Creative Inquiry Electronics Project

Lab Manual

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Introduction

This document is based on the “Learn-by-Doing”® principle because simply reading about a technical subject is not the best way to learn. After all, you don't read about putting together a jigsaw puzzle, you put the puzzle together to solve the picture! Reading about a maze may help you to move through but doing the maze gives you the course you must take to get through it. Engineering is the same way. You must actually build circuits and programs in order to really understand the concepts.

The topics are covered in a straightforward, simplified manner which allows you to quickly understand the fundamental principles. After the main topic of each chapter is introduced, sub-topics are explored in a step by step manner with explanations given for each new engineering principle. Each chapter contains single topic-usually. First, you read about the topic and then you see examples that let you work in the virtual world to understand how the concepts can be applied to actual circuits. You then work in the real world with real electronic components to see how they differ from the mathematical models and what their limitations might do to an engineered design.

Each section finishes with a review of what was covered in the material in that section. The principles usually come from the text or are deducible from the text, but occasionally you might need to experiment a little to really understand how to use them. After completing each section you'll begin to understand more of the concepts and realizing that now you know the answers can be a big confidence builder.

LabVIEW Package and Driver Installation Tutorial

It is important that student should install all the required software for the course before continuing to next section. A tutorial is provided on course webpage for step by step installation of the LabVIEW, NI Multisim and MyDAQ drivers.

WARNING: SHOCK HAZARD

Never connect any component or lead to electrical outlets in any way

WARNING: EXTERNAL POWER SOURCES

Use external power sources or batteries at your own risk as they may cause damage to components or Computer USB ports.

Basic Troubleshooting

1. Most circuit problems are due to incorrect assembly, always double check that your circuit exactly matches the drawing for it.
2. Be sure that parts with positive or negative markings are positioned as shown in the drawings.
3. Be sure that all connections are securely fastened.
4. Always use a power switch to remove power when building circuits.
5. Always check circuits before turning on power.
6. Use myDAQ digital multi-meter (DMM) to test MySnap components if they appear to be damaged or not working properly.
7. Use eye protection when experimenting on your own circuits.
8. Always remove power if circuit does not perform properly, and then use myDAQ DMM to check circuit for shorts or opens.

Files on ENGR190_VIs.zip

The ENGR190_Vis.zip file is available to students on following course webpage.

www.clemson.edu/ces/departments/ece/undergrad/ElectronicsProject.html

Students should download above file and unzip in on his/her computer. The Zip file contains LabVIEW VIs and other files which will be used in some of the experiments during the course.

- Resistors.pdf - Description of how resistors are manufactured and constructed.
- Cap.gif - Water pipe analogy of a Capacitor.
- Coil.gif - Water pipe analogy of an Inductor.
- Diode.gif - Water pipe analogy of a diode.
- RinParallel.gif - Water pipe analogy of two resistors in parallel.
- **VI's on zip file:** C_Meter.vi, Diode.vi, LCR_Meter.vi, PartsTest1.vi, R_Graph.vi, RinSeries.vi, Karaoke myDAQ.vi

Lab 01: myDAQ, LabVIEW®, and MySnap™

1.1 Overview

This section explores using a National Instruments myDAQ to measure the resistance Conductors, Insulators, and Resistors. The measurements will be taken with the myDAQ DMM (Digital Multi-Meter). The components needed are supplied in the MySnap™ kit for myDAQ. Real life applications apply to any occupation that uses electrical components or devices.

1.2 Topics covered in Lab 01

- Objective
- What You Need
- Instructions
- Resistors
- Insulators
- Review
- myDAQ and LabVIEW®
- Building the Front Panel
- Coding Strategy
- How It Works
- Storing Data
- Tips and Tricks

1.3 Objective:

Use the DMM terminals on the NI myDAQ and LabVIEW to measure and record the DC resistance of various conductors, resistors, and insulators supplied in the MySnap™ kit.

1.4 What You Need:

- NI myDAQ
- Computer with LabVIEW and NI ELVISmx installed
- MySnap™ kit

1.5 Instructions:

Assemble the circuit shown in Figure 1-3 using MySnap kit.

Connect the myDAQ to your computer system with the proper software installed.

Click on the DMM button in the Instrument Launcher when it appears.

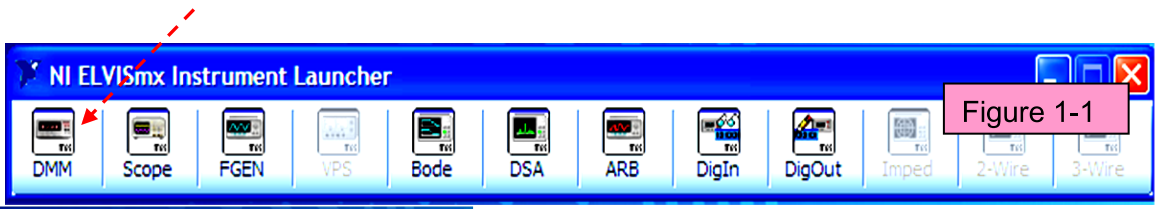


Figure 1-1

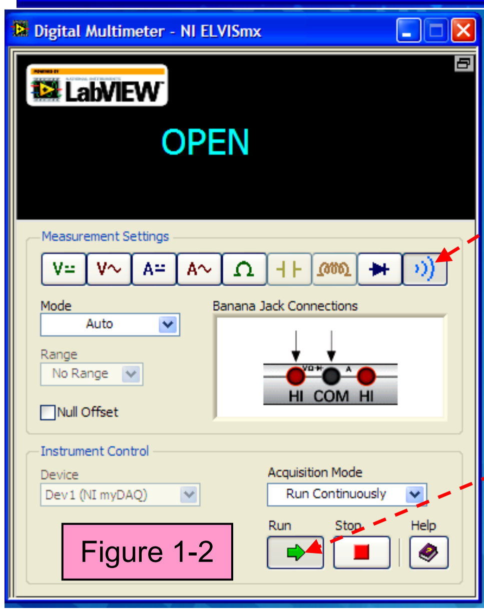


Figure 1-2

When the Digital Multimeter window appears;

- Click on the run button.
- Click on the sound button.
- Connect leads as shown below.

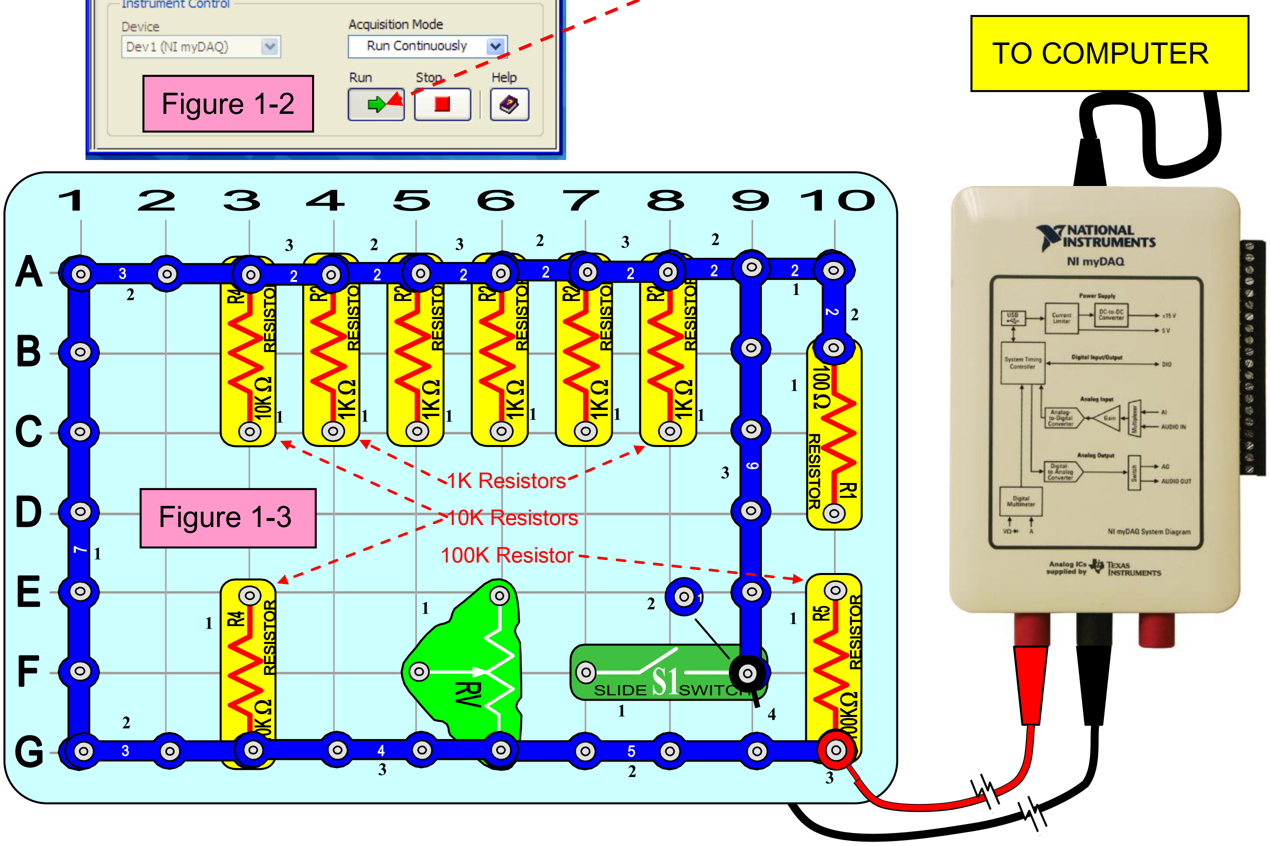


Figure 1-3

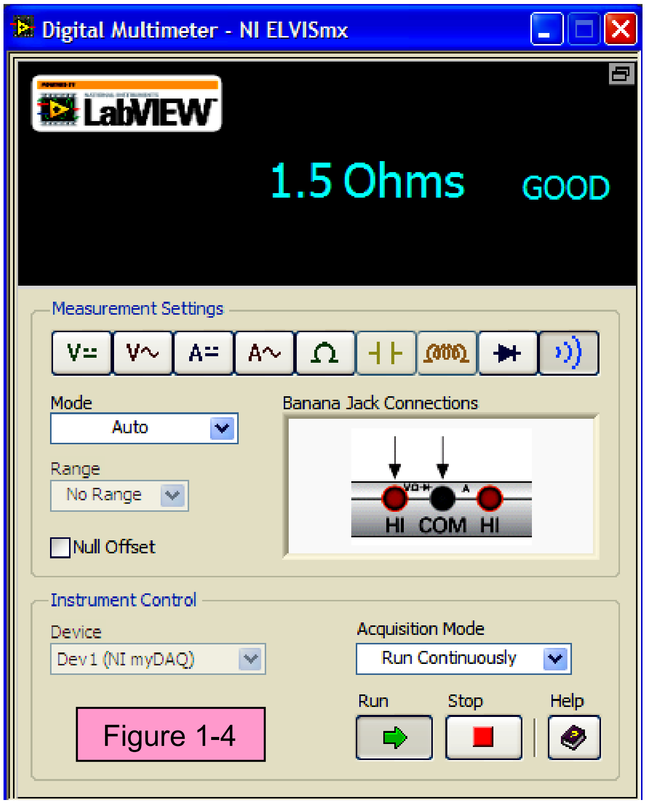


Figure 1-4

The DMM should appear as shown in Figure 1-4 and if computer sound is activated a beep will indicate a low resistance. The actual value of the resistance is shown on the display as 1.5 Ohms and should be less than 3 ohms for your reading. The resistance measured is for the red snap lead, shorting snap wires 1(x1), 2(x6), 3(x2), 4, 5, 6, & 7, and the black snap lead all in series. Like garden hoses connected one after the other, the same current flows through each conductor. If any one of these is open the DMM will read as OPEN. Snap the red and black DMM leads across press switch S2 to verify that it is near zero when ON and OPEN when OFF. The lowest the DMM ohm scale can read is 0.1 ohms. Snap the meter lead tips together and observe the amount of resistance in the leads themselves. This process can be repeated for each snap piece connected to the series chain by placing the DMM red snap lead on the open end of that component.

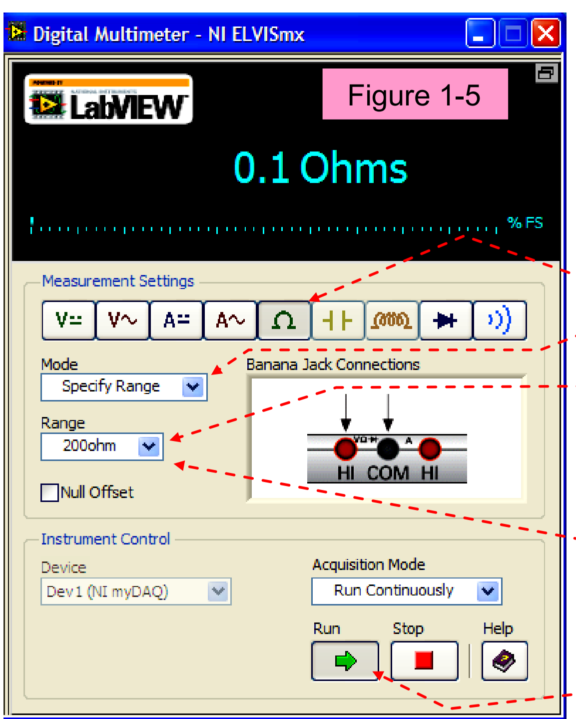


Figure 1-5

Click Run button

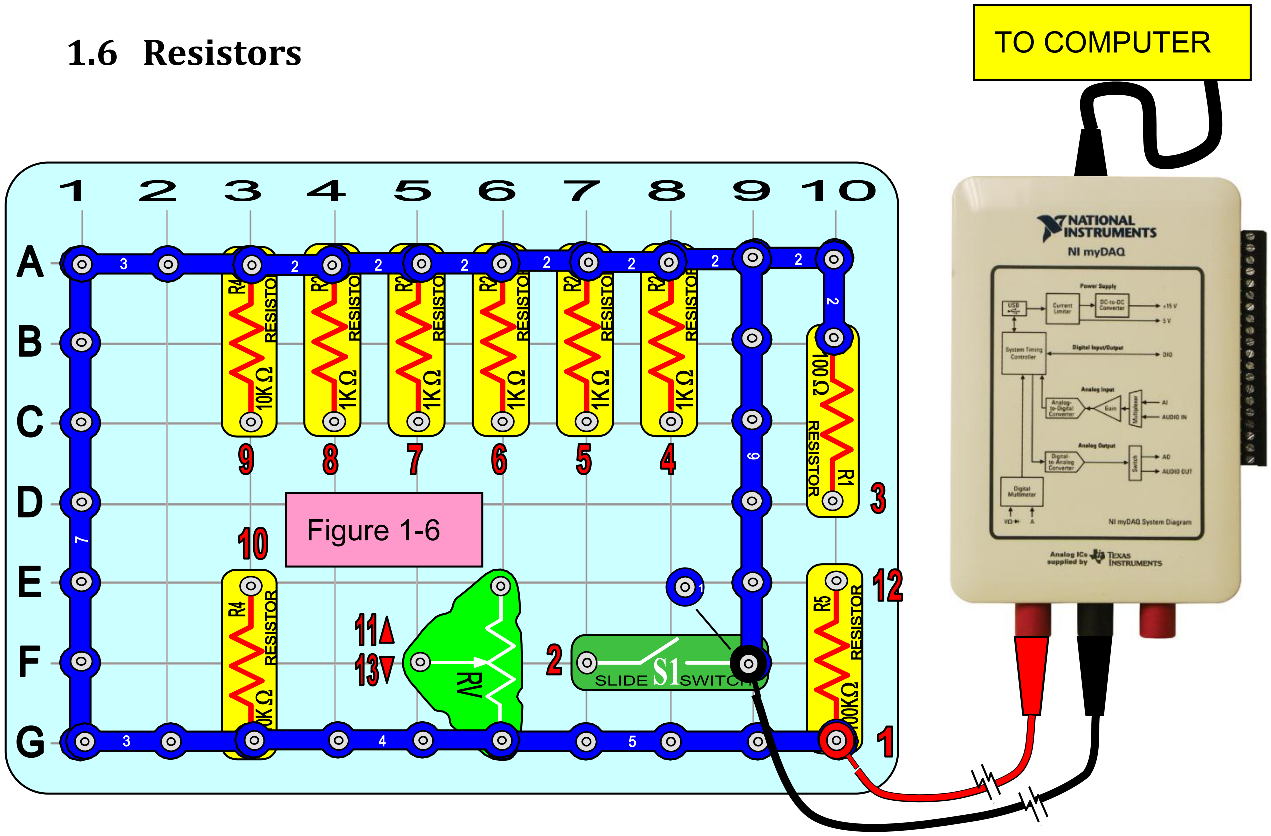
Click on Ω button

Change to Specify Range

Set range to 200 ohms

Snap the DMM leads together to read their resistance then change the range level to next highest level. On this range, anything below 1 Ω will read 0.

1.6 Resistors



Change the mode to Auto on the Ohm Measurement Setting of your myDAQ DMM and read the values for the resistors by placing the red probe snap at:

PRINT LAST PAGE IN THIS MANUAL FOR YOUR WORKSHEET

1 Strips (1-7 in series) Value of reading _________(shown above)

2 $S1_{ON}$ Value of reading ____________________

2 $S1_{OFF}$ Value of reading ____________________

3 R1 Value of reading ____________________

4 R2 Value of reading ____________________

5 R2 Value of reading ____________________

6 R2 Value of reading ____________________

7 R2 Value of reading ____________________

8 R2 Value of reading ____________________

9 R4 Value of reading ____________________

10 R4 Value of reading ____________________

11 RV_{max} SLIDER UP Value of reading ____________________

12 R5 Value of reading ____________________

13 RV_{min} SLIDER DOWN Value of reading ____________________

1.7 Insulators

Using the DMM pointed probes try measuring the resistance of the myDAQ case, the MySnapTM base grid, or the outside of the wire on the jumper leads. Take care when measuring wire insulation and do not push points into the insulation. Use the flat side of the probe tips.

1.8 Review

- Conventional electric current moves from the positive surplus side of the battery (+) to the deficiency side of the battery (-)
- **Conductors** allow electrical current to easily flow because of their free electrons.
- **Resistors** allow current to flow to some degree in proportion to their resistance in ohms.
- **Insulators** oppose electrical current.
- The MySnapTM system includes components that can be classified as conductors, resistors, or insulators.
- The myDAQ DMM can be used to determine the class of a component and can measure the value of resistance in most components that are not insulators or good conductors.

1.9 MyDAQ® and LabVIEW®:

LabVIEW® was designed to quickly check and record electronic data. In this section you will use LabVIEW® to measure and record the resistance values of the components you measured previously. Each part will be measured and data recorded in a similar fashion to the testing performed when these components were manufactured. The numeric indicator will display the instantaneous value and the table will store the data when the record button is clicked. The values will be graphed for a quick visual display of all the values.

Open LabVIEW program that has been installed on your computer. When the getting started screen appears, pick the Blank VI option to build the program that will be used to check your MySnapTM parts. Your process will be as follows;

1.) Build the front panel screen.
2.) Open the programming window and build program to drive front panel.
3.) Measure, Display, and Store resistive data about each part.

1.10 Building the Front Panel:

After opening a blank VI, right click on the background and bring up the Controls Express screen.

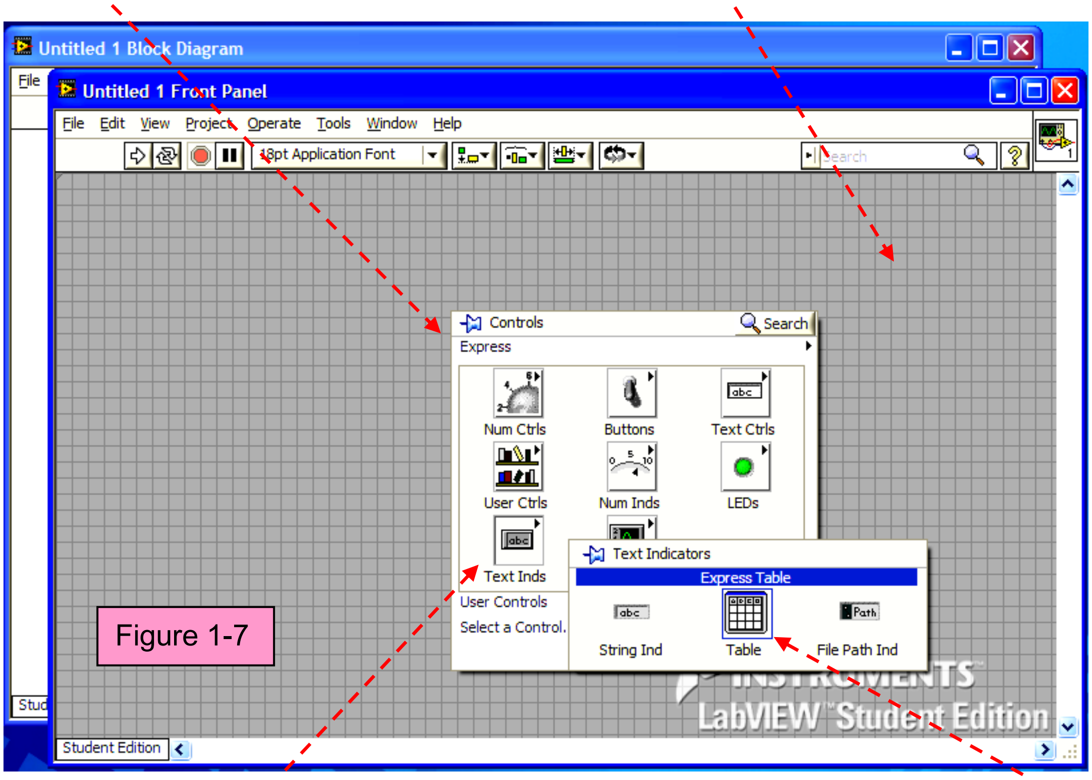
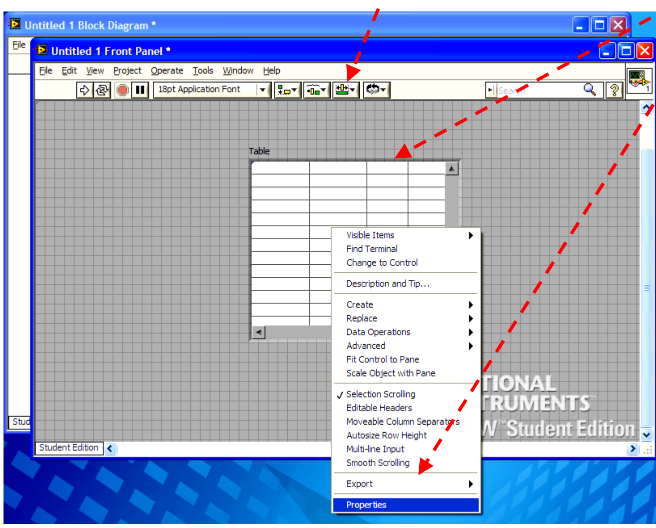
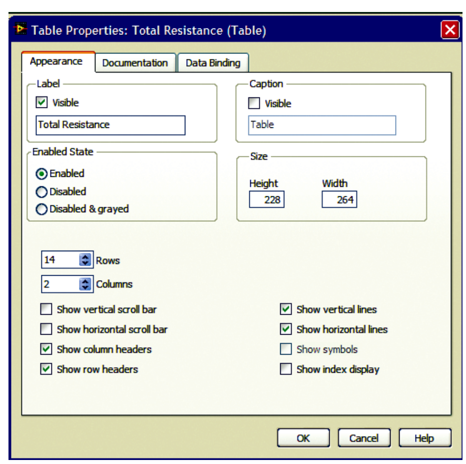


Figure 1-7

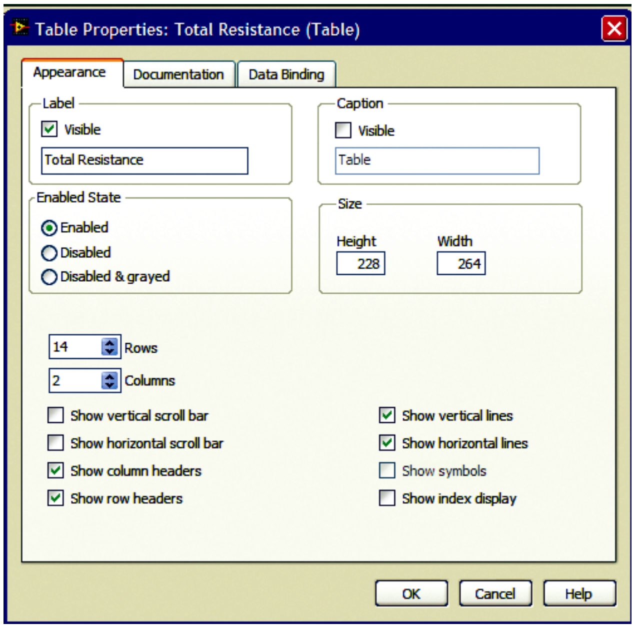
Click on the Text Inds to bring up the Express Table then click on the Table Icon and place it on the front panel.

Right click on the table and open the properties window to make the table that will record the data we are going to measure.





Figures 1-8



Change table appearance to settings shown here. Ignore Height and Width settings.

Figure 1-9

Save the front panel as PartsTest1.VI. Add the XY graph screen by;

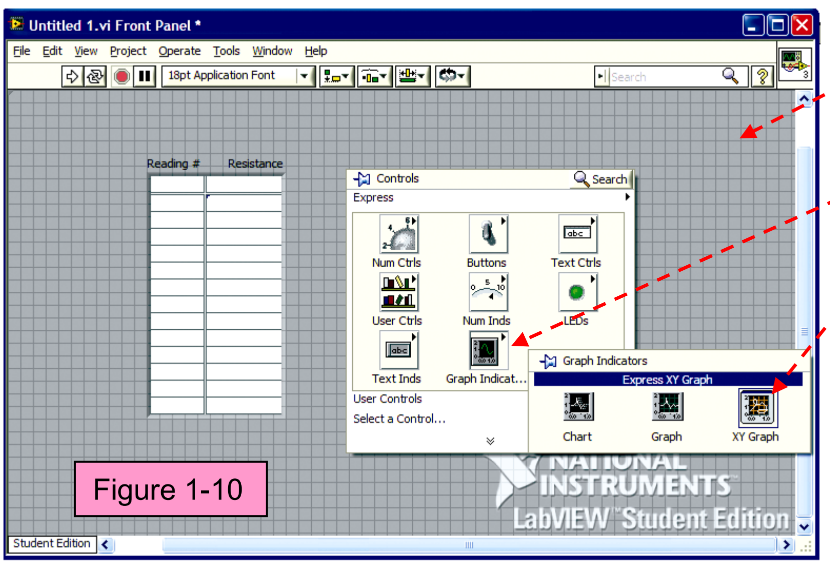


Figure 1-10

Right click to get the Express menu,

Then click on the Graph icon to get the XY Graph and place it on the front panel next to the table as shown on the next page.

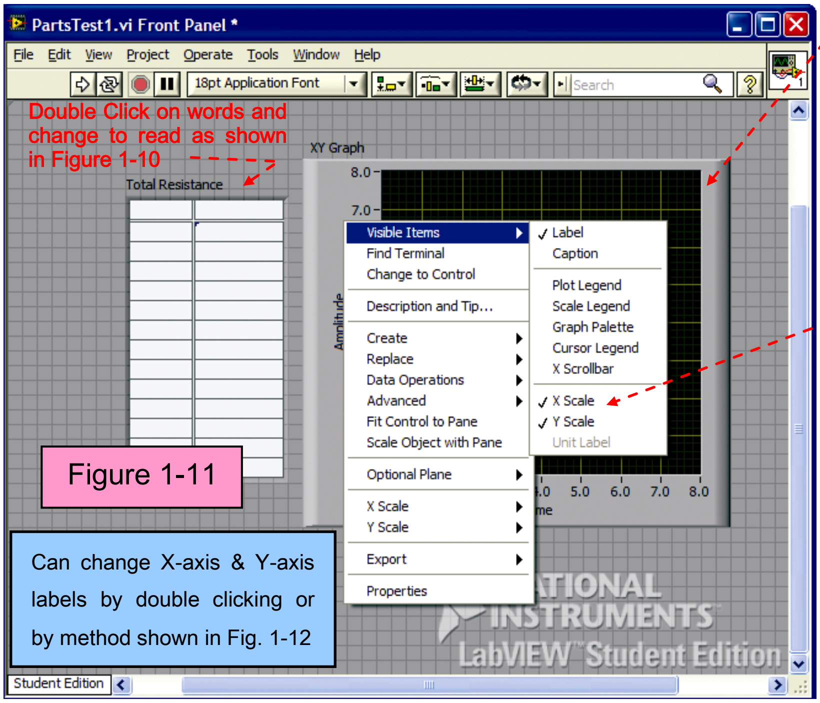
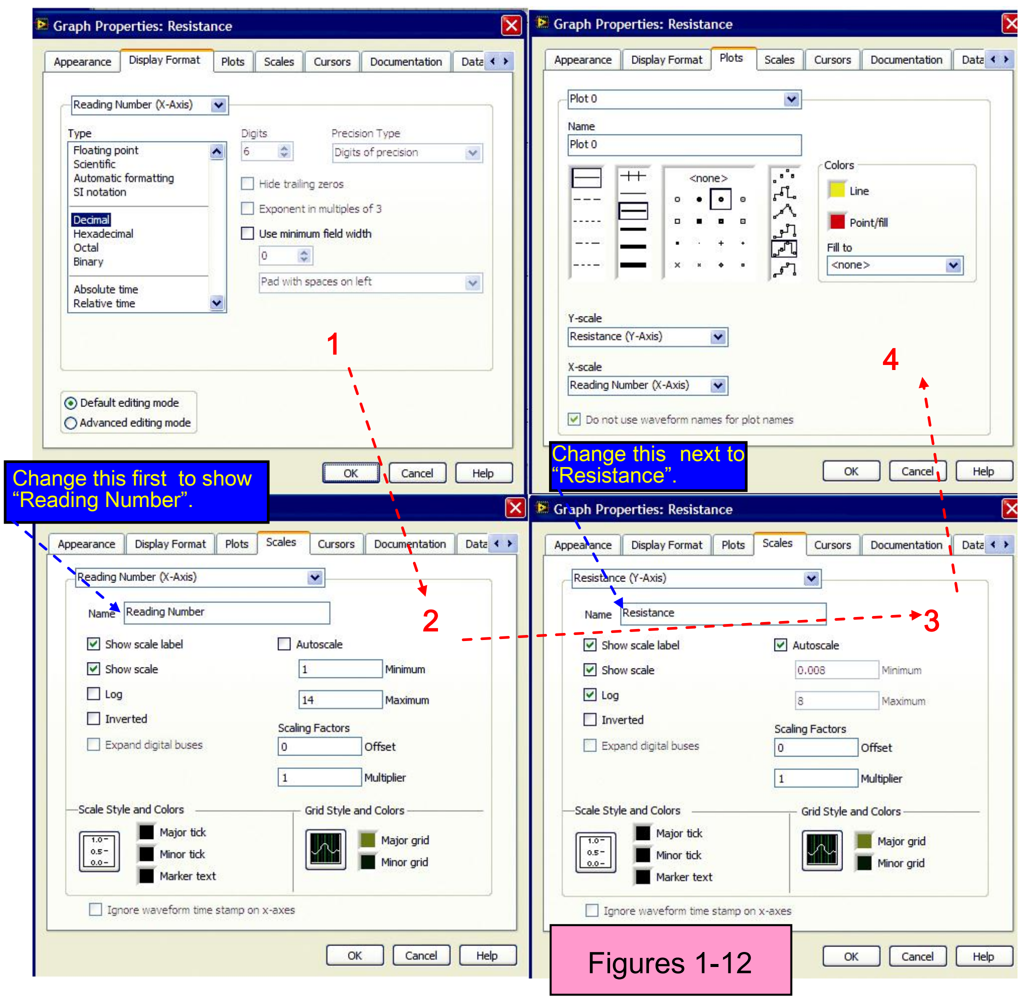


Figure 1-11

Right click on the XY Graph frame to bring up its menu and select visible pane. Adjust the visible items as shown on next page. Set checked items as shown here. Click on Properties and make changes shown in blue boxes first then set the other properties in the order shown in the red boxes below.



