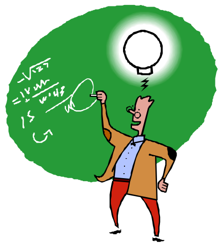
LABORATORY MANUAL

ELEC 199

Laboratory in Engineering Fundamentals

This manual was prepared by:

Adam Zielinski



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Acknowledgement

Acknowledgement

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1. Introduction

1.1 Justification and Motivation

Students enrolled in the Bachelor of Engineering Programs (Electrical, Computer, and Mechanical Engineering) come into contact with engineering courses late in their programs. This situation has undesirable effects:

a) students who are potentially interested in engineering may get discouraged,
a) some students who are not inclined to engineering discover it too late, and
a) Students are not given the opportunity to sample different engineering disciplines before making their decision on which program to choose.

In the past, the Faculty considered a new, general engineering course for the First Year students. However, it was not implemented primarily because of the lack of resources and a suitable textbook. ELEC 199 intends to address this need. Its introduction is expected to enhance our programs, add to the engineering design/science components as defined by the accreditation requirements, and increase CO-OP employability of our junior students.

The advances in electronics, materials, and computer technology make it possible to accomplish breathtaking tasks such as sending men to the moon, launching space shuttles, and sending unmanned robots to ocean depths or to other planets. Modern technology is being used in computer games, musical instruments, automobiles, house appliances, and in numerous other applications. The typical key components of systems used in such applications are sensors, microprocessors, and actuators. A sensor senses a physical variable such as force, pressure, temperature, or light intensity and converts it into an electrical quantity such as current or voltage. The latter is called a signal. The signal is then processed by electronic circuits and often converted into digital form to be manipulated by a microprocessor or computer. After the processing is done, a suitable electric signal is used to control actuators such as motors, power amplifiers, lights, car breaks, and others.

In this course, you, the student, will walk along a similar path. You will start by getting familiar with basic mechanical, electrical and computer concepts as well as electrical components and subsystems. You will explore simple sensors that convert non-electrical quantity such as position or force to electrical quantity such as resistance or voltage. You will build and test a simple force-to-frequency converter and a force-to-voltage converter to be interfaced with a micro-processor. By suitable programming of such a microprocessor diverse tasks can be accomplished. You will see your design working and find out numerous new applications for them. We hope that this course will be a fun learning experience for you.

1.2 Calendar Description (2001-02 Calendar)

ELEC 199 Units: 1 S (0-1.5-1) **Laboratory in Engineering Fundamentals**

The objective of this course is to introduce students to concepts in electrical, computer, and mechanical engineering through a practical project to be undertaken by teams of students. The project will involve mechanical construction, sensing of mechanical quantity by electrical means, as well as interfacing to and programming of a simple microcontroller. Students will be required to acquire suitable components, demonstrate their designs, and write a report documenting their efforts.
Grading: COM, N or F

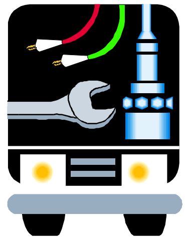
1.3 Course Implementation

One faculty member will coordinate the course with the help of several teaching assistants. A laboratory space with several PC stations to test and to program the microprocessor will be provided and a suitable technical staff will be assigned to look after this space. Before the second week of classes, students are to form groups of threes and acquire the required components and tools. Before starting the project on the fourth week, students must complete all the required exercises and pass a multiple-choice test. A test failed is to be repeated within one week. Before the tenth week, each group must demonstrate the completed project. The final report documenting designs and findings must be submitted before the end of classes. The students should select the specific topic and research should be done using the Internet and other resources. The report should contain independent research on a suitable sensor, converter or transducer to sense a non-electrical quantity using electrical means. It should also include suggestions for interesting future projects. The guidelines on report format can be found at:
http://www.coop.engr.uvic.ca/engrweb/WTR.HTML#ch33

Summary of the tasks is shown in the Table below.

TASKS	When (weeks in the term)
Form a group of 3 students	2
Pass the test	4
Demonstrate the Designs	10
Submit the Final Report	End of classes

The course will be graded based on the test, demonstration, and the final report as COM (Completed), N (not Completed) or F (Failed).



2. Mechanical Fundamentals

2.1 Basic Ideas

Distance

The distance between two points is measured in meters (m) or kilometers (km).

Motion

An object can move with a velocity (speed) measured in meters per second (m / s). A car's speed is usually measured in kilometers per hour (km / h.)

Acceleration

Acceleration is the measure of the increase in velocity in time and is measured in meters per second over a period of one second or in m/s^2. A car that can accelerate to 60km / h in 6 seconds has an average acceleration of 10 km/s^2 or 6000m/s^2.

Mass

Mass is an inherent property of all material objects. It is measured in kilograms (kg) or grams (g).

Force

Force is a basic mechanical quantity encountered in everyday life. If you want to move a car, you have to push it with a certain force. The same applies to an object of a certain mass on the smooth ice surface where, ideally, the object can move without friction.

The force **F** needed to speed up an object having a mass **m** with acceleration **a** is given by Newton's Law:

$$\mathbf{F = ma} \tag{2.1}$$

Force is a vector and therefore it has magnitude and direction. The unit of force is called Newton (N). One Newton (1N) is the force required to accelerate a mass of 1 kg to 1 m/s^2.

Gravity

Objects attract (pull) each other with a certain force. On a planet, this attraction demonstrates itself as a gravitational force that pulls down an object with a force proportional to its mass.

$$\mathbf{F = gm} \tag{2.2}$$

The proportionality constant on Earth $g = 9.81\ m/s^2$. The constant g for other planets is different. Mass can be measured by measuring the force of gravity also called a weight. An instrument to measure weight is called a scale. Not recommended but a convenient measure of force is a force by which a mass of 1 kg is pulled by the gravitational force on Earth. This unit of force is called a kilogram-force (kgf). Using eq. (2.2) we note that: 1 kgf = 9.81 N. The gravity force is distributed over all volume of the object however for many situations it is sufficient to model this force as one vector attached at the center of gravity of the object.

Pressure

Force **F** applied over a certain area **S** exercises a pressure **P** given by:

$$\mathbf{P = F/S} \tag{2.3}$$

Pressure is measured in Pascals. One Pascal is the pressure exercised by one Newton of force applied to a surface of $1m^2$. Not a recommended measure of pressure is one atmosphere (atm) that is 1 kgf applied over 1 cm^2 area.

Spring

Springs (or springing members) are made from an elastic material that can be reversibly deformed under the force applied. This deformation, if within a certain limit, is proportional to the force applied with the proportionality constant **k** (spring constant). When deformed by amount **d**, a spring exercises a restoring force **F** equal to that of the applied force and opposing that force. This force can be found by using Hook's Law

$$\mathbf{F = kd} \tag{2.4}$$

As illustrated in Figure 2.1.

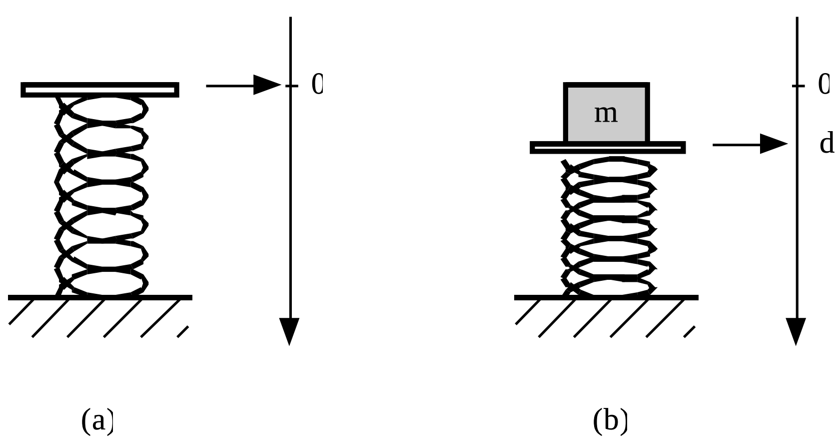


Figure 2.1 Spring and Force

Shown in Figure 2.1(a) is a spring with a platform attached to it. The position of the platform is set to zero. Suppose now that an object with a mass **m** is placed on the platform. The gravitational force exercised on the object will displace the platform by a certain amount **d**. At the equilibrium these forces must be equal, therefore:

$$mg = kd \tag{2.5}$$

Equation (2.5) allows us to calculate the mass **m** if the other three variables **g, k**, and **d** are known. This arrangement is the basis for a scale.

