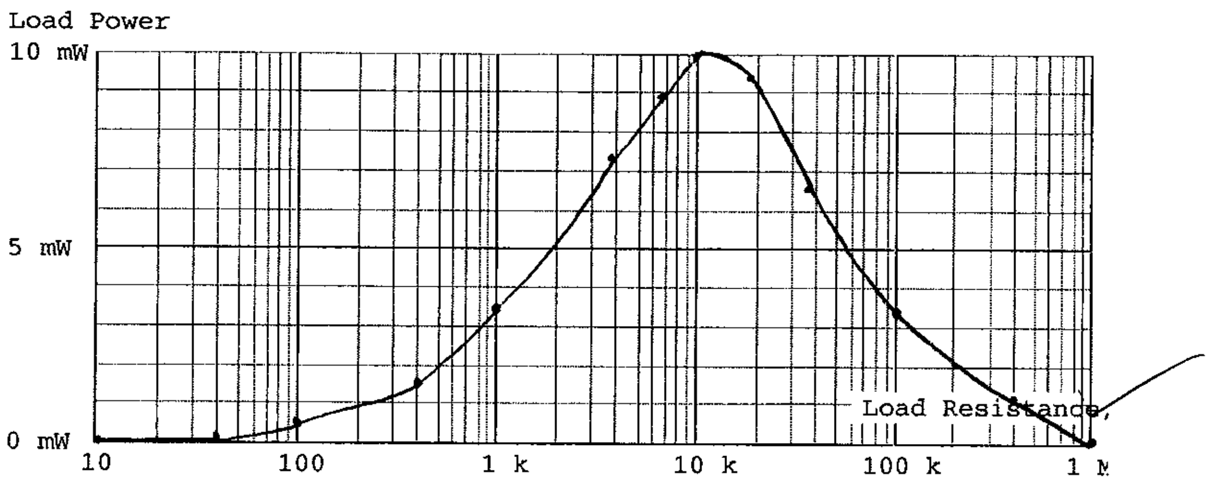
Graph 13-1. Theoretical Load Power versus Load Resistance



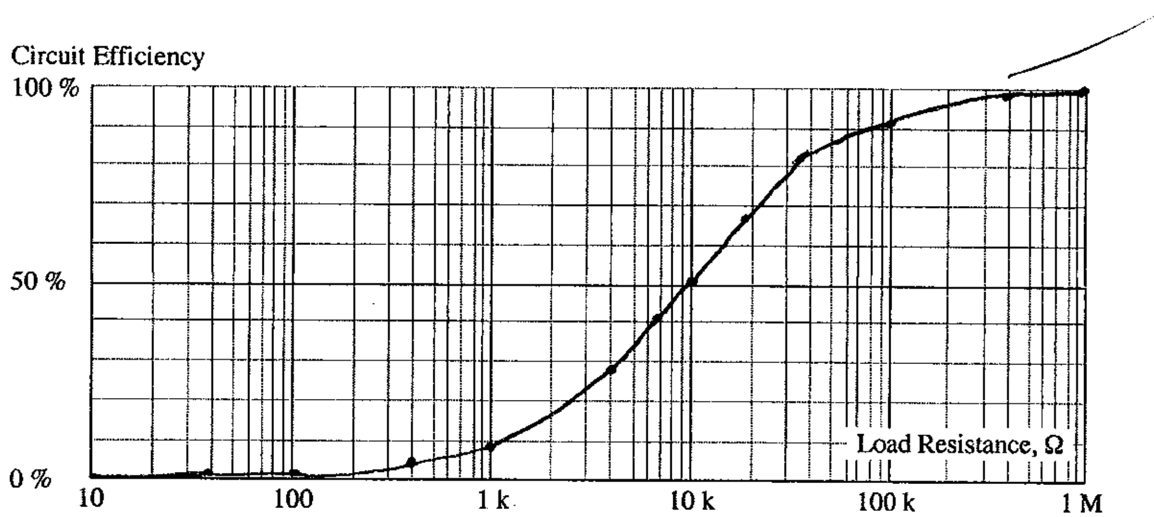
Graph 13-2. Theoretical Circuit Efficiency versus Load Resistance

13 **Data Sheet** Name Oleksandr Vladyka

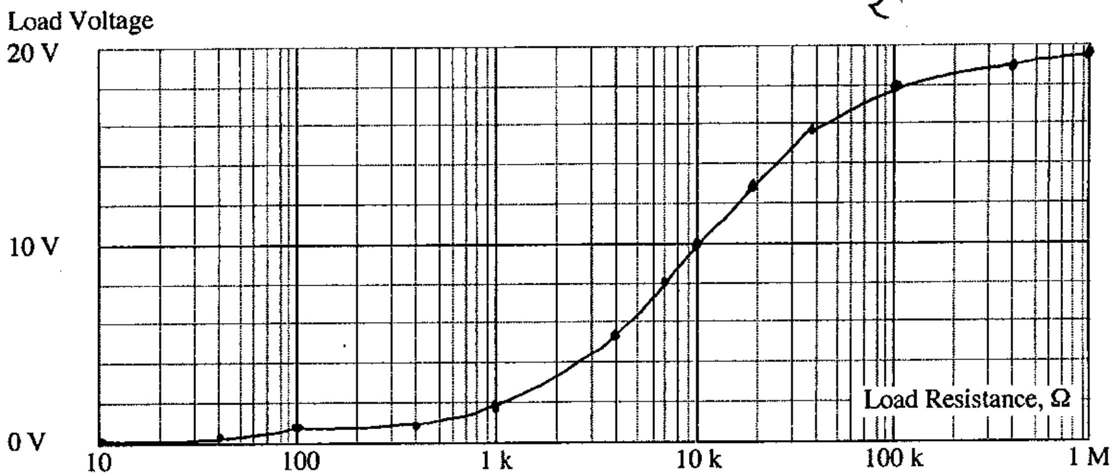
1. Use the data from Table 13-2 to plot graphs of load power, efficiency, and load voltage versus load resistance. These will be Graphs 13-3, 13-4, and 13-5 respectively.



Graph 13-3. Measured Load Power versus Load Resistance



Graph 13-4. Measured Circuit Efficiency versus Load Resistance



Graph 13-5. Measured Load Voltage versus Load Resistance

Questions

1. Explain the significance of the plotted results of Graph 13-3.

The graph shows us that the 10kΩ is the max power point.
The graph also shows us power curve.

2. Refer to Table 13-2. Explain why total circuit power decreases as load resistance increases.

As R_{eq} is going up, the current goes down.
Power is $P_{total} = I \cdot V$ The voltage is constant, so as the current is dropping so the the power.

$P_{diss} = \frac{E^2}{R_I + R_L}$

3. Refer to Graph 13-4. Explain why circuit efficiency continues to increase for load resistance values greater than that which causes maximum power transfer.

The circuit efficiency being measured is the percentage of the power in the circuit that is going to our load, so the higher resistance our load is the higher percentage of the total power is going to the load. $\eta = \frac{100 R_L}{R_I + R_L}$, $\eta \rightarrow 100$ as $R_L \rightarrow \infty$

4. Refer to Graph 13-5. What value of load resistance is required to cause maximum transfer of voltage from the source to the load?

1 MΩ causes max transfer of voltage from the source to the load.

5. Refer to Graph 13-5. What minimum load resistance is required to achieve the transfer of 99% of the voltage from the source to the load?

$$0.99\,(20) = 19.8 = \frac{20(R_L \cdot 10)}{R_L + 10}$$

$R_L = 1.099\ M\Omega$ for 99% of 20V

6. Compare the theoretical data from Table 13-1 with the measured data of Table 13-2. Explain any significant differences.

They appear to be the same values. I believe that the uncertainty is from minor calculation errors.

7. If the load resistance of Figure 13-2 were a 50 kΩ potentiometer, describe a method that would allow you to easily determine the load required for maximum power transfer.

14 The Wheatstone Bridge

Objectives

1. To evaluate the conditions required to balance a Wheatstone bridge.
2. To determine the characteristics of nulling.
3. To design a Wheatstone bridge to measure resistance.

Equipment

Two DC power supplies, voltmeter, ammeter

1/4 W resistors:	100 Ω	1 kΩ	5.6 kΩ	10 kΩ	15 kΩ	22 kΩ	33 kΩ
	47 kΩ	100 kΩ	150 kΩ	220 kΩ	330 kΩ	470 kΩ	

10 kΩ Potentiometer, 3/4 W, Part # 01B14 available from Digi-Key Corporation

Information

The main concept used in a Wheatstone bridge is the comparison of two voltages. It is also a simple application of Kirchhoff's Voltage Law. The concept can be viewed easiest by considering the circuit of Figure 14-1. By knowing the voltages V_A and V_B, the voltage V_X can be determined with Kirchhoff's Voltage Law. The polarity of the voltage V_X can also be determined. If $V_A > V_B$, the polarity of V_X will be positive on the left side. If the voltages V_A and V_B are equal, V_X will be zero volts, which is a condition of balance between V_A and V_B. The same principles may be applied to the circuit of Figure 14-2, which is a normal Wheatstone bridge in an unbalanced condition.

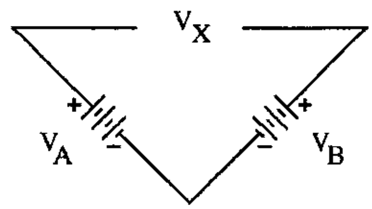


Figure 14-1. Wheatstone Concept

The bottom portion of Figure 14-2, consisting of R2, R4 and the voltmeter can be compared with Figure 14-1. Since the voltmeter is a high resistance instrument, no significant current can flow through it. Ohm's Law will show the voltages across R2 and R4 to be 10.91 V and 12.00 V, respectively. If, on Figure 14-1, V_A and V_B were 10.91 V and 12.00 V, respectively, V_X would be seen to be 1.09 V, with positive polarity on the right side.

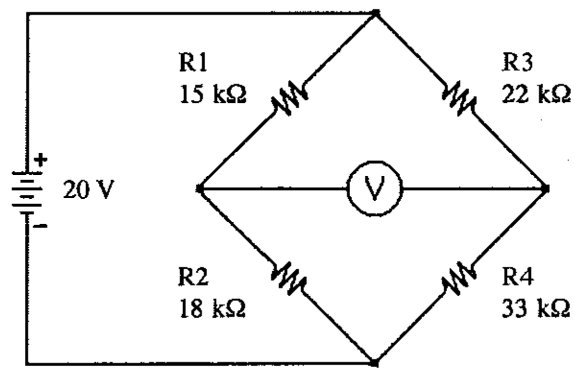


Figure 14-2. Wheatstone Bridge

This bridge is presently in an unbalanced condition since the voltages across R2 and R4 are not equal, or since the voltages across R1 and R3 are not equal. When the voltages are equal, the bridge is said to be nulled, or at balance. When at null, Equation 14-1, the balance equation, is valid.

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$ .... Equation 14-1

If any three resistors in the Wheatstone bridge are known, the fourth can be calculated. As an example, consider a circuit like Figure 14-2 where R4 is unknown. With fixed resistors for R1 and R3, a potentiometer could be used in place of a fixed value for R2. As R2 is varied, the bridge could be brought into balance by observing the voltmeter. When the voltmeter reads zero volts, the bridge would be balanced, and R4 could be calculated with Equation 14-2.

$$R_4 = \frac{R_2 \times R_3}{R_1}$$ .... Equation 14-2

Techniques to accomplish a resistance measurement such as the above will be explored in this experiment.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Refer to the circuit of Figure 14-4. Use Equation 14-1 to solve for the setting of R2 which will provide a balanced bridge condition for each value of R4 given in Table 14-1.

Table 14-1. Potentiometer Balance Settings

Resistance of R4	10 kΩ	15 kΩ	22 kΩ	33 kΩ	47 kΩ
Balance setting for R2					

2. Refer to the circuit of Figure 14-4. Assume that R1 is changed from 1 kΩ to 100 Ω. Again, use Equation 14-1 to solve for the setting of R2 which will provide a balanced bridge condition for each value of R4 given in Table 14-2.

Table 14-2. Potentiometer Balance Settings

Resistance of R4	100 kΩ	150 kΩ	220 kΩ	330 kΩ	470 kΩ
Balance setting for R2					

3. Transfer the data from Tables 14-1 and 14-2 into the same tables on the Prep Sheet.

Procedure

1. For the circuit of Figure 14-3, use a voltmeter to set each power supply as closely as possible to 20.0 V, then connect the voltmeter between the two positive power supply terminals.

2. Although both supplies have apparently been set to the same voltage, one supply will be set slightly higher than the other.

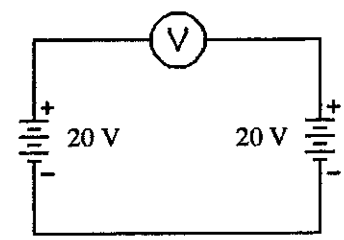


Figure 14-3. Null Measurement Circuit

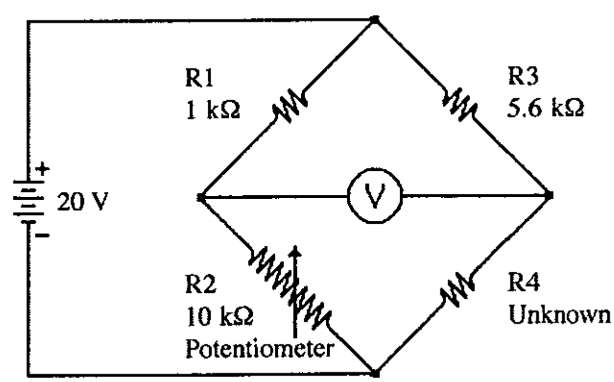
3. Reduce the range of the voltmeter to as low as possible. It may be necessary to reverse the voltmeter test leads. Record the difference voltage between the two supplies in the space below, and on the Data Sheet.

Difference Voltage = ______________

4. Before building the circuit of Figure 14-4, measure the resistance of R1 and R3, the resistors that you will be using for the two upper legs of the bridge. Record in Table 14-3.

5. Connect the circuit of Figure 14-4, using a 10 kΩ resistor as the unknown R4 value. If you have a choice of voltmeters, an analogue meter would be preferred over a digital meter for this circuit. Set the voltmeter to a 10 V range, or higher.

6. If the voltmeter needle is deflecting in the wrong direction, reverse the voltmeter test leads.



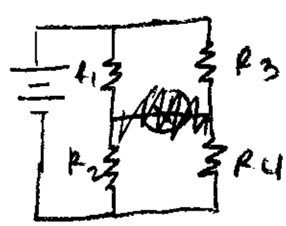


Figure 14-4. Wheatstone Bridge Measurement Circuit

7. Carefully adjust the potentiometer R2 so as to bring the bridge into balance, as observed by the voltmeter reading coming closer to 0 V. As the voltage reading comes closer to 0 V, keep reducing the voltmeter range. This will increase your ability to sensitively adjust the potentiometer until the bridge is as close to a null as possible.

8. When the bridge is at balance, turn the voltmeter back to a 10 V or higher range, turn the power off, and remove the potentiometer being careful not to alter the setting of the potentiometer.

9. Measure the resistance setting of potentiometer R2 and record in Table 14-3.

10. Use Equation 14-2 to calculate the unknown resistance R4 using the measured values of R1, R2, and R3, and record this calculated value of R4 in Table 14-3.

11. Remove R4 from the circuit and measure its resistance and record in Table 14-3.

12. Repeat steps 6 through 11 for each of the unknown R4 resistors in Table 14-3.

Table 14-3. Bridge Measurements (R1 = 1 kΩ)

Measured Leg Resistances		R1 = 0.99 kΩ	R3 = 5.53 kΩ
R4	Measured R2 after bridge is balanced	R4 calculated from measured values of R1, R2, and R3	R4 measured with ohmmeter
10 kΩ	1.72 kΩ		
15 kΩ	2.64 kΩ		
22 kΩ	3.97 kΩ		
33 kΩ	5.64 kΩ		
47 kΩ	7.98		

13. Change the upper left bridge resistor, R1, from 1 kΩ to 100 Ω. Record the measured value of this resistor as well as the previously measured value of R3 in Table 14-4.

14. The new Wheatstone bridge circuit will now be able to measure larger unknown values of R4.

15. Begin with R2 set to a minimum value of 1 kΩ, otherwise the 100 Ω resistor will burn up.

16. Follow the previous procedures in order to complete Table 14-4.

17. Transfer the data from Tables 14-3 and 14-4 into the same tables on the Data Sheet.

Table 14-4. Bridge Measurements (R1 = 100 Ω)

Measured Leg Resistances		R1 =	R3 =
R4	Measured R2 after bridge is balanced	R4 calculated from measured values of R1, R2, and R3	R4 measured with ohmmeter
100 kΩ			
150 kΩ			
220 kΩ			
330 kΩ			
470 kΩ			

14 Prep Sheet 5/5 Name Oleksandr Vladyka

1. Complete the data required for Table 14-1 as described in the Lab Prep section of this experiment.

Resistance of R4	10 kΩ	15 kΩ	22 kΩ	33 kΩ	47 kΩ
Balance setting for R2	1.79kΩ	2.68kΩ	3.93kΩ	5.89kΩ	8.39kΩ

2. Complete the data required for Table 14-2 as described in the Lab Prep section of this experiment.

Resistance of R4	100 kΩ	150 kΩ	220 kΩ	330 kΩ	470 kΩ
Balance setting for R2	1.79 kΩ	2.68 kΩ	3.93 kΩ	5.89 kΩ	8.39 kΩ

5/5

14 Data Sheet

Name Oleksandr Vladyka

1. Record the measured voltage from procedure step 3 in the space below.

Difference Voltage = ____________

2. Complete the data required for Table 14-3 below.

Measured Leg Resistances		R1 = 0.987 kΩ	R3 = 5.52 kΩ
R4	Measured R2 after bridge is balanced	R4 calculated from measured values of R1, R2, and R3	R4 measured with ohmmeter
10 kΩ	1.76 kΩ	9.84 kΩ	9.87 kΩ
15 kΩ	2.64 kΩ	14.76 kΩ	14.6 kΩ
22 kΩ	3.9 kΩ	21.81 kΩ	21.74 kΩ
33 kΩ	5.8 kΩ	32.44 kΩ	36.6 kΩ
47 kΩ	8.36 kΩ	46.76 kΩ	46.6 kΩ

3. Complete the data required for Table 14-4 below.

Measured Leg Resistances		R1 =	R3 =
R4	Measured R2 after bridge is balanced	R4 calculated from measured values of R1, R2, and R3	R4 measured with ohmmeter
100 kΩ			
150 kΩ			
220 kΩ			
330 kΩ			
470 kΩ			

Questions

1. Refer to the circuit of Figure 14-4. Assuming that R2 could be adjusted only between values of 1 kΩ and 9 kΩ, for what range of R4 values would this bridge balance?

$$R_4 = \frac{R_2 \cdot R_3}{R_1} \qquad R_4 = \frac{(1k\Omega)(5.52k\Omega)}{0.987k\Omega} = 5.59\ k\Omega$$

$$5.59k\Omega \le R_4 \le 50.33k\Omega$$

$$R_3 = 5.52\ k\Omega \qquad R_4 = \frac{(9k\Omega)(5.52\ k\Omega)}{0.987\ k\Omega} = 50.33k\Omega$$

$$R_1 = 0.987k\Omega$$

2. Refer to the circuit of Figure 14-4. If the resistor values were: R1 = 10 kΩ, R2 = 12 kΩ, R3 = 15 kΩ and R4 = 18 kΩ, would this bridge be in balance?

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \Rightarrow \frac{10k\Omega}{12\ k\Omega} = \frac{15\ k\Omega}{18k\Omega}$$

$$\frac{5}{6} = \frac{5}{6}$$

Yes, it would be balanced.

3. Refer to the circuit of Figure 14-4. Describe the characteristics of a nulled Wheatstone bridge.

4. Refer to the circuit of Figure 14-4. When R1 was changed from 1 kΩ to 100 Ω, how did this affect the measurement capability of the bridge?

5. Refer to the circuit of Figure 14-4. What could be done to improve the capability of this bridge to measure R4 more accurately?

If the potentiometer was more precise then we would measure R_4 more accurately.

EE336F14 – THERMISTOR MEASUREMENTS - LAB 7 – WHEATSTONE BRIDGE

Name Oleksandr Vladyka

(Hand this completed sheet in with your regular Lab 7 data sheet. All you have to do is fill in your observations in the space below.)

1) Use the same circuit as in Figure 14-4, except the thermistor becomes your R4 unknown.
2) Adjust the 10 Kohm pot to achieve balance in the bridge. You will not be able to achieve zero difference but stabilize the voltage measured at the lowest possible level. As with the regular part of the experiment you will find the pot setting very sensitive.
3) Separate the pot from the bridge by disconnecting one wire.
4) Record the pot resistance that was able to balance the bridge. Rx = 5.83kΩ ohms
5) Reassemble the bridge.
6) Use your body heat to raise the temperature of the thermistor. Keep contact. There is not a big temperature difference between your body's surface and the room ambient. The time constant is long for the thermistor so you will have to be patient.
7) When the bridge voltage stabilizes, again at the lowest possible level, disconnect one wire of the pot from the bridge and check the pot's resistance. Ry = 3.38kΩ ohms
8) Find the difference between the resistance readings. This gives an indirect measurement of the change in temperature of the thermistor.
9) Determine the change in temperature by using the slope of the thermistor's characteristic curve. Temperature change = +2.75° F

$$R_y - R_x = \Delta R = -2.45\,k\Omega \times 10^3 = -2450\,k\Omega$$

$$\frac{-2450}{890} = \Delta T = -2.75$$

Wrong Sign
Increase in Temp

MR, Sept. 2014

15 Oscilloscope Familiarization

Objectives

1. To produce a waveform on an oscilloscope graticule.
2. To critique the effects of manipulating various typical oscilloscope controls.
3. To manipulate a waveform so as to optimize its appearance.
4. To evaluate a variety of basic oscilloscope waveforms.

Equipment

Dual trace oscilloscope with x 1 and x 10 probes
Sinewave oscillator or waveform generator, ac voltmeter

Information

This experiment will be concerned with the use of the various controls and switches found on typical basic oscilloscopes. There are many different oscilloscopes presently being manufactured, each having their own characteristics as well as their own layout of controls. Despite this variety in the marketplace, most controls have similar names and functions from one manufacturer to another. Rather than use a particular make and model of scope, a "generic" scope is presented in Figure 15-1 as a vehicle by which typical operation can be explained.

Scope controls are grouped together as to function. The upper left block of Figure 15-1 contains controls which relate to the overall appearance of the waveform. These are often called "trace-related" controls. The lower left and lower middle blocks are both vertical sections. Their controls relate totally to the vertical movement of the scope trace. This scope has two vertical sections so that it can display two waveforms simultaneously. The lower right block is the horizontal section. Its controls relate to the horizontal movement of the scope trace, and to the triggering or synchronization of the waveform. The last block contains the cathode ray tube, or CRT, and has a marked graticule on its face, used for measurement purposes.

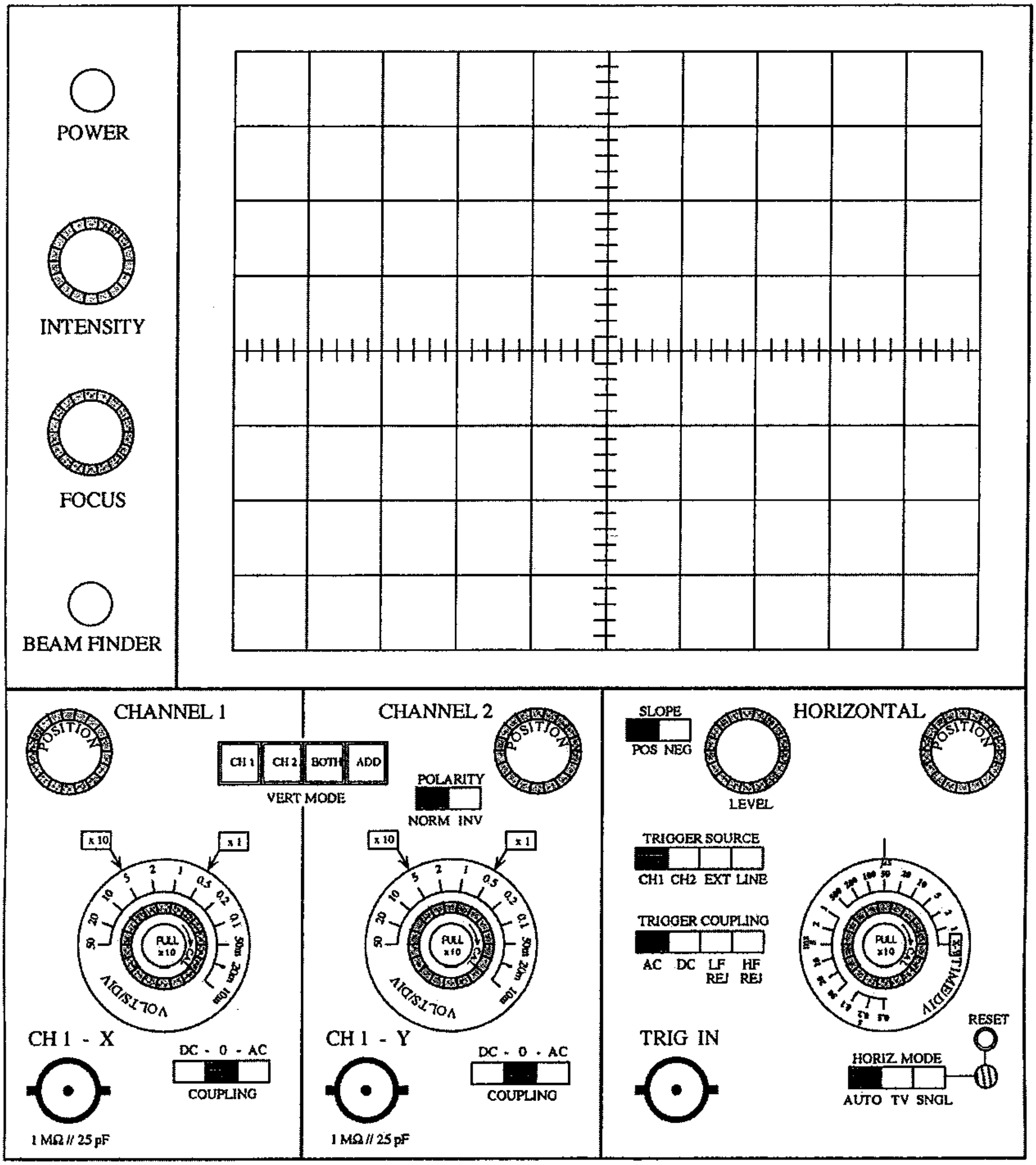


Figure 15-1. A Basic Oscilloscope

The individual controls, their positions, and their functions will be explained briefly in Tables 15-1 to 15-3. The student should realize that a scope is an intimidating instrument when confronted for the first time. Give it a little time and the mystery will disappear.