Figures 1-12

After adjusting the graph, add the row headings for the measurements to the table.

Then add two indicators by right clicking the front panel and picking the Num Inds icon from the Express menu.

Finally add the buttons shown here.

Record was an OK button with text changed to RECORD.

Under window on the main menu click "Show Block Diagram". A window similar to the following will open;

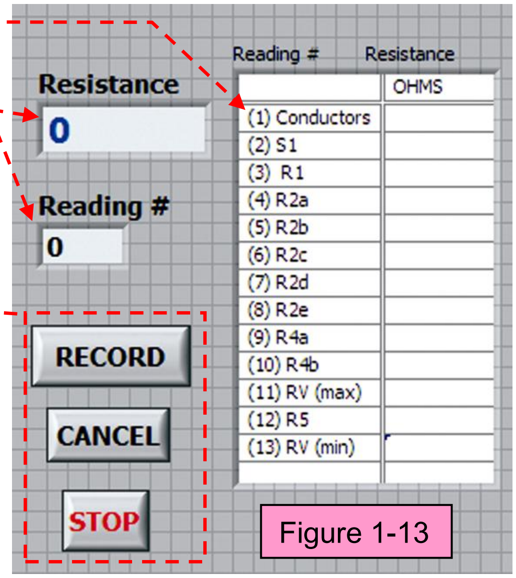


Figure 1-13

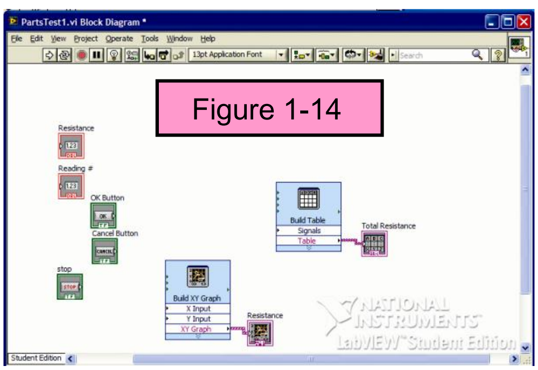


Figure 1-14

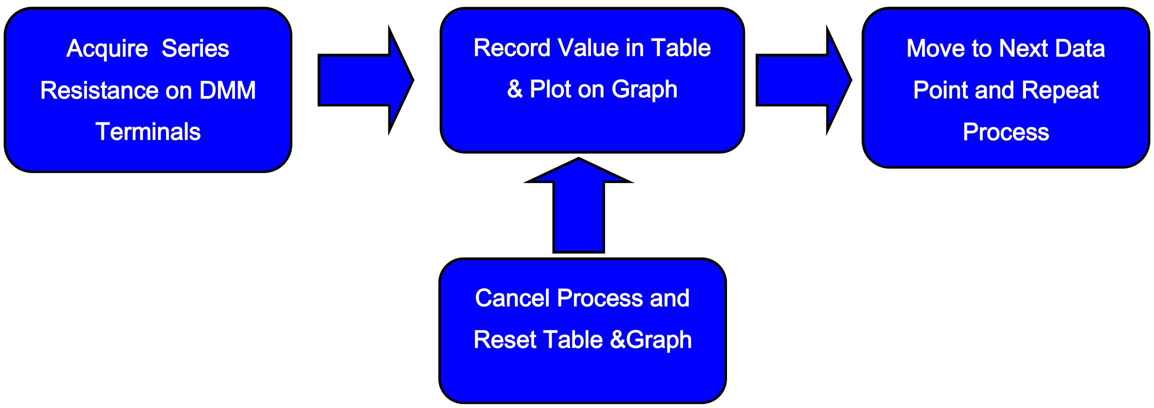
Before we proceed with the coding, let's add the myDAQ multi-meter to the block diagram by following these steps.

1. Be sure your myDAQ is connected
2. Press Ctrl-Space to bring up the Quick Drop Window (takes a few minutes to load on the first use)
3. Search for DAQ Assistant and double click on it when it appears in the list
4. Drop it on the Block diagram (white window)
5. When the Create a New Express Task configuration pane appears, select
    a. Acquire Signals
    b. Analog Input
    c. Resistance
    d. Dev 1 (NI myDAQ) **Note: If you have other NI hardware installed, the myDAQ will not be Dev1.*
    e. DMM
    f. Finish
6. Timing Settings should be 1 Sample (On Demand), Iex Source should be set to Internal, and Signal Input Range should be 200K in top box and 0 in bottom box.
7. Press OK

1.11 Coding Strategy:

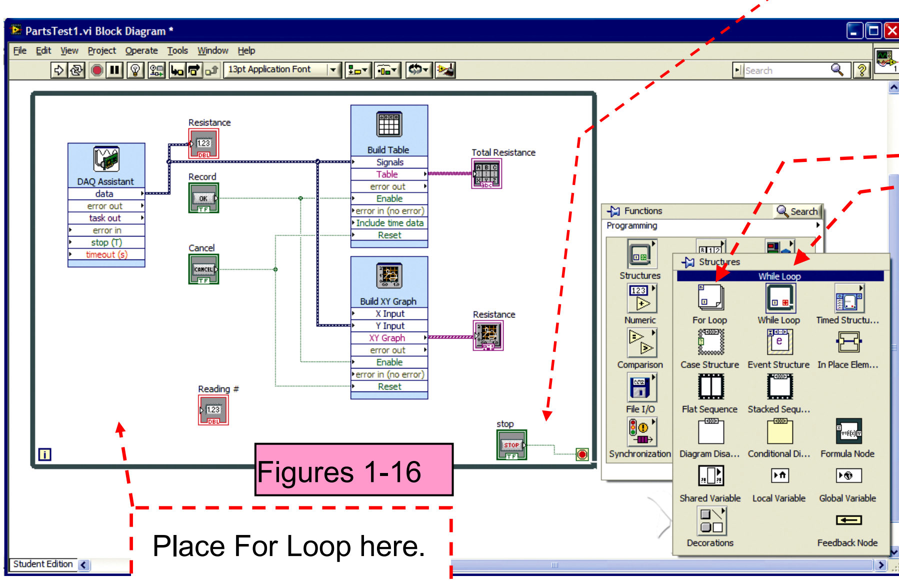
A front panel to display the resistance values in a numerical indicator, a table to store this data, and a graph to display data has been created in LabVIEW®. We will acquire the data using the DAQ Assistant you just placed on the block diagram and then pass the data to the indicator. After the reading appears, we will store the data in the table and on the graph. The reading number is then incremented, the resistance probe is moved, and the process is repeated.

Figure 1-15: Coding Block Diagram



The LabVIEW® block diagram will be very similar to the coding block diagram. After some wiring and clean up, add a “while Loop” to repeat the process.

Right Click on white area or empty space to bring up programming window. Click on while loop under structures and use it to surround all the objects in the block diagram. Add wiring from stop button and data source.



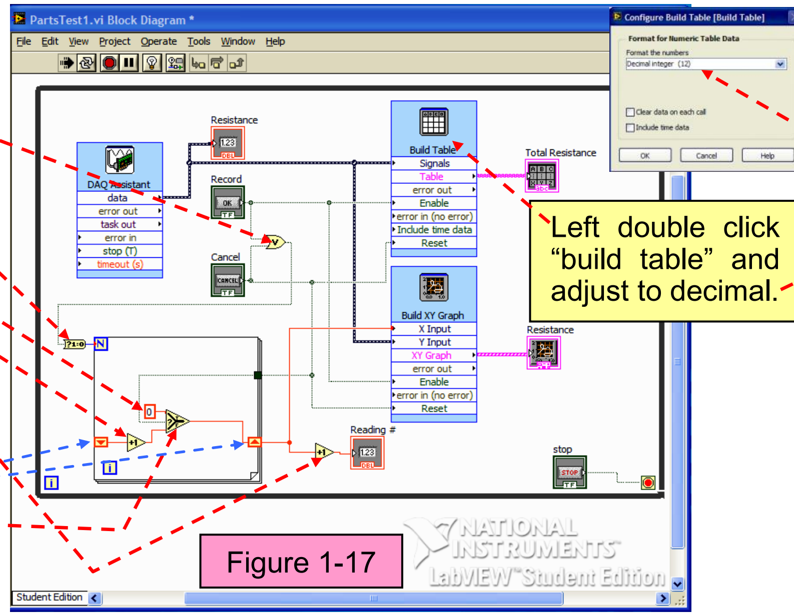
Use this icon to add for Loop.

To expand the boxes use pull down arrow at bottom of box.

It is highly recommended to learn LabVIEW® you add logic and numeric functions to block diagram as shown here and save your work as PartsTest1.VI.

Items added ……
From Boolean;
OR Gate
Bool to 0,1
From Numeric;
DBL Numeric
Increment
From Comparison;
Select

Replace tunnels with shift register to get orange arrows by right click on tunnel.



Left double click "build table" and adjust to decimal.

Figure 1-17

LabVIEW® PartsTest1 Block Diagram

Run LabVIEW® and PartsTest1.VI from ENGR190_Vis.zip or your saved program to open the front panel screen. With S1 "ON", use Figure 1-6 to move red snap lead to the number shown in the Reading # indicator before clicking the record button.

Y scale has been changed from log to linear, and from automatic to min of –1100 and max of 110000.

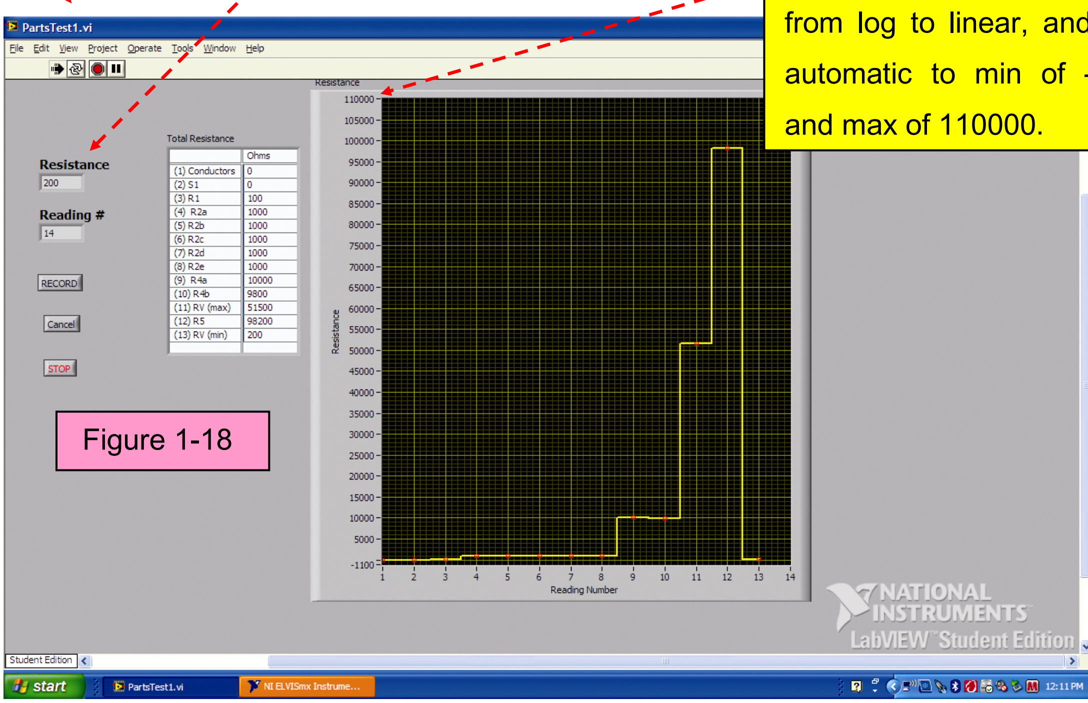


Figure 1-18

{THE PREVIOUS VIRTUAL INSTRUMENT WAS SHOWN IN DETAIL TO HELP THE USER UNDERSTAND THE POWER OF LABVIEW®. FUTURE VI'S WILL BE PROVIDED WITHOUT THIS IN DEPTH DETAIL.}

1.12 How It Works:

Inside the while loop on the upper-left is the DAQ Assistant used to input the resistance data from the DMM terminals. The resistance values are indicated on the front panel in the Measurements numeric indicator labeled "Resistance". In this VI the DAQ Assistant is configured for on-demand input on the analog channel. Therefore every time the red snap lead is moved, the Resistance Indicator will be updated. After the record button is clicked, the Reading number will increment for the next reading. The red snap in Figure 1-7 should always be on the number label that is the same as the Reading # when the record button is clicked.

1.13 Storing Data:

After table is populated with data and the graph is finished, they can be stored in a word document, spread sheet, or picture file by right clicking on the front panel object and using the export menu. Figure 1-19 shows "Export Simplified Image" storage of the data and chart shown in Figure 1-18.

Total Resistance

	Ohms
(1) Conductors	0
(2) S1	0
(3) R1	100
(4) R2a	1000
(5) R2b	1000
(6) R2c	1000
(7) R2d	1000
(8) R2e	1000
(9) R4a	10000
(10) R4b	9800
(11) RV (max)	51400
(12) R5	98200
(13) RV (min)	200

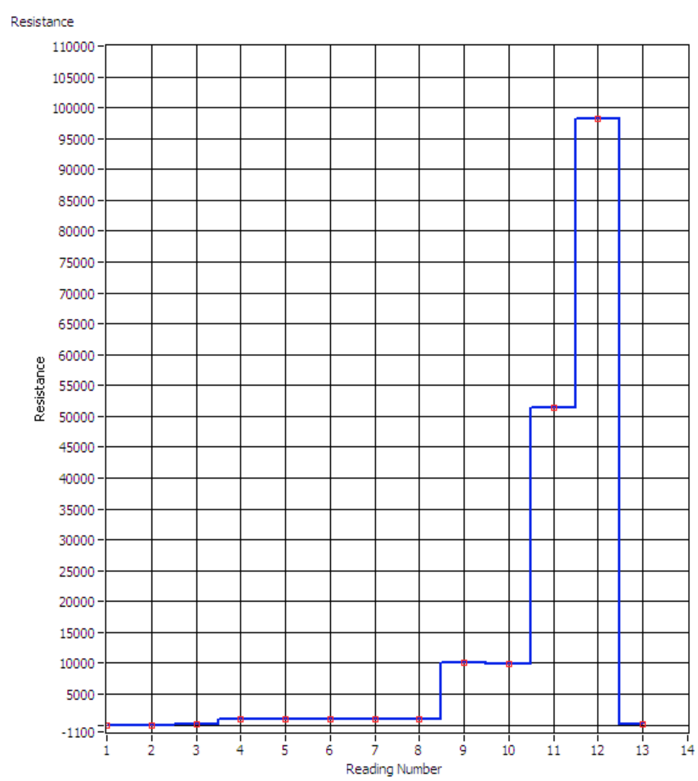


Figure 1-19

1.14 Tips and Tricks:

- Run the animated gif file called RinParallel.gif that is on the MySnap™ disc for an analogy of resistance using water pipes. The top water pipe is filled with rocks and has low resistance, while the lower pipe is filled with sand and has high resistance.
- Review the Resistors.pdf file for more information on how resistors are manufactured and the different types of resistors.
- Use the R_Colors.exe program on MySnap™ disc to get values of standard resistors and to determine their markings. You can use the phrase { Blacky Brown Rode Our Young Green Bull " Violence Gone Wild"} to remember the value of each color.

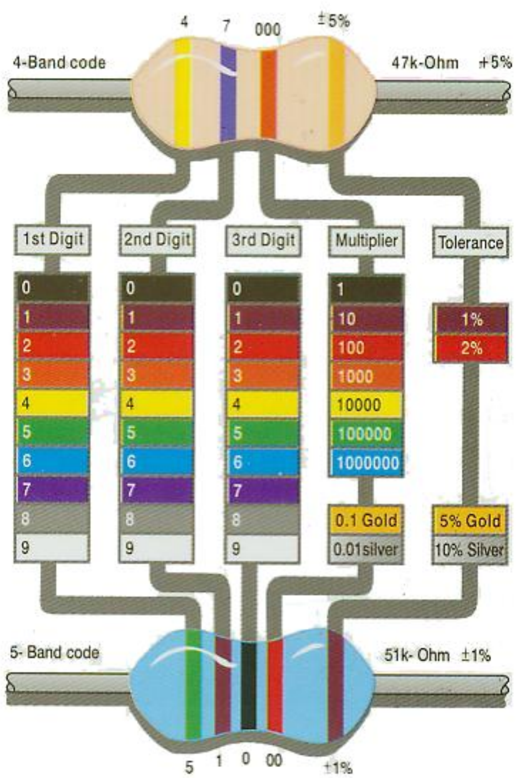


Figure 1-20

BLACKY	= BLACK	= 0
BROWN	= BROWN	= 1
RODE	= RED	= 2
OUR	= ORANGE	= 3
YOUNG	= YELLOW	= 4
GREEN	= GREEN	= 5
BULL	= BLUE	= 6
VIOLENCE	= VIOLET	= 7
GONE	= GREY	= 8
WILD	= WHITE	= 9

A four band resistor is shown in the chart on the left using the color code above. On the bottom of the chart a five band resistor is shown. Note that one band is used as a multiplier to cover the full range of resistance. The R_Colors.exe program on the MySnap™ CD will also tell you if the value is available and can be bought from standard sources.

Lab 02 (Part I): Multisim & Resistors in Series

This portion explains using Multisim, myDAQ, LabVIEW® , and MySnap™ to study and observe the effect of resistors that are connected in a manner that forces the same current to pass through each resistor. This type of connection is called series connection.

2.1 Topics covered in Lab 02 (Part I)

- Objective
- What You Need
- Multisim & Circuit Emulation
- MyDAQ & Real World
- LabVIEW®
- How it Works

2.2 Objective:

Use Multisim to emulate and study a circuit on a computer, and then use myDAQ with LabVIEW® to measure and observe the same circuit as resistors are placed in series on the MySnap™ base. Real life applications apply to any occupation that uses electronic test equipment to measure resistance.

2.3 What You Need:

- Multisim
- NI myDAQ
- LabVIEW®
- MySnap™ BASIC ELECTRONICS EE100 kit
- Computer System with above software installed.

2.4 Multisim & Circuit Emulation

Open NI Multisim program and start a new Design. Save the design as "Series Resistors". Place the resistors on the grid as shown below. Add Multimeter and double click its icon to open the display. Start with Ground at C2, (Fig 2-2).

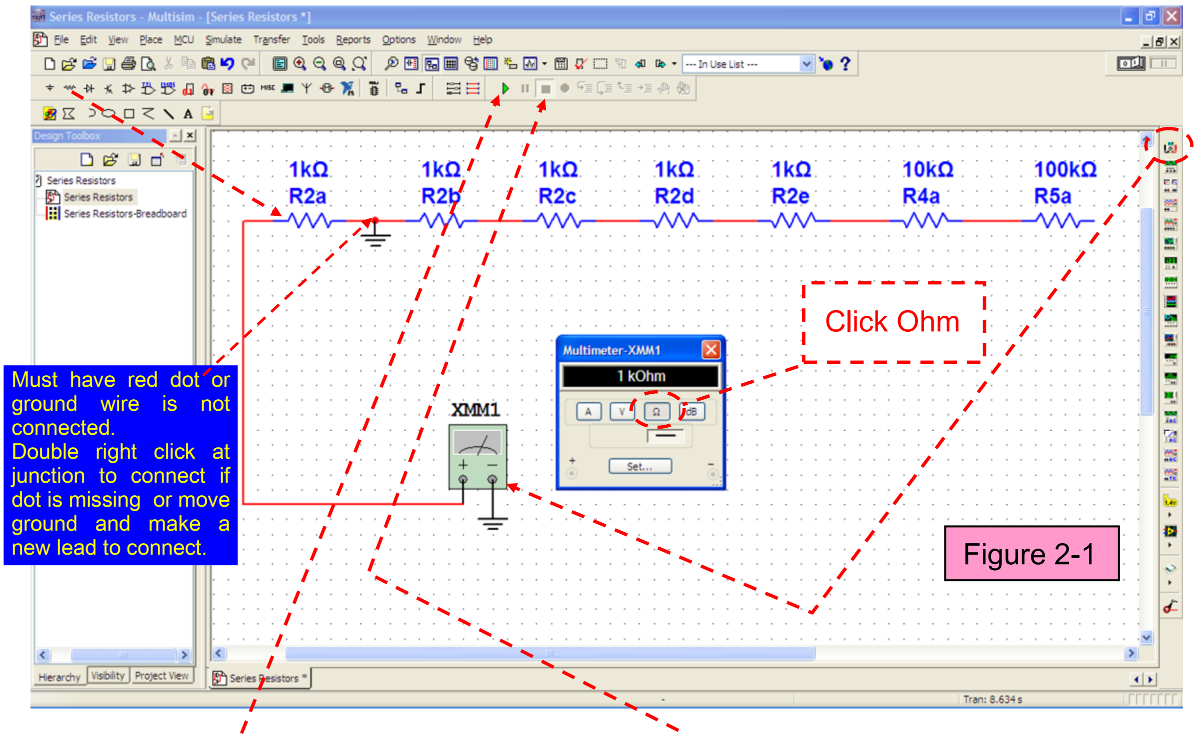


Figure 2-1

Click run button to display value then click stop button. Move ground to C5 as shown above and repeat measurement. Move ground (easier to move than wire in Multisim) to C8 and other points as shown here and repeat process. Enter results in Table below under Multisim column.

Junction	Multisim	MyDAQ
C2		
C5		
C8		
D10		
D7		
D4		
E2		
E4		

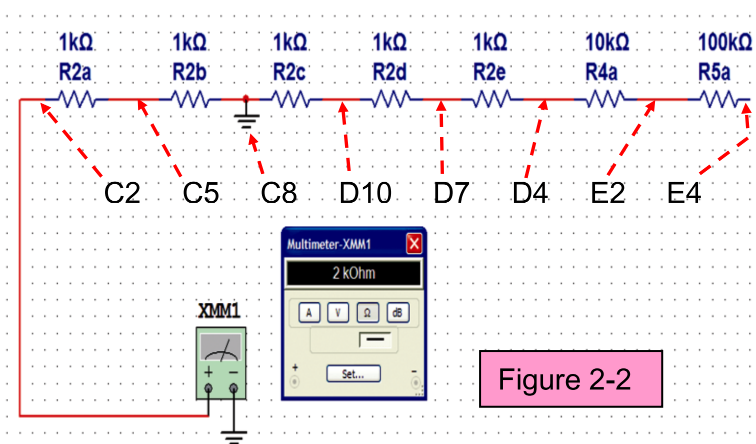


Figure 2-2

2.5 NI myDAQ and Real World

Open the myDAQ multimeter with the NI ELVISmx Instrument Launcher and set to ohms in auto mode. Use MySnap™ kit to build the circuit shown here. Connect the leads as shown below and read the resistance. Record the first reading in the table above under the myDAQ column. Move the black snap lead (ground lead to match Multisim) to base grid locations C5, C8, D10, D7, D4, E2, and E4. Enter new reading with each move to complete the column data.

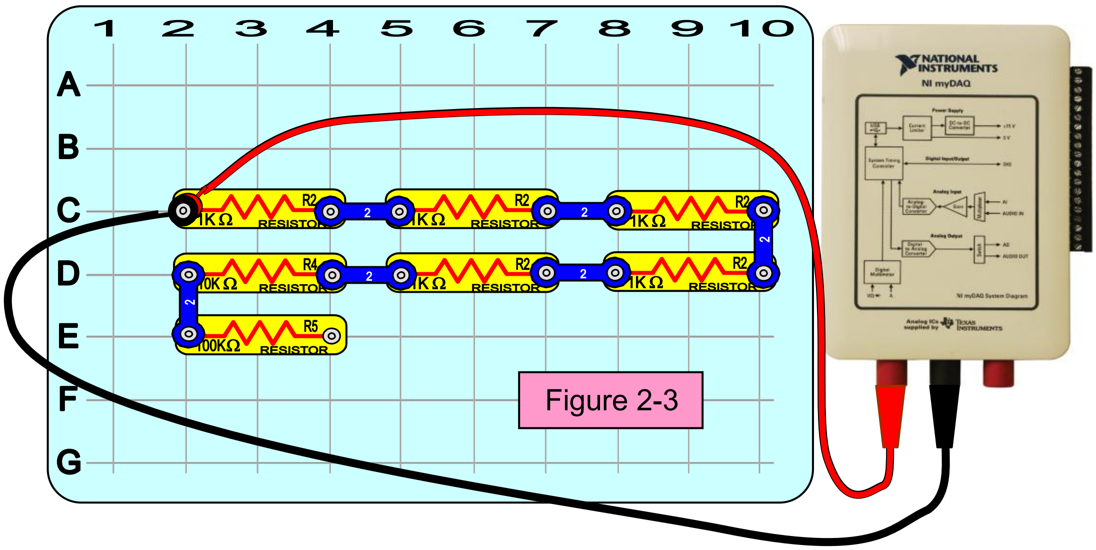


Figure 2-3

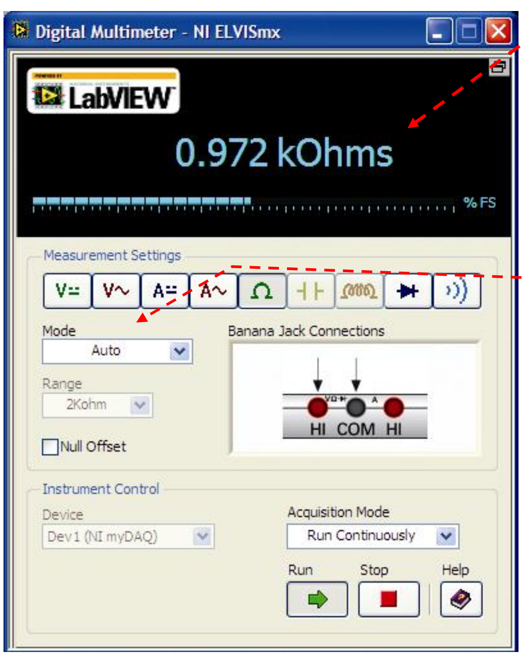
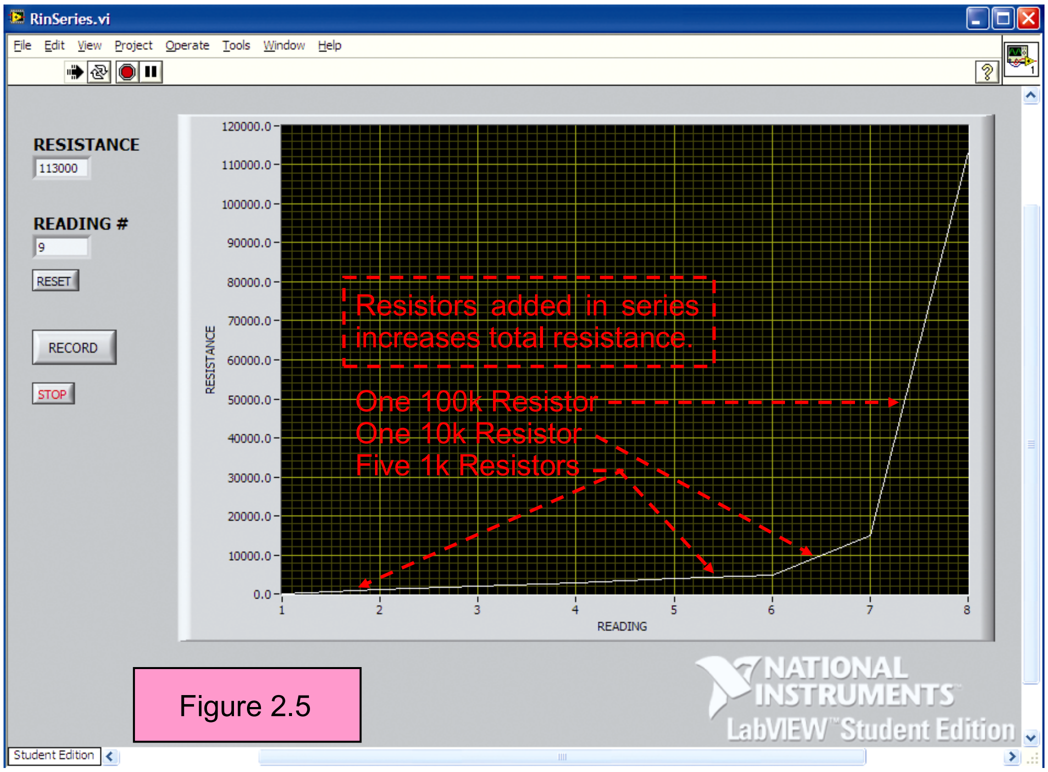


Figure 2-4 shows DMM reading at position C5. As the process is repeated for C8, D10, D7, D4, E2, and E4 the resistance will increase. The bar graph under the reading shows the % of the full scale reading for this value. Because the Mode is set to auto, the scale will change as required for best reading.

