

Introduction to NI ELVIS

by Professor Barry Paton
Dalhousie University

March 2004 Edition
Part Number 323777B-01

Copyright

© 2004 National Instruments Corporation. All rights reserved.

Universities, colleges, and other educational institutions may reproduce all or part of this publication for educational use. For all other uses, this publication may not be reproduced or transmitted in any form, electronic or mechanical, including photocopying, recording, storing in an information retrieval system, or translating, in whole or in part, without the prior written consent of National Instruments Corporation.

Trademarks

DIAdem™, LabVIEW™, National Instruments™, NI™, and ni.com™ are trademarks of National Instruments Corporation. Product and company names mentioned herein are trademarks or trade names of their respective companies.

Patents

For patents covering National Instruments products, refer to the appropriate location: **Help»Patents** in your software, the **patents.txt** file on your CD, or ni.com/legal/patents.

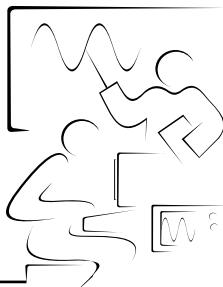
National Instruments Corporate Headquarters

11500 North Mopac Expressway Austin, Texas 78759-3504 USA Tel: 512 683 0100

Worldwide Offices

Australia 1800 300 800, Austria 43 0 662 45 79 90 0, Belgium 32 0 2 757 00 20, Brazil 55 11 3262 3599,
Canada (Calgary) 403 274 9391, Canada (Ottawa) 613 233 5949, Canada (Québec) 450 510 3055,
Canada (Toronto) 905 785 0085, Canada (Vancouver) 514 685 7530, China 86 21 6555 7838, Czech Republic 420 224 235 774,
Denmark 45 45 76 26 00, Finland 385 0 9 725 725 11, France 33 0 1 48 14 24 24, Germany 49 0 89 741 31 30,
Greece 30 2 10 42 96 427, India 91 80 51190000, Israel 972 0 3 6393737, Italy 39 02 413091, Japan 81 3 5472 2970,
Korea 82 02 3451 3400, Malaysia 603 9131 0918, Mexico 001 800 010 0793, Netherlands 31 0 348 433 466,
New Zealand 0800 553 322, Norway 47 0 66 90 76 60, Poland 48 22 3390150, Portugal 351 210 311 210,
Russia 7 095 783 68 51, Singapore 65 6226 5886, Slovenia 386 3 425 4200, South Africa 27 0 11 805 8197,
Spain 34 91 640 0085, Sweden 46 0 8 587 895 00, Switzerland 41 56 200 51 51, Taiwan 886 2 2528 7227,
Thailand 662 992 7519, United Kingdom 44 0 1635 523545

Contents



Lab 1

NI ELVIS Workspace Environment

Goal	1-1
Soft Front Panels (SFP) Used in this Lab	1-2
Components Used in this Lab	1-2
Exercise 1-1 Measurement of Component Values.....	1-3
Exercise 1-2 Building a Voltage Divider Circuit on the NI ELVIS Protoboard	1-5
Exercise 1-3 Using the DMM to Measure Current.....	1-7
Exercise 1-4 Observing the Voltage Development of a RC Transient Circuit	1-8
Exercise 1-5 Visualizing the RC Transient Circuit Voltage.....	1-10
What's Cool!	1-12

Lab 2

Digital Thermometer

Goal	2-1
Soft Front Panels (SFP) Used in this Lab	2-2
Components Used in this Lab	2-2
Exercise 2-1 Measurement of the Resistor Component Values.....	2-3
Exercise 2-2 Operating the Variable Power Supply	2-4
Exercise 2-3 A Thermistor Circuit for DAQ Operation	2-5
Exercise 2-4 Calibration of the Thermistor	2-7
Exercise 2-5 Building an NI ELVIS Virtual Digital Thermometer	2-8
Exercise 2-6 Digital Thermometer with a Logging Feature	2-10
What's Cool!	2-10

Lab 3

AC Circuit Tools

Goal	3-1
Soft Front Panels (SFP) Used in this Lab	3-1
Components Used in this Lab	3-1
Exercise 3-1 Measurement of the Circuit Component Values.....	3-2
Exercise 3-2 Measurement of Component and Circuit Impedance Z.....	3-3
Exercise 3-3 Testing a RC Series Circuit with the Function Generator and Oscilloscope	3-6
Exercise 3-4 The Gain/Phase Bode Plot of the RC Circuit	3-10
What's Cool!	3-12

Lab 4

Op Amp Filters

Goal.....	4-1
Soft Front Panels (SFP) Used in this Lab	4-1
Components Used in this Lab.....	4-2
Exercise 4-1 Measurement of the Circuit Component Values.....	4-3
Exercise 4-2 Frequency Response of the Basic Op Amp Circuit	4-4
Exercise 4-3 Measuring the Op Amp Frequency Characteristic	4-7
Exercise 4-4 High Pass Filter.....	4-9
Exercise 4-5 Low Pass Filter	4-11
Exercise 4-6 Band Pass Filter	4-13
What's Cool!.....	4-14

Lab 5

Digital I/O

Goal.....	5-1
Soft Front Panels (SFP) Used in this Lab	5-2
Components Used in this Lab.....	5-2
Exercise 5-1 Visualizing Digital Byte Patterns	5-3
Exercise 5-2 555 Digital Clock Circuit.....	5-5
Exercise 5-3 Building a 4-bit Digital Counter	5-8
Exercise 5-4 LabVIEW Logic State Analyzer.....	5-10
What's Cool!.....	5-12

Lab 6

Magnetic Field Sensor

Goal.....	6-2
Soft Front Panels (SFP) Used in this Lab	6-2
Components Used in this Lab.....	6-2
Exercise 6-1 Testing the Analog Magnetic Field Sensor with NI ELVIS Tools.....	6-3
Exercise 6-2 Hysteresis Characteristic of a Magnetic Field Switch	6-5
Exercise 6-3 Counting Pulses with a Magnetic Switch Sensor	6-6
Exercise 6-4 Automatic Counting using a LabVIEW Program.....	6-7
What's Cool!.....	6-8

Lab 7

LEDs to the Rescue!

Goal.....	7-2
Soft Front Panels (SFP) Used in this Lab	7-2
Components Used in this Lab.....	7-2
Exercise 7-1 Testing Diodes and Determining their Polarity	7-3
Exercise 7-2 Characteristic Curve of a Diode.....	7-4

Exercise 7-3 Manual Testing and Control of a 2-way Stoplight Intersection.....	7-6
Exercise 7-4 Automatic Operation of the 2-way Stoplight Intersection.....	7-9
What's Cool!.....	7-10

Lab 8**Free Space Optical Communication**

Goal.....	8-1
Soft Front Panels (SFP) Used in this Lab	8-2
Components Used in this Lab.....	8-2
Exercise 8-1 A Phototransistor Detector.....	8-3
Exercise 8-2 Infrared Red Optical Source	8-5
Exercise 8-3 Free Space IR Optical Link (Analog)	8-7
Exercise 8-4 Amplitude and Frequency Modulation (Analog).....	8-8
What's Cool!.....	8-8

Lab 9**RF Wireless Communication**

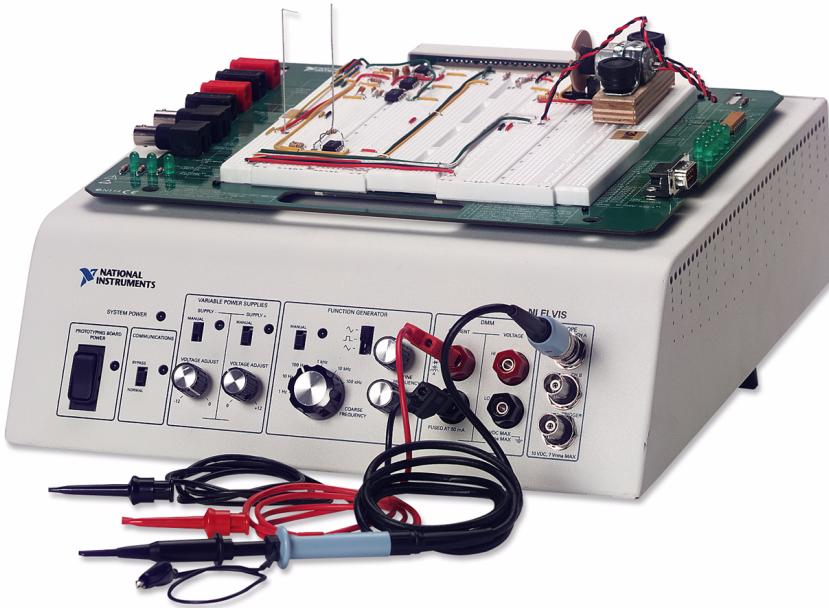
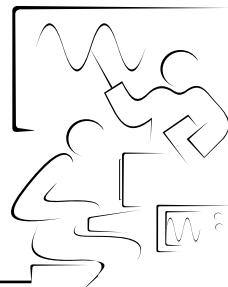
Goal.....	9-1
Soft Front Panels (SFP) Used in this Lab	9-2
Components Used in this Lab.....	9-2
Exercise 9-1 The Transmitter.....	9-3
Exercise 9-2 The Receiver	9-4
Exercise 9-3 Testing the RF Transmitter and Receiver	9-5
Exercise 9-4 Marconi's First Trans-Atlantic Signal	9-6
Exercise 9-5 Building a Unique Test Signal with the Arbitrary Waveform Analyzer.....	9-7
Exercise 9-6 A Demonstration of Marconi's RF Transmission Signal	9-10
What's Cool!.....	9-11

Lab 10**Mechanical Motion**

Goal.....	10-1
Soft Front Panels (SFP) Used in this Lab	10-2
Components Used in this Lab.....	10-2
Exercise 10-1 Gentlemen, Start your Engines!.....	10-3
Exercise 10-2 The Tachometer	10-4
Exercise 10-3 Building a Rotary Motion System	10-6
Exercise 10-4 Testing the Rotary Motion System	10-7
Exercise 10-5 A LabVIEW Measurement of RPM	10-8
What's Cool!.....	10-9

Lab 1

NI ELVIS Workspace Environment



The NI ELVIS environment consists of the hardware workspace for building circuits and interfacing experiments, and the NI ELVIS software. The NI ELVIS software, all created in LabVIEW has two main types: the soft front panel (SFP) instruments and LabVIEW APIs, which are just additional LabVIEW VIs for custom control and access to the features of the NI ELVIS benchtop workstation.

Goal

This lab introduces the NI ELVIS workstation to show how electronic component properties can be measured. Circuits are then built on the protoboard and later analyzed with the NI ELVIS software suite of LabVIEW based soft front panels (SFP) or software instruments. In addition, this experiment demonstrates the use of NI ELVIS within a LabVIEW programming environment.

Soft Front Panels (SFP) Used in this Lab

Digital Ohmmeter DMM[Ω], Digital Capacitance meter DMM[C], and the Digital Voltmeter DMM[V]

Components Used in this Lab

1.0 k Ω resistor R₁ (Brown, Black, Red)

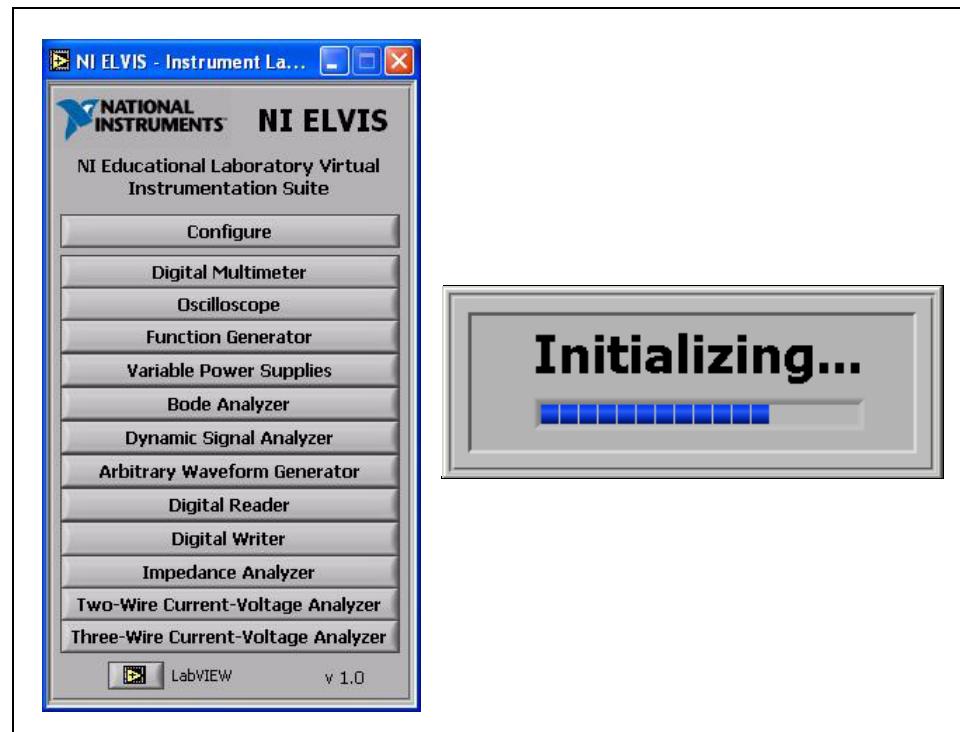
2.2 k Ω R₂ (Red, Red, Red)

1.0 M Ω resistor R₃ (Brown, Black, Green)

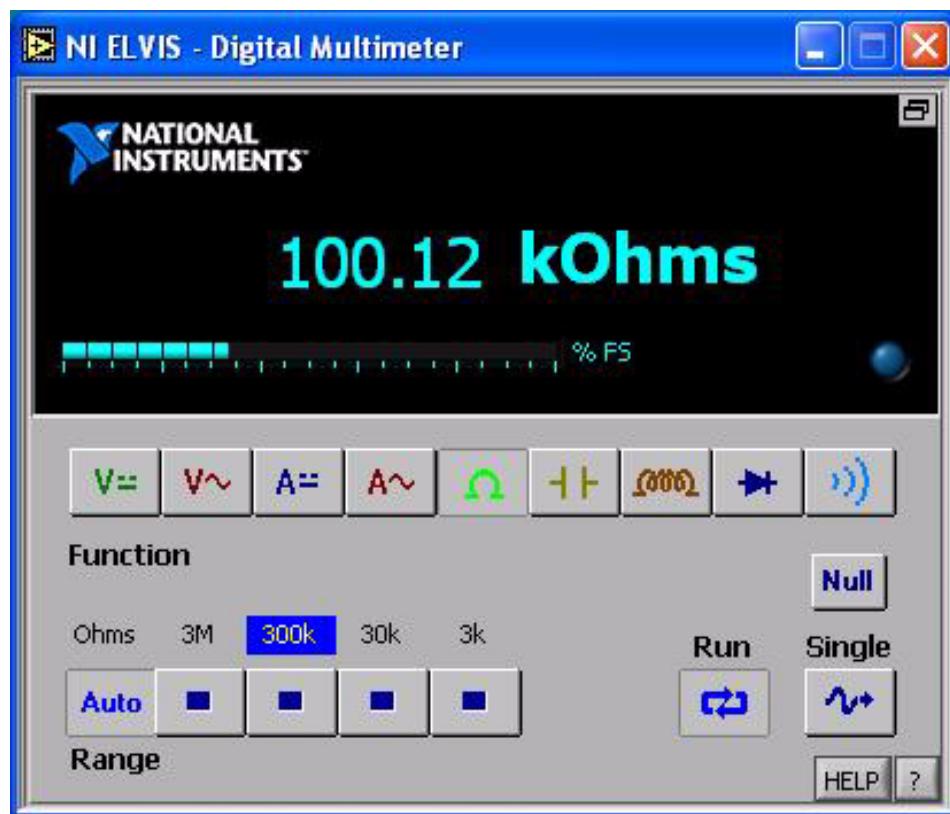
1 μ F capacitor C

Exercise 1-1 Measurement of Component Values

Connect two banana type leads to the DMM current inputs on the workstation front panel. Connect the other ends to one of the resistors. Launch NI ELVIS. After initializing, the suite of LabVIEW software instruments pops up on the computer screen.



Select **Digital Multimeter**.



The Digital Multimeter SFP can be used for a variety of operations. We will use the notation DMM[X] to signify the X operation. Click on the **Ohm** button [Ω] to use the Digital Ohmmeter function DMM[Ω]. Measure R_1 , R_2 , and R_3 . Using the capacitor button [||], measure the capacitor C with DMM[C] using the same leads. Fill in the following table.

R_1	_____	Ω	(1.0 k Ω nominal)
R_2	_____	Ω	(2.2 k Ω nominal)
R_3	_____	Ω	(1.0 M Ω nominal)
C^*	_____	(μ f)	(1 μ F nominal)

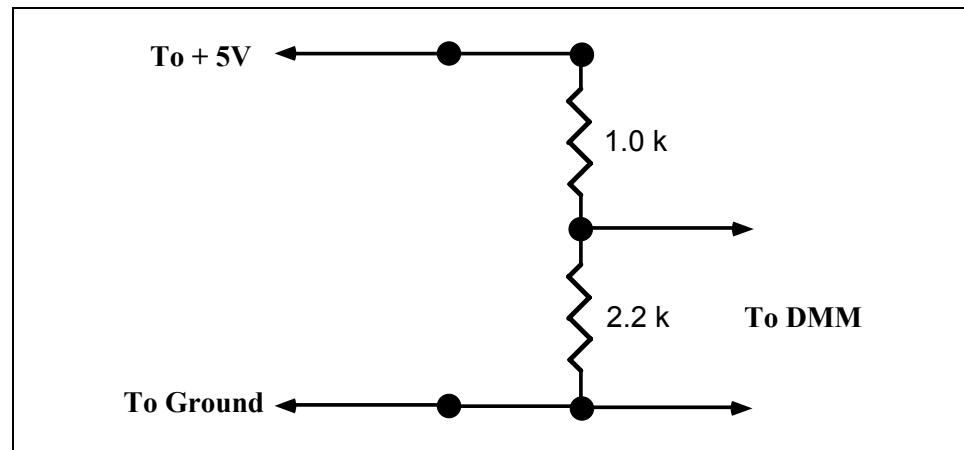


Note If you are using an electrolytic capacitor be sure to connect the + lead of the capacitor to the DMM current +input and click on the electrolytic button of the DMM[C].

End of Exercise 1-1

Exercise 1-2 Building a Voltage Divider Circuit on the NI ELVIS Protoboard

Using the two resistors, R_1 and R_2 , assemble the following circuit on the NI ELVIS protoboard.



The input voltage V_o is connected to the [+5 V] pin socket and the common to the NI ELVIS [Ground] pin socket. Connect the external leads to the DMM voltage inputs (HI) and (LO) on the front panel of the NI ELVIS workstation.



Note NI ELVIS has separate input leads for voltage and impedance/current measurements.

Check your circuit and then apply power to the protoboard by switching the Prototyping Board Power switch to the upper position. The three power indicator LEDs +15V, -15V, and +5V should now be lit.



Note If any of these LEDs are OFF while the others are ON, the fuse for that power line has probably blown. Refer to Appendix B of the *NI ELVIS User Manual* for fuse replacement.

Connect the DMM front panel leads to V_o and measure the input voltage using the DMM[V].

Circuit theory tells us that the output voltage V_1 should be $R_2/(R_1+R_2) * V_o$. Using the previous measured values for R_1 , R_2 , and V_o , calculate V_1 . Then, use the DMM[V] to measure the actual voltage V_1 .

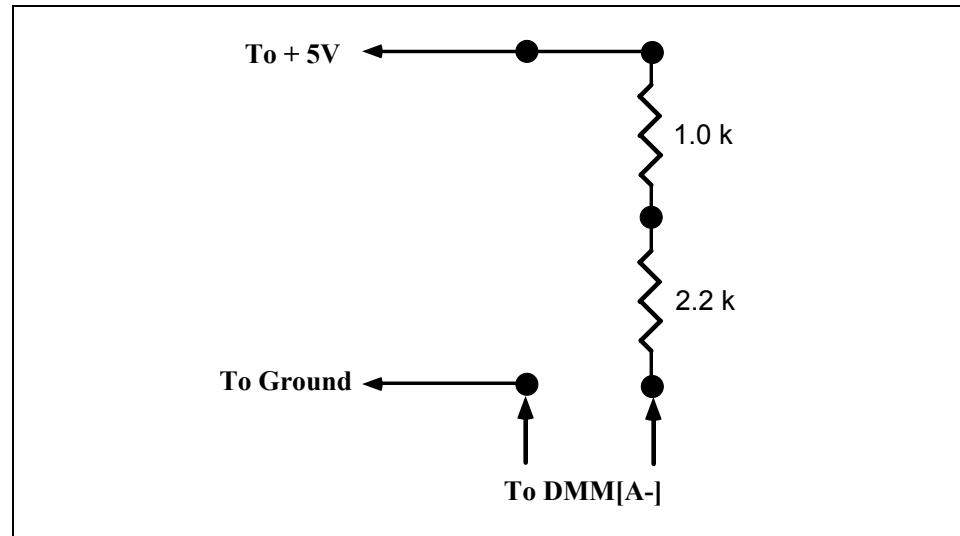
V_1 (calculated) _____ V_1 (measured) _____

How well does the measured value agree with your calculated value?

End of Exercise 1-2

Exercise 1-3 Using the DMM to Measure Current

From Ohms law, the current I flowing in the above circuit is equal to V_1/R_2 . With the measured values of V_1 and R_2 , calculate this current. Next, do a direct measurement. Do this by moving the external leads to the workstation front panel DMM (Current) inputs HI and LO. Connect the other ends to the circuit as shown below.



Select the function DMM[A–] and measure the current.

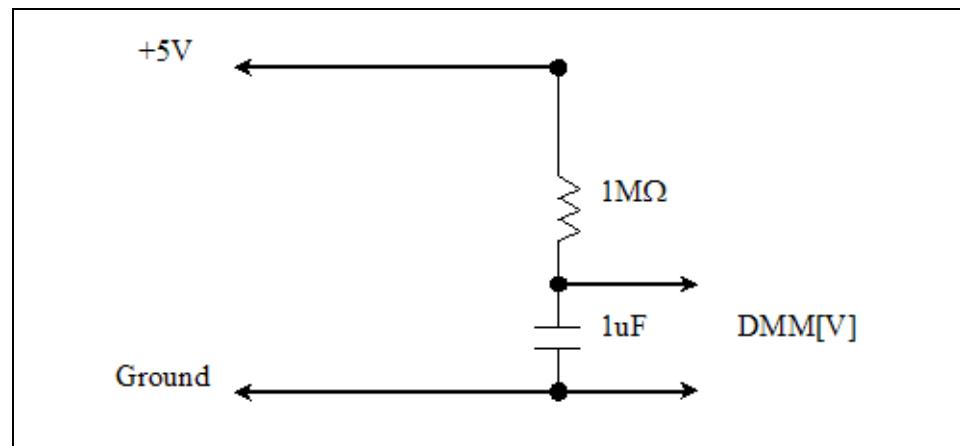
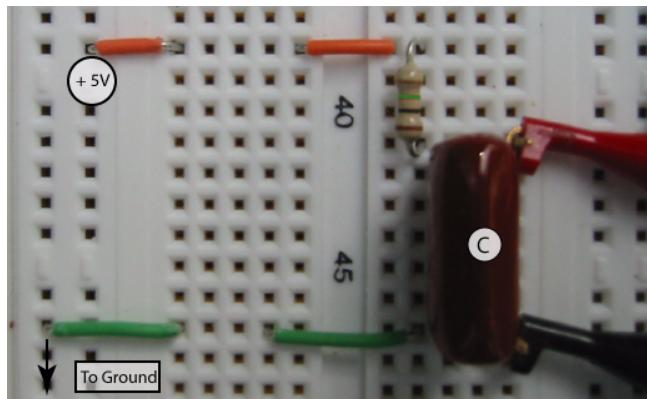
I (calculated) _____ I (measured) _____

How well does the measured value agree with your calculated value?

End of Exercise 1-3

Exercise 1-4 Observing the Voltage Development of a RC Transient Circuit

Build the RC transient circuit as shown below. It uses the voltage divider circuit where R_1 is now replaced with R_3 ($1\text{ M}\Omega$ resistor) and R_2 is replaced with the $1\text{ }\mu\text{F}$ capacitor C. Move your front panel leads back to the DMM(VOLTAGE) inputs and select DMM[V].



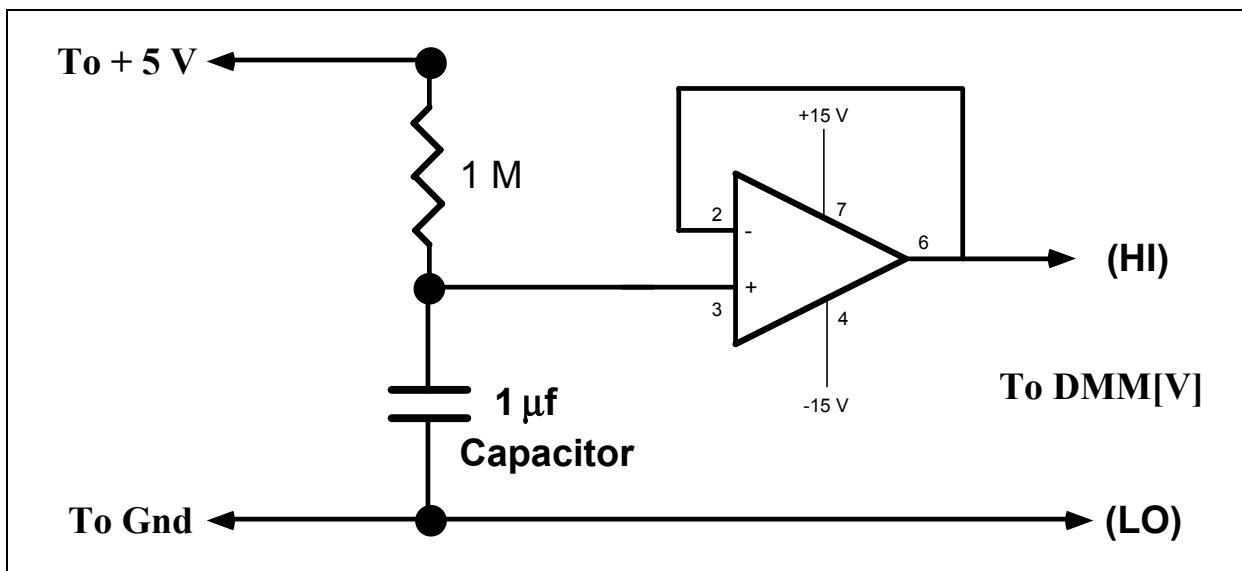
Note NI ELVIS version 1 has limited input impedance ($1\text{ M}\Omega$) for the DMM channel. To read the correct voltage values, you will need to buffer the input voltage for this measurement. Refer to the *Limited Input Impedance Solution* section for a simple solution using a unity gain circuit using a FET Op Amp. This limitation will be remedied in a future version. Also, notice that if you use the Analog Input channels of the DAQ card as in Exercise 1-5, this is not a problem.

When you power up the circuit, the voltage across the capacitor will rise exponentially. Turn on the power and watch the voltage change on the DMM display. It takes about 5 seconds to reach the steady state value of V_o . When you power off the circuit, the voltage across the capacitor will fall exponentially to 0 volts. Try it!

It would be interesting to view this transient effect on a plot of capacitor voltage versus time.

Limited Input Impedance Solution

Using an FET Op Amp such as the LM356, build a unity gain circuit and connect it as shown below. By connecting the output (pin 6) to the – input (pin 2), the gain of this circuit is set to 1. However, the + input impedance on (pin 3) is now hundreds of megaohms and the ouput voltage (pin 6) will faithfully follow the capacitor voltage allowing the DMM voltage input to read the correct values.