Moment of force

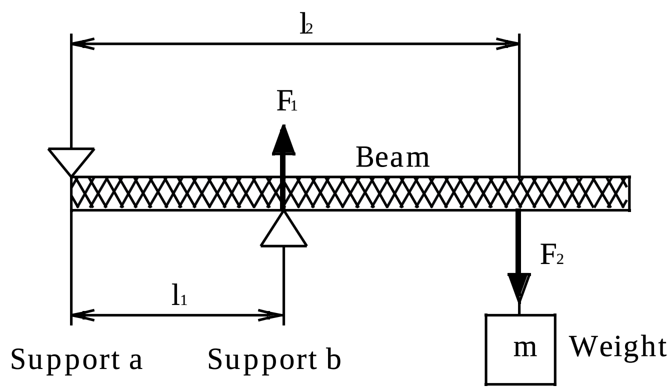


Figure 2.2 Beam

Consider an ideal (weightless) beam supported by support-a and support-b as illustrated in Figure 2.2. Suppose that a weight with mass **m** is suspended at a certain point of the beam. This mass is exercising gravity force F_2 applied at distance l_2 from the support a. This distance is called **an arm**. The force applied times its arm is called a **moment of force**. The force F_2 applied to the beam generates an opposing force F_1 at the support b. This force has moment $F_1 l_1$.

Moments of force law

In equilibrium, sum of all moments (with proper sign) must be equal to zero.

In our case:

$$F_1 l_1 - F_2 l_2 = 0 \tag{2.6}$$

Torque

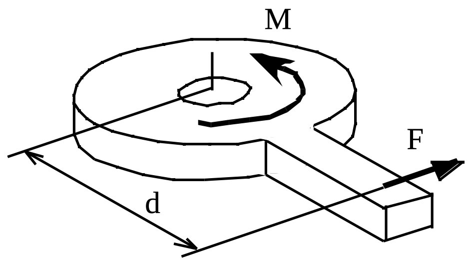


Figure 2.3 Rotating body

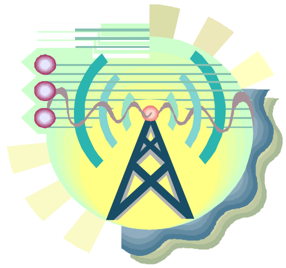
Moment of force applied to a rotating body is called a torque. Torque applied to a wrench shown in Figure 2.3 is given by **d** x **F**.

2.2 Exercises

The exercises must cover all the material in Section 2 and be useful for designs described in Sections 5.1 and 5.2.

Exercise 1. Compare pressures exercised by the foot of an elephant with that of a person on high heels. Assume reasonable parameters.

Exercise 2
Exercise 3
Exercise 4
Exercise 5



3. Electronic Fundamentals

3.1 Basic ideas and components

Current

Electrons are negatively charged particles. The movement of electrons constitutes the flow of electric current. The movement of a negative charge in one direction can be thought of as the movement of a positive charge in the opposite direction. The direction of the positive charge is the direction of current flow. You can think of an electric charge as water and of an electric current as water flowing in a river or a pipe. The water flows in a certain direction – from the higher ground to the lower ground. The measure of current is ampere (A). An instrument called ammeter is used to measure the current that must pass through it.

Battery and Voltage

You can think of an electric battery as a generator of a positive charge. Once an electric load is connected to the battery, the current flows from its positive terminal (+) to its negative terminal (-) through the connecting wires and the load. The batteries come with different voltage ratings expressed in volts (V). For instance, a car battery is a 12-volt battery. The higher the voltage, the more current will flow from the battery when you connect an electric load to it. You can think of a battery as a pump, which pumps the water from the lower ground (usually referenced as zero) to a higher ground. You can think of a battery's voltage as the height of the elevated water level. The battery is often called a voltage source. Voltages are measured by an instrument called a voltmeter. To measure the voltage, the voltmeter must be connected between two points where there is a certain voltage difference (like between the + and the - terminals of the battery). The reference point used to measure voltages is called ground. For example, one of the terminals of the car battery is connected to the car's body and is considered an electric ground. Drawings of batteries and associated symbols are shown in Figure 3.1.

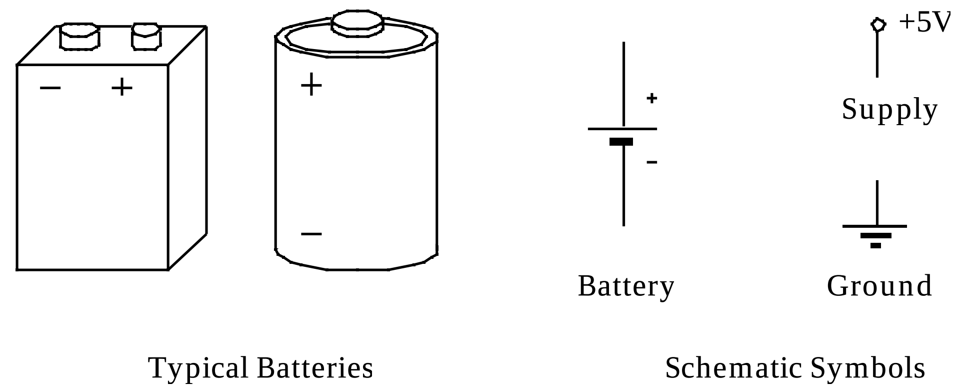


Figure 3.1 Batteries and ground

Resistance

Some materials like metals are good conductors of current while some are not. Electrical connecting wires are made from good conductors (usually copper). The degree in which a material "resists" the flow of electric current is called resistance and is measured in ohms. An electronic component called a resistor has a specific and constant value of its resistance. An instrument called an ohmmeter measures the resistance placed in its path as illustrated in Figure 3.2.

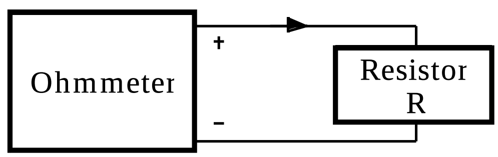
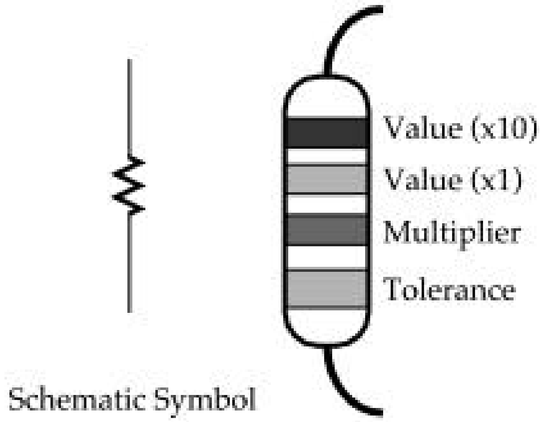


Figure 3.2 Measure of resistance using an ohmmeter

The symbol and value codes used for resistors are shown in Figure 3.3.



Color	Value	Multiplier
Black	0	10^0
Brown	1	10^1
Red	2	10^2
Orange	3	10^3
Yellow	4	10^4
Green	5	10^5
Blue	6	10^6
Violet	7	10^7
Gray	8	10^8
White	9	10^9

Color	Tolerance
Gold	5%
Silver	10%
No Color	20%

Figure 3.3 Symbol and code used for the resistors

A multi-meter (or tester) is an instrument that combines the functions of a voltmeter, an ammeter, and an ohmmeter.

Ohm's Law

If you connect a battery rated **E** volts to a resistor **R** using a wire as shown in Figure 3.4, a current **I** will flow through the resistor in the direction as indicated. The voltage across battery terminals can be measured by voltmeter V, while the current **I** through resistor R can be measured by ammeter A.

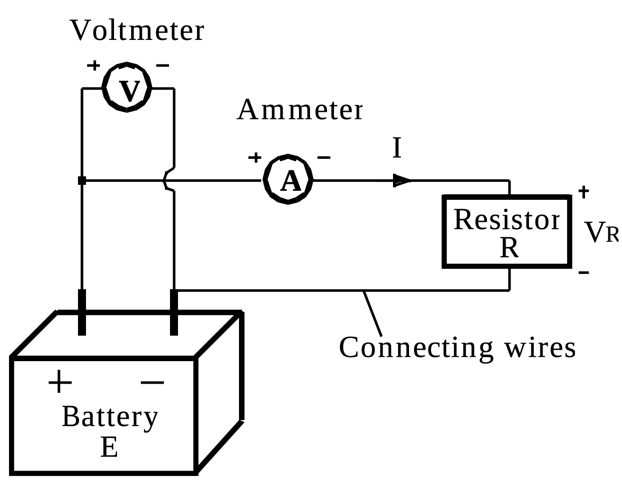


Figure 3.4 Battery connected to a resistor

The value of current **I** can be found using a simple relation called Ohm's Law, that is:

$$\mathbf{I = E/R} \qquad (3.1)$$

For instance, if you connect a car cigarette lighter which has **R** =0.5 ohm resistance to the car battery rated **E** =12 volts, the resulting current **I** will be **I=**12/0.5=24 A. The current needed for a starter motor can reach several hundreds of Amps.