Figure 2-4

2.6 LabVIEW®

The LabVIEW® program uses both graph and numeric indicator. The numeric indicator will display the instantaneous value and the graph will display the history of the resistance as the common lead is moved. To best learn the power of LabVIEW® build the front panel shown here or download the RinSeries.VI from the ENGR190_Vis.zip file.



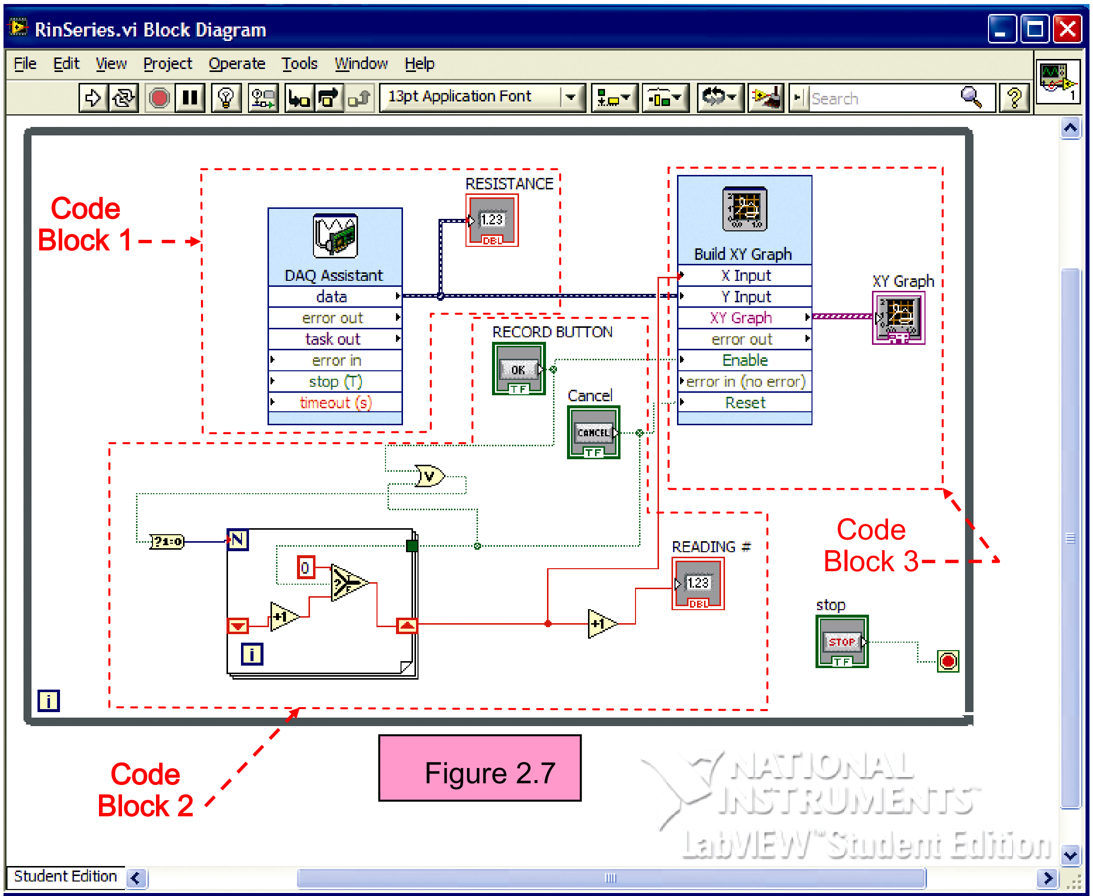
LabVIEW® Front Panel for RinSeries.VI

Coding Strategy:

To best use LabVIEW®, after the front panel to display the values of resistance in a numerical and graphical indicator is created, a Coding Block Diagram should be written. We will acquire the data using the DAQ Assistant and then pass the data to the indicators as shown below.

Figure 2-6: Coding Block Diagram *(For clarification only, no work required)*

The LabVIEW® block diagram is a graphical interface to perform the coding block diagram shown in Figure 2-6.



LabVIEW® Block Diagram

2.7 How It Works:

The different values for total resistance are indicated on the front panel with both a numeric indicator and the graph indicator. After recording a reading on the graph the X axis is incremented to display the next reading.

It will be shown later that resistors in series each have the same current because there is simply no other physical path for current. The final graph shows the total resistance is simply the sum of the values of all the resistors in the string.

Lab 02 (Part II): Multisim and Resistors in Parallel

This procedure explains how to use the myDAQ to measure and plot ohms as resistors are placed in parallel. The resistance will be acquired and plotted using a similar technique as for resistors in series.

2.8 Topics covered in Lab 02 (Part II)

- Objective
- Multisim and Circuit Emulation
- MyDAQ & Real World
- LabVIEW®
- Review

2.9 Objective:

Use Multisim, LabVIEW®, MySnap™, and the DMM terminals on the NI myDAQ to acquire and plot the overall resistance as resistors are added in parallel.

2.10 Multisim & Circuit Emulation

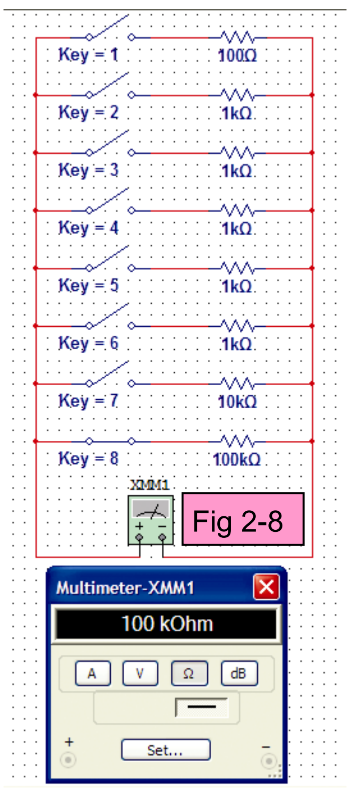


Fig 2-8

Open your Multisim program and start a new Design. Save the design as “Parallel Resistors”. Place the resistors on the grid as shown here. Add the Multimeter and double click its icon to open the display. Add the 8 switches as shown in Figure 3-8 by clicking on the resistor icon and select switch family from the drop down menu. In the list of switches select the SPST switch and add as shown. Double-click on the “Key = Space” message for each switch and select proper number from drop down menu under the check box. Click the run button.

Key No	Multisim	MyDAQ
8	100k	
7		
6		
5		
4		
3		
2		
1		

Press the 8 key on your keyboard closing switch 8 and the meter should register 100k as shown in Fig. 2-8. Press the 7 key closing switch 7 and the Multi-meter reading will show the value for the 100k and the 10k in parallel.

The meter reading should change to 9.091k. After recording this {ON WORKSHEET} in Table 2-2 next to Key 7, press key 6 on your keyboard. This puts the bottom three resistors in Parallel. Repeat the process until all the resistors are in parallel and their equivalent resistances have been recorded. While the program is running you can open and close different switches to see what the parallel resistance is for the resistors attached to the closed switches.

{THE POWER AND SIMPLICITY OF MULTISIM CAN ONLY BE APPRECIATED BY USING THE PROGRAM TO BUILD AND RUN CIRCUITS. FOR THIS REASON THE MULTISIM PROGRAMS ARE NOT INCLUDED ON DISC. }

2.11 MyDAQ & Real World

Assemble the circuit shown in Figure 2-9. Connect the DMM leads to the ends of the first resistor as shown in Figure 2-9 and set the DMM to read ohms with Mode in auto. The column numbers of the MySnap™ grid will correspond to the switch Key Number in Table 2-2. After recording 8 in Table 2-2, snap R4 into position "7" shown by dashed red arrow under MySnap™ & grid column 7. The reading will automatically change. Record the value on the DMM in Table 2-2 for row Key 7 and column MyDAQ. Continue this process until all the resistors are in parallel and have been recorded.

Use the banana cables with snap termination as shown here.

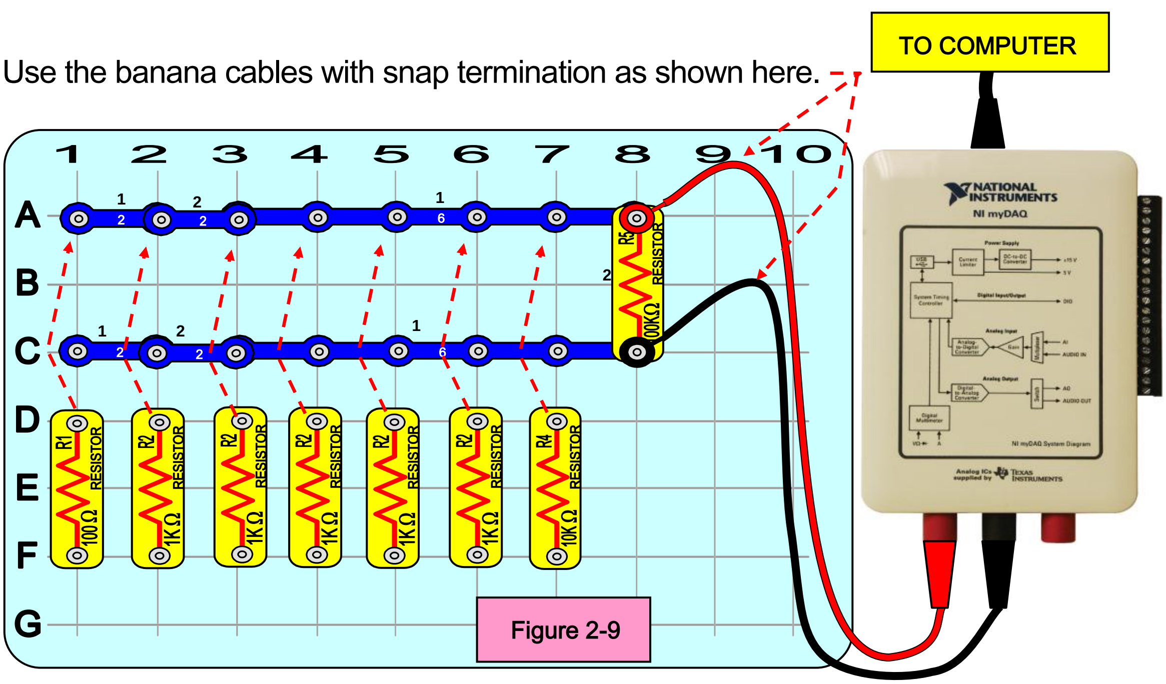


Figure 2-9

2.12 LabVIEW®:

Since the program required is very close to the RinSeries.VI there is no need to create a whole new program. Make a copy of the RinSeries.VI and change the name to "R_Graph.VI". This program can be used whenever any group of resistances needs to be measured with a graph of the reading history.

Run the renamed program "R_Graph.VI" and modify the graph and MyDAQ properties to make the chart appear as shown below. Repeat the process described in MyDAQ & Real World section, starting at reading B (the 100k and 10k are already in parallel). Graph the data by clicking the "Record" button. The following screen will be generated.

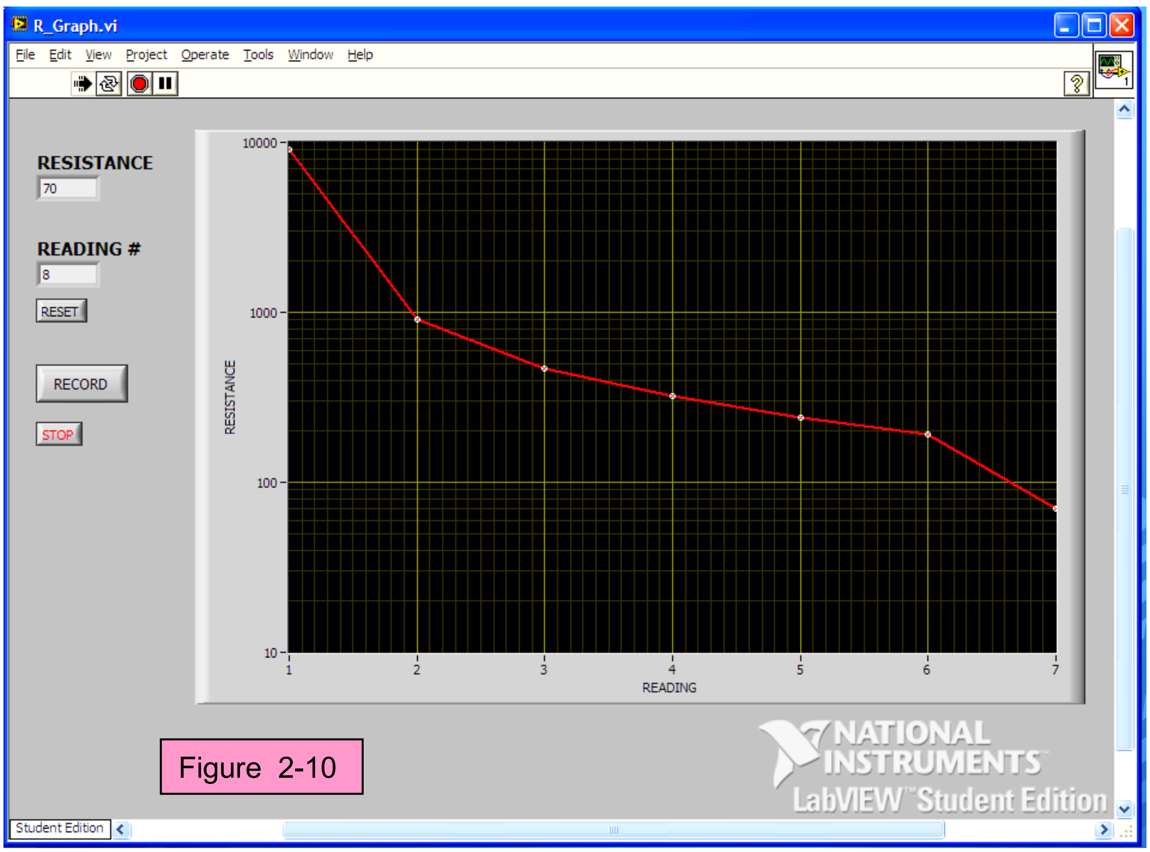


Figure 2-10

LabVIEW® Front Panel R_Graph.VI

A program as powerful as LabVIEW® with its graphical programming should be used often to learn its true potential. You can find the program R_Graph.VI on the

MySnap™ disc for inspection and comparison to your work. LabVIEW programs take a few minutes to load. Do not load again when a load is in progress.

2.13 Review

In this Section you emulated series and parallel resistive circuits in Multisim and studied their properties. Design engineers do this frequently in the course of investigation for the best circuit to be used in a product. Multisim also provides the engineer with many tools for detailed observance as circuits are under construction and investigation. You then used the myDAQ digital multi-meter to measure real world resistive circuits similar to the ones constructed in Multisim. Design engineers also build prototypes to test their circuit designs. MySnap™ provides the engineer with physical components that quickly snap into place to prototype circuits in the real world. Finally you used LabVIEW® to record your reading history as you checked the values in the real world example. Engineers use LabVIEW® to measure final products and graph variances that pick out failures or defects in manufacturing. Later in this course you will use LabVIEW® to monitor conditions measured by test equipment and make decisions that are needed for those conditions. It is a small step, but you have just begun to,

"DO ENGINEERING!"

Lab 03: Voltage Generators and Viewers

This portion explains using the Function Generator and Oscilloscope in myDAQ to study and observe the effect of voltages that produce current in the MySnap™ components.

3.1 Topics covered in Lab 03

- Objective
- What you need
- Definitions
- Water Pipe Analogy
- Building the Lab: DC and AC Voltage Sources
- Summary

3.2 Objective:

Use myDAQ devices to produce and study different voltages on a computer, and then use myDAQ devices to measure and observe these voltages as they are applied to components on the MySnap™ base. Real life applications apply to any occupation that works with voltage.

3.3 What You Need:

- NI myDAQ
- MySnap™ BASIC ELECTRONICS EE100 kit
- NI ELVISmx Instrument Launcher
- Computer System with above software installed

3.4 Definitions

Voltage (V) is a measure of the energy available to move an electric charge from one point to another or the "*Electro Motive Force* (EMF)" between those points.

There are two different types of voltage in common use today. Direct current (DC) that moves the current in only one direction, and Alternating current (AC) that reverses direction periodically, usually many times per second.

3.5 Water Pipe Analogy

A simple analogy for an electric circuit is water flowing in a closed loop of pipes, driven by a plunger. For DC or Battery Circuits consider the following;

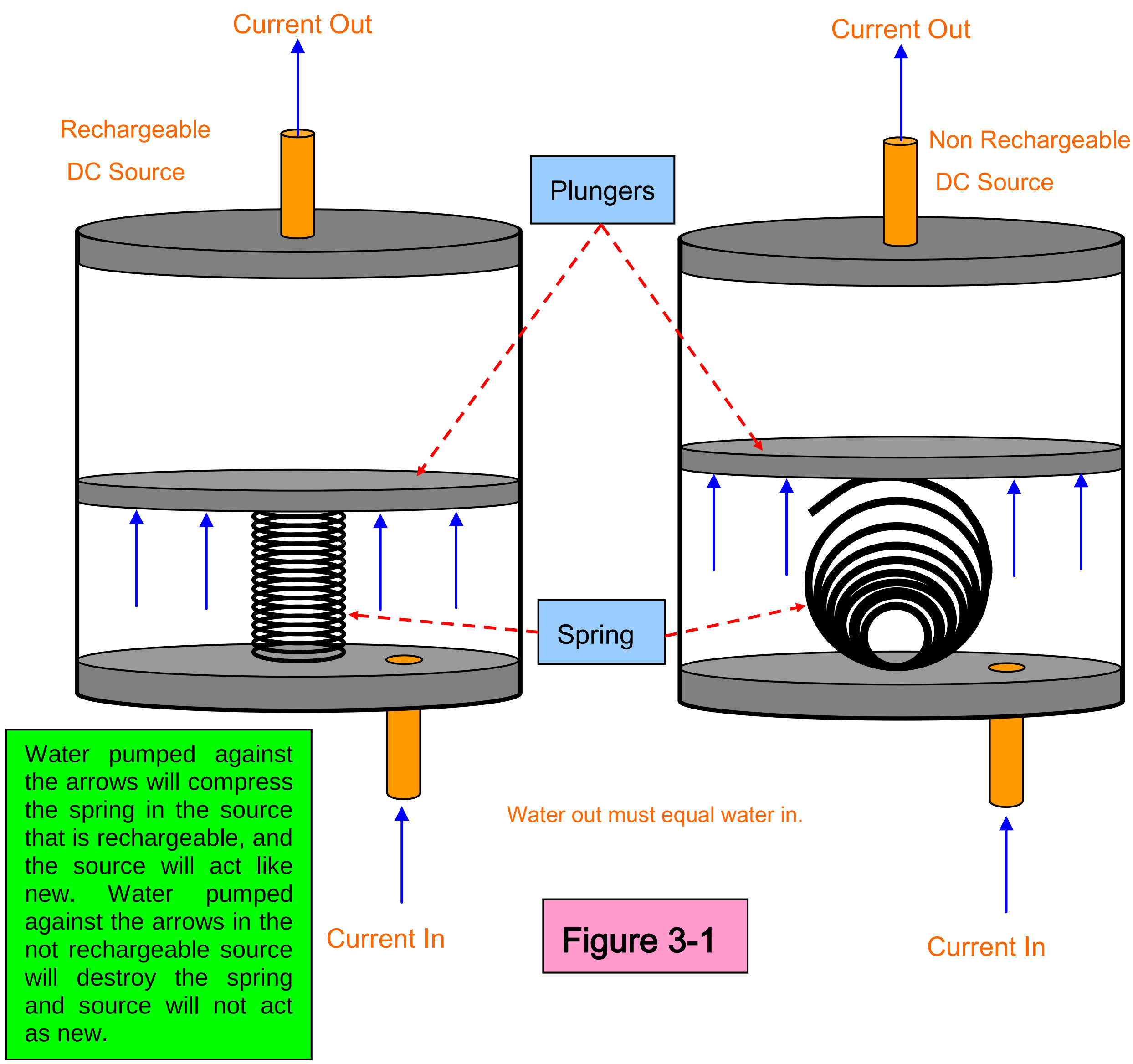


Figure 3-1

In the water sources above, the water leaving the + side of the source must equal the water entering in the – side of the source. If the return path is not connected, suction on that side will stop the plunger from moving and there will be no current flow. A closed loop as shown in Figure 3-2 could be called a *water circuit*.

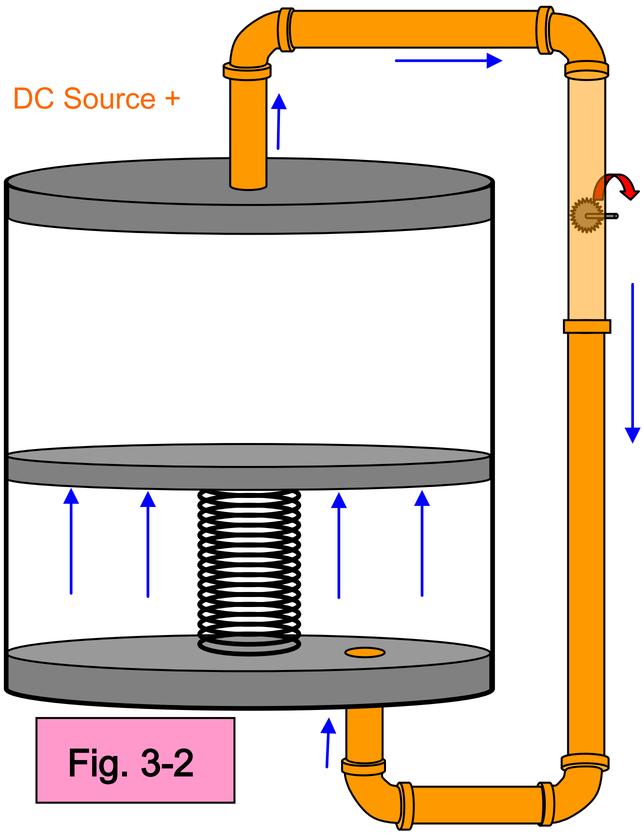


Fig. 3-2

Potential difference between two points corresponds to the water pressure difference between two points in the loop. If there is a water pressure difference between two points, then water flow (due to the plunger) from the first point to the second will be able to do work, such as driving a water wheel. In a similar way, work can be done by the electric current driven by the potential difference due to an electric battery: for example, a flashlight battery can force enough current through the filament of a bulb to make it glow white hot.

If the plunger shown above is not pushing, it produces no pressure difference, and the gear will not rotate. If a flashlight battery is discharged, then it will not heat the filament and the light will be out. For AC circuits consider the analogy in Figure 3-3. As the wheel at the bottom is rotated the plunger moves up and down producing an alternating current. The current is zero when it changes direction at 0º, 180º, and 360º and has maximum water flow to the left at 90º and maximum to the right at 270º. Since current and

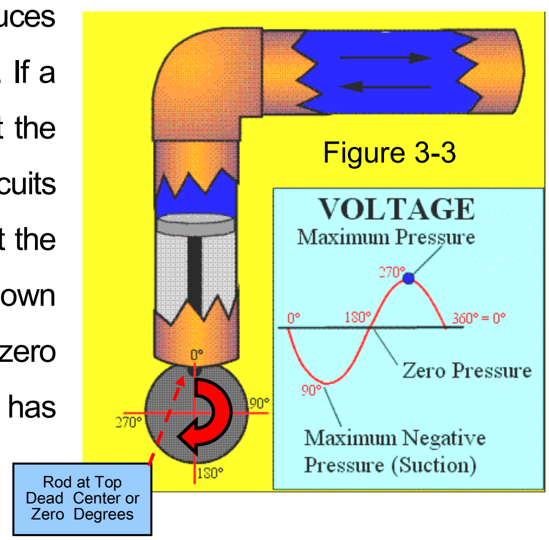


Figure 3-3

voltage are in phase for resistors, the voltage across a resistor would appear as shown in Figure 3.3.

These water flow analogies are useful ways of understanding many electrical concepts. In such a system, the work done to move water is equal to the pressure multiplied by the volume of water moved. Similarly, in an electrical circuit, the work done to move electrons or other charge-carriers is equal to "electrical pressure" (an old term for voltage) multiplied by the quantity of electrical charge moved. Voltage is a convenient way of measuring the ability to do work. In relation to "flow", the larger the "pressure difference" between two points (potential difference or water pressure difference) the greater the flow between them (either electric current or water flow).

3.6 Building in the Lab: AC and DC Voltage Sources

A potential difference can be produced between two conductors by connecting one electrical lead from a generator to the first conductor, the other lead to the second conductor as shown in Fig. 3-4.

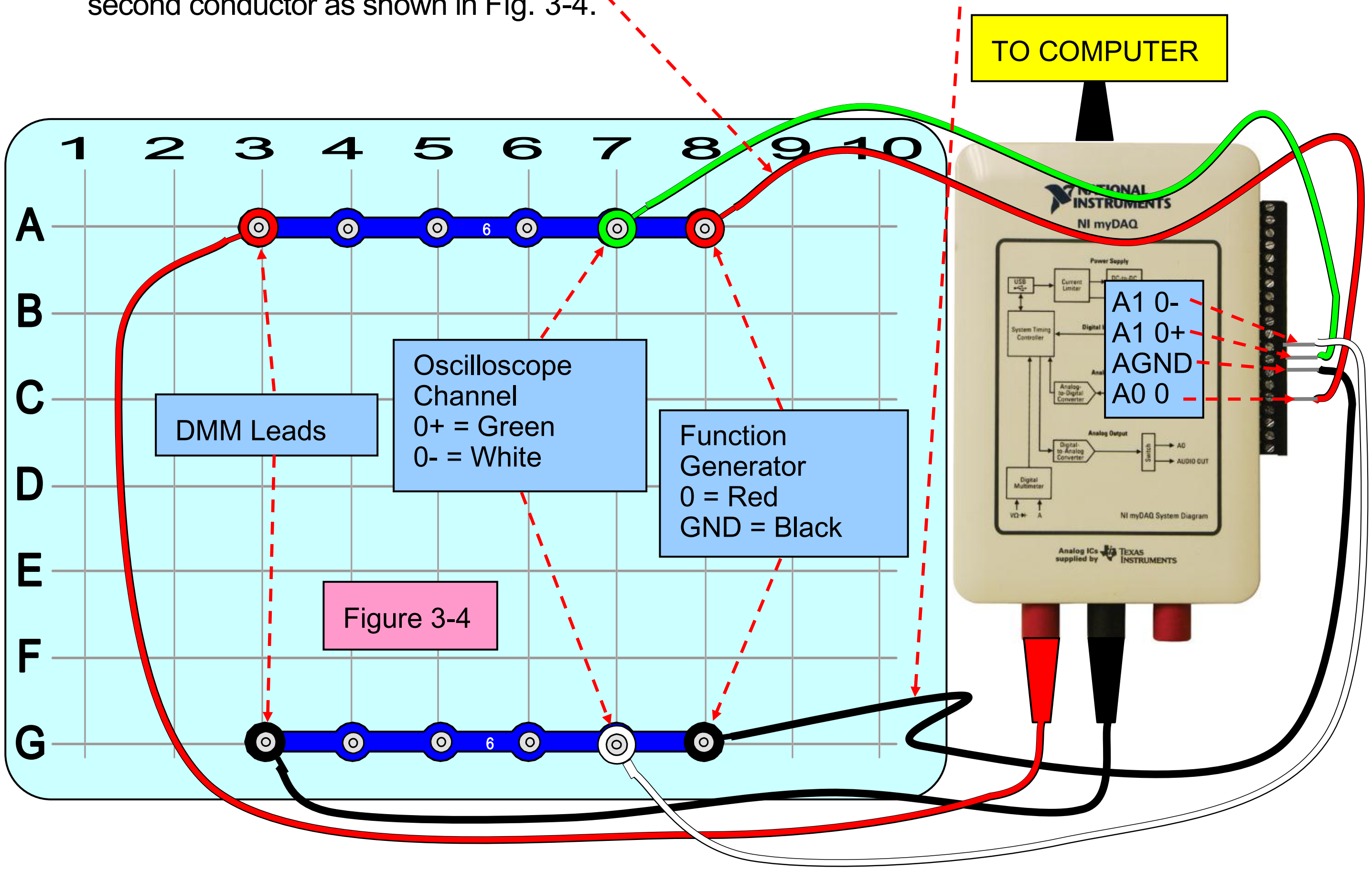
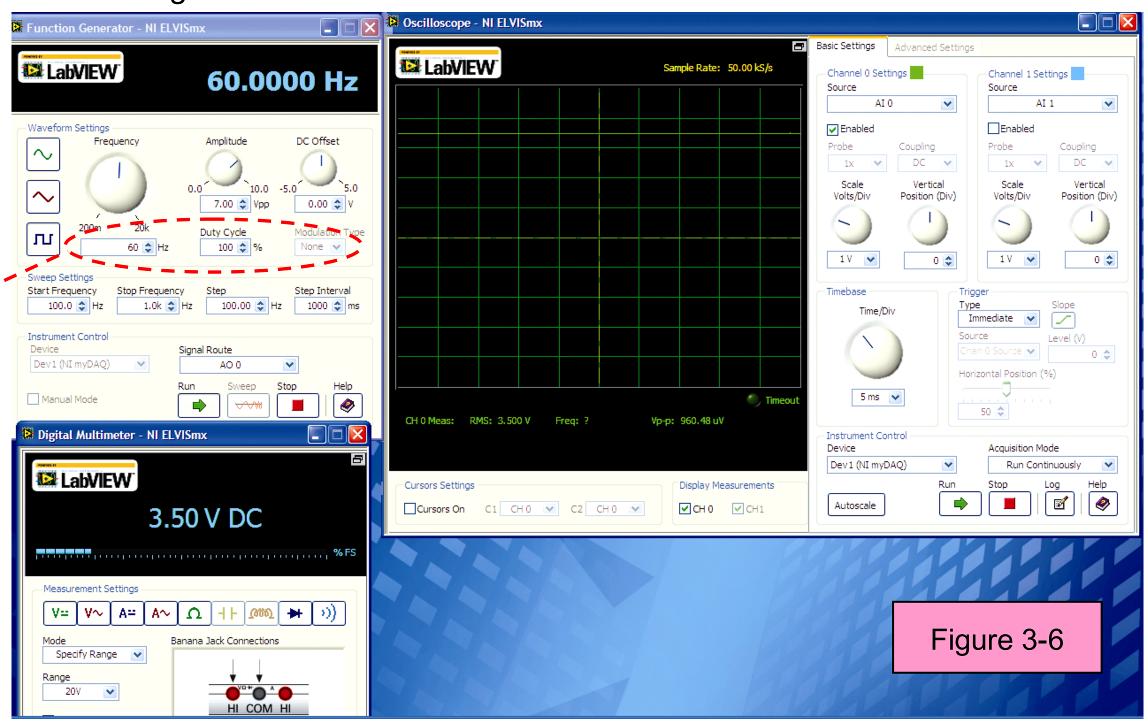


Figure 3-4

After inserting the socket with screw connectors into your myDAQ attach the leads by turning screw counter-clockwise several turns, place wire under screw, and tighten by turning screw clockwise until tight. Then build the MySnap™ circuit as shown above.