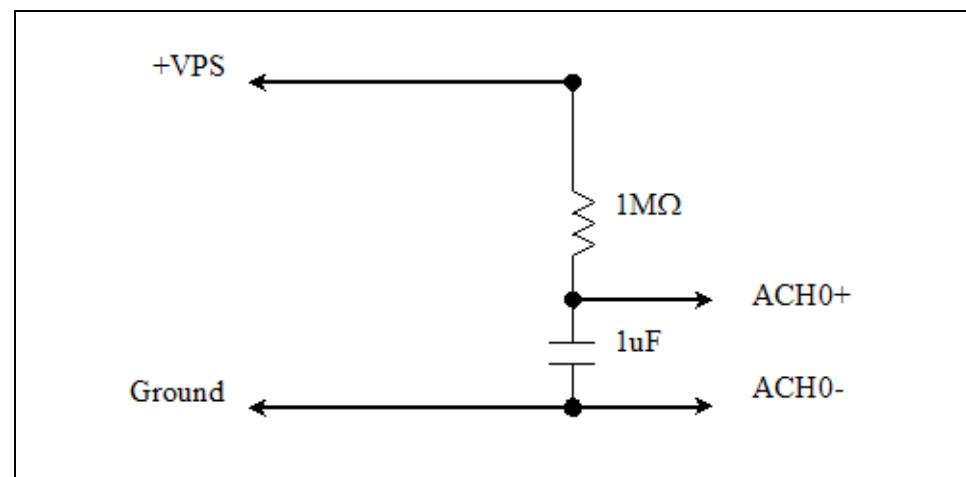
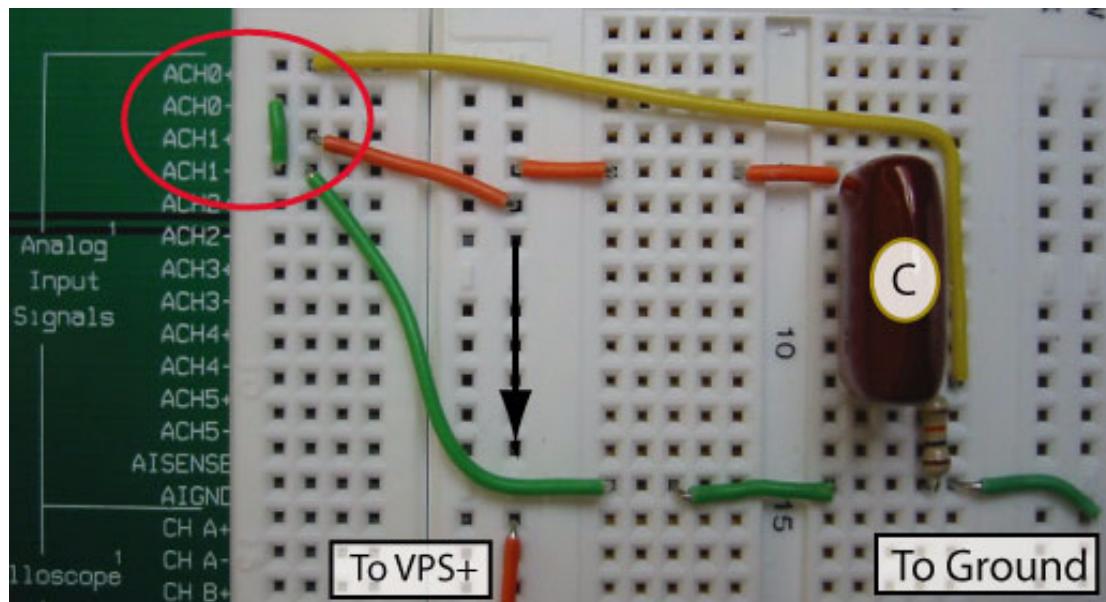


This limitation will be corrected in future versions of NI ELVIS.

End of Exercise 1-4

Exercise 1-5 Visualizing the RC Transient Circuit Voltage

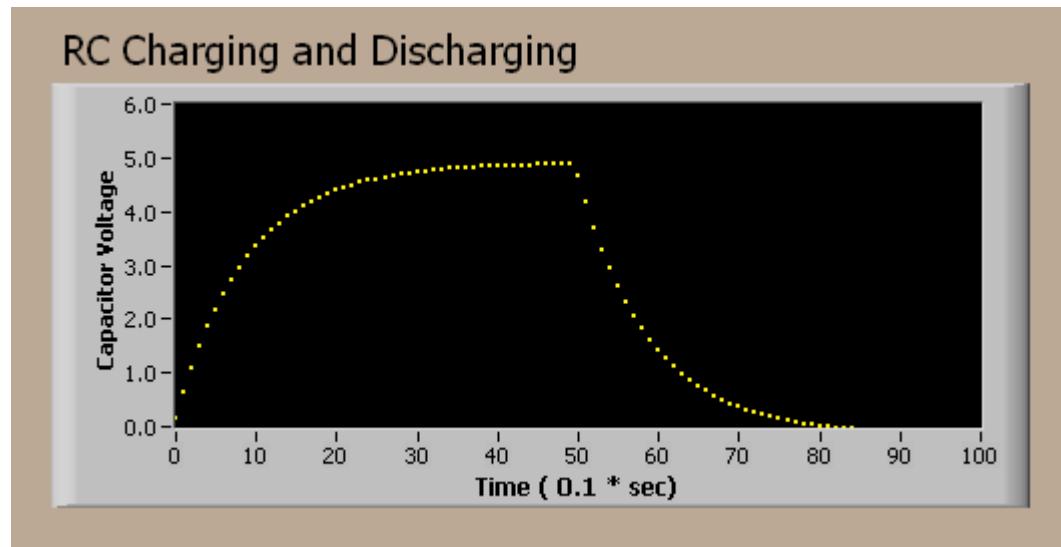
Remove the + 5V power lead and replace it with a wire connected to the Variable Power Supply socket pin VPS[+]. Connect the output voltage, V_1 , to ACH0[+] and ACH0[−].



Close the NI ELVIS software suite and launch LabVIEW.

From the Hands-On NI ELVIS VI Library, select RC Transient.vi.

This program uses LabVIEW APIs to turn the power supply ON for 5 seconds then OFF for 5 seconds while the voltage across the capacitor is displayed on a LabVIEW chart.



This type of square wave excitation dramatically shows the charging and discharging characteristics of a simple RC circuit. The circuit time constant τ is defined as the product of R_3 and C .

From Kirchoff's laws it is easy to show that the charging voltage V_C across the capacitor is given by:

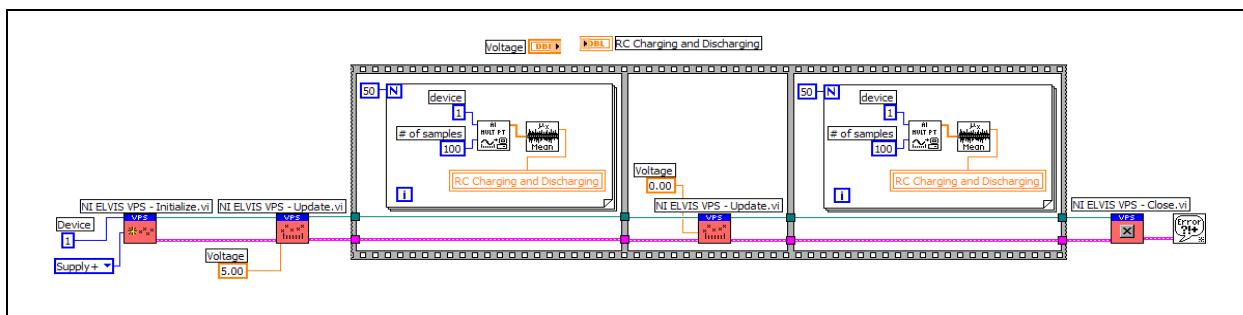
$$V_C = V_0 (1 - \exp(-t/\tau))$$

and the discharge voltage V_D is given by:

$$V_D = V_0 \exp(-t/\tau)$$

Can you extract the time constant from the measured chart?

Take a look at the LabVIEW diagram window to see how this program works.



The VPS Initialization VI on the left starts NI ELVIS and selects the + power supply. The next VI sets the output voltage on VPS+ to 5 volts. Next, the first sequence measures 50 sequential voltage readings across the capacitor at 1/10 of a second intervals. In the For Loop, the Analog Input Multiple

Point VI takes 100 readings at rate of 1000 samples per second and passes the values to an array (thick orange line). The array is then passed to the Mean VI which returns the average value of the 100 readings. The average is then passed to the chart via a local variable terminal (RC Charging and Discharging). The next sequence sets the VPS+ voltage equal to 0 volts and then the last sequence measures another 50 averaged samples for the discharge cycle.

End of Exercise 1-5

What's Cool!

This exercise has introduced the software instrument DMM and has shown how the workstation front panel connectors can be used for the DMM measurements.



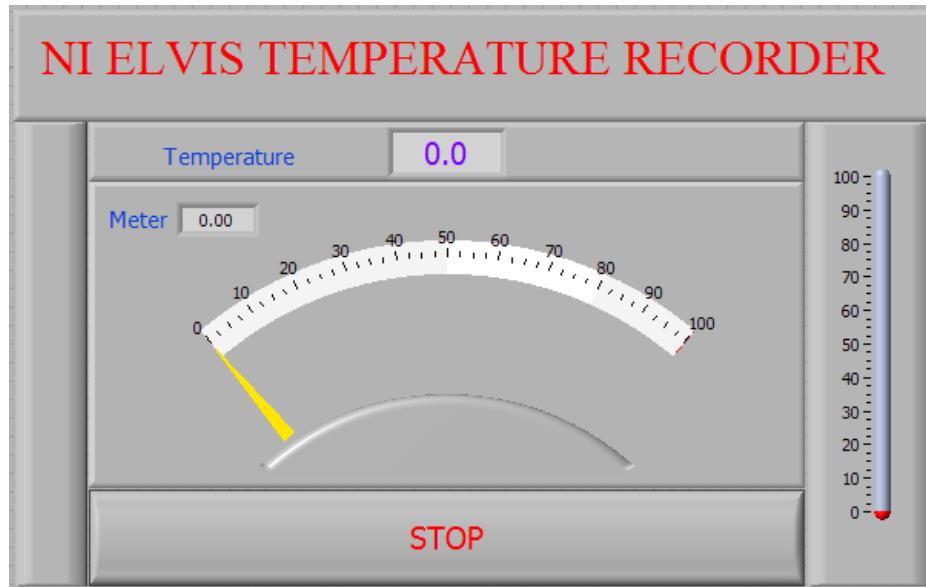
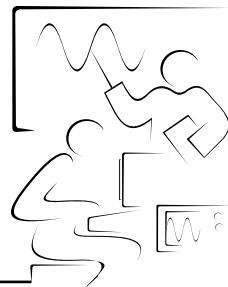
However, one is not restricted to these 4 inputs as they are also present on the protoboard strip sockets, labeled as:

Front Panel Workstation	Protoboard
DMM(voltage) HI	DMM ² Voltage +
DMM(voltage) LO	DMM ² Voltage -
DMM(current) HI	DMM ² Current +
DMM(current) LO	DMM ² Current -

Check it out.

Lab 2

Digital Thermometer



A thermistor is a 2 wire device manufactured from a semiconductor material. It has a nonlinear response curve and a negative temperature coefficient. Thermistors make ideal sensors for measuring temperature over a wide dynamic range and are also useful in temperature alarm circuits.

Goal

This lab introduces the NI ELVIS variable power supply. It can be used with the workstation front panel controls, with the virtual controls on your computer screen or embedded inside a LabVIEW program. The VPS is used to excite a $10\text{ k}\Omega$ thermistor in a voltage divider circuit. The voltage measured across the thermistor is related to its resistance which in turn is related to its temperature. This lab demonstrates how LabVIEW controls and indicators together with NI ELVIS APIs are used to build a digital thermometer.

Soft Front Panels (SFP) Used in this Lab

Digital Ohmmeter DMM[Ω] and the Digital Voltmeter DMM[V],
VPS APIs

Components Used in this Lab

10 k Ω resistor R_1 (Brown, Black, Orange)

10 k Ω thermistor R_T

Exercise 2-1 Measurement of the Resistor Component Values

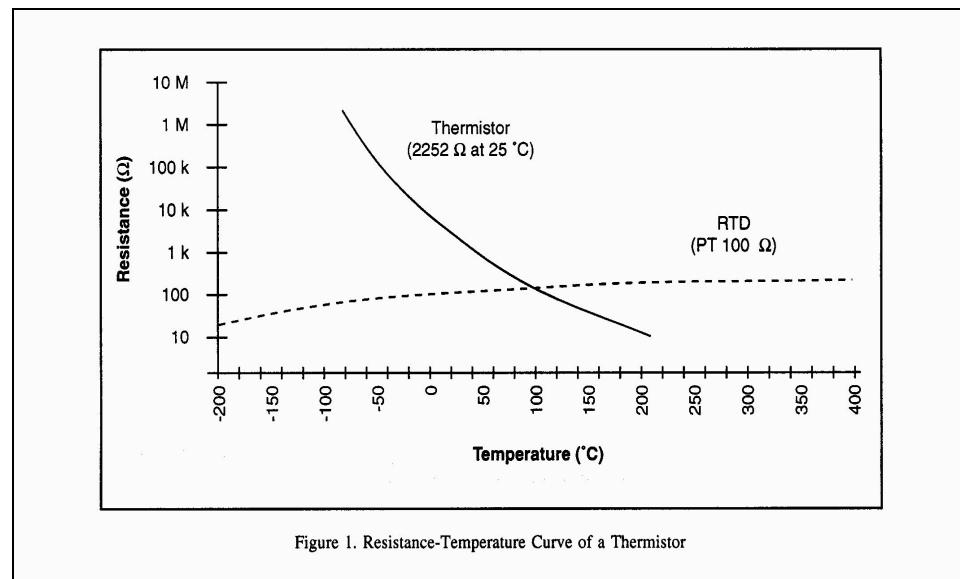
Launch NI ELVIS, select **Digital Multimeter** and click on the **Ohms** button. First connect the $10\text{ k}\Omega$ resistor and then the thermistor and measure their component values.

Fill in the following chart.

$10\text{ k}\Omega$ resistor _____ Ohms

Thermistor _____ Ohms

Now place the thermistor between your finger tips to heat up the thermistor and watch the resistance change. The fact that the resistance decreases with increasing temperature (negative temperature coefficient) is one of the key characteristics of a thermistor. Thermistors are manufactured from semiconductor material whose resistivity depends exponentially on ambient temperature and results in the following nonlinear response. Compare the thermistor response with an RTD (100 Ω Platinum Resistance Temperature Device) shown below.



End of Exercise 2-1

Exercise 2-2 Operating the Variable Power Supply

From the NI ELVIS Instrument Launcher, select **Variable Power Supplies**. There are two controllable power supplies with NI ELVIS, 0 to –12 volts and 0 to +12 volts, each with a 500 mA current limit.



On the NI ELVIS workstation, slide the VPS+ switch to **Manual**.

Notice on the virtual VPS window how the controls are now grayed out and can *not* be operated with the mouse. A green LED also signals the fact that the VPS is in manual control. Only the front panel controls can change the output voltage.

Connect the leads from [VPS+] and [Ground] sockets to the workstation DMM voltage inputs.

Select DMM[V].

Rotate the manual VPS knob on the workstation and observe the voltage change on the DMM[V].



Note The zero voltage position for VPS+ control is counter-clockwise (CCW) and for VPS– control is clockwise (CW).

Slide the workstation switch for VPS+ down (not Manual). You can now use the virtual VPS controls on the computer screen. Click and drag the virtual knob to change the output voltage. Notice the [RESET] button that quickly resets the voltage back to zero. VPS– works in a similar fashion, only the output voltage is negative.

End of Exercise 2-2

Exercise 2-3 A Thermistor Circuit for DAQ Operation

On the workstation protoboard, build a voltage divider circuit using the 10 k Ω resistor and a thermistor. The input voltage is wired to [VPS+] and [Ground] sockets. Measure the voltage across the thermistor with the DMM[V] and workstation leads.

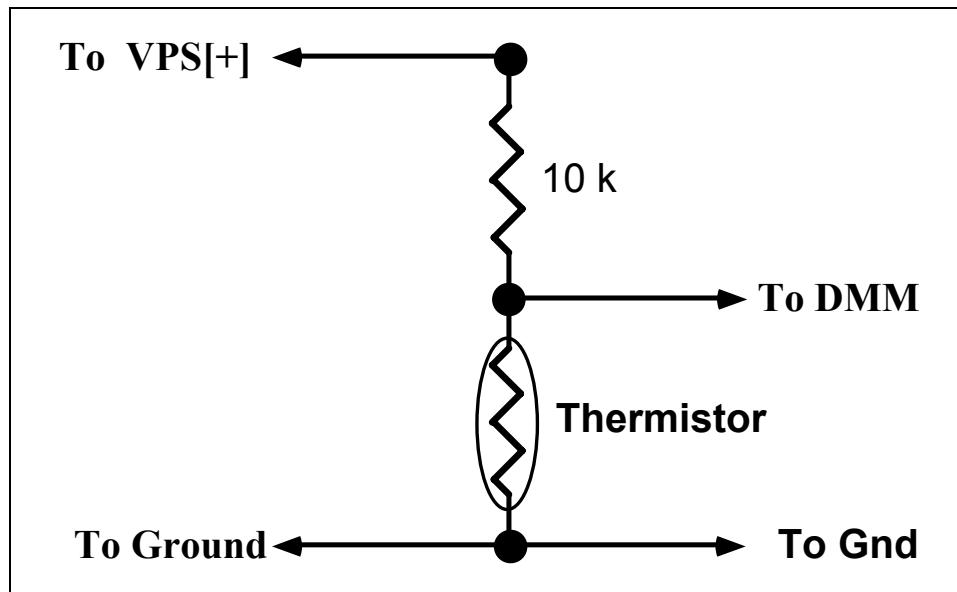


Figure 2-1. Thermistor Circuit

Make sure the workstation VPS+ knob is set CCW (zero volts position) and the slide switch is set to **Manual**. Power up the protoboard and observe the voltage levels on the DMM[V]. As you increase the voltage from 0 to +5 volts, the voltage across the thermistor V_T should increase to about 2.5 volts. Reduce the power supply voltage to +3 volts.

Heat the thermistor with your finger tips and watch the voltage decrease.

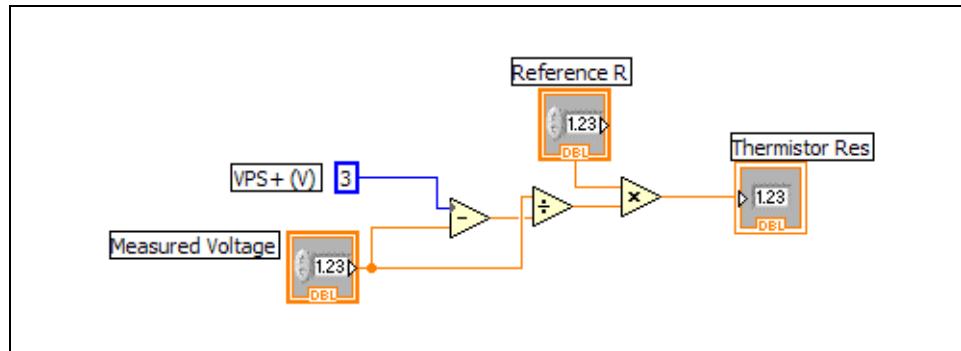
We can now rearrange the standard voltage divider equation to calculate the thermistor resistance.

$$R_T = R_1 * V_T / (3 - V_T)$$

At an ambient temperature of 25 °C, the resistance should be about 10 k Ω . Check it out!

This equation, called a scaling function, allows one to convert the measured voltage into the thermistor resistance. V_T can easily be measured with the NI ELVIS DMM or within a LabVIEW program.

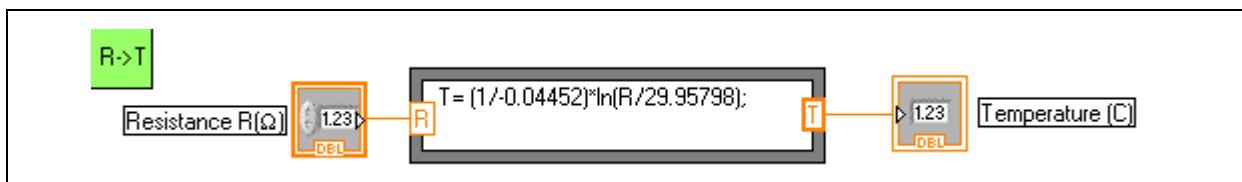
In LabVIEW, the above scaling equation is coded as a subVI and looks like the following:



End of Exercise 2-3

Exercise 2-4 Calibration of the Thermistor

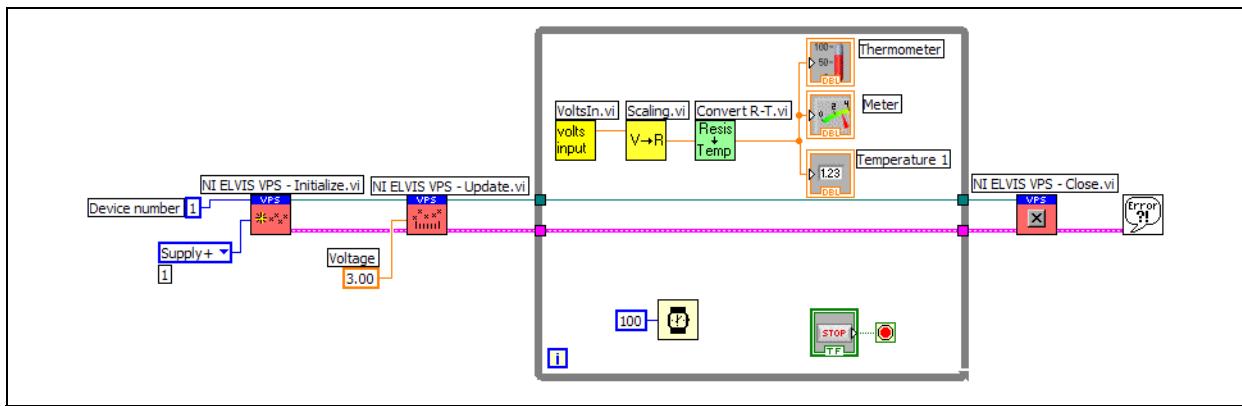
A typical thermistor response curve demonstrates the relationship between device resistance and temperature. It is clear from this curve that a thermistor has three characteristics: the temperature coefficient $\Delta R/\Delta T$ is negative, the response curve is nonlinear (exponential), and the resistance varies over several decades (refer to the diagram in Exercise 2-1). A calibration curve can be produced by fitting a mathematical equation to the response curve. LabVIEW is rich in mathematical tools to fit such a relationship. Once it is found, then the temperature can be calculated for any resistance within the calibrated region. The following calibration VI is typical for a thermistor and demonstrates how the LabVIEW formula node can be used to evaluate mathematical equations.



End of Exercise 2-4

Exercise 2-5 Building an NI ELVIS Virtual Digital Thermometer

The digital thermometer program turns on the VPS to power up the thermistor circuit, then reads the voltage across the thermistor and converts it into temperature. The basic program is a variation of the Simple Variable Power Supply Application found in the *NI ELVIS User Manual*, Figure 4-1. The Block Diagram is shown below.



NI ELVIS has the same Device Number (usually 1) as your DAQ card. The NI ELVIS Initialization selects VPS Supply+. Then the voltage level on the power supply is set with the VPS[Update] VI to + 3 volts.

Measurement, scaling, calibration, and display occur in sequence within the While Loop. VoltsIn.vi measures the thermistor voltage. Scaling.vi converts the measured voltage to resistance according the scaling equation above. Convert R-T.vi uses a known calibration equation to convert the thermistor resistance into temperature. Finally, the temperature is displayed on the LabVIEW front panel in a variety of formats.

The Wait function of 100 milliseconds ensures the voltage is sampled every 1/10 of a second.

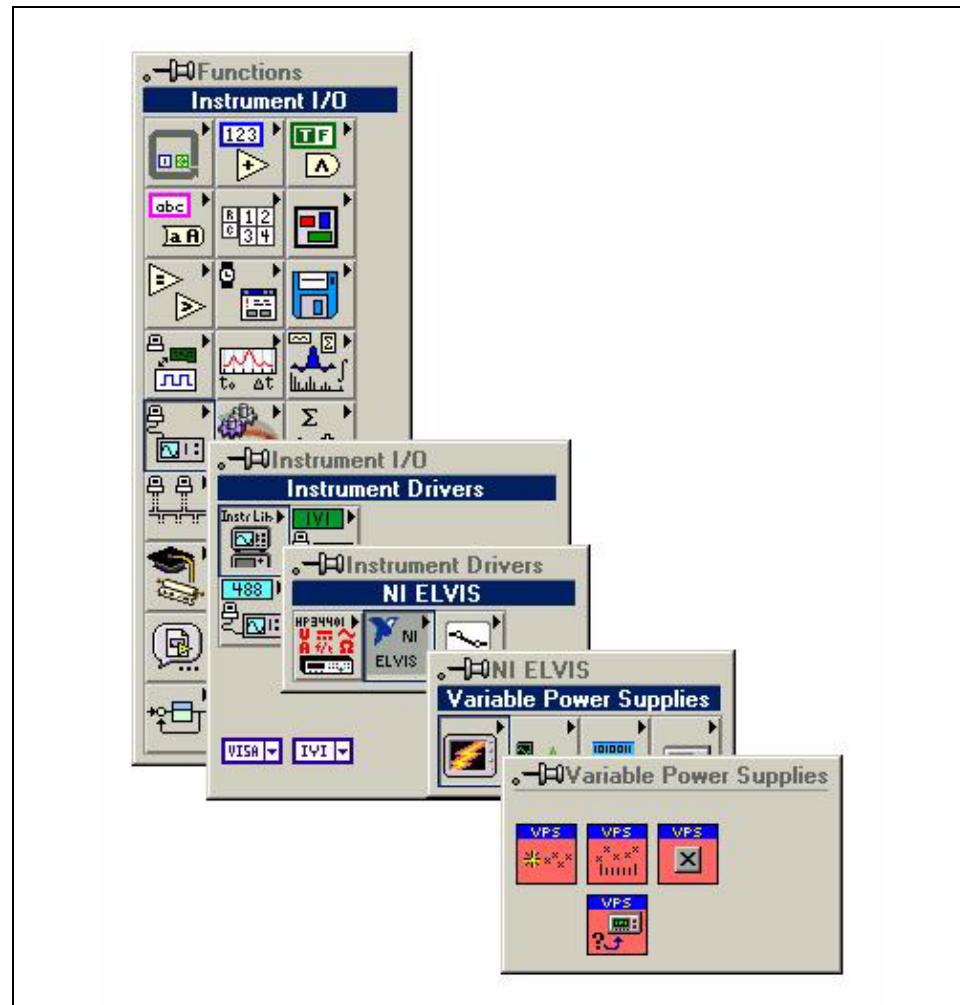
The digital thermometer continues running until the [Stop] button on the front panel button is activated. When the loop ends, the supply reference is closed and the VPS is set to zero volts.

From the Hands-On NI ELVIS VI Library, open Digital Thermometer.vi.

Open up the program and sub VIs to view the program flow and see how the subVIs, Read and Convert functions are coded.

With the calibration file for *your* thermistor, you can generate the proper subVI (Convert R->T) and use it to have a functioning digital thermometer.

For those wishing to write their own program, you can use the DT Template.vi (found in the Hands-On NI ELVIS VI Library) and add your own programming style. You will find the VPS APIs in **Functions»All Functions»Instrument I/O»Instrument Drivers»NI ELVIS»Variable Power Supplies**.



End of Exercise 2-5

Exercise 2-6 Digital Thermometer with a Logging Feature

The simple digital thermometer program displays three indicators on the front panel: a digital display, a meter, and a thermometer. Often only one or two display formats are required. However, adding a logging feature allows the temperature trend to be observed. In `DT Logger.vi` (found in the Hands-On NI ELVIS VI Library), a chart on the front panel has been added. This feature can be added as a single LabVIEW control (Waveform Chart) on the front panel, found in the Controls/Graph menu.

From the Hands-On NI ELVIS VI Library, load and view the program `DT Logger.vi`.

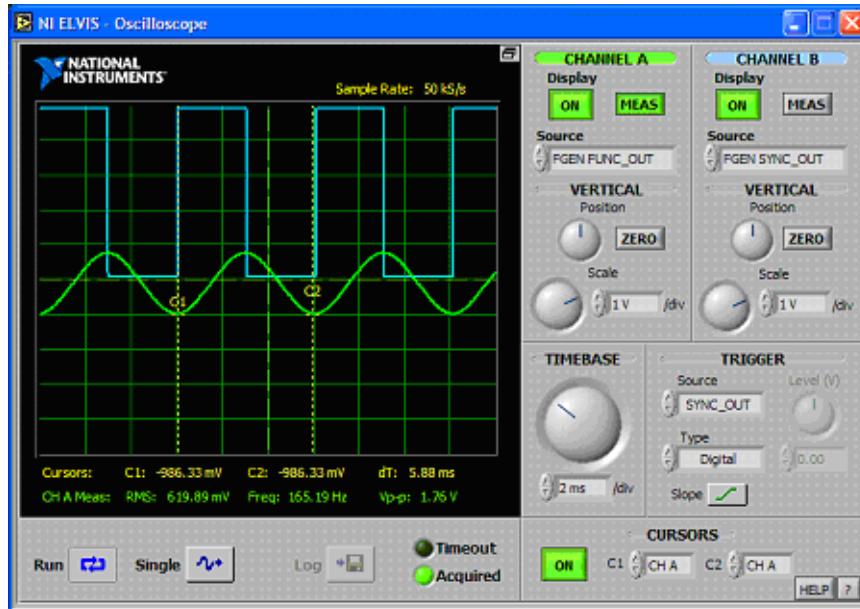
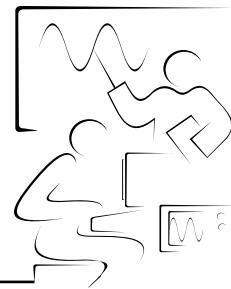
End of Exercise 2-6

What's Cool!

NI ELVIS VPS can be used with WS front panel controls or Virtual controls or within a LabVIEW program to build that special instrument. There are many other features just wanting to be added to the digital thermometer program. How about a [Hold/Update] button so you can sample and hold the current value on a digital display. Later by toggling a button, the temperature is updated. How about plotting ΔT versus time and you decide the reference temperature. Enjoy!

Lab 3

AC Circuit Tools



Most electronic circuits are AC (alternating current) and our ability to design good circuits depends on the tools to measure components, measure impedance, and display circuit properties. With good tools and a little circuit knowledge, one can tweak any circuit to give optimal response.

Goal

This lab introduces the NI ELVIS tools for AC circuits: digital multimeter, function generator, oscilloscope, impedance analyzer, and the Bode analyzer.

Soft Front Panels (SFP) Used in this Lab

Digital Ohmmeter DMM[Ω], Function Generator FGEN, Oscilloscope OSC, Impedance Analyzer IA, and the Bode Analyzer BodeA.