A current **I** that flows through a resistor **R** will develop a voltage drop V_R across it with its direction opposing the flow of current as shown in Figure 3.4. The opposing direction occurs when sign "+" is facing the current flow arrowhead. This voltage can be found using Ohm's Law:

$$\mathbf{V_R = I * R} \qquad (3.2)$$

In electronic circuits, we usually use resistors in the range of 10^3 ohm = 1 kohm (1k) and current is usually expressed in milliamps (1 mA=10^{-3} A)

Because current through a resistor is proportional to the voltage applied, we call such a resistor a linear resistor. There are also nonlinear resistors (elements) where dependence between current and voltage applied is a nonlinear function. An example of such a nonlinear element is a diode that will be described later.

Series/Parallel Connections

Resistors can be connected by conducting wires (or paths) in series or in parallel as shown in Figure 3.5 (a) and (b). In Figure 3.5 we use the symbols designated for battery and resistors.

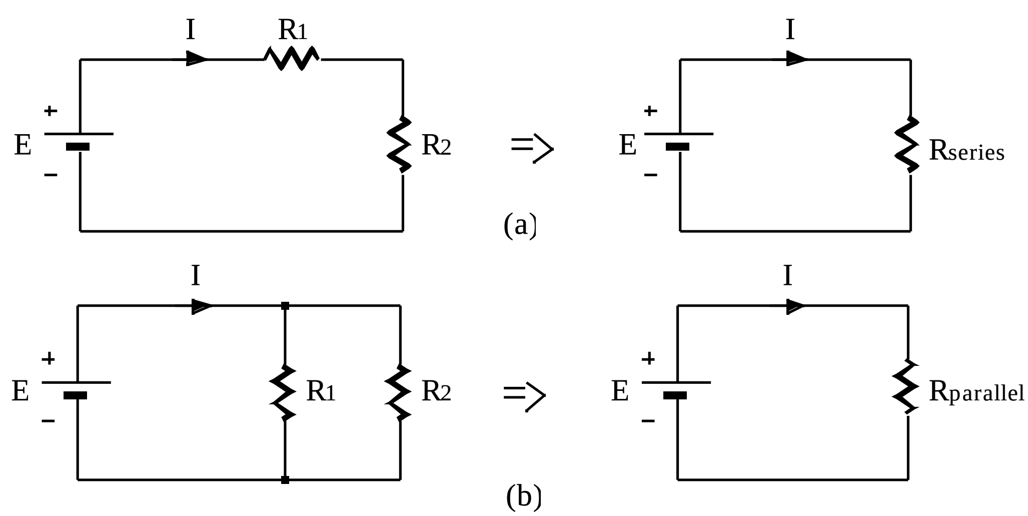


Figure 3.5 (a) Series and (b) parallel connections

The equivalent resistors will draw the same current **I** from the battery. Their value can be calculated as:

$$R_{series} = R_1+R_2 \quad (3.3)$$
$$R_{parallel} = R_1 || R_2 = 1/(1/R_1+1/R_2) \quad (3.4)$$

Voltage Divider

Shown in Figure 3.6(a) is a simple circuit called voltage divider.

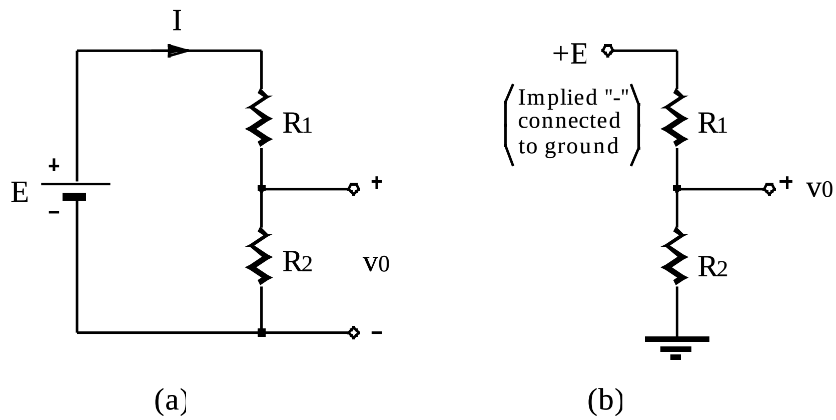


Figure 3.6 Voltage Divider

The current flowing through both series resistors is given by $I = E/(R_1+R_2)$. This current, following Ohm's law, will cause a voltage drop across the resistor R_2. This voltage drop is given as:

$$\mathbf{V_0 = I*R_2 = E*R_2/(R_1+R_2) = E/(1+R_1/R_2)} \quad (3.5)$$

By selecting a proper ratio of R_1/R_2, we can obtain any voltage V_0 between zero and E.

Figure 3.6 (b) shows a simplified way of drawing the circuit shown in Figure 3.6(a). Here we use the symbol "ground" to indicate common connection (or common node). Any voltage indicated without additional reference information is taken with respect to the ground.

Potentiometer

A voltage divider can be conveniently built using a variable resistor called a potentiometer (or pot for short). A potentiometer has a sliding electrode (a wiper), the position of which can be manually adjusted at a desired location resulting in a variable resistance. A voltage divider using a potentiometer is shown symbolically in Figure 3.7.

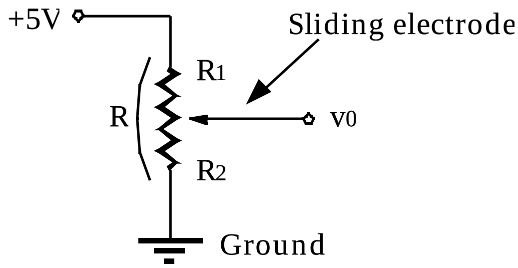


Figure 3.7 Potentiometer

The total resistance of the potentiometer is $R = R_1+R_2$. A potentiometer usually has the form of a round drum with a central rotating shaft that controls the position of the wiper as shown in Figure 3.8.

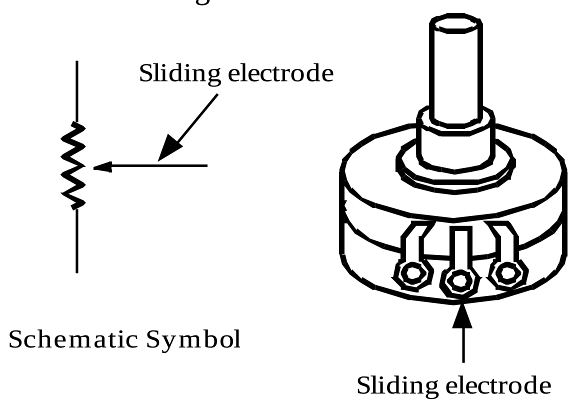


Figure 3.8 Potentiometer

Current and Voltage laws

A circuit <u>node</u> is a point where two or more wires are electrically connected together. Any closed path along a circuit is called a <u>loop</u>. All voltages directed in clockwise directions (from negative sign to positive sign) are considered positive and all voltages opposing that direction are negative.

<u>Current Law:</u>

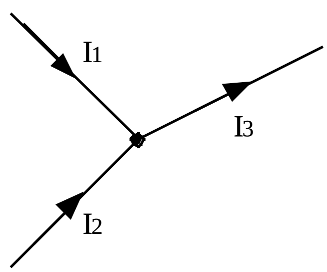
The sum of all currents flowing into a node must be equal to the sum of all currents leaving this node.

This law is quite obvious if you think of a node as a point where flowing rivers (wires) meet. All the water leaving such a junction must equal the water supplied.

<u>The Voltage law</u>:

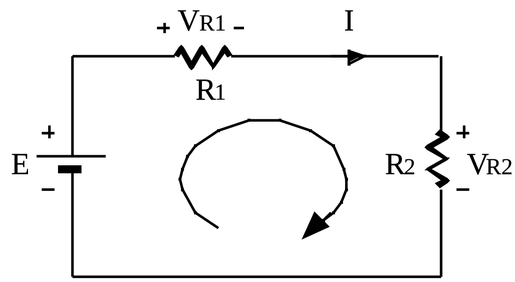
The sum of all voltages (with proper sign) along a closed loop is equal to zero.