Figure 3-5

Use the Instrument Launcher to open the DMM, Scope, and Function Generator on the same screen. Click the run button on all three instruments and arrange as shown in Figure 3-6.

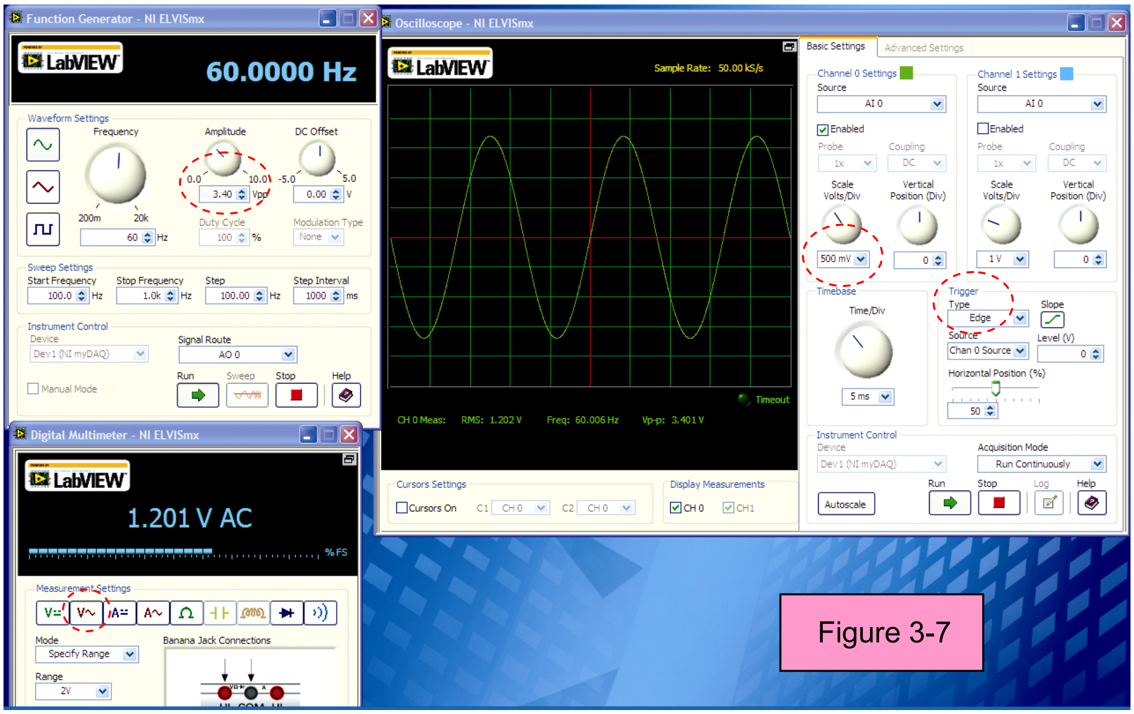


Note: Set the Function Generator on square wave with a duty cycle of 100% to make a variable DC source.

Use the generator as a DC source and set it to 7.00 volts amplitude. This would be the peak to peak amplitude of a square wave that varied from –3.5 volts to + 3.5 volts. Since we are only looking at the positive peak (100% duty cycle) the DMM and the scope show a DC of 3.5 volts. The amplitude control of the Function Generator can be used to vary the DC voltage from 0 volts to 5 volts

DC. The Offset control can be used to move the voltage window to 5 to 10 volts or –5 to 0 volts.

To generate an AC voltage simply click on the Sine wave button on the Function Generator and adjust controls on your lab equipment to match those shown in Figure 3-7. Be sure to click run on all three instruments.



Note: Change Scope to 500 mv/div & Edge Trigger Type. Put Generator at 3.40 Volts peak to peak. Set DMM on V~.

Sinusoidal Voltages produce an alternating current in most linear devices. Alternating current is shown diagrammatically in figure below. In this diagram it is assumed that the current is alternating in sinusoidal manner.

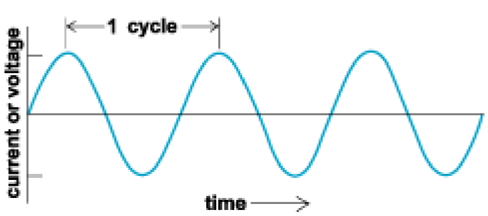


Figure 3-8

A useful measure of alternating current is defined as the square root of the average of the square of instantaneous current. This value is known as the root-mean-square (rms) or effective current. It is measured in amperes. It is a useful measure for current of any frequency. The rms value of current is identical with its dc value. The rms value of sinusoidally alternating current is the peak current divided by the square root of 2.

Notice that a voltage of 1.20 rms has a peak to peak value of 3.40 volts. This means that the 120 volts in a common household outlet has a peak to peak voltage of 340 volts.

Because of the high voltage present in electrical outlets the following warning must be obeyed at all times.

WARNING: SHOCK HAZARD

Never connect any component or lead to electrical outlets in any way !

3.7 Summary

You have just built an electronics lab with variable power sources, Digital measurement equipment, Analog measurement capability, and snap together prototype capability. You used this lab to generate a variable DC voltage, a variable AC voltage, and measured both with the DMM and Scope. After a few improvements to the power source, this lab will be used to investigate the AC and DC characteristics of electronic circuits and electronic components.

Lab 04: Ohms Law

This portion explains using Multisim, myDAQ, LabVIEW®, and MySnap™ to study Ohms Law for resistors using DC and AC voltages and currents.

4.1 Topics covered in Lab 04

- Objective
- What You Need
- Ohms Law
- Multisim: Virtual World
- MySnap™: Real World
- Hardware Limits
- Summary
- Know Your Equipment Review

4.2 Objective:

Use Multisim to emulate and study Ohm's Law on a computer, and then use myDAQ to measure and observe the same circuit built in the real world on the MySnap™ base. Real life applications apply to any occupation that uses electronic circuits and the engineering of those circuits.

4.3 What You Need:

- Multisim
- NI myDAQ
- LabVIEW®
- MySnap™ BASIC ELECTRONICS EE100 kit
- Computer System with above software installed.

4.4 Ohms Law:

A common use of the term "voltage" is in describing the voltage dropped across an electrical device (such as a resistor). The voltage drop across the device can be understood as the difference between measurements at each terminal of the device with respect to a common reference point (or ground).

Ohm's law states that current through a resistive component is directly proportional to the voltage across the component, and inversely proportional to the resistance of the component.

Mathematically:

$$I = V/R \quad \text{or} \quad V = IR \quad \text{or} \quad R = V/I$$

Where, I is the current through the component in units of amperes, V is the voltage measured *across* the component in units of volts, and R is the resistance of the component in units of ohms. The symbol for ohms = Ω

4.5 Multisim: Virtual World

Use Multisim to build the circuit shown below.

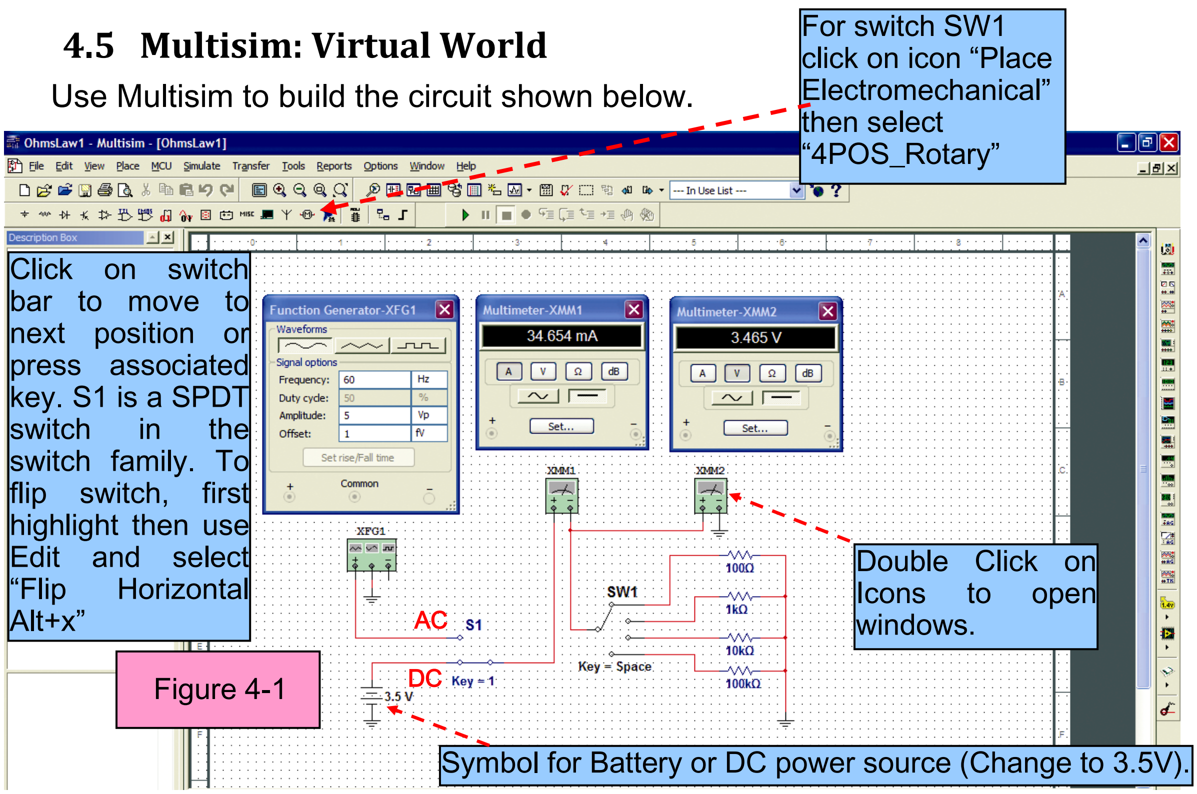
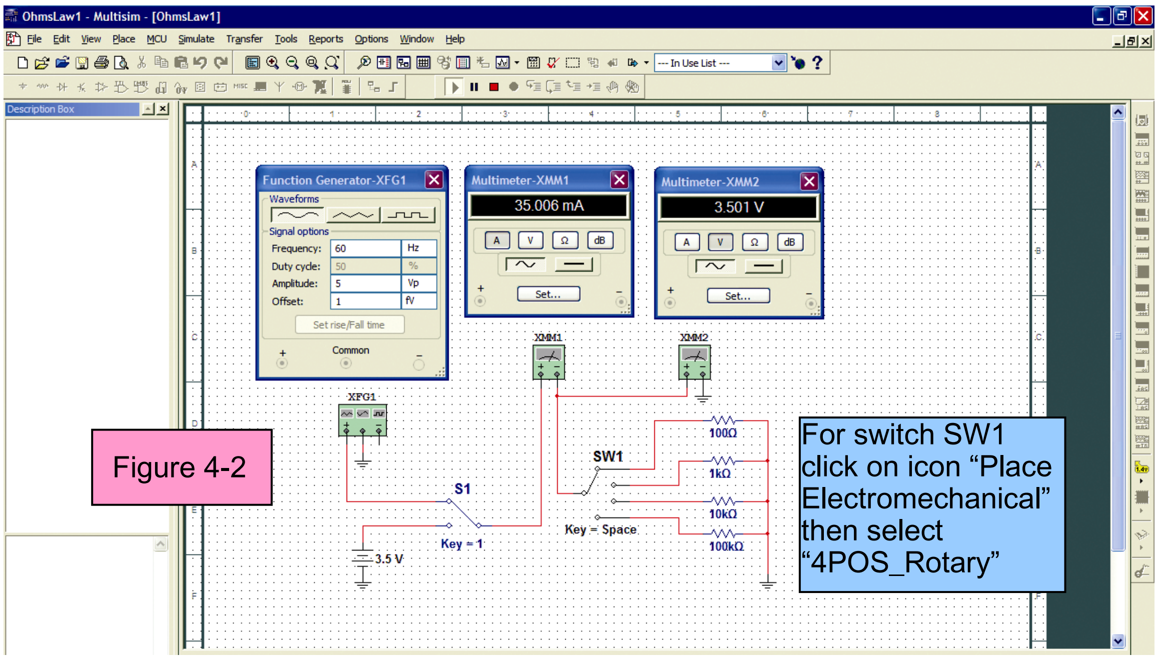


Figure 4-1

Use the circuit above with S1 in the DC position and both DMMs set at DC to finish the chart below {ON WORKSHEET}. Use chart data to verify Ohm's Law for DC circuits.

Current (ma)	Current (I)	Voltage (V)	SW1 Position	Resistance (Ω) R=V/I
			100k	
			10k	
			1k	
			100	
34.654	.034654	3.465	100	99.988(example)

Move S1 and both DMMs to the AC position as shown here and fill in chart below.



Current (ma)	Current (I)	Voltage (V)	SW1 Position	Resistance (Ω) R=V/I
			100k	
			10k	
			1k	
			100	
35.006	.035006	3.501	100	100.011(example)

Use chart {ON WORKSHEET} data to verify Ohm's Law for AC circuits.

4.6 MySnap™: Real World

Use your MySnap™ components and build the circuit shown here.

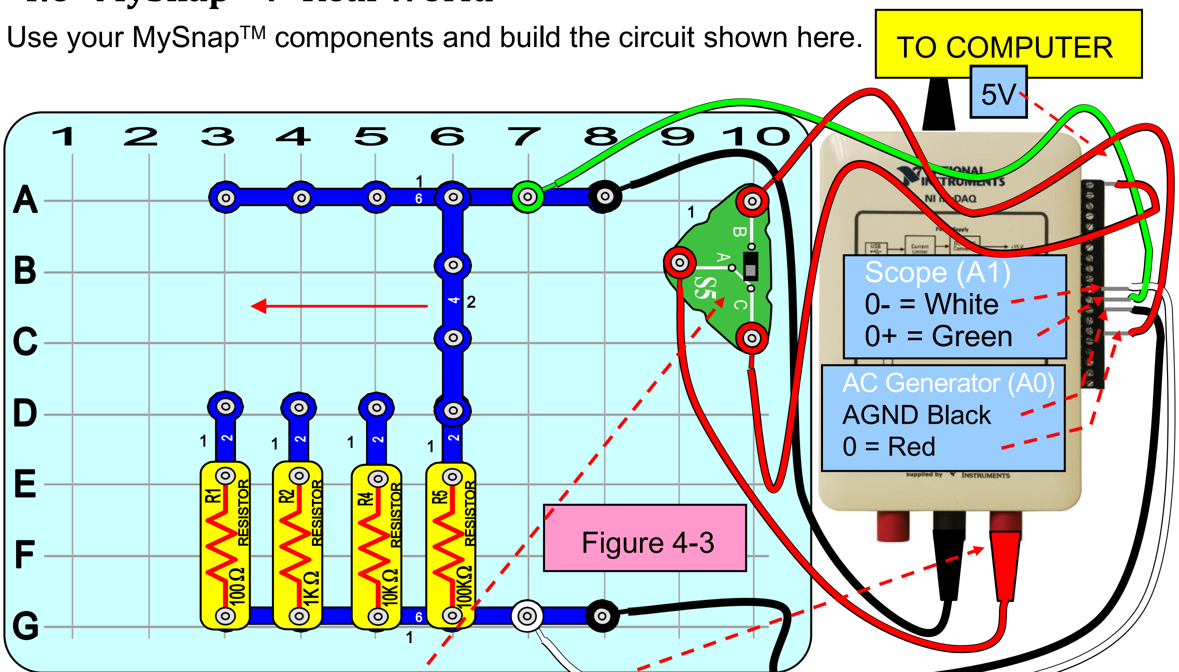


Figure 4-3

Place switch S5 in position "C".

Move DMM plug to "A" position.

Connect the myDAQ and open the DMM and Scope. Set the DMM to DC current and Auto Mode. Set the scope trigger and vertical section as shown here. Click run on both.

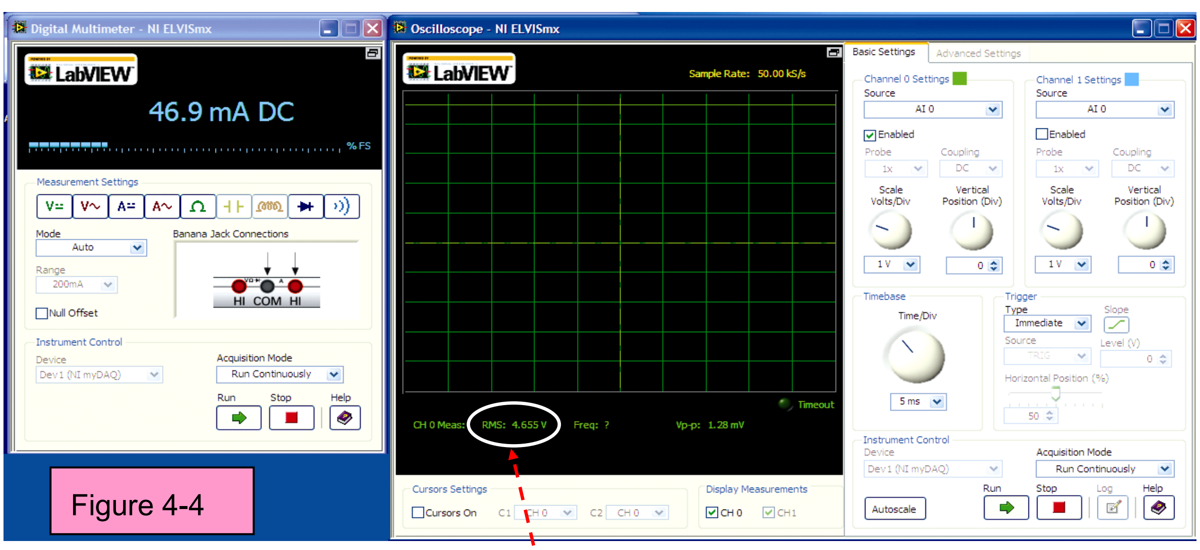


Figure 4-4

Use DMM for current and Scope RMS value for DC voltage. Fill in chart on next page for all four resistors by moving 4 snap as shown in Figure 4-3 (red arrow).

{TABLES FOUND ON WORKSHEET LAST PAGE OF THIS MANUAL}

Current (ma)	Current (I)	Voltage (V)	R Position	Ohms (Ω) R=V/I
			100k	
			10k	
			1k	
			100	
46.9	.0469	4.655	100	99.254(example)

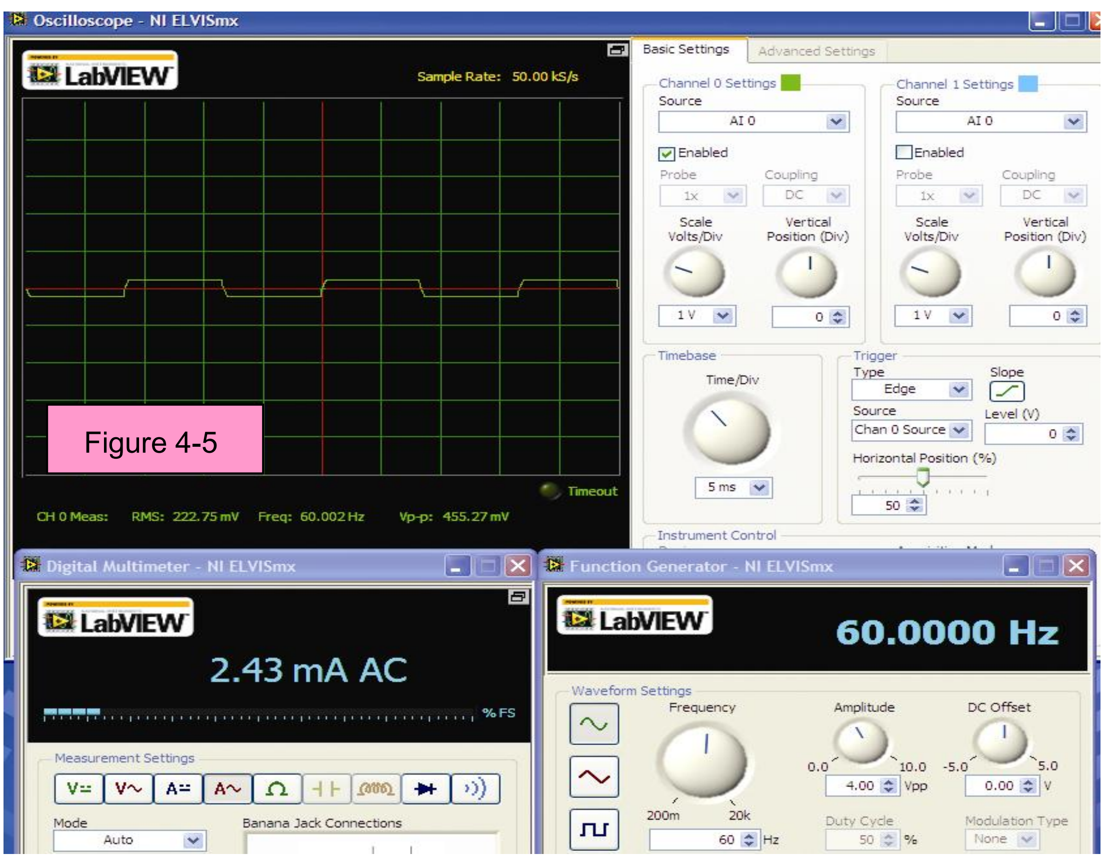
Put the 4 Snap in the 100K position. Switch the S5 switch to B. Change the DMM to read AC amps in auto mode. Open the function generator and set it to 4 volts peak to peak at 60 hertz. (See Figure 4.5) Fill in the table below for AC voltages.

Current (ma)	Current (I)	Voltage (V)	R Position	Ohms (Ω) R=V/I
			100k	
			10k	
			1k	
* see note			100	
46.9	.0469	4.655	100	99.254(example)

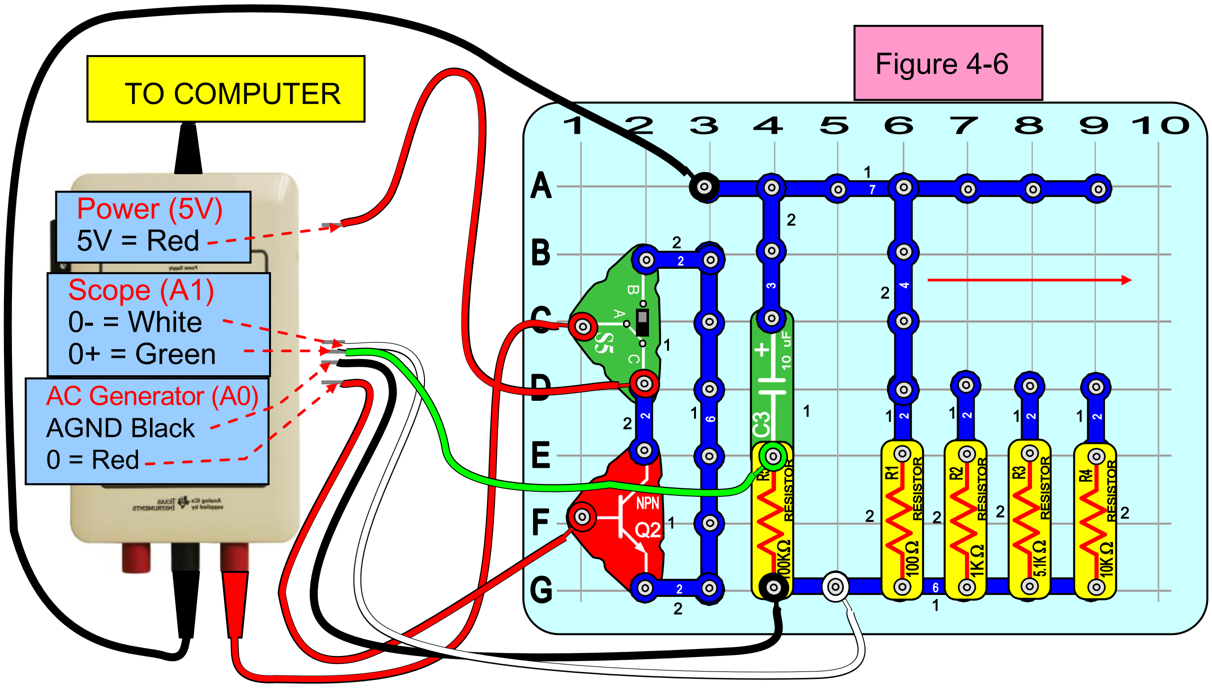
Note: Function Generator can only supply 2ma AC, and then voltage is clipped and is no longer a sine wave. RMS voltage assumes signal is a sine wave with no DC component.

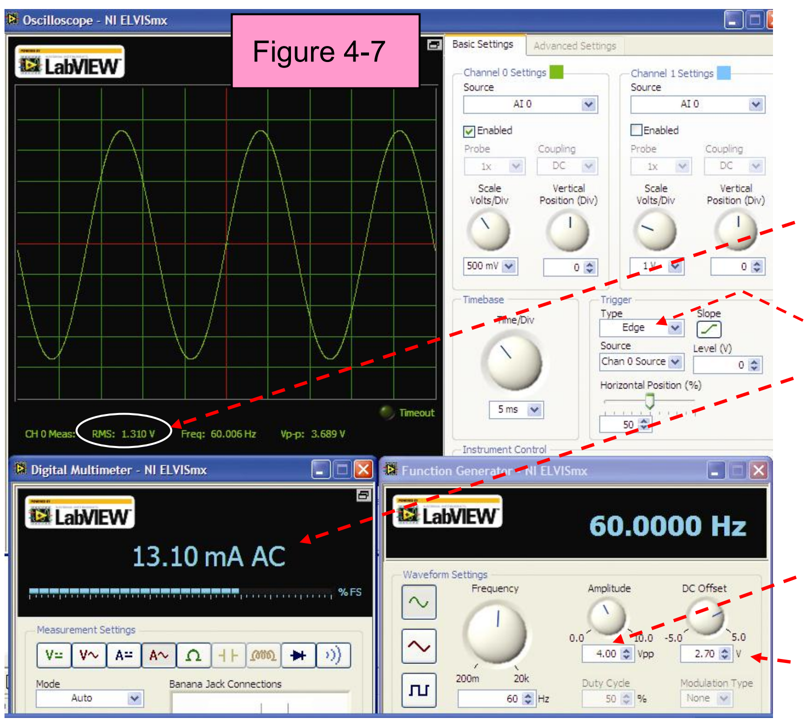
4.7 Hardware Limits

Due to limitation of the function generator the 100 ohm measurement may appear as follows;



Rebuild your circuit as shown here.





Set the instruments to read AC voltage and currents shown here (S5 in "B" position).

Use the AC voltage from the scope to fill in the table that follows.

Change to edge trigger.

This circuit removes the error produced by the function generator being limited to 2ma.

Set AC at 4 volts peak to peak and the offset at 2.7 volts.