Components Used in this Lab

1 $k\Omega$ resistor R (Brown, Black, Red)

1 μF capacitor C

Exercise 3-1 Measurement of the Circuit Component Values

Launch the NI ELVIS Instrument Launcher and select **Digital Multimeter**. Use the DMM[Ω] to measure the resistor R and then use DMM[C] to measure the capacitor C.

Fill in the following chart.

Resistor	R	<hr/>	Ω	(1k Ω nominal)
Capacitor	C	<hr/>	μF	(1 μF nominal)

Close the DMM.

End of Exercise 3-1

Exercise 3-2 Measurement of Component and Circuit Impedance Z

For a resistor, the impedance is the same as the DC resistance. It can be represented on a 2-D plot as a line along the X axis often called the real component. For a capacitor, the impedance (or more specifically, the reactance) X_C is imaginary, depends on frequency and can be represented as a line along the Y axis of a 2-D plot. It is called the imaginary component. Mathematically, the reactance of a capacitor is represented by:

$$X_C = 1/j\omega C$$

where ω is the angular frequency (measured in radians/sec) and j is a symbol used to represent an imaginary number. The impedance of a RC circuit in series is the sum of these two components where R is the resistive (real) component and X_C is the reactive (imaginary) component.

$$Z = R + X_C = R + 1/j\omega C \text{ (Ohms)}$$

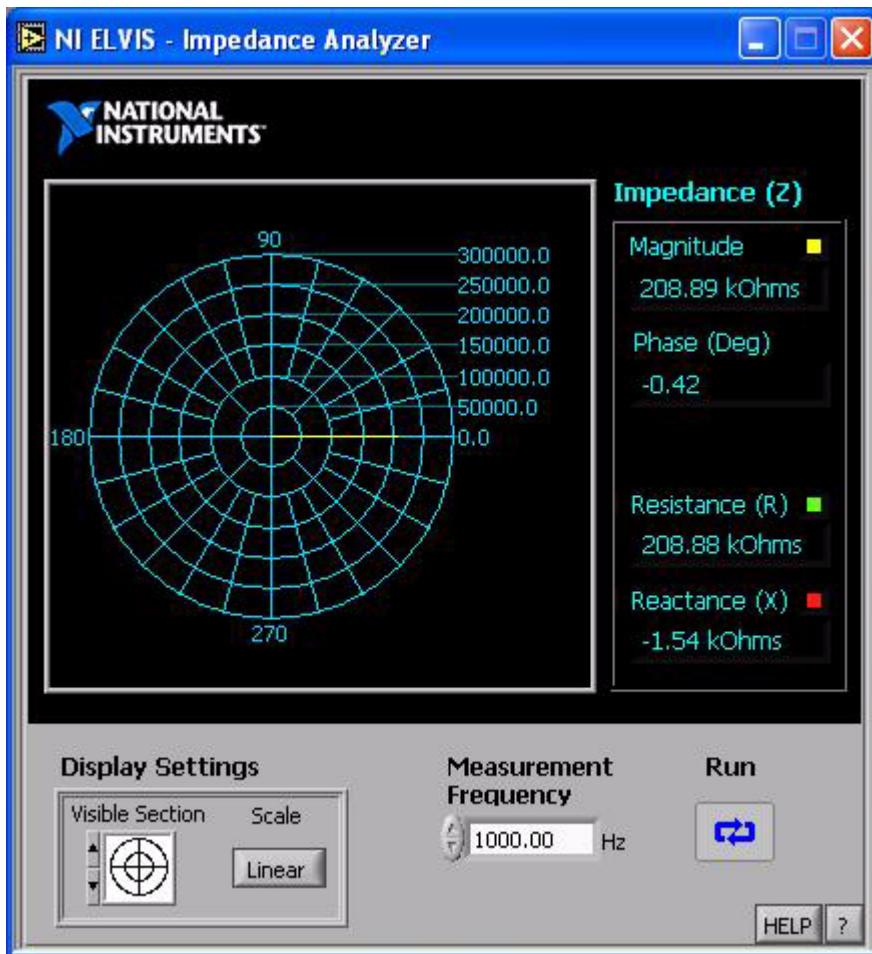
This can also be represented as a phasor vector on a polar plot with:

$$\text{Magnitude} = \sqrt{(R^2 + X_C^2)} \quad \text{and} \quad \text{Phase } \theta = \tan^{-1}(X_C / R)$$

A resistor has a phasor along the real (X) axis. A capacitor has a phasor along the negative imaginary (Y) axis. Recall from complex algebra that $1/j = -j$.

Wouldn't it be great to visualize this phasor in real time?

Select **Impedance Analyzer** from the NI ELVIS Instrument Launcher menu.



Connect leads from the front panel DMM (current) inputs to the $1\text{ k}\Omega$ resistor. Verify that the phasor is along the real axis and the phase is zero. Now connect the leads to the capacitor. Verify the phasor is along the negative imaginary axis and the phase is 270 or -90 degrees. Adjust the Measurement Frequency control box to observe that the reactance (length of the phasor) gets smaller when you increase the frequency and larger when you decrease the frequency. Now connect the leads across the resistor and capacitor in series (be sure to verify the circuit is not connected to ground). The circuit phasor has both a real and an imaginary component. Change the frequency and watch the phasor move.

Adjust the frequency until the reactance component (**X**) is equal to the resistance component (**R**). This is a special frequency value where the phase is:

_____ degrees

The magnitude also has special meaning at this frequency or phase angle.

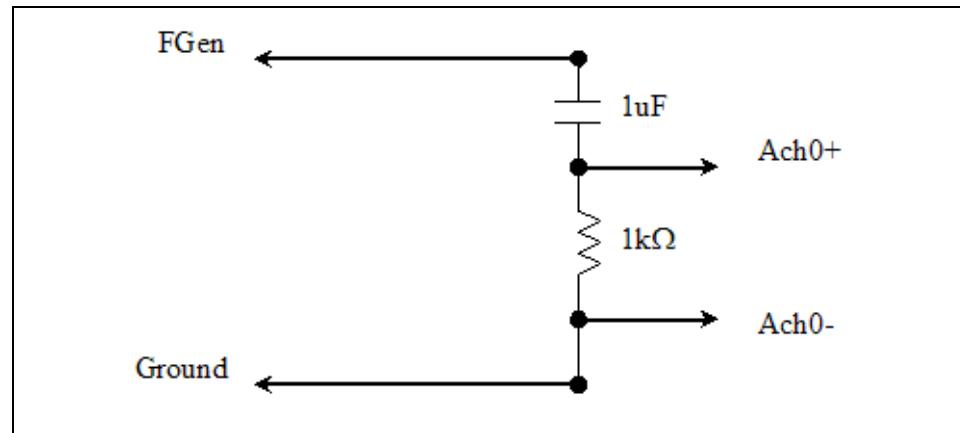
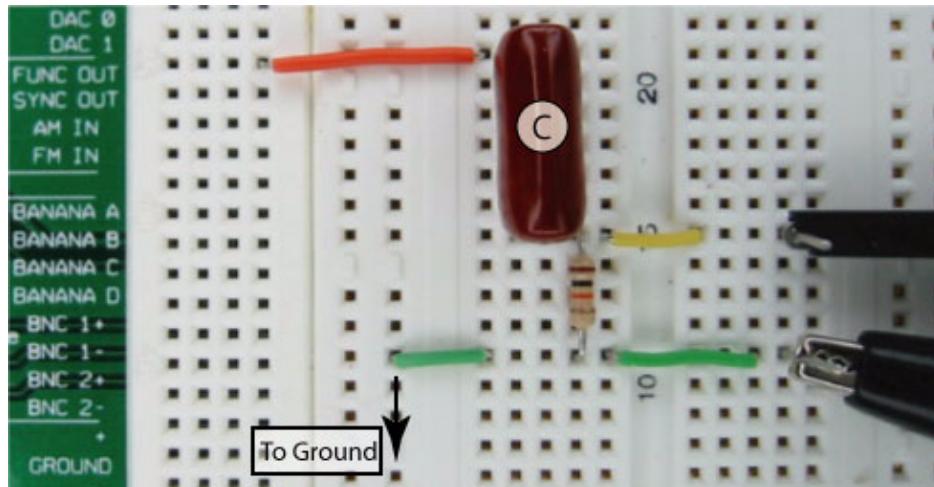
What is the magnitude of the phasor at this point? Answer: $R\sqrt{2}$

Close the Impedance Analyzer.

End of Exercise 3-2

Exercise 3-3 Testing a RC Series Circuit with the Function Generator and Oscilloscope

On the workstation protoboard, build a voltage divider circuit, with a $1 \mu\text{F}$ capacitor and a $1 \text{k}\Omega$ resistor. Connect the RC circuit inputs to [FGEN] and [Ground] pin sockets.



The power supply for an AC circuit is often a function generator and we will be using it to test our RC circuit. From the NI ELVIS Instrument Launcher, select **Function Generator**.



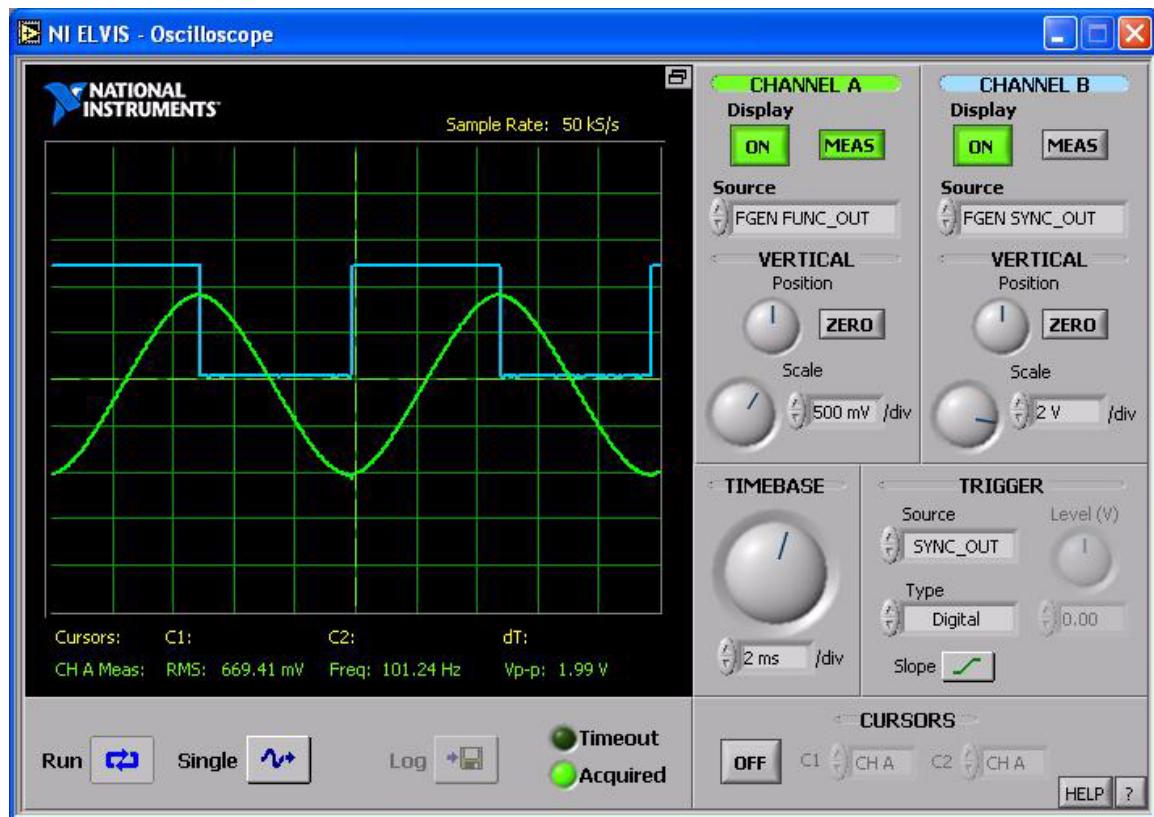
The FGEN SFP has the usual controls for setting the Frequency by decades (Course) and by Hertz (Fine), for selecting the waveform type (Sine, Square, or Triangle) and for selecting the waveform amplitude. All of these controls are also available on the workstation front panel as real controls. They can be selected by sliding the workstation front panel function generator switch to Manual. As with the Variable Power Supply, manual control turns on the green LED display on the SFP and grays out the virtual controls.



Note If you wish to add a DC offset to the AC signal, it is only available on the SFP FGEN.

We will use the oscilloscope to analyze the voltage signals of the RC circuit.

From the NI ELVIS Instrument Launcher, select **Oscilloscope**.



The oscilloscope SFP is similar to most oscilloscopes, but the NI ELVIS oscilloscope can automatically connect inputs to a variety of sources. Click on the **CHANNEL A Source** box and see the list.

BNC/Board CH A, ACH0, ACH1, ACH2, ACH5, FGEN FUNC_OUT, FGEN SYNC_OUT, and DMM Voltage

Set the **Source** on Channel A, **Source** on Channel B, **TRIGGER** and **TIMEBASE** inputs as shown above. This configuration allows the oscilloscope to look at the output of the function generator on channel A, the FGEN TTL synchronization signal (SYNC_OUT) on channel B and be triggered with the SYNC_OUT signal. Make sure you have clicked on the **Run** button of the FGEN SFP and on the OSC SFP. Play with the FGEN controls (virtual or real) and observe the changes on the oscilloscope window.

There are measurement options such as frequency, Amplitude P-P etc. accessed by clicking on the **MEAS** buttons for either channel A or B. Measurements show up at the bottom of the oscilloscope screen.

Even cursors for channel A or B can be activated for making amplitude and time measurements.

Now connect the workstation BNC SCOPE input CH B to the $1\text{ k}\Omega$ resistor.



Note You could also have used the channel B inputs on the protoboard pin sockets labeled Oscilloscope CH B+ and CH B-.

You will see the input signal as before on Channel A and the output signal for our RC circuit on channel B. Trigger as before on the FGEN SYNC_OUT and select a Sine wave on the FGEN. The ratio of the amplitude on channel B to the amplitude on channel A defines the circuit gain at a particular frequency. Since there is no amplifier in the circuit, the gain will be less than one. By looking at different frequencies, you can get a feel for the frequency characteristics of the RC passive filter circuit.

Challenge

Find the frequency for which the gain equals $1/\sqrt{2}$. On the oscilloscope screen, measure the phase difference between the Channel A trace and Channel B trace at this frequency.

Can you relate this phase measurement to the Phasor phase measurement found with the Impedance Amplifier in Exercise 3-2?

Close the function generator and oscilloscope.

End of Exercise 3-3

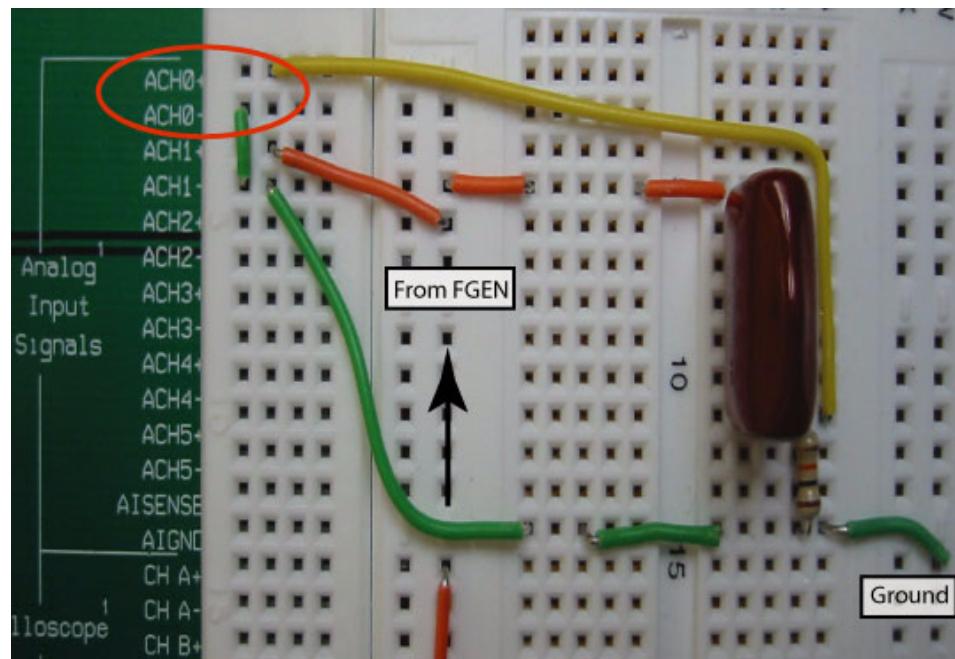
Exercise 3-4 The Gain/Phase Bode Plot of the RC Circuit

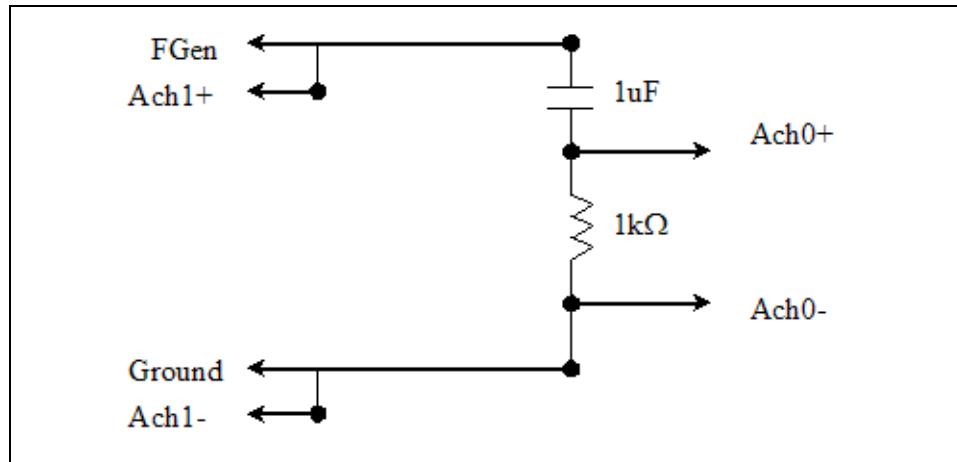
A Bode plot defines in a very real graphical format the frequency characteristics of an AC circuit. Amplitude response is plotted as the circuit gain measured in decibels as a function of log frequency and the Phase response is plotted as the phase difference between the input and output signals on a linear scale as a function of log frequency.

From the NI ELVIS Instrument Launcher, select **Bode Analyzer**.

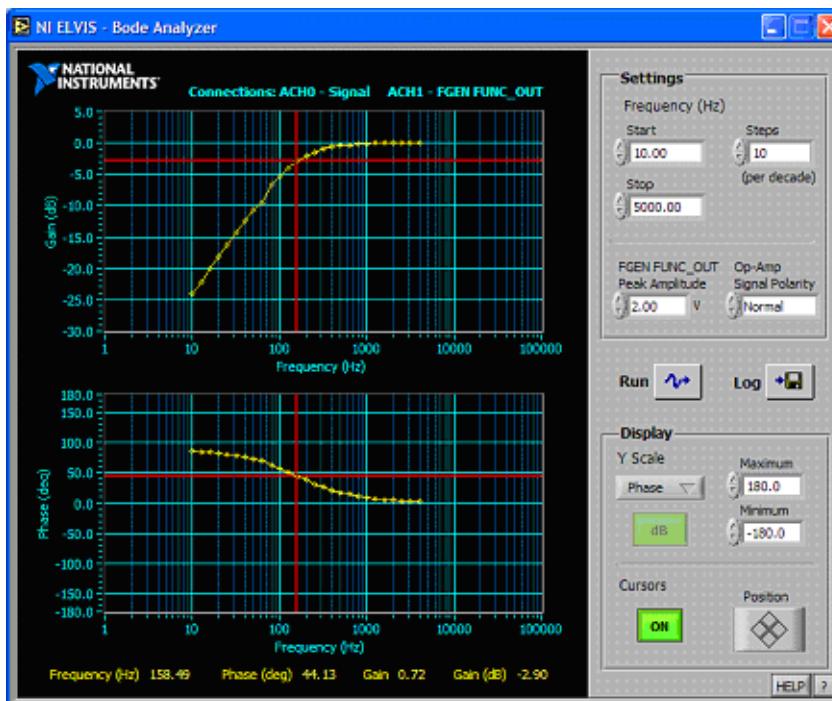
The Bode Analyzer allows one to scan over a range of frequencies; from a start frequency to a stop frequency in steps of ΔF . You can also set the amplitude of the test sine wave. The Bode Analyzer uses the SFP function generator to generate the test waveform. The FGEN output sockets must be connected to your test circuit and *also to ACH1*. The output of the circuit under test goes to ACH0. Further details can be found by clicking on the [HELP] button on the lower right corner of the Bode Analyzer window.

Re-build on the NI ELVIS protoboard the RC circuit, similar to the following circuit and make connections as described above.





Verify your circuit is connected as above and click on the **Run** button.



Use the Display options to select the graphing format and the cursors to read points off the frequency characteristic.



Note The frequency where the signal amplitude has fallen to -3 dB, is the same frequency where the phase is 45 degrees.

End of Exercise 3-4

What's Cool!

Both the Oscilloscope and Bode Analyzer SFPs have a Log button. When activated the data presented on the graphs is written to a spreadsheet file on your hard drive. You can now read this data for further analysis with Excel, LabVIEW, DIAdem, or any other analysis or plotting program.

11/07/2003 4:09 PM

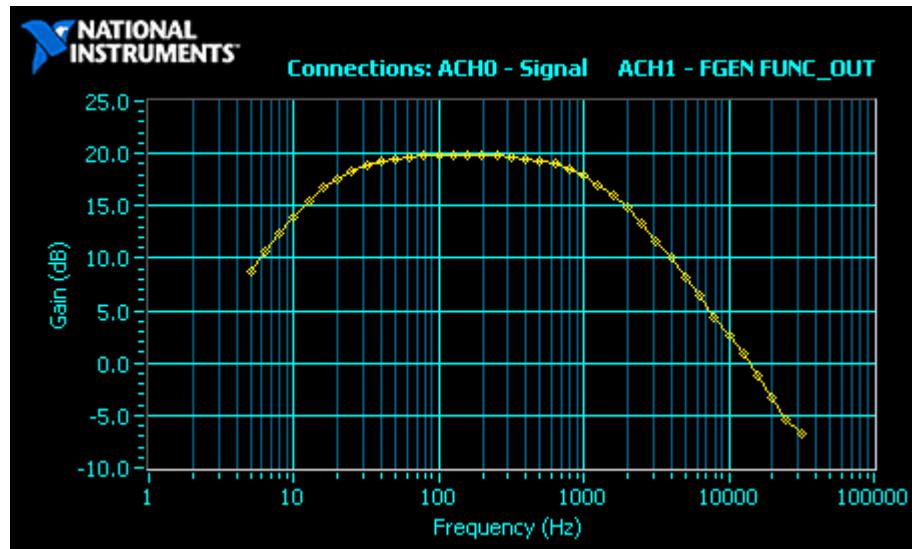
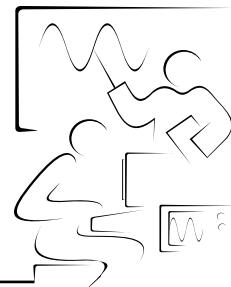
Amplitude: 2.00 V

Frequency (Hz), Gain (dB), Phase (deg)

5.000,	-11.313,	73.929
6.295,	-9.341,	69.780
7.924,	-7.661,	65.278
9.976,	-6.104,	60.025
12.559,	-4.649,	54.057
15.811,	-3.507,	48.012
19.905,	-2.504,	41.384
25.059,	-1.735,	34.955
31.548,	-1.177,	29.064
39.716,	-0.779,	23.805
50.000,	-0.512,	19.374
62.946,	-0.292,	14.617
79.245,	-0.195,	11.932
99.763,	-0.122,	9.445

Lab 4

Op Amp Filters



Adding a few capacitors and resistors to the basic Op Amp circuit can yield many interesting analog circuits such as active filters, integrators, and differentiators. Filters are used to pass specific frequency bands, integrators are used in proportional control and differentiators are used in noise suppression and waveform generation circuits.

Goal

This lab uses the NI ELVIS suite of instruments to measure the characteristics of a low pass, high pass, and band pass filter.

Soft Front Panels (SFP) Used in this Lab

Digital Multimeter DMM, Function Generator FGEN, Oscilloscope OSC, Impedance Analyzer IA, and the Bode Analyzer

Components Used in this Lab

10 k Ω resistor R₁ (Brown, Black, Orange)

100 k Ω resistor R_f (Brown, Black, Yellow)

1 μ F capacitor C₁

.01 μ F capacitor C_f

741 Op Amp

Exercise 4-1 Measurement of the Circuit Component Values

Launch NI ELVIS, select **Digital Multimeter** and use DMM[Ω] to measure the resistors then use DMM[C] to measure the capacitors.

Fill in the following chart.

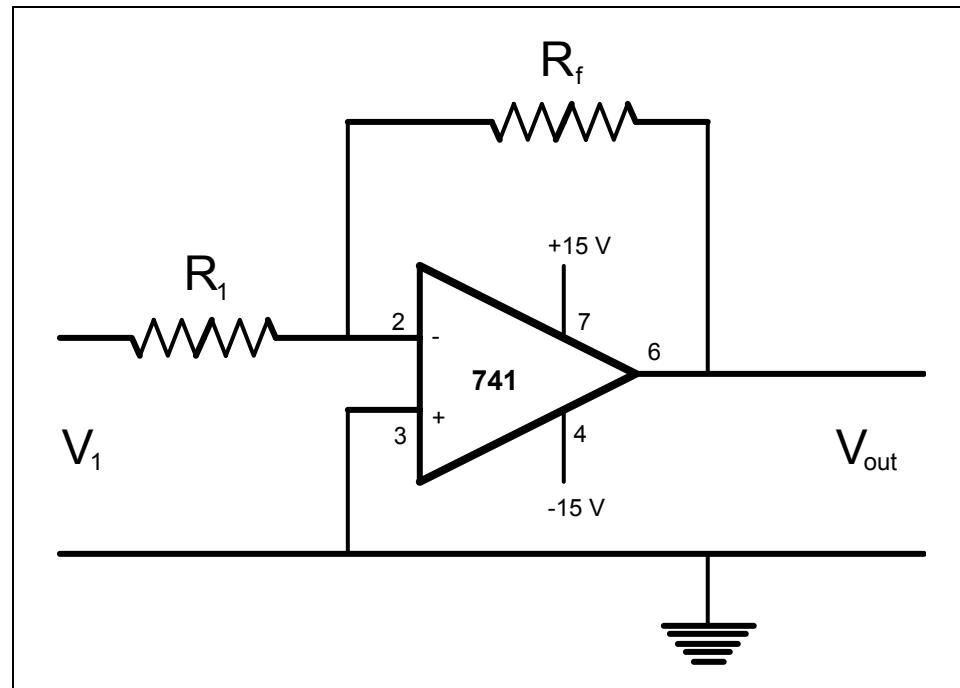
R_1	_____ Ω	(10 k Ω nominal)
R_f	_____ Ω	(100 k Ω nominal)
C_1	_____ μF	(1 μF nominal)
C_f	_____ μF	(.01 μF nominal)

Close the DMM.

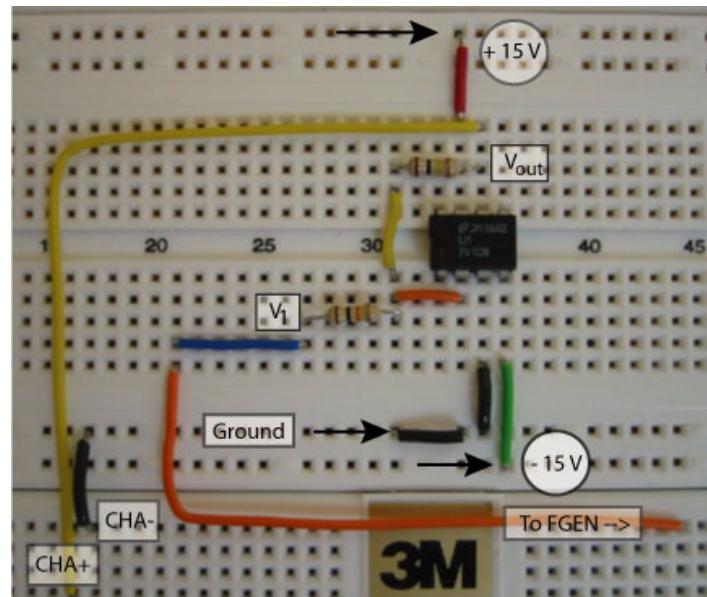
End of Exercise 4-1

Exercise 4-2 Frequency Response of the Basic Op Amp Circuit

On the workstation protoboard, build a simple 741 inverting Op Amp circuit with a gain of 10 as shown in the schematic diagram below.



What the circuit looks like on NI ELVIS protoboard.



Notice that the Op Amp uses both the + 15 V and – 15 V DC power supplies. These are found on the protoboard pin sockets (labeled as +15V, –15V, and Ground). Connect the Op Amp input voltage V_1 to [FGEN] and [Ground] pin sockets. Connect the Op Amp output voltage V_{out} to the oscilloscope input pin sockets [CHA+] and [CHA–].

From the NI ELVIS Instrument Launcher, select **Function Generator** and **Oscilloscope**.

On the oscilloscope panel, set Channel A Source to [BNC/Board CH A]. To view the input signal, set Channel B Source to [FGEN FUNC_OUT].



Note This shortcut on channel B allows one not to have to provide wires on the protoboard linking the channel B input to the oscilloscope.