This law is obvious if you think of voltage as an elevation. Walking along the closed loop will always bring you to the starting point with no gain in altitude. Both current and voltage laws are illustrated in Figure 3.9.



$I_3 = I_1 + I_2$

(a)



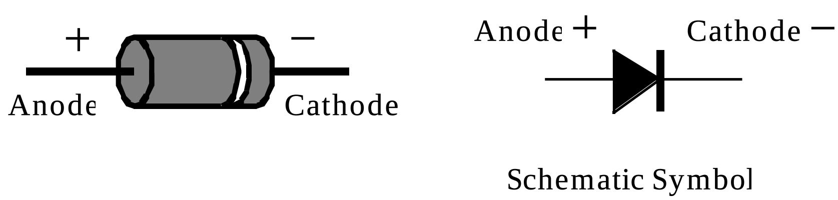
$E - V_{R1} - V_{R2} = 0$

(b)

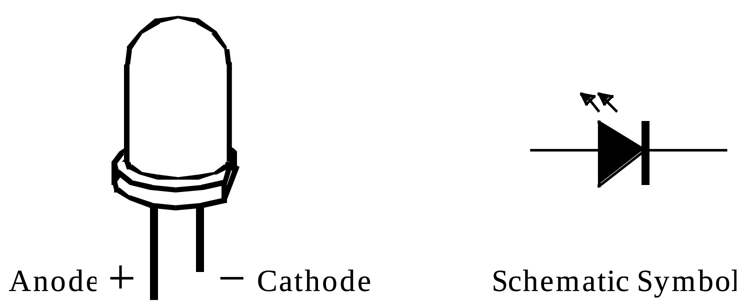
Figure 3.9 Current and Voltage Laws

Diodes

A diode is an electrical “valve” that conducts current only in one direction - from Anode to Cathode as shown in Figure 3.10. A special diode called Light Emitting Diode (LED) emits light whenever there is current flowing through it. An LED is often used as an indicator of the voltage presence (LED is “on”) or absence (LED is “off”).



Diode



LED (Light Emitting Diode)

Figure 3.10 Diodes

A simple circuit with LED is shown in Figure 3.11.

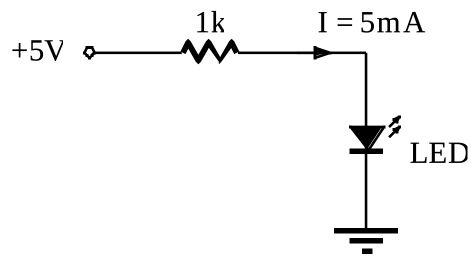


Figure 3.11 LED in action

Capacitor

A capacitor is an electronic device capable of storing the electric charge. This capacity is measured in units called Farads (F) or μFarads (1μF = 10^{-6}F). Once a capacitor is charged, it will have a certain voltage present between its terminals. You can think of a capacitor as a water reservoir and the voltage across it as the water height. When a discharged capacitor (zero voltage across its terminals) is connected to a voltage source through a resistor as shown in Figure 3.12(a), it will gradually be charged. The voltage across the capacitor will increase in time and will eventually reach the voltage supplied to it as illustrated in Figure 3.12(b).

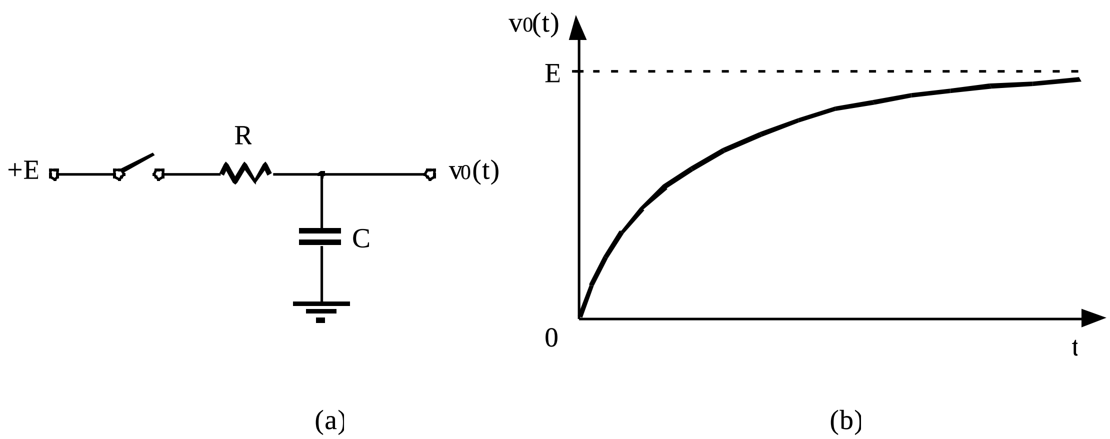


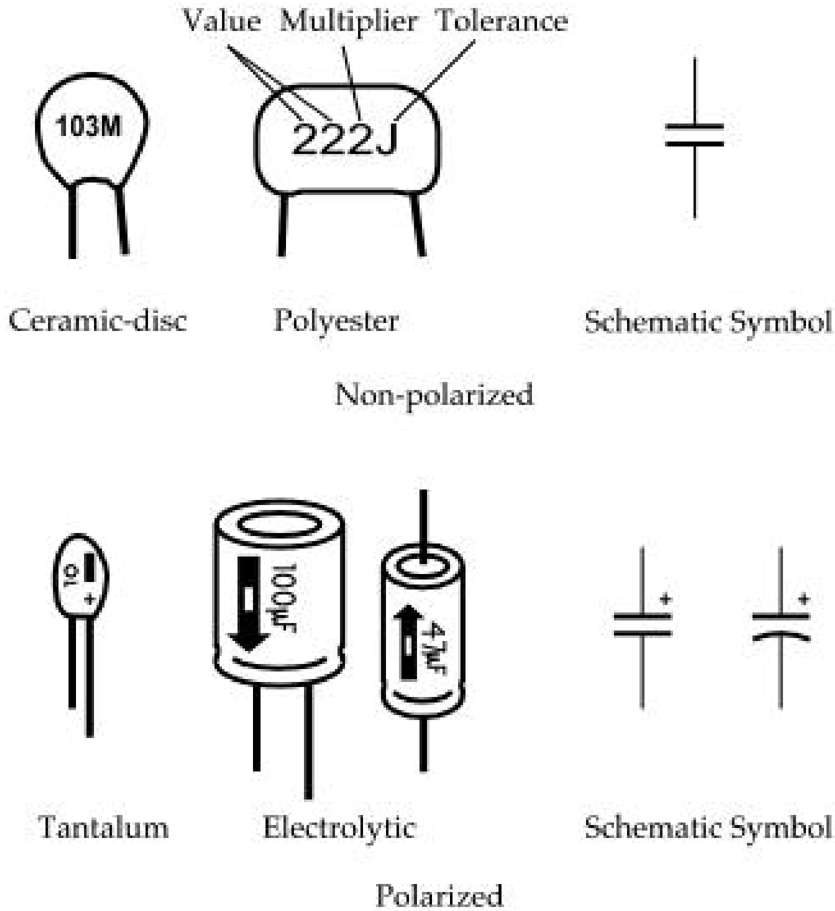
Figure 3.12 Charging a capacitor

Assuming that the switch S is turned on at time t=0, the voltage on the capacitor is given by:

$$\mathbf{V_0(t) = E\,(1 - e^{-t/RC})} \qquad (3.6)$$

The value of RC is called the time constant for this circuit.

Symbols and codes for capacitors are shown in Figure 3.13.



Multiplier	in pF	in µF
0	10^0	10^{-6}
1	10^1	10^{-5}
2	10^2	10^{-4}
3	10^3	10^{-3}
4	10^4	10^{-2}
5	10^5	10^{-1}

Tolerance	
F	1%
G	2%
H	3%
J	5%
K	10%
M	20%

Figure 3.13 Symbols and values for capacitors

Comparator

A comparator is an electronic subsystem that compares two voltages applied to its inputs as illustrated in Figure 3.14.