Notice that the AC current is now over 13 mA and the sine wave is not clipped. Fill in table that follows by moving the 4 snap in Figure 4-6 (red arrow) and calculate values of resistance for AC current and voltage with the improved AC source.

Current (ma)	Current (I)	Voltage (V)	R Position	Ohms (Ω) R=V/I
			10k	
			5.1k	
			1k	
			100	
13.10 ma	.0131 amps	1.310	100	100.0 (example)

{ON WORKSHEET}

4.8 Summary:

In Section 4 resistors were used with both AC and DC voltages to demonstrate Ohms law. Whenever the resistor values were changed the value of the measured voltages and currents would adjust according to Ohms law. The law applies to both AC and DC voltages for the linear resistors used. Errors may occur in the measurements if the limits of the equipment are exceeded. These errors must be corrected in all applications in order to achieve the desired results.

4.9 Know Your Equipment Review:

1. Why was the capacitor C3 used in Figure 4-6?
2. What is the maximum current that can be drawn from the 5 volt MyDAQ DC source?
3. At what AC current from the Function Generator does a sine wave start to get clipped?
4. Is the scope RMS reading a true reading for all shapes and all sine waves?
5. Does the trigger of the scope affect the RMS reading?

Answers

1. To make the scope AC coupled and eliminate the 2.7 volt DC offset from the reading for RMS voltage.
2. 100 mA.
3. Approximately 1.75 mA.
4. Sine waves with no DC shift or component.
5. Signal must be triggered to get reading.

Lab 05: Kirchhoff's Voltage Law

The Kirchhoff's voltage law is one of two fundamental laws in electrical engineering developed by German physicist Gustav Robert Kirchhoff in 1845. The Kirchhoff's voltage law states

"The sum of the electrical potentials (voltages) around any closed circuit is zero."

This portion explains using a National Instruments myDAQ to measure voltages around a closed circuit. The measurements will be taken with the myDAQ DMM. The components to be measured are supplied in the MySnap™ model "BASIC ELECTRONICS EE100". Real life applications apply to any occupation that uses electrical components with measurement equipment.

5.1 Topic covered in Lab 05

- Objective
- What You Need
- The Circuit
- Multisim Verification of Kirchhoff's Voltage Law (KVL)
- MyDAQ DMM Measurements
- Sources for Error

5.2 Objective:

Use Multisim, the DMM in the NI myDAQ, and MySnap™ to measure and record both DC and AC voltage sums around a closed circuit loop and thus verify Kirchhoff's Voltage Law.

5.3 What You Need:

- Multisim
- NI myDAQ
- MySnap™ BASIC ELECTRONICS EE100 kit
- Computer System with NI software installed

5.4 The Circuit:

When using Multisim more than one voltmeter is available. By placing a voltmeter across each component in the circuit all the voltages can be obtained at once. In this example a negative voltage indicates a source and a positive voltage indicates a voltage drop. If you would like all voltage sources to be positive and voltage drops to be negative then reverse all the meter leads.

5.5 Multisim Verification of Kirchhoff's Voltage Law (KVL):

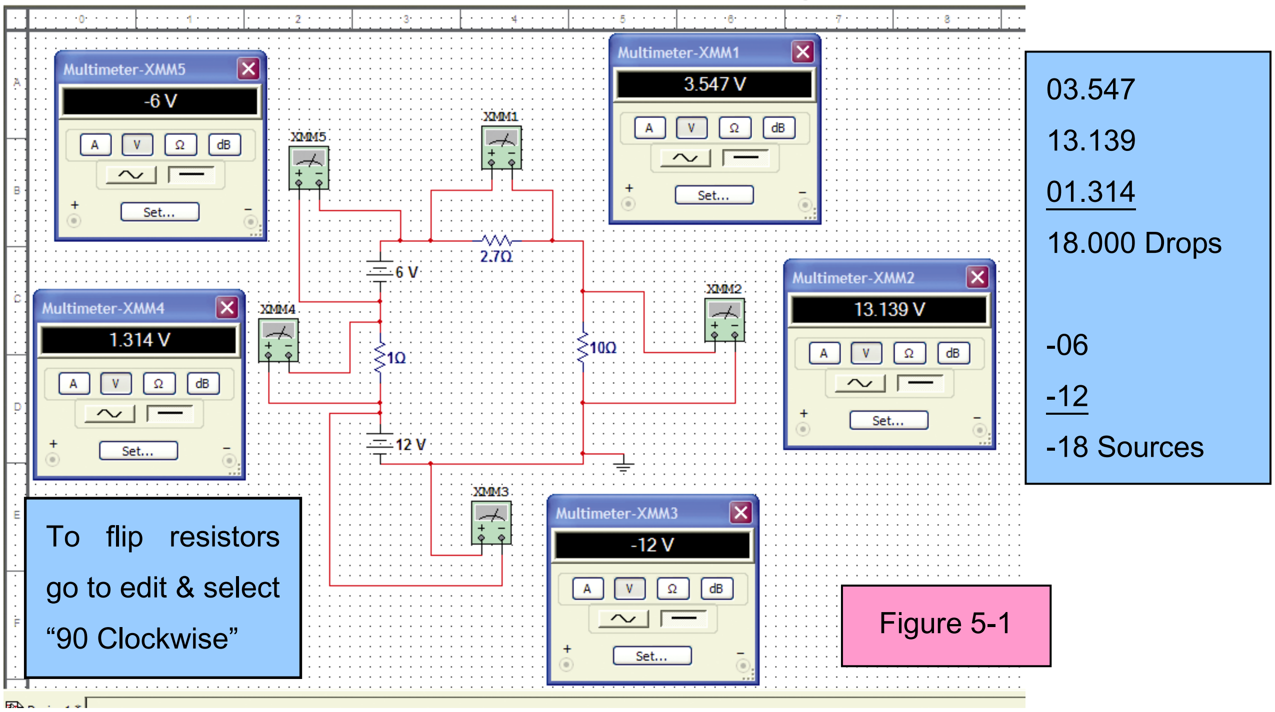


Figure 5-1

Build the above circuit and change the value of both sources and resistors to verify that Kirchhoff's Voltage Law is always true.

"The sum of the electrical potentials (voltages) around any closed circuit is zero."

5.6 MyDAQ DMM Measurements

In the real world only one voltage measurement device may exist. Build the following circuit on MySnap™ and use the MyDAQ DMM to measure the voltage drops across each component. When moving the snap probes, replace the red snap with the black and move the red snap to the other side of the next component to be measured as shown with arrows in Figure 5-2.

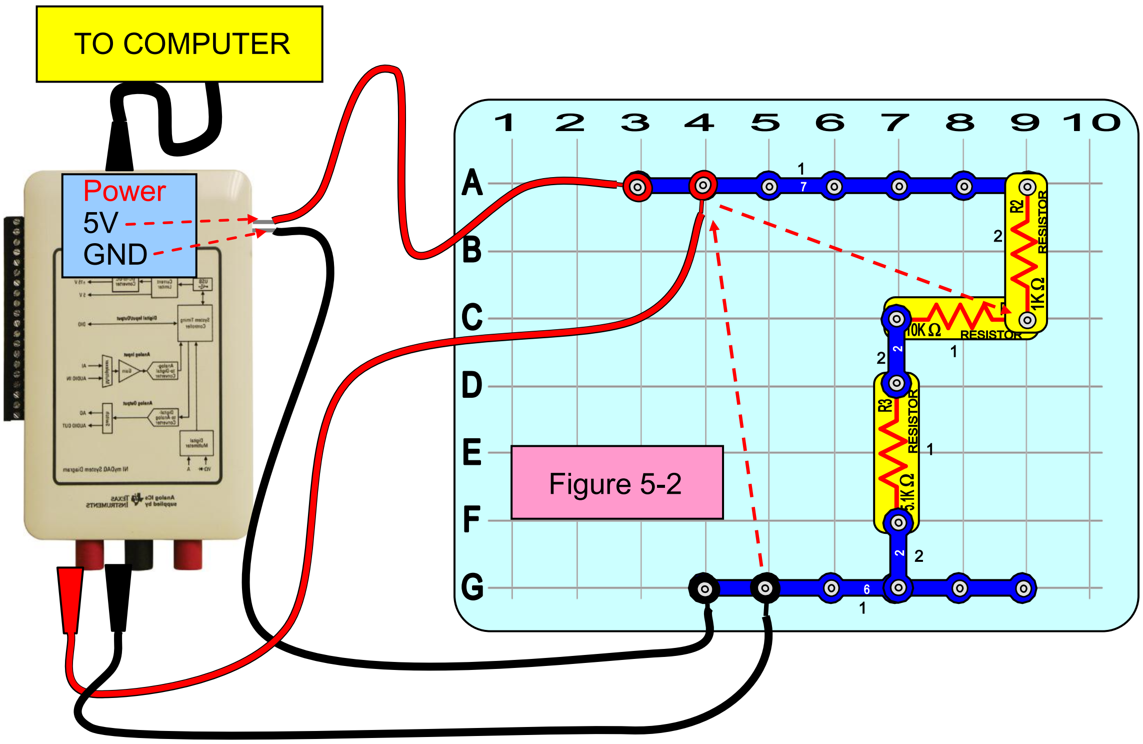


Figure 5-2

Read the DC voltages around the circuit loop with the DMM on auto mode and record here {ON WORKSHEET};

Black Snap Grid Location	Red Snap Grid Location	Voltage	
G5	A4		Reading G5-A4
A4	C9		Reading A4-C9
C9	C7		Reading C9-C7
C7	G5		Reading C7-G5
Sum of all the voltages around the loop =			Add Above

Your sum may not equal exactly zero due to rounding and meter tolerances.

5.7 Sources for Error

In the real world the equipment used to take measurements is limited by factors such as “resolution” and “equipment tolerance” to name a couple. The user should look in the specifications of the MyDAQ DMM to make sure the error in the sum is within the resolution and tolerance of that instrument.

Lab 06: Capacitors

The capacitor is an electrical device characterized by its capacity to store an electric charge, pass AC, block DC, and change the phase relationship between current and voltage in a circuit. This section will explain capacitors using analogies, virtual capacitors using Multisim, real capacitors using MySnap™ and circuits that demonstrate their properties. In the real world, measurements will be taken with the myDAQ DMM and their properties observed with the MyDAQ scope. The components to be measured are supplied in the MySnap™ model “BASIC ELECTRONICS EE100”. Real life applications apply to power supplies, appliances, television, cell phones, satellite receivers, and almost anything electronic.

6.1 Topics covered in Lab 06

- Objective
- What you need
- Water Pipe Analogy
- Understanding Capacitor Properties
- Multisim Capacitor Circuit
- More About Capacitor Properties
- Transient Responses
- RC time constant
- The Real World - MySnap™
- Actual Values and Tolerances
- LabVIEW® RC meter
- How it Works
- Review

6.2 Objective:

Use Multisim, the NI myDAQ, LabVIEW®, and MySnap™ to investigate both DC and AC properties of electronic capacitors. Introduce transient responses and phase relationship between current and voltage.

6.3 What You Need:

- Multisim
- NI myDAQ
- MySnap™ BASIC ELECTRONICS EE100 kit
- Computer System with NI software installed

6.4 Water Pipe Analogy:

In Lab 03, you were introduced to the water pipe analogy for the AC voltage source shown here.

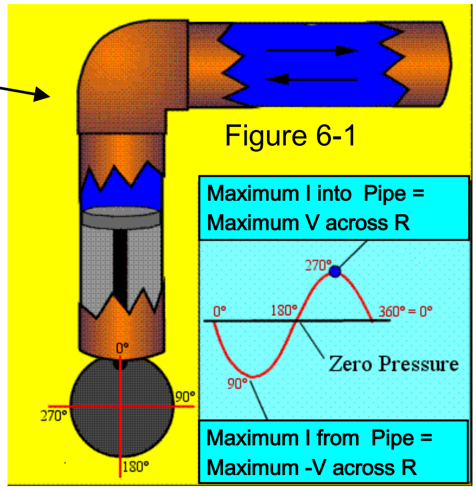


Figure 6-1

For a resistor the voltage and current peaks occur at the same time so the peak is reached at 270° when the current into the pipe is at a maximum. The negative peak is reached at 90° when the current being sucked from the pipe is maximum. When the piston is changing direction the water must stop flowing for an instant. At this point the pressure (voltage) across a resistor drops to zero.

Now, lets consider a new water pipe component where the pressure across it does not reach a peak at the same time the current through it reaches a peak. We will call this device the water pipe Capacitor.

If a diaphram is sealed inside a pipe and it is made from an elastic or flexible material, such as rubber, the device might look like this;

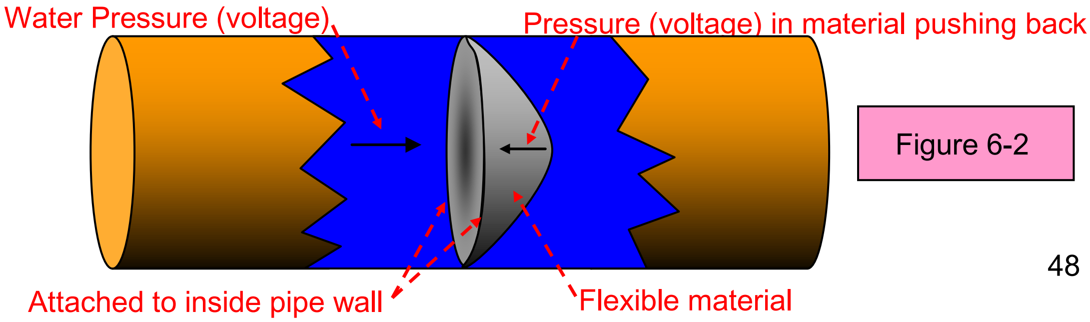


Figure 6-2

If the total drops of water = Q and the pressure in the material pushing back = V we could define the value of the capacitor (C) as;

$$C = \frac{Q}{V} \quad \frac{\text{Number of Drops of Water}}{\text{Back Pressure due to Stretching}}$$

6.5 Understanding Capacitor Properties:

The relationship between water flow (current) and back pressure (voltage) shows that water must flow FIRST in order to produce a back pressure. Therefore the current leads the back pressure (voltage). They no longer occur at the same time as in the resistor. To better see this relationship, play the animated gif file called Cap.gif on the disc that came with the MySnap™ parts. It can be viewed using a player such as "Windows Media Player", "Windows Picture and Fax Viewer" or "QuickTime" just to name a few. Points of interest that should be noted in the analogies are;

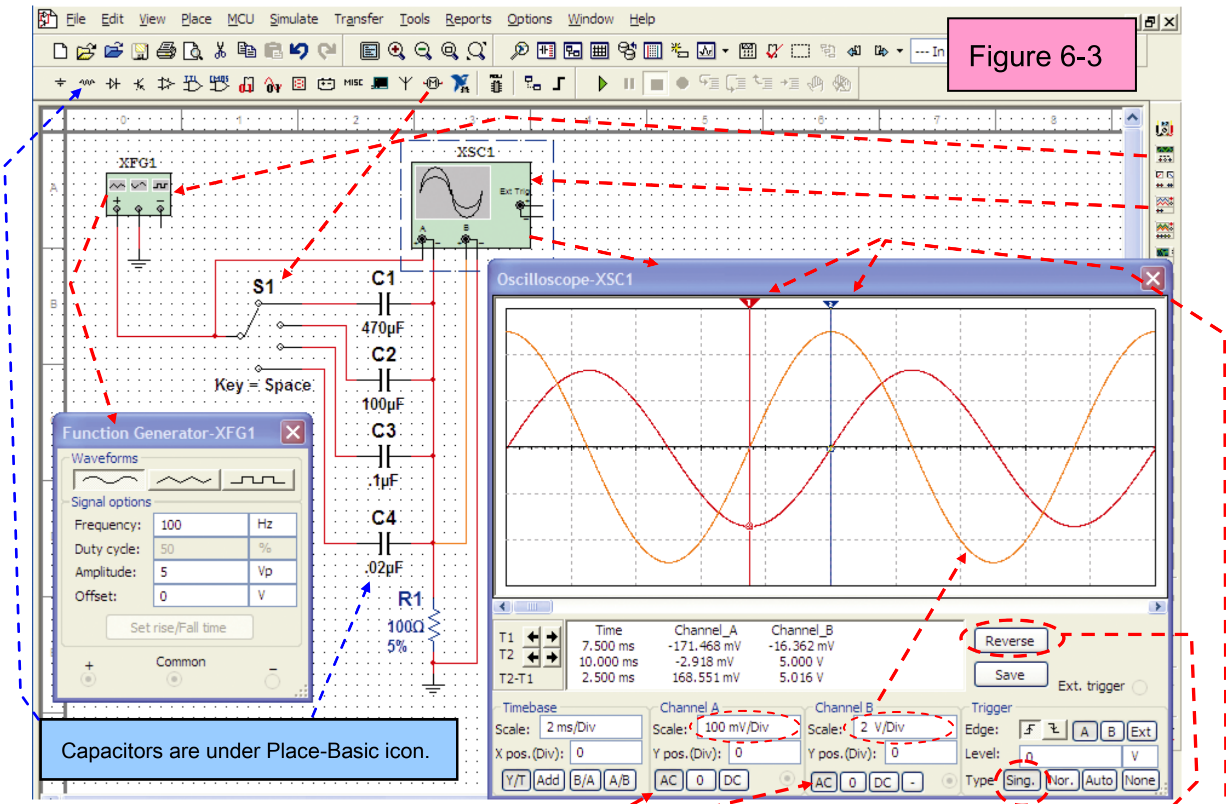
- Water flow (current) leads the Back Pressure (voltage) by 90°.
- Alternating water flow (AC) passes through the capacitor easily.
- When a Capacitor stores water (charge) a back pressure (voltage) exist.
- One way water flow (DC) is blocked by capacitor when back pressure (voltage on C) = forward pump pressure (battery voltage).
- It takes time for a Capacitor to charge (water must enter diaphram).
- Maximum AC current occurs when there is no back pressure.
- Peak back pressure occurs when AC current changes direction.
- Size and material can change Capacitors properties.

An electronic capacitor consists of two conductive surfaces (plates) separated by a non-conductive material called the dielectric. The plates hold equal and opposite charges on their facing surfaces, and the dielectric develops an electric field. In SI units, a capacitance of 1 Farad (F) means that 1 Coulomb of charge on each plate produces a voltage of 1 Volt across the Capacitor. If an electronic capacitor is represented by the constant C, then the ratio of charge ±Q on each plate to the voltage V between them defines the Capacitor as:

$$C = \frac{Q}{V} \quad \frac{\text{Charge on each plate}}{\text{Electric field in dielectric}}$$

6.6 Multisim Capacitor Circuit:

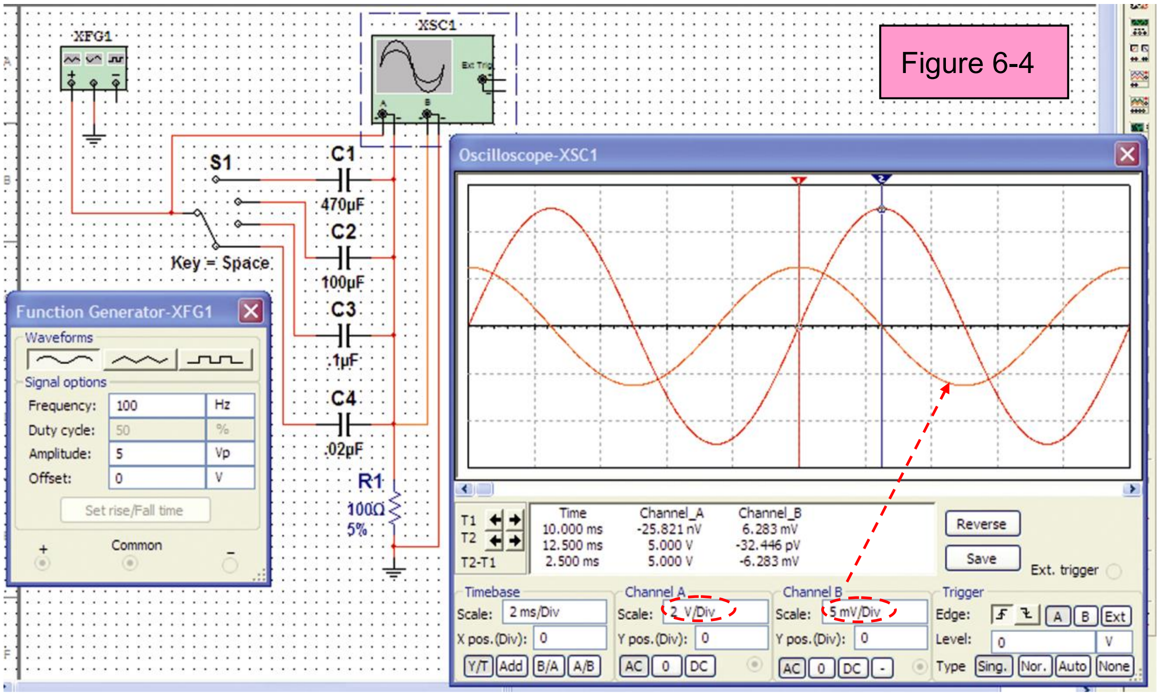
Open Multisim and build the following circuit. Set properties as shown here and run the program. Channel A shows the voltage across the selected Capacitor. Channel B uses a 100 ohm resistor to show the current through the Capacitor selected.



Set the coupling on both channels to AC. To eliminate dark screen click Reverse. After running a single trace click stop and set the T1 and T2 markers with T1 at the zero crossing for current and T2 at the current peak. The current through the capacitor must go through the 100 ohm resistor (there is no other path except the scope which is a very high resistance). Current and voltage are in phase in a resistive component. Then the voltage across the resistor (channel B) divided by the value of the resistor is equal to the current through the resistor and the capacitor at any point in time.

Clearly, the scope shows the current through the capacitor (Orange Trace) leads the voltage across by 2.5ms. Since the entire cycle takes 10ms the current can be said to lead the voltage by ¼ of a cycle. The AC cycle is produced by a wheel rotating 360 degrees therefore ¼ of a cycle equals 90 degrees. It shows that the current in a capacitor leads the voltage on the capacitor by 90 degrees.

Move switch S1 to the 0.02uf capacitor and repeat above process. Adjust scope settings to get a display similar to the one shown here.



In this display the T1 marker was set at the voltage zero crossing and the T2 marker at the voltage peak. Figure 6-4 shows the current still leads the voltage in the capacitor by 90 degrees. Current again reaches a peak when voltage is near zero (-25.821 nV = 0.000000025821 volts). In a similar manner you can see that at 12.5ms, when the current is very small and reversing direction (crossing the zero axis), the voltage across the 0.02uf Capacitor reaches a peak of 5 volts. Clearly the current leads the voltage by 90 degrees.

6.7 More About Capacitor Properties:

Fill in the table to include data for the other two values of capacitance in the Multisim example. Let V_p equal the peak voltage in volts and I_p (V_R/100) equal the peak current in Amps. Keep the Function Generator at 100 Hz and 5 V peak. Calculate X_c.

Table 6-1

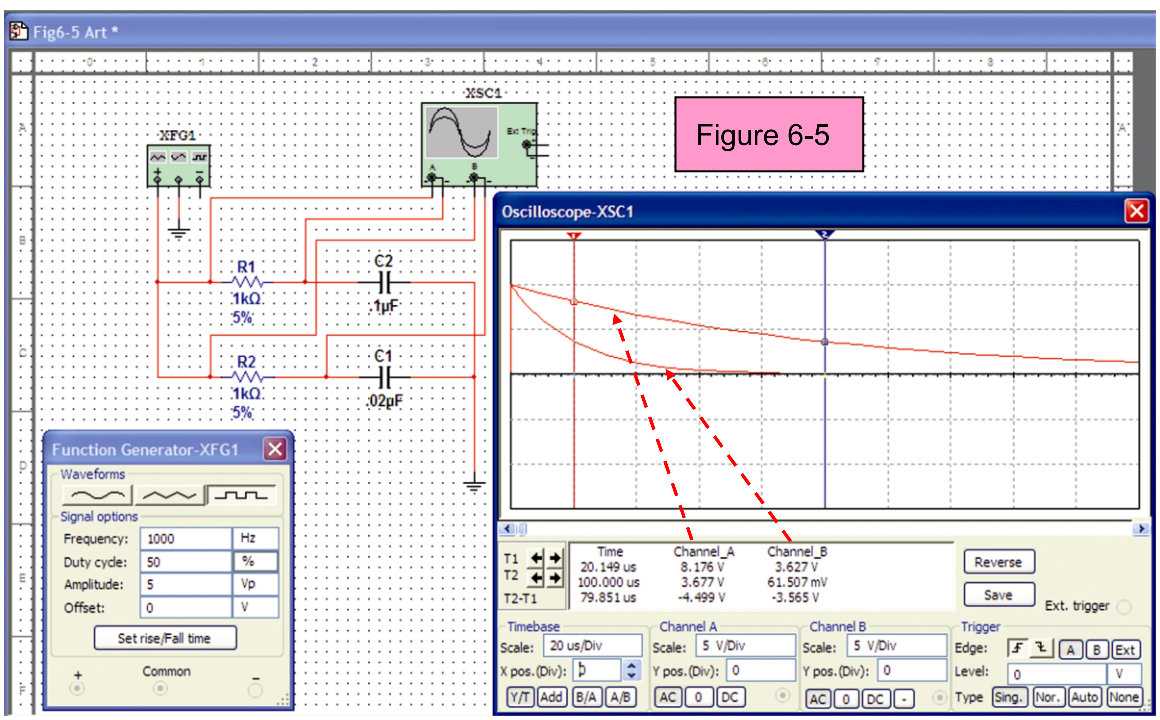
Frequency	Generator Vp	C Value	V_p across C	I_p through C	$X_c = V_p/I_p$ Ω
100 Hz	5 Vp	470 uF	.171468 V	.05 A	3.42936 Ω
100 Hz	5 Vp	100 uF			
100 Hz	5 Vp	0.1 uF			
100 Hz	5 Vp	0.02 uF	5.0 V	.0000628 A	79,617.8 Ω

{ON WORKSHEET}

The above table shows that a larger Capacitor (470uF) has much less AC resistance (X_c) than a smaller value (0.02uF) at a frequency of 100Hz. This should be easy to see if you consider the analogy shown in Figure 6-2. A large diaphragm will hold many drops of water before pushing back, but a small one will fill quickly and current will stop.

6.8 Transient Responses:

When voltages are first placed across a circuit the capacitors may need to charge to a stable state. This is known as the Transient Response on start up. This property can be observed by changing the sine wave to a square wave and using the following Multisim circuit. Figure 6-5 shows the current for the 0.02uF (Channel B) and the 0.1uF (Channel A) capacitors.



Notice that both capacitors start at exactly the same charging current (10V/1k=10ma), but the 0.02uF charging current drops to 3.62ma in 20.149us and the .1uf charging takes five times longer (100us) to drop to the same value which is a drop of 63.2% from the starting value.

6.9 RC time constant:

This decay (or charge) time is related to the product of the current limiting resistor and the value of the capacitor (RC). The time required for the current to fall to I_0 / e (63.2% of original value) is called the RC time constant and is given by the symbol tau as τ = RC. The symbol e is known as the natural log. It is an irrational number but we will approximate it as 2.71828. After each RC time constant the current will decrease by 63.2% of the remaining value during the next time constant.

Unlike resistance which has a fixed value with frequency, a Capacitors resistance (called Reactance, and shown as X_C in Table 6-1) varies with frequency. As the frequency applied to the capacitor increases its reactance (measured in ohms) decreases and as the frequency decreases its reactance increases. Reactance can be calculated from the equation X_C = $1/2\pi fC$ or $1/\omega C$ where $\omega = 2\pi f$ and f = frequency in Hertz. Example, using Table 6-1 last row information;

X_C = $1/(6.28 x 100 x .02 x 10^{-6})$ = 1/(0.00001256) = 79,617.8 (same as Table6-1 V_p/I_p)

If the frequency is increased by 1000 times (from 100 Hz to 100,000 Hz) the reactance will drop by 1000 times. The new value becomes;

X_C = $1/(6.28 x 100000 x .02 x 10^{-6})$ = 1/(0.01256) = 79.6178 ohms

6.10 The Real World - MySnap™:

Build the MySnap™ circuit shown below and set the MyDAQ up as indicated.

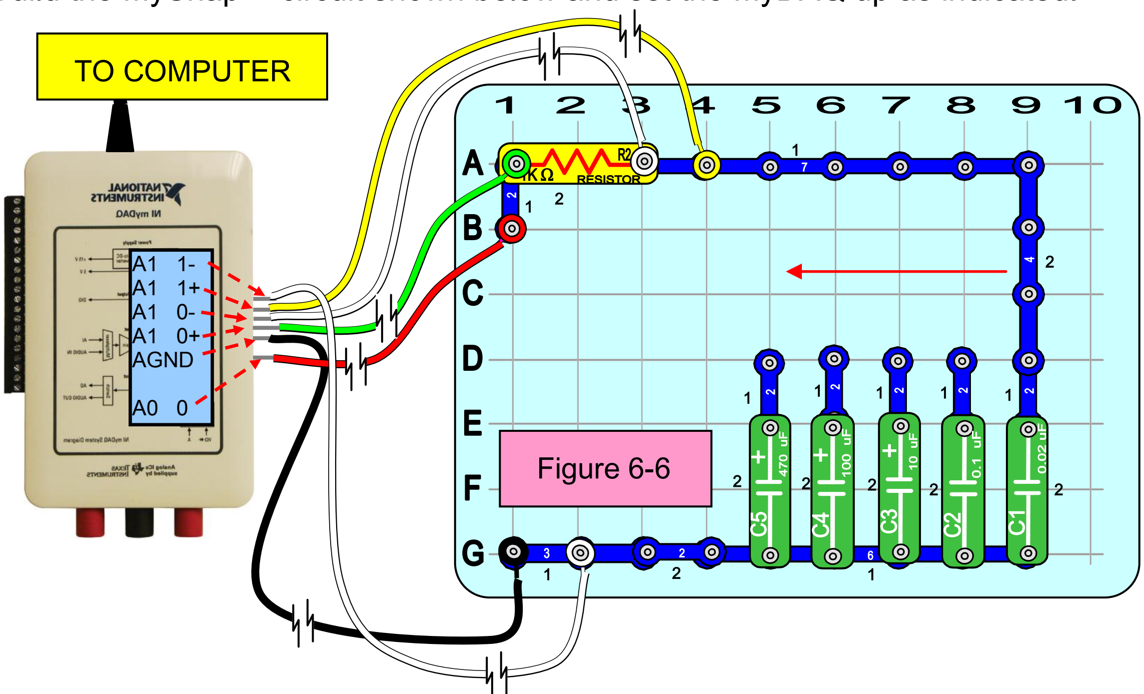


Figure 6-6

Set the Function Generator Frequency at 100Hz, Amplitude at 2.84 and Scope as shown here then run both.