On the function generator panel, set the following parameters:

Waveform: **Sine wave**

Peak Amplitude: **.1 V**

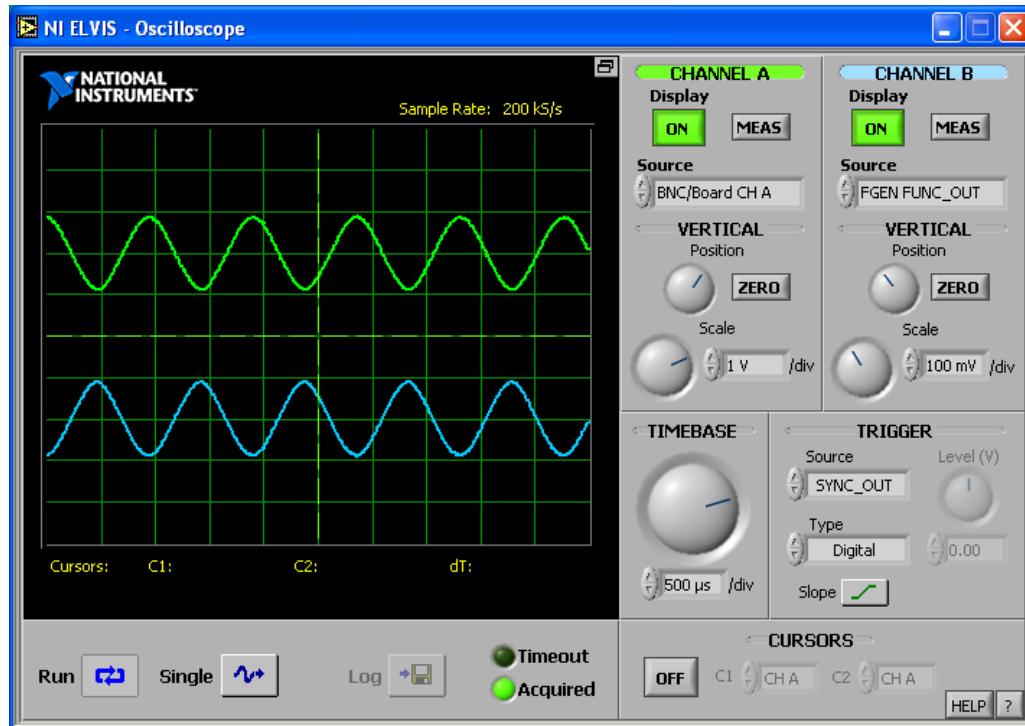
Frequency: **1 kHz**

DC Offset: **0.0 V**

Check your circuit, then power up the protoboard. Run the FGEN and OSC continuously.

Observe the test voltage V_1 appears on channel B and the Op Amp output voltage V_{out} on channel A.

Since the test signal originates from FGEN, you can select SYNC_OUT for the trigger source.



Measure the amplitude of the Op Amp input (CH B) and output (CH A) from the oscilloscope window. Notice the output signal is inverted with respect to the input. This is to be expected for an inverting Op Amp circuit.

Calculate the voltage gain (the amplitude ratio channel A /channel B). Try a range of frequencies from 100 Hz to 10 kHz. Any change?

How do your measurements agree with the theoretical gain of (R_f/R_1)?



Note You could have used an analog trigger source from CH A or CH B. This choice sets the Trigger Type to Analog (SW), allowing one to set the trigger slope and level. Try it!

Close the FGEN and OSC windows.

End of Exercise 4-2

Exercise 4-3 Measuring the Op Amp Frequency Characteristic

The best way to study the Op Amp's AC characteristic response curve is to measure its Bode plot. It is basically a plot of Gain (dB) and Phase (degrees) as a function of log frequency. The transfer function for an Inverting Op Amp circuit is given by:

$$V_{\text{out}} = -(\frac{R_f}{R_1}) V_1$$

where V_{out} is the Op Amp output and V_1 is the Op Amp input (the amplitude of FGEN in our circuit). The Gain is just the quantity (R_f/R_1) . Notice how the minus sign inverts the output signal with respect to the input signal. On a Bode plot, one expects a straight line with a magnitude of $20 \cdot \log(\text{Gain})$. For a gain of 10, the Bode amplitude should be 20 dB.

From the NI ELVIS Instrument Launcher, select **Bode Analyzer**.

The signals, input (V_1), and output (V_{out}), must be connected to the Analog Input pins as follows:

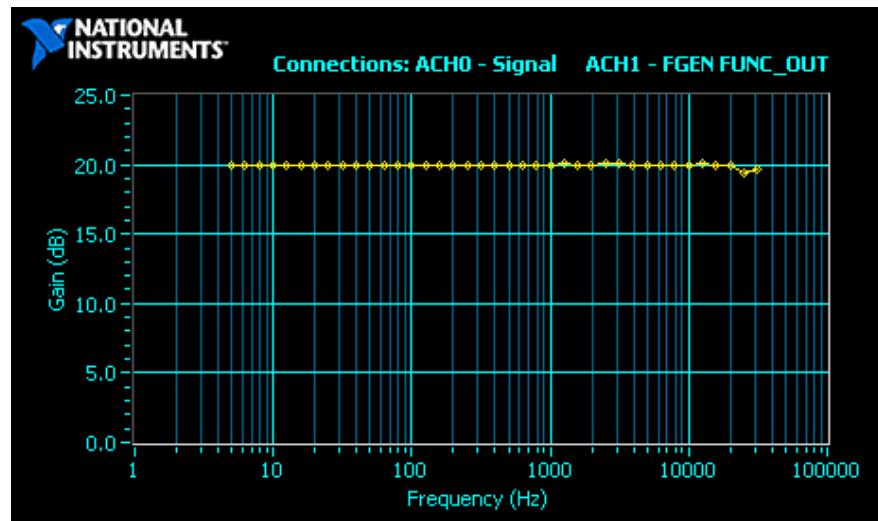
V_1+	ACH1+	(from the FGEN Output)
V_1-	ACH1-	
$V_{\text{out}}+$	ACH0+	(from the Op Amp Output)
$V_{\text{out}}-$	ACH0-	

From the Bode Analyzer, set the scan parameters as follows:

Start	5 (Hz)
Stop	50000 (Hz)
Steps	10 (per decade)

Press **Run** and observe the Bode plot for the Inverting Op Amp circuit.

Also check out the phase response.



The gain is indeed flat up until about 10,000 Hertz where it starts to roll off. This graph is as expected as the high frequency response of an Op Amp does depend on the circuit gain in the high frequency limit. For this lab, we will take this curve as the basic Bode plot for a 741 Op Amp.

End of Exercise 4-3

Exercise 4-4 High Pass Filter

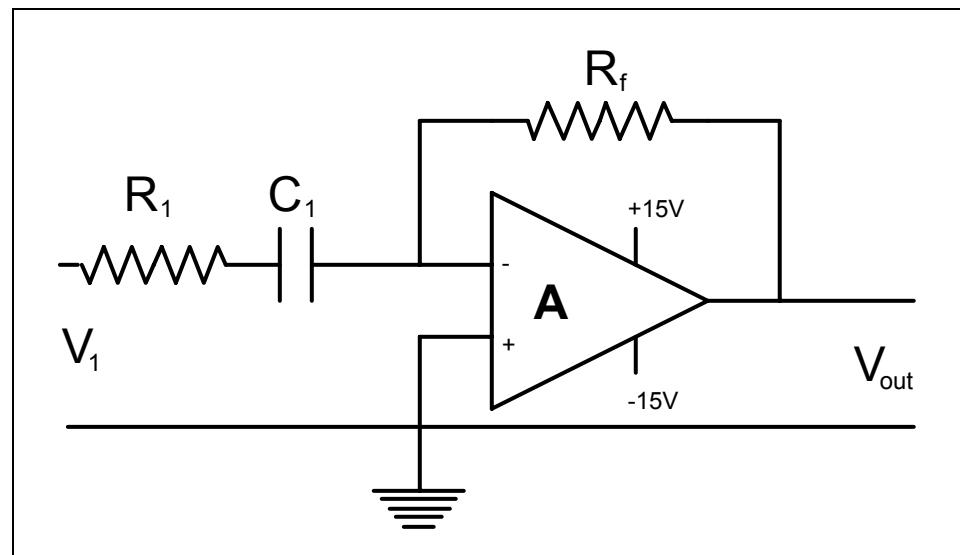
Adding a capacitor C_1 in series with the input resistor R_1 generates a high pass filter. The low frequency cutoff point f_L is given by the equation:

$$2\pi f_L = 1 / R_1 C_1$$

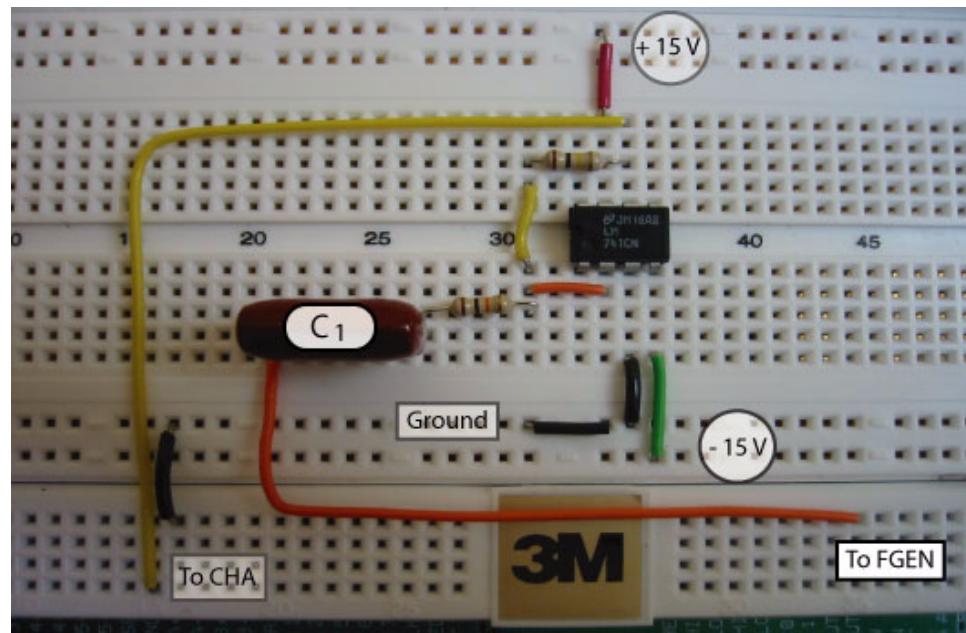
where f_L is measured in Hertz. This is the frequency where the Gain (dB) has fallen by -3 dB. This point (-3 dB) occurs when the impedance of the capacitor equals that of the resistor. The high pass Op Amp filter equation is similar. At the -3 dB point, the impedance of the input resistor is equal to the impedance of the input capacitor:

$$R_1 = 1 / (2\pi f_L C_1) = X_C$$

Add a $1 \mu F$ capacitor C_1 in series with the $1 k\Omega$ input resistor R_1 in the Op Amp circuit.

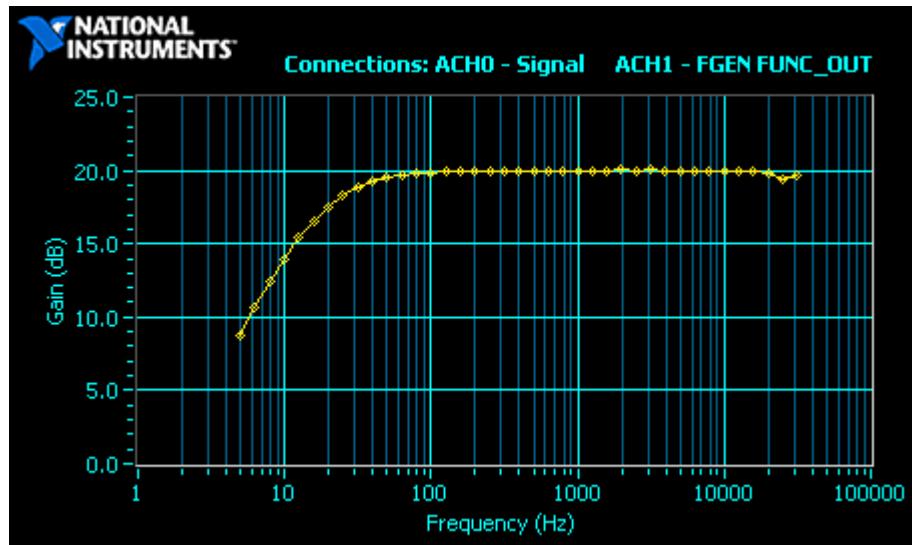


Circuit on NI ELVIS protoboard.



Run a second Bode plot using the same scan parameters as in Exercise 4-3.

Observe that the low frequency response is attenuated while the high frequency response is similar to the basic Op Amp Bode plot.



Use the cursor function to find the low frequency cutoff point; that is, the frequency at which the amplitude has fallen by -3 dB or the phase change is 45 degrees.

How does it agree with the theoretical prediction of $2\pi f_L = 1/R_1 C_1$?

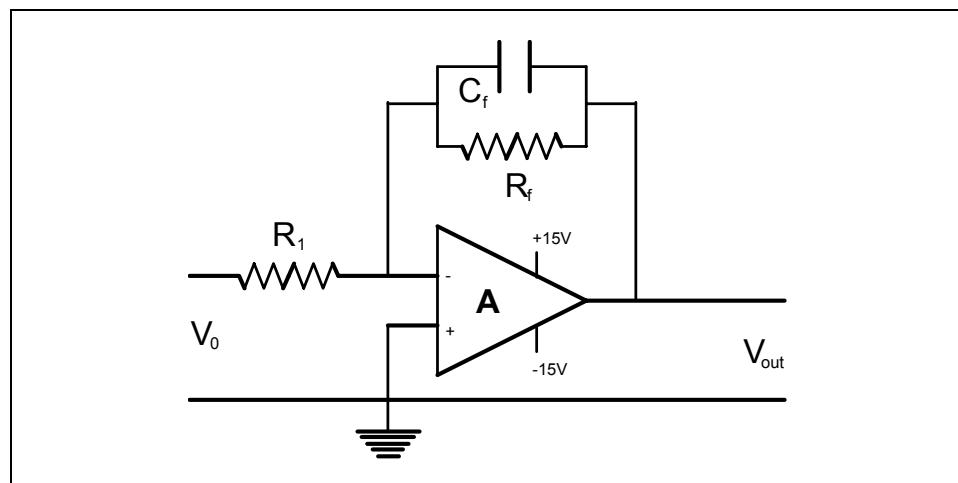
End of Exercise 4-4

Exercise 4-5 Low Pass Filter

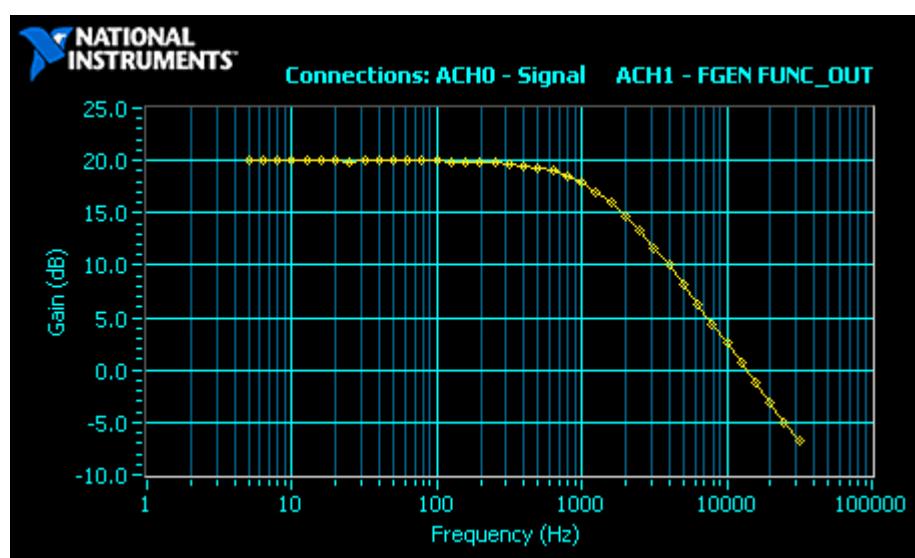
The high frequency roll off in the Op Amp circuit is due to the internal capacitance of the 741 chip being in parallel with the feedback resistor R_f . If we add an external capacitor C_f in parallel with the feedback resistor R_f , one can reduce the upper frequency cutoff point to f_U . It turns out that this new cutoff point can be predicted from the equation:

$$2\pi f_U = 1 / R_f C_f$$

Short the input capacitor (do not remove, as we will use this in Exercise 4-6) and add the feedback capacitor C_f in parallel with the $100 \text{ k}\Omega$ feedback resistor.



Run a third Bode plot using the same scan parameters.



Now you will see that the high frequency response is attenuated more than the basic Op Amp response. Use the cursor function to find the high frequency cutoff point; that is, the frequency at which the amplitude has fallen by -3 dB or the phase change is 45 degrees.

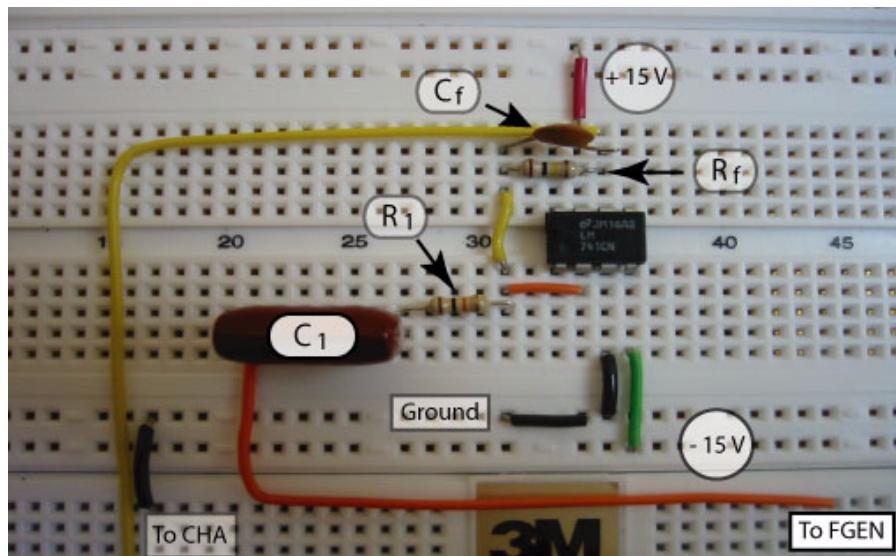
How closely does it agree with the theoretical prediction $2\pi f_U = 1/ R_f C_f$?

End of Exercise 4-5

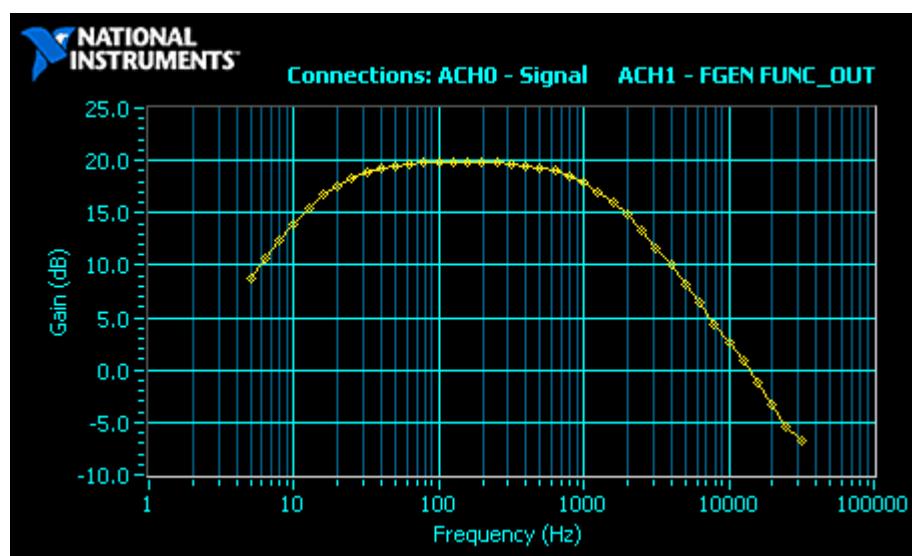
Exercise 4-6 Band Pass Filter

If you allow both an input capacitor and a feedback capacitor in the Op Amp circuit, then the response curve has both a low cutoff frequency f_L and a high cutoff frequency f_U . The frequency range ($f_U - f_L$) is called the bandwidth. For example, a good stereo amplifier would have a bandwidth of at least 20,000 Hz.

A Bandpass filter on NI ELVIS protoboard.



Remove the short on C_1 and run a fourth Bode plot using the same scan parameters as before.



By drawing a line at 3 dB below the maximum amplitude region, the frequency range contained by all frequencies above this line defines the pass band.

End of Exercise 4-6

What's Cool!

The generalized the Op Amp transfer curve is given by the phasor equation

$$V_{\text{out}} = - (Z_f/Z_1) V_{\text{in}}$$

where the Impedance values for the four circuits are:

Op Amp	Z_f	Z_1	Gain
Basic	R_f	R_1	R_f / R_1
High Pass	R_f	$R_1 + X_{C1}$	$R_f / (R_1 + X_{C1})$
Low Pass	$R_f + X_{Cf}$	R_1	$(R_f + X_{Cf}) / R_1$
Band Pass	$R_f + X_{Cf}$	$R_1 + X_{C1}$	$(R_f + X_{Cf}) / (R_1 + X_{C1})$

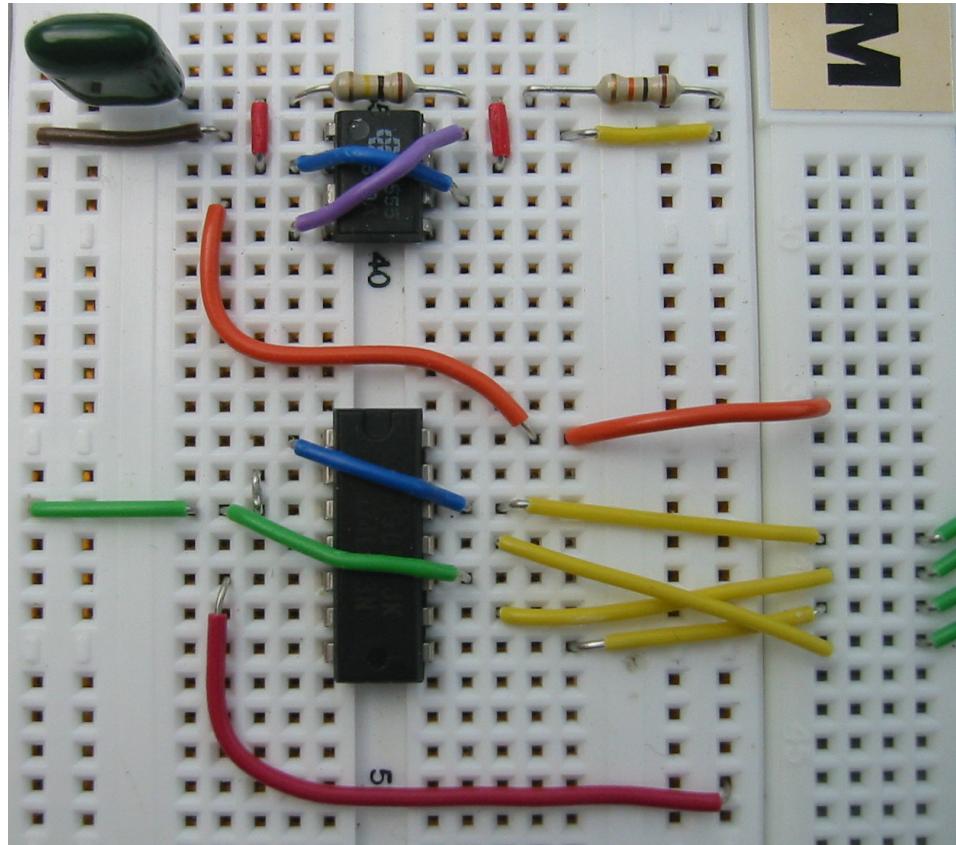
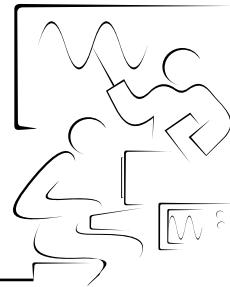
For any frequency, you can use the **Impedance Analyzer** to measure the impedances Z_f and Z_1 . A LabVIEW program can calculate the ratio of two complex numbers. The magnitude of the ratio $|Z_f/Z_1|$ is the gain. Try it!



Note You could also use the Impedance Analyzer to find the frequencies where R_1 equals X_{C1} and R_f equals X_{Cf} to verify that the lower and upper frequency cutoff points from the Bode plot are equal to these frequencies.

Lab 5

Digital I/O



Digital electronics is the heart and soul of modern computers. The ability to set and read digital lines is essential to digital circuit diagnostics.

Goal

This lab focuses on the NI ELVIS digital tools to study circuits such as a digital clock, digital counter, and a logic state analyzer.

Soft Front Panels (SFP) Used in this Lab

Digital Writer, Digital Reader, FGEN (TTL outputs), and the Oscilloscope

Components Used in this Lab

10 k Ω resistor R_A (Brown, Black, Orange)

100 k Ω resistor R_B (Brown, Black, Yellow)

1 μ F capacitor C

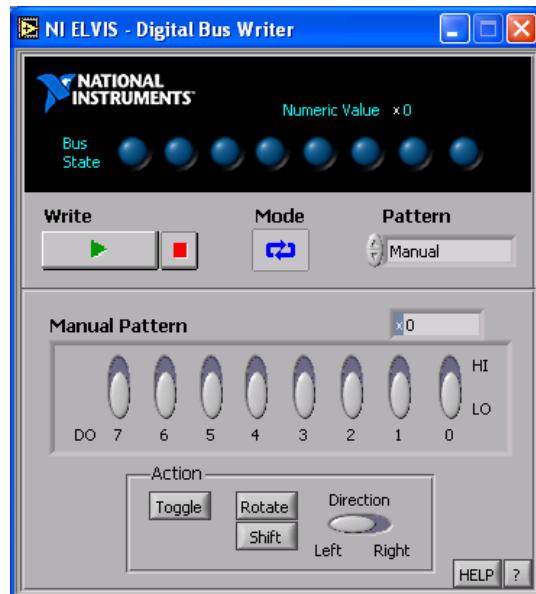
555 Timer chip

7493 4-bit binary counter

Exercise 5-1 Visualizing Digital Byte Patterns

The NI ELVIS protoboard has a bank of eight green LEDs with pin sockets labeled LED <0–7>. They can be used as visual indicators of digital logic states (On = HI and Off = LO). For this exercise, wire the LEDs to the 8-bit parallel output bus sockets pins labeled Write <0–7>. For example, connect Write<0> alias Bit 0 to the pin socket LED<0>, etc. Only one lead is required as the grounds are connected internally within NI ELVIS.

Launch the NI ELVIS Instrument Launcher and select **Digital Writer**. A new digital logic diagnostic window pops up which allows the user to set/reset any of the Write lines to a HI or LO state.



The Digital Output (DO) bits are labeled 0 to 7 reading right to left in the Manual Pattern box. Any bit can be set/reset (HI/LO) by clicking on the top or bottom portion of the virtual switch. Collectively, these 8 bits constitute a byte which can be read in a binary, hexadecimal or decimal format in the display box above the switches.

By clicking on the grayed out portion, you can set the radix (format) of this indicator.



Once a digital pattern has been set, click **Write** (green arrow) to send the pattern to the parallel output port Write lines <0–7> which in turn is passed onto the green LEDs.



Note The Mode can be set to output a single pattern or to continuously output the pattern. In continuous operation, the pattern can be changed on the fly.

The set pattern is echoed on blue “LED” indicators of the Bus State on the SFP. Also on the SFP in the Action box you can Toggle, Rotate, or Shift your bit pattern right or left.

Press the **Stop** (red box) button to cease updating the port.

In testing digital circuits, there are several patterns often used for diagnostic checks. Click the **Pattern** selector on the SFP to view the options available.

Manual	Load any 8-bit pattern
Ramp (0–255)	Computer Instruction INC
Alternating 1/0's	Computer Instruction INVERT
Walking 1's	Computer Instruction SHIFT LEFT LOGIC

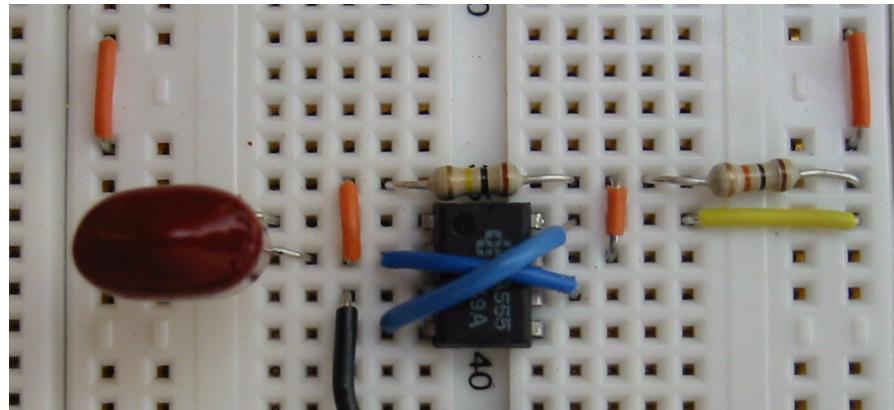
Take your bits for a stroll!