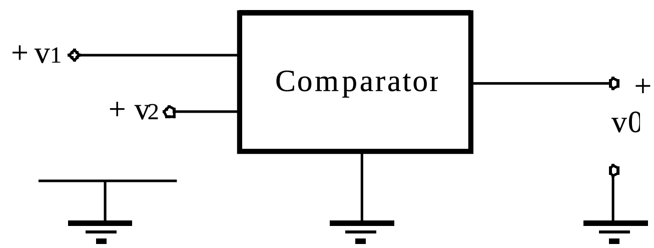


Figure 3.14 Comparator

The function implemented by a comparator is mathematically described as:

For V_2-V_1 > 0 we got V_0 = High (typically 5 volts) (3.7)
For V_2-V_1< 0 we got V_0 = Low (typically zero volts)

Figure 3.14 shows an example of a circuit with a comparator using two pots and an LED. The LED is "on" whenever V_1 >V_2 and is "off" otherwise.

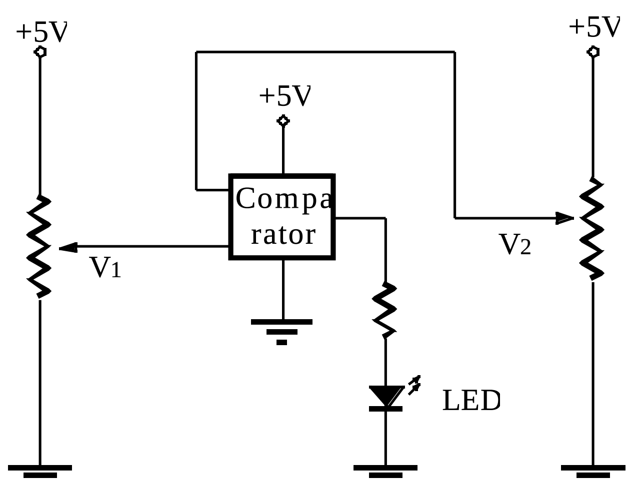


Figure 3.15 Comparator with LED indicator.

Oscillator

An oscillator is a circuit which can generate a waveform at a certain frequency expressed in cycles per second or Hertz (Hz). The frequency range from approximately 50 Hz to 20,000 Hz (20 kHz) is called an audible frequency range. This is because a signal with such a frequency, if applied to a speaker, will generate an audible tone.

The frequency of an oscillator can be changed (controlled) by an external voltage applied to it. Such a circuit is called Voltage Controlled Oscillator (VCO). It is also possible to change the frequency of the oscillator by varying the value of a resistor that is part of the oscillating circuit. Oscillators are often built using a comparator and a capacitor charged / discharged through a suitable resistor.

Sensors/Converters

A sensor is an electronic device that typically converts a non-electrical quantity such as angular or linear displacement, force, light intensity and others into an electrical quantity such as resistance, capacitance, voltage or current. An example of an angular sensor is a rotary potentiometer that changes its resistance as a function of the angular position of its control shaft. This resistance can, in turn, be used to change the frequency of an oscillator. One can call such a circuit an angle-to-frequency converter. Used in a voltage divider configuration as shown in Figure 3.7, a potentiometer can be used to build a simple angle-to-voltage converter. If changing the pot’s shaft angle requires overcoming a certain restoring force (say generated by a spring) we then have a force-to-frequency or force-to-voltage converter.

Using a thin conductive film, one can produce a force sensor that changes its resistance with the applied force or pressure. Such sensors are called Force Sensing Resistors (FSR’s) and are available commercially. The resistance of such a sensor decreases nonlinearly with the applied force and eventually levels off (saturates) at a certain force. The accuracy of such a sensor is relatively low in +/- 10% range. An FSR can be used to control the frequency of an oscillator or to produce variable voltage using a suitable voltage divider.

Multi-meter

A multi-meter is a measuring instrument that combines the functions of an ammeter, a voltmeter, and an ohmmeter. When using the multi-meter make sure that it is set for the proper function. For example, you can damage it if you try to measure a voltage when the device is set for ohmmeter function.

3.2 Exercises

These exercises must cover all the material in Section 3 and be useful in designs from Sections 5.1 and 5.2

Exercise 1
Exercise 2
Exercise 3
Exercise 4
Exercise 5

4. Microcontroller Fundamentals

4.1 Basic ideas and components

Microcontroller

Most of us know what a computer looks like. It usually has a keyboard, a monitor, a Central Processing Unit (CPU), a printer, and a mouse. These types of computers, like the Mac or PC, are primarily designed to communicate or "interface" with humans. But did you know that there are computers all around us, running programs and quietly doing calculations, not interacting with humans at all? These computers are in your car, on the airplane, in your kid brother's toy, and maybe even inside your hairdryer. We call these devices <u>microcontrollers</u>. *Micro* because they are small, and *controller* because they control machines, gadgets, whatever. Microcontrollers are designed to be connected to machines, rather than to people. They are handy because you can build a machine or device, write programs to control it, and then let it work for you automatically. In this course we will use the BASIC Stamp II microcontroller.

Port

A <u>port</u> is a physical connection that allows devices such as a keyboard, mouse, monitor, printer, etc. to connect to and communicate with a computer. A computer has serial and parallel ports that differ in their number of pins and the rules associated for communication. A microcontroller also has ports. These are often referred to as I/O (Input/Output) pins. An I/O pin has two usable/known states: a high state or a low state and it can also be floating. A high state in the digital circuits represents voltage of approximately +5V, and a low state is approximately 0V (ground). The BASIC Stamp II has 16 I/O pins that can be used to directly connect (interface) to devices such as switches, LED's, displays, potentiometers, etc.

LCD

The acronym <u>LCD</u> stands for Liquid Crystal Display. This device, if connected to a microcontroller, can display numbers, characters, graphs, etc. Examples of LCD's are the screen on your notebook computer, calculator, digital watch, etc.

Software Program

A <u>software program</u> is a list of precise instructions for the microcontroller to follow. A typical program looks at the inputs, processes them, and uses the information to decide what the states of the outputs should be.

Programming Language

A programming language is a set of words and rules for combining those words, like the vocabulary and grammar of a human language. A programming language is either understood by a microcontroller, or readily converted to a form that the microcontroller understands. High level programming languages are available to program such a device. In this course you will use Stamp Microcontroller which uses BASIC programming language to implement diverse operations.

Memory

A software program is stored in memory. The microcontroller reads from or writes into this memory. Some computers store the software program on an Electrically Erased Programmable Read Only Memory (or EEPROM). This type of memory can be programmed many times. The microcontroller fetches one instruction at a time from memory and performs the appropriate operation on the input/output pins or internal structures within the microcontroller.

4.2 STAMP

The BASIC Stamp II is one very popular microcontroller. In order for our microcontroller to function, we need to assemble some hardware. We'll be using a pre-assembled Printed Circuit Board (PCB) that contains several parts. Refer to Figure 4.1 for the block layout of the Stamp Board.

This board was created to simplify connecting "real world stuff" to the BASIC Stamp. Connectors are provided for the power supply (wall adaptor or 9 volt battery), the programming cable (serial port) and the Input / Output pins of the BASIC Stamp. There is also a "prototyping area" or breadboard (the white board with all the holes in it). You will be using an additional prototype board to build your circuits on.

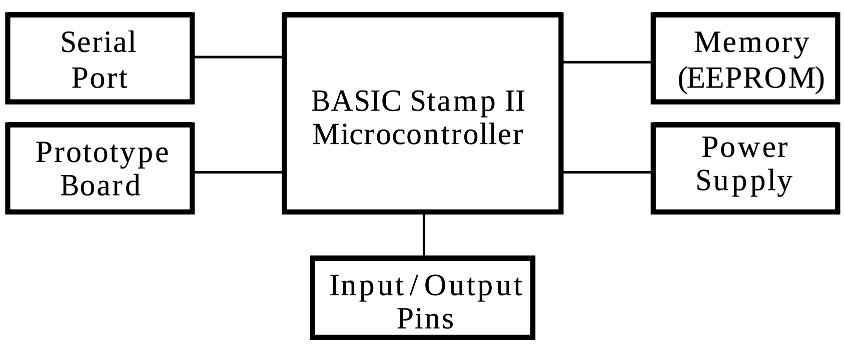


Figure 4.1 Block diagram of Stamp board

We also require a language to program the microcontroller. One of the most popular languages is called BASIC that stands for Beginner's All-purpose Symbolic Instruction Code. The Stamp stores the software program on EEPROM.

To understand how a BASIC program is written, let us look at the program in Figure 4.2. Anywhere you see the tick mark ('), the text that follows it (to the end of the line) is a comment. The computer ignores comments; they provide an explanation of the program.