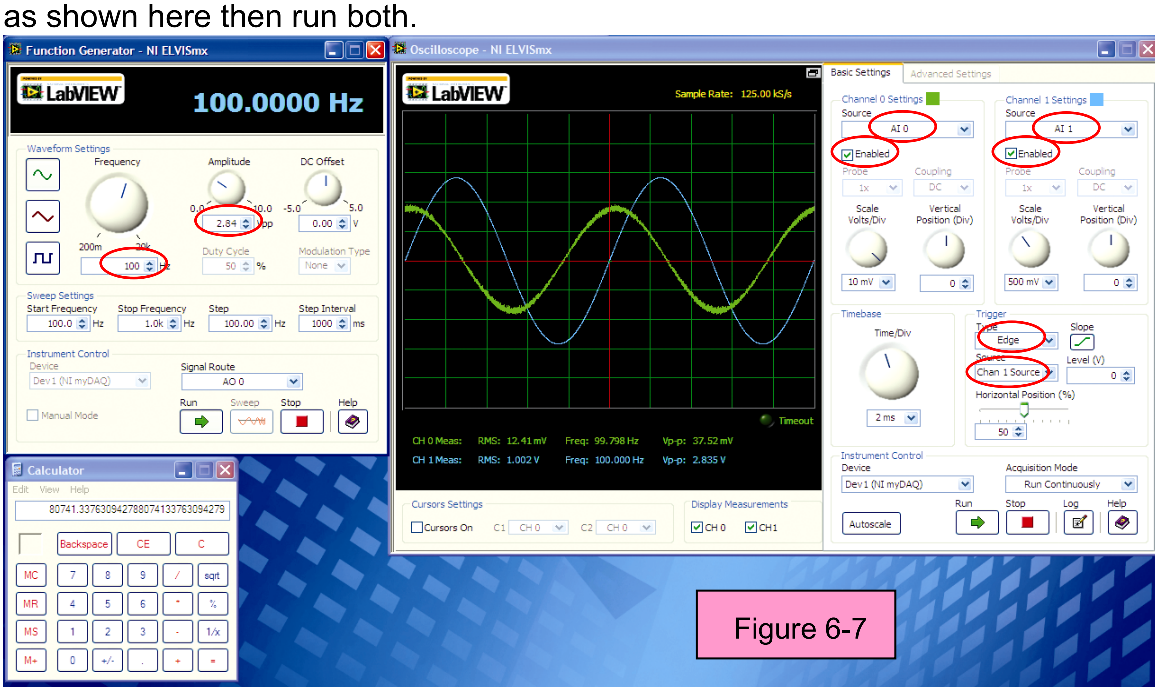


Figure 6-7

Voltage across capacitor = 1.002 Vrms (Yellow & Grey leads).

Current through capacitor equals current through resistor which equals 12.41mv/ 1k or .01241ma which becomes .00001241 amps (Orange & White leads)

XC = 1.002/.00001241, Using calculator XC = 80741.33763 ohms.

Using the reactance just calculated and the equation for reactance, the actual value of the capacitor can be calculated as follows;

$C = 1/(2\pi f X_C) = 1/(2)(3.14)(100)(80741.33763) = 1.972 \times 10^{-8} = 0.01972uF$

6.11 Actual Values and Tolerances:

Table 6-2 was created by using the above procedure and by moving the four snap in the direction of the arrow shown in Figure 6-6 to measure each value. When voltage levels were small the frequency was changed to get better readings. Note how the ohm value changes with frequency but not the C value.

Table 6-2

Generator	C Label	V across C	I through C	X_c = Vp/Ip	C Value
100Hz/2.84V	0.02uF	1.002 Vrms	.0124mA rms	80,741 ohms	.01972uF
100Hz/2.84V	0.1uF	.9996 Vrms	.0626 mA rms	15,968 ohms	.09972uF
100Hz/2.84V	10uF	.1668 Vrms	.9855 mA rms	169.25 ohms	9.408 uF
100Hz/2.84V	100uF	.0169 Vrms	1.002 mA rms	16.9 ohms	94.22 uF
100Hz/2.84V	470uF	.00389 Vrms	1.003 mA rms	3.89 ohms	409.34 uF
10kHz/2.84V	0.02uF	.64420 Vrms	.763 mA rms	844.3 ohms	.0188 uF
1kHz/2.84V	0.1uF	.84792 Vrms	.5289 mA rms	1603.2 ohms	.0993 uF
10Hz/2.84V	10uF	.85531 Vrms	.5149 mA rms	1661.1 ohms	9.586 uF
1Hz/2.84V	100uF	.83344 Vrms	.5473 mA rms	1522.8 ohms	104.56 uF
1Hz/2.84V	470uF	.30042 Vrms	.9443 mA rms	318.1 ohms	500.52 uF

Using the Labeled value as a reference, the % off labeled value (tolerance) can be calculated as follows to see if parts are within manufacturers specifications;

.02 uF - .0188 uF = .0012 then .0012/.02 = .06 or 6% low

.1 uF- .0993 uF = .0007 then .0007/.1 = .007 or .7% low

10 uF – 9.586 uF = .414 then .414/10 = .0414 or 4.14% low

100 uF – 104.56 uF = 4.56 then -4.56/100 = -.0456 or 4.56% high

470 uF – 500.52 uF = -30.52 then –30.52/470 = -.065 or 6.5% high

Large value capacitors are usually manufactured to be +80%to -20% of Labaled value while smaller capacitors are ± 10% . The above parts would all pass these specifications. Since your parts will be different than the ones shown here, you should use the MySnap™ circuit and MyDAQ to fill in your own table for the values of your parts.

6.12 LabVIEW® RC Meter:

In Lab 01, we used LabVIEW® to measure and graph the resistance. Now we will use LabVIEW® to measure resistance, reactance, and Capacitance. LabVIEW® will also adjust the frequency for the best measurement value. This is just a small taste of the power available in the National Instruments student package supplied with your myDAQ. First build the following circuit and connect the myDAQ as shown here.

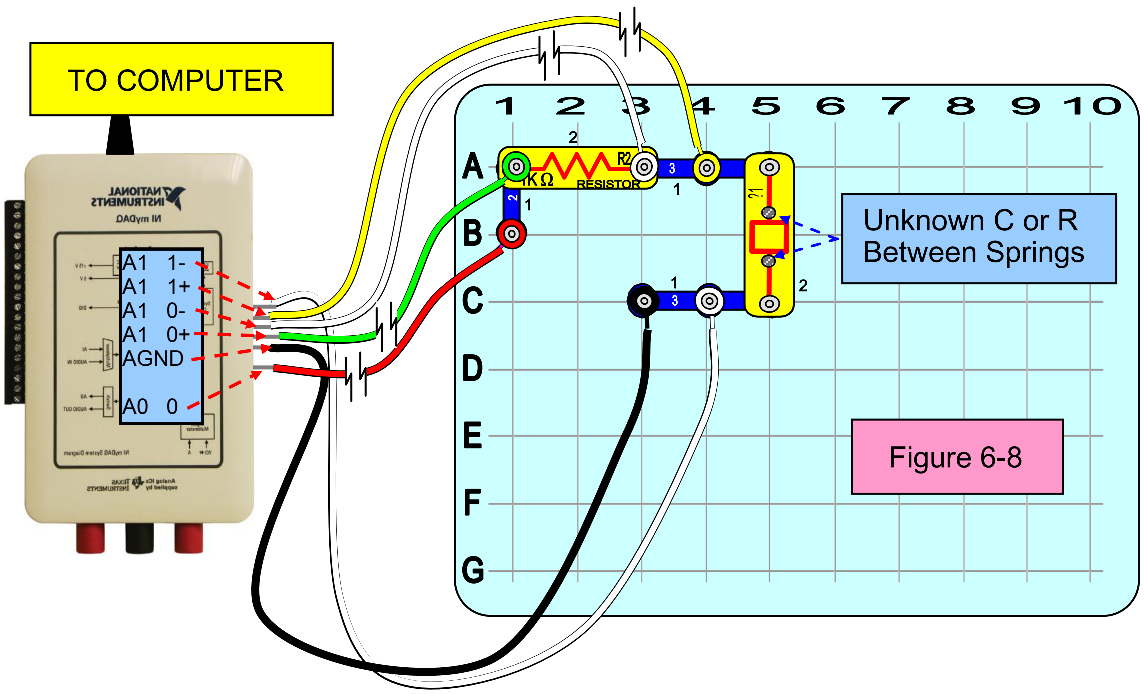


Figure 6-8

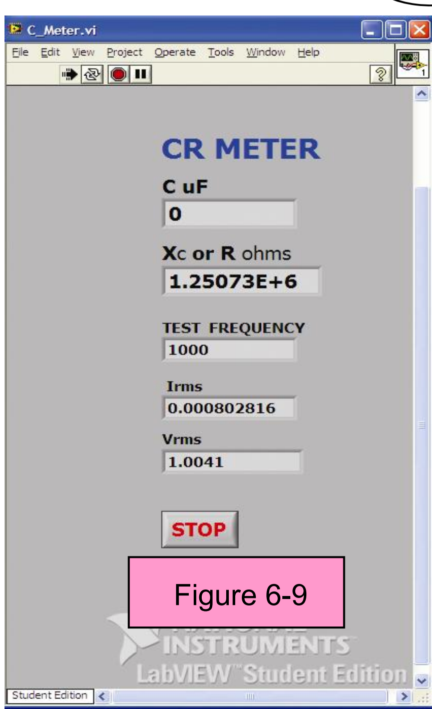


Figure 6-9

Next open LabVIEW® and run the virtual instrument (VI) named C_meter.vi. You can find this program on the disc supplied with your MySnap™ parts. The following window should appear.

Place one of the MySnap™ capacitors across the terminals shown in Figure 6-8 for unknown C or R. The Function Generator starts out at 1000 Hertz and places 1 volt rms across the resistor and capacitor. The voltage across the capacitor and the current through the capacitor is measured using the myDAQ Scope. Then LabVIEW® calculates the reactance of the capacitor and using 1000 Hertz the value of C required to produce that reactance. If the value of C is greater than 0.6 uF, the frequency is changed to 10 Hertz and a new measurement and calculation is made and displayed. When measuring a resistor, the value of C displayed is the value of capacitance that would have the same reactance at the frequency being used to measure the resistor.

6.13 How it Works:

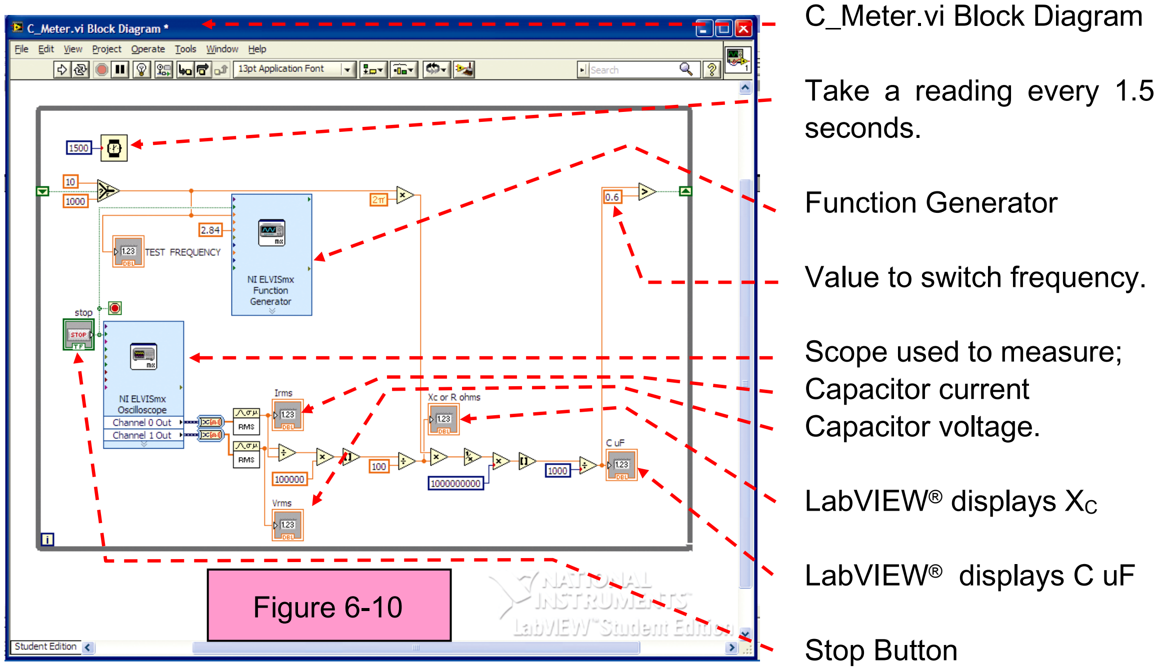


Figure 6-10

Notice how LabVIEW® does all the calculations and even changes the frequency for the best reading. LabVIEW® is a very powerful programming language that can incorporate real world or virtual instruments and make decisions on data received. It is best undrstood when used to create specific programs that accomplish a desired task. Although it is not required to complete this course, students should try to write their own programs in LabVIEW® if time permits.

6.14 Review:

Capacitors have the following characteristics;

- A Capacitor acts like a rubber diaphram inside a water pipe
- There must be current into capacitor before there can be voltage across the capacitor.
- In AC circuits the current into a capacitor leads the voltage by 90 degrees.

- The resistance of a capacitor in AC circuits is called Reactance (X_C).
- The Reactance of a Capacitor drops when Frequency increases according to the equation $X_C = 1/(2\pi fC)$
- A capacitor blocks Direct Current by charging and producing an equal and opposite DC voltage.
- For DC voltages capacitors produce a “Transient Response” on start up.
- The charge time (or discharge time) to 63.2% of final value is called the RC time constant and is given by the symbol tau as $\tau = RC$.
- Because it takes time to charge a Capacitor, the voltage across a capacitor cannot be changed instantly as for a resistor.
- LabVIEW® can control the virtual instruments in the myDAQ.
- LabVIEW® can calculate values and display results using external measurements.

Some common uses of capacitors are,

- Set time delay to turn lights on-off slowly.
- Remove AC ripple when converting AC to DC in power supplies.
- Tune circuits to receive specific frequencies in radios and TV sets.
- Store charges and release later as in flash on cameras.
- Supply extra current to help air conditioning motors start.
- Act like a battery in small toys to prevent batteries from discharging.
- Produce large currents for short period of time as in spot welding.

Lab 07: Inductors

The Inductor is an electrical device characterized by its capacity to store energy in a magnetic field, pass DC, block AC, and change the phase relationship between current and voltage in a circuit. This lab will explain inductors using analogies, virtual inductors using Multisim, real inductors using MySnap™ and circuits that demonstrate their properties. In the real world, measurements will be taken with the myDAQ DMM and their properties observed with the MyDAQ scope. The components to be measured are supplied in the MySnap™ model "BASIC ELECTRONICS EE100". Real life applications apply to power supplies, appliances, television, cell phones, satellite receivers, and almost anything electronic.

7.1 Topics covered in Lab 07

- Objective
- What you need
- Water pipe analogy
- In electrical circuit
- Multisim Inductor Circuit
- More About Inductor Properties
- Transient Responses
- RL time constant
- The Real World - MySnap™
- Actual Values and Tolerances
- Labview® RLC meter
- How it Works
- Review

7.2 Objective:

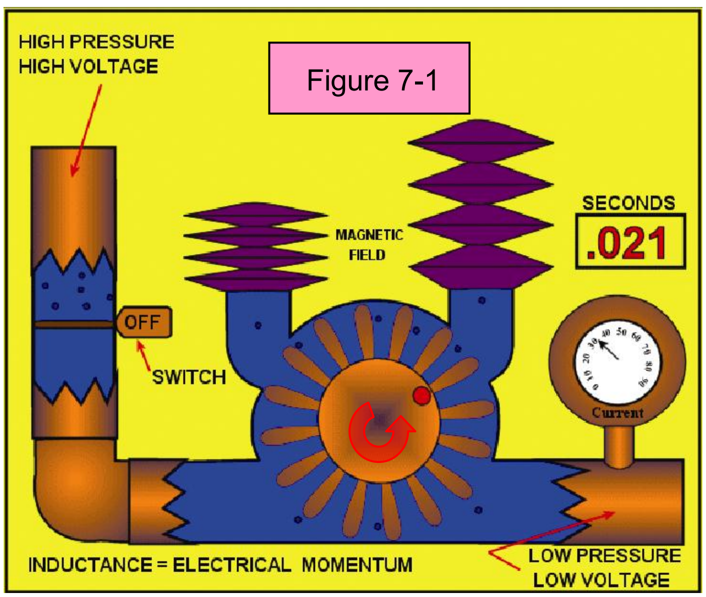
Use Multisim, the NI myDAQ, LabVIEW®, and MySnap™ to investigate both DC and AC properties of inductors in electronic circuits. Study inductive responses and phase relationship between current and voltage.

7.3 What You Need:

- Multisim
- NI myDAQ
- MySnap™ BASIC ELECTRONICS EE100 kit
- Computer System with NI software installed

7.4 Water Pipe Analogy:

In lab 06, you were introduced to the water pipe analogy for the Capacitor as a rubber diaphragm in a water pipe. The inductor can be described as electrical momentum and can be represented in a water pipe analogy by the device shown here.



When current is flowing the wheel spins in the direction shown allowing current to flow.

When the switch closes as shown, current keeps flowing and the magnetic bellows returns to neutral position forcing wheel to keep turning in same direction.

Now lets consider this water pipe component where the pressure across it does not reach a peak at the same time the current through it reaches a peak. When the switch is first opened the wheel cannot start turning instantly so no current flows but the full pressure is impressed across the water pipe inductor. As the wheel starts to turn the current starts flowing and the pressure across the pipe starts to drop. Current also flows inside the bellows pushing one up and sucking one down. Eventually when the wheel is spinning as fast as the current, the bellows are stretched and compressed in proportion to the current flowing, and the pressure across the inductor pipe is at a minimum. In this device the voltage (pressure) is present before the current (water) flows or the voltage leads the current. To better see this relationship, play the animated .gif file called Coil.gif on the disc that came with the MySnap™ parts. It can be viewed using an animated .gif player such as "Windows Media Player", "Windows Picture and Fax Viewer" or "QuickTime" just to name a few. Points of interest that should be noted in the analogy are;

- Water pressure (voltage) leads the current by 90°.
- Direct water flow (DC) passes through the inductor easily after wheel spins and bellows are charged (magnetic field is established).
- When an Inductor stores energy in a magnetic field (offset bellows) a condition exist to keep current flowing.
- Alternating water flow (AC) is blocked by inducter if water (current) reverses direction before wheel (magnetic field) can start to spin (high frequency).
- It takes time for current in an inductor to start flowing.
- Maximum DC current occurs when there is only back pressure from the wheel due to friction (resistance in inductor).
- Peak magnetic field occurs (bellows stretched and compressed) when current is at maximum.
- Size of wheel and weight or mass of wheel can change Inductors properties.

7.5 In electric circuits:

An electronic inductor consists of a coil of wire usually wound on a magnetic core. The size and shape of the coil can greatly increase the value of inductance. The magnetic core can also change the Inductance. The energy (measured in joules, in SI units) stored by an inductor is equal to the amount of work required to establish the current flowing through the inductor, and the magnetic field established. This is given by:

$E_{stored} = \frac{1}{2} LI^2$

Where, L is inductance and I is the current flowing through the inductor.

7.6 Multisim Inductor Circuit:

Open Multisim and build the following circuit. Set properties as shown here and run the program. Channel A shows the voltage across the Inductor selected. Channel B uses the 1000 ohm series resistor to view current through the selected Inductor.

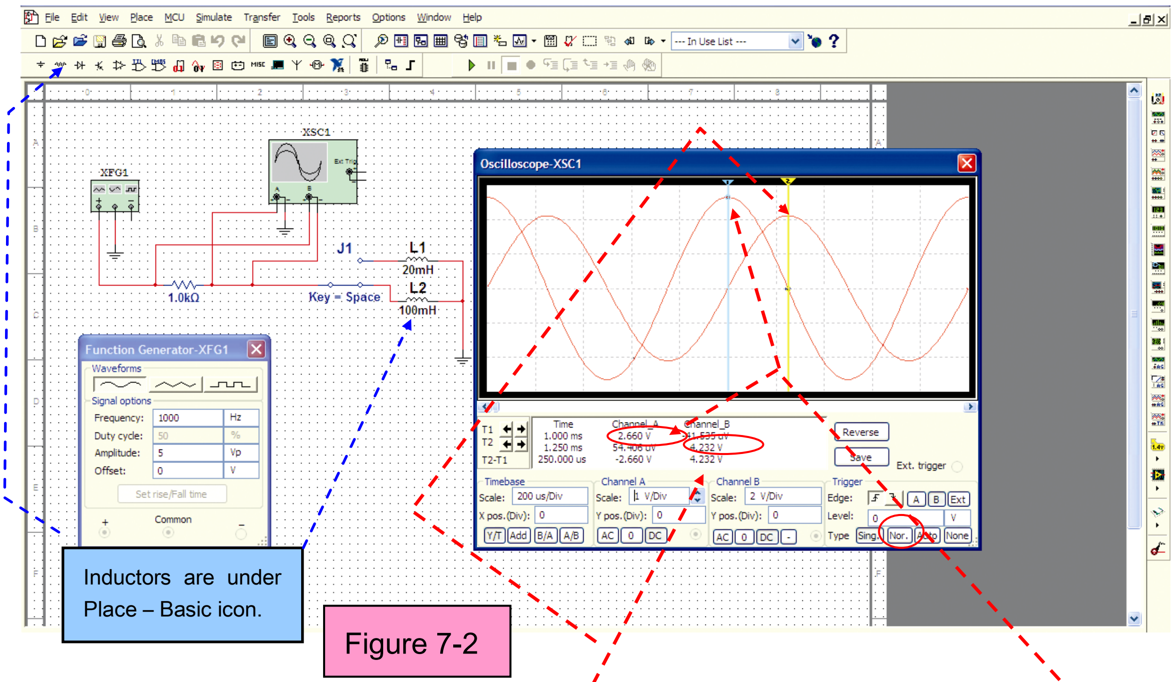


Figure 7-2

L peak current = 4.232V/1000Ω = .004232 Amps. L peak voltage = 2.66 Volts.

For a sinusoidal wave $X_L = V_{peak}/I_{peak}$ or X_L = 2.66/.004232 = 628.54 ohms

Also $X_L = 2\pi fL$, therefore $L = X_L/2\pi f$ or L = 628.54/6282 = .1H or 100mH

Note: The Voltage peak leads the Current peak. The time between peaks is 250us or ¼ of the total wavelength, therefore voltage leads the current by 90 degrees.

7.7 More About Inductor Properties:

First, fill in the table that follows to include data for the other value of inductance in the multisim example. Let V_p equal the peak voltage and I_p equal the peak current. Keep the Function Generator at 1000 Hz and 5 V peak.

Table 7-1

Frequency	L Value	Vp across L	Ip through L	$X_L = V_p/I_p$
1000 Hz	100 mH	2.66 V	.004232 A	628.54
1000 Hz	22 mH			

The above table shows that a larger Inductor (100 mH) has a greater AC resistance (X_L) than a smaller value (22 mH). This should be easy to see if you consider the analogy shown in Figure 7-1. A large paddle wheel will hold back water longer before starting to turn, but a small one will turn sooner for the same amount of pressure.

7.8 Transient Responses:

When, electric potential is first applied across a circuit the inductors will need time to allow current to flow. This is known as the Transient Response on start up. This property can be observed by changing the sine wave to a square wave and using the following Multisim circuit. Figure 7-3 shows the currents for a 100 mH (Channel B) inductor and a 20 mH (Channel A) inductor.

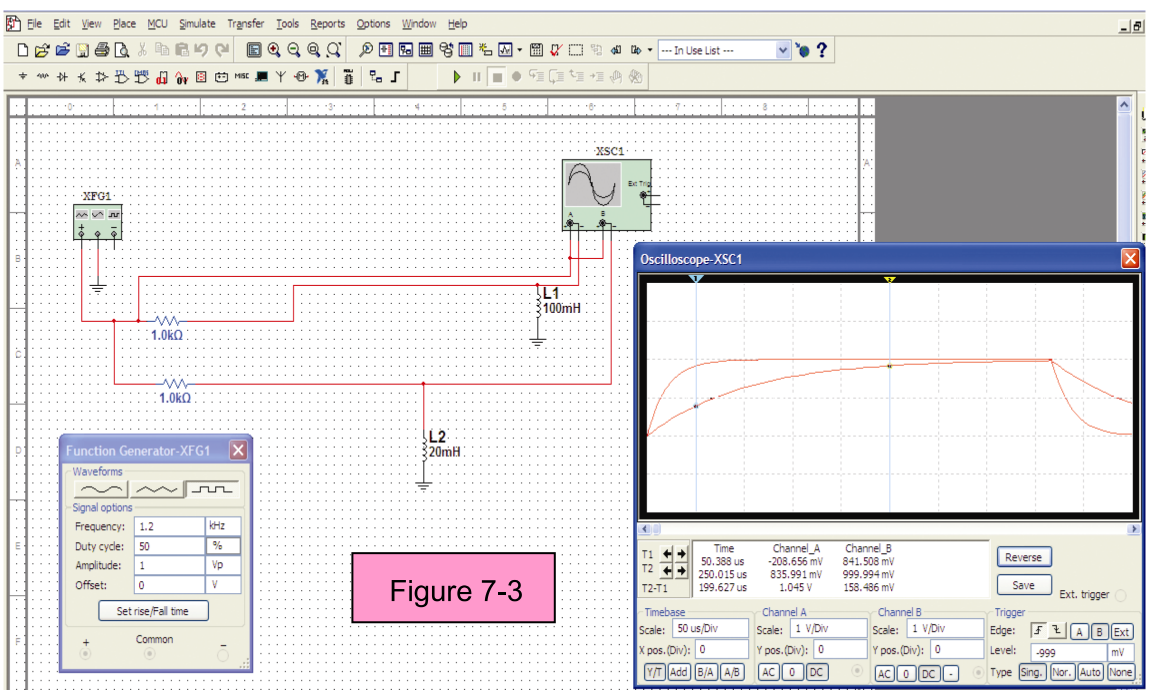


Figure 7-3

Notice that both inductors start at exactly the same charging current, but the 20mH charging current increases to 841 micro-amps (841mV/1000Ω) five times faster (T2/T1) than the 100 mH inductor.

7.9 RL time constant:

This current rise (or decay) time is related to the product of the current limiting resistor and the value of the inductor (RL). The time required for the current to rise to I_0 / e (63.2% of final value) is called the RL time constant and is given by the symbol tau as τ = RL. After each RL time constant the current will increase by 63.2% of the remaining value to final current during the next time constant.

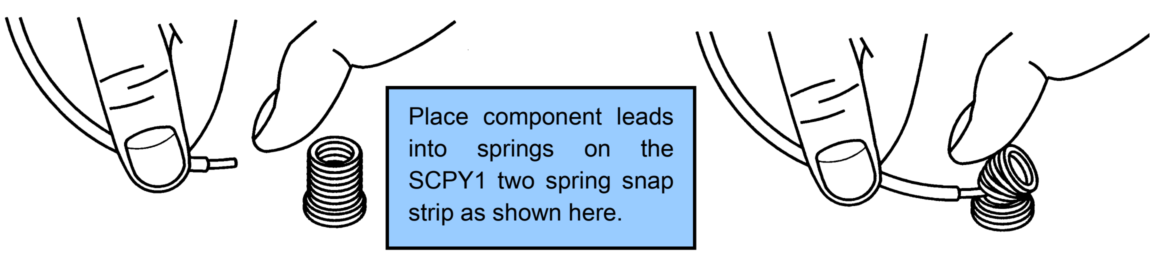
Unlike resistance which has a fixed value with frequency, an Inductors resistance (called Reactance, and shown as X_L in Table 7-1) varies with frequency. As the frequency applied to the inductor increases its reactance (measured in ohms) increases and as the frequency decreases its reactance decreases. Reactance can be calculated from the equation $X_L = 2\pi fL$ or ωL where $\omega = 2\pi f$ and f = frequency in Hertz. Example, using Table 7-1 last row information;

X_L = 6.28x1000x.1H = 6280x.1 = 628 (same as Table 7-1 V_p/I_p)

If the frequency is increased by 10 times (from 1000 Hz to 10,000 Hz) the reactance will increase by 10 times. The new value becomes;

X_L = 6.28x10000x.1H) = 6280 ohms

7.10 The Real World - MySnap™:



Build the MySnap™ circuit shown next and connect the MyDAQ as indicated. Put the 100mH inductor into the two spring snap holder and snap into 5A - 5C.