Close the Digital Writer.

End of Exercise 5-1

Exercise 5-2 555 Digital Clock Circuit

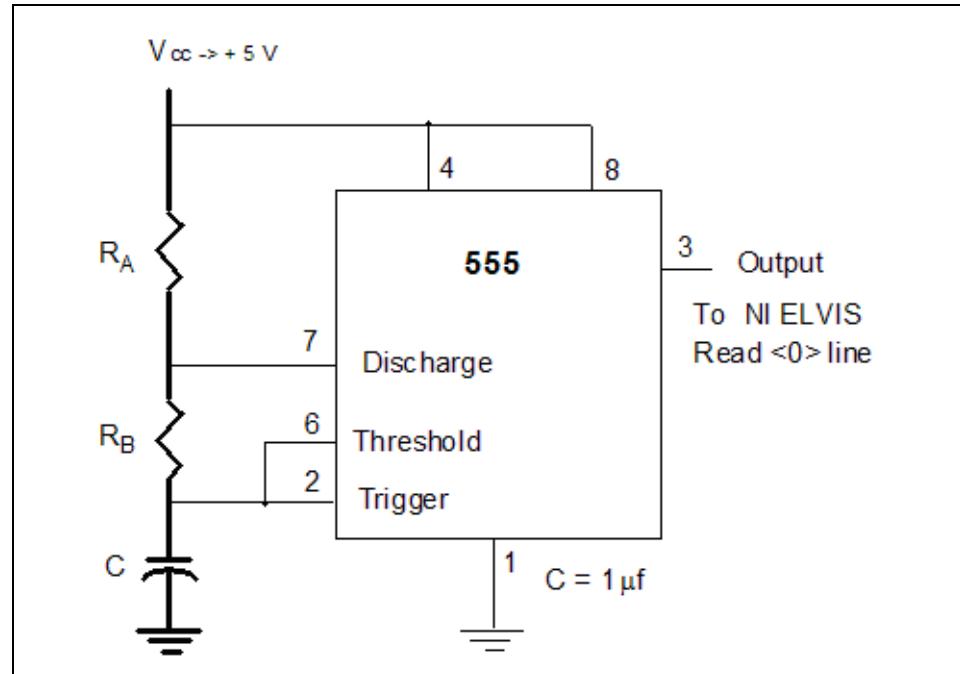
A 555 Timer chip together with resistors R_A , R_B and capacitor C can be configured to act as a digital clock source.



Using the DMM[Ω] and DMM[C] measure the component values and fill in the following table.

R_A	_____	Ω	(10 k Ω nominal)
R_B	_____	Ω	(100 k Ω nominal)
C	_____	μF	(1 μF nominal)

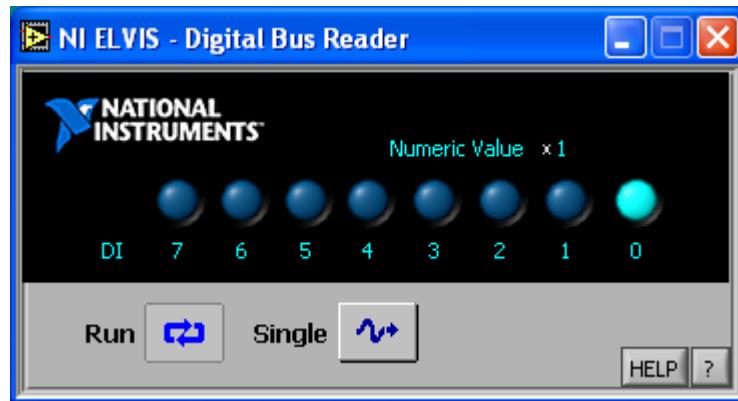
Build the clock circuit on the protoboard as shown below.



Power (+5V) goes to pins 8 and 4. Ground goes to pin 1. The timing chain of R_A , R_B , and C straddles the power supply with a connection between the resistors going to pin 7 and connection between R_B and C going to pins 2 and 6.

Wire the 555 output pin 3 to the parallel input port pin socket Read <0>.

From the NI ELVIS Instrument Launcher, select **Digital Reader** and enable power to the protoboard on the NI ELVIS workstation.



The Digital Bus Reader allows the current state of the parallel input port to be read on demand (single shot) or continuously. If the clock circuit is running correctly, then you should see the least significant bit flashing if you are running continuously (as shown above). If not, use the DMM[V] to check the voltage on the 555 pins. With the clock circuit running, one can now make some useful circuit measurements.

The 555 Timer oscillator circuit has a Period T of:

$$T = 0.695 (R_A + 2 R_B)C \text{ seconds}$$

The 555 Timer oscillator circuit frequency is related to the period by:

$$F = 1/T \text{ Hertz}$$

The 555 Timer oscillator circuit has a Duty Cycle (On time/Period) of:

$$DC = (R_A + R_B) / (R_A + 2 R_B)$$

Close all SFPs and select the **Oscilloscope**.

Connect the front panel BNC Scope CH A input leads to pin 3 of the 555 Timer chip and any Ground. You should now be observing the digital waveform on channel A of the oscilloscope. Select Trigger Source CH A. This option takes the signal from channel A, sets the Trigger Type to

[Analog (SW)] and allows the user to set the Trigger slope and Level. Set the Level to +1 V.

Utilizing the [MEAS] option for channel A, observe the frequency in the scope window. Turn CURSORS CH A button [ON]. By clicking and dragging the cursors, measure the period and duty cycle.

Fill in the following table.

T = _____ (seconds)

T_{on} = _____ (seconds)

DC = _____

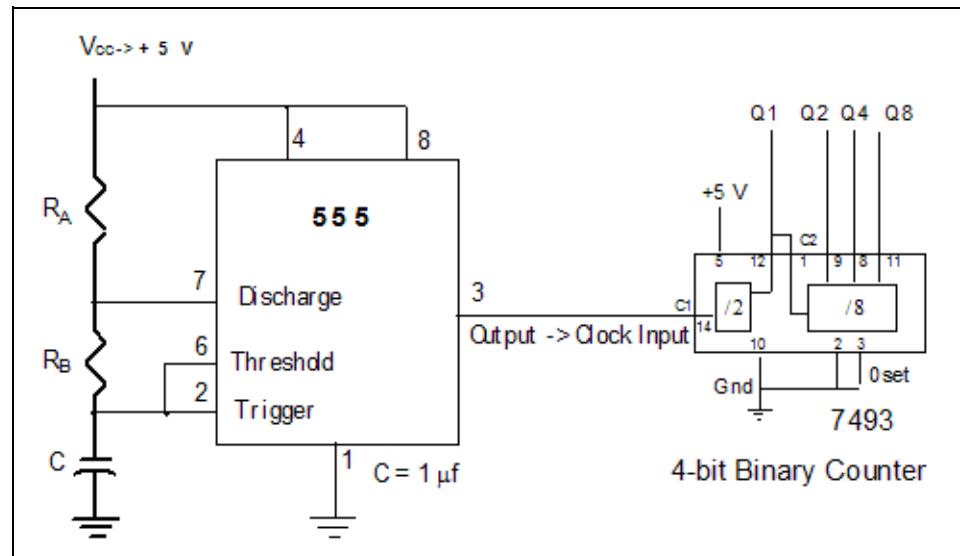
F = _____ (Hertz)

Compare your measurements with the theoretical predictions above.
Close any SFPs.

End of Exercise 5-2

Exercise 5-3 Building a 4-bit Digital Counter

Next to the 555 digital clock circuit, insert a 7493 4-bit binary ripple counter into the protoboard. This chip contains a divide-by-two and a divide-by-eight counter. To configure the chip as a divide-by-sixteen counter, pin 12 (Q1) must be jumpered to pin 1 Clock 2 on the 7493 chip, as shown below.



For the 7493 binary counter chip, +5 V power is connected to pin 5 and ground to pin 10. Also ensure the 0set, pins 2, and 3 are grounded. Wire the outputs onto five green LEDs and Read pin sockets according to the following mapping scheme.

Q1 pin 12	to	LED<4> and Read<4>
Q2 pin 9	to	LED<5> and Read<5>
Q4 pin 8	to	LED<6> and Read<6>
Q8 pin 11	to	LED<7> and Read<7>
555 Clock pin 3	to	LED<0> and Read<0>

Connect the 555 digital clock output (pin 3) to the 7493 clock1 input (pin 14). A photograph of a typical circuit on the NI ELVIS protoboard is shown on the first page of this lab.

Power the chips and watch the binary counts accumulate on the LEDs!

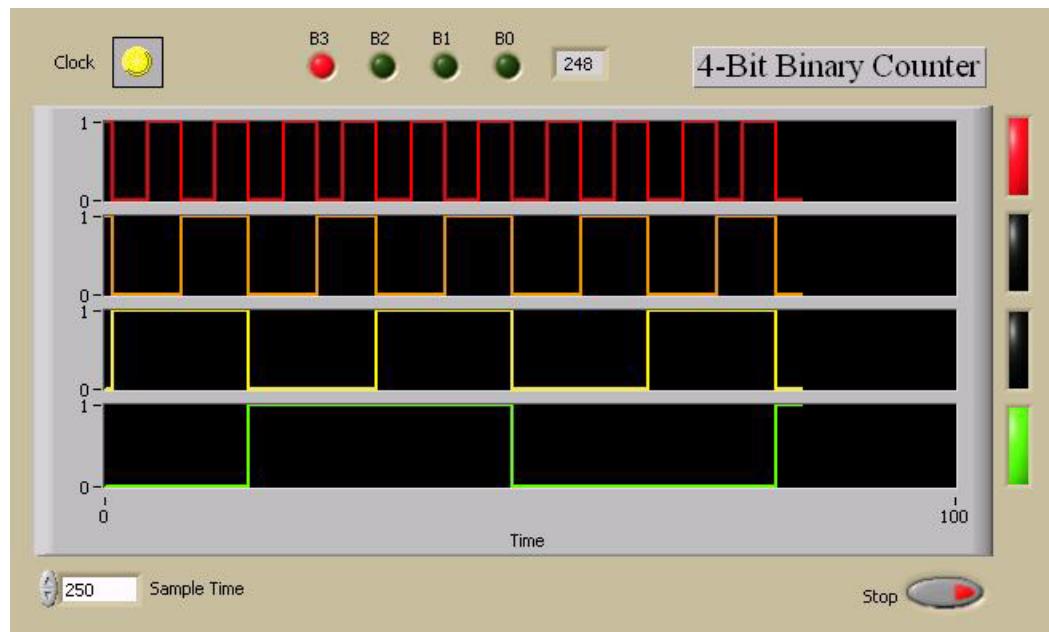
From the NI ELVIS Instrument Launcher, select the **Digital Reader**. This allows you to monitor the binary states on the computer and at the same time see the states on the green LEDs.

Close NI ELVIS.

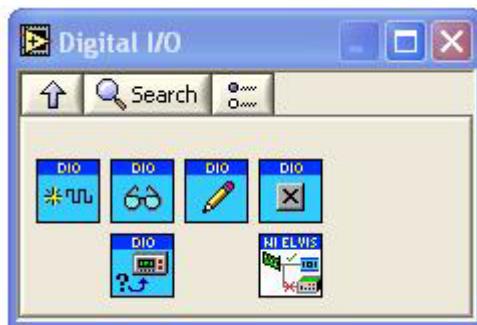
End of Exercise 5-3

Exercise 5-4 LabVIEW Logic State Analyzer

Up to this point, we have only looked at the state of digital outputs at one point in time. A timing diagram is formed by stringing sequential states together sampled uniformly in time. Plotting several digital lines together on the same graphs generates a digital timing diagram. A binary counter has a unique timing diagram where the following falling edge of the previous bit causes the next bit to toggle.



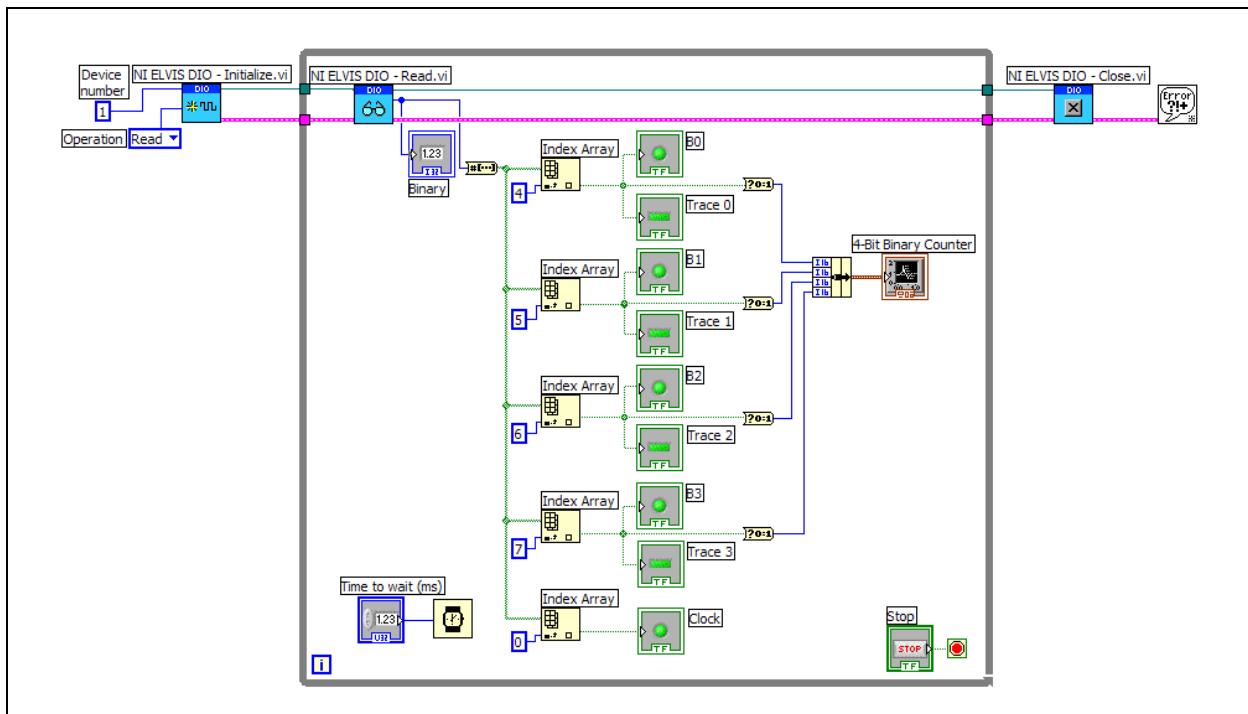
Using the LabVIEW APIs for the Digital I/O, one can build a simple 4-bit logic state analyzer. You will find the Digital I/O palette in **Functions»All Functions»Instrument I/O»Instrument Drivers»NI ELVIS**.



The top row of DIO VIs (from left to right) are Initialize, Read, Write, and Close.

Launch LabVIEW and then select `Binary Counter.vi` from the Hands-On NI ELVIS Library.

On the diagram panel, the NI ELVIS DIO Icon (on the left) initializes the Read function on device 1 (default) and creates a refnum (green line). The middle DIO Icon reads the port and the DIO Icon (on the right) closes the DIO operation freeing up any memory used in running the program and passing any error messages onto the front panel.



The 4 bit logic state analyzer samples NI ELVIS parallel port (NI ELVIS DIO – Read.vi) and presents the bits as a numeric number (blue line). LabVIEW then converts the numeric number into an 8-bit boolean array (thick green line). Bit 4 on the port (Q1) is mapped to the fifth element (index 4) of the array. The Index Array VI extracts a particular bit, say (index 4) and sends Q1 to the Trace 0 and then onto the plot routine. Each Boolean bit is converted back to a numeric value (either 0 or 1) then bundled together with the other traces for plotting the timing diagram for Q1, Q2, Q3, and Q4. The many formats of LabVIEW chart options allow the data to be presented in an expected format for a timing diagram.

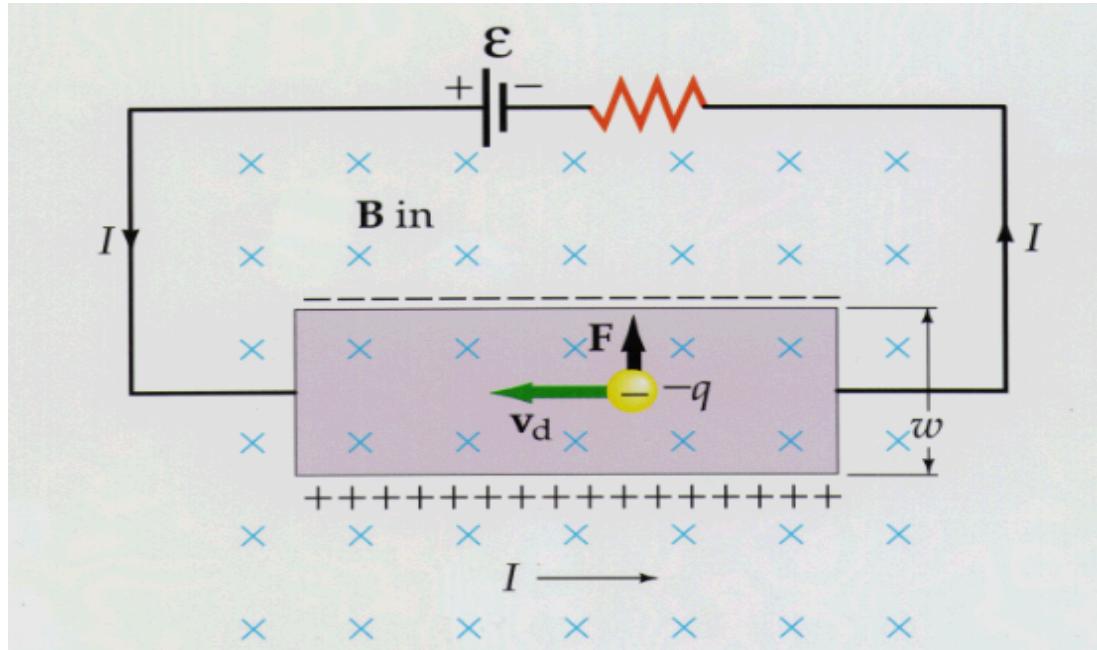
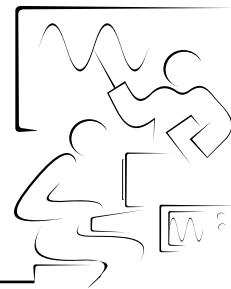
End of Exercise 5-4

What's Cool!

If you chose a 74393 IC (8-bit binary counter), then you can modify the above LabVIEW program to build an 8-bit logic state analyzer.

Lab 6

Magnetic Field Sensor



In 1879, Erwin Hall discovered that when a current flows through a block of semiconductor material in the presence of a magnetic field, a voltage is generated across it. He found that this voltage, now named after him, was equal to the vector cross product of the current and magnetic field.

$$V_H = \gamma |I \times \mathbf{B}|$$

This means that a Hall probe can be used to measure current, magnetic field, or the angle between the sensor axis and an external field. Today, integrated Hall Effect sensors have an internal constant current source and an Op Amp amplifier to buffer the output signal. These sensors are inexpensive, robust, and can be interfaced to both analog and digital circuits.

Goal

This lab focuses on using NI ELVIS tools to study the properties of Hall Effect sensors. Along the way, a simple Gaussmeter and a digital counter interface are built using a linear Hall Effect sensor and a Hall Effect switch respectively.

Soft Front Panels (SFP) Used in this Lab

DMM[V], Oscilloscope OSC, and LabVIEW VIs for the digital counter

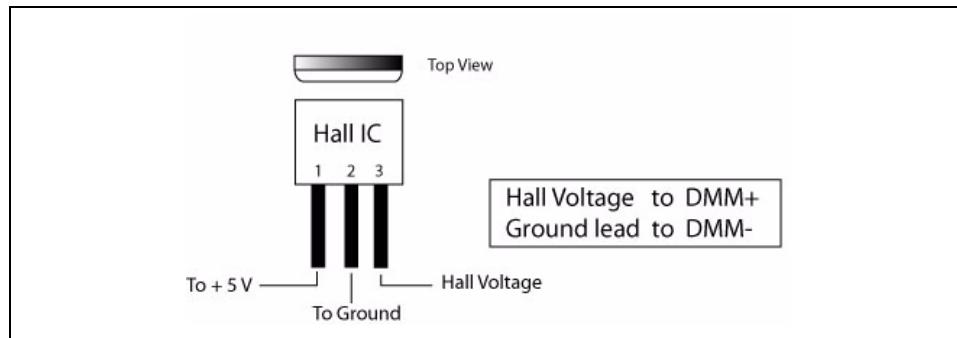
Components Used in this Lab

Linear magnetic field sensor Allegro A3240UA and Hall Effect switch Allegro A3212UA.

Contact Allegro at www.allegro.com and request a free sample of these sensors.

Exercise 6-1 Testing the Analog Magnetic Field Sensor with NI ELVIS Tools

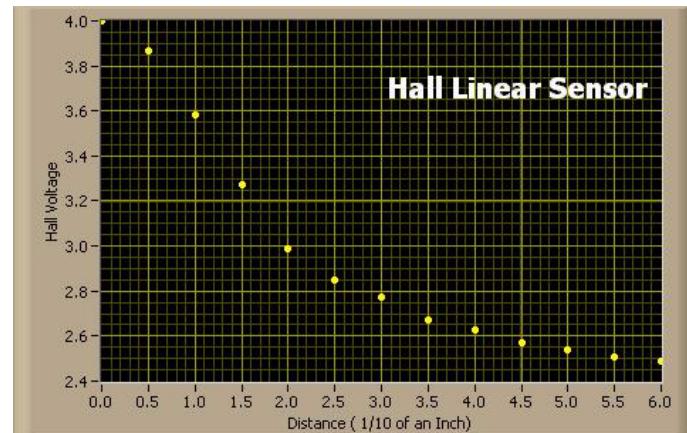
The Allegro devices have only three terminals: $+V_{cc}$ power, Gnd, and the Hall output. Insert a linear Hall device (A3240) into the protoboard. Connect the power $+5V$ pin socket to $+V_{cc}$, Ground pin socket to Gnd. Connect the DMM (voltage) leads to Hall output and Gnd.



Launch the NI ELVIS Instrument Launcher and select **Digital Multimeter**.

Bring a small magnet (field intensity of several hundred gauss) in close proximity to the face of the Hall sensor. In the absence of a magnetic field, the sensor reads 1/2 of $+V_{cc}$ or about 2.5 volts. As the magnet is brought closer to the sensor, the Hall voltage either rises greater than 2.5 V or falls less to than 2.5 V depending on the magnet polarity. The south end of the magnet causes a rise, the north end a fall. The sensor will saturate near +5 or 0 volts in a field in excess of ± 500 gauss. Observe that the Hall voltage is quite nonlinear with the distance between the sensor and the magnet face. To observe this relationship, let's make distance and voltage measurements and then plot on a piece of paper our observations.

The distance between adjacent pin socket holes is 1/10 of an inch. Place the magnet on the protoboard directly in front of the sensor and measure the Hall voltage in 0.1 or 0.05 inch increments over a distance of about one inch. Record each reading on paper. Now plot the Hall voltage versus distance.

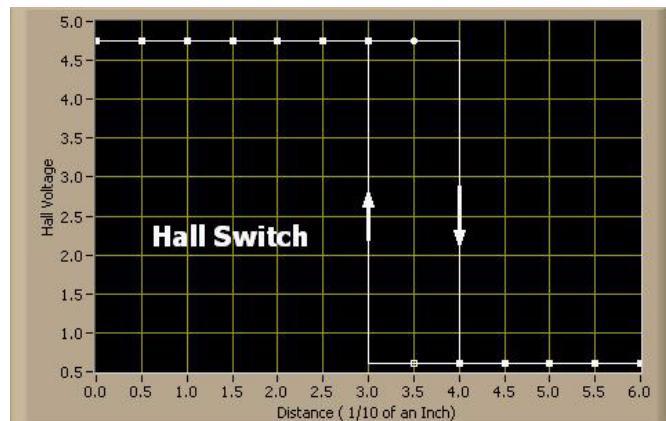


Your plot should be similar to the graph shown above. Notice that the response is quite nonlinear. This demonstrates the importance of knowing the operating distance between the sensor and the magnet.

End of Exercise 6-1

Exercise 6-2 Hysteresis Characteristic of a Magnetic Field Switch

Replace the linear sensor with the Hall Effect switch A3212. Power connections are the same as the linear circuit. Repeat the measurements for Hall voltage versus distance for both an increasing and a decreasing distance. Plot each graph on the same set of axes. It should look similar to the following graph.



The Hall switch is a digital sensor whose output is either HI ($\sim +5$ V) or LO (0.8 V). There exists a critical field B_{\max} above which the output is always HI and a critical field B_{\min} below which the output is LO. A graph of Hall Voltage versus range from sensor demonstrates hysteresis between the response of approaching the sensor and of leaving the sensor. The difference between the two limits:

$$h = B_{\max} - B_{\min}$$

is a measure of the noise immunity of the sensor. For example, if the sensor takes a particular field to switch from LO to HI, it then requires a much smaller field ($B_{\max} - h$) to switch to the opposite state HI to LO. Since we are using a fixed magnet, these critical fields can be translated from previous exercise into critical positions.

Close the Digital Multimeter.

End of Exercise 6-2

Exercise 6-3 Counting Pulses with a Magnetic Switch Sensor

Initially place the magnet far enough away from the sensor so it is in the LO state. Now let the South end of a magnet approaches the sensor. The magnetic field will eventually exceed B_{\max} and the logic state will toggle HI. Then as the magnet is pulled away and the magnetic becomes less than B_{\min} , it will switch back to the LO state. The entire sequence LO-HI-LO generates a positive pulse. Repeating this operation over and over generates a train of positive pulses.

From the NI ELVIS Instrument Launcher, select **Oscilloscope**. Connect the workstation front panel BNC connector (Channel A) to the output signal from the Hall Effect switch (pins 3 and 2).

On the oscilloscope panel, select:

Source: BNC/Board CH A

Trigger:

Level (V): 0.2 volts

Observe the Hall voltage on channel A as you rapidly move the magnet in and out from the sensor. With the oscilloscope trace on a long time base (100 ms/div), you should be able to observe the pulse train. Try it!

An angle shaft encoder, a tachometer, and a dwell sensor all use magnetic switches to generate pulses. Counting pulses accumulates events. Counting pulses within a select time interval measures frequency. Next, we will use a LabVIEW VI to count pulses generated by your sensor.

Close all SFPs and remove the voltage probe.

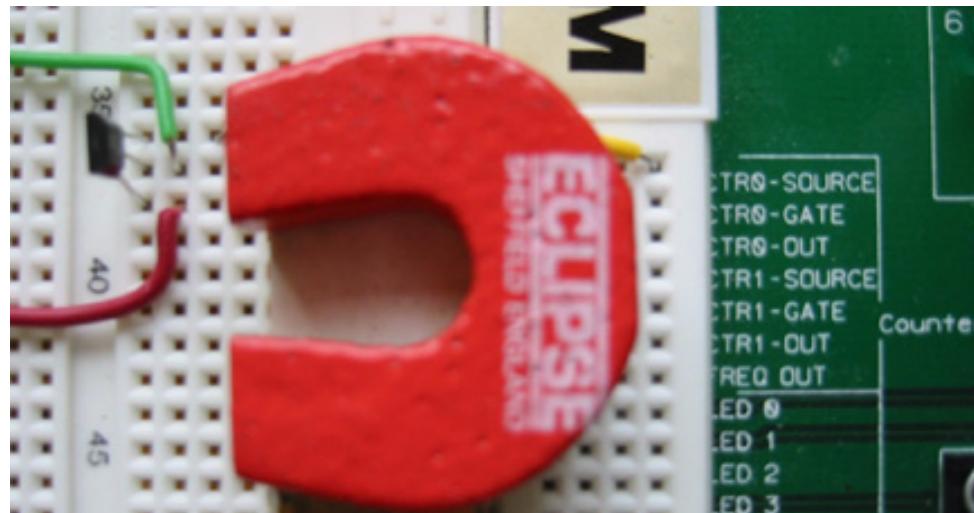
End of Exercise 6-3

Exercise 6-4 Automatic Counting using a LabVIEW Program

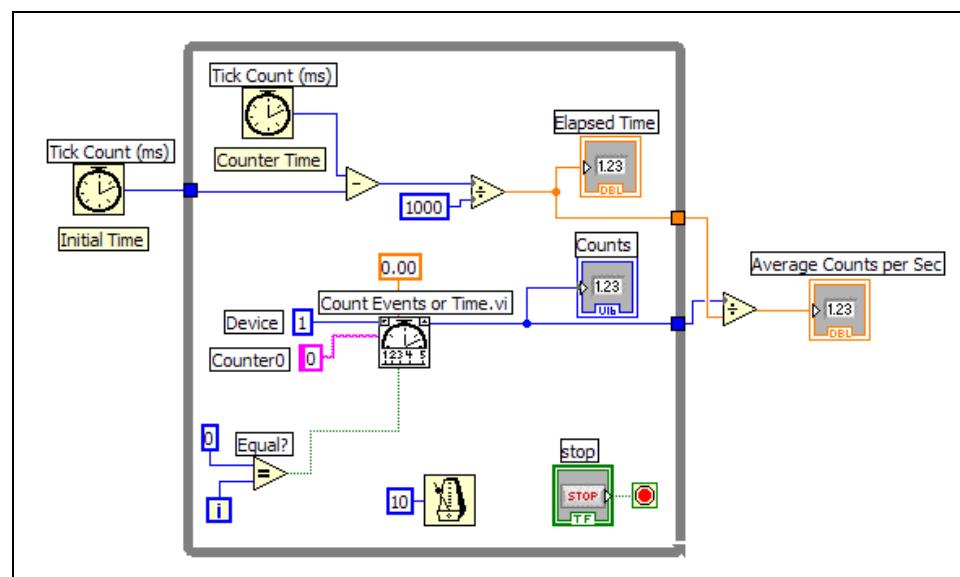
Connect the output of the Hall Effect switch to the NI ELVIS counter inputs:

Hall Output (pin 3) → CTRO_SOURCE

Hall Ground (pin1) → GROUND



Launch LabVIEW. From the Hands-On NI ELVIS Library, select Hall Counter.vi. This simple program allows one to accumulate counts as a magnetic field is passed in and out from the Hall effect switch. The program also allows one to start and stop the counting operation and at the same time keeping track of the count time. Dividing the accumulated counts by the Elapsed (count) time generates the average time per count or the frequency.