The first line in the program that is not a comment is the label loop. Labels serve two purposes in a BASIC program:

- Like comments, they can provide a hint to the readers about the purpose of a section of code.
- They serve as markers for instructions that change the order in which the program is carried out.

The command "Goto" tells the program to go back to the beginning of the program and do some more work. The command "End" tells the computer that there are no further instructions.

```
' Access PIC16C7x A/D
loop:
        ADCON0 = $45                    ' Start Conversion
        Pause 1                         ' Wait 1ms for conversion
        Serout SO,N2400,[#ADRES,10]     ' Send variable to serial out
        Goto loop

        End
```

Figure 4.2 Example of BASIC programming

To program the BASIC Stamp II, you plug it into the Board of Education, connect it to a Windows or Mac computer and run the editor software to create and download your program via a serial cable. The BASIC Stamp Manual Version 2.0 describes the BASIC command set and can be found on your CD in the Board of Education folder. Additional information and software is available at: http://www.stampsinclass.com.

4.3 Interfacing to the LCD

For this course a serial display is used. It is a 2-line by 8-character Liquid Crystal Display (LCD) module. This unit accepts data transmitted by the Stamp's "Serout" instruction. The serial LCD allows you to display text, numbers, and symbols using simple "Serout" instructions. The display is connected through the RS233, 3-pin connector. These pins are connected as illustrated in Figure 4.3. For further information, refer to the Serial LCD "User Manual – BPI-216 Serial LCD Modules".

Pin	Symbol	Level	Function
===	======	====	========
1	+5V	+5V	Positive power pin (Vdd)
2	GND	0V	Negative power pin (Vss)
3	SER	Pulses	Serial data pin
4	GND	0V	Duplicate negative power pin (Vss)
5	+5V	+5V	Duplicate positive power pin (Vdd)

Figure 4.3 Pin connection for the BPI-216 serial LCD module.

4.4 Exercises

Here are a couple of simple BASIC programs that will introduce you to some programming rules, as well as the BASIC Stamp computer.

Exercise 1

Connect the power adapter cable and serial cable to the Board of Education as per page 26 of the Basic Stamp Manual on your CD. You may need a DB9 to DB25 adapter and may have to remove the 2 screws on your serial cable to plug it into your serial port.

Connect the circuit of Figure 4.4 for this first exercise. This circuit can be connected on the Stamp II prototype board. Write and run the program of Figure 4.5. This program will turn the LED on and off every half second.

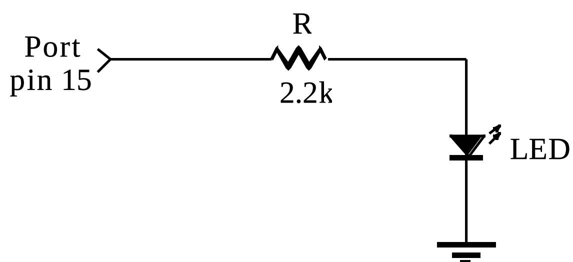


Figure 4.4 LED output circuit

```
' Example program to blink an LED connected to I/O pin 15

loop:   High 15           ' Turn on LED connected to I/O pin 15
        Pause 500         ' Delay for .5 seconds

        Low 15            ' Turn off LED connected to I/O pin 15
        Pause 500         ' Delay for .5 seconds

        Goto loop         ' Go back to loop and blink LED forever
        End
```

Figure 4.5 Program will blink an LED

Exercise 2

Connect a switch to the I/O pin 14 as illustrated in Figure 4.6. Leave the circuit of exercise 1 connected. Write and run the program of Figure 4.7. This program is a modification of exercise 1. It will turn the blinking LED on when the switch is closed, and turn the blinking LED off when the switch is open.

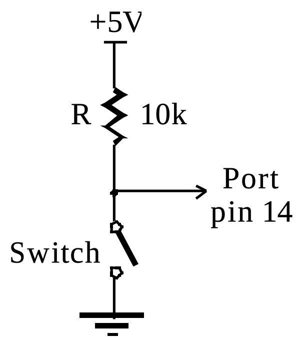


Figure 4.6 Switch input circuit

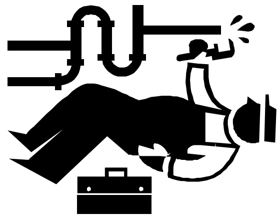
```
' Example program to read the state of I/O pin 14, and switch a blinking LED
on/off

loop:   if in14 = 0 then blink        ' Is switch on? Read I/O pin 14
        Goto loop                     ' Switch is off ; do nothing
blink:  High 15                       ' Turn on LED connected to I/O pin 15
        Pause 500                     ' Delay for .5 seconds

        Low 15                        ' Turn off LED connected to I/O pin 15
        Pause 500                     ' Delay for .5 seconds

        Goto loop                     ' Go back to loop and blink LED forever
        End
```

Figure 4.7 Program will switch on/off a blinking LED



5. Projects

Students must complete, demonstrate, and document two projects described in Sections 5.1 and 5.2. These projects can be implemented using simple parts and procedures described in this manual. However, students are encouraged to incorporate their own ideas and solutions. Students can also propose a new project but must first seek approval from the course instructor.

5.1 Project 1: Force/Sensor Measurements

5.1.1 Beam Construction

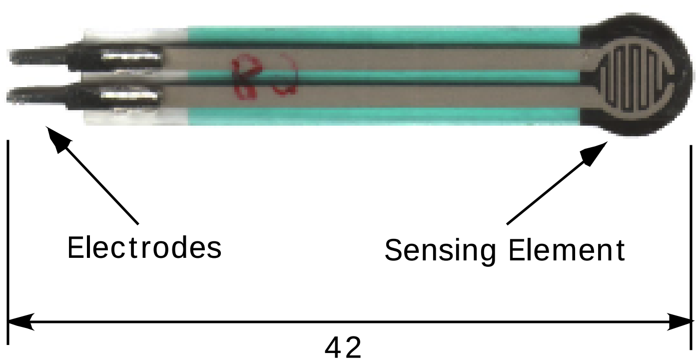


Figure 5.1 Force Sensing Resistor (Interlink Electronics)

Force Sensing Resistor (FSR)

A Force Sensing Resistor (FSR) will be used for various experiments. The sensor shown in Figure 5.1 has a sensing element made of a conductive material. Two electrodes deposited on a plastic sheet are in contact with the material. Applying a force **F** to the sensing element decreases the resistance **R** between the electrodes. This forces the electrodes into more intimate contact with the conducting layer. It takes a certain time before this resistance settles. Repeated measurements with the same applied force yields different values of resistance. This is due to a certain randomness of the process. Calculating the standard deviation will determine the accuracy one can expect from this sensor (approximately ± 10% in our case). The maximum error can also be used as a measure of accuracy. The FSR characteristics **R** = f (**F**) is nonlinear and can be approximated by a suitable function such as:

$$\mathbf{R} = \mathbf{a} + \mathbf{b}/\mathbf{F} \quad \text{(a and b are suitable constants)} \qquad (5.1)$$

For forces **F** in the range of 1 N to 10 N, the resistance **R** will vary between several hundred kohms to a few kohms. The FSR shows different characteristics depending on whether the applied force is increasing or decreasing. This phenomenon is called hysteresis and is an attribute of most sensors. In order to minimize the effects of hysteresis, a force must be applied in a consistent manner that is in a specified direction if at all possible.