Table 15-1. Trace Related Controls

Name	Positions	Functions
POWER	OFF ON	Disconnects power to all circuitry Applies power to all circuitry
INTENSITY	Variable	Controls the brightness of the trace
FOCUS	Variable	Controls the sharpness of the trace
BEAM FINDER	OFF ON	No effect Compresses vertical and horizontal deflection as an aid to location of the oscilloscope display

Table 15-2. Vertical Related Controls

Name	Positions	Functions
VERT MODE	CH 1 CH 2 BOTH ADD	Selects the signal from channel 1 for the vertical display Selects the signal from channel 2 for the vertical display Selects both channel's signals for simultaneous display Presents a single trace which is the algebraic sum of both channels, or the difference if channel 2 is inverted
CH 1 - X or CH 2 - Y	BNC connectors	Signal input terminals for both channels, or input points for an X-Y display if selected on the TIME/DIV control
POLARITY	NORM INV	Normal phase presentation of the channel 2 waveform Inverts the phase of channel 2 by 180°, allowing a display of CH 1 - CH 2 when the ADD mode is selected
POSITION	Variable	Moves entire display up and down for user convenience
COUPLING	DC 0 AC	Allows composite DC and AC signals to be displayed Disconnects the input to obtain a horizontal reference line Removes DC levels from composite input signals
VOLTS/DIV	Many steps	Determines the vertical sensitivity or range switch in use
V/DIV Variable	Variable CAL PULL x 10	Allows selection of uncalibrated vertical sensitivities Fixes vertical sensitivity to the selected V/DIV position Divides V/DIV selection by 10, increasing sensitivity

Table 15-3. Horizontal Related Controls

Name	Positions	Functions
POSITION	Variable	Moves entire display left and right for user convenience
TIME/DIV	Many steps X-Y	Determines the horizontal sweep rate; controls the time display of each horizontal division Allows presentation of an X versus Y display
TIME/DIV Variable	Variable CAL PULL x 10	Allows selection of uncalibrated horizontal sensitivities Fixes the sweep rate to the selected TIME/DIV position Divides T/DIV selection by 10, increasing the sweep rate
SLOPE	POS NEG	Starts trace somewhere on the waveform's positive slope Starts trace somewhere on the waveform's negative slope
LEVEL	Variable	Determines the voltage level at which the trace will begin
HORIZ MODE	AUTO TV SNGL RESET	Provides automatic synchronization of the waveform to prevent a moving display. Will also trigger the display without a signal being present. Provides automatic synchronization with the horizontal sweep frequency used in television receivers. Allows the presentation of a single sweep of the display, often used for photographic purposes. Triggers a single sweep; light indicates sweep is ready.
TRIGGER SOURCE	CH 1 CH 2 EXT LINE	Obtains a synchronization signal from channel 1 Obtains a synchronization signal from channel 2 Obtains a synchronization signal from TRIG IN terminal Obtains a synchronization signal from the power line
TRIG IN	BNC terminal	Used to apply a signal to externally trigger the sweep
TRIGGER COUPLING	AC DC LF REJ HF REJ	Removes DC levels from all triggering signals Allows AC and DC composite triggering signals Removes low frequency components from trigger signals Removes high frequency components from trigger signals

Lab Prep

1. Study the basic oscilloscope shown in Figure 15-1, along with the explanations of the various controls described in Tables 15-1, 15-2, and 15-3.

2. If possible, obtain the manufacturer's Operation Manual for the scope which you will be using and study the control names and functions.

3. Make a list of control names which are the same on your scope as those found on Figure 15-1.

4. Make a list of control names which are named differently on your scope from those found on Figure 15-1, but appear to have the same function.

5. Make a list of control names which appear on your scope, but are not found on Figure 15-1.

Procedure

1. Turn on your scope and obtain a horizontal line trace. If a trace is not visible, set some of the scope controls as follows:

VERTICAL MODE:	Select channel 1
CH 1 POSITION:	Set midway
HORIZONTAL MODE:	AUTO
LEVEL:	Set midway
HORIZONTAL POSITION:	Set midway
TRIGGER SOURCE:	Select CH 1
INTENSITY:	Set midway

2. If a trace is still not visible, press the BEAM FINDER if your scope is so equipped. If this does not help you find a trace, you will probably need your instructor's assistance.

3. After you have obtained a visible trace, you may continue with the procedure, which has been designed to allow the student to become familiar with the effect that various controls have upon the trace. The procedure is separated into trace related controls, vertical related controls, and horizontal related controls. No actual measurements will be made in this experiment, only observations of control effects. The next experiment will instruct the student on actual measurement techniques.

Trace Related Controls

4. The effect of the POWER switch has already been observed. Use the INTENSITY, FOCUS, and BEAM FINDER controls at this time. Record any observations you wish to make in the space below.

Vertical Related Controls

5. Use your ac voltmeter to set your sinewave generator to 3.0 V, and adjust the frequency to 400 Hz.

6. Set the following scope controls to the indicated positions and connect a "times one" probe, or a BNC to alligator test lead set, from the CH 1 scope input to the generator. If a "times ten" probe is all that is available, set the scope controls as indicated in brackets below.

VERTICAL MODE:	Select channel 1	
COUPLING:	DC	
VOLTS/DIV:	2 V/DIV	(0.2 V/DIV)
VOLTS/DIV Variable:	Set on CAL	
TIME/DIV:	1 ms/DIV	
TIME/DIV Variable:	Set on CAL	
HORIZONTAL MODE:	AUTO	
TRIGGER SOURCE:	Select CH 1	

7. About four cycles of a sinewave should now be observable on the screen. The display should be using about 10 divisions horizontally and between 4 and 5 divisions vertically. You should obtain a correct display before proceeding.

8. Adjust the vertical POSITION control to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make. Consider question 1 on the Data Sheet at this time.

9. Adjust the vertical VOLTS/DIV control to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make. Consider questions 2 and 3 on the Data Sheet at this time.

10. Adjust the vertical VOLTS/DIV Variable control to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

11. Adjust the vertical VOLTS/DIV magnifier, or "PULL x 10" control, if so equipped, to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make. Consider question 4 on the Data Sheet at this time.

12. Switch the CH 1 COUPLING control through its three positions to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

Horizontal Related Controls

13. Reset the scope controls as described in step 6. Switch the SLOPE control through its two positions to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

14. Vary the LEVEL control to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make. Consider question 5 on the Data Sheet at this time.

15. Adjust the horizontal POSITION control to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

16. Adjust the horizontal TIME/DIV switch to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make. Consider question 6 on the Data Sheet at this time.

17. Adjust the horizontal TIME/DIV Variable control to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

18. Adjust the horizontal TIME/DIV magnifier, or "PULL x 10" control, if so equipped, to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

19. Set the TRIGGER SOURCE control to the EXT, then to the LINE position and observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

20. Vary the HORIZ MODE switch through its available positions to observe the effect of this control on the displayed waveform. Use the space below to record any observations you wish to make.

21. Move the scope test leads from the signal generator to your hands and observe the waveform which is present on your hands.

22. Try using any other scope controls which have not specifically been tested by this time. Use the space on the back of the Prep Sheet to record any observations you wish to make.

15 Prep Sheet Name

1. List all control names which are the same on your scope as those found on Figure 15-1.

2. List all control names which are named differently on your scope from those found on Figure 15-1, but appear to have the same function.

3. List all control names which appear on your scope, but are not found on Figure 15-1.

15 Data Sheet Name

Questions related to observations, and answered as a part of the procedure of this experiment:

1. Does the vertical POSITION control alter the shape or size of the displayed waveform in any way?

2. If a higher VOLTS/DIV position is selected, does the observed waveform become larger vertically, or smaller?

3. Does the VOLTS/DIV switch position affect the displayed waveform horizontally?

4. Describe the effect of the vertical magnification switch on the appearance of the display, and on the VOLTS/DIV selected position.

5. Does the LEVEL control affect the shape of the waveform or its position?

6. If the TIME/DIV switch is changed from 1 ms/DIV to 500 μs/DIV, will you see more or fewer cycles of the display? Is the sweep speed now faster or slower?

Questions

1. Sketch a waveform as you would expect it to appear, assuming the LEVEL control is set greater than midway, and the SLOPE is set to NEG.

2. Describe what you would expect to see if a signal were connected to CH 2, and the TRIGGER SOURCE were set to CH 1.

3. Describe the difference between the BOTH and ADD positions of the VERT MODE switch.

4. Describe the difference between the terms "sweep time" and "sweep rate."

5. Do any of the scope controls actually change the ac signal which is connected at the input terminals?

Experiment

16 Oscilloscope Voltage Measurements

Objectives

1. To measure peak to peak voltages with an oscilloscope.
2. To convert peak to peak voltage measurements into RMS measurements.
3. To measure dc voltages with an oscilloscope.
4. To measure combined dc and ac voltages with an oscilloscope.
5. To operate vertically-related oscilloscope controls.

Equipment

Dual trace oscilloscope with x 1 and x 10 probes, dc power supply
Sinewave oscillator or waveform generator, ac voltmeter
1/4 W resistors: 15 kΩ 27 kΩ 56 kΩ

Information

Voltage measurement with a scope is concerned with the vertical deflection of the display, although the settings of some horizontal controls can affect the ease and accuracy of the resulting vertical measurements.

Vertical measurements are most often made in units of peak to peak volts, and expressed, for example, as 33.0 Vpp. The measurement is accomplished by measuring the vertical deflection of the waveform from one peak to the other, in units of "divisions peak to peak." This vertical distance is then multiplied by the vertical sensitivity, which is in units of "volts per division." When divisions peak to peak is multiplied by volts per division, the resulting number has units of "volts peak to peak," since the division terms cancel. An example is shown on the next page and illustrated in Figure 16-1.

Example: 6.60 divisions peak to peak x 5 V / division = 33.0 volts peak to peak = 33.0 Vpp

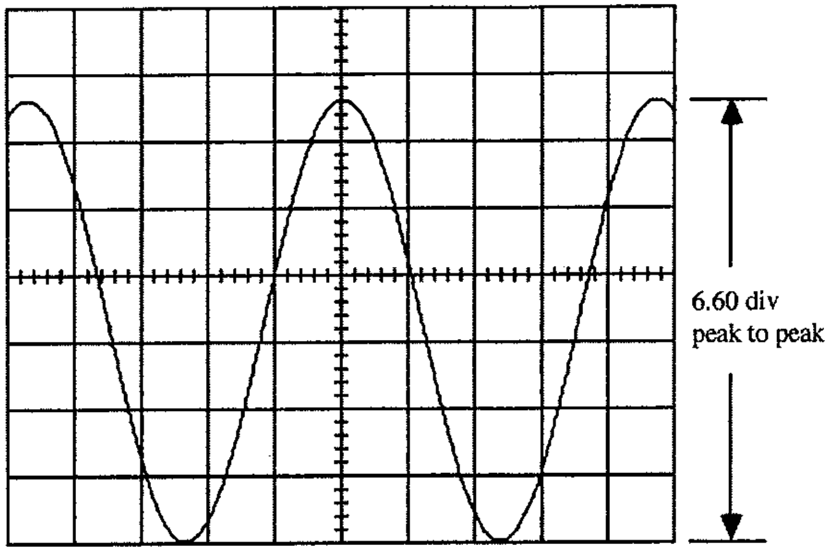


Figure 16-1. Oscilloscope Voltage Measurement

The resulting measurement can now be converted into peak volts by dividing by two, therefore 33.0 Vpp is equal to 16.5 Vp. This peak voltage can be converted to RMS voltage by dividing by $\sqrt{2}$, or 1.41, which calculates to 11.7 V. These are all the same voltages, they are only expressed differently, thus, 33.0 Vpp = 16.5 Vp = 11.7 V.

Some users prefer measuring peak voltage. This can be accomplished by measuring the number of peak divisions from the vertical centre of the waveform to either peak, then multiplying by volts per division, resulting in units of volts peak. In the case of Figure 16-1, this would demand that the user position the waveform in the centre of the screen vertically.

DC voltages can also be measured with a scope. A dc voltage appears as a horizontal line on the scope, since the voltage does not vary with time. To measure a dc voltage, first position the trace to a convenient horizontal graticule line as a reference with vertical COUPLING set to 0, then switch the COUPLING to DC, measure the vertical displacement of the line, and multiply by the vertical sensitivity. Combined dc and ac voltages can also be measured in this fashion.

When the VERT MODE is set to BOTH, two waveforms may be measured independently of each other, and their settings of the VOLTS/DIV switches can be different from each other.

Two independent waveforms can be added algebraically by setting VERT MODE to ADD and the POLARITY on CH 2 to NORM; this is often referred to as "CH 1 + CH 2." Two waveforms can also be subtracted by setting VERT MODE to ADD and the POLARITY on CH 2 to INV; this is often referred to as "CH 1 - CH 2." When either of these functions are used, it is important to realize that the settings of the VOLTS/DIV switch on each channel must be identical in order to have meaningful results.

Note that the use of a MAGNIFIER switch increases the vertical sensitivity and will enlarge the display. As an example, a vertical setting of 200 mV/DIV combined with a x10 MAGNIFIER setting, results in a vertical sensitivity of 20 mV/DIV.

Lab Prep

1. For the scope display shown in Figure 16-2, determine the voltages required in Table 16-1. Record your answers on the Prep Sheet as well.

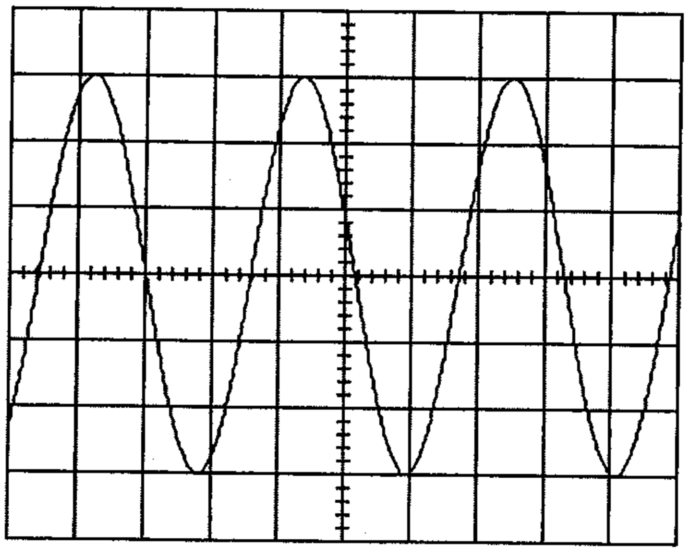


Figure 16-2. Oscilloscope Display

Table 16-1. Scope Readings

VOLTS/DIV MAGNIFIER	0.2 V/DIV x 1	5 V/DIV x 10	10 mV/DIV x 1	20 V/DIV x 10
Desired Measurement	Peak to Peak Voltage	RMS Voltage	Peak Voltage	Peak to Peak Voltage
Measurement				

2. For the scope display shown in Figure 16-3, determine the voltages required in Table 16-2. Record your answers on the Prep Sheet as well.

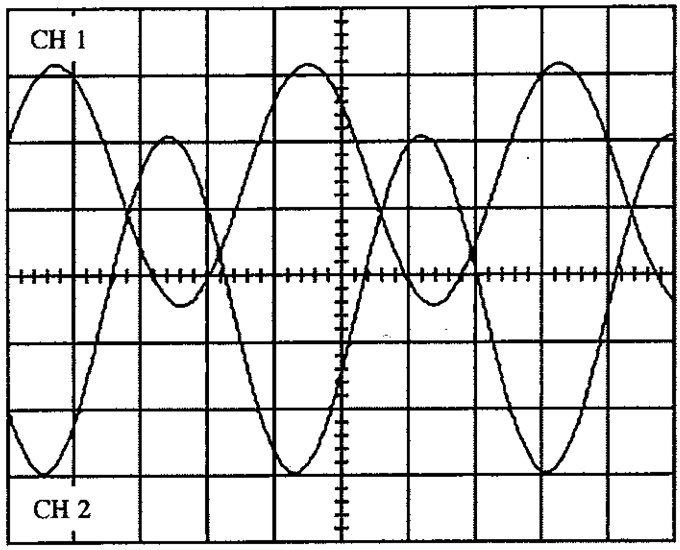


Figure 16-3. Oscilloscope Display

Table 16-2. Scope Readings

MODE VOLTS/DIV MAGNIFIER	CH 1 0.1 V/DIV x 1	CH 2 20 mV/DIV x 10	CH 1 10 V/DIV x 10	CH 2 0.5 V/DIV x 1
Desired Measurement	Peak Voltage	Peak to Peak Voltage	RMS Voltage	Peak to Peak Voltage
Measurement				

Procedure

Oscilloscope AC Voltage Measurements

1. Use an ac voltmeter to set your sinusoidal output of the signal generator to 3.0 V at a frequency of 1.0 kHz. (Remember that 3.0 V, in the context of AC, means 3.0 VRMS)

2. Measure the peak to peak voltage of the generator with each channel, one at a time, of your scope. Record your measurements in Table 16-3.

3. Using your peak to peak measurements, calculate the RMS value of each measurement for Table 16-3.

Table 16-3. Generator Measurements and Calculations

CH 1 Measured	CH 2 Measured	CH 1 Calculated	CH 2 Calculated

4. Connect the circuit of Figure 16-4, grounding one side of the generator. After the circuit is connected, use the scope to set the generator to 8.0 Vpp at a frequency of 2.0 kHz.

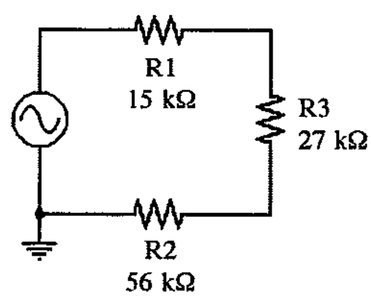


Figure 16-4. Series Circuit Measurements

5. With the resistors fixed in their positions in the circuit, measure the peak to peak voltage across each resistor and record in Table 16-4. Note that this will cause some erroneous measurements because the ground leads will not always be in the same place. This is intentional.

6. Repeat the resistor voltage measurements, but this time move the resistors around such that when each resistor's voltage is measured, it is in the location of R2 in Figure 16-4 Keep both the generator and the scope ground leads together. Record in Table 16-4.

Table 16-4. Oscilloscope Measurements

Resistors	Scope voltages with resistors fixed	Scope voltages moving resistors
R1		
R2		
R3		

Oscilloscope DC Voltage Measurements

7. With no input connected, adjust the scope for a horizontal trace centered vertically on the graticule. Set the vertical sensitivity at 2 V/DIV, and the COUPLING to DC.

8. Connect a dc power supply, set to about 5 V, to the scope input and observe the vertical movement of the scope trace. Measure the dc voltage with the scope and assure that it agrees with the setting of the power supply. Confirm the voltage measurement with a dc meter if you wish.

9. Reverse the scope connections to the power supply and observe that the vertical movement of the scope trace is opposite to that observed in step 8.

10. Switch the COUPLING from DC to the AC position and observe the results.

Oscilloscope Combined DC and AC Voltage Measurements

11. Set the scope to a vertical sensitivity of 1.0 V/DIV, with the trace centered 2 divisions below the centre of the graticule, and the VERTICAL COUPLING set to DC. Connect the circuit of Figure 16-5.

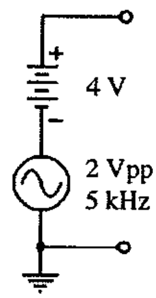


Figure 16-5. Combined DC and AC

12. Connect the scope input to the circuit of Figure 16-5 and draw the observed waveform on the graticule provided in step 3 of the Data Sheet.

13. Switch the COUPLING from DC to the AC position and draw the observed waveform on the graticule provided in step 4 of the Data Sheet.

Other Oscilloscope Measurements

14. If your oscilloscope is not equipped with two vertical inputs, omit this portion of the procedure.

15. Set your signal generator to 6 Vpp at a frequency of 10 kHz.

16. Set both scope vertical sensitivities to 2 V/DIV, and set the POSITION controls so that channel 1 is 2 divisions above the centre of the graticule and channel 2 is 2 divisions below the centre.

17. Connect both scope inputs to the generator. Set the VERT MODE switch to the BOTH function, and observe the positions and sizes of the waveforms.

18. Try changing the VOLTS/DIV and position controls for each channel to observe that they are independent of each other, then return the settings to that described in step 15.

19. Switch the VERT MODE to the ADD function, with the POLARITY on the NORM position, and measure the resulting waveform to assure yourself that it is 12 Vpp, the sum of the two signals.

20. Switch the POLARITY to the INV position, and observe the resulting waveform. It should be 0 Vpp, the difference between the two signals.

21. Switch back to the BOTH function. Set the VOLTS/DIV on CH 1 to 20 V/DIV and the channel 1 magnifier to its x 10 position. The observed channel 1 waveform should still be the same as the channel 2 waveform.

Oscilloscope Probes

22. Refer to the Operator's Manual for your particular scope to learn the operation of whatever probes you have available at your lab station.

23. Study the front panel controls of your vertical sections of your scope and determine how you can tell which VOLTS/DIV setting you are supposed to read when a x 10 probe is connected, or when a x 1 probe is connected.

24. If a square wave signal is available, your instructor may wish to have you learn how to compensate your z 10 probe at this time.

16 Prep Sheet

5/5

Name Oleksandr Vladyka

1. Complete the data required for Table 16-1 below.

VOLTS/DIV MAGNIFIER	0.2 V/DIV x 1	5 V/DIV x 10	10 mV/DIV x 1	20 V/DIV x 10
Desired Measurement	Peak to Peak Voltage	RMS Voltage	Peak Voltage	Peak to Peak Voltage
Measurement	1.2 V_{pp}	1.065 V	0.03 V_p	12 V_{pp}

2. Complete the data required for Table 16-2 below.

MODE VOLTS/DIV MAGNIFIER	CH 1 0.1 V/DIV x 1	CH 2 20 mV/DIV x 10	CH 1 10 V/DIV x 10	CH 2 0.5 V/DIV x 1
Desired Measurement	Peak Voltage	Peak to Peak Voltage	RMS Voltage	Peak to Peak Voltage
Measurement	0.175 V_p	0.0101 V_{pp}	1.17 V	2.53 V_{pp}

5/5

16 Data Sheet

Name Oleksandr Vladyka

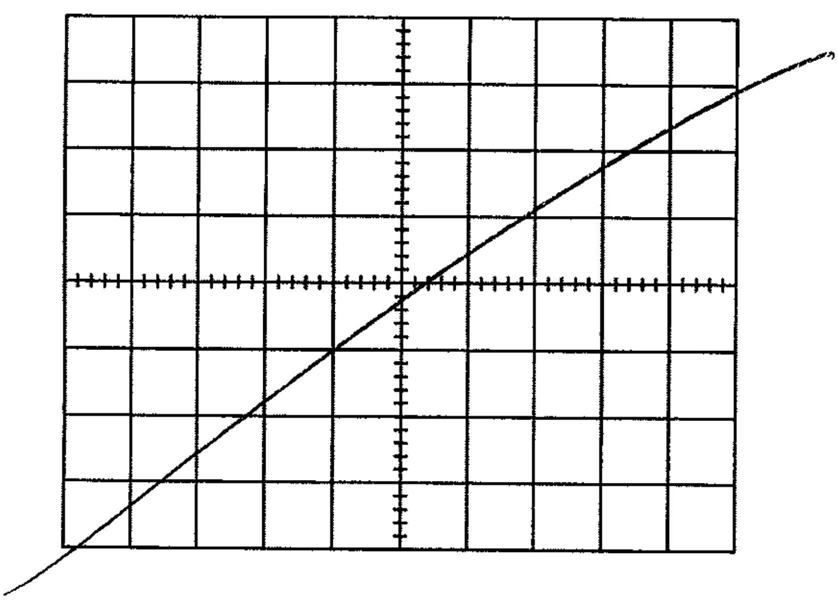
1. Complete the data required for Table 16-3 below.

CH 1 Measured	CH 2 Measured	CH 1 Calculated	CH 2 Calculated

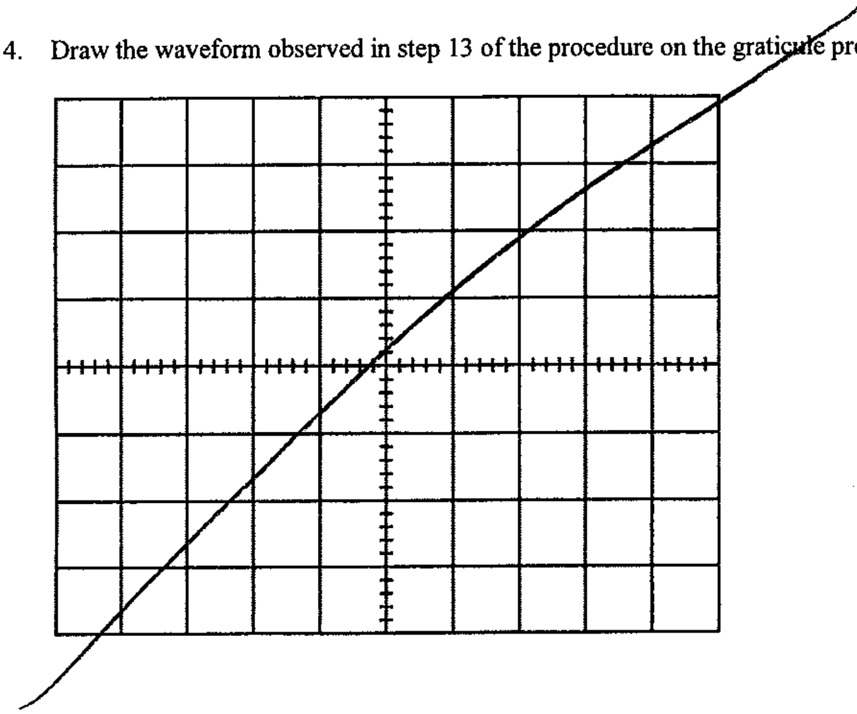
2. Complete the data required for Table 16-4 below.