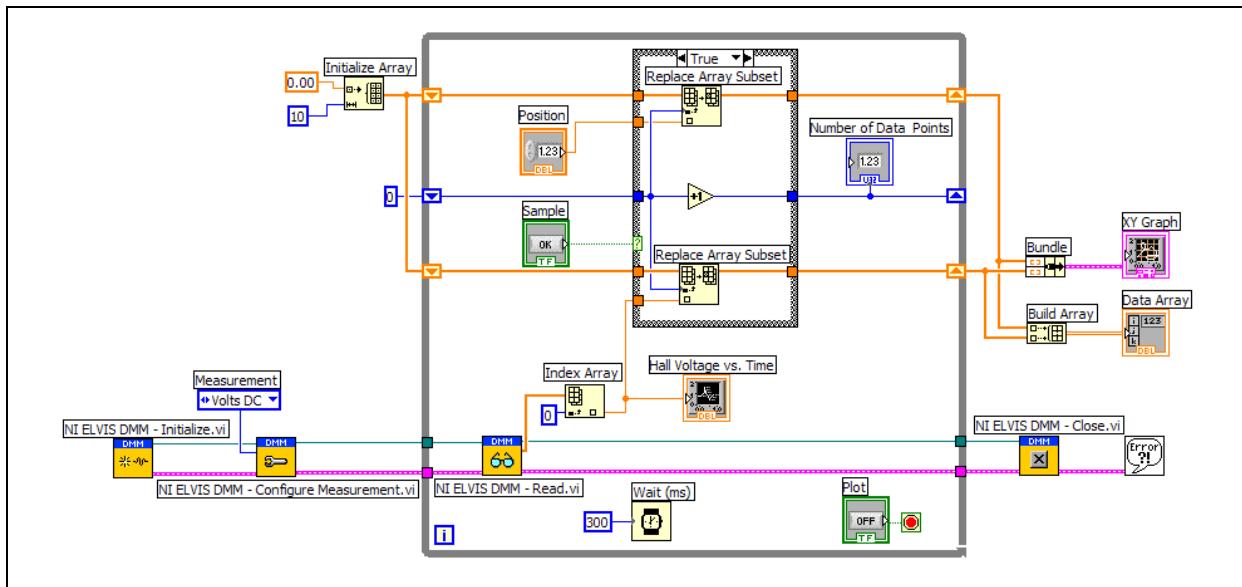
NI ELVIS has access to the DAQ card counters and this lab uses Device Number 1, Counter 0. Notice that the loop counter goes to the [Count Events or Time] subVI. This option ensures that the counter is reset to zero each time you run the program. Two [Tick Count] functions are used to measure the timing interval.

End of Exercise 6-4

What's Cool!

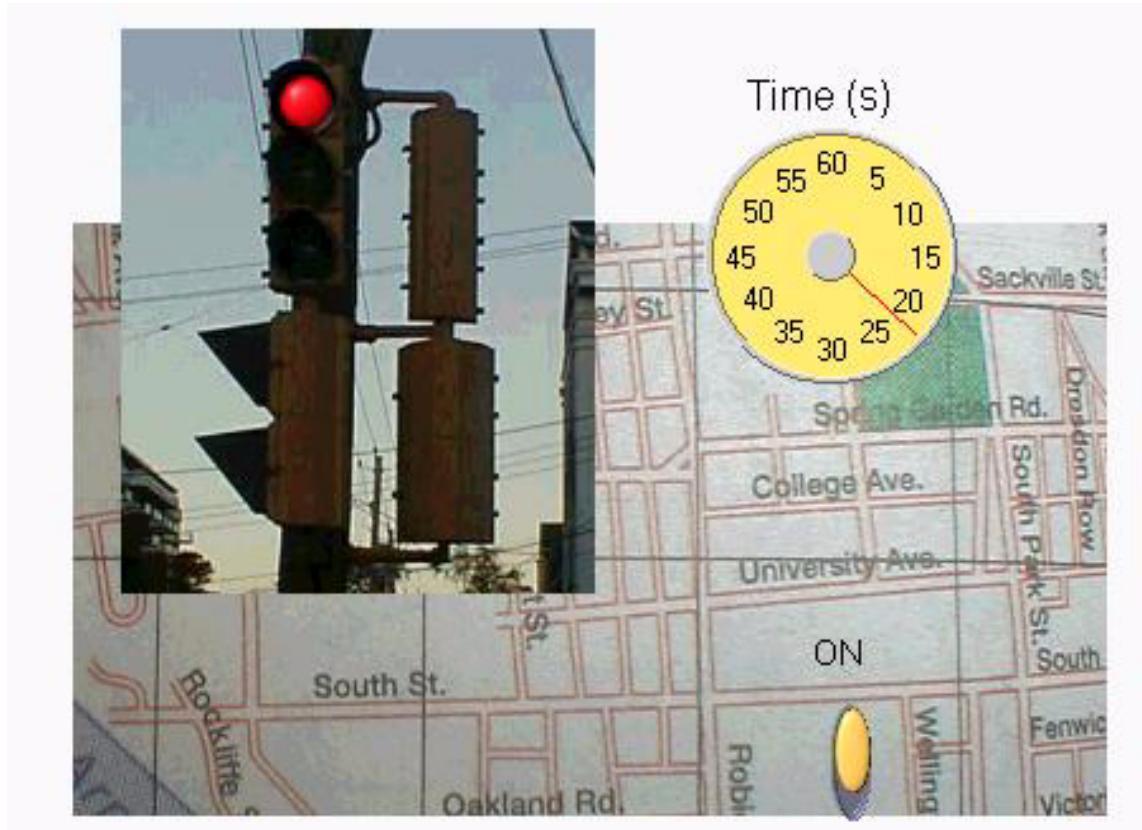
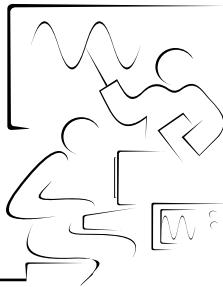
In an earlier exercise, you collected data by hand and then plotted a graph. However, using the NI ELVIS APIs for the digital voltmeter DMM[V] within LabVIEW, one can build a simple program to collect the Hall data “on-demand,” a semi-automated solution.

From the Hands-On NI ELVIS Library, select `Hall Sample.vi`. Place the magnet a known distance in front of the linear Hall sensor (A3240) and enter the end face position of the magnet in the Position box. Press the sample button when ready. This data point (Position, Hall Voltage) will be automatically entered into an array of sampled points. When you have finished sampling, press plot and the graph appears. Open up the diagram panel to see the program flow.



Lab 7

LEDs to the Rescue!



An electronic diode has the property that in one direction current flows easily (forward biased) while in the other direction current flow is blocked. This simple switching nature of diodes; an OFF state and an ON state, yields many interesting analog and digital circuits.

Goal

This lab focuses on using NI ELVIS to illuminate diode properties, diode test methods, bit patterns for a 2-way stop light intersection, and the use of NI ELVIS APIs in a LabVIEW program to run the stoplights automatically.

Soft Front Panels (SFP) Used in this Lab

Digital Diode tester DMM[►], Two Wire Current-Voltage Analyzer,
Digital Writer

Components Used in this Lab

A silicon diode and 6 light emitting diodes (2 Red, 2 Yellow, and 2 Green)

Exercise 7-1 Testing Diodes and Determining their Polarity

A semiconductor junction diode is a polar device with one end often labeled with a band that is called the cathode while the other lead is called the anode. While there are many ways to indicate this polarity in the packaging of a diode, one thing is always the same. A positive voltage applied to the anode will result in the diode being forward biased so that current can flow. We can use NI ELVIS to figure out the diode polarity.

Launch the NI ELVIS Instrument Launcher and select **DMM**.

Click on the [➤] button.

Connect one of the LEDs to the workstation leads DMM(current) HI and LO. When the diode blocks the current, the display will read the same value as it does when no diode is connected (open circuit). When the diode allows current to flow, the LED will give off light and the display will read a voltage level less than the open circuit value. Try a red LED in both directions. When you see light, the diode lead connected to the LO or Black banana jack is the anode.

You can use this simple test on other diodes to determine their polarity. For a silicon rectifying diode in the forward bias direction, the display will show a voltage less than 3.5 volts and display the word “Good.” In the reverse bias direction, the display will read the open circuit value (~ 3.5 volts) and display the word “Open.” Try it!

How does this work? The display shows the voltage required to generate a small current flow of about 1 ma. In the forward bias region, this voltage level is small and related to the materials used in the manufacture of the diode. In the reverse bias direction, no current flows and the tester displays the open circuit voltage, about 3.5 volts.

End of Exercise 7-1

Exercise 7-2 Characteristic Curve of a Diode

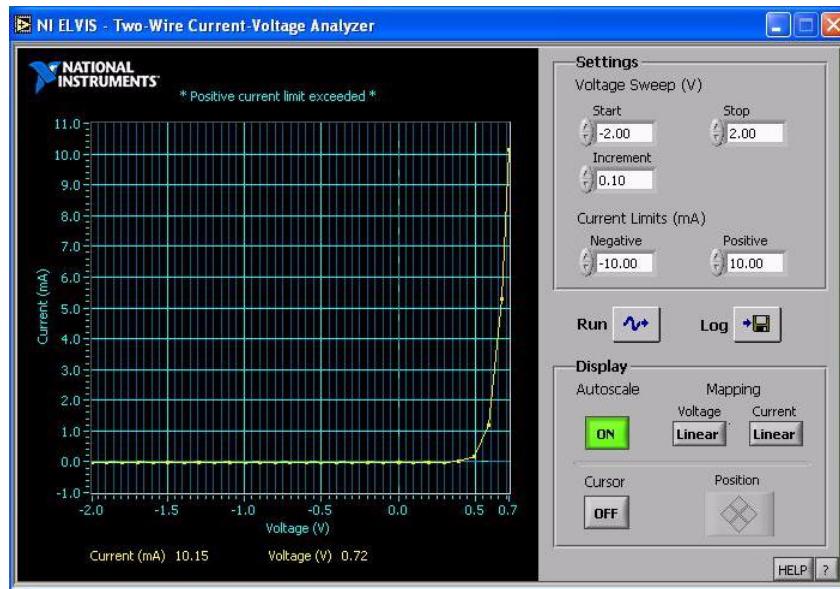
The characteristic curve of a diode, that is a plot of the current flowing through the device as a function of the voltage across the diode, best displays its electronic properties. Place the silicon diode across the DMM(current) leads. Make sure the anode is connected to the black banana input.

Launch the NI ELVIS Instrument Launcher and select **Two Wire Current-Voltage Analyzer**. A new SFP will pop up which allows one to display the (I -V) curve for the device under test. This SFP will apply a test voltage to the diode from a starting voltage level to an ending level in incremental voltage steps (all user selectable).

For a silicon diode, set the following parameters:

Start	-2 V
Stop	+2.0 V
Increment	0.1 V

Notice the maximum current in either direction can be set to ensure the diode does not operate in a current region where damage may occur. Click on **Run** and see the I-V curve appear.



In the reverse bias direction, the current should be very small (microamps) and negative. In the forward bias direction, you should see that above a threshold voltage the current rises exponentially to the maximum current limit. Try changing the **Display** buttons [Linear/Log] to see the curve

plotted on a different scale. Try the **Cursor** operation. It gives the (I,V) coordinate values as you drag the cursor along the trace.

It turns out that the threshold voltage is related to the semiconductor material of the diode. For silicon diodes, the threshold voltage is about 0.6 volts while for germanium diodes it is about 0.3 volts. One way to estimate the threshold voltage is to fit a tangent line in the forward bias region near the maximum current (refer to the following figure). The point where the tangent intersects, the voltage axis defines the threshold voltage.

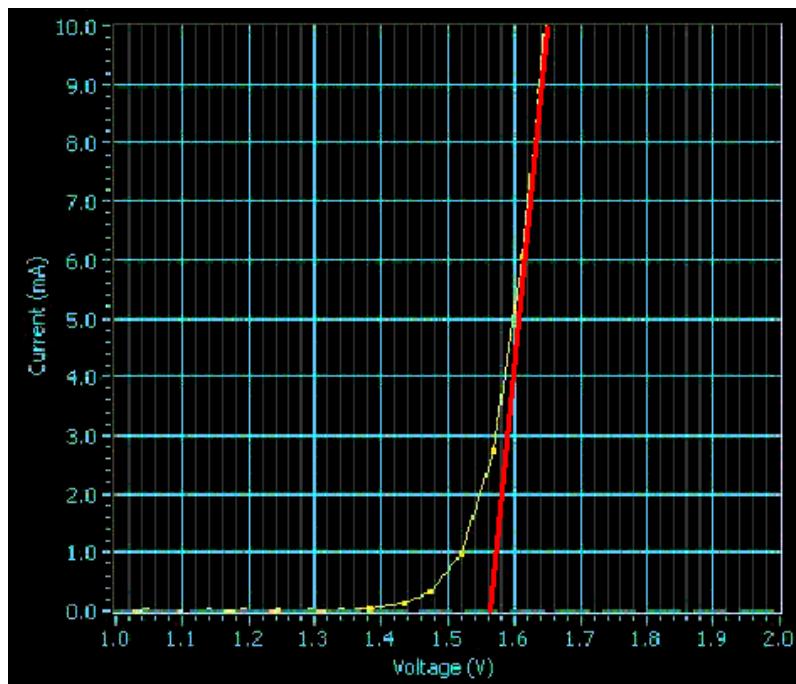


Figure 7-1. The (I,V) characteristic curve for a light emitting diode. The threshold Voltage V_T is given by the intersection of the tangent line with the voltage axis.

Using the **Two Wire Current-Voltage Analyzer** determine the threshold voltage for a red, a yellow and a green LED and fill in the following chart.

Red LED _____ V

Yellow LED _____ V

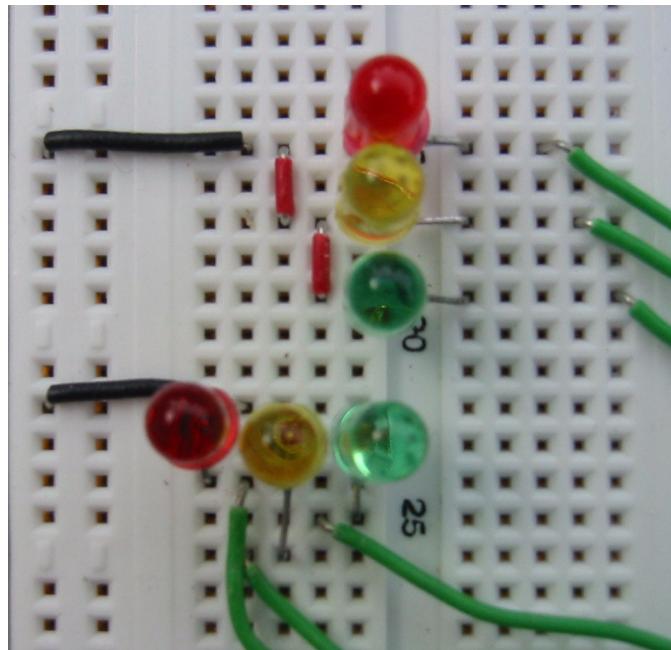
Green LED _____ V

Do you see any trend?

End of Exercise 7-2

Exercise 7-3 Manual Testing and Control of a 2-way Stoplight Intersection

Install six colored LEDs on the NI ELVIS protoboard positioned as a 2-way stoplight intersection.



Each LED will be controlled by one binary bit on the 8-bit parallel bus on the NI ELVIS protoboard. Output pin sockets are labeled Write <0–7>. Connect the pin socket Write <0> to the anode of the red LED in the North-South (Up-Down) direction. Connect the other end of the LED to digital ground. Connect the remaining colored LEDs in a similar fashion.

Here is the complete mapping scheme.

Write<0> Red	N-S direction	Write<4> Red	E-W direction
Write<1> Yellow	N-S direction	Write<5> Yellow	E-W direction
Write<2> Green	N-S direction	Write<6> Green	E-W direction

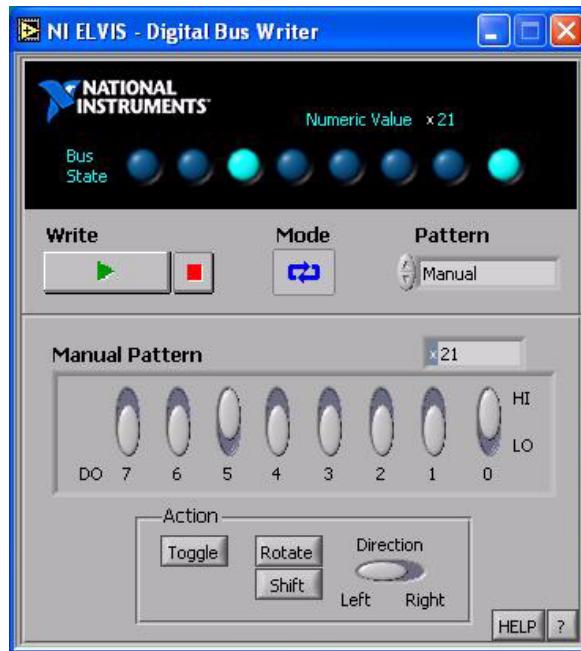
From the NI ELVIS Instrument Launcher, select **Digital Writer**.

Using the vertical slide switches, you can select any 8-bit pattern and output it to the NI ELVIS digital lines. Recall that Bit 0 is connected to the pin socket on the protoboard labeled Write<0> etc.

Set the **Mode** to **Continuous** and **Pattern** to **Manual** (as shown in the following figure).

To activate the port, click on the **Write** button.

When all switches (Bits 0–2 and 4–6) are HI, all the LEDs should turn on.
When all these switches are LO, all the LEDs should be off.



You can now use these switches to find out what 8-bit codes are necessary to control the various cycles of a stoplight intersection.

Here are some clues for our intersection. The basic operation of a stoplight is based on a 60 second time interval with 30 seconds for red, followed by 25 seconds for green followed by 5 seconds for yellow. For a 2-way intersection the yellow light, say in the North-South direction is on while the red light in the East-West direction is also on. This modifies the 30 second red timing interval to two timing intervals; a 25 second cycle followed by a 5 sec cycle. There are four timing periods (T1, T2, T3, and T4) for a 2-way intersection.

Study the following chart to see how a 2-way stoplight intersection works.

Direction		N-S	E-W	8-Bit Code	Numeric Value
Lights		RYG	RYG		
Bit #		0 1 2	4 5 6		
T1	25 s	0 0 1	1 0 0	00010100	20
T2	5 s	0 1 0	1 0 0		
T3	25 s	1 0 0	0 0 1		
T4	5 s	1 0 0	0 1 0		

Use the Digital Writer to figure out what 8-bit code needs to be written to the digital port to control the stop lights in each of the 4 timing intervals.

For example: Timing period 1 requires the code[00101000]. Computers read the bits in the reverse order (least significant bit on the right). The above code then becomes {00010100}. In the box above, the DO switches for NI ELVIS Digital Bus Writer, you can read the radix of the switch pattern in binary {00010100}, decimal {20}, or hexadecimal {14}. Click on the white X in a gray background to change the radix. You can use this feature to determine the numeric codes for the other timing intervals T2, T3, and T4. Now if you output the 8-bit code for each of the timing intervals in sequence, you can manually operate the stoplights.

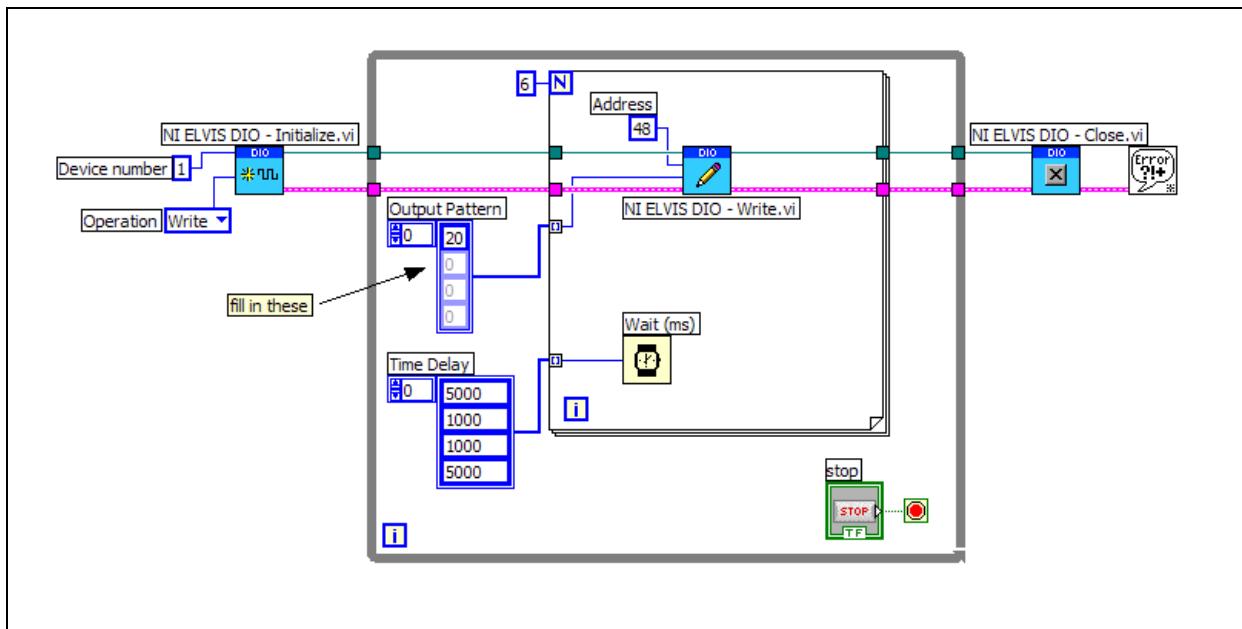
Repeating this four cycle sequence brings automation to our intersection.

End of Exercise 7-3

Exercise 7-4 Automatic Operation of the 2-way Stoplight Intersection

Close NI ELVIS and launch LabVIEW. Open the program, StopLights.vi. On the Front Panel is only one control, a Boolean switch used to stop the operation of the stoplights. Switch to the Block Diagram (**Window»Show Block Diagram**). Observe the 4 cycle sequence generated by the For-Loop. The subVI with the pencil (NI ELVIS DIO-Write) is the structure that outputs the 8-bit code to the stoplights. This subVI expects the code input to be a numeric number. For example, the first timing interval T1 requires the code 20 (twenty numeric). The four 8-bit codes (numeric value) need to be transferred from your table above into the four blank elements of the code array (blue) labeled Output Pattern.

The NI ELVIS DIO – Initialize subVI on the left requires the digital port number (1) and the IO operation (Write). Like all NI ELVIS programming structures, the DIO channel needs to be closed by the subVI DIO[X] on the right after completion (While Loop is stopped).



The timing intervals are stored in the four elements of the Time Delay array (orange). To speed up operation, the 25 sec time interval is reduced to 5 seconds and the 5 sec time interval is reduced to 1 second.

End of Exercise 7-4

What's Cool!

LEDs are amazing devices. If you multiply the Threshold Voltage, V_T times the electronic charge e , the product is energy and it is close to the band gap energy of the semiconductor material used in the manufacture of the semiconductor diode. Further, in the forward biased region, the light from the LED has an energy of hc/λ where h is Planck's constant, c is the speed of light, and λ is the wavelength of the center of the energy distribution. Conservation of energy yields the equation:

$$eV_T \sim hc/\lambda$$

where e is the electron charge.

From the LED specifications, you can determine the wavelength or colour of the LED. For example, red LEDs have a wavelength of about 560 nanometers. From the I-V characteristic curve of the LED (refer to Exercise 7-2), you can measure the threshold voltage V_T . If you plot V_T versus $1/\lambda$ for the three different coloured LEDs, you will find a straight line with a slope approximately equal to hc/e , a fundamental constant.

Lab 8

Free Space Optical Communication

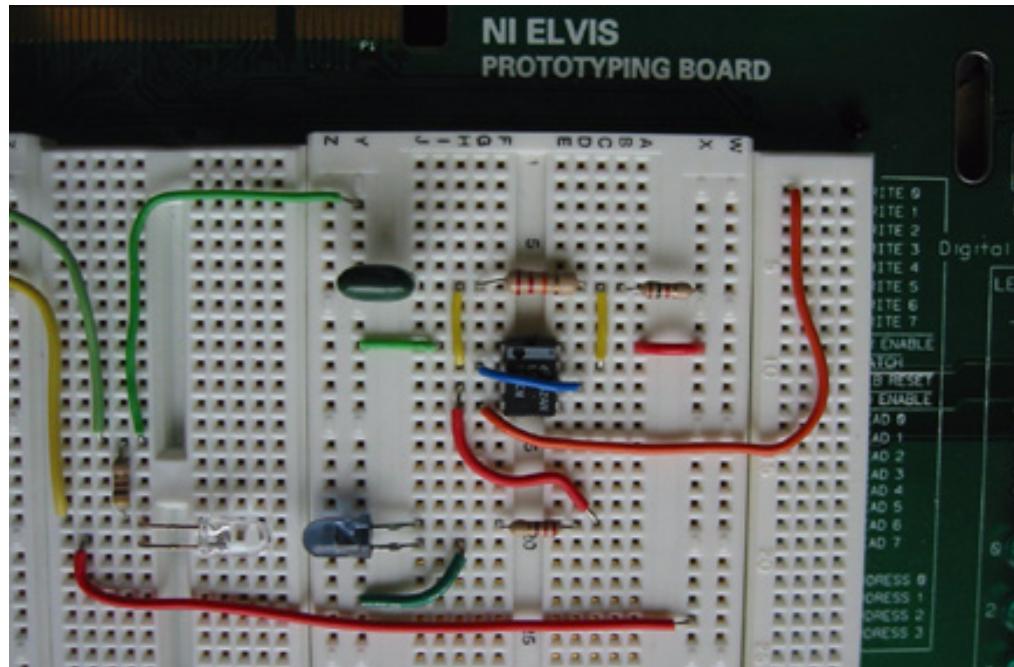
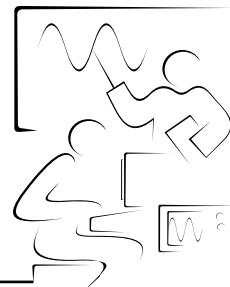


Figure 8-1. Free Space Infrared Optical Digital Communications Link

We are all familiar with the bevy of remote controllers lying around the house controlling TVs, Stereos, DVDs, etc. How do they work? The secret is an infrared optical data link, a type of free space optical communication link.

Goal

This lab uses an infrared optical source to communicate information over free space to a phototransistor detector. Several modulation schemes including amplitude modulation and Non-Return-Zero (NRZ) digital modulation are featured.

Soft Front Panels (SFP) Used in this Lab

Two Wire I-V Analyzer, Three-wire I-V Curve Tracer, Function Generator, Oscilloscope and Digital Writer

Components Used in this Lab

220 Ω resistor (Red, Red, Brown)

470 Ω resistor (Yellow, Violet, Brown)

1 k Ω resistor (Brown, Black, Red)

22 k Ω resistor (Red, Red, Orange)

0.01 μ F capacitor

IR Emitter (LED)

IR Detector (photoresistor)¹

2N3904 npn transistor

555 Timer chip

¹. Available at www.radioshack.com RS276-142 IR Emitter and Detector pair.