i. Scale construction

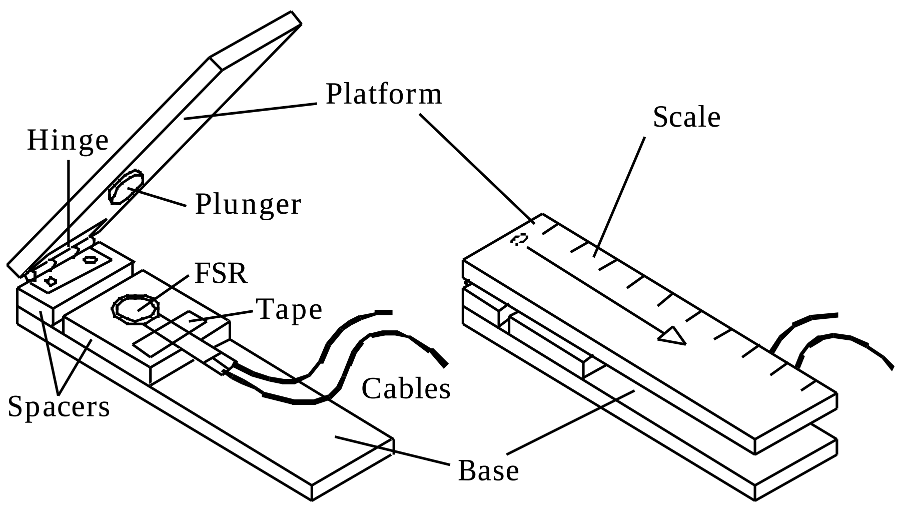


Figure 5.2 Beam-scale

In order to investigate the properties of the FSR sensor you need a suitable mechanism to apply a force to it. You will build a beam-scale as shown in Figure 5.2. You can use two wooden boards as beams and connect them with a low-friction hinge. The beam on the bottom is the base while the other is the platform where test-weights are placed. Include a suitable scale on the platform (mm resolution) so you can determine the position of the weight. The beams can be metal or plastic; however, the platform must be stiff enough to support an applied weight without bending. The platform should not be too heavy, as this will reduce the force sensing range. Place the FSR on the base, securing it with Scotch tape. The FSR is pressed by the platform through a suitable round plunger that covers the face of the sensing element. The material for the plunger should be elastic so that it will return to its original shape shortly after the force is released. The material should not be so soft that the applied force deforms it. A sheet of rubber, plastic foam, vinyl, leather or cork may be suitable. Make sure that the plunger pushes the FSR uniformly. During series of measurements, keep FSR under constant pressure of the platform to obtain consistent measurements. Spacers between the two beams are added in order to make enough space for the platform to bend slightly under the applied weight. It also allows for variation of the FSR position by sliding it on the base.

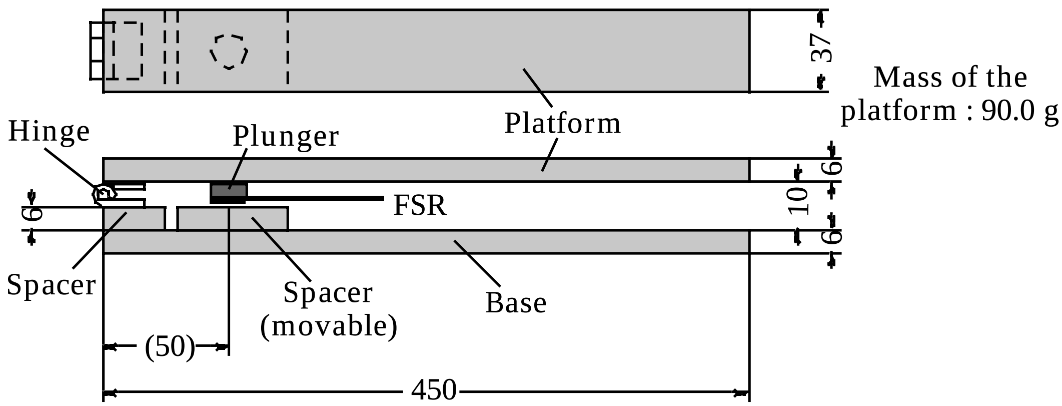


Figure 5.3 Sample dimensions of a beam-scale

The suggested dimensions of the beam-scale (in millimeters) are shown in Figure 5.3.

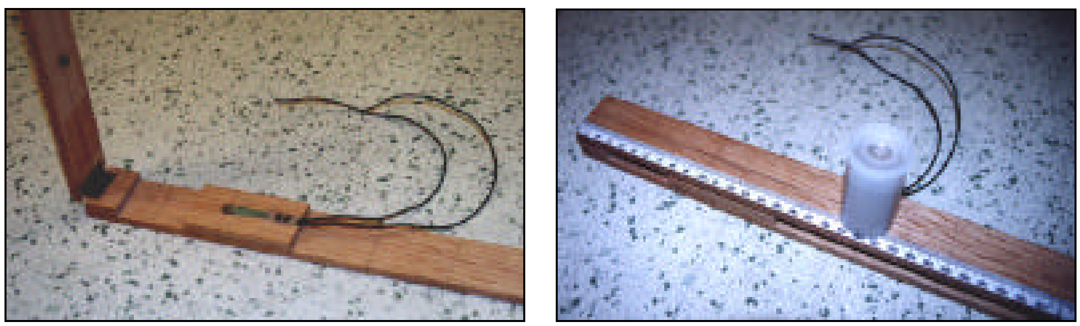


Figure 5.4 The actual beam-scale

The photograph of an actual design is shown in Figure 5.4

5.1.2 Force Measurement Principle

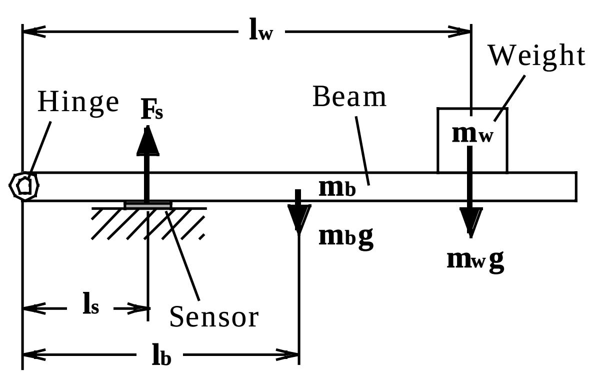


Figure 5.5 A model for beam-scale

The beam scale constructed earlier can be idealized as shown in Figure 5.5. By placing a known mass $\mathbf{m_w}$ and by varying its position on the platform we can vary the force applied to the FSR. Measure the resulting resistance using an Ohmmeter. The force applied to the sensor can be calculated using the principle of balance of moments. There are three forces at the beam. The applied weight and the weight of the beam itself will push down the platform. The sensor pushes up the beam to keep the balance. As all moments must be balanced, the following equation applies:

$$\mathbf{F_s\, l_s - m_b\, g\, l_b - m_w\, g\, l_w = 0} \qquad (5.2)$$

where,

$\mathbf{F_s}$: force on sensor (unknown)
$\mathbf{l_s}$: distance to center of FSR (measured, known)
$\mathbf{l_w}$: distance to center of weight (measured, known)
$\mathbf{l_b}$: distance to center of beam mass (measured, known)
$\mathbf{m_b}$: mass of platform (measured, known)
$\mathbf{m_w}$: mass of weight (known or unknown)
$\mathbf{g}$: gravity constant (known: $g = 9.81\ m/s^2$)

All distances are measured from the hinge.

5.1.3 Experiments

a. FSR characteristics

Apply a known weight (mass) at a certain location on the platform. Using eq. (5.2), calculate the force applied on the sensor. Any object with simple geometry can serve this purpose since the center of its mass is easily determined. A cylindrical pile of one-dollar coins may be used (one loonie is about 7g). Coins can be packed into a plastic film container (6g). Make sure the coins are kept aligned. Considering the sensor range, it is recommended that you use 20 loonies as a known reference weight, $\mathbf{m_w}$ = 146 g (they can be put to good use after the course is over ☺). Place a reference mass at several locations $\mathbf{l_w}$ on the platform and use your multi-meter to read the FSR resistances **R** corresponding to a given distance. Measurements must be done several times for the same applied force. To avoid hysteresis errors, remove the weight before each measurement and place it again. Convert your data to the applied force $\mathbf{F = F_s}$. Construct a conversion table, and indicate any errors (standard deviation and/or maximum errors). Plot the relation between the force **F** and the average resistance **R**. Comment on your results and observations.

A sample results table using a Microsoft Excel spreadsheet is presented in Table 5.1 – Calibration Table and plotted in Figure 5.6. The vertical bars in Figure 5.6 indicate maximum absolute errors encountered based on n repeated measurements.