Resistors	Scope voltages with resistors fixed	Scope voltages moving resistors
R1	1.56 Vpp	1.22 Vpp
R2	4.72 Vpp	4.56 Vpp
R3	2.45 Vpp	2.22 Vpp

3. Draw the waveform observed in step 12 of the procedure on the graticule provided below.



4. Draw the waveform observed in step 13 of the procedure on the graticule provided below.



Questions

1. For your particular scope, describe how you determine which VOLTS/DIV setting to read when you are using a x 10 probe.

Most scopes have indicators printed on the scope face or use see through windows on the VOLTS/DIV switch to direct the user to the correct setting.

2. Describe the effect that the various positions of the vertical COUPLING control will have on a combined dc and ac signal.

The "O" position disconnects the signal being tested and allows the user to observe a flat horizontal line for positioning purposes. The "DC" position allows all of a combined signal to be observed on the CRT. The "AC" position removes all of the DC portion of the signal, allowing only the AC portion to be observed.

5/5

17 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 17-1 below.

TIME/DIV MAGNIFIER	100 μs/DIV x 1	20 ms/DIV x 10	500 μs/DIV x 1	0.1 s/DIV x 10
Period Measurement	310 μs	6.2 ms	1550 μs	0.0315 s
Frequency Measurement	3.23 KHz	0.161 KHz	0.645 KHz	0.032 KHz

2. Complete the data required for Table 17-2 below.

MODE TIME/DIV MAGNIFIER	CH 1 20 μs/DIV x 1	CH 2 1 ms/DIV x 10	CH 1 0.5 s/DIV x 10	CH 2 10 μs/DIV x 1
Period Measurement	76 μs	0.38 ms	0.19 s	38 μs
Frequency Measurement	13.16 KHz	2.63 KHz	0.00526 KHz	26.31 KHz

5/5

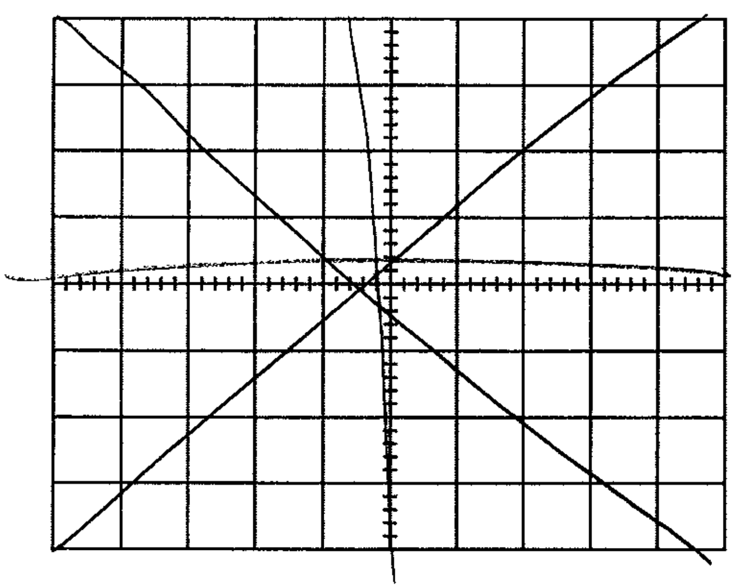
17 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 17-3 below.

	Randomly Selected Frequencies				
	100 Hz - 800 Hz	800 Hz - 6 kHz	6 kHz - 40 kHz	40 kHz - 200 kHz	200 kHz - 1 MHz
Measured Period	5 mS	200ms	47.5ms	24.5ms	1ms
Calculated Frequency	200Hz	5kHz	21.05 kHz	40.82 kHz	1 MHz

2. Draw the ripple waveform from procedure step 14 on the graticule provided below.



3. Record the minimum and maximum generator frequencies in Table 17-4 below.

~~Minimum Generator Frequency~~	
~~Maximum Generator Frequency~~	

Questions

1. Describe the effect of the horizontal magnifier control with respect to the sweep speed, sweep time, and on the number of cycles observed.

2. Describe a situation where the availability of the LINE position on the TRIGGER SOURCE switch could be useful.

3. Explain why period can be measured more accurately when the display shows 2 cycles over the length of the graticule, than when 20 cycles are displayed.

The period can be measured accuratly because the cycles are zoomed in where when 20 cycles are displayed it is zoomed out.

Experiment

17 Oscilloscope Time & Frequency Measurements

Objectives

1. To measure the period time of a repetitive waveform.
2. To determine frequency from period measurements.
3. To operate typical horizontally-related oscilloscope controls.

Equipment

Dual trace oscilloscope with x 1 and x 10 probes, dc power supply
Sinewave oscillator or waveform generator, ac voltmeter

Information

The previous experiment dealt with vertical measurements. This experiment will be concerned with horizontal measurements. The horizontal section of a scope is often called the "timebase," since the horizontal axis of a scope display is almost always a time display.

The sequence of events associated with time measurements are very similar to voltage measurements. The horizontal distance, in units of "divisions," is measured between two points of interest. That distance is then multiplied by the "sweep speed," in units of "seconds per division," resulting in a measurement in units of seconds. If the time measured was the time for one cycle of a waveform, the resulting measurement would be the number of "seconds per cycle," or the period of the waveform. The reciprocal of the period is the frequency, or the number of "cycles per second," which is expressed in units of "Hertz."

An example of the determination of frequency through the measurement of period is given below and illustrated in Figure 17-1.

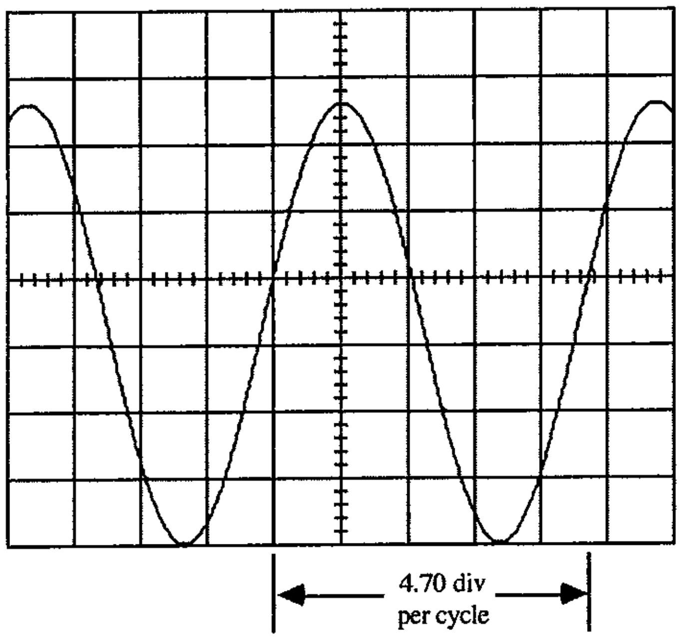


Figure 17-1. Determining Frequency

Assuming that the timebase, or TIME/DIV control, is set at 20 μs/DIV, the period would be calculated as 4.70 divisions per cycle times 20 μs per division, equaling 94.0 μs per cycle. This is the period of the waveform, but it is normally stated as 94.0 μs, rather than 94.0 μs per cycle. The frequency is the reciprocal of 94.0 μs per cycle, or 10.6 kHz.

The period of a waveform can be measured from any point of the waveform to the next identical point of the waveform, along any horizontal line. Care must be taken that the next identical point is at the same slope as well as at the same voltage. This can be confusing, particularly when measuring the period of a square wave.

Note that the use of a MAGNIFIER switch increases the horizontal sweep speed and will expand the horizontal display. As an example, a sweep speed of 200 μs/DIV combined with a x5 MAGNIFIER setting, results in a sweep speed of 40 μs/DIV.

Lab Prep

1. For the scope display shown in Figure 17-2, determine the periods and frequencies required in Table 17-1. Record your answers on the Prep Sheet as well.

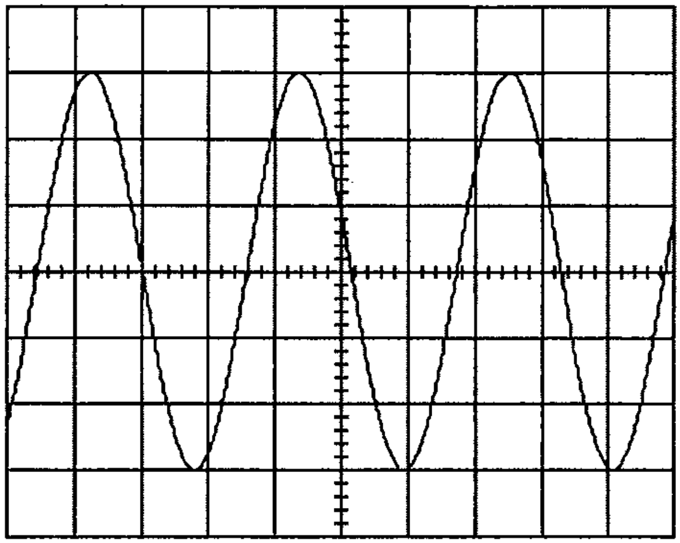


Figure 17-2. Oscilloscope Display

Table 17-1. Scope Readings

TIME/DIV MAGNIFIER	100 μs/DIV x 1	20 ms/DIV x 10	500 μs/DIV x 1	0.1 s/DIV x 10
Period Measurement				
Frequency Measurement				

2. For the scope display shown in Figure 17-3, determine the periods and frequencies required in Table 17-2. Record your answers on the Prep Sheet as well.

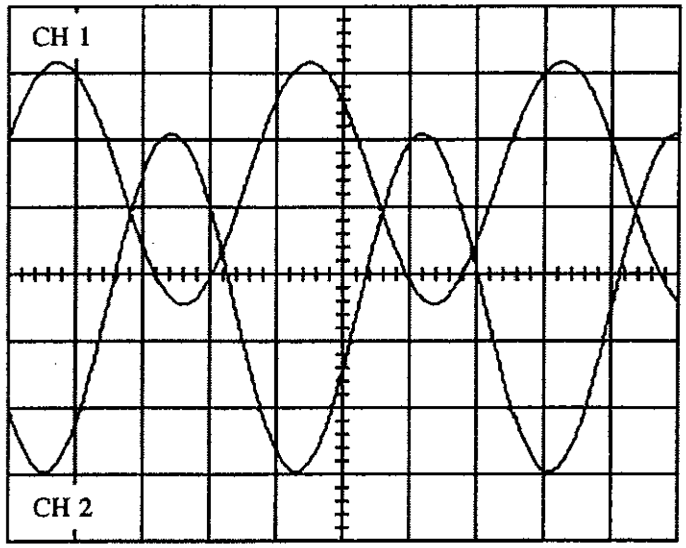


Figure 17-3. Oscilloscope Display

Table 17-2. Scope Readings

MODE TIME/DIV MAGNIFIER	CH 1 20 μs/DIV x 1	CH 2 1 ms/DIV x 10	CH 1 0.5 s/DIV x 10	CH 2 10 μs/DIV x 1
Period Measurement				
Frequency Measurement				

Procedure

Period and Frequency Measurement

1. Set your signal generator to a random frequency between 100 Hz and 800 Hz. Do not record the generator setting as it does not matter at this time.

2. Connect the scope to the generator and set the generator amplitude to any convenient voltage.

3. Measure the period time of the waveform, then calculate the frequency using the measured period. Record the period and frequency in Table 17-3.

4. Confirm that your measurements are correct by reading the actual generator frequency setting. If the measurement error is more than 10%, repeat the measurement, perhaps with your instructor's assistance.

5. Repeat the above procedure for random frequencies between 800 Hz and 6 kHz, 6 kHz and 40 kHz, 40 kHz and 200 kHz, 200 kHz and 1 MHz.

Table 17-3. Frequency Measurements

	Randomly Selected Frequencies				
	100 Hz - 800 Hz	800 Hz - 6 kHz	6 kHz - 40 kHz	40 kHz - 200 kHz	200 kHz - 1 MHz
Measured Period					
Calculated Frequency					

Observing Unrelated Frequencies

6. If you do not have a dual trace scope, you will be unable to complete this part of the procedure.

7. Connect a signal, set between 10 kHz and 50 kHz to the CH 1 scope input. The voltage level of the signal is not critical.

8. Connect the CH 2 scope input to a signal generator at an adjacent lab station, which will also be set to a frequency between 10 kHz and 50 kHz.

9. With the TRIGGER SOURCE set for CH 1, note that the channel 1 signal is synchronized, while the channel 2 signal is moving.

10. Switch the TRIGGER SOURCE to CH 2 and note how the signal synchronization is reversed.

Observing Power Supply Ripple

11. Connect a dc power supply, set to 10 V to the scope input. Set the COUPLING to the AC position.

12. Adjust the VOLTS/DIV control downwards towards a more sensitive selection until a sawtooth ripple voltage waveform is visible. You may have to use the magnifier as well.

> **The symbol shown to the left is an international symbol indicating a shock hazard.**

13. If the ripple waveform is still not visible, you may have to set the power supply to its maximum voltage. You may also require a load for your particular power supply. Check with your instructor before continuing.

14. Carefully sketch the ripple waveform on the graticule provided on the Data Sheet, and measure its voltage and frequency as well. Record these below.

Ripple Voltage = ______________

Ripple Frequency = ______________

15. Adjust the TRIGGER SOURCE switch to the LINE position and note that the ripple waveform stays in synchronization.

16. Remove the dc power supply and connect your signal generator, set to a frequency of 120 Hz, to the CH 1 scope input while the TRIGGER SOURCE is still on the LINE position and note that the generator waveform will not be in synchronization.

17. Adjust the TRIGGER SOURCE switch back to the CH 1 position and note that the waveform becomes synchronized.

Measuring Extreme Frequencies

18. Measure the minimum and maximum frequencies obtainable from your signal generator. Record these in Table 17-4, and also on the Data Sheet.

Table 17-4. Extreme Frequency Measurements

Minimum Generator Frequency	
Maximum Generator Frequency	

19. While measuring the maximum generator frequency, use the horizontal magnifier control, if available, and make notes of its effect on sweep speed, sweep time, and the number of cycles observed.

Experiment

18 Oscilloscope Phase Measurements

Objectives

1. To construct a phasor diagram directly from the scope display of two waveforms which are out of phase.
2. To measure the phase angle between two waveforms by measuring the time difference between the waveforms.
3. To determine phase angles from time differences.
4. To measure phase angle using Lissajous figures.

Equipment

Dual trace oscilloscope, with x 1 and x 10 probes
Sinewave oscillator or waveform generator, ac voltmeter

1/4 W Resistors:	220 Ω	330 Ω
Capacitor:	100 nF, any voltage rating	

Information

A phasor diagram is a representation of two or more waveforms of the same frequency, but of different phases. The diagram consists of lines, each starting from the same point, but drawn at an angle which represents the phase of each waveform. Each line, or phasor, has two characteristics. The first is the length of the line, which represents the magnitude or amplitude of the waveform, usually expressed in RMS units. The second is the angle at which the line is drawn, in degrees, representing the phase of that waveform relative to others. Phasors represent ac voltages and currents, which are constantly changing, consequently phasors are constantly rotating. We look at phasor diagrams at frozen moments of time, thus they represent conditions at some particular instant.

Figure 18-1 illustrates typical phasor diagrams, the left one showing two phasors, one having a magnitude of 15 V and a phase angle of 10°, the other being 30 V at an angle of 55°. It is important to realize that this diagram represents one moment of time; a few milliseconds later, both phasors will have rotated counterclockwise to a new position such as that shown at the right, where both have rotated by 20°.

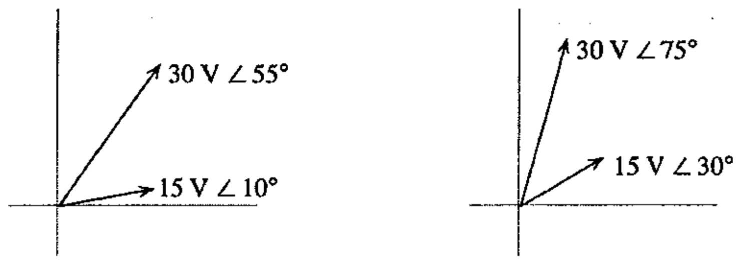


Figure 18-1. Phasor Diagrams

Since phasor rotation is counterclockwise, if an observer were stationed along the 90° reference line, that observer would see the approach of the 30 V phasor before the 15 V phasor, thus the 30 V phasor is "leading" the 15 V phasor by 45°, or the 15 V phasor is "lagging" the 30 V phasor by 45°. An oscilloscope display would represent both waveforms for all moments of time. It is therefore useful to be able to draw a phasor diagram by looking at an oscilloscope display. As an example of this, consider the waveforms shown in Figure 18-2.

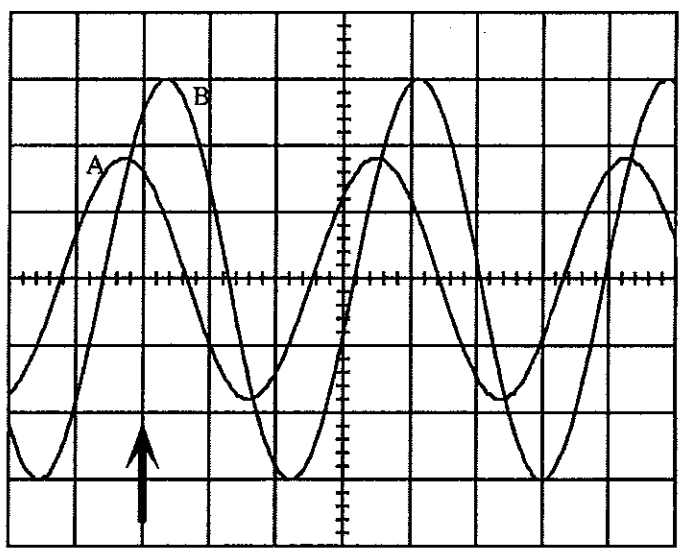


Figure 18-2. An Oscilloscope Phase Display

On the scope display, each vertical line represents one instant of time. Consider the instant of time marked by the arrow in Figure 18-2. At this instant of time, waveform A is somewhere between 90° and 180°, but closer to 90°, while waveform B is between 0° and 90°, but closer to 90°. This is sufficient information to sketch a rough phasor diagram of the phasors A and B. This is shown in Figure 18-3. The phasor diagram clearly shows that waveform A is leading waveform B. The next step is to measure the actual phase difference between the two waveforms.

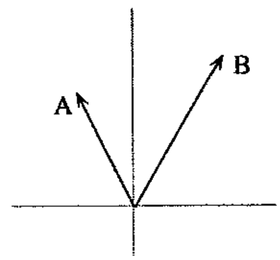


Figure 18-3. A Phasor Sketch

We will assume that for the display shown in Figure 18-2, that the timebase is set for 20 μs/DIV. Notice that both waveforms are exactly centered vertically on the centre horizontal graticule line. Unless two waveforms are exactly the same amplitude, phase can only be measured along the zero volt levels of the two waveforms.

Two measurements are required to determine the phase difference between the two waveforms. The first is the time difference horizontally between the two waveforms. The second is the period time for either one of the waveforms. The time difference between the waveforms is 0.63 divisions times 20 μs per division, which is a time of 12.6 μs. The period of the waveform is 3.78 divisions times 20 μs per division, which is a time of 75.6 μs. The frequency of the waveforms is the reciprocal of 75.6 μs, which is 13.2 kHz.

Since the period of 75.6 μs represents one complete cycle or 360°, the question is to find out how much phase shift in degrees is represented by the 12.6 μs interval. This is easily solved by forming a ratio as follows:

$$\frac{12.6\ \mu s}{75.6\ \mu s} = \frac{\text{Phase Shift}}{360^\circ}$$

$$\text{Phase Shift} = \frac{12.6\ \mu s \times 360^\circ}{75.6\ \mu s} = 60.0^\circ$$

Another method of measuring phase angle is with the use of a Lissajous figure, which is an X-Y scope display. One waveform is connected as a vertical input, the other as a horizontal input, with the timebase disabled. The resulting display is illustrated in Figure 18-4. The vertical and horizontal sensitivities are of no consequence to this measurement, but the zero centre position of the waveform must be known.

Two measurements are required. The first is the vertical distance, in divisions, from the centre of the waveform to the point at which the waveform crosses the vertical axis. The second is the vertical distance, in divisions, from the centre of the waveform to the highest point of the waveform. When these two distances are known, the solution is as follows:

$$\text{Phase Shift} = \sin^{-1}\left(\frac{\text{crossing distance}}{\text{highest distance}}\right)$$

For the waveform of Figure 18-4, the numerical solution is as follows:

$$\text{Phase Shift} = \sin^{-1}\left(\frac{2.25\ \text{div}}{3.70\ \text{div}}\right) = \sin^{-1}(0.608) = 37.5^\circ$$

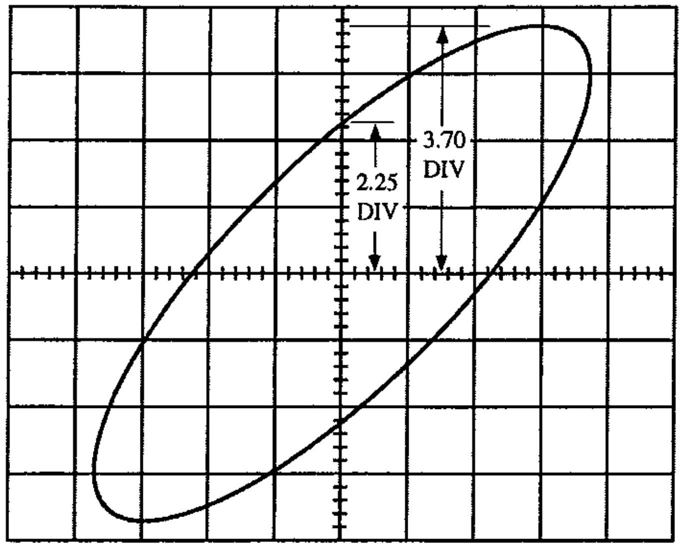


Figure 18-4. A Lissajous Figure

More accuracy can be obtained when using Lissajous figures by moving the zero centre of the waveform to the bottom of the graticule, then increasing the vertical sensitivity such that the maximum height of the waveform is again near the top of the graticule. With care, the centre can often be moved below the graticule, yet with its position still known. Lissajous figures can often provide phase measurement accuracy of ± 2° or better.

Lab Prep

1. Use the waveforms of Figure 18-5 to determine the phase shift in time, the period of the waveform, the frequency of the waveform, and the phase shift in degrees. Assume the sweep speed is 10 μs/DIV. Record your data in Table 18-1 and on the Prep Sheet.

2. Use the Lissajous figure of Figure 18-6 to determine the two measurement distances and the phase shift in degrees. Record your data in Table 18-1 and on the Prep Sheet.

Table 18-1. Phase Shift Determinations

Prep Step 1	Phase shift in time	
	Period of the waveform	
	Frequency of the waveform	
	Phase shift in degrees	

Prep Step 2	Crossing distance	
	Highest distance	
	Phase shift in degrees	

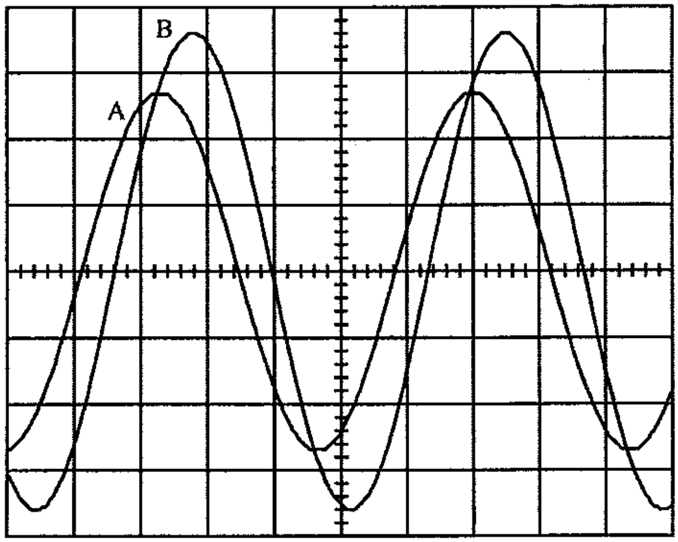


Figure 18-5. Phase Measurement Waveform

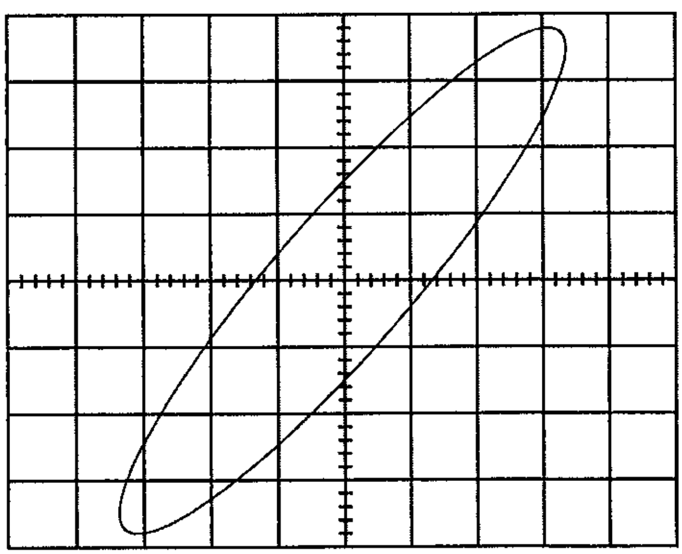


Figure 18-6. Lissajous Measurement Waveform

Procedure

Time and Phase Measurement

1. Connect the circuit of Figure 18-7. Note that no knowledge of capacitors, other than using their color codes, is presumed at this time. The capacitor is used to produce phase shifts which can be measured in this experiment.

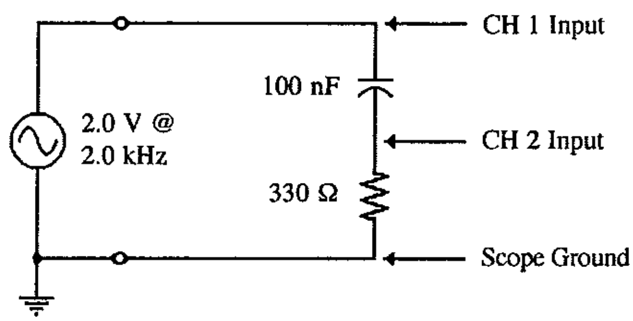
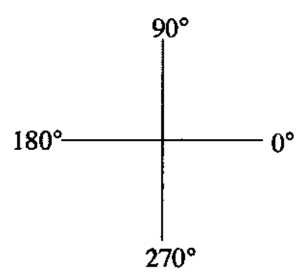


Figure 18-7. Phase Shift Circuit

2. Connect the scope leads as indicated in Figure 18-7. Set the scope so that it is triggering on either CH 1 or CH 2; it does not matter which for this experiment.