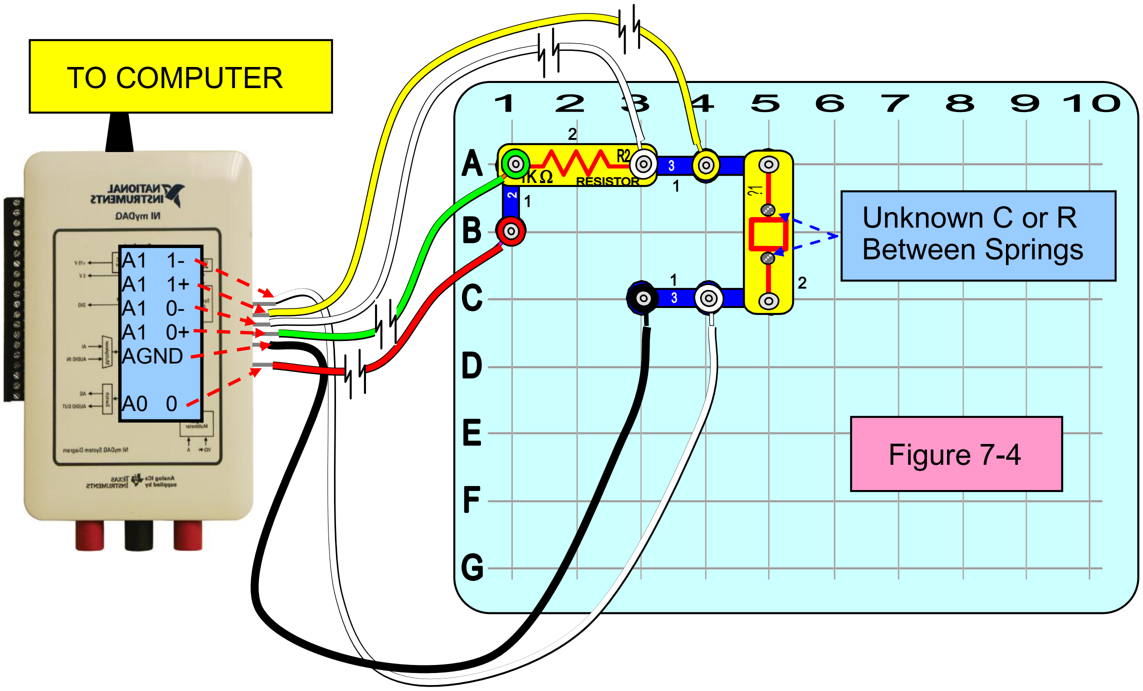


Figure 7-4

Set up Scope and Function Generator as shown here and run both.

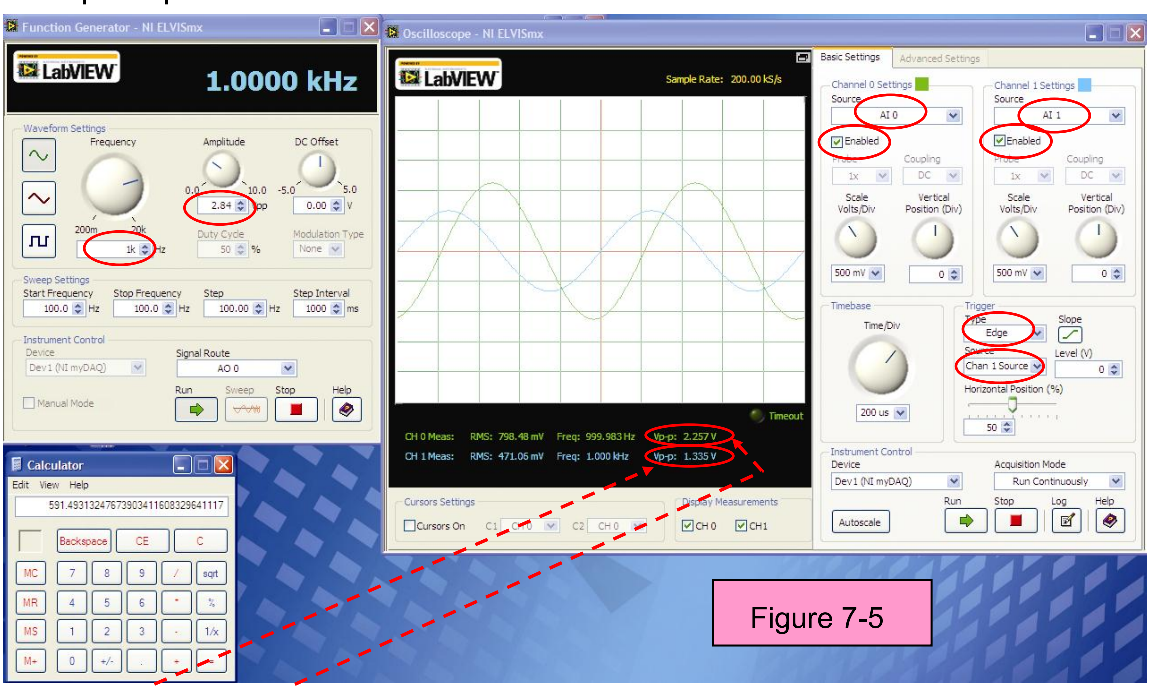


Figure 7-5

X_L = 1.335V/(2.257V/1kΩ)= 1.335/.002257 = Using calculator XL = 591.4931

Using the reactance just calculated and the equation for an inductive reactance, the actual value of the inductor can be calculated as follows;

$L = X_L/(2\pi f)$ = (591.4931)/(6283) = .094142 H = 94.142 mH

7.11 Actual Values and Tolerances:

Table 7-2 uses the above procedure to measure and calculate each inductance value. At a frequency of 1 kHz the voltage and current readings were adaquate for accurate calculations.

Table 7-2

Generator	L Label	V across L	I through L	$X_L = V_{pp}/I_{pp}$	L Value
1kHz/2.84V	100 mH	1.335 Vpp	2.257 mApp	591.5 ohms	94.14 mH
1kHz/2.84V	22 mH	.3478 Vpp	2.7 mApp	128.8 ohms	20.5 mH

Using the Labeled value as a reference, the % off labeled value (tolerance) can be calculated as follows to see if parts are within manufacturers specifications;

100 mH – 94.14 mH = 5.86   then 5.86/100 = .0586 or 5.86% low

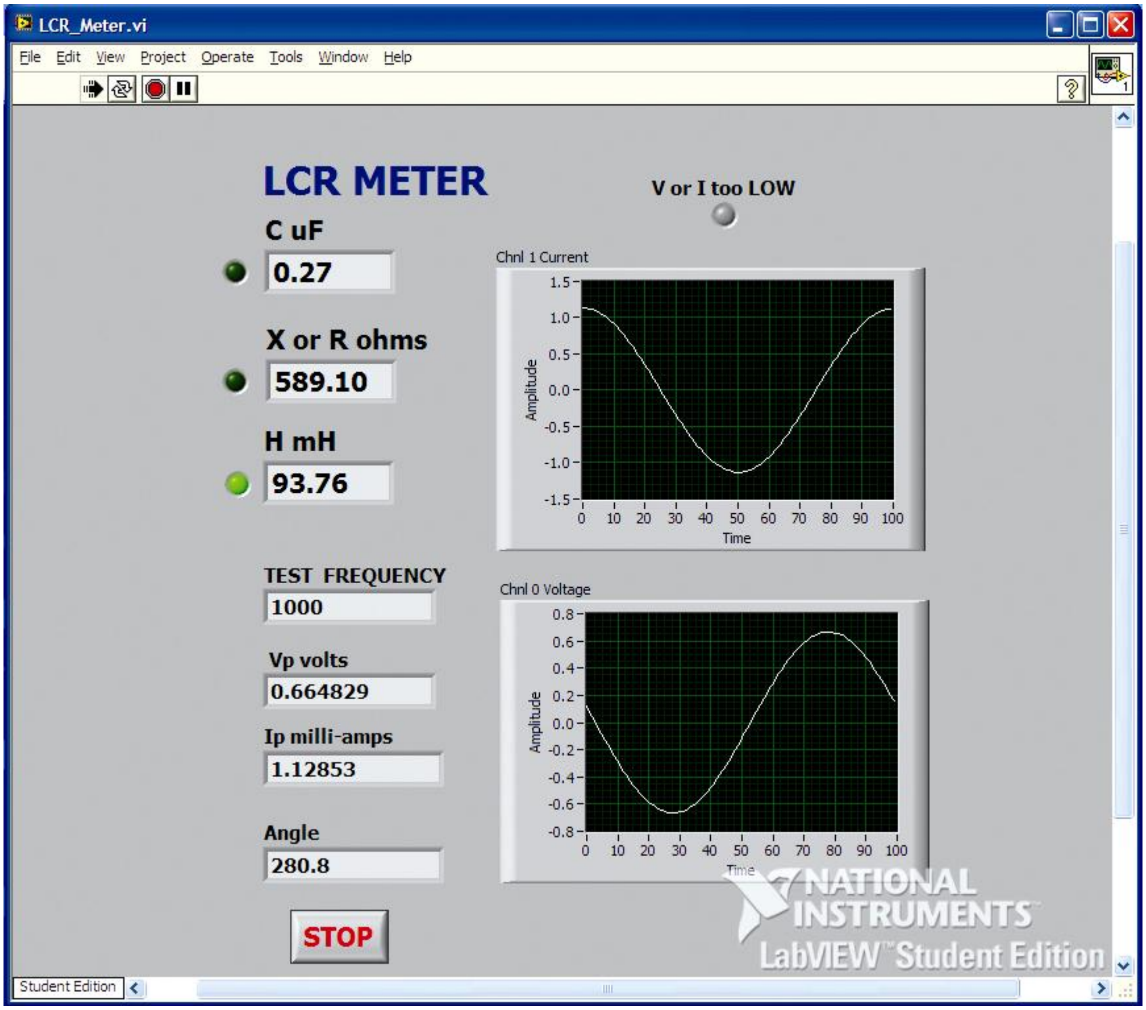
22 mH – 20.5 mH = 1.5   then 1.5/22 = .068 or 6.8% low

Inductors are usually manufactured to be ± 10% of labaled value. The above parts would both pass this specification. Since your parts will be different than the ones shown here, you should use the MySnap™ circuit and MyDAQ to fill in your own table for the values of your parts.

7.12 LabVIEW® LCR Meter:

In lab 06 we used LabVIEW® to measure resistance, reactance and capacitance. Now we will use LabVIEW® to measure resistance, reactance, capacitance and inductance. LabVIEW® will use a fixed frequency of 1kHz for all inductance measurements and either 1kHz or 10Hz for capacitance. Use the circuit shown in Figure 7-4. Place the 100mH coil in the Snap-to-Springs holder and snap into the circuit for testing.

Open LabVIEW® and run the virtual instrument (VI) named LCR_meter.vi. You can find this program on the disc supplied with your MySnap™ parts. The following window should appear.

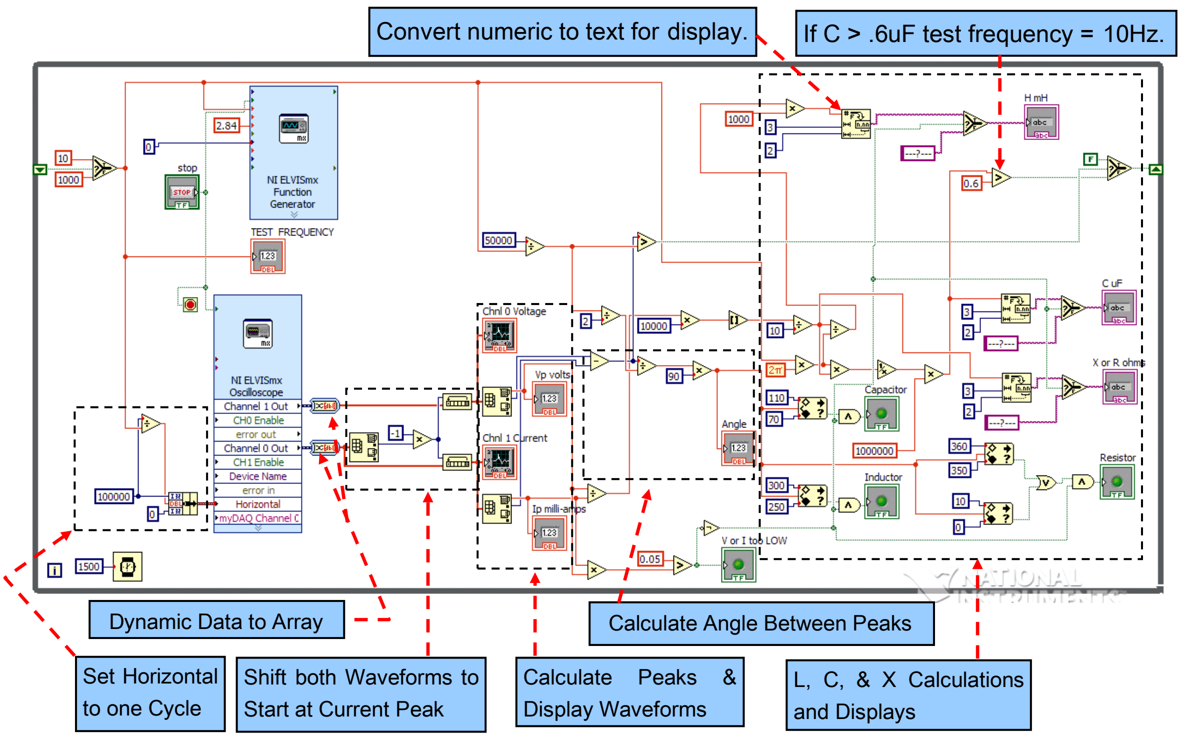


The Function Generator starts out at 1000 Hertz and places 1 volt rms across the resistor and inductor. The voltage across the inductor and the current through the inductor is measured and sent to LabVIEW® using the myDAQ Scope. Then LabVIEW® converts this dynamic data to an array, finds the peak for one cycle, and shifts both voltage and current arrays to start at the peak current. LabVIEW® displays both waveforms and calculates the reactance of the inductor using the Function Generator frequency of 1000Hz. The value of Inductance required to produce this reactance is calculated and displayed. If the Voltage leads the current by approximately 90 degrees (or lags by 270 degrees) the Inductor LED is turned ON.

Finally the value of C displayed is the value of capacitance that would have the same reactance at the frequency being used to measure the inductor.

This is also the capacitance needed to make a resonant circuit at the test frequency.

7.13 How it Works:



The sections above are less complicated if they are analized seperatly.

7.14 Review:

Inductors have the following characteristics;

- An Inductor acts like a paddle wheel inside a water pipe.
- There must be pressure (voltage) on the wheel before it can rotate and allow current to flow, voltage across inductor leads current through inductor.
- In AC circuits the voltage across an inductor leads the current through it by 90 degrees.
- The resistance of an inductor in AC circuits is called Reactance (X_L).
- The Reactance of an Inductor increases when Frequency increases according to the equation $X_L = 2\pi fL$
- An inductor blocks Alternating Current by not allowing current to start before the current changes direction, but eventually allows DC current to flow freely.
- For DC currents inductors produce a “Transient Response” on start up.
- The current rise time (or fall time) to 63.2% of final value is called the RL time constant and is given by the symbol tau as τ = RL.

- Because it takes time to start current flowing in an inductor, the current in an inductor cannot be changed instantly as for a resistor.
- LabVIEW® LCR meter shows phase angle between current and voltage for components being measured.
- LabVIEW® LCR meter uses a components characteristics to calculate the type of component being tested, its values at a given frequency, and display results.

Lab 08: The Diode

The Diode is an electrical device characterized by its capacity to conduct current in one direction and block current flow in the opposite direction. This lab will explain the diode using a water pipe analogy, virtual diodes using Multisim, real diodes using MySnap™ and the diode curve tracer virtual instrument called *DIODE.VI*. This VI can be found in ENGR190_Vis.zip file. In the real world, measurements will be taken with the myDAQ DMM and then displayed on the diode curve tracer. The components to be measured are supplied in the MySnap™ model “BASIC ELECTRONICS EE100”. Real life applications apply to anything that converts AC to DC or detects and demodulates signals, such as power supplies, radios, and television just to name a few.

8.1 Topics covered in Lab 08

- Objective
- What you need
- Water pipe analogy
- In electronic circuits
- Multisim diode circuit
- AC to DC conversion
- More about diode properties
- The real world diode
- Diode (D1) measured parameters
- Diode equation
- Review

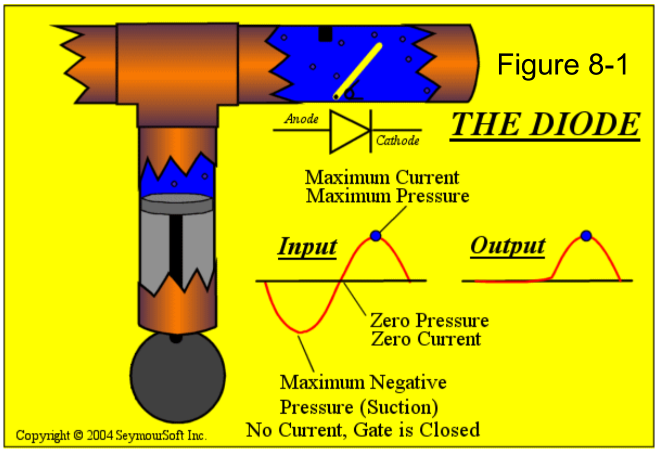
8.2 Objective:

Use Multisim, the NI myDAQ, LabVIEW®, and MySnap™ to investigate both DC and AC properties of diodes in electronic circuits. Study diode responses and relationship between current and voltage using a diode curve tracer.

8.3 What You Need:

- Multisim
- NI myDAQ
- MySnap™ BASIC ELECTRONICS EE100 kit
- Computer System with NI software installed

8.4 Water Pipe Analogy:



In Lab 03, Figure 3.3, you were introduced to Alternating Current in a water pipe analogy. The diode can be described as a check valve and can be represented in a water pipe analogy by the device shown here. When current is flowing away from the pump, the check valve opens and current flows. When the pump tries to suck current back from the pipe, the check valve closes and stops current from flowing. The diode converts AC (current flowing in two directions) to pulses of DC (current flowing in only one direction).

Now let's consider this water pipe check valve shown above. Notice the spring on the valve plate trying to push it shut. This requires a small amount of pressure to push the valve open. Depending on the material the spring is made of, the pressure to open the check valve may vary from .2 to 2 lbs/sq in (or .2 to 2 volts in electronic world). In the closed position the plate can bend slightly acting like a very small capacitor (varacter diode in electronics). If the spring is strong, the current flowing may heat the tip of the valve and cause it to emit light of a particular color when it opens (Light Emitting Diode or LED). To better understand the diode, play the animated .gif file called Diode.gif on the disc that came with the MySnap™ parts. It can be viewed using an animated .gif player such as "Windows Media Player", "Windows Picture and Fax Viewer" or "QuickTime" just to name a few.

Points of interest that should be noted in the analogy are;

- Water pressure (voltage) must overcome spring pressure before current can flow.
- Direct water flow (DC) passes through the diode easily in one direction after spring pressure is passed and not at all in the opposite direction.
- Alternating water flow (AC) is converted to pulses of one direction water flow (DC) if peak AC preasure is greater than spring pressure.
- Some electronic diodes may produce light.
- Reverse biased (Pressure in shut direction only) may be used to act like a very small variable capacitor.

8.5 In Electronic Circuits:

A solid state electronic diode is constructed from different types of semiconductor materials depending on their application. In manufacturing diodes, the construction process of changing a semiconductor material from a P type to an N type creates a built in depletion region as the plus carriers combine with the negative carriers to make an area depleted of all carriers. This region acts like an insulator and prevents current flow. Figure 8-2 illustrates this type of diode.

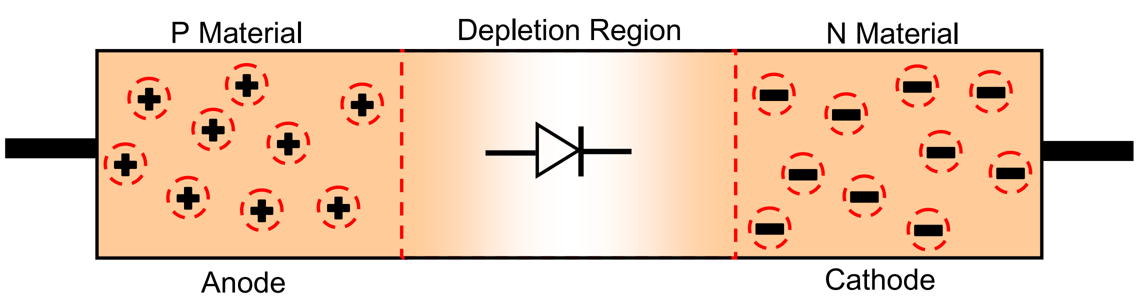


Figure 8-2

Plus voltage on the anode pushes the plus charges into the material and narrows the depletion region. Likewise, a negative voltage on the cathode will repel negative charges and narrow the depletion region. As these voltages increase the current will start to flow and increase exponentially. In the water pipe analogy this voltage required is represented by the spring holding the check valve shut. If these voltages are reversed, the depletion region will be greater and no current will flow. Similar to the water pipe analogy, no current flows in the water pipe check valve during the reverse cycle.

8.6 Multisim Diode Circuit:

Open Multisim and build the following circuit. Set properties as shown here and run the program. Channel A shows the current through the LED diode. Channel B uses the 1.0 KΩ series resistor to view current through the 1N4001 diode.

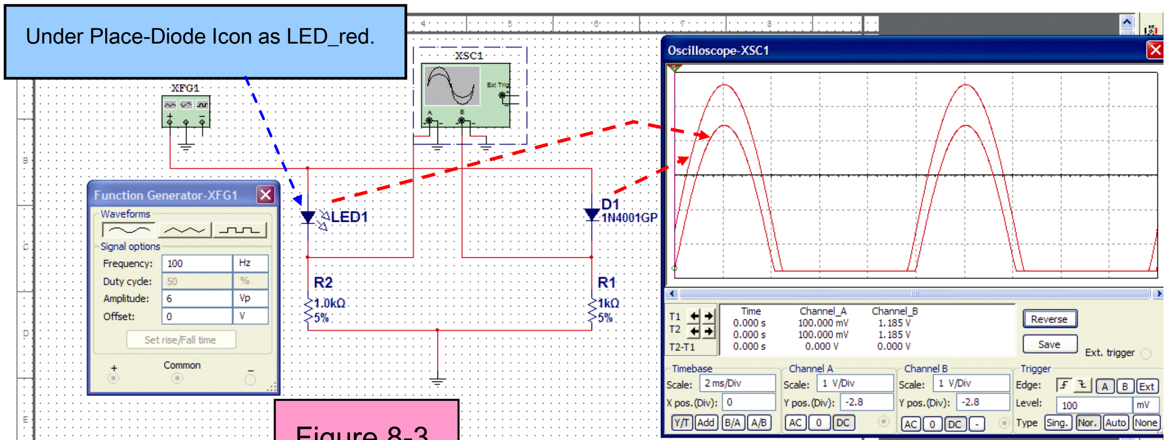


Figure 8-3

8.7 AC to DC Conversion:

Notice how the negative portion of the AC current has been blocked by both the LED diode and the 1N4001 diode. The 1N4001 allows more current to flow because it has a lower turn on voltage. You could say in the water pipe analogy that the spring holding the valve shut is weaker.

8.8 More About Diode Properties:

By making the frequency 250Hz and using a triangular wave from the generator with a peak voltage of 3 volts the waveform shown here is generated.

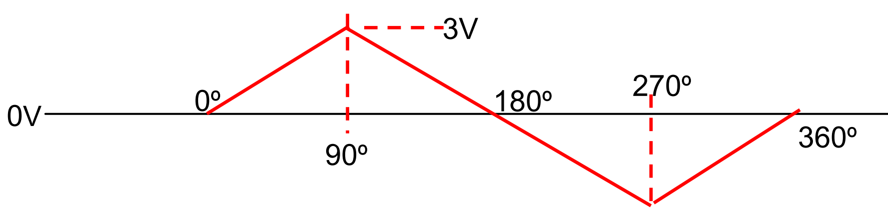


Figure 8-4

Wavelength is equal to 1/f or 1/250 or 4ms. Therefore 0º to 90º is 1 ms. The voltage rise in this 1ms region is 3 volts. By dividing this up into ten 0.1ms (or ten 100us) divisions, we produce a sweep of voltage that rises 0.3 volts every division. Also by using a one ohm resistor in series with each diode, each milli-volt across the resistor will equal 1 mA through the diode. Rebuild the Multisim circuit and expand the sweep to observe the current through the diode as voltage increases will produce the graph shown in Figure 8.5. With the scope set at a horizontal of 100us per division, every division = .3 volts.

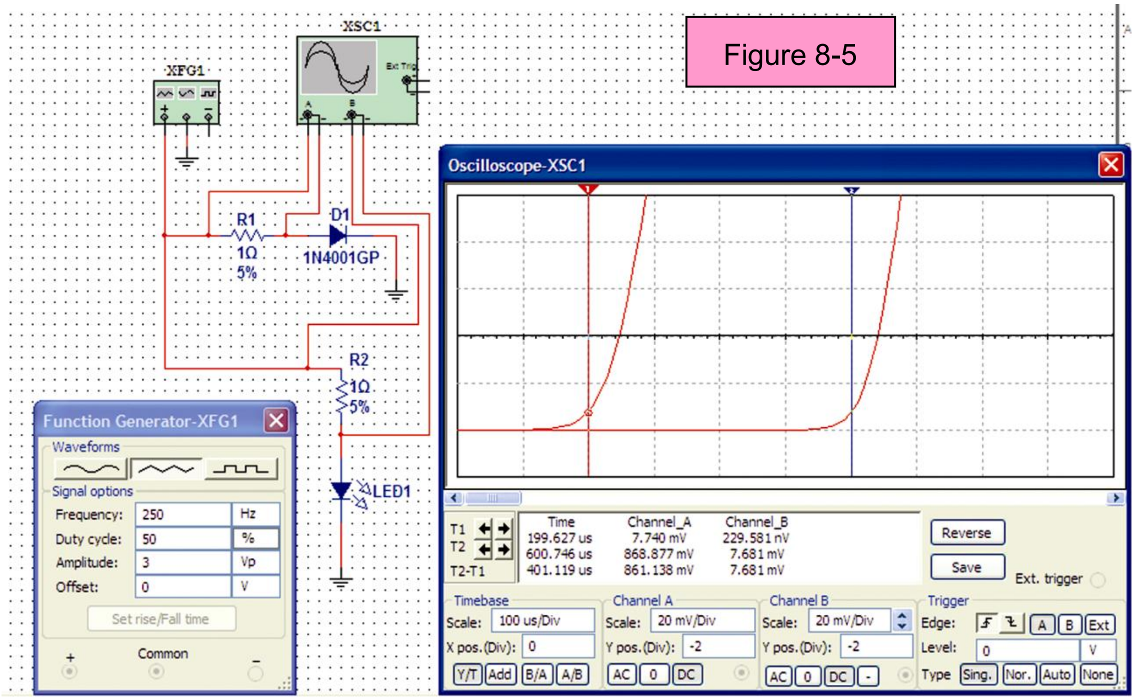


Figure 8-5

Notice that both diodes start at zero current, but the 1N4001 allows current to flow at .6 volts while current does not start to flow in the LED until 1.8 volts.

8.9 The Real World Diode:

The diode is a non-linear device with a decreasing resistance as current increases. To see the current – voltage relationship build the circuit shown here.

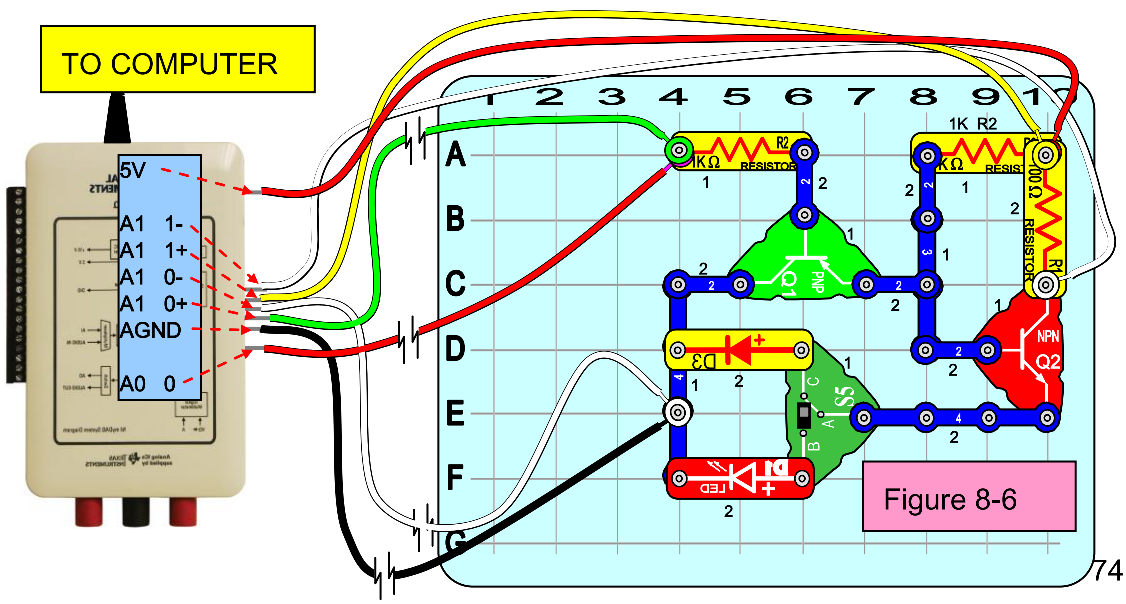


Figure 8-6

Open LabVIEW® and run the Diode.VI to sweep the D3 diode. The S5 switch should be in the “C” position to obtain the curve shown below.