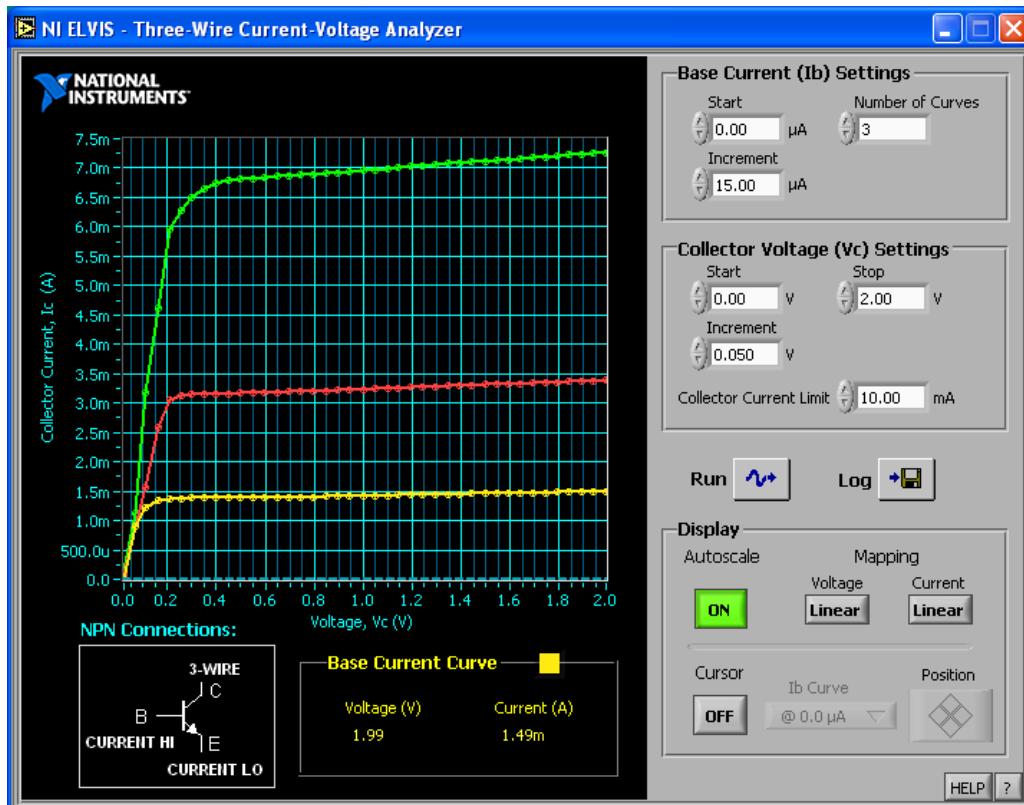
Exercise 8-1 A Phototransistor Detector

Understanding how a phototransistor works starts with understanding transistor characteristic curves. A transistor is basically a current controlled current amplifier. A small base current controls the current flowing through the transistor from the collector to the emitter. Insert a 2N3904 transistor on NI ELVIS protoboard into the pin sockets labeled Current +, Current -, and 3-wire as shown below.



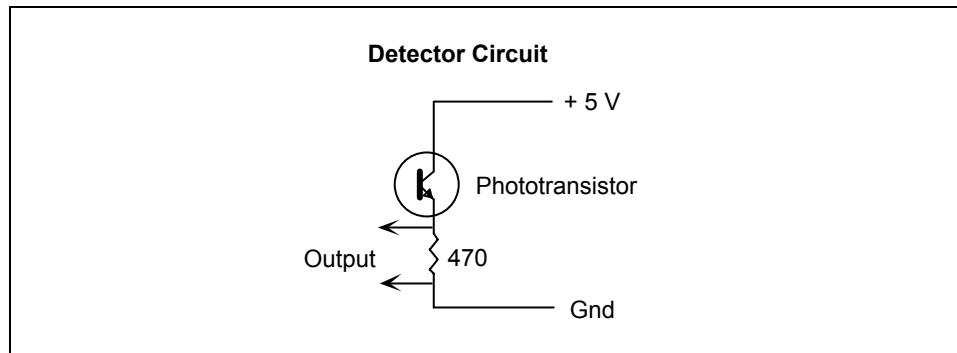
Note Current + → Base, Current - → Emitter, and 3-Wire → Collector leads.

Launch the NI ELVIS Instrument Launcher and select **Three-Wire Current-Voltage Analyzer**. Power up the protoboard. Set the Base Current and Collector Voltage as shown below and click **Run**.



The graph displays the Collector Current versus Collector Voltage for different values of the base current. Notice that one can set many parameters for the Collector Voltage and the Base Current ranges. When run, this SFP first outputs the set base current, second outputs the collector voltage, and then measures the collector current. Data points (I, V) are plotted and sequential points with the same base current connected with a line. You can see the curves developed on the fly, resulting in a family of [IV] curves each with a different base current. Observe that for a given collector voltage, the collector current increases with an increase in base current.

A phototransistor has no Base lead. Instead light falling on the transistor generates a base current proportional to the light intensity. For example, with no light, the transistor follows the bottom (yellow) curve. A low light level follows the middle (red) curve and a higher light intensity generates the upper (green) curve. For Collector voltages greater than say 0.2 volts say at 1.0 volts, the collector current follows the light intensity falling on the base region in an almost linear fashion. To build an optical detector, all that is needed is a power supply, a current limiting resistor and a phototransistor.



Close any SFPs.

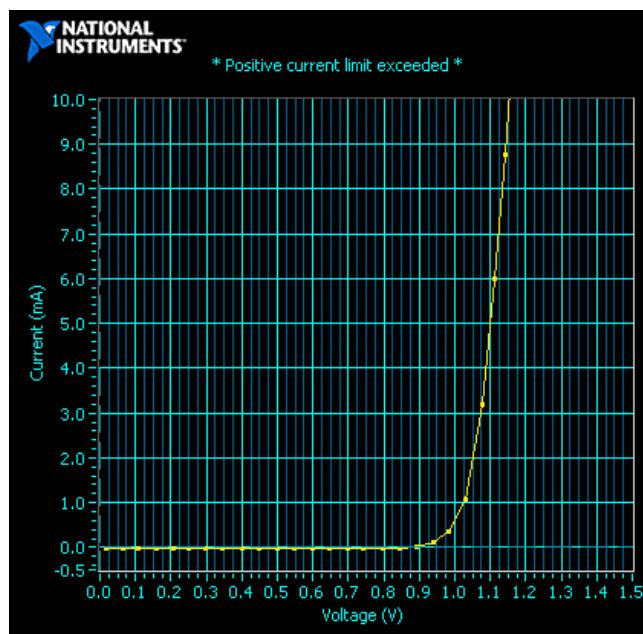
End of Exercise 8-1

Exercise 8-2 Infrared Red Optical Source

The optical transmitter is made up of just two components: an IR LED (forward biased) and a current limiting resistor. Connect the IR LED to the DMM current inputs. Make sure the black lead is connected to the LED anode (short lead). Select the **Two-Wire Current-Voltage Analyzer**, set voltage sweep parameters to:

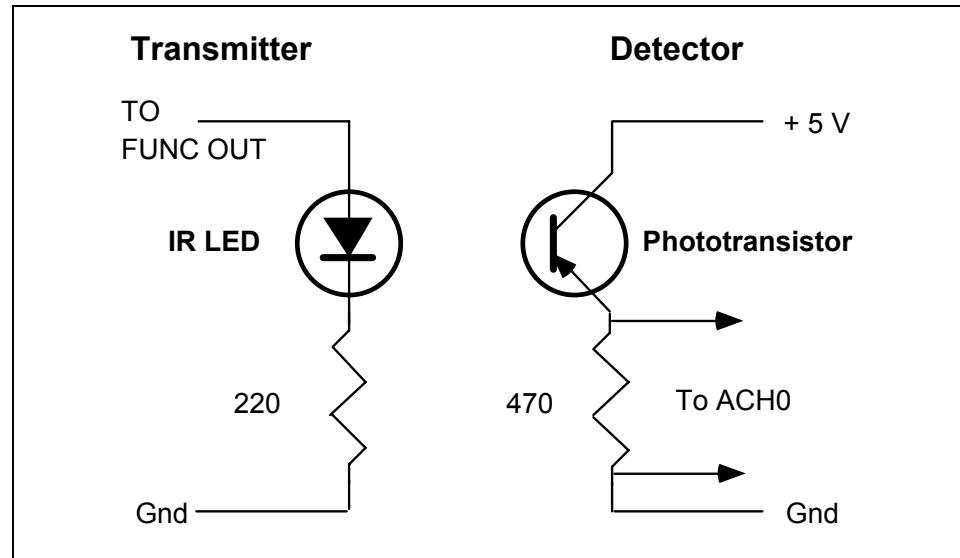
Start	0.0 V
Stop	+2.0 V
Increment	0.05 V

and press **Run**. The [IV] curve for the infrared diode is developed and displayed.

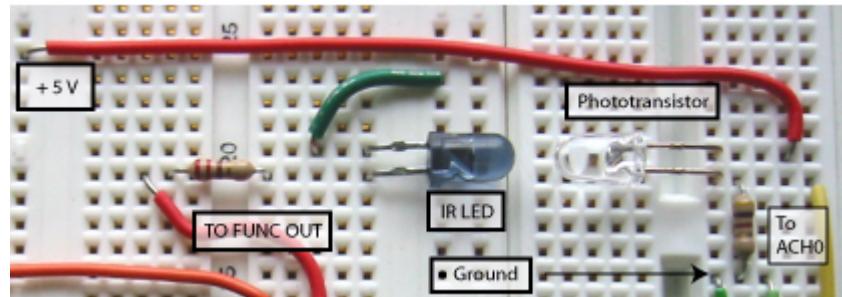


In the forward bias region, the IR LED emits light for voltages greater than about 0.9 volts. Light is emitted at a wavelength of 950 nm, outside the spectral range of our eyesight and in the near Infrared region. The LED specs tell us that the maximum allowed current is over 100 mA, making IR LEDs about 10 times brighter than normal visible LEDs. This is what gives the remote controllers so much range. Connecting the LED in series with a $220\ \Omega$ resistor and a +5 V power supply produces a current of about 11 mA yielding about 10 mW of invisible optical power. It will take a special detector like our phototransistor to see it.

Build the LED transmitter circuit and the phototransistor circuit on the protoboard, as shown below.



Connect the LED power source to the output of the function generator. Connect the output of the phototransistor to ACH (1) pin sockets. Taken together, these circuits form a simple optical data link. A picture of this circuit on NI ELVIS protoboard follows:



Close any SFPs.

End of Exercise 8-2

Exercise 8-3 Free Space IR Optical Link (Analog)

From the NI ELVIS Instrument Launcher, select **Function Generator** and **Oscilloscope**. The function generator will provide the analog signal to be transmitted. The oscilloscope will monitor the input signal CH A (Select FUNC_OUT) and the output signal CH B (Select ACH0).

In order to transmit an analog signal on the LED, it is necessary to bias the LED into the “linear” region with a voltage greater than the critical voltage. Make sure the function generator is *not* set for Manual mode on the front panel workstation. On the FGEN virtual control panel, set the offset voltage to +1.5 volts.

Set the following parameters on the FGEN SFP:

Amplitude	0.5 volts
Waveform	Sine
Frequency	1 kHz

Run the function generator and oscilloscope to observe the transmitted and received signals. Play with the offset voltage and amplitude levels. When the received sine wave starts to distort, the transmitter becomes nonlinear. Find the best values of offset and amplitude for a linear (no distortion) transmission link. Your link is now ready to send data.

Leave the function generator and oscilloscope SFPs open.

End of Exercise 8-3

Exercise 8-4 Amplitude and Frequency Modulation (Analog)

Wire the digital-to-analog output pin sockets DAC0 and DAC1 to the function generator pin sockets on NI ELVIS protoboard labeled [AM IN] Amplitude Modulation and [FM IN] Frequency Modulation, respectively. Launch LabVIEW. Select `Modulation.vi` from the Hand's-On NI ELVIS Library. This program sends DC signals from NI ELVIS DAC output to the function generator to produce an amplitude or frequency modulated signal. The modulated signal is converted to light pulses, sent across our free space link and then detected on the phototransistor and converted back into an electrical signal. You have just built an elementary free space optical communication link for analog signals.

Close any SFPs and LabVIEW.

End of Exercise 8-4

What's Cool!

NRZ Digital Modulation

IR remote controllers use a special encoding scheme called NRZ. A HI level is signaled by a tone burst of 40 KHz square waves while a LO level is signal by the absence of any signal. The tone burst is generated using the 555 Timer circuit shown below. A digital switch is connected to pin 4 [RESET], so when the switch is HI, a tone burst is generated, when LO no oscillations occur.

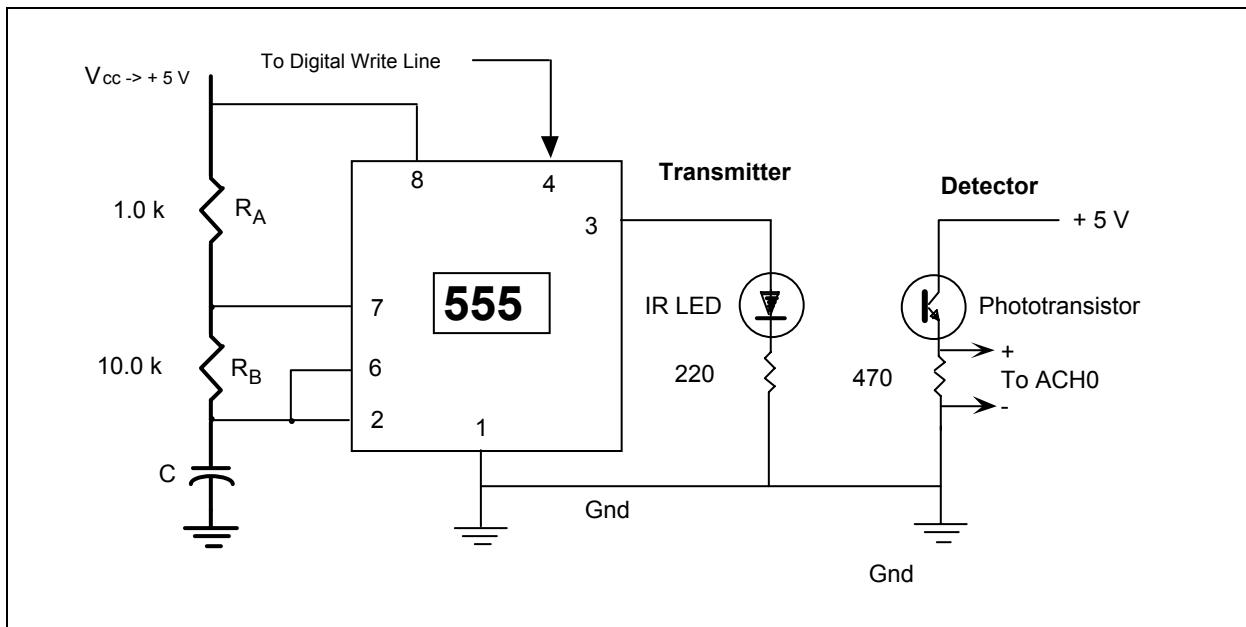
To demonstrate the modulation scheme, we will uses a 1.0 k Hz tone burst so it is easier to see on the oscilloscope.

Build a gated oscillator using a 555 Timer chip and the following components:

$$R_A \rightarrow 1.0 \text{ k}\Omega$$

$$R_B \rightarrow 10.0 \text{ k}\Omega$$

$$C \rightarrow 0.1 \mu\text{F}$$



Pin 4 on the 555 Timer chip goes to the digital line Write <0> output parallel port on the NI ELVIS protoboard. The oscillator output pin 3 becomes the IR LED transmitter power source. The output of the detector circuit is connected to ACH0 pin sockets. Ground is pin 1 of the 555 Timer chip.

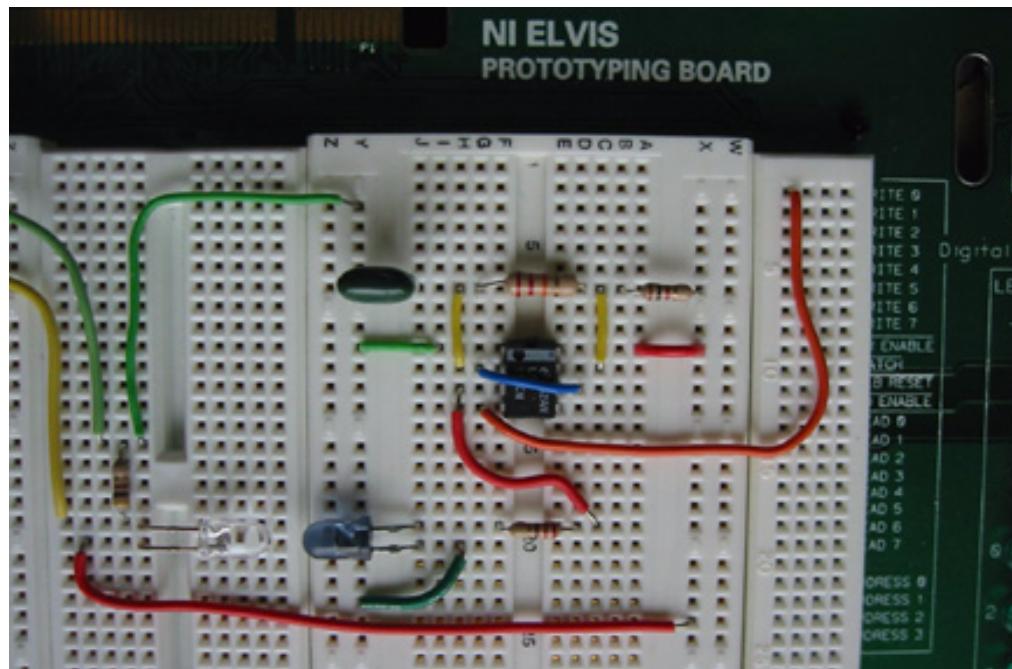
From the NI ELVIS Instrument Launcher, select the **Oscilloscope** and **Digital Writer**.

For the oscilloscope, select Channel A Source as ACH0. Use the Channel A analog trigger with a trigger level at 0.5 volts.

In operation, everytime you set Bit 0 (Write <0>) of the Digital Writer to **HI**, a 1.0 kHz signal will appear on the oscilloscope. No signal is presented when Bit 0 is **LO**.

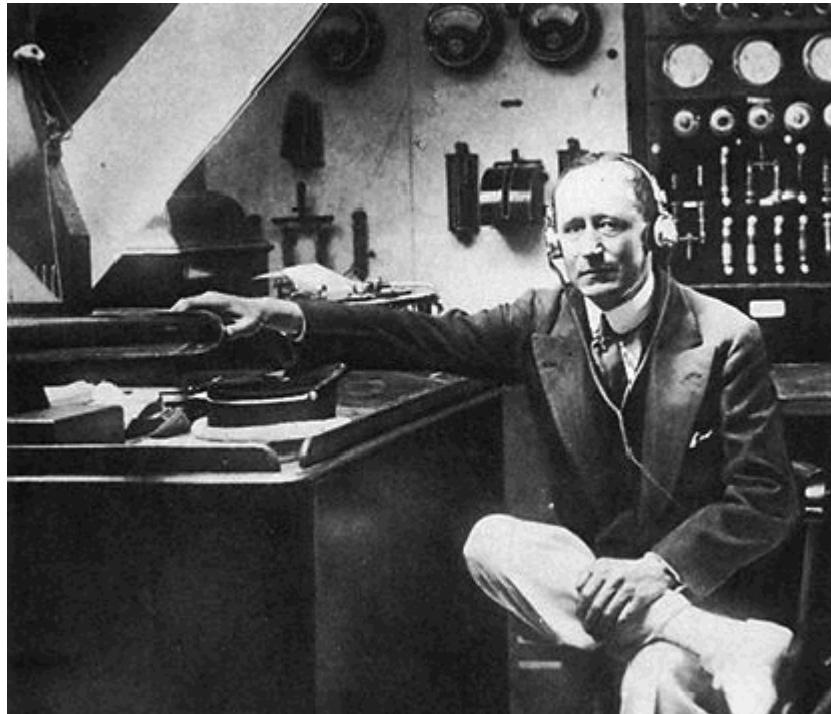
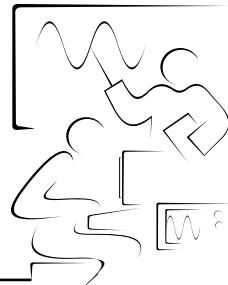
Try some of the other digital patterns like Walking 1's or Ramp and view the modulation scheme on the Oscilloscope panel.

In remote controllers, the encoding scheme is slightly more complicated. If you are interested in building your own computer controlled IR Remote transmitter to control your own stereo, etc., check out Chapter 6, *Sensors, Transducers and LabVIEW*, for more details.



Lab 9

RF Wireless Communication



Midday at Signal Hill, St. John's Newfoundland in Canada, Guglielmo Marconi pressed his ear to a telephone head set connected to an experimental wireless receiver. 1700 miles away at Poldu Cornwall, in England, his co-workers were about to send the Morse code letter "S" three dots. Faintly but clearly "psht-psht-psht" pause "psht-psht-psht" came through the earphone. The date was December 12, 1901 and the first Trans-Atlantic message has just been sent and received.

Goal

In this lab, a paper clip antenna is used to send this classic message and much more over a wireless Radio Frequency link. The NI ELVIS function generator is the transmitter and a high gain Op Amp is used for the receiver. The classic message is formulated using the NI ELVIS arbitrary waveform generator.

Soft Front Panels (SFP) Used in this Lab

Oscilloscope (OSC) and Arbitrary Waveform Generator (ARB)

Components Used in this Lab

1 1 k Ω resistor (Brown, Black, Red)

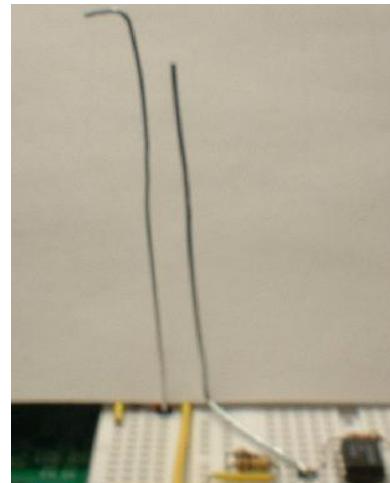
2 100 k Ω resistor (Brown, Black, Yellow)

741 Op Amp or FET Op Amp 753

Paper clip

Exercise 9-1 The Transmitter

A paper clip is straightened and cut into a piece about 2.5 inches long. One end is pushed into the output pin socket of the function generator. When FGEN is Run, the output voltage leaks out the pin socket to the paper clip antenna and radiates a small RF signal. A similar antenna about a centimeter away can pick up this signal and amplify it to a higher signal level.



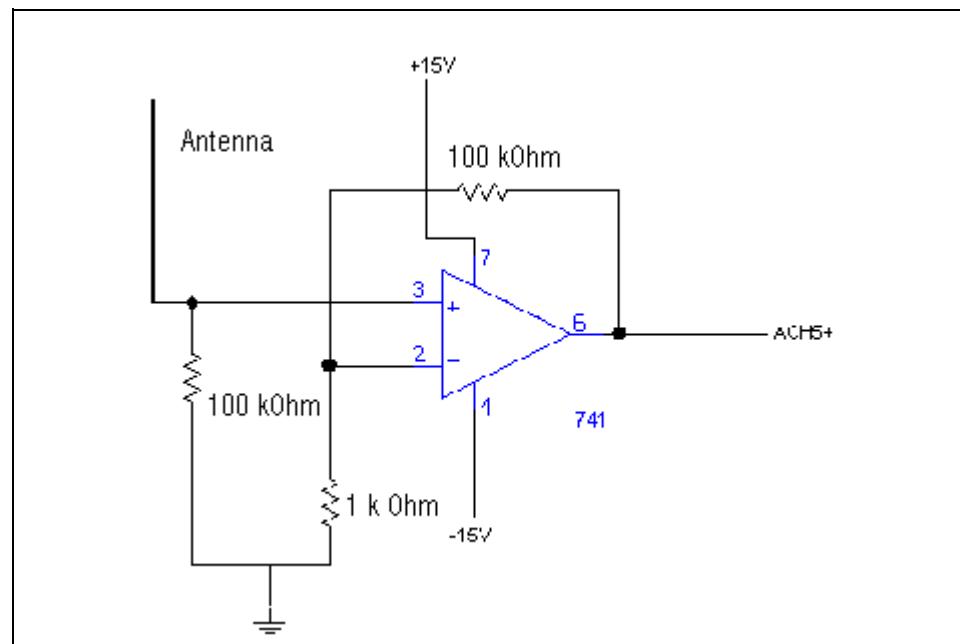
Initially, we will use a sine wave to test the transmitter. Set the function generator to sine waveform, 5 volts amplitude and 10 kHz frequency. Build a simple antenna from a paper clip.

End of Exercise 9-1

Exercise 9-2 The Receiver

A second paper clip is bent into step shape with the long side about 2.5 inches long, the step height about 1/4 inch and the step width about 1/2 inch. The short end is inserted into a pin socket. The mid-section supports the antenna on the protoboard and allows one to rotate the antenna about the short end. The long side sits vertical and is parallel to the transmitter antenna (see diagram above).

A high gain amplifier is built using a 741 Op Amp or 753 FET Op Amp in the simple inverting configuration.



Tie the $1\text{ k}\Omega$ resistor to the – input (pin 2) and tie a $100\text{ k}\Omega$ bias resistor for the + input (pin 3) with the other end connected to Ground. Use the other $100\text{ k}\Omega$ resistor for the feedback resistor R_f . Power is +15 V on pin 7 and -15 V on pin 4. Nominally the Op Amp has a gain of 100. Other resistor combinations can be used for higher gains. The receiver antenna is connected to the input (pin 3). The Op Amp output pin 6 will be connected to the oscilloscope. Build this circuit on NI ELVIS protoboard.

End of Exercise 9-2

Exercise 9-3 Testing the RF Transmitter and Receiver

A sine wave signal is used to test the transmitter-receiver pair. Check your wiring, then power up the protoboard. Move the receiver antenna a few millimeters from the transmitter antenna. Connect the oscilloscope workstation BNC Channel A inputs to the Op Amp output, Pin 6, and ground. Typical oscilloscope settings are:

Channel A BNC/Board
Trigger Settings FUNC_SYNC

Increase the oscilloscope gain until you see a sine wave. If you can not see a signal right away, touch the two antenna tips with your finger tip. This will simulate the high impedance of the atmosphere and allow a small signal to propagate. Now tinker with the FGEN amplitude and frequency until you get a good signal. Measure the signal level as you separate the receiver antenna from the transmitter antenna. The separation can easily be measured with a ruler. You can quickly get an idea of how rapidly the signal level falls off with distance. A long antenna helps and Marconi, at Signal Hill, used a kite to carry his antenna hundreds of feet up into the atmosphere.

Now that the transmitter-receiver is working, it is time to duplicate Marconi's classic message.

End of Exercise 9-3

Exercise 9-4 Marconi's First Trans-Atlantic Signal

Marconi's first RF transmitter consisted of a spark gap connected to a resonant circuit and a very long antenna often carried high on a balloon or kite. When a spark discharged between the electrodes, an intense RF pulse is generated with a short time duration of a few milliseconds. Recall that it takes 30,000 volts to produce a spark between electrodes separated by 1 centimeter and the current can be large. A single spark followed by a pause was a dot. A longer spark followed by a pause was a dash. Together this was all the ingredients needed for Morse code transmission. The letter "S" is just three dots in rapid succession. The letter "O" is just three dashes in rapid succession. The distress call S-O-S (Save Our Souls) is just:

dot-dot-dot dash-dash-dash dot-dot-dot

For the first Trans-Atlantic message, Marconi chose the simpler signal dot-dot-dot.

End of Exercise 9-4

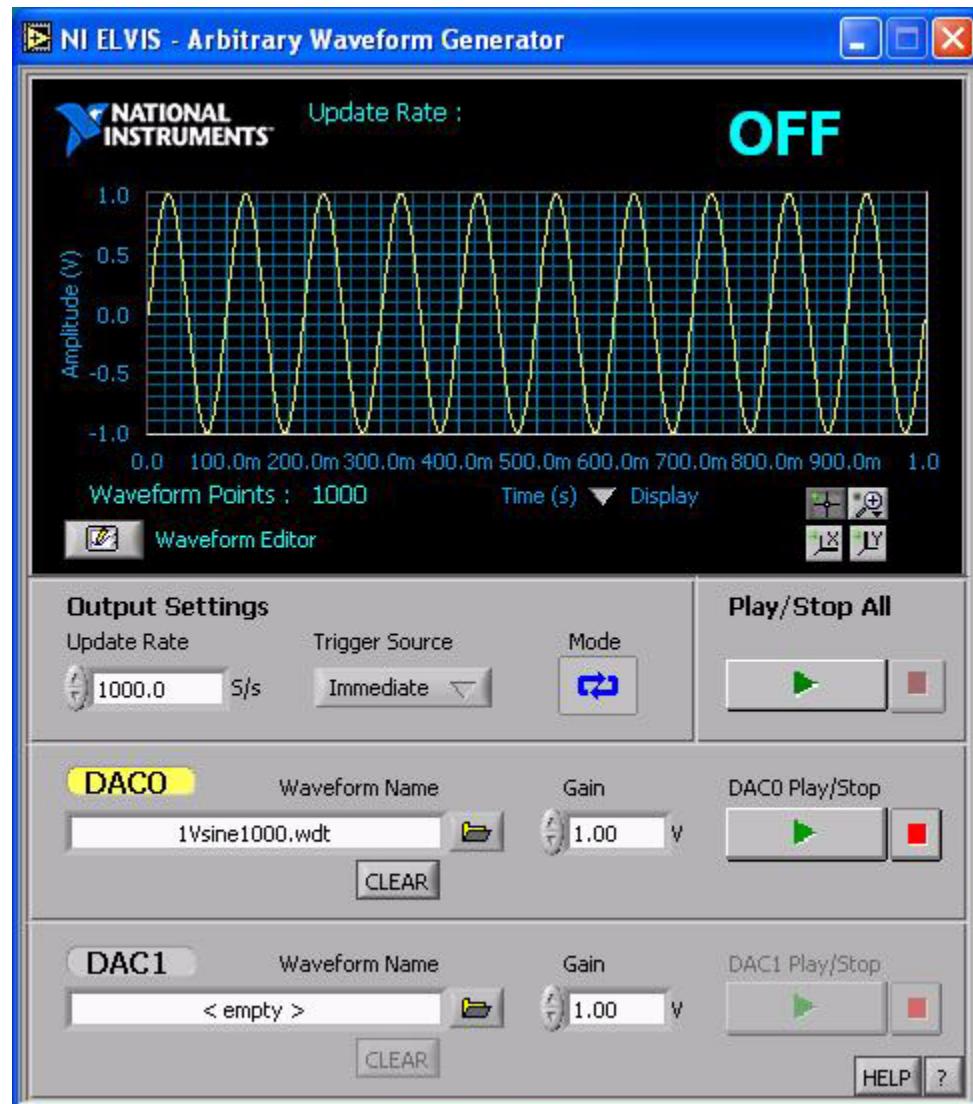
Exercise 9-5 Building a Unique Test Signal with the Arbitrary Waveform Analyzer

A dot is a signal usually an oscillation, followed by silence (no signal). Each part lasts for about 1/10th of a second. A dash is just a signal lasting for the duration of three dots, or 3/10^{ths} of a second, followed by a pause. The encoding scheme is a simple tone burst with different duration times. The letter “S” is encoded as dot-dot-dot or in binary 101010 where 1 is the dot and 0 is the pause. A longer message consisting of multiple letters like “SSS” has a longer pause (4/10 of a second) placed between each letter. This message in binary is:

101010 0000 101010 0000 101010 0000

If we can generate this waveform on the NI ELVIS Digital to Analog Converter (DAC), then the DAC output can be used to gate the function generator. The resulting tone burst signal from the FGEN can radiate our message to the world.