3. Use the reference lines below to sketch a phasor diagram based on the scope display now being observed. Determine if CH 1 leads or lags CH 2. (The correct answer is "lags." If you cannot determine this, read the first half of the Information section again, or ask your instructor for assistance.)



4. Measure the phase shift in time between the channel 1 and channel 2 signals, and the period time of either of the waveforms. Record in Table 18-2.

5. Calculate the frequency and the phase shift using your measured data and record in Table 18-2.

6. Repeat the procedures of steps 4 and 5 for the other frequencies listed in Table 18-2.

Table 18-2. Time and Phase Determinations

Frequency	Measured Phase Shift in Time	Measured Period of the Waveform	Calculated Frequency of the Waveform	Calculated Phase Shift in Degrees
2.0 kHz				
4.0 kHz				
6.0 kHz				
8.0 kHz				
10 kHz				

7. With the frequency still set to 10 kHz, adjust the generator to 1.0 V, and repeat the last measurement of phase shift to assure yourself that the phase shift is independent of the voltage level. You should obtain the same answer as the last measurement in Table 18-2.

Lissajous Phase Measurement

8. If your scope does not have X-Y display capability, you will have to omit the remaining steps of this procedure.

9. Replace the 330 Ω resistor with a 220 Ω resistor, and reset the frequency to 2.0 kHz.

10. Connect the X input of the scope to the point on Figure 18-7 designated as CH 1, and the Y input to the point designated as CH 2.

11. Adjust the scope for a Lissajous display and carefully centre the waveform vertically and horizontally.

12. For each frequency listed in Table 18-3, measure the crossing distance and the highest distance, then calculate the phase shift between the waveforms.

Table 18-3. Lissajous Measurements

Frequency	Crossing Distance	Highest Distance	Phase Shift
2.0 kHz			
4.0 kHz			
6.0 kHz			
8.0 kHz			
10 kHz			

18 Prep Sheet

Name Oleksandr Vladyka

move 5.8μs

1. Complete the data required for Table 18-1 below.

10/12

Prep Step 1		
	Phase shift in time	10μs
	Period of the waveform	47μs
	Frequency of the waveform	21.28KHz
	Phase shift in degrees	34.47°

Prep Step 2		
	Crossing distance	1.5
	Highest distance	3.8
	Phase shift in degrees	23.25°

18 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 18-2 below.

Frequency	Measured Phase Shift in Time	Measured Period of the Waveform	Calculated Frequency of the Waveform	Calculated Phase Shift in Degrees
2.0 kHz	−94 μs	500 μs	2 kHz	67.68°
4.0 kHz	−35 μs	250 μs	4 kHz	50.4°
6.0 kHz	−18.1 μs	167 μs	6 kHz	39.01°
8.0 kHz	−11 μs	125 μs	8 kHz	31.68°
10 kHz	−7.2 μs	100 μs	10 kHz	25.92°

2. Complete the data required for Table 18-3 below.

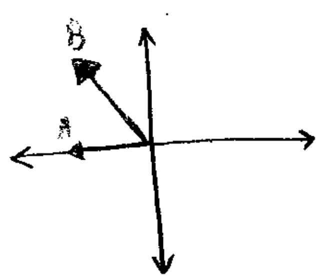
Frequency	Crossing Distance	Highest Distance	Phase Shift
2.0 kHz			
4.0 kHz			
6.0 kHz			
8.0 kHz			
10 kHz			

Questions

1. Refer to Figure 18-2. Explain why phase difference must be measured along the 0 V axis of the waveforms.

The phase difference must be measured along the 0V because if you measured it anywhere else, the measurements would be inconsistent.

2. Refer to Figure 18-2. Sketch a phasor diagram representing the waveforms at an instant of time exactly 7 divisions from the left edge of the graticule.



3. Did your results of step 7 of the procedure verify that phase shift is independent of voltage?

19 RC Transient Circuits

Objectives

1. To illustrate the existence of a series RC time constant.
2. To observe and measure the exponential charge and discharge of capacitor voltage in a series RC circuit.
3. To observe and measure the exponential decay of resistor voltage in a series RC circuit.

Equipment

Variable dc voltage supply
Impedance bridge or capacitance checker
Voltmeter, with 10 MΩ input resistance
Oscilloscope, with 1 MΩ input resistance

1/4 W Resistors:	10 MΩ	82 kΩ
Capacitors:	4.7 μF, 20 V	1.2 nF

Square wave generator, to complete optional procedures.

Information

When a capacitor is placed across a dc voltage source, the voltage across the capacitor charges up to the power supply voltage almost instantaneously, since there is little resistance present to limit the current flow. This allows charge to transfer rapidly into the capacitor. An uncharged capacitor acts as a short circuit, but when fully charged, acts as an open circuit. The charging resistance of the capacitor, then, changes from 0 Ω to ∞ Ω during the charging process.

When, as in Figure 19-1, a resistor is added in series with the capacitor, the charging current is limited to some maximum value. The charging process must now be nonlinear, because of a fixed resistance being in series with a resistance which is changing from 0 Ω to ∞ Ω. The resulting charging process is exponential, and depends upon the values of R and C in the circuit.

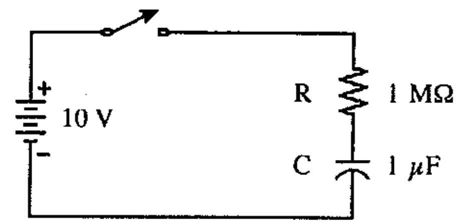


Figure 19-1. RC Charging Circuit

The product of the resistance times the capacitance is called the circuit time constant, and is represented by the Greek letter τ (tau), and is measured in units of seconds. This relationship is shown in Equation 19-1.

$$\tau = R \times C \qquad \text{Equation 19-1}$$

It seems odd to multiply units of ohms and farads and result in seconds. The fact that the units are correct can be shown using the relationships $V = IR$, $Q = CV$, and $Q = It$, as illustrated below.

$$\tau = R \times C = \frac{V}{I} \times \frac{Q}{V} = \frac{V}{I} \times \frac{I \times t}{V} = t \text{, in seconds}$$

An equation by which exponentially increasing or decreasing voltages can be calculated is given in Equation 19-2 as follows.

$$v(t) = V_f - (V_f - V_i)\, e^{-\left(\frac{t}{\tau}\right)} \qquad \text{Equation 19-2}$$

where: $v(t)$ is the instantaneous voltage at time, t,
V_f is the final voltage,
V_i is the initial voltage,
e is the mathematical exponentiation function,
t is the instantaneous time, and
τ is the time constant of the circuit.

The use of Equations 19-1 and 19-2 will verify the graphs of capacitor and resistor voltage presented in Figure 19-2 for the circuit of Figure 19-1.

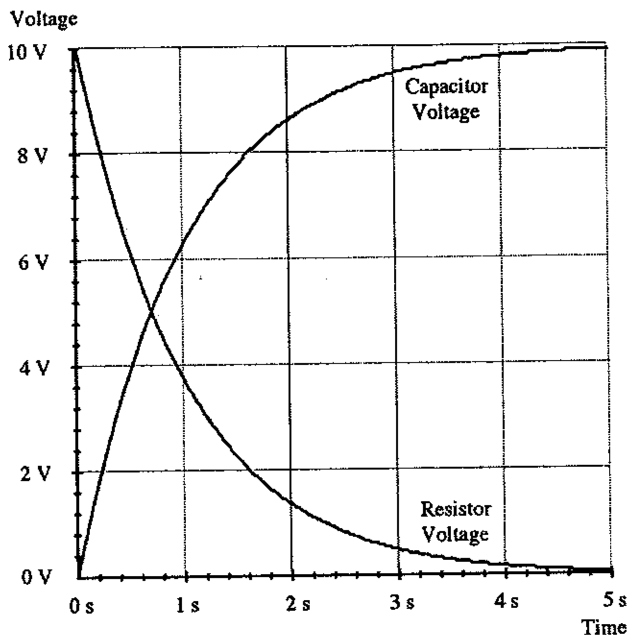


Figure 19-2. RC Circuit Waveforms

During the interval of one time constant, the voltage across the capacitor will increase by about 63% of the difference between the initial voltage and the final voltage. During the second time constant, the voltage will increase by about 63% of the difference between the voltage at the end of the first time constant and the final voltage. After five time constants, it is considered that the capacitor will have essentially reached full charge. Since the sum of the voltages across the resistor and across the capacitor must, at all times, equal the power supply voltage, it is apparent that as the voltage across the capacitor increases exponentially, the voltage across the resistor must decrease exponentially.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Using the circuit of Figure 19-3, and assuming the 4.7 μF capacitor will charge up to 5.00 V through a resistance of 5.00 MΩ, calculate the time at the end of each of the time constants in Table 19-1, and calculate the capacitor voltage at the end of each of the time constants as well. Record your calculations in Table 19-1 and on the Prep Sheet.

Table 19-1. Capacitor Charging Voltages

Capacitance	4.7 μF	1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds						
Calculated voltages						

2. Using the circuit of Figure 19-3, and assuming the 4.7 μF capacitor will discharge from 5.00 V to 0 V through a resistance of 10.0 MΩ, calculate the time at the end of each of the time constants in Table 19-2, and calculate the capacitor voltage at the end of each of the time constants as well. Record your calculations in Table 19-2 and on the Prep Sheet.

Table 19-2. Capacitor Discharging Voltages

Capacitance	4.7 μF	1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds						
Calculated voltages						

3. Using the circuit of Figure 19-5, and assuming the resistor voltage will decay from 5.00 V to 0 V, and that the circuit resistance is 5.00 MΩ, and the capacitance is 4.7 μF, calculate the time at the end of each of the time constants in Table 19-3, and calculate the resistor voltage at the end of each of the time constants as well. Record your calculations in Table 19-3 and on the Prep Sheet.

Table 19-3. Resistor Decaying Voltages

Capacitance	4.7 μF	1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds						
Calculated voltages						

Procedure

Observing Capacitor and Resistor Charging and Discharging

1. Connect the circuit of Figure 19-3, leaving the switch open at this time. Note that the capacitor in this circuit is an electrolytic and must be connected with the polarity as shown.

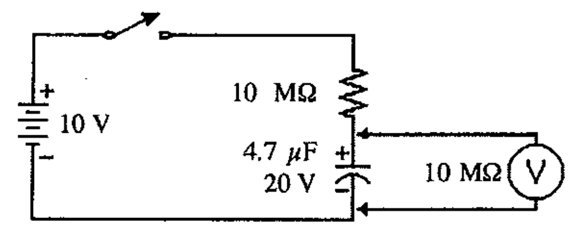


Figure 19-3. RC Circuit

2. Short the leads of the 4.7 μF capacitor together to be sure that there is no initial charge on the device.

3. Note that the Thévenin equivalent for this circuit will show that the capacitor will charge up to 5 V at the maximum, and that the time constant for the circuit is 23.5 seconds.

4. Close the switch and observe the voltage charge of the capacitor. Allow the capacitor to charge up close to 5 V.

5. When the switch is opened, the capacitor will discharge through the 10 MΩ meter resistance. The time constant now changes to 47 seconds, so it will take twice as long to discharge as it took to charge.

6. Open the switch at this time and observe the discharge of the capacitor voltage. When this is done, short the capacitor leads again to be sure that the device is completely discharged.

7. Reposition the voltmeter across the resistor as shown in Figure 19-4.

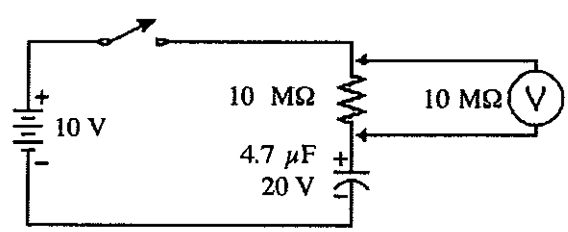


Figure 19-4. RC Circuit

8. The circuit time constant is again 23.5 seconds, however in this circuit, the capacitor will charge up to 10 V, and the resistor voltage will decrease from 10 V down to 0 V.

9. Close the switch and observe the exponential decrease in resistor voltage. If you wish to repeat this part, you will have to manually discharge the capacitor first.

Measuring Capacitor Charging and Discharging Voltages

10. Reposition the voltmeter as in Figure 19-3, and be sure the capacitor is fully discharged.

11. Use an impedance bridge or capacitance checker to measure the value of the capacitor, and record in Tables 19-4, 19-5, and 19-6.

12. Assuming the charging resistance in the circuit is 5 MΩ, use the measured capacitance to calculate the time to the end of each of the time constants shown in Table 19-4. Round to the nearest second.

13. Close the switch at time $t = 0$ s, and read the voltage on the meter at the end of each time interval, and record in Table 19-4.

Table 19-4. Measuring Capacitor Charging Voltage

Capacitance		1τ	2τ	3τ	4τ	5τ
Time intervals in seconds						
Measured voltages						

14. When the switch is opened, the capacitor will discharge through to 10 MΩ meter resistance. Use the measured capacitance to calculate the time to the end of each of the time constants shown in Table 19-5. Round to the nearest second.

15. Open the switch at time $t = 0$ s, and read the voltage on the meter at the end of each time interval, and record in Table 19-5.

Table 19-5. Measuring Capacitor Discharging Voltage

Capacitance		1τ	2τ	3τ	4τ	5τ
Time intervals in seconds						
Measured voltages						

Measuring Resistor Voltages

16. Connect the circuit of Figure 19-5, after making sure that the capacitor is fully discharged. Note that this circuit is the same as Figure 19-4, except that the power supply has been changed to 5 V.

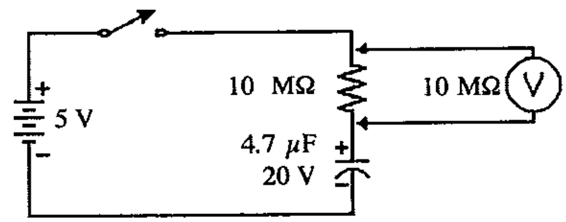


Figure 19-5. RC Circuit

17. Assuming the charging resistance in the circuit is 5 MΩ, use the measured capacitance to calculate the time to the end of each of the time constants shown in Table 19-6. Round to the nearest second.

18. Close the switch at time t = 0 s, and read the voltage on the meter at the end of each time interval, and record in Table 19-6.

Table 19-6. Measuring Resistor Decaying Voltage

Capacitance		1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds						
Measured voltages						

19. Copy the data from Tables 19-4, 19-5, and 19-6 into the duplicate tables on the Data Sheet.

Observing Exponential Voltages With The Oscilloscope

20. Connect the circuit of Figure 19-6, and set the scope for a sweep speed of 0.5 SEC/DIV.

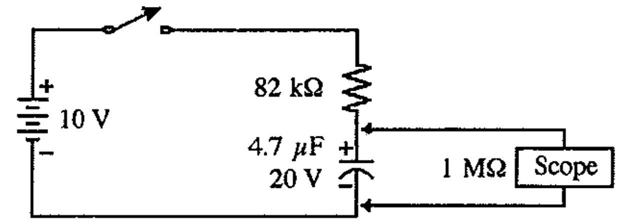


Figure 19-6. RC Charging Circuit

21. As the scope trace begins at the left of the graticule, close the switch and observe the exponentially rising capacitor voltage. Although you will be observing a moving dot of light on the CRT, the display will usually remain visible long enough to observe the shape of the charging voltage.

22. Open the switch and allow the capacitor voltage to decay to 0 V, or short the capacitor leads together.

23. Repeat steps 21 and 22 until you are satisfied that the waveform is an exponential rise in voltage.

24. You may wish to experiment with different sweep speeds and component values. If you have a storage scope, you will be able to obtain a stable display of the exponential voltage rise.

Optional

25. If you have a square wave generator available, set the voltage to 10 Vpp and the frequency to 1 kHz, and connect the circuit of Figure 19-7. Note that the capacitor value has been changed.

26. This circuit will display a charge and discharge of the capacitor once every period of the square wave.

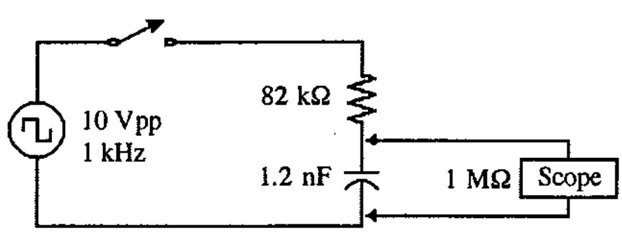


Figure 19-7. RC Charging Circuit

27. You may wish to experiment with different frequencies and different component values.

28. If you wish to observe the resistor voltage, and the generator has one side connected to ground, interchange the positions of the resistor and the capacitor.

5/5

19 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 19-1 below.

$\tau = 23.5$

Capacitance	4.7 μF	1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds		23.5	47	70.5	94	117.5
Calculated voltages		3.16	4.32	4.75	4.90	4.96

2. Complete the data required for Table 19-2 below.

Capacitance	4.7 μF	1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds		47	94	141	188	235
Calculated voltages		+1.83	+0.67	+0.24	+0.091	-0.033

3. Complete the data required for Table 19-3 below.

Capacitance	4.7 μF	1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds		23.5	47	70.5	94	117.5
Calculated voltages		-1.83	-0.67	-0.24	-0.091	-0.033

5/5

19 Data Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 19-4 below.

Capacitance		1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds		23.5	47	70.5	94	117.5
Measured voltages		3.16	4.32	4.75	4.90	4.16

2. Complete the data required for Table 19-5 below.

Capacitance		1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds		47	94	141	188	235
Measured voltages		-1.83	-0.67	-0.24	-0.091	-0.033

3. Complete the data required for Table 19-6 below.

Capacitance		1 τ	2 τ	3 τ	4 τ	5 τ
Time intervals in seconds		23.5	47	70.5	94	117.5
Measured voltages		+1.83	+0.67	+0.24	+0.091	+0.033

X This is a supposed to use charging circuit. ~~...~~

(I interpreted the PRELAB ~~...~~ differently.)

Questions

1. Thévenize the circuit of Figure 19-3, assuming the switch is closed and the capacitor is the load. Use the Thévenin equivalent circuit to calculate the circuit time constant.

$\tau = 23.15\ s$

2. Compare your measured data from Table 19-4 with the calculations in Table 19-1 and explain any significant differences.

19-1	2.95	4.11	4.60	4.81	4.90
19-4	3.16	4.323	4.751	4.908	4.966

They are close, the difference is due to human error in timing

3. Table 19-6 contains data showing a decay of voltage from 5 V to 0 V across a resistance. Table 19-4 contains data showing a voltage charging from 0 V to 5 V across a capacitor. Add the voltages from each table, for each time constant interval. They should add up to 5 V in each case. Explain any differences.

They all add to barely over 5 V (max .36 V over this is due to human error in timing.

4. Describe any significant observations which you made using the oscilloscope.

20 AC Series RC Circuits

> **NOTE:** With the exception of tables and some diagrams, the text of this and subsequent experiments will use bold face characters, such as $\mathbf{X}_C$ to denote phasor quantities which have associated phase angles. Thus, for example, $\mathbf{X}_C = X_C \angle -90° = -jX_C$, or $\mathbf{R} = R \angle 0° = R$. A value for impedance might be expressed as $\mathbf{Z}$ = 2.24 kΩ ∠–26.6°, or it might be expressed as $Z = 2.24$ kΩ.

Objectives

1. To compare current and voltage relationships in a series RC circuit.
2. To determine the capacitance of an unknown component through measurement techniques.
3. To measure phase angles in a series RC circuit.

Equipment

Oscilloscope, ac ammeter, sinusoidal waveform generator

1/4 W Resistors:	1 kΩ	1.8 kΩ	5.6 kΩ	12 kΩ	27 kΩ
Capacitors:	10 nF	(any voltage rating)			
	several unmarked capacitors				

Information

An earlier experiment demonstrated that the current through a capacitor always leads the voltage across a capacitor by 90°. For example, if the voltage across a capacitor was 3.0 V ∠ 50°, the current through that capacitor might be 3.0 mA ∠ 140°. The voltage and current amplitudes might be any value, but the angles will always be 90° apart. Using Ohm's Law for the above, the reactance of the capacitor is as shown in Solution 20-1.

Solution 20-1 . . . .

$$\mathbf{X}_C = \frac{\mathbf{V}_C}{\mathbf{I}_C} = \frac{3.0\text{ V} \angle 50°}{3.0\text{ mA} \angle 140°} = 1.0\text{ k}\Omega \angle -90°$$

Any other examples will always yield a capacitive reactance value at an angle of -90°. Since there is no difference between the phase angles of the voltage across and the current through a resistor, a similar calculation to that in Solution 20-1 might be as shown in Solution 20-2.

Solution 20-2 . . . .

$$\mathbf{R} = \frac{\mathbf{V}_R}{\mathbf{I}_R} = \frac{2.0\ \text{V} \angle 120°}{1.0\ \text{mA} \angle 120°} = 2.0\ \text{k}\Omega \angle 0°$$

If the resistor is placed in series with the capacitor, the result would be some total amount of ac resistance, which is called impedance, Z. Since $\mathbf{R}$ is always at 0°, and $\mathbf{X}_C$ is always at -90°, they must be added vectorially, as is shown in Figure 20-1. This diagram is called an impedance diagram. The elements on the diagram, since they are not time-dependent, are called vectors, rather than phasors.

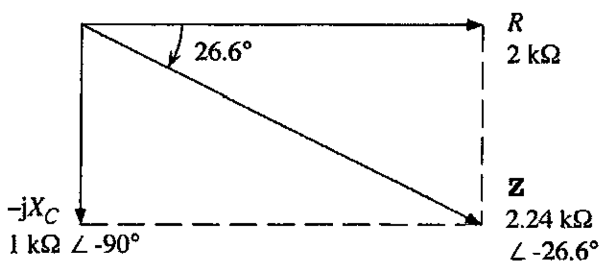


Figure 20-1. An Impedance Diagram

The representation of Figure 20-1 can also be shown mathematically in Solution 20-3, where rectangular to polar conversion yields the same answer as the graphical example of Figure 20-1.

Solution 20-3 . . . .

$$\mathbf{Z} = (R \angle 0°) + (X_C \angle -90°)$$

$$\mathbf{Z} = R - \mathrm{j}\, X_C$$

$$\mathbf{Z} = 2.0\ \text{k}\Omega - \mathrm{j}\ 1.0\ \text{k}\Omega$$

$$\mathbf{Z} = 2.24\ \text{k}\Omega \angle -26.6°$$

The circuit phase angle is sometimes calculated, although its definition is somewhat arbitrary. One definition often used is that the magnitude of the circuit phase angle, Ø, is equal to the angle between generator voltage and generator current. Generator current is considered as the reference phasor, so Ø is positive if the generator voltage leads the generator current, and Ø is negative if the generator voltage lags the generator current. Thus, in either series or parallel circuits, Ø will always be the same magnitude and sign as the circuit impedance. Circuit phase angles are really more useful in later courses when Bode plots are studied.

Basically, all laws of circuits are valid in ac as well as dc. The only complication is the addition of angles to the calculations. Consider Solution 20-4, which illustrates the calculations of the typical series RC circuit of Figure 20-2 from start to finish. By convention, all voltages and currents are calculated and expressed in RMS units. Figure 20-3 illustrates the resulting impedance and phasor diagrams for the circuit of Figure 20-2.

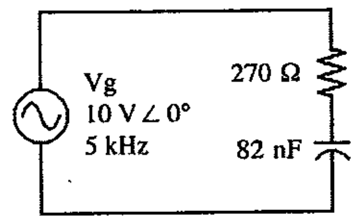


Figure 20-2. A Typical Series RC Circuit

Solution 20-4 . . . .

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2 \times \pi \times 5000 \times 82 \times 10^{-9}} = 388\ \Omega$$

$$\mathbf{Z} = R - \mathrm{j}\,X_C = 270\ \Omega - \mathrm{j}\ 388\ \Omega = 473\ \Omega \angle -55.2^\circ$$

$$\mathbf{I} = \frac{\mathbf{V}_g}{\mathbf{Z}} = \frac{10\ \mathrm{V} \angle 0^\circ}{473\ \Omega \angle -55.2^\circ} = 21.1\ \mathrm{mA} \angle 55.2^\circ$$

$$\mathbf{V}_R = \mathbf{I} \times R = (21.1\ \mathrm{mA} \angle 55.2^\circ) \times 270\ \Omega = 5.71\ \mathrm{V} \angle 55.2^\circ$$

$$\mathbf{V}_C = \mathbf{I} \times \mathbf{X}_C = (21.1\ \mathrm{mA} \angle 55.2^\circ) \times (388\ \Omega \angle -90^\circ) = 8.21\ \mathrm{V} \angle -34.8^\circ$$

$$\begin{aligned}\text{Check: } \mathbf{V}_g = \mathbf{V}_R + \mathbf{V}_C &= (5.71\ \mathrm{V} \angle 55.2^\circ) + (8.21\ \mathrm{V} \angle -34.8^\circ) \\ &= (3.26\ \mathrm{V} + \mathrm{j}\ 4.69\ \mathrm{V}) + (6.74\ \mathrm{V} - \mathrm{j}\ 4.69\ \mathrm{V}) \\ &= 10.0\ \mathrm{V} + \mathrm{j}\ 0\ \mathrm{V} \\ &= 10.0\ \mathrm{V} \angle 0^\circ\end{aligned}$$

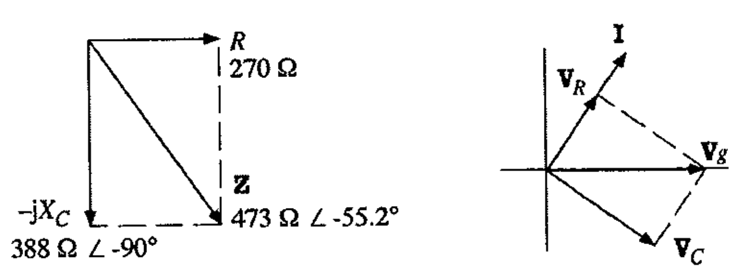


Figure 20-3. Impedance Diagram & Phasor Diagram

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Refer to the circuit of Figure 20-4. For each value of *R*, calculate the theoretical values for the quantities listed in Table 20-1, assuming the following:

    (a) If you wish to include angles for all quantities, assume that Vg is at 0°.

    (b) For the quantity listed as "Phase," calculate the phase angle between generator current and generator voltage. If the current leads the voltage, the angle is negative, indicating the circuit is capacitive. This angle will be the same as the angle of impedance.