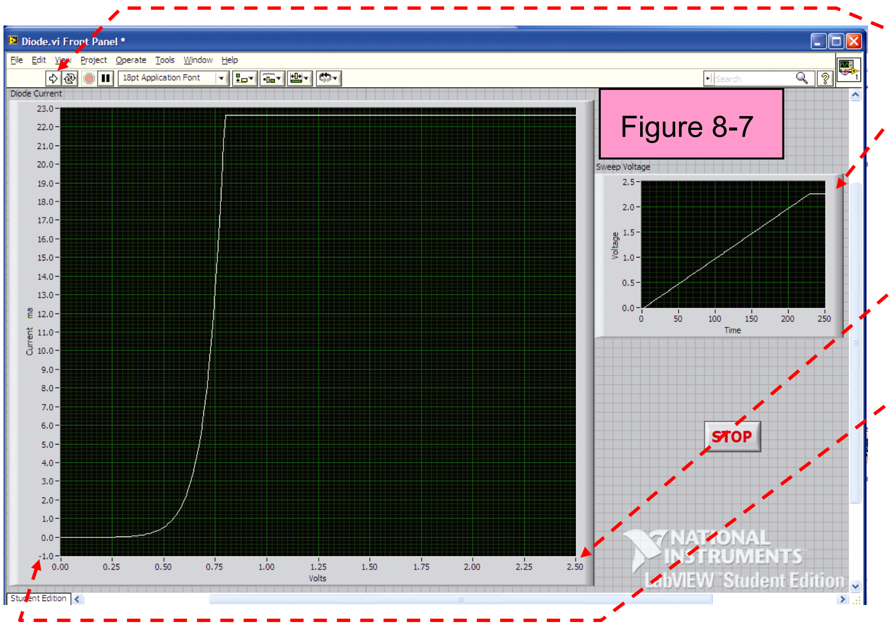


Figure 8-7

The D3 diode is a 1N4001 power diode mainly used in small power supplies. Notice how the diode turns on around 0.5 volts and allows over 22 milli-amps at around .75 volts. Figure 8-8 below shows this area in detail.

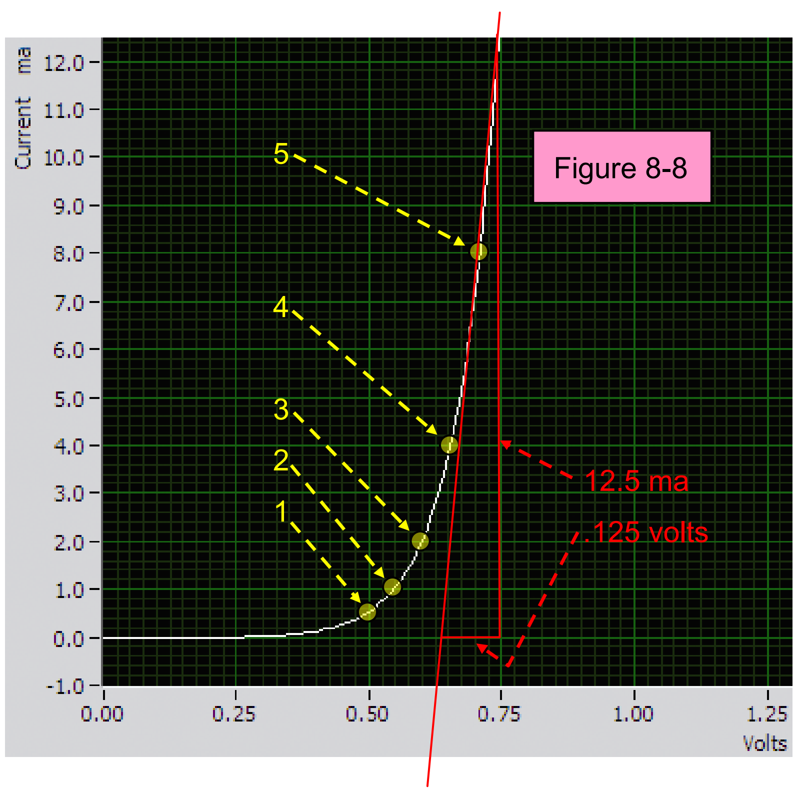


Figure 8-8

The circles on the curve mark the spots where the current has doubled, starting at .5ma.

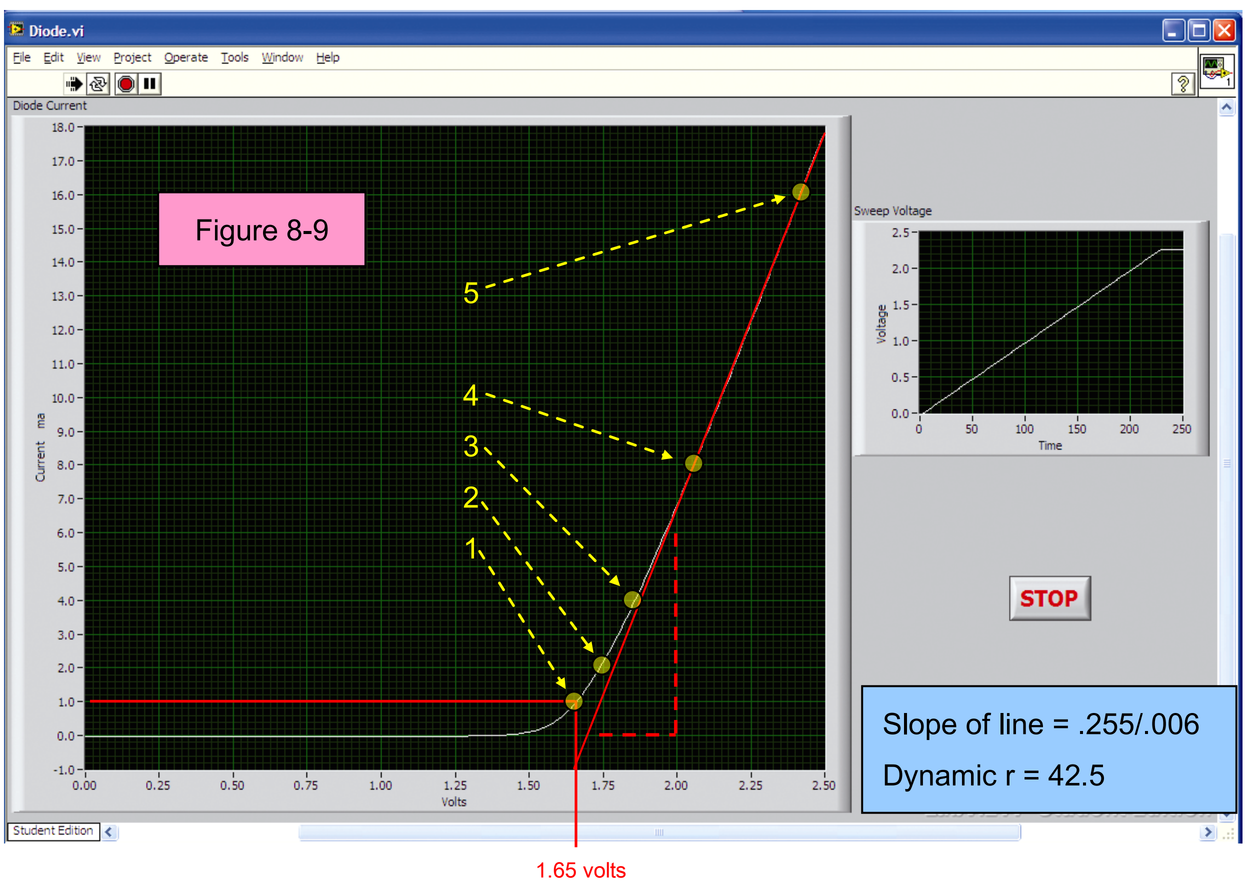
Using these current levels the Table 8-1 was constructed to study the D3 diode curve and compare it to the Ideal Diode curve. Dynamic r = .125/.0125; r = 10 ohms

TABLE 8-1 Measured D3

No.	Current (I)	Voltage (V)	Static Ohms (R=V/I)	% of Previous
1	.0005	.5	1000	--------
2	.001	.55	550	55%
3	.002	.60	300	54.5%
4	.004	.65	162.5	54%
5	.008	.70	87.5	53.9%

8.10 Diode (D1) Measured Parameters

Flip switch S5 in Figure 8-6 to get the Red LED (D1) sweep shown in Figure 8-9



Snap part D1 has an internal 33 ohm resistor to limit current and protect the LED from wrong wiring. The dynamic r from the LED equals the measured 42.5 ohms in Figure 8-9 minus the 33 ohm in series with the LED or 9.5 ohms. Notice how the resistance for the LED also changes to approximatly half each times the current doubles.

No.	Current (I)	Voltage (V)	Ohms (r = V/I)	% of Previous
1	.001	1.65	1650	--------
2	.002	1.75	875	53%
3	.004	1.85	462.5	52.9%
4	.008	2.075	259	56%
5	.016	2.425	152	58.7%

Table 8-3

8.11 Diode Equation

The relationship between the diode current and voltage is given by the diode equation

$$I_D = I_S\left(e^{V_D/nV_T} - 1\right)$$

The terms in Equation are defined as follows:

I_D = the diode current (amperes).

V_D = the voltage across the diode (volts).

I_S = the reverse saturation current or the reverse leakage current (amperes).

I_S is a function of the diode material, the doping densities on the p-side and n-side of the diode, the geometry of the diode, the applied voltage, and temperature. I_S is usually ultra small current which is the order of 1μA to 1mA for a germanium diode at room temperature and of the order of 1pA = 10^{-12}A for a silicon diode at room temperature. I_S increases as the temperature rises.

V_T = kT/q = the thermal equivalent voltage = 0.0258 V at room temperature

where

q = 1.6 x 10^{-19} Coulombs = the electric charge,

k = 1.38 x 10^{-23} J/K = Boltzmann's constant,

and

T = absolute temperature (Kelvin) [room temperature = 300 K].

n = the ideality factor or the emission coefficient.

8.12 Review:

Diodes have the following characteristics;

- A Diode acts like a check valve inside a water pipe.
- There must be forward pressure (voltage) on the check valve before it can open and allow current to flow, no current will flow if voltage across diode is less than the threshold voltage.
- In AC circuits the diode will convert alternating current into pulses of direct current.
- The resistance of a diode is nonlinear and changes with current.
- A reverse biased diode can act as a very small capacitor.
- Voltage and current in a diode are in phase, no phase shift.
- Diode turn on voltages can vary depending on materials and type of diode.
- Some diodes can produce light when current flows.
- LabVIEW® Diode.VI shows diode current when a forward sweep voltage is applied.

Appendix A: Basic Definitions and Conventions

AC
: Alternating current. Consists of a periodic oscillation between two different voltages. Usually said to look like a sine wave, but is not always.

Ampere (A)
: The SI unit for the electrical current. An Ampere of current flow represents electron movement at a rate of one coulomb per second: that amount of current through one ohm of resistance with one volt applied.

Amplify
: To increase the strength of the signal.

Anode
: An electron collector. An anode has a more positive voltage relative to a cathode.

Attenuate
: Decrease the strength of a signal.

Capacitor
: An electronics component that stores energy in the form of electric charge (static electricity). It resists a sudden change in voltage.

Cathode
: An electron emitter. A cathode has a more negative voltage relative to an anode.

Charge
: Particles can have two possible types of charge: positive or negative. Electrons are negatively charged, protons are positively charged. Opposite charges attract, while particles with the same charge (either positive or negative) repel each other.

Choke
: Another name for an inductor, specifically referring to those used in power regulation.

Circuit
: The paths electrons take as they are pushed by some power source, flow through various electrical components then return to the power source.
: *Short Circuit* exist, when there is no resistance between two points. Current flows without a change in voltage.
: *Open Circuit* exist when there is infinite resistance between two points. Current is unable to flow, but there is still a voltage between the two points.

Coil
: A helix of wire. Its height, width, thickness, and material can all vary. Often used as an inductor.

Condenser
: Another name for capacitor.

Conductance
: The inverse of resistance. Measured in siemens (obsolete name mhos), which are the inverse of ohms. 1 S = 1/Ω = 1 A/V

Conductor:
: A material that has many free electrons.

Coulomb (C)
: The SI unit for electric charge *Q*. Defined in terms of the **ampere**. 1 coulomb is the amount of electric charge carried by a current of 1 ampere flowing for 1 second. It is also about 6.24×10^{18} times the charge on an electron. 1 C = 1 A·s

Current
: The movement of charges in an electric field. This is perceived as a flow. It is measured in **amperes**.

Cycles per second (cps)

An obsolete name for Hertz, the standard SI unit for frequency. As the name implies, a measurement of frequency in full cycles of a wave per second.

DC

Direct current. A constant voltage and a constant current flow in one direction.

Diode

A one way valve for current. Semiconductor diodes typically have a voltage drop of 0.6 V (silicon) or 0.2V (germanium) when conducting in the forward direction.

Electron:

The negatively charged particle in an atom orbiting the atom's nucleus.

EMF (*E*)

Electro-Motive Force. A force for moving electrons. See **Voltage**.

Farad (F)

The SI unit for capacitance (*C*). A capacitor has a capacitance of 1 Farad when a charge of 1 Coulomb raises its potential 1 Volt.

Forward Biased

The voltage polarity through a part which causes it to conduct current.

Farad:

Unit of measurement of capacitance. A capacitor has a capacitance of 1 Farad when a charge of 1 Coulomb raises its potential 1 Volt.

Frequency (*f*)

Number of times a periodic waveform repeats itself in a unit time (generally seconds). Units of measurement are Hertz.

Gain

A multiplier of voltage or current.

Ground

Ground is defined as the point in the circuit which is at zero voltage. Voltage is relative, and is the same throughout a conductor, so any point in the circuit can be defined as ground, and all other voltages are referenced to it. Usually it is defined as the most negative point in the circuit, for convenience. Sometimes it is defined in the middle of two bi-polar rails, for "balanced" circuits. In many cases this circuit point is connected to the Earth (Ground) by a conductor.

Henry (H)

The SI unit for inductance. A coil has 1 Henry of inductance if an emf of 1 Volt is induced when current through the inductor is changing at a rate of 1 Ampere per second.

Hertz (Hz)

The SI unit for frequency. One Hz is one cycle per second.

Impedance

A more generalized form of resistance. The impedance of a device varies with the frequency of the electricity applied. A perfect resistor will have a constant impedance for all frequencies. Capacitors and inductors have varying impedances at different frequencies. Measured in **ohms or Ω**.

Inductor

An inductor is a device that stores energy in a magnetic field. It opposes a sudden change in the flow of current. Units of measurement are Henrys.

Kirchhoff's Current Law:

At any junction of conductors in a circuit, the algebraic sum of currents is zero.

Kirchhoff's Voltage Law:

The algebraic sum of voltages around a circuit is zero.

Length (*l*)

A measure of distance usually in meters (m).

Load:

Resistance connected across a circuit that determines power used.

Meter (m)

The SI unit for distance. The distance light travels in 1/299,792,458 second.

Ohm (Ω)

The basic unit of resistance or impedance: the amount of electrical resistance limiting the current to one ampere with one volt applied.

Ohm's Law:

Mathematical relationship between current, voltage and resistance stating that when a voltage is applied to a conductor, the current moving through the conductor is proportional to the applied voltage. Discovered by Georg Simon Ohm. (Name spelled correctly)

Op-amp

Short for operational amplifier. An op-amp amplifies the voltage between its two inputs.

Parallel:

Used to describe two or more circuits or circuit elements so connected that the total current flow is divided between them.

PCB

Printed circuit board. This is a piece of plastic or fiberglass with copper attached. The copper is typically chemically etched away to leave "traces" for the electricity to be conducted through. Other electrical components are soldered to the traces.

Period

The time between cycles of a periodic wave.

Power

Voltage times current. The amount of work being done by a circuit.

Rectify

Convert AC current to DC current.

Reactance

Opposition to ac as a result of inductance or capacitance.

Resistance

Properties of a circuit that impede the flow of electrons. Resistance converts electrical energy into photons that are given off as waste heat. Resistance is measured in ohms.

Reversed Biased

The inverted voltage polarity on a part.

Root-Mean Squared (RMS)

The effective DC value for an AC value.

Second (s)

The SI unit for time.

Series Circuit:

A circuit that contains only one possible path for electron flow supplied by a common voltage source.

SI

The standard system of units.

Time (t)

The symbol for time in seconds (s).

Transistor

A device in which the resistance of the channel is controlled by a current or voltage at the base or gate. Can be thought of as an electronic-controlled resistor.

Volt (V)

A potential due to an electric field. One volt is defined as the potential difference across a resistor that is passing one ampere and dissipating one watt. 1 V = 1 W/A

Voltage (V)

An electric field between two charges. Similar to gravity this acts as an electric potential. Measured in volts.

Watt (W)

A measure of power (*P*). A watt is a joule (1 J) of work done in a second (1 s). 1 W = 1 J/s

Wavelength (λ)

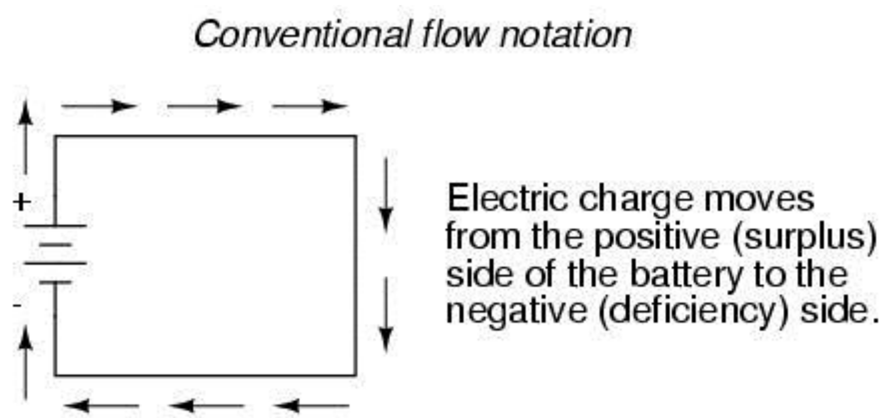
The length in space occupied by one cycle of a periodic wave.

Zener Diode:

A pn junction diode that makes use of the breakdown properties of a pn junction. The diode is designed to conduct in the reverse direction when its value of breakdown voltage is reached. Beyond this point, the diode will maintain a relatively constant voltage despite variations in current. Widely used for voltage regulation in electronic products.

CONVENTIONS

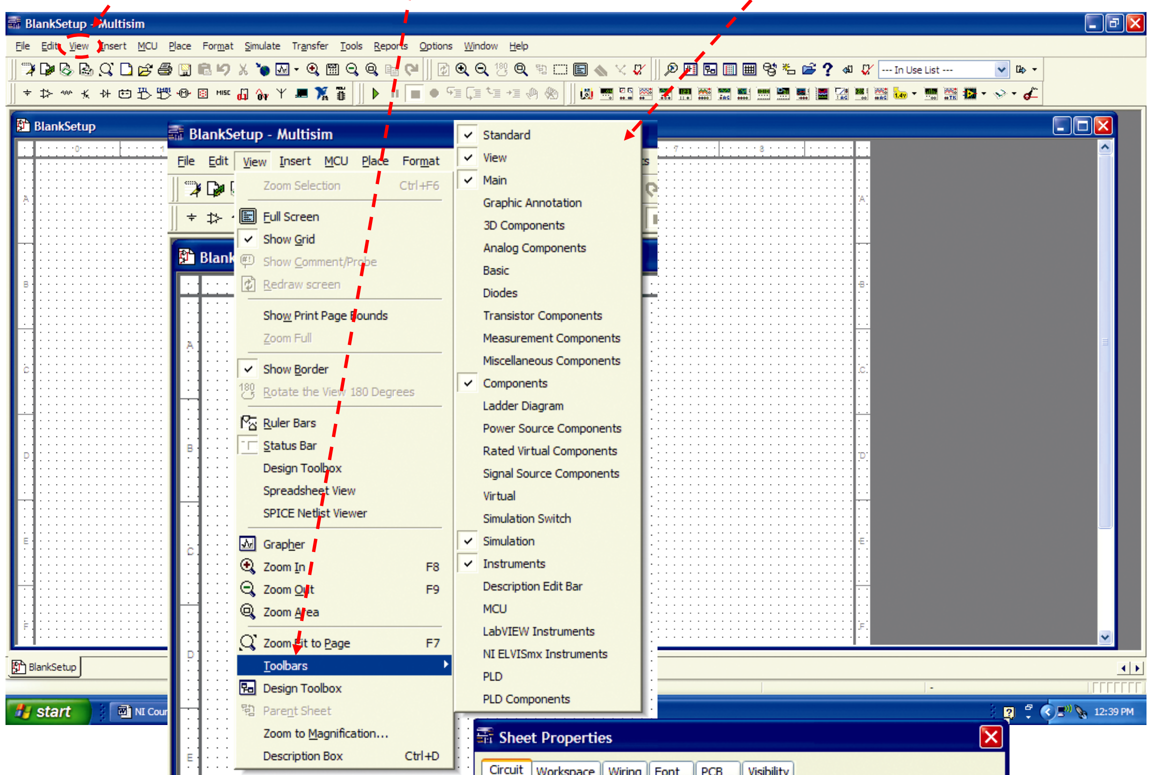
"Current" is defined as the rate of flow of electric charge and is measured in amperes. When Benjamin Franklin made his conjecture regarding the direction of charge flow he associated the word "positive" with "surplus" and "negative" with "deficiency". Because of this, many engineers decided to retain the old concept of electricity with "positive" referring to a surplus of positive charges (lack of electrons), and label charge flow (current) accordingly. This became known as **conventional flow** notation and is the notation that will be used.



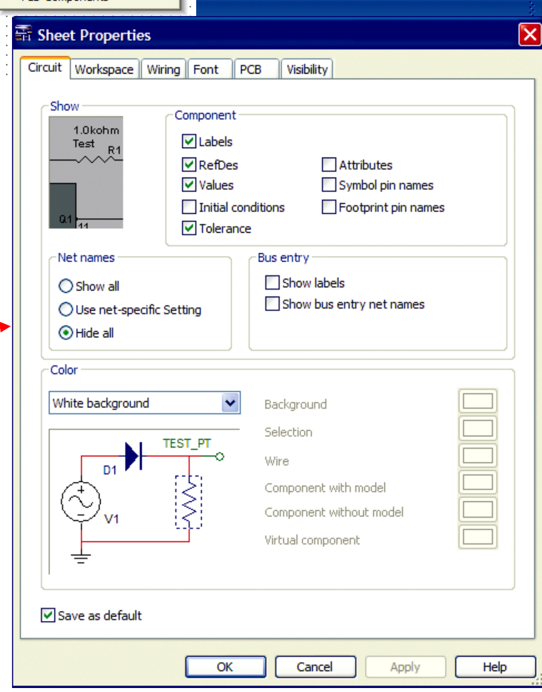
Some choose to designate charge flow according to the actual motion of electrons in a circuit. This form of symbology became known as **electron flow** notation. Electron flow notation will **not** be used.

Appendix B: Multisim Setup

To set Multisim for the same display shown in the projects in this course; click on view then click on toolbars and set as shown here.

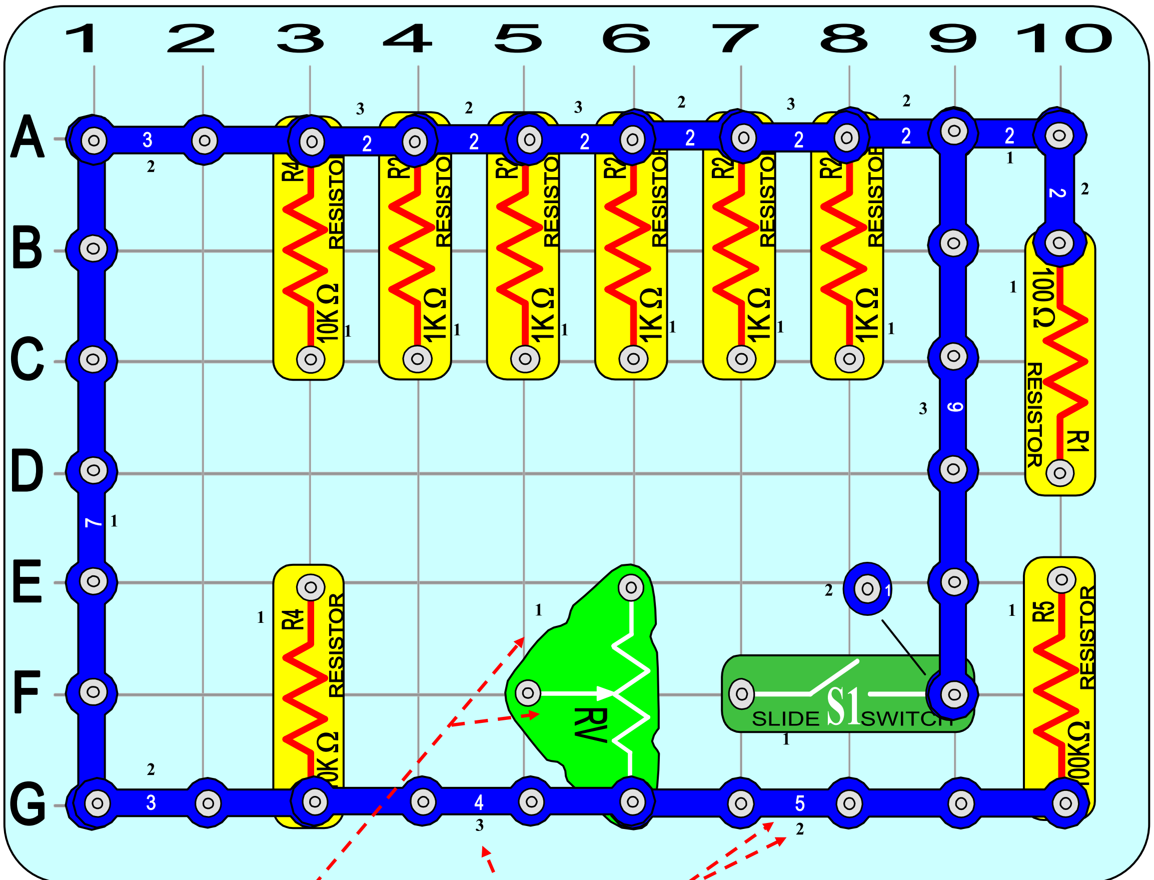


After setting toolbars, click on "Options", then "Sheet Properties" and set as shown here.



Appendix C: Building Snap-Circuits ®

Build the circuits shown in this course by placing all the parts with a black 1 next to them on the grid first. Then, assemble parts marked with a 2. Continue install parts on the levels as they are marked.



- RV is on level 1 or on the grid.
- 5 wire is on level 2
- 4 wire is on level 3

Appendix D: Worksheets

Page 1-12

1	Strips (1-7 in series)	Value of reading ________(shown above)
2	$S1_{ON}$	Value of reading ________________
2	$S1_{OFF}$	Value of reading ________________
3	R1	Value of reading ________________
4	R2	Value of reading ________________
5	R2	Value of reading ________________
6	R2	Value of reading ________________
7	R2	Value of reading ________________
8	R2	Value of reading ________________
9	R4	Value of reading ________________
10	R4	Value of reading ________________
11	RV_{max} SLIDER UP	Value of reading ________________
12	R5	Value of reading ________________
13	RV_{min} SLIDER DOWN	Value of reading __________

Junction	Multisim	MyDAQ
C2		
C5		
C8		
D10		
D7		
D4		
E2		
E4		
	Page 2-23	

Chart for Page 4-40 DC Circuits

Current (ma)	Current (I)	Voltage (V)	SW1 Position	Resistance (Ω) R=V/I
			100k	
			10k	
			1k	
			100	
34.654	.034654	3.465	100	99.988(example)

Table2-2 for Page 2-27

Key No.	Multisim	MyDAQ
8	100K	
7		
6		
5		
4		
3		
2		
1		

Chart for Page 4-40 AC Circuits

Current (ma)	Current (I)	Voltage (V)	SW1 Position	Resistance (Ω) R=V/I
			100k	
			10k	
			1k	
			100	
35.006	.035006	3.501	100	100.011(example)

Table for Page 4-42 DC Circuits

Current (ma)	Current (I)	Voltage (V)	R Position	Ohms (Ω) R=V/I
			100k	
			10k	
			1k	
			100	
46.9	.0469	4.655	100	99.254(example)

Table for Page 4-42 AC Circuits

Current (ma)	Current (I)	Voltage (V)	R Position	Ohms (Ω) R=V/I
			100k	
			10k	
			1k	
* see note			100	
46.9	.0469	4.655	100	99.254(example)

Black Snap Grid Location	Red Snap Grid Location	Voltage
G5	A4	
A4	C9	
C9	C7	
C7	G5	
Sum of all the voltages around the loop =		

Table for Page 4-44

Current (ma)	Current (I)	Voltage (V)	R Position	Ohms (Ω) R=V/I
			10k	
			5.1k	
			1k	
			100	
13.10 ma	.0131 amps	1.310	100	100.0 (example)

Table for Page 6-53

Freq.	Gen. Vp	C Value	V_p across C	I_p through C	$X_c = V_p/I_p$ Ω
100 Hz	5 Vp	470 uF	.171468 V	.05 A	3.42936 Ω
100 Hz	5 Vp	100 uF			
100 Hz	5 Vp	0.1 uF			
100 Hz	5 Vp	0.02 uF	5.0 V	.0000628 A	79,617.8 Ω

Table 7-1 page 7-64

Frequency	L Value	Vp on L	Ip in L	$X_L=V_p/I_p$
1000 Hz	100 mH	2.66 V	.004232 A	628.54
1000 Hz	22 mH			