From the NI ELVIS Instrument Launcher, select **Arbitrary Waveform**. The arbitrary waveform generators allows one to create unique waveforms such as Marconi’s first message. A special program called the Waveform editor can be used to create all kinds of unique diagnostic and control waveforms. Clicking on the Waveform Editor button links you to this program.

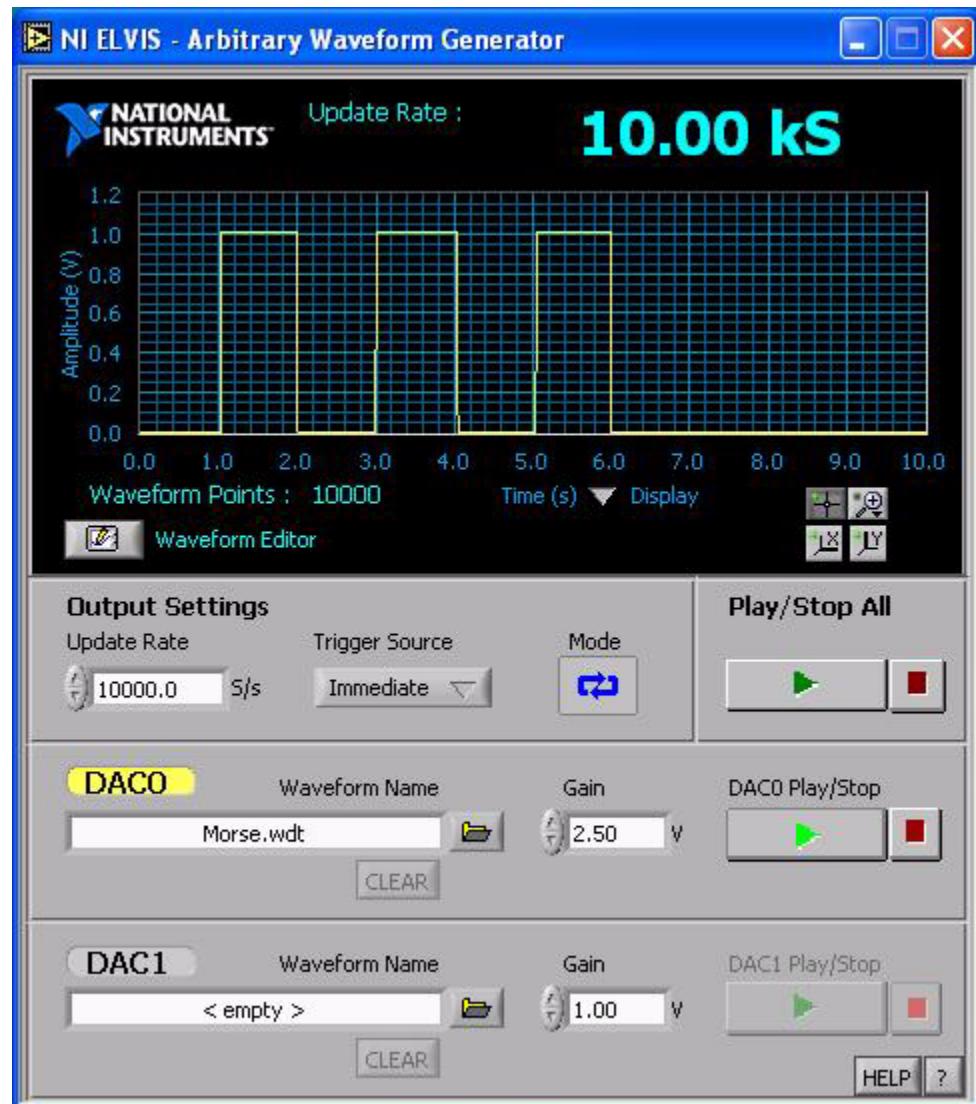


The SFP {Arbitrary Waveform} provides waveform control over the DAC0 and DAC1 outputs. Click on the browse icon next to the DAC0 Waveform Name box. From the waveform menu, select `1VSine1000.wdt` file. When you click on the DAC0 play button, a 1.0 V amplitude sine wave at 1000 Hz will be applied to the DAC0 pin socket. Connect the oscilloscope Channel A input to the DAC0 pin socket. When DAC0 [Play/Stop] button is pressed, observe a 1 kHz sine wave signal on the oscilloscope window.



Note For a steady signal trace, trigger on Channel A.

Return to the DAC0 browse icon and navigate to the Hands-On NI ELVIS Library and select the file `Morse.wdt`. This file provides the waveform for the letter "S" in Morse code. Click **Play** and observe this signal on the oscilloscope.

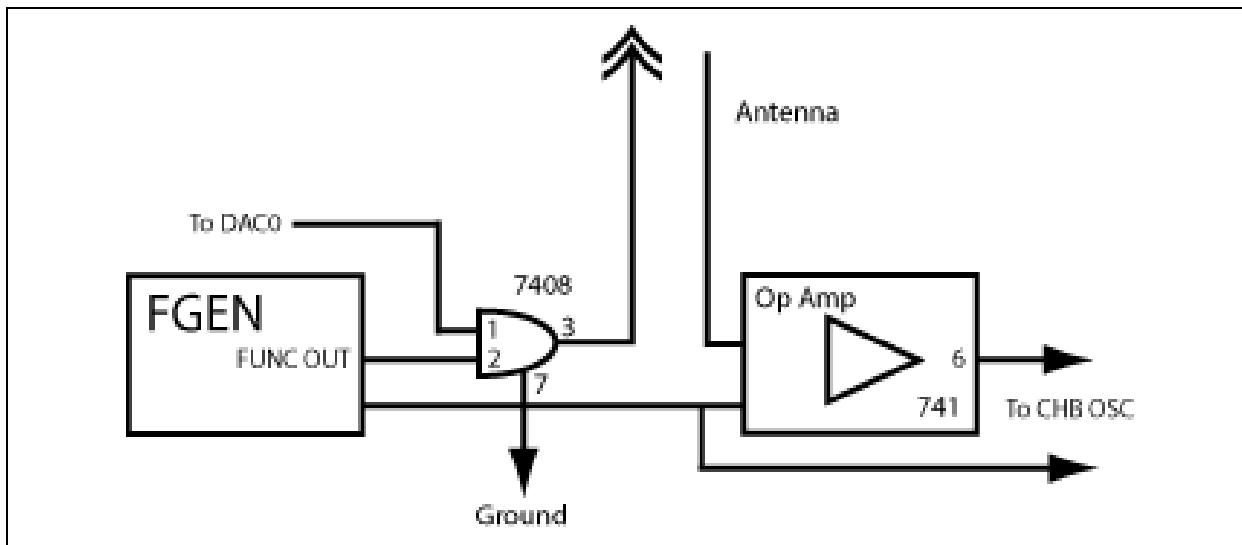


For the real transmission, you will need to change the Update Rate box to 10000.00 S/s.

End of Exercise 9-5

Exercise 9-6 A Demonstration of Marconi's RF Transmission Signal

To complete our transmitter station, install a 7408 (quad 2-input AND) digital IC to the protoboard. Power (+5V) is pin 14 and Ground is pin 7. Connect the DAC0 output pin socket on NI ELVIS protoboard to pin 1 of the 7408 IC. Connect the FGEN output to pin 2 of the 7408 IC. The transmitter now pin 3 of the 7408 IC is connected to the paper clip transmitter antenna.



Now configure the SFP function generator for TTL output levels.

Select	Amplitude	→	2.2 V
	Offset	→	2.5 V
	Waveform	→	Square
	Frequency	→	1 kHz

You can observe the transmitted and received signals on the oscilloscope,

Channel A goes to pin 3 of the 7408 chip (the transmitter signal)

and Channel B goes to pin 6 of the Op Amp (the receiver signal).

Trigger on Channel A

You should be able to see the transmitted message "S" on Channel A and the received signal on Channel B.

End of Exercise 9-6

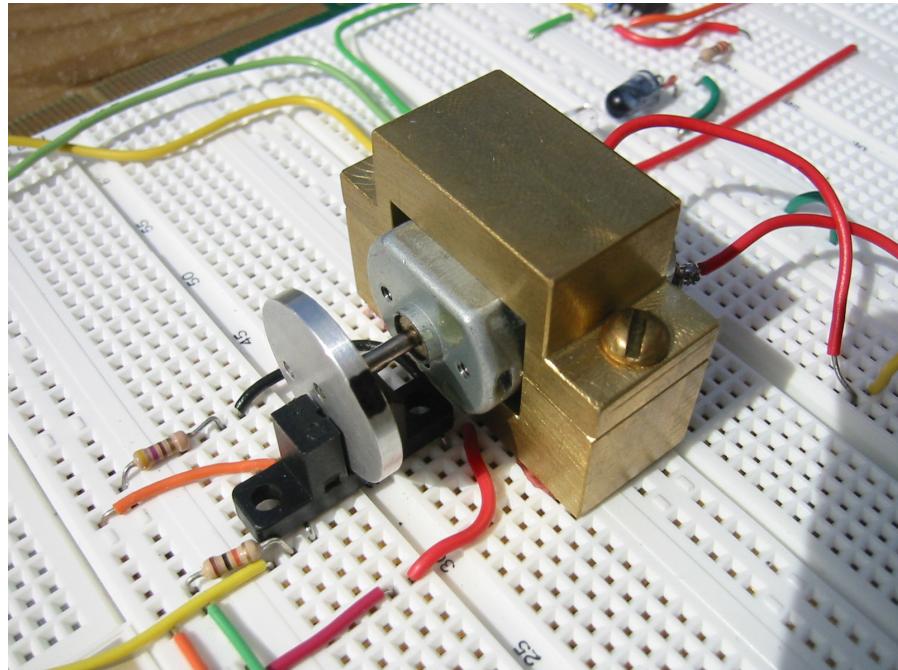
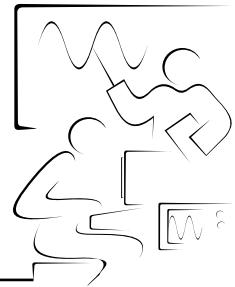
What's Cool!

Hearing is Believing

With a little more gain on the receiver side and a conversion of the signal into a current, you can drive a small loudspeaker to hear faintly but clearly “beep-beep-beep-pause- beep-beep-beep”. Enjoy the challenge.

Lab 10

Mechanical Motion



Our ability to translate electrical signals into motion in the real world, coupled with our ability to measure position, allows one to exploit the power of the computer to generate computer automation; the source of much of our modern world conveniences.

Goal

In this lab, the power capacity of the NI ELVIS variable power supply is used to run and control the speed of a small DC motor. Using a modified free space IR link, a tachometer is built to measure the speed of the motor. Coupling the motor and tachometer together with a LabVIEW program brings computer automation to the system.

Soft Front Panels (SFP) Used in this Lab

Variable Power Supply VPS, Oscilloscope OSC, LabVIEW

Components Used in this Lab

1 k Ω resistor (Brown, Black, Red)

10 k Ω resistor (Brown, Black, Orange)

IR LED/Phototransistor module

DC motor

Exercise 10-1 Gentlemen, Start your Engines!

You can purchase for a few dollars a small DC motor such as the Radio Shack SR65S DC motor found at many electronic supply or hobby stores. These motors require a voltage source from 0 to 12 volts producing a maximum RPM of about 15,000 at 12 volts. With no load, the current requirement is about 300 mA. NI ELVIS VPS can supply up to 500 mA at 12 volts. Further, by changing the polarity of the applied voltage, one can change the direction of rotation. Connect a DC motor to the VPS+ output terminals (Supply+ and Ground).

Launch the NI ELVIS Instrument Launcher and select **Variable Power Supply**.

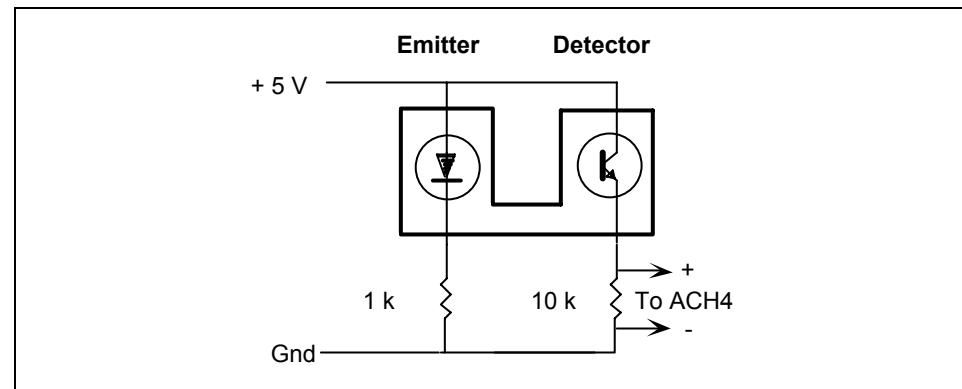


From either the workstation front panel controls or the SFP virtual controls, take your motor for a test run.

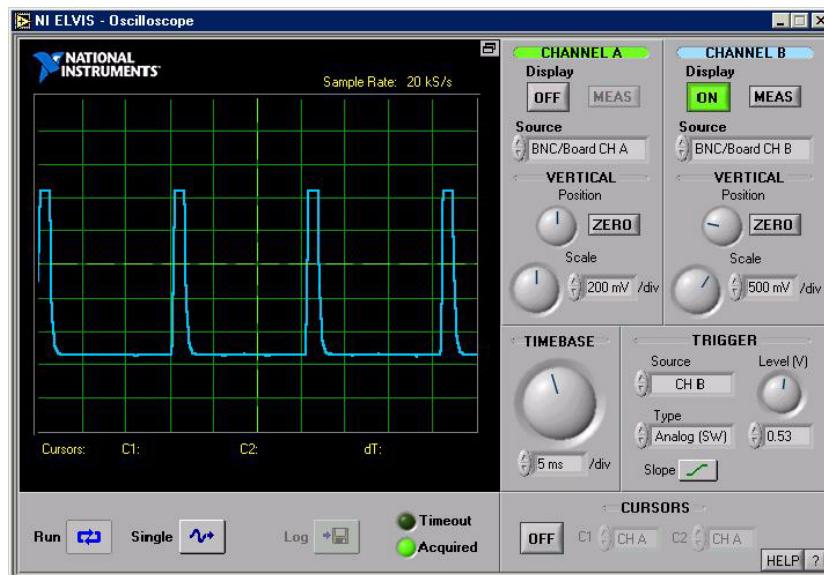
End of Exercise 10-1

Exercise 10-2 The Tachometer

Using an IR LED and phototransistor or an integrated LED/phototransistor module, one can build a simple motion sensor. On the protoboard insert the components shown in the circuit diagram below. In the case of an LED/phototransistor module, an internal LED is used for the optical source and is powered from the + 5 V power supply. Notice that a $1\text{k}\Omega$ resistor is used in series with the LED to limit the current. A $10\text{k}\Omega$ resistor is connected from the phototransistor emitter to ground and the same power supply is connected to the phototransistor collector. The voltage developed across the $10\text{k}\Omega$ resistor is the phototransistor or tachometer signal. Connect leads from the $10\text{k}\Omega$ resistor to ACH4+ and ACH4– pin sockets.



Select **Oscilloscope** from NI ELVIS Instrument Launcher and select the settings shown below:



Note ACH4 inputs are the same Source as BNC/Board CH B on the protoboard.

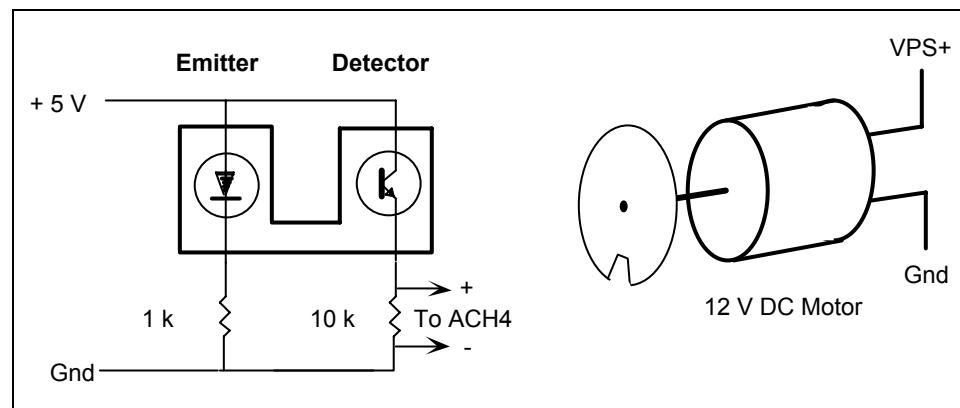
Power up the protoboard and run the **Oscilloscope SFP**.

Using a piece of paper, pass it through the IR motion sensor. You should see the oscilloscope trace change (HI-LO-HI). With a thin piece of paper, you might be able to catch the pulse generated as you drag it through the sensor. Try a comb with many teeth. Dragging it through the sensor will generate a train of pulses. You can even run it back and forth like a saw to generate a continuous stream of pulses as shown above.

End of Exercise 10-2

Exercise 10-3 Building a Rotary Motion System

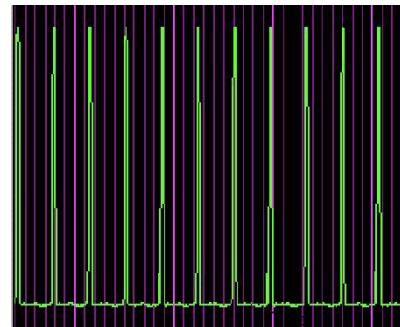
Our rotary motion demonstration system will consist of the DC motor controlled by the variable power supply and the IR motion sensor configured as a tachometer. To complete the tachometer, a disk of about 2 inches in diameter needs to be fixed to the shaft of the motor. Cut the disk from a piece of thin but sturdy cardboard or plastic. Cut a slot about 1/4 of an inch wide and 1/4 of an inch deep near the perimeter of the disk. Punch or drill a small hole at the center point. Now glue the disk to the end of the motor shaft. Mount the motor so that the slot lines up with the IR transmitter/receiver beam. In operation, each revolution will generate one pulse.



End of Exercise 10-3

Exercise 10-4 Testing the Rotary Motion System

Power up the protoboard and run the motor manually from the workstation control of the VPS. Adjust the motor position so that the disk does not touch the sensor slot. Observe on the oscilloscope trace, the pulses generate by the rotating motor.



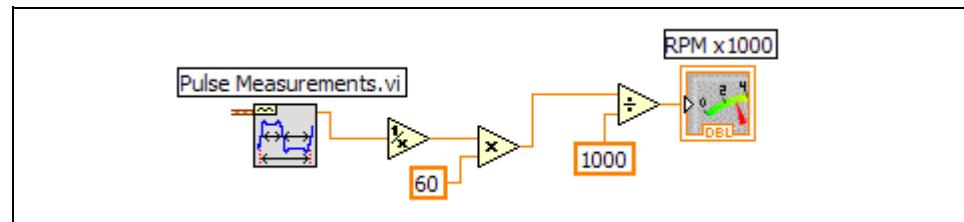
Using the measurement option Channel B [MEAS], take the frequency measurements at a variety of power supply levels. A plot of frequency versus VPS voltage will demonstrate the linearity of our rotary motion system.

Close NI ELVIS and all SFPs.

End of Exercise 10-4

Exercise 10-5 A LabVIEW Measurement of RPM

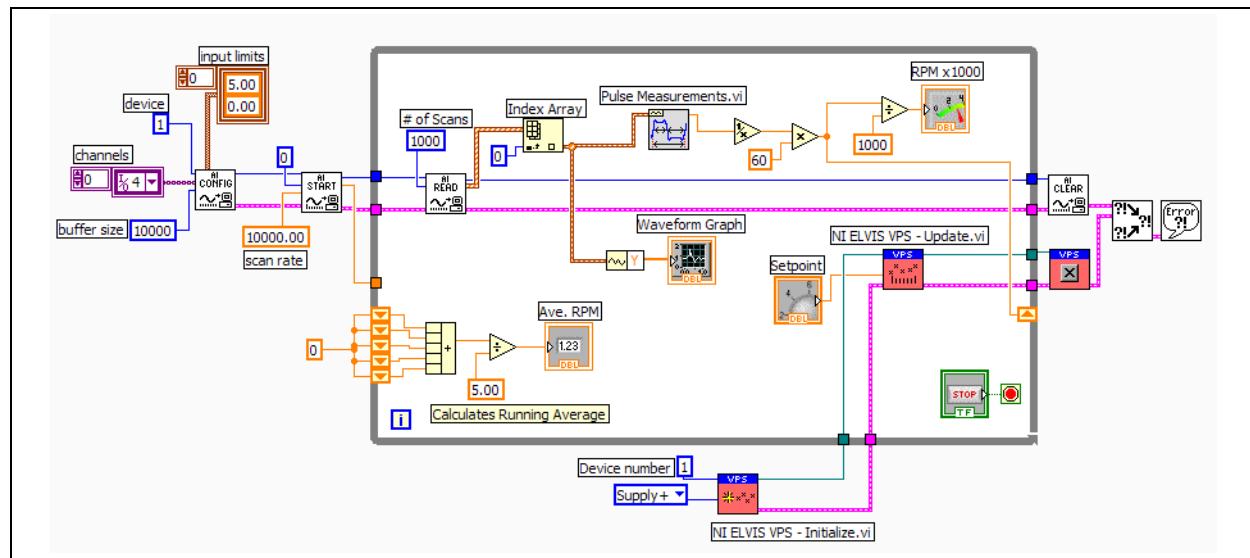
LabVIEW has several VIs found in the **Functions»All Functions»Waveform»Waveform Measurements** palette that are convenient for measuring timing periods of a continuous waveform. The **Pulse Measurements.vi** can measure the period, pulse duration, or duty cycle from a waveform array.



Note If you are using LabVIEW 7.0, then you can use the Express template for Timing and Transitions Measurements.

The period measurement can be converted to Revolutions Per Minute by inverting the period to get frequency; then, multiplying by 60 to get RPM. For scaling, we will divide by 1000 to get kRPM.

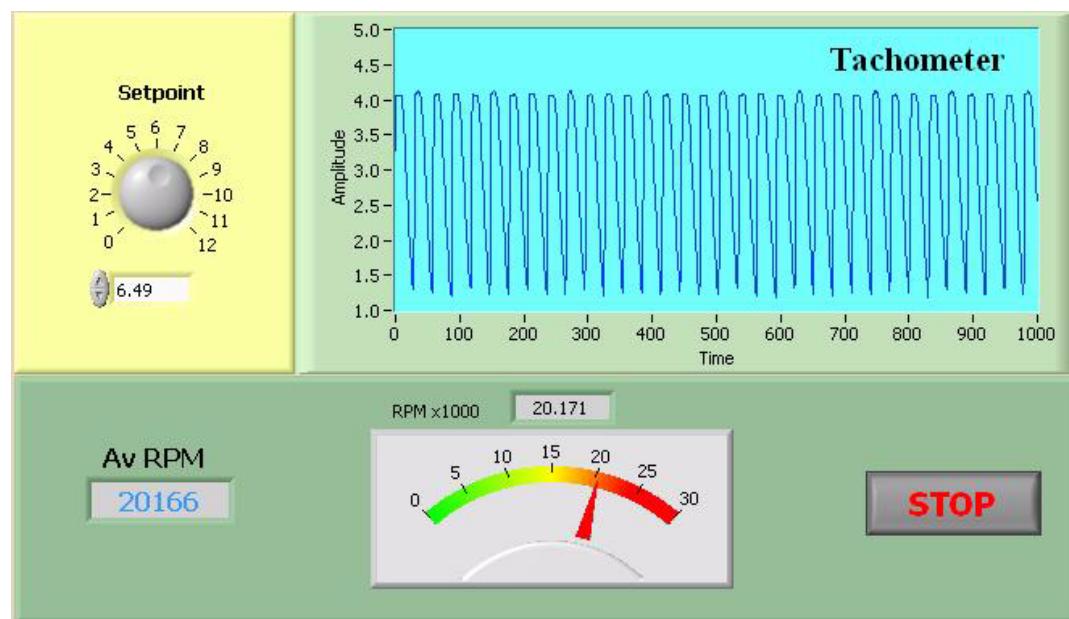
Launch LabVIEW and open the program **RPM.vi** from the Hands-On NI ELVIS Library. Open up the diagram window and study the program.



DAQ VIs are used to sample the tachometer signal and provide an input signal array for **Pulse Measurements.vi**. The RPM signal is sent to a front panel meter and displayed in units of kRPM. The RPM signal also goes to a shift register with 5 elements. This provides an averaged RPM signal on the front panel. The motor speed is manually controlled by the

front panel knob labeled [Setpoint]. Also available on the front panel is a graph of the tachometer signal as a function of time.

Run this VI and take your motor for a spin. See and hear how responsive the motor is to a rapid change in the RPM setpoint.

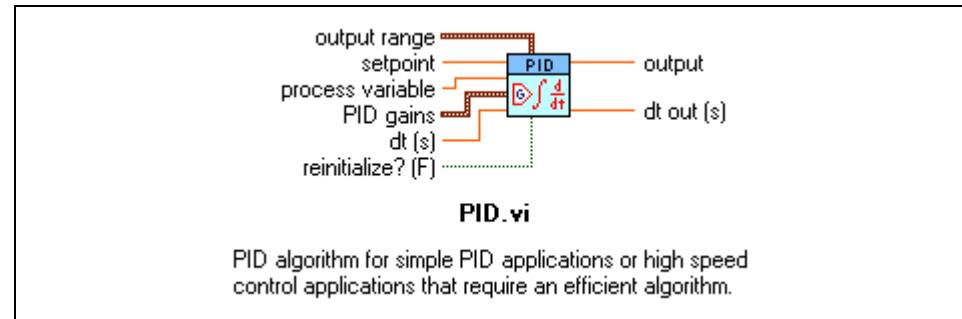


End of Exercise 10-5

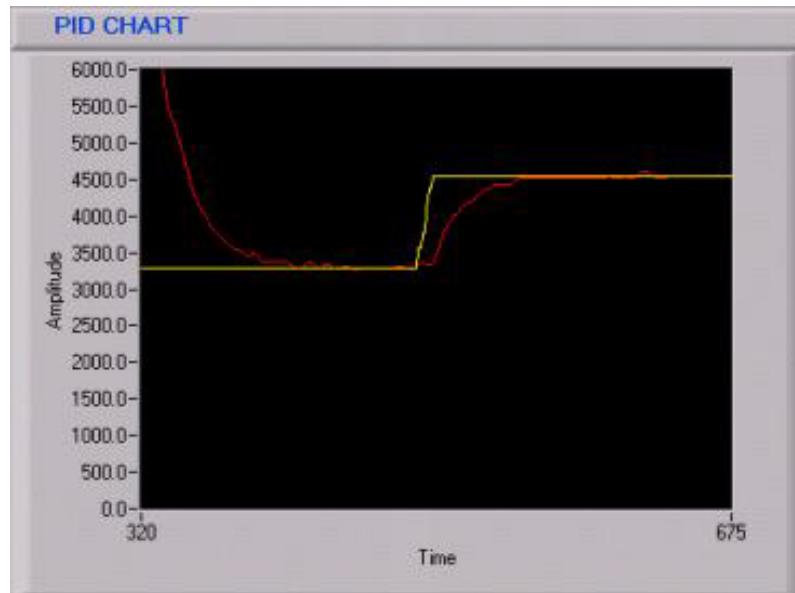
What's Cool!

Computer Automation of the Rotary Motion System

National Instruments provides a PID Toolkit that has additional LabVIEW VIs to add computer automation to our rotary system. PID stands for proportional integral and derivative. These control algorithms move a system from one setpoint (initial RPM) to another setpoint (final RPM) in an optimized manner. The addition of a single VI (PID.vi) brings optimal control to our program. The algorithm compares the target RPM (final RPM) with the current RPM (averaged RPM signal) to generate a DC error signal which drives the variable power supply. Integration and differentiation parameters are used to adjust the VPS voltage smoothly from one measurement to the next.



For those more familiar with control, another VI (PID Autotuning.vi) can be used to set the initial PID parameters automatically. Then one can fine tune the parameters to your specific system. Check these out at ni.com.



I never realized computer automation could be so easy.