Table 20-1. Series RC Circuit Calculations

R	1.8 kΩ	5.6 kΩ	12 kΩ	27 kΩ
Z				
Ig				
V_R				
V_C				
Phase				

2. Show your calculations for the case where R = 12 kΩ in detail on the Prep Sheet.

3. For the case where R = 12 kΩ, draw an impedance diagram on the Prep Sheet, labelling all vectors.

4. For the case where R = 12 kΩ, draw a phasor diagram on the Prep Sheet, labelling all phasors.

Procedure

1. Connect the circuit of Figure 20-4, using a 1.8 kΩ resistor as *R*. After the circuit is connected, set the generator voltage to 3.0 V, at a frequency of 2.0 kHz.

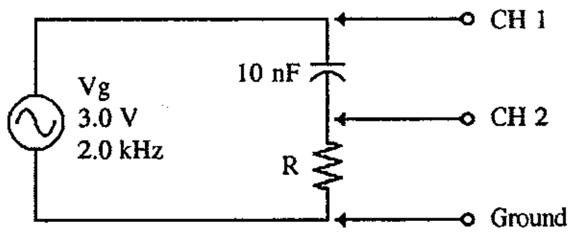


Figure 20-4. Series RC Measurement Circuit

2. Measure V_R with an ac voltmeter or with a scope. If using a scope, convert the measurement to RMS units before recording in Table 20-2.

3. Measure V_C with an ac voltmeter or with a scope. If your generator has one side grounded, you can interchange the positions of the resistor and capacitor. Another method of obtaining V_C is to use the CH 1 - CH 2 function of your scope, if so equipped. Convert the measurement to RMS units before recording in Table 20-2.

4. Measure the phase angle between generator voltage (CH 1) and generator current (CH 2). Check to make sure that the current leads the voltage and record the angle as negative, indicating the circuit is capacitive.

5. Use your measured resistor voltage to calculate the generator current and record in Table 20-2.

6. Calculate the circuit impedance using the generator voltage and your calculated current.

Table 20-2. Series RC Circuit Measurements & Calculations

R	1.8 kΩ	5.6 kΩ	12 kΩ	27 kΩ
Measured V_R				
Measured V_C				
Measured Phase				
Calculated Ig				
Calculated Z				

7. Repeat steps 1 through 6 for the remaining values of *R* listed in Table 20-2.

Determining An Unknown Capacitance

8. Your instructor may provide you with one or more unmarked capacitors in order to have you determine their capacitances. There are several methods of doing this, which are outlined below. Your instructor will indicate which methods you are to use.

Method One

9. Use the circuit of Figure 20-4 with a 1 kΩ resistor as *R*. Set your scope to trigger on channel 2, exactly at 0 V. Start with a frequency of 5 kHz.

10. Adjust the TIME/DIV Variable control until one half cycle requires exactly 8 divisions, as shown in Figure 20-5. At this point, you have calibrated the timebase to 22.5°/DIV, therefore 2 horizontal divisions equals 45°.

11. Now, vary the frequency of the generator until the observed phase shift is exactly 45°, or 2 divisions. As you adjust the frequency, you will also have to continuously readjust the TIME/DIV Variable control to maintain one half cycle at 8 divisions.

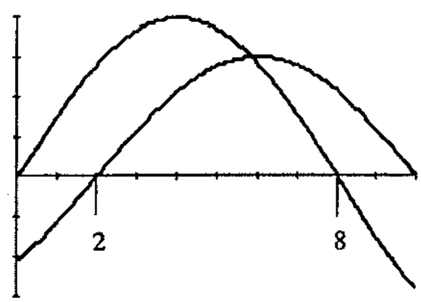


Figure 20-5. Adjusting For 45° Phase Shift

12. When the phase shift is exactly 45°, the capacitive reactance is equal to the resistance. Measure and record the frequency and the resistance which you used (you may have to try other resistance values).

13. Solve as indicated below.

Since $X_C = R$

and $X_C = \dfrac{1}{2\pi f C}$, or $C = \dfrac{1}{2\pi f X_C}$

then $C = \dfrac{1}{2\pi f R}$

Method Two

14. If you have a floating generator (one that has neither output terminal connected to ground), place a resistor in series with the unknown reactance, and connect the scope as shown in Figure 20-6.

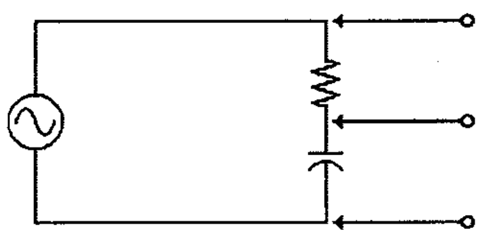


Figure 20-6. Floating Generator Circuit

15. Vary the frequency of the generator until the two waveforms are at exactly the same amplitude. Be sure that both scope inputs are set at the same sensitivity, and that both waveforms are zero-centered.

16. When both waveforms are the same amplitude, $V_C = V_R$, and $X_C = R$.

17. Measure and record the frequency and the resistance which you used, and solve as indicated below.

Since $X_C = R$

and $X_C = \dfrac{1}{2\pi f C}$, or $C = \dfrac{1}{2\pi f X_C}$

then $C = \dfrac{1}{2\pi f R}$

Method Three

18. Connect the unknown capacitance as in Figure 20-4, using a resistance such as 1 kΩ.

19. Measure V_R and the frequency.

20. Calculate the current flowing through the resistor, then measure the capacitor voltage and divide it by the current to yield a value for X_C.

21. Use X_C and the frequency to determine the value of capacitance as shown below.

$$C = \frac{1}{2\pi f X_C}$$

Method Four

22. Connect the unknown capacitance into the circuit of Figure 20-7 and measure the voltage across the capacitor and the current through the capacitor.

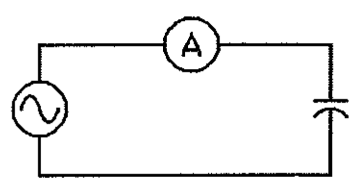


Figure 20-7. Measuring Current & Voltage

23. The measured voltage divided by the measured current yields a value for X_C. Use X_C and the frequency to determine the value of capacitance as shown below.

$$C = \frac{1}{2\pi f X_C}$$

415

20 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 20-1 below.

R	1.8 kΩ	5.6 kΩ	12 kΩ	27 kΩ
Z	$8.2\angle -77.31^\circ$	$9.7\angle -55.008^\circ$	$14.42\angle -33.69^\circ$	$28.16\angle -16.5$
Ig	$0.365\angle 77.31^\circ$	$0.307\angle 55.008^\circ$	$0.208\angle 33.68^\circ$	$0.106\angle 16.5^\circ$
V_R	$2.99\angle -3.82^\circ$	$2.97\angle 0^\circ$	$2.99\angle 1.9\times10^{-13}$	$2.98\angle -1.9\times10^{-13}$
V_C	$2.92\angle -12.69^\circ$	$2.45\angle -34.99$	$1.66\angle -56.31$	$0.848\angle -73.5$
Phase	$\cancel{8.2}\angle -77.31^\circ$	$\cancel{9.7}\angle -55.008^\circ$	$\cancel{14.42}\angle -33.69$	$\cancel{28.16}\angle -16.5^\circ$

2. Show your calculations for the case where $R = 12\ k\Omega$ as described in the Lab Prep section of this experiment.

3. For the case where $R = 12\ \text{k}\Omega$, draw an impedance diagram, labelling all vectors as described in the Lab Prep section of this experiment.

4. For the case where $R = 12\ \text{k}\Omega$, draw a phasor diagram, labelling all phasors as described in the Lab Prep section of this experiment.

20 Data Sheet 516 Name Oleksandr Vladyka

1. Complete the data required for Table 20-2 below.

R	1.8 kΩ	5.6 kΩ	12 kΩ	27 kΩ
Measured V_R	1.36V	3.44V	4.83 V	5.48V
Measured V_C	5.51V	5.53 V	5.53V	5.53 V
Measured Phase	-75°	-52°	-31°	-15°
Calculated Ig	0.755A	0.614	0.402	0.202
Calculated Z	7.29	9.00	13.75	27.37

Need angles too WLO

2. Record below any data which pertains to determining an unknown capacitance using procedure steps 8 through 23.

Questions

1. If capacitance were increased in a series RC circuit, would impedance increase or decrease? Explain your answer.

If the capacitance were increased, the impedence would decrease because the voltage would be remaining constant. So through the equation $i = C \frac{dV}{dt}$ and $V = iR$ we see R decreasing as C goes up.

2. If the frequency applied to a series RC circuit were decreased, would the magnitude of the angle of impedance be larger or smaller?

If the frequency were decreased the period would be getting larger, thus the angle of impedance would be larger since the Im axis would be longer.

3. For each of the four cases of Table 20-2, calculate the circuit phase angle using the measured voltages and the following relationship.

$$\varnothing = -\tan^{-1}\left(\frac{V_C}{V_R}\right)$$

$\phi(1.8) = -\mathrm{Tan}^{-1}\left(\frac{5.5}{1.36}\right) = -76.11°$

$\phi(5.6) = -\mathrm{Tan}^{-1}\left(\frac{5.53}{3.44}\right) = -58.120°$

$\phi(12) = -\mathrm{Tan}^{-1}\left(\frac{5.52}{4.83}\right) = -48.81°$

$\phi(27k) = -16.4°$

4. Which of the four methods of determining an unknown capacitance appears to be the easiest method for general use? List some drawbacks of each of the methods.

21 AC Series RLC Circuits

Objectives

1. To evaluate current and voltage relationships in a series RLC circuit.
2. To determine the characteristic of an unknown component through measurement techniques.
3. To measure phase angles in a series RLC circuit.
4. To determine through phase measurements if a series RLC circuit is acting inductively or capacitively.

Equipment

Oscilloscope, sinusoidal waveform generator

1/4 W Resistors:	1.5 kΩ	
Capacitors:	68 nF	6.8 nF
Inductors:	56 mH	(part # TK4422, available from Digi-Key Corporation)

Unmarked series LC components to complete optional procedures

Information

Previous experiments have shown that inductive reactance is a vector which is always at 90°, while the capacitive reactance vector is always at -90°. When a capacitor and an inductor are placed in series, these two reactances have a cancellation effect on each other, in fact, it is possible for the two effects to cancel each other entirely. That situation is called resonance. It is a special condition which will be investigated by itself in a later experiment.

A typical series RLC circuit is shown in Figure 21-1. In this case, the inductive reactance is larger in magnitude than the capacitive reactance.

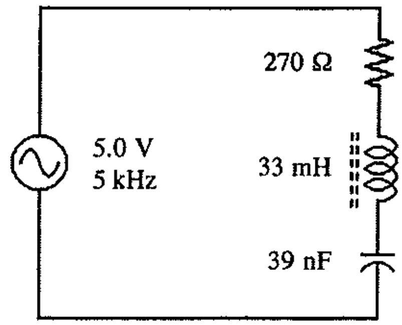


Figure 21-1. Series RLC Circuit

The circuit of Figure 21-1 is solved in Solution 21-1. Notice the addition of a new vector called the "net reactance." This vector represents the addition of inductive and capacitive reactances.

Solution 21-1 ......

$$X_L = 2\,\pi f L = 2 \times \pi \times 5000 \times 33 \times 10^{-3} = 1.04\ \text{k}\Omega$$

$$X_C = \frac{1}{2\,\pi f C} = \frac{1}{2 \times \pi \times 5000 \times 39 \times 10^{-9}} = 816\ \Omega$$

$$\mathbf{X}_{net} = \mathbf{X}_L + \mathbf{X}_C = \left(1.04\ \text{k}\Omega \angle 90°\right) + \left(816\ \Omega \angle \text{-}90°\right)$$

$$= \left(0 + \text{j}\ 1.04\ \text{k}\Omega\right) + \left(0 - \text{j}\ 816\ \Omega\right)$$

$$= \left(0 + \text{j}\ 221\ \Omega\right) = 221\ \Omega \angle 90°$$

$$\mathbf{Z} = \mathbf{R} + \mathbf{X}_{net} = \left(270\ \Omega \angle 0°\right) + \left(221\ \Omega \angle 90°\right)$$

$$= \left(270\ \Omega + \text{j}\ 0\right) + \left(0 + \text{j}\ 221\ \Omega\right)$$

$$= \left(270\ \Omega + \text{j}\ 221\ \Omega\right) = 349\ \Omega \angle 39.2°$$

$$\mathbf{I}_g = \frac{\mathbf{V}_g}{\mathbf{Z}} = \frac{5.00\ \text{V} \angle 0°}{349\ \Omega \angle 39.2°} = 14.3\ \text{mA} \angle \text{-}39.2°$$

$$\mathbf{V}_R = \mathbf{I}_g \times R = \left(14.3\ \text{mA} \angle \text{-}39.2°\right) \times 270\ \Omega = 3.87\ \text{V} \angle \text{-}39.2°$$

$$\mathbf{V}_L = \mathbf{I}_g \times \mathbf{X}_L = \left(14.3\ \text{mA} \angle \text{-}39.2°\right) \times \left(1.04\ \text{k}\Omega \angle 90°\right) = 14.9\ \text{V} \angle 50.8°$$

$$\mathbf{V}_C = \mathbf{I}_g \times \mathbf{X}_C = (14.3 \text{ mA} \angle -39.2°) \times (816\ \Omega \angle -90°) = 11.7 \text{ V} \angle -129°$$

$$\mathbf{V}_{Xnet} = \mathbf{V}_L + \mathbf{V}_C = (14.9 \text{ V} \angle 50.8°) + (11.7 \text{ V} \angle -129°)$$

$$= (9.41 \text{ V} + \text{j } 11.5 \text{ V}) + (-7.41 \text{ V} - \text{j } 9.07 \text{ V})$$

$$= (2.00 \text{ V} + \text{j } 2.45 \text{ V}) = 3.16 \text{ V} \angle 50.8°$$

Check: $\mathbf{V}_g = \mathbf{V}_R + \mathbf{V}_L + \mathbf{V}_C$

$$= (3.87 \text{ V} \angle -39.2°) + (14.9 \text{ V} \angle 50.8°) + (11.7 \text{ V} \angle -129°)$$

$$= (3.00 \text{ V} - \text{j } 2.45 \text{ V}) + (9.41 \text{ V} + \text{j } 11.5 \text{ V}) + (-7.41 \text{ V} - \text{j } 9.07 \text{ V})$$

$$= (5.00 \text{ V} + \text{j } 0 \text{ V}) = 5.00 \text{ V} \angle 0°$$

Figure 21-2 presents the impedance and phasor diagrams for the circuit of Figure 21-1. Notice the addition of a new phasor called "net reactive voltage." This phasor represents the addition of the reactive voltages across the inductor and capacitor only.

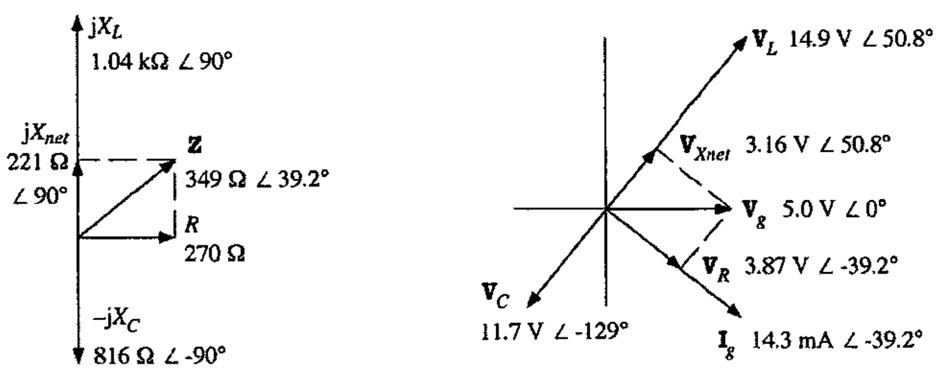


Figure 21-2. Impedance and Phasor Diagrams

Lab Prep

Parts of the following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. For the circuit of Figure 21-3, complete the calculations required for Table 21-1. If you wish to include angles with your calculations, assume the generator voltage is at an angle of 0°.

2. For the phase calculation required in Table 21-1, calculate the phase angle between generator voltage and generator current. If the voltage leads the current, the circuit is inductive and the phase angle should be recorded as a positive angle.

3. Repeat the calculations for the circuit of Figure 21-3 using a value of 6.8 nF in place of 68 nF.

Table 21-1. Series RLC Calculations

	Calculations	
C	68 nF	6.8 nF
X_L		
X_C		
X_{net}		
Z		
Ig		
V_R		
V_L		
V_C		
V_{Xnet}		
Phase		

$$\mathbf{V}_C = \mathbf{I}_g \times \mathbf{X}_C = (14.3 \text{ mA} \angle -39.2°) \times (816\ \Omega \angle -90°) = 11.7 \text{ V} \angle -129°$$

$$\mathbf{V}_{Xnet} = \mathbf{V}_L + \mathbf{V}_C = (14.9 \text{ V} \angle 50.8°) + (11.7 \text{ V} \angle -129°)$$

$$= (9.41 \text{ V} + \text{j } 11.5 \text{ V}) + (-7.41 \text{ V} - \text{j } 9.07 \text{ V})$$

$$= (2.00 \text{ V} + \text{j } 2.45 \text{ V}) = 3.16 \text{ V} \angle 50.8°$$

Check: $\mathbf{V}_g = \mathbf{V}_R + \mathbf{V}_L + \mathbf{V}_C$

$$= (3.87 \text{ V} \angle -39.2°) + (14.9 \text{ V} \angle 50.8°) + (11.7 \text{ V} \angle -129°)$$

$$= (3.00 \text{ V} - \text{j } 2.45 \text{ V}) + (9.41 \text{ V} + \text{j } 11.5 \text{ V}) + (-7.41 \text{ V} - \text{j } 9.07 \text{ V})$$

$$= (5.00 \text{ V} + \text{j } 0 \text{ V}) = 5.00 \text{ V} \angle 0°$$

Figure 21-2 presents the impedance and phasor diagrams for the circuit of Figure 21-1. Notice the addition of a new phasor called "net reactive voltage." This phasor represents the addition of the reactive voltages across the inductor and capacitor only.

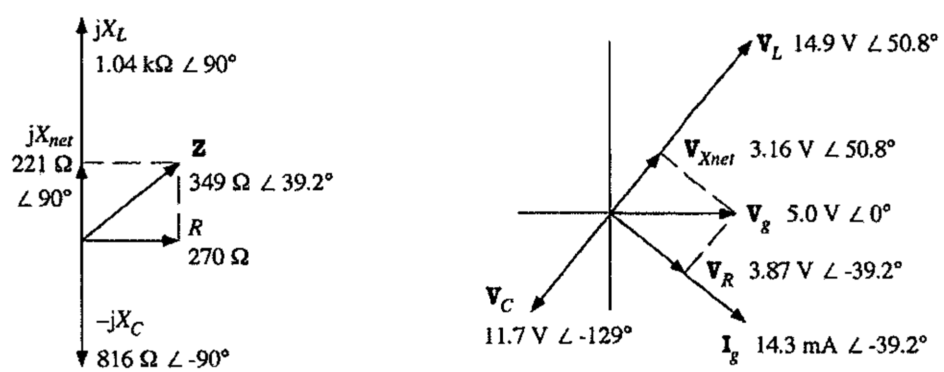


Figure 21-2. Impedance and Phasor Diagrams

Lab Prep

Parts of the following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. For the circuit of Figure 21-3, complete the calculations required for Table 21-1. If you wish to include angles with your calculations, assume the generator voltage is at an angle of 0°.

2. For the phase calculation required in Table 21-1, calculate the phase angle between generator voltage and generator current. If the voltage leads the current, the circuit is inductive and the phase angle should be recorded as a positive angle.

3. Repeat the calculations for the circuit of Figure 21-3 using a value of 6.8 nF in place of 68 nF.

Table 21-1. Series RLC Calculations

	Calculations	
C	68 nF	6.8 nF
X_L		
X_C		
X_{net}		
Z		
Ig		
V_R		
V_L		
V_C		
V_{Xnet}		
Phase		

Procedure

1. Connect the circuit of Figure 21-3, then adjust the generator to 2.0 V at a frequency of 7.0 kHz.

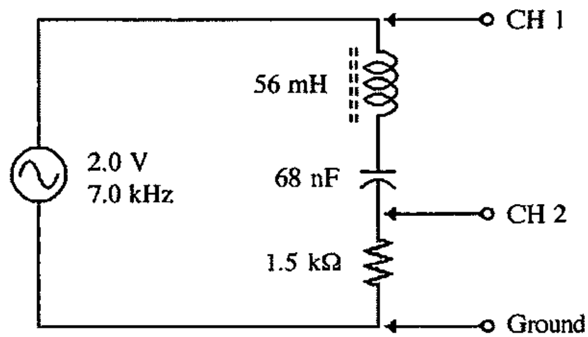


Figure 21-3. RLC Measurement Circuit

2. Measure the generator voltage and the voltages across each component using an oscilloscope. Convert the voltages to RMS units before recording in Table 21-2. NOTE: If your generator is not floating, you may have to interchange the components to avoid shorting components through ground loops.

3. Measure the phase angle between the two voltages with the scope connected as shown in Figure 21-3. If the phase of the generator voltage (CH 1) is leading the phase angle of the generator current (CH 2), the circuit is predominantly inductive, and the phase angle should be recorded as a positive angle.

Table 21-2. RLC Measurements

	Measurements			Calculations	
C	68 nF	6.8 nF	C	68 nF	6.8 nF
V_g			I_g		
V_R			X_L		
V_L			X_C		
V_C			X_{net}		
V_{Xnet}			Z		
Phase			Phase		

4. Complete the calculations required for Table 21-2 using the following relationships.

$$I_g = \frac{V_R}{R}$$

$$X_L = \frac{V_L}{I_g}$$

$$X_C = \frac{V_C}{I_g}$$

$$X_{net} = \frac{V_{Xnet}}{I_g}$$

$$Z = \frac{V_g}{I_g}$$

$$\text{Phase} = \tan^{-1}\left(\frac{V_L - V_C}{V_R}\right)$$

5. Replace the 68 nF capacitor in the circuit of Figure 21-3 with a 6.8 nF capacitor and repeat steps 1 through 4 for this case. Record all data in Table 21-2.

Determining Unknown Series Components (Optional)

6. Your instructor may provide you with an unmarked series LC circuit and require that you determine the unknown values of L and C by measurement techniques.

7. A suggested procedure is to connect a 1 kΩ resistor in series with the combination and apply a voltage generator, starting with a frequency of 5 kHz. Vary the frequency of the generator, and perhaps the value of the resistor, until the voltages across each component are similar to each other, then take the required measurements to determine the values of inductive and capacitive reactances. Record the frequency, and calculate L and C.

8. Record your measurements and observations on the Data Sheet.

21 Prep Sheet

4/5

Name Oleksandr Vladyka

1. Complete the data required for Table 21-1 below.

	Calculations	
C	68 nF	6.8 nF
X_L	$2.4\,k\Omega$	$2.4\,k\Omega$
X_C	$334.3\,\Omega$	$3.3\,k\Omega$
X_{net}	$2.06\,k\Omega \angle 90°$	$900\,\Omega \angle -90°$
Z	$2.54\,k\Omega \angle 53.75°$	$1.74\,\Omega \angle -30.96$
Ig	$0.78\,A \angle -53.93°$	$1.14\,mA \angle 30.96$
V_R	$1.17\,V \angle -53.93°$	$1.7\,V \angle 30.96$
V_L	$1.8\,V \angle 36.07°$	$2.7\,V \angle -59.04$
V_C	$2.6\,V \angle 36.07°$	$3.7 \angle -59.04°$
V_{Xnet}	$1.34\,V \angle 28.2°$	$1.003\,V \angle 45°$
Phase	$54.8°$	-30.4

?

21 **Data Sheet** 5/5 **Name** Oleksandr Vladyka

1. Complete the data required for Table 21-2 below.

	Measurements			Calculations	
C	68 nF	6.8 nF	C	68 nF	6.8 nF
V_g	2V	2V	I_g	0.756 mA	1.05 mA
V_R	1.11 V	1.55 V	X_L	2.39 kΩ	2.94 kΩ
V_L	1.81V	2.57 V	X_C	1.52 kΩ	3.55 kΩ
V_C	1.15V	3.73 V	X_{net}	1.98 kΩ	0.914 kΩ
V_{Xnet}	1.5 V	0.96 V	Z	2.64 kΩ	1.9 kΩ
Phase	50°	-27°	Phase	30.73°	-36.81°

2. Record your measurements and observations for the optional procedure steps in the space below.

Questions

1. Account for any serious disagreements (differences greater than 10%) between the calculations of Table 21-1 and the data of Table 21-2.

All of our initial data in 21-1 was off/incorrect

2. Explain why a circuit is referred to as inductive if the generator voltage leads the generator current.

Current lags the voltage in inductive circuits putting the inductive circuit in a positive phase.

3. Explain how you can measure V_{Xnet} in a circuit such as Figure 21-3, if you have a generator with one output terminal grounded, and one side of the scope input is grounded.

4. Refer to Figure 21-3. What was the most significant difference between the measurements taken with 68 nF and those taken with 6.8 nF?

22 RC & RL Frequency Response

Objectives

1. To categorize the variations in circuit impedance, generator current, and phase angle caused by changing frequency in a series RC circuit while generator voltage is held constant.
2. To evaluate the variations in circuit impedance, generator voltage, and phase angle caused by changing frequency in a parallel RL circuit while generator current is held constant.
3. To measure and graph circuit response as a function of frequency.

Equipment

Oscilloscope, ac voltmeter, sinusoidal waveform generator

1/4 W Resistors:	10 Ω	1 kΩ
Inductors:	56 mH	(part # TK4413, available from Digi-Key Corporation)
Capacitors:	100 nF	

Information

The variations in inductive reactance and capacitive reactance due to frequency changes, which were studied in an earlier experiment, will be investigated more thoroughly in this experiment. The fact that inductive reactance increases with an increase in frequency, and the fact that capacitive reactance decreases with an increase in frequency should be quite familiar by this time. Understanding those concepts, as well as the concepts involved in series and parallel RC and RL circuits, is fundamental to achieving success with this experiment.

In a series RC circuit, as frequency is increased, there is no change to the resistance, but the capacitive reactance will decrease. The effect that this has on impedance is illustrated in Figure 22-1. As frequency is increased, the vectors representing reactance and impedance are shown as progressively heavier lines.

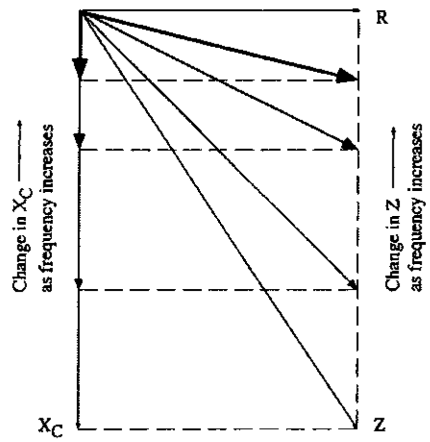


Figure 22-1. Series RC Impedance Variation with Frequency

Two things can be seen in Figure 22-1: the magnitude of the impedance decreases as frequency increases, and the magnitude of the phase angle of impedance also decreases. By studying Figure 22-1, it will become obvious that if frequency is lowered, there is no limit to how large the circuit impedance can become. Also, it will become obvious that the phase angle must always be between -90° and 0°. For a series circuit, it can be shown that the phase angle between generator voltage and generator current will always be the same as the angle of impedance. If generator voltage lags generator current, the phase angle will be negative, indicating a circuit that is acting capacitively. Therefore, the magnitude and the sign of the impedance phase angle is always the same as the phase angle between generator voltage and generator current (which many people refer to as "the circuit phase angle"). Understanding the illustration of Figure 22-1 is thus helpful in visualizing the variation in circuit phase angle versus frequency which is shown in Figure 22-2.

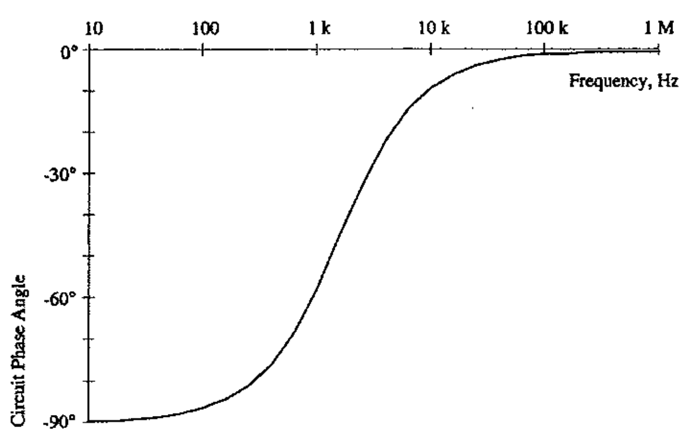


Figure 22-2. Series RC Circuit Phase Response Versus Frequency

Other effects in the series RC circuit can also be deduced from studying Figure 22-1. As frequency increases, the impedance decreases, but cannot be smaller than the value of *R*. If the generator voltage is held constant, this decrease in impedance will cause an increase in generator current. Since the minimum value of impedance is *R*, the maximum value of *Ig* must be *Vg* ÷ *R*. Also, since generator current is increasing, the voltage across *R* must increase as well, up to a maximum of *Ig* × *R*. The voltage across the capacitor is harder to predict, since it is the product of generator current (which is increasing) times capacitive reactance (which is decreasing). The capacitor voltage will, however, decrease as the frequency is increased.

Parallel circuit response versus frequency is analyzed in a similar fashion as with series circuits. Consider the admittance diagram shown in Figure 22-3 for a parallel RL circuit.

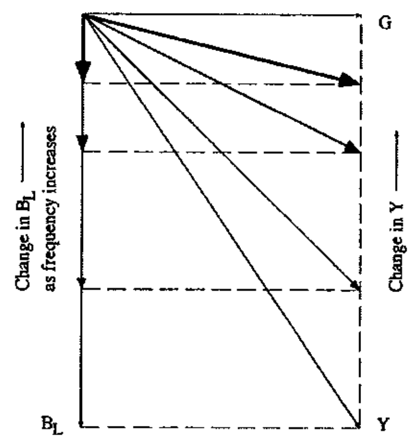


Figure 22-3. Parallel RL Admittance Variation with Frequency

Studying Figure 22-3 will reveal that, as frequency increases, the admittance vector becomes smaller in magnitude and its phase angle varies from -90° towards 0°. Since impedance is the inverse of admittance, the impedance is thus increasing, and its phase angle varies from 90° towards 0°. If generator current is held constant, an increasing impedance will cause the voltage across the parallel circuit to increase. As frequency is increased, *Y* cannot become smaller than the value of *G*, thus *Z* cannot become larger than the value of *R*. The maximum voltage across the parallel circuit is therefore *Ig* × *R*. Since the voltage across the parallel circuit increases with frequency, the current through *R* will also increase to a maximum value of *Vg* ÷ *R*, which is *Ig*. The current through *L* is more difficult to predict since it is the generator voltage (which is increasing) divided by the inductive reactance (which is also increasing). The current through *L* will, in fact, decrease as frequency is increased.

Again, it can be shown that for a parallel circuit, the phase angle between generator voltage and generator current will always be the same as the angle of impedance. If generator voltage leads generator current, which it will for a parallel RL circuit, the phase angle will be positive, indicating a circuit that is acting inductively. The circuit phase angle versus frequency for a parallel RL circuit is shown in Figure 22-4.

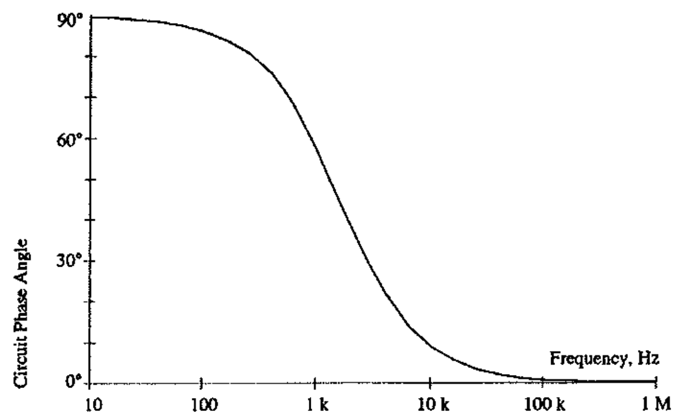


Figure 22-4. Parallel RL Circuit Phase Response Versus Frequency

This experiment will confirm, through measurement and graphing techniques, the circuit characteristics versus frequency which have been described in this information section of this experiment.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. For the circuit of Figure 22-5, calculate magnitudes for the quantities required in Table 22-1.

Table 22-1. Series RC Circuit Calculations

Frequency	Calculations					
	X_C	Z	Ig	V_C	V_R	Phase
3 kHz						

2. For the circuit of Figure 22-6, calculate magnitudes for the quantities required in Table 22-2. Assume the generator current is 2.83 mA.

Table 22-2. Parallel RL Circuit Calculations

Frequency	Calculations					
	X_L	Z	Vg	I_R	I_L	Phase
3 kHz						

Procedure

Series RC Frequency Response

1. Connect the circuit of Figure 22-5, then set the generator frequency to 10 Hz. If your generator cannot be set to a frequency that low, start at the lowest frequency of those listed in Table 22-3.

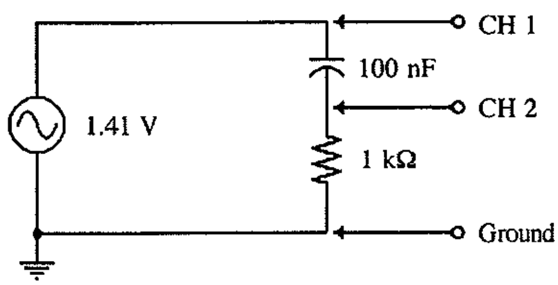


Figure 22-5. Series RC Measurement Circuit

2. Set the VOLTS/DIV control of the CH 1 scope input to a sensitivity of 0.5 V/DIV, and adjust the generator voltage until the CH 1 waveform is exactly 8.0 divisions, from peak to peak. This will set the generator voltage to 4.00 Vpp, or 1.41 V.

3. Measure the resistor voltage at the CH 2 input, convert it into an RMS voltage, and enter the measurement into Table 22-3.

4. Repeat steps 2 and 3 for the remaining frequencies listed in Table 22-3, or for as many as your generator will allow. Be sure to maintain the CH 1 voltage at 8 divisions peak to peak, in order to keep the generator voltage constant.

5. Complete the calculations required for Table 22-3 using the following relationships.

$$I_g = \frac{V_R}{1\ \text{k}\Omega}$$

$$Z = \frac{V_g}{I_g}$$

$$V_C = \sqrt{V_g^2 - V_R^2}$$

$$\text{Phase} = -\cos^{-1}\left(\frac{V_R}{V_g}\right)$$

6. Use the data from Table 22-3 to plot graphs of *Ig* , *Z*, and phase angle versus frequency on the Data Sheet.

Table 22-3. Series RC Circuit Measurements

Frequency	Measurements		Calculations			
	V_g	V_R	Ig	Z	V_C	Phase
10 Hz	1.41 V					
30 Hz	1.41 V					
60 Hz	1.41 V					
100 Hz	1.41 V					
300 Hz	1.41 V					
600 Hz	1.41 V					
1 kHz	1.41 V					
3 kHz	1.41 V					
6 kHz	1.41 V					
10 kHz	1.41 V					
30 kHz	1.41 V					
60 kHz	1.41 V					
100 kHz	1.41 V					
300 kHz	1.41 V					
600 kHz	1.41 V					
1 MHz	1.41 V					

Parallel RL Frequency Response

7. Connect the circuit of Figure 22-6, then set the generator frequency to 10 Hz. If your generator cannot be set to a frequency that low, start at the lowest frequency of those listed in Table 22-4.

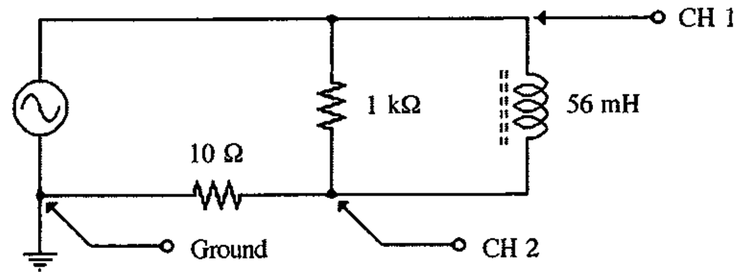


Figure 22-6. Parallel RL Measurement Circuit

8. Set the VOLTS/DIV control of the CH 2 scope input to a sensitivity of 10 mV/DIV, and adjust the generator voltage until the CH 2 waveform is exactly 8.0 divisions, from peak to peak. This will set the voltage across the 10 Ω resistor to 80 mVpp, or 28.3 mV. With 28.3 mV set across the 10 Ω resistor, the generator current will be set at 2.83 mA.

9. Measure the generator voltage at the CH 1 input, convert it into an RMS voltage, and enter the measurement into Table 22-4.

10. Repeat steps 8 and 9 for the remaining frequencies listed in Table 22-4, or for as many as your generator will allow. Be sure to maintain the CH 2 voltage at 8 divisions peak to peak, in order to keep the generator current constant.

11. Complete the calculations required for Table 22-4 using the following relationships.

$$I_g = \frac{V_{10\,\Omega}}{10\,\Omega}$$

$$Z = \frac{V_g}{I_g}$$

$$I_R = \frac{V_g}{1\text{ k}\Omega}$$

$$I_L = \sqrt{I_g^2 - I_R^2}$$

$$\text{Phase} = \cos^{-1}\left(\frac{I_R}{I_g}\right)$$

12. Use the data from Table 22-4 to plot graphs of *Z*, *Vg* , and phase angle versus frequency on the Data Sheet.

Table 22-4. Parallel RL Circuit Measurements

Frequency	Measurements		Calculations				
	$V_{10\ \Omega}$	Vg	Ig	Z	I_R	I_L	Phase
10 Hz	28.3 mV						
30 Hz	28.3 mV						
60 Hz	28.3 mV						
100 Hz	28.3 mV						
300 Hz	28.3 mV						
600 Hz	28.3 mV						
1 kHz	28.3 mV						
3 kHz	28.3 mV						
6 kHz	28.3 mV						
10 kHz	28.3 mV						
30 kHz	28.3 mV						
60 kHz	28.3 mV						
100 kHz	28.3 mV						
300 kHz	28.3 mV						
600 kHz	28.3 mV						
1 MHz	28.3 mV						

4/5

22 Prep Sheet

Name Oleksandr Vladyka

1. Complete the data required for Table 22-1 below.

Frequency	Calculations					
	X_C	Z	Ig	V_C	V_R	Phase
3 kHz	530Ω	1132Ω	1.01mA	0.575V	1.01V	-27.4°

should include angles too

2. Complete the data required for Table 22-2 below.

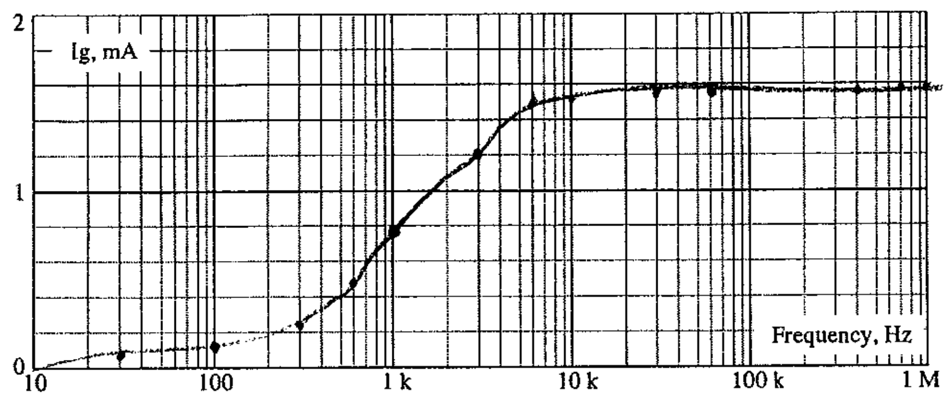
Frequency	Calculations					
	X_L	Z	Vg	I_R	I_L	Phase
3 kHz	1055Ω	733Ω	2.08V	0.00208A	0.00142A	42.7°

5 15

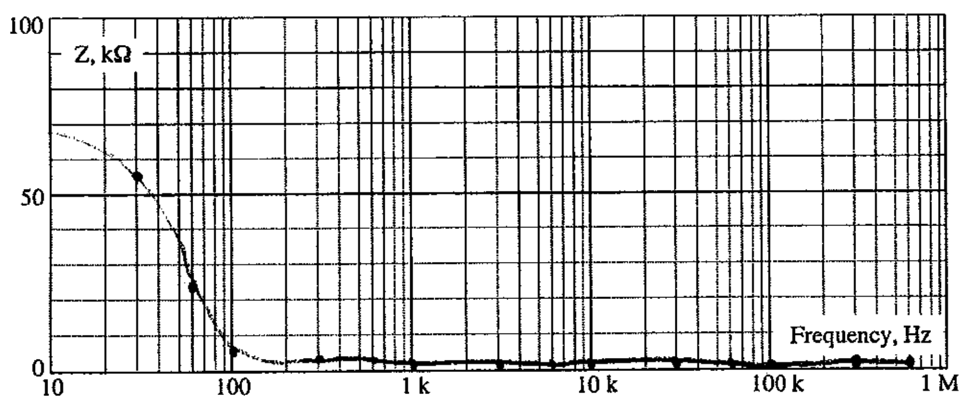
22 Data Sheet

Name Oleksandr Vladyka

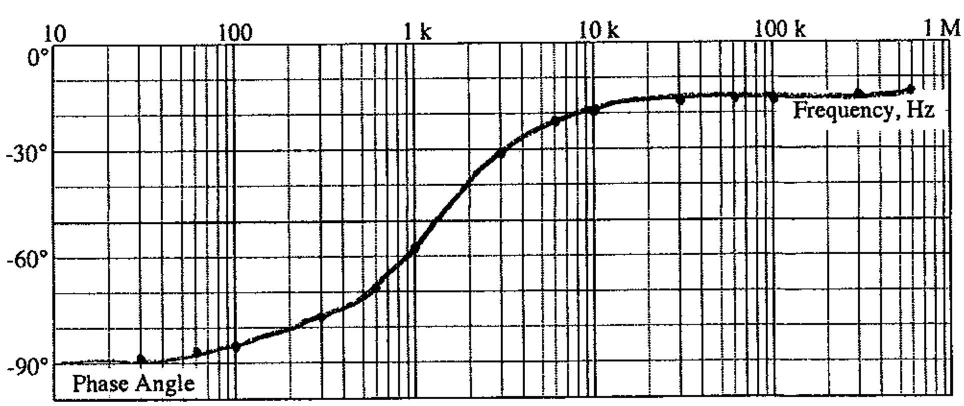
Graph 22-1. Series RC Generator Current vs Frequency



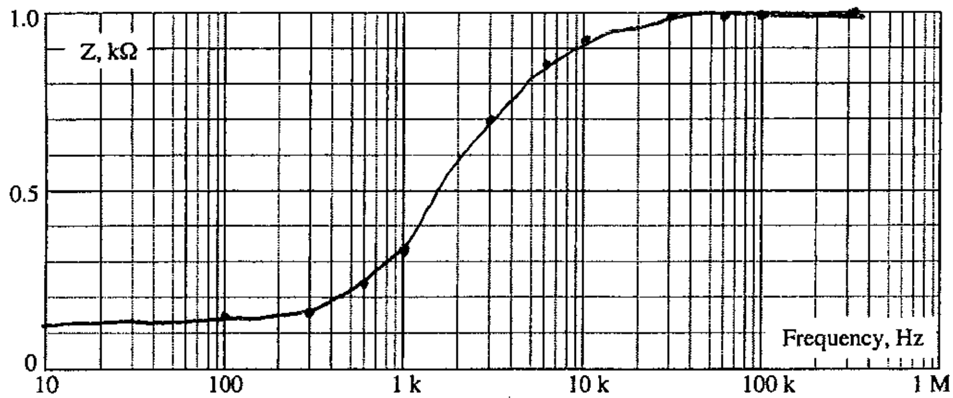
Graph 22-2. Series RC Circuit Impedance vs Frequency



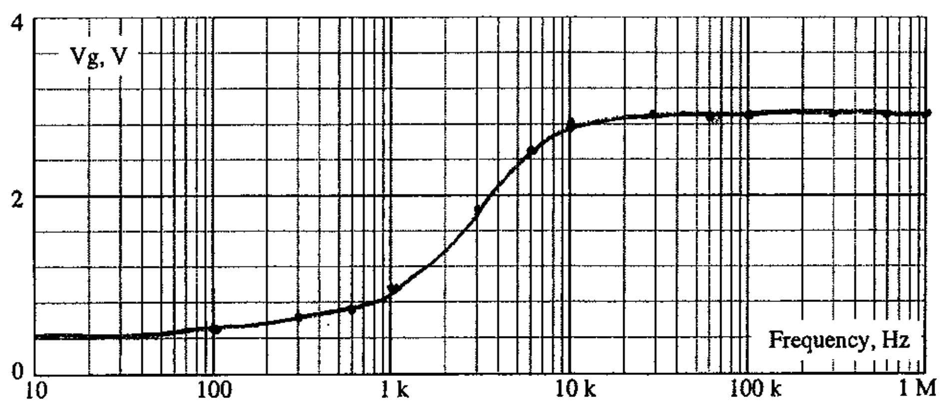
Graph 22-3. Series RC Phase Angle vs Frequency



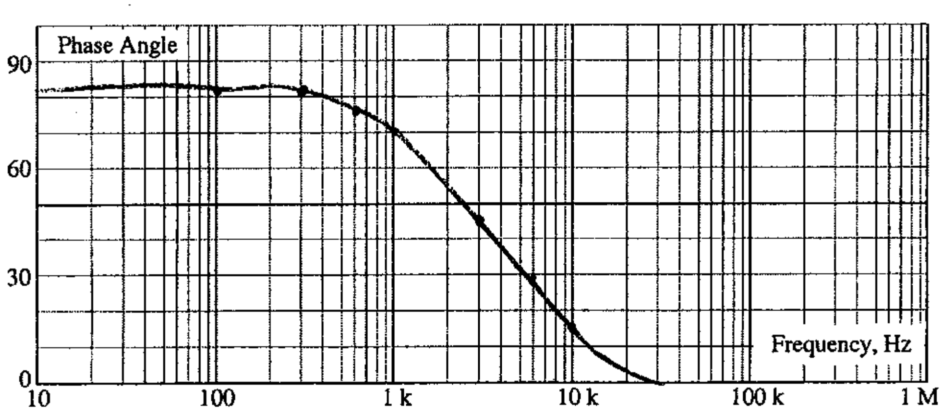
Graph 22-4. Parallel RL Circuit Impedance vs Frequency



Graph 22-5. Parallel RL Generator Voltage vs Frequency



Graph 22-6. Parallel RL Phase Angle vs Frequency



Questions

1. Compare your calculations in Table 22-1 with the data in Table 22-3, for the 3 kHz frequency.

Our calculations slightly lower than our lab data. This could be a result of the tolerance of the lab equipment.

2. Refer to Table 22-3. For the frequency of 1 kHz, do your values of resistor voltage and capacitor voltage add up to the generator voltage of 1.41 V?

This value added up equal 1.8 V which is larger than the generator up for voltage of 1.4V
The phasors will add, but the magnitude will not

3. Refer to Graph 22-1. Explain why the generator current reached a high frequency level of 1.41 mA.

4. Refer to Graph 22-3. Estimate, from your graph, the frequency at which the circuit phase angle is -45°. Compare this frequency to what is called "the circuit break frequency," and is calculated with the relationship:

$$f = \frac{1}{2\pi RC}$$

5. Refer to Table 22-4. An error occurs in the determination of the impedance of the 1 kΩ resistor in parallel with the 56 mH inductor at low frequencies. Explain the nature of this error.

6. Refer to Graph 22-6. Compare your graph to the graph presented in Figure 22-4 of the Information section, which is an exact theoretical plot for the parallel circuit used in this experiment.

7. Refer to Table 22-4. For a frequency of 6 kHz, does the sum of the resistor current and the inductor current add up to the generator current?

23 Low Pass & High Pass Filters

Objectives

1. To measure the frequency response of an RC and an RL low pass filter.
2. To measure the frequency response of an RC and an RL high pass filter.
3. To determine the cutoff frequencies of low and high pass filters.

Equipment

Oscilloscope, ac voltmeter, sinusoidal waveform generator		
1/4 W Resistors:	680 Ω	2.2 kΩ
Inductor:	56 mH	(part # TK4413, available from Digi-Key Corporation)
Capacitor:	33 nF	

Information

Frequency filters exist in many circuit configurations. There are RC filters, RL filters, and RLC filters. They can be connected in an "L" configuration, a "T" configuration, a "π" configuration, or in other ways. These types are called passive filters since they contain no amplifying devices. There are many other active filters as well. They all have one thing in common. Their effect upon an ac signal varies as a function of frequency. This experiment will explore only a few simple examples of the many types of filters presently available to the circuit designer.

The frequency response of a filter is characterized as a plot of its voltage gain, in decibels, versus frequency. The voltage gain at any particular frequency is determined with Equation 23-1.

$$A_V(\text{dB}) = 20 \log \left(\frac{V_o}{V_i}\right) \qquad \text{.................. Equation 23-1}$$

Ideal low pass filters would pass, unchanged, all frequencies up to the desired cutoff frequency, then totally reject all higher frequencies. Simple RC and RL filters are not ideal. They can leave the desired frequencies almost unchanged, but can only progressively attenuate frequencies greater than the cutoff frequency. The result is a response plot which is relatively flat for low frequencies, then, at the cutoff frequency, slopes downwards for higher frequencies. This slope rate will be –20 dB per decade, or, –20 dB for each factor of ten change in frèquency. The frequency that is termed the cutoff frequency, f_c, is defined by Equation 23-2, where $\tau = RC$ or L/R.

$$f_c = \frac{1}{2\pi\tau} \qquad \text{...................... Equation 23-2}$$

The term cutoff suggests that the filter actually cuts frequencies off at some particular point. This is not the case. The low pass response plot will undergo a smooth transition from a line of zero slope to one with -20 dB/decade. At the cutoff frequency, the circuit response will be -3 dB, or 3 dB down from its low frequency level. Equation 23-2 determines f_c, the frequency at which the circuit gain is at -3 dB.

High pass filters are similar, but opposite to low pass filters. As frequency is decreased, they progressively attenuate frequencies below the cutoff frequency. The low pass response plot will undergo a smooth transition from a line of 20 dB per decade slope to one of zero slope. Equations 23-1 and 23-2 are equally valid for high pass filters.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. For the RC low pass and high pass circuits of Figures 23-1 and 23-3, calculate the cutoff frequency, f_c, and record in Table 23-1.

2. For the RC low pass circuit of Figure 23-1, calculate the voltage gain in decibels at 20 kHz and record in Table 23-1.

3. For the RC high pass circuit of Figure 23-3, calculate the voltage gain in decibels at 800 Hz and record in Table 23-1.

Table 23-1. Filter Calculations

	RC Low Pass	RC High Pass
fc		
Av (dB)		

4. Sketch the bode response plots as described on the Prep Sheet.

Procedure

Low Pass RC Filter

1. Connect the circuit of Figure 23-1 and set the generator to 100 Hz at about 2 V.

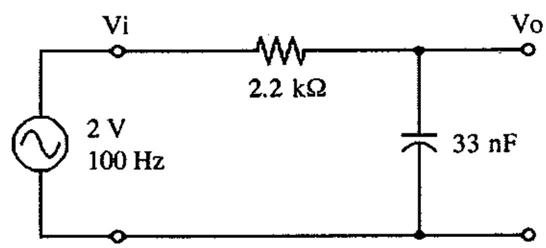


Figure 23-1. Low Pass RC Filter

2. Measure V_i and V_o, and calculate the voltage gain in decibels. Record in Table 23-2.

3. Repeat step 2 for the remaining frequencies listed in Table 23-2.

Table 23-2. Low Pass RC Measurements

Frequency	Vi	Vo	Av (dB)
100 Hz			
300 Hz			
600 Hz			
1 kHz			
2 kHz			
3 kHz			
6 kHz			
10 kHz			
30 kHz			
60 kHz			
100 kHz			

Low Pass RL Filter

4. Connect the circuit of Figure 23-2 and set the generator to 100 Hz at about 2 V.

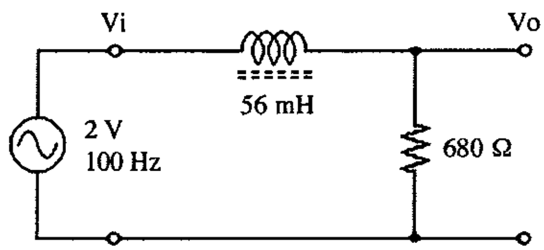


Figure 23-2. Low Pass RL Filter

5. Measure V_i and V_o, and calculate the voltage gain in decibels. Record in Table 23-3.

6. Repeat step 5 for the remaining frequencies listed in Table 23-3.

Table 23-3. Low Pass RL Measurements

Frequency	Vi	Vo	Av (dB)
100 Hz			
300 Hz			
600 Hz			
1 kHz			
2 kHz			
3 kHz			
6 kHz			
10 kHz			
30 kHz			
60 kHz			
100 kHz			

High Pass RC Filter

7. Connect the circuit of Figure 23-3 and set the generator to 100 Hz at about 2 V.

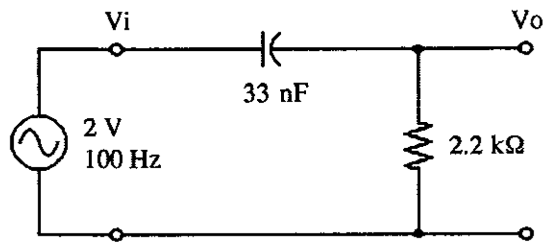


Figure 23-3. High Pass RC Filter

8. Measure V_i and V_o, and calculate the voltage gain in decibels. Record in Table 23-4.

9. Repeat step 8 for the remaining frequencies listed in Table 23-4.

Table 23-4. High Pass RC Measurements

Frequency	Vi	Vo	Av (dB)
100 Hz			
300 Hz			
600 Hz			
1 kHz			
2 kHz			
3 kHz			
6 kHz			
10 kHz			
30 kHz			
60 kHz			
100 kHz			

High Pass RL Filter

10. Connect the circuit of Figure 23-4 and set the generator to 100 Hz at about 2 V.

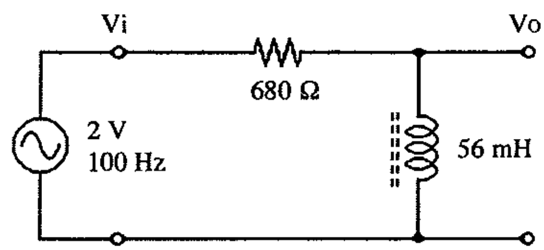


Figure 23-4. High Pass RL Filter

11. Measure V_i and V_o, and calculate the voltage gain in decibels. Record in Table 23-5.

12. Repeat step 11 for the remaining frequencies listed in Table 23-5.

Table 23-5. High Pass RL Measurements

Frequency	Vi	Vo	Av (dB)
100 Hz			
300 Hz			
600 Hz			
1 kHz			
2 kHz			
3 kHz			
6 kHz			
10 kHz			
30 kHz			
60 kHz			
100 kHz			

23 Prep Sheet

5/5

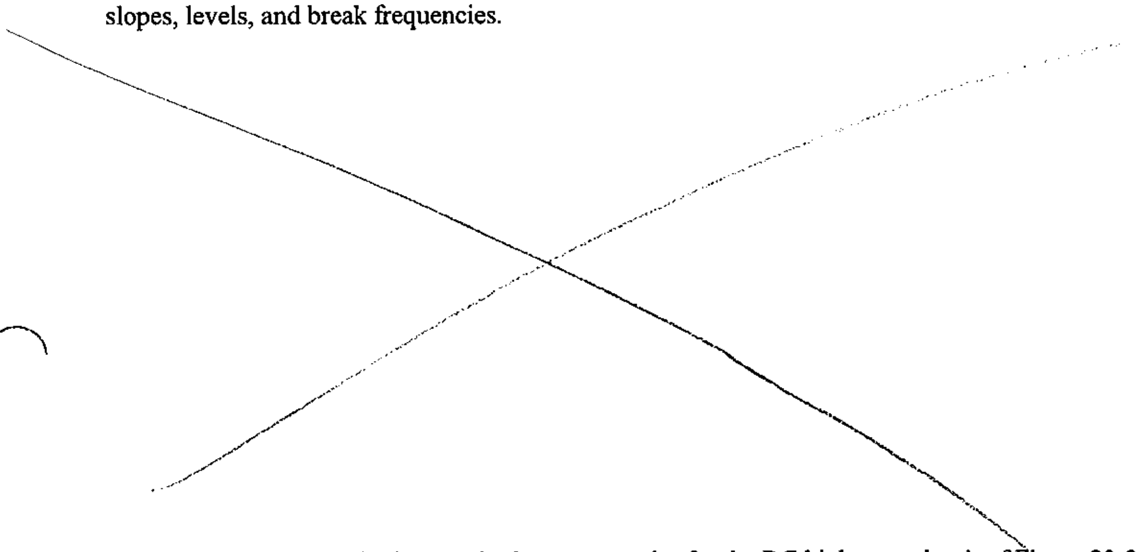
Name Oleksandr Vladyka

1. Complete the data required for Table 23-1 below.

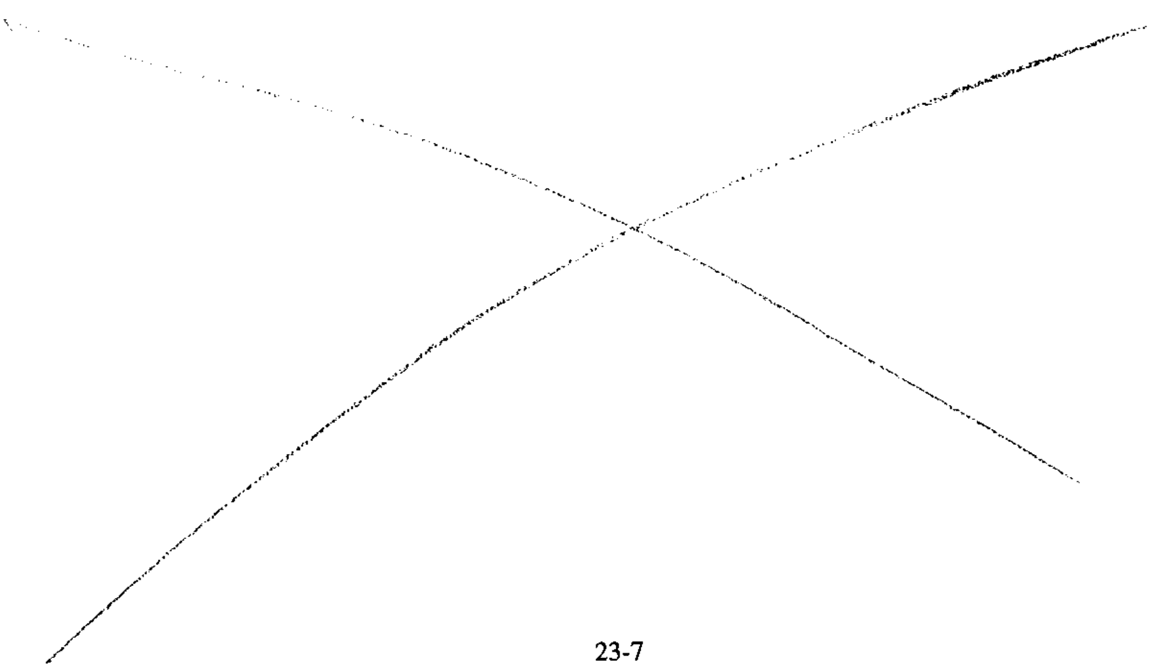
	RC Low Pass	RC High Pass
fc	2.2 kHz	2.2 kHz
Av (dB)	−17.6	−10.6

close enough

2. Sketch the straight line bode magnitude response plot for the RC low pass circuit of Figure 23-1. Label all slopes, levels, and break frequencies.



3. Sketch the straight line bode magnitude response plot for the RC high pass circuit of Figure 23-3. Label all slopes, levels, and break frequencies.

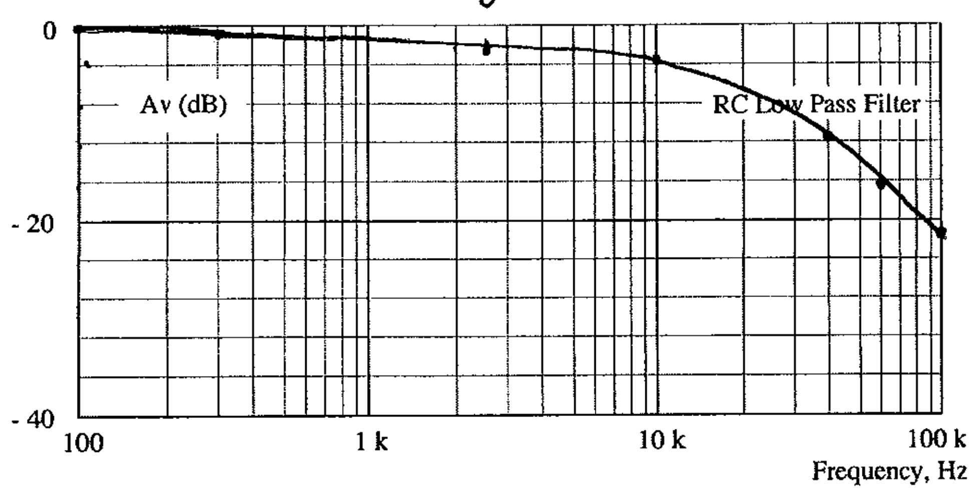


5/5

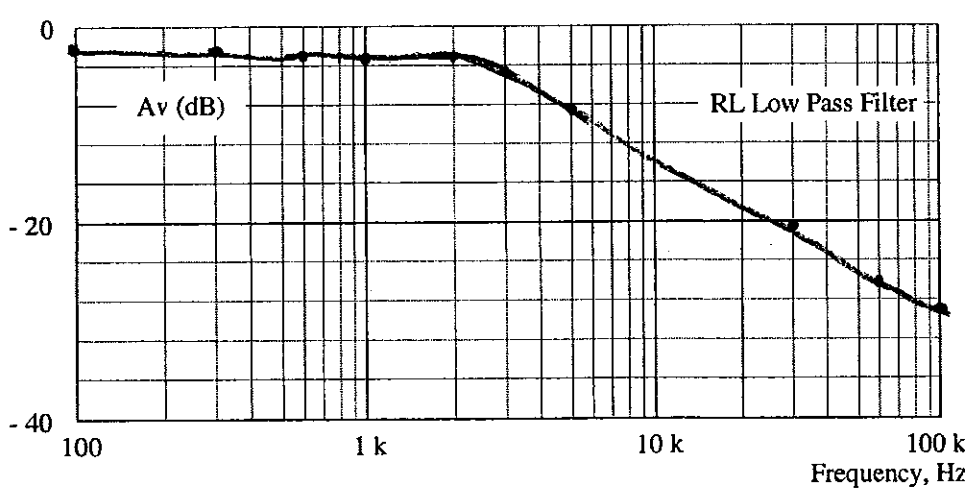
23 Data Sheet

Name Oleksandr Vladyka

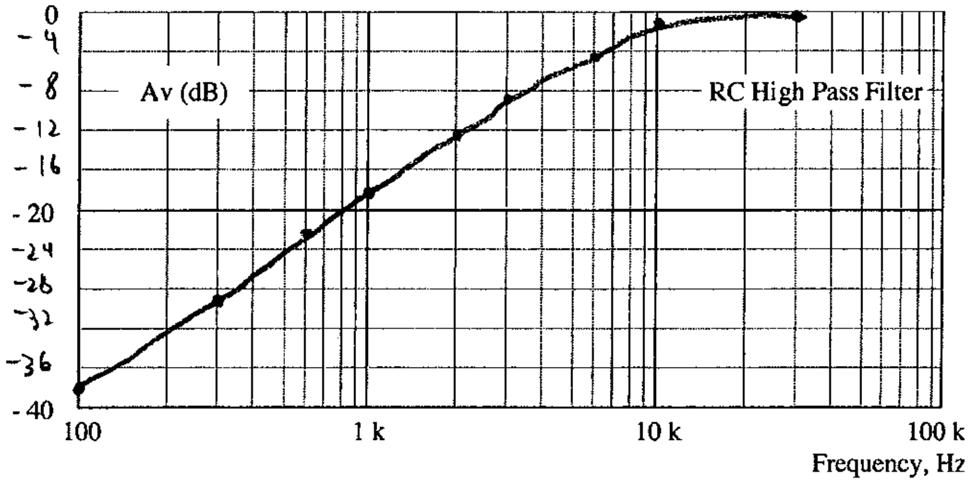
1. Use the data from Table 23-2 to plot the actual response curve for the filter circuit of Figure 23-1 on the graph provided below.



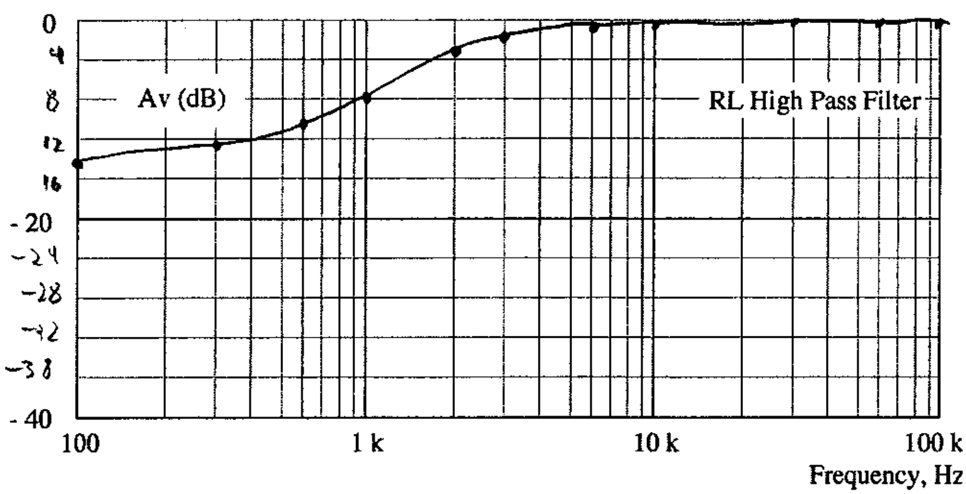
2. Use the data from Table 23-3 to plot the actual response curve for the filter circuit of Figure 23-2 on the graph provided below.



3. Use the data from Table 23-4 to plot the actual response curve for the filter circuit of Figure 23-3 on the graph provided below.



4. Use the data from Table 23-5 to plot the actual response curve for the filter circuit of Figure 23-4 on the graph provided below.



Questions

1. Refer to your graph for the RC low pass filter. Draw a horizontal line at -3 dB and read the frequency at which your response curve intersects this line. Compare this frequency with the calculated f_c from Table 23-1.

There approximately 7kHz

2. Refer to your graph for the RC high pass filter. Draw a horizontal line at -3 dB and read the frequency at which your response curve intersects this line. Compare this frequency with the calculated f_c from Table 23-1.

There approximately 8 kHz

3. Refer to your graph for the RC low pass filter. Read the voltage gain from this graph at a frequency of 20 kHz, and compare with the calculated value in Table 23-1.

4. Refer to your graph for the RC high pass filter. Read the voltage gain from this graph at a frequency of 800 Hz, and compare with the calculated value in Table 23-1.

5. Refer to your graph of the RL low pass filter. Read the voltage gains at 10 kHz and at 100 kHz, and calculate the slope of the graph between these two frequencies.

6. Refer to your graph of the RL high pass filter. Read the voltage gains at 100 Hz and at 1 kHz, and calculate the slope of the graph between these two frequencies.

24 Band Pass & Band Reject Filters

Objectives

1. To measure the frequency response of a series RLC band pass filter.
2. To measure the frequency response of a series RLC band reject filter.
3. To determine the cutoff frequencies of band pass and band reject filters.
4. To verify the ability of a band reject filter to reject unwanted frequencies.

Equipment

Oscilloscope, ac voltmeter, sinusoidal waveform generator

1/4 W Resistors:	100 Ω	1 kΩ
Inductor:	56 mH	(part # TK4413, available from Digi-Key Corporation)
Capacitor:	33 nF	

Information

Just as there are many varieties of low and high pass filters, many types of band pass and band reject filters exist also. The characteristics of a series resonant circuit, that its impedance is minimum at resonance, is often exploited for use in either a band pass or band reject filter. So too is the characteristic of a parallel resonant circuit, that its impedance is maximum at resonance, used for both of these filter types. There are many varieties of active filters available as well.

Two forms of a series resonant circuit are shown in Figure 24-1. The circuit on the left side of this illustration will operate as a band pass filter. At resonance, its LC portion is ideally 0 Ω, therefore the circuit gain is 1, or 0 dB, and this frequency is passed. On either side of the resonant frequency, either the L or the C will have a large reactance, causing the output to be smaller than the input, and signals are stopped, or at least reduced in amplitude.

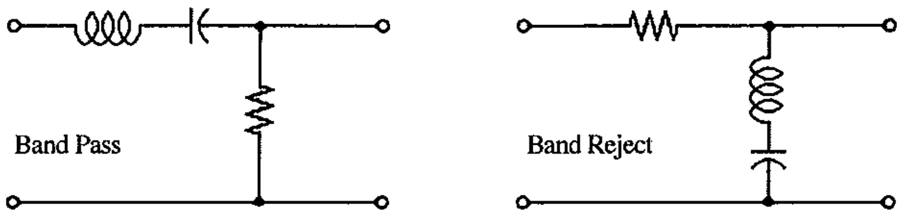


Figure 24-1. Series Resonant Filters

Now consider the right side of Figure 24-1. This circuit functions as a band reject filter. At resonance, the LC portion ideally looks like 0 Ω, thus shorting the output, or rejecting this frequency. On either side of resonance, either the L or the C will have a large reactance, causing the voltage gain to be closer to 1, thereby passing these frequencies.

The circuit of Figure 24-1 (left) functions on the principle that the LC impedance is much less, at resonance, than R. Similarly, the circuit of Figure 24-1 (right) functions on the same principle. Figure 24-2 illustrates two circuits, utilizing parallel resonance, which will function in much the same way.

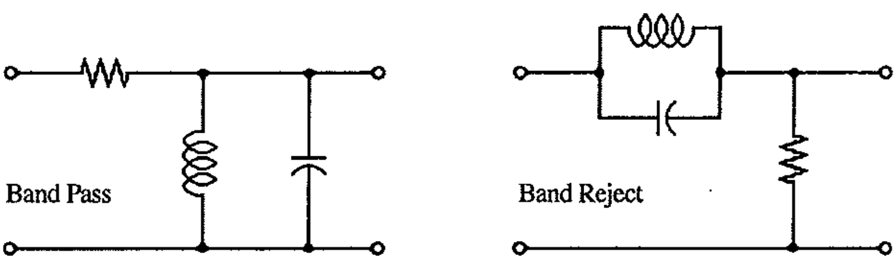


Figure 24-2. Parallel Resonant Filters

Consider Figure 24-2 (left). At resonance, the LC impedance is much larger than the resistance, thereby passing the signal. On either side of resonance, either the L or the C will have a low reactance, shorting the signal and reducing the output. In Figure 24-2 (right), at resonance, the LC impedance is much greater than R, causing the signal to be lost across the LC portion and thus no output signal. On either side of resonance, either the L or the C will have a low reactance, causing the LC portion to appear as a low impedance, thus passing these frequencies.

This experiment, will investigate the two circuit examples illustrated in Figure 24-1.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. For the circuit of Figure 24-3, solve Equation 24-1 to obtain the voltage gain of the circuit, in decibels, for as many different frequencies as is necessary to plot a smooth response curve for this circuit. Plot this curve on the graph provided on the Data Sheet, and label it as "Theoretical."

$$A_V(\text{dB}) = 20 \log\left[\frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}\right] \qquad \text{............. Equation 24-1}$$

2. For the circuit of Figure 24-4, solve Equation 24-2 to obtain the voltage gain of the circuit, in decibels, for as many different frequencies as is necessary to plot a smooth response curve for this circuit. Plot this curve on the graph provided on the Data Sheet, and label it as "Theoretical."

$$A_V(\text{dB}) = 20 \log\left[\frac{|X_L - X_C|}{\sqrt{R^2 + (X_L - X_C)^2}}\right] \qquad \text{............. Equation 24-2}$$

3. No separate Prep Sheet is required to be handed in for this experiment.

Procedure

Series Band Pass Filter

1. Connect the circuit of Figure 24-3. Set the generator to 2 V at a frequency of 100 Hz.

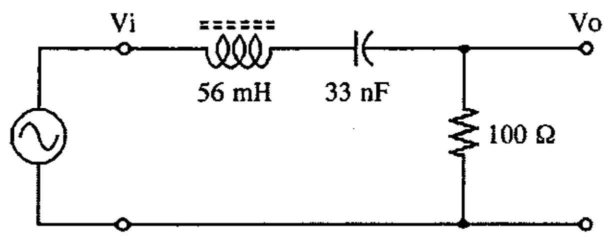


Figure 24-3. Band Pass Filter

2. Measure V_i and V_o, then calculate the voltage gain in decibels. Record in Table 24-1.

3. Repeat step 2 for the other frequencies listed in Table 24-1. V_i does not have to be kept constant. The blank frequency in Table 24-1 is reserved for the resonant frequency, which may be observed at the input or at the output.

Table 24-1. Band Pass Measurements

Frequency	Vi	Vo	Av (dB)
100 Hz			
300 Hz			
600 Hz			
1 kHz			
3 kHz			
fr			
4 kHz			
5 kHz			
6 kHz			
10 kHz			
30 kHz			
60 kHz			
100 kHz			

Series Band Reject Filter

4. Connect the circuit of Figure 24-4. Set the generator to 2 V at a frequency of 100 Hz.

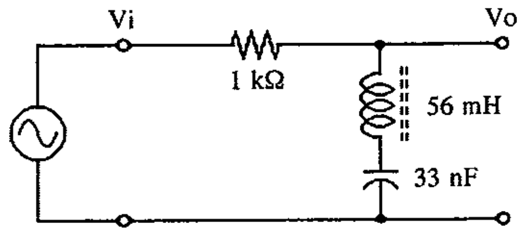


Figure 24-4. Band Reject Filter

5. Measure V_i and V_o, then calculate the voltage gain in decibels. Record in Table 24-2.

6. Repeat step 5 for the other frequencies listed in Table 24-2. V_i does not have to be kept constant. The blank frequency in Table 24-2 is reserved for the resonant frequency, which may be observed at the input or at the output.

Table 24-2. Band Reject Measurements

Frequency	Vi	Vo	Av (dB)
100 Hz			
300 Hz			
600 Hz			
1 kHz			
3 kHz			
fr			
4 kHz			
5 kHz			
6 kHz			
10 kHz			
30 kHz			
60 kHz			
100 kHz			

Testing a Band Reject Filter (Optional)

7. If sufficient signal generators are available, connect the circuit of Figure 24-5.

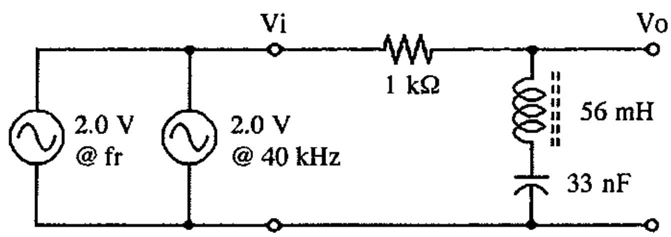


Figure 24-5. Mixed Frequency Test Circuit

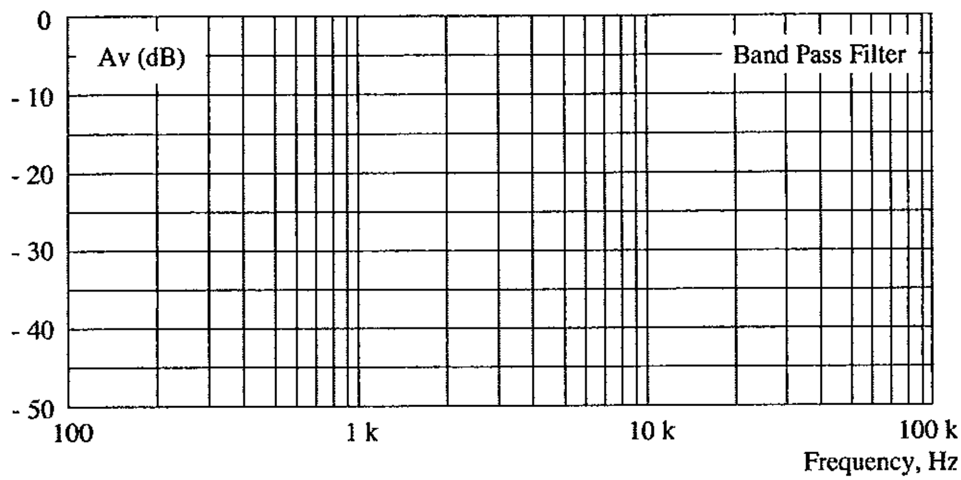
8. Set the left generator to 2.0 V at the resonant frequency determined in Table 24-2.

9. Set the right generator to 2.0 V at 40 kHz.

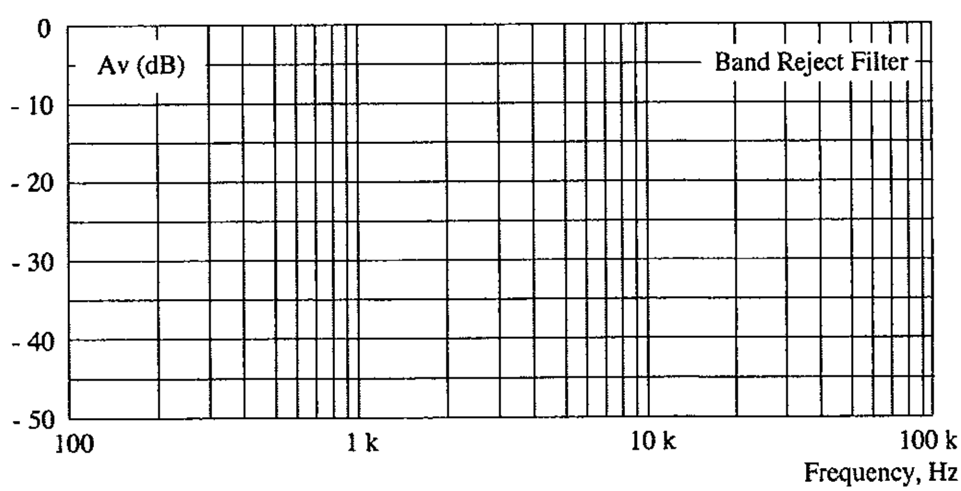
10. Observe the waveforms at V_i and V_o with an oscilloscope. Is the low frequency component sufficiently rejected at the output?

11. Use the space available below if you wish to sketch the V_i and V_o waveforms.

1. Use the data from Table 24-1 to plot the actual response of the band pass filter circuit on the graph provided below. Label your plot so as to differentiate it from the theoretical plot.



2. Use the data from Table 24-2 to plot the actual response of the band reject filter circuit on the graph provided below. Label your plot so as to differentiate it from the theoretical plot.



Questions

1. Comment on the agreement between the calculated and actual response plots for the band pass filter circuit.

2. Comment on the agreement between the calculated and actual response plots for the band reject filter circuit.

25 Series Resonant Circuits

Objectives

1. To observe and measure the resonant frequency of a series RLC circuit.
2. To evaluate Q-multiplication of voltage in a series resonant RLC circuit.
3. To test that impedance in a series RLC circuit exhibits a minimum at the resonant frequency.
4. To test that current in a series RLC circuit exhibits a maximum at the resonant frequency.
5. To observe and measure the phase angle of a series RLC circuit in the vicinity of resonance.

Equipment

Oscilloscope, sinusoidal waveform generator

1/4 W Resistors:	56 Ω	
Inductors:	56 mH (part # TK4413, available from Digi-Key Corporation)	
Capacitors:	33 nF	1.0 μF

Information

Resonance exists whenever the inductive reactance and the capacitive reactance in a series LC or RLC circuit are exactly equal. From this fact, Equation 25-1 is derived, which allows the calculation of f_r, the resonant frequency of the circuit.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad \text{.................... Equation 25-1}$$

At frequencies below resonance in a series RLC circuit, capacitive reactance is larger than inductive reactance, which can make the circuit impedance very large and the circuit current very small. At resonance, capacitive reactance is equal to inductive reactance, and the impedance is minimum and equal to the resistance in the circuit. This minimum impedance at resonance causes the circuit current to be at a maximum, assuming the circuit is driven by a voltage source. At frequencies above resonance, capacitive reactance is smaller than inductive reactance, which can again make the circuit impedance very large and the circuit current very small. Below resonance, the circuit phase angle will be negative since the circuit is capacitive. Above resonance, the phase angle will be positive. The phase angle makes a transition from -90° to 90° as frequency is increased through resonance.

Typical graphs of Z, I_g, and phase angle versus frequency are presented in Figure 25-1.

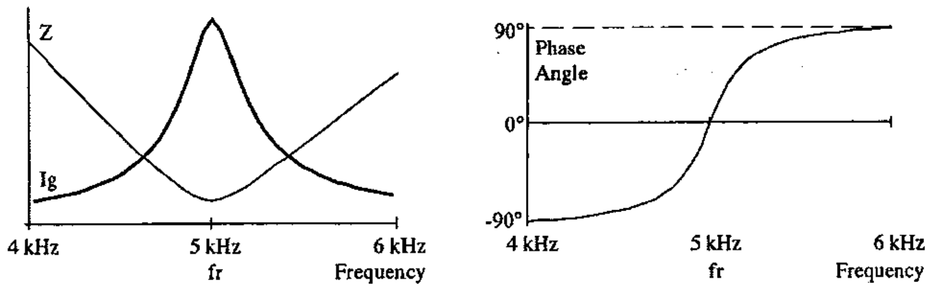


Figure 25-1. Impedance, Circuit Current and Phase Angle Versus Frequency

Q_S, the quality factor of a series resonant circuit is given by Equation 25-2, where R_S is the total series circuit resistance and includes any dc resistance within the inductor. Since Q_S is meaningful only at the resonant frequency, it may be determined using either inductive or capacitive reactance.

$$Q_S = \frac{X_L}{R_S} = \frac{X_C}{R_S} \quad \text{.......................... Equation 25-2}$$

A resonant rise in voltage occurs across both the capacitor and the inductor when at resonance. As an example, assume a series RLC circuit is driven by a 1.5 V source at the resonant frequency of 12 kHz. If, at that frequency, $\mathbf{X}_L = +j\ 495\ \Omega$, and $\mathbf{X}_C = -j\ 495\ \Omega$, and $R = 22\ \Omega$, the following will be true:

$$\mathbf{Z} = 22\ \Omega + j\ 495\ \Omega - j\ 495\ \Omega = 22\ \Omega + j\ 0\ \Omega = 22\ \Omega \angle 0°$$

$$\mathbf{I}_g = \mathbf{V}_g \div \mathbf{Z} = 1.5\text{ V} \angle 0° \div 22\ \Omega \angle 0° = 68.2\text{ mA} \angle 0°$$

$$\mathbf{V}_R = \mathbf{I}_g \times R = 68.2\text{ mA} \angle 0° \times 22\ \Omega = 1.5\text{ V} \angle 0°$$

$$\mathbf{V}_L = \mathbf{I}_g \times \mathbf{X}_L = 68.2\text{ mA} \angle 0° \times 495\ \Omega \angle 90° = 33.8\text{ V} \angle 90°$$

$$\mathbf{V}_C = \mathbf{I}_g \times \mathbf{X}_C = 68.2\text{ mA} \angle 0° \times 495\ \Omega \angle -90° = 33.8\text{ V} \angle -90°$$

For this circuit, Q_S is 495 Ω ÷ 22 Ω, or 22.5. The reactive voltages are equal to the source voltage multiplied by Q_S, which yields 33.8 V. This effect is called Q-multiplication of voltage. Although the reactive voltages are 180° out of phase, and cancel each other out, they are still individually present and measurable.

Lab Prep

The following preparation work may be completed as described below or by using circuit simulation software. Your instructor will describe which method you are expected to use.

1. Calculate the resonant frequency for the circuit of Figure 25-2 and record in Table 25-1.

2. Using the resonant frequency, calculate the inductive reactance of the inductor and record in Table 25-1.

3. In a previous experiment, you may have measured the dc resistance of the 56 mH inductor. Enter this resistance in Table 25-1. If you do not have this data, use a value of 43 Ω.

4. Add the coil resistance to the circuit value of R to obtain the total circuit resistance, R_S, and record in Table 25-1.

5. Calculate the circuit quality factor, Q_S, and record in Table 25-1.

Table 25-1. Theoretical Calculations

fr	X_L	R_{coil}	Rs	Qs

Procedure

Observing Resonance

1. Connect the circuit of Figure 25-2. Set the generator to about 1 V at a frequency of about 1 kHz.

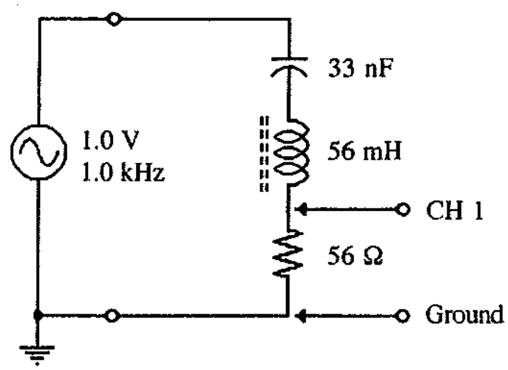


Figure 25-2. Series Resonant Circuit

2. Slowly increase the frequency until resonance is observed on the scope waveform. Remember that at resonance, the *Z* is at a minimum and current is at a maximum, therefore the resistor voltage should be at a maximum.

3. When resonance is reached, measure the resonant frequency and the voltage across the resistor and record in Table 25-2. Record this and other voltages in peak to peak units.

Table 25-2. Resonance Measurements

fr		V_L		Circuit Q	
V_R		V_C		C (used)	
Vg		Ig		fr (diff. C)	

4. Being careful not to disturb the generator settings, measure the generator voltage and the voltages across the capacitor and the inductor. If your generator is grounded, you will have to interchange the positions of the components to avoid ground loops. Record in Table 25-2.

5. Calculate the generator current using the measured resistor voltage and the 56 Ω resistance. Record in Table 25-2.

6. Calculate the *Q* of the circuit from the rise in capacitor voltage using $V_C \div V_g$. Record in Table 25-2.

7. Find the resonant frequency for this circuit using a different capacitor value. Record the capacitor value and the new resonant frequency in Table 25-2.

Measuring Resonance Characteristics

8. Connect the circuit of Figure 25-3. Set the scope to trigger on the channel 1 signal.

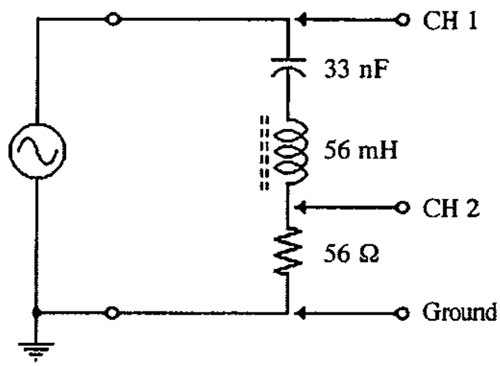


Figure 25-3. Series Resonance Measurement Circuit

NOTE: The following steps are critical to the success of this experiment. At resonance, the circuit impedance is at its lowest. This puts high demands on the signal generator and reduces its output voltage capability. Since generator voltage must be kept constant throughout this procedure, the generator settings used will be determined at resonance for your particular generator. If you make an error in any part it will be necessary to begin again at step 9.

9. Set the generator frequency to 1.0 kHz and the generator voltage to about 80% of its maximum amplitude or to 5.0 V, whichever is lowest.

10. Increase the frequency until the circuit is at resonance, as indicated by the generator voltage on CH 1 decreasing to a minimum. Make sure the CH 1 VOLTS/DIV VARIABLE control is in its calibrated position.

11. While at resonance, adjust the generator amplitude control and the CH 1 VOLTS/DIV switch until the CH 1 waveform is exactly 8.0 divisions vertically from peak to peak. Be sure the waveform is centered vertically on the scope graticule. This will be the reference waveform that you use to keep the generator voltage constant throughout this procedure.

12. From this point on, do not adjust either the CH 1 VOLTS/DIV switch, or the CH 1 VOLTS/DIV VARIABLE control. If you do, you will have to start over again.

13. Measure the resonant frequency with the scope and record in Table 25-3.

14. Measure the generator voltage on CH 1. Record in Table 25-3. Record this and all other voltages in peak to peak units. You can fill in the entire column for V_g in Table 25-3 with your measured value since this is the level which will be maintained.

15. Measure the resistor voltage on CH 2. Make sure the CH 2 VOLTS/DIV VARIABLE control is in its calibrated position. Record in Table 25-3.

16. Adjust the generator frequency to the lowest value in Table 25-3.

17. Adjust the generator amplitude control until the CH 1 signal is again at exactly 8.0 divisions vertically from peak to peak.

18. Measure the resistor voltage on CH 2. Record in Table 25-3.

19. Repeat steps 17 and 18 for all other frequencies listed in Table 25-3.

Table 25-3. Series Resonance Measurements

Settings		Measured	Calculated		
Frequency	Vg	V_R	Ig	Z	Phase
100 Hz					
300 Hz					
600 Hz					
1.0 kHz					
2.0 kHz					
3.0 kHz					
fr					
5.0 kHz					
6.0 kHz					
8.0 kHz					
10 kHz					
30 kHz					
60 kHz					
100 kHz					

20. Calculate I_g using: $V_R \div 56\ \Omega$, calculate Z using: $V_g \div I_g$, and calculate phase angle using: cos-1 ($V_R \div V_g$). The phase is negative below resonance and positive above. Record in Table 25-3.

21. Using data from Table 25-3, draw graphs of I_g, Z, and phase angle versus frequency as required on the Data Sheet.

25 Prep Sheet

Name ______________________

1. Complete the data required for Table 25-1 below.

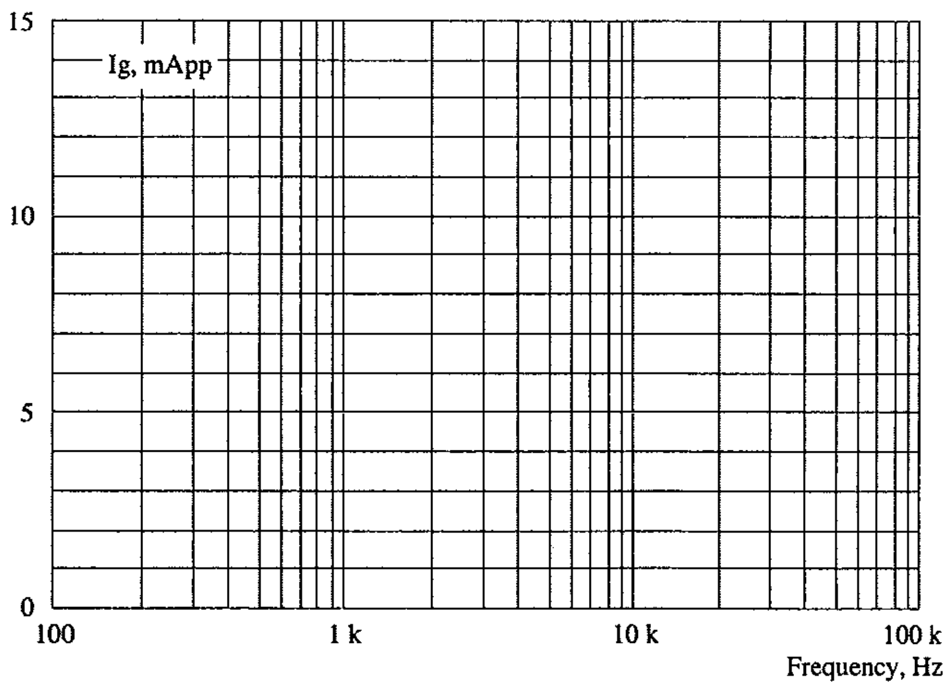
fr	X_L	R_{coil}	Rs	Qs

25 Data Sheet Name

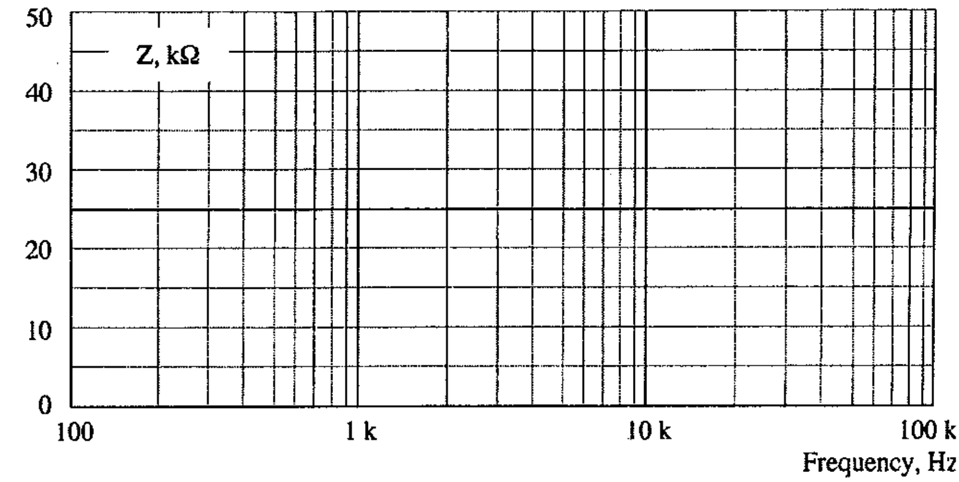
1. Complete the data required for Table 25-2 below.

fr		V_L		Circuit Q	
V_R		V_C		C (used)	
Vg		Ig		fr (diff. C)	

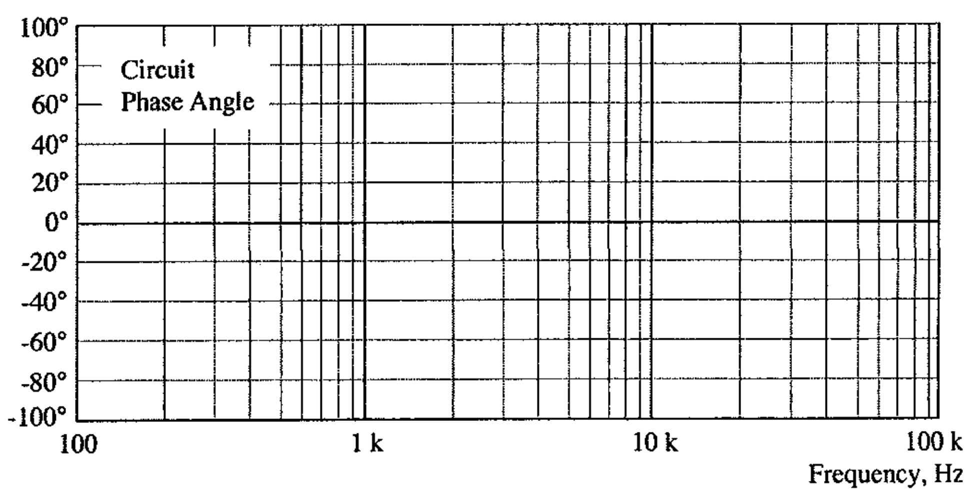
2. Using your data from Table 25-3, draw a graph of I_g versus frequency on the graph provided below. It may be necessary for you to alter the given scales for best presentation of your data.



3. Using your data from Table 25-3, draw a graph of Z versus frequency on the graph provided below. It may be necessary for you to alter the given scales for best presentation of your data.



4. Using your data from Table 25-3, draw a graph of circuit phase angle versus frequency on the graph provided below.



Questions

1. Compare the calculated resonant frequency from Table 25-1 with the measured resonant frequency from Table 25-2. Account for any differences.

2. Compare the theoretical Q_S calculated in Table 25-1 with the Q rise in voltage determined in Table 25-2. Account for any differences in the Q values.

3. Refer to Table 25-2. Calculate the theoretical f_r for the different capacitance value used in step 7, and compare this to the measured f_r.

4. Explain why your minimum impedance value determined in Table 25-3 was not 56 Ω.

5. Comment on how well your graphs displayed the characteristics of a series resonant circuit. Did your graphs meet the objectives of this experiment?

26 Basic Op-Amp Circuits

Objectives

1. To study the ac characteristics of the non-inverting op-amp configuration.
2. To study the ac characteristics of the inverting op-amp configuration.
3. To observe the 180° phase shift associated with the inverting op-amp configuration.
4. To simulate non-inverting and inverting op-amp circuits using available software.

Equipment

8 Resistors: 1 kΩ, 10 kΩ, 33 kΩ, 39 kΩ, 68 kΩ, 180 kΩ, 220 kΩ, 820 kΩ
1 LM741 operational amplifier

Information

The basic non-inverting op-amp configuration is shown in Figure 26-1. The operational amplifier itself, within the triangle, has a very large open loop voltage gain, a reasonably high Ri and a fairly low Ro. These are all desirable characteristics. Resistors R1 and R2 are feedback resistors which generally improve the amplifier's characteristics at the expense of voltage gain. At the same time, the voltage gain is stabilized to a particular value, which is also a desirable characteristic.

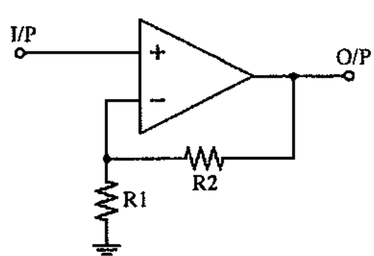


Figure 26-1. Basic Non-Inverting Amplifier

The op-amp with feedback will have characteristics determined mostly by the two external resistors. The characteristics of the non-inverting op-amp are given in Equations 26-1, 26-2 and 26-3.

$$R_i = \infty\,\Omega \qquad \text{. . . . . Equation 26-1}$$

$$R_o = 0\,\Omega \qquad \text{. . . . . Equation 26-2}$$

$$A_v = \frac{\mathrm{R1} + \mathrm{R2}}{\mathrm{R1}} \qquad \text{. . . . . Equation 26-3}$$

Sometimes an additional resistor is connected from (+) to ground in order to set the input resistance to a specific value. A very common configuration of the non-inverting op-amp is the "buffer" amplifier used to isolate stages. The buffer is made by replacing R2 in Figure 26-1 with a short circuit, and replacing R1 with an open circuit. Equation 26-3 will show that this will provide a voltage gain of exactly one.

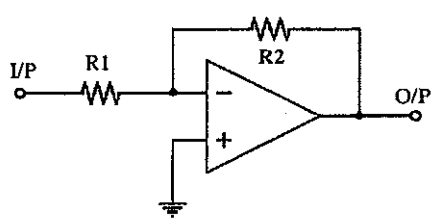


Figure 26-2. Basic Inverting Amplifier

Figure 26-2 illustrates the basic inverting op-amp configuration. Again, the characteristics are determined largely by the external biasing resistors, and are given in Equations 26-4, 26-5 and 26-6.

$$R_i = \mathrm{R1} \qquad \text{. . . . . Equation 26-4}$$

$$R_o = 0\,\Omega \qquad \text{. . . . . Equation 26-5}$$

$$A_v = \frac{-\mathrm{R2}}{\mathrm{R1}} \qquad \text{. . . . . Equation 26-6}$$

Integrated Circuit Measurement Precautions

1. Set DC power supply voltages without any circuitry connected, then turn the supplies OFF.
2. Connect the circuit under test. If a generator is connected, be sure it is turned OFF.
3. Carefully double-check all connections, then switch the DC power supplies ON.
4. After confirming correct DC operation, the generator may be switched ON.
5. To make a circuit change, turn the generator OFF first, then turn the DC supplies OFF.

Circuit Simulation

If circuit simulation software is not available, the student may complete the required theoretical calculations for Ri, Ro and Av below using formulae presented earlier.

1. Simulate the circuit of Figure 26-3 using available software. Use a generator set to 100 mV and 1.0 kHz.

2. Complete the circuit measurements of Vg, Vi, Vo and Voc required to calculate Ri, Ro and Av as required for Table 26-1.

Table 26-1. Non-Inverting Amplifier Simulator Measurements

Vg	Vi	Vo	Voc	Ri	Ro	Av

3. Simulate the circuit of Figure 26-4 using software. Use a generator set to 500 mV and 1.0 kHz.

4. Complete the circuit measurements of Vg, Vi, Vo and Voc required to calculate Ri, Ro and Av as required for Table 26-2.

Table 26-2. Inverting Amplifier Simulator Measurements

Vg	Vi	Vo	Voc	Ri	Ro	Av

Procedure

Non-Inverting Amplifier Measurements

1. Connect the circuit of Figure 26-3 using an 8-pin LM741 op-amp.

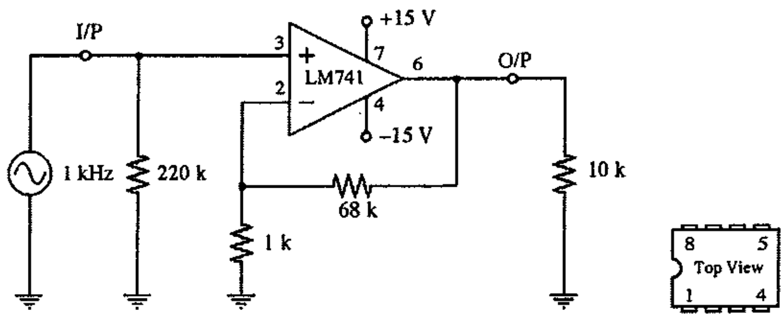


Figure 26-3. Non-Inverting Amplifier Circuit

2. Using a 180 kΩ sensing resistor, and the techniques learned in earlier experiments, complete the four amplifier measurements required for Table 26-3. Use a generator frequency of 1 kHz.

Table 26-3. Amplifier Measurements

Voc	Vo	Vg	Vi

3. Using the data measured in Table 26-3, calculate the amplifier characteristics required for Table 26-4.

Table 26-4. Amplifier Calculations

Ii	Io	Ri	Ro	
Avo	Av	Ai	Ap	Units
				None
				dB

4. Check the input signal and the output signal simultaneously to make sure that there is 0° phase shift in this amplifier.

Inverting Amplifier Measurements

5. Connect the circuit of Figure 26-4 using an 8-pin LM741 op-amp.

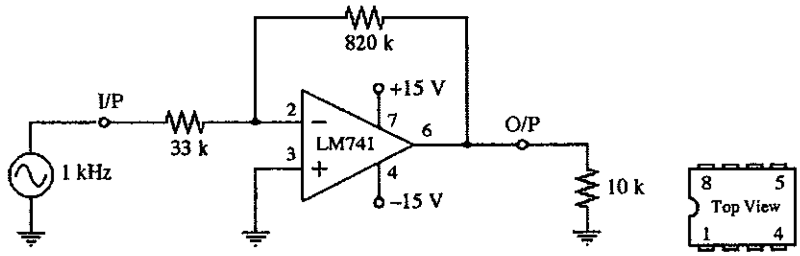


Figure 26-4. Inverting Amplifier Circuit

6. Using a 39 kΩ sensing resistor, and the techniques learned in earlier experiments, complete the four amplifier measurements required for Table 26-5. Use a generator frequency of 1 kHz.

Table 26-5. Amplifier Measurements

Voc	Vo	Vg	Vi

7. Using the data measured in Table 26-5, calculate the amplifier characteristics required for Table 26-6.

Table 26-6. Amplifier Calculations

Ii	Io	Ri	Ro

Avo	Av	Ai	Ap	Units
				None
				dB

8. Check the input signal and the output signal simultaneously to make sure that there is 180° phase shift in this amplifier.

9. If you have any time remaining, connect a buffer amplifier using the 8-pin LM741 op-amp, as described in the information section of this experiment.

1. Complete the simulator data required for Table 26-1 below.

Vg	Vi	Vo	Voc	Ri	Ro	Av

2. Complete the simulator data required for Table 26-2 below.

Vg	Vi	Vo	Voc	Ri	Ro	Av

26 Data Sheet Name

1. Complete the data required for Table 26-3 below.

Voc	Vo	Vg	Vi

2. Complete the data required for Table 26-4 below.

Ii	Io	Ri	Ro

Avo	Av	Ai	Ap	Units
				None
				dB

3. Complete the data required for Table 26-5 below.

Voc	Vo	Vg	Vi

4. Complete the data required for Table 26-6 below.

Ii	Io	Ri	Ro

Avo	Av	Ai	Ap	Units
				None
				dB

Questions

1. Refer to Table 26-3. Explain why the measurements of Voc and Vo are the same, within measurement accuracy.

2. Calculate the theoretical Ri, Ro and Av for the circuit of Figure 26-3 and compare these values to those determined from measurements.

3. Calculate the theoretical Ri, Ro and Av for the circuit of Figure 26-4 and compare these values to those determined from measurements.

4. If you had time to complete step 9 of the procedure, describe your observations.