Table 5.1 Calibration Table - FSR resistance against force for n=8 measurements.

l_w [m]	F_s [N]	Average **R** [kohm]	Maximum error [%]
0.000 (*)	1.99	5.45	2.69
0.100	3.41	4.45	1.88
0.200	4.83	3.78	0.86
0.300	6.25	3.43	1.31
0.400	7.68	3.18	0.51

(*) no reference mass applied (force is due to mass of platform)

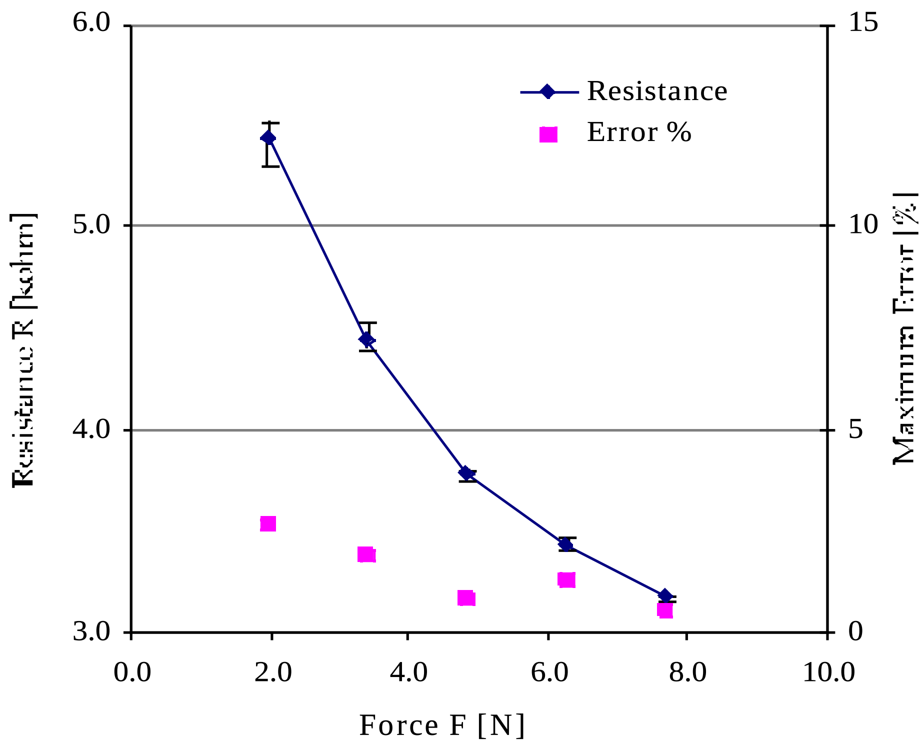


Figure 5.6 FSR resistance vs. force (n=8)

b. Hysteresis of the FSR

Put a weight on the platform at the end close to the hinge, and read the FSR resistance. Gently slide the weight, without lifting it, and read the corresponding resistances. Take measurements every 50mm until the end of the platform is reached. Plot your results **R** vs. **F.**

A sample result is presented in Figure 5.7 for n=3 repeated measurements.

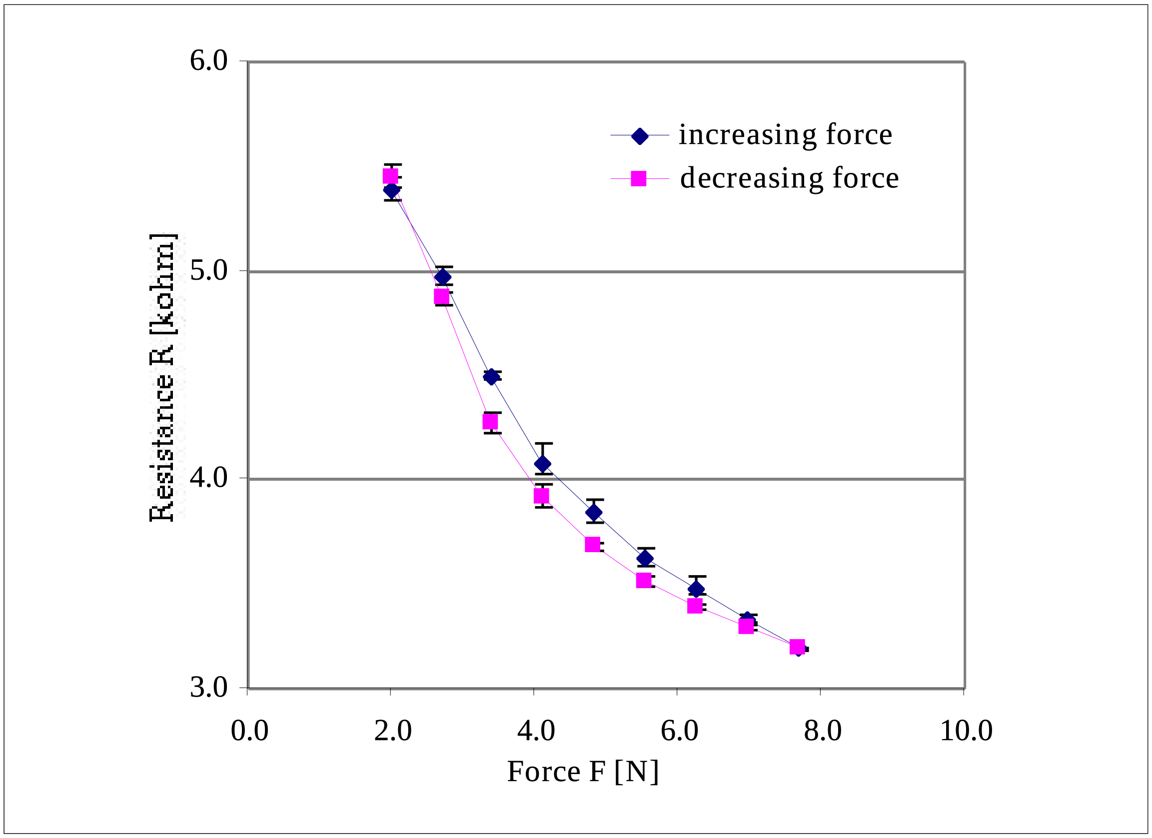


Figure 5.7 Hysteresis of FSR (n=3)

c. <u>Mass Measurement</u>

You will use the scale to make a measurement of an unknown weight (mass), predict the error of such a measurement and verify your finding by using another high precision scale (say, at your friendly grocery store ☺). The unknown weight should be such that FSR resistance is in the measurable range. Three methods can be used.

Method 1: Using ratio of positions

Put an object with an unknown weight, but with a symmetric shape, on the platform and find the position that yields the same resistance as that obtained in your calibration Table 5.1. Measure this position and calculate the unknown mass of the object using eq. (5.2).

Method 2: Using linear interpolation

Put an object on the platform at a known distance and read the corresponding FSR resistance **R**. Apply linear interpolation between two adjacent reference points from your calibration Table 5.1 to find the corresponding force **F** applied to the sensor. Based on this result, and knowing the distance of your weight, you can calculate the mass of the object.

Method 3: Global Interpolation

Using equation (5.1) and your calibration Table 5.1 you can find suitable coefficients a and b. Use this information to link any measured **R** at a known distance with applied force **F** and therefore with the mass of an object.

Try all three methods on 2-3 objects. Discuss the results and comment on your findings.

5.2 Project 2: Hand Gripper Exerciser

5.2.1 Principle of Operation

Design task:

Using a commercially available handgrip spring exerciser, design a suitable exercise monitoring system. The microprocessor should display a number of hand contractions that exceed a predetermined force level.

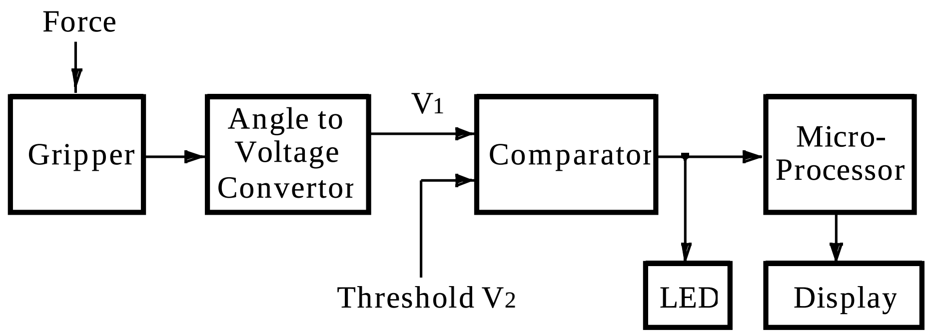


Figure 5.8 Block diagram of hand gripper exerciser

The block diagram of the system is shown in Figure 5.8. The force applied to the gripper will change the angular position of its handles. This angle can be monitored using a potentiometer suitably attached to the gripper. Such a potentiometer serves as an angle-to-voltage converter that generates voltage V_1 proportional to the angle. The voltage V_1 increases with the applied force. In order to complete the exercise cycle, the force must exceed a certain predetermined level. A comparator with an adjustable threshold voltage V_2 can detect this event. The output of the comparator goes high for $V_1 > V_2$ and turns on an LED to indicate this event. The signal from the comparator will be used by the microprocessor to count and to display the number of exercises completed (see Sections 5.2.4 and 5.2.5 for details).

5.2.2 Mechanical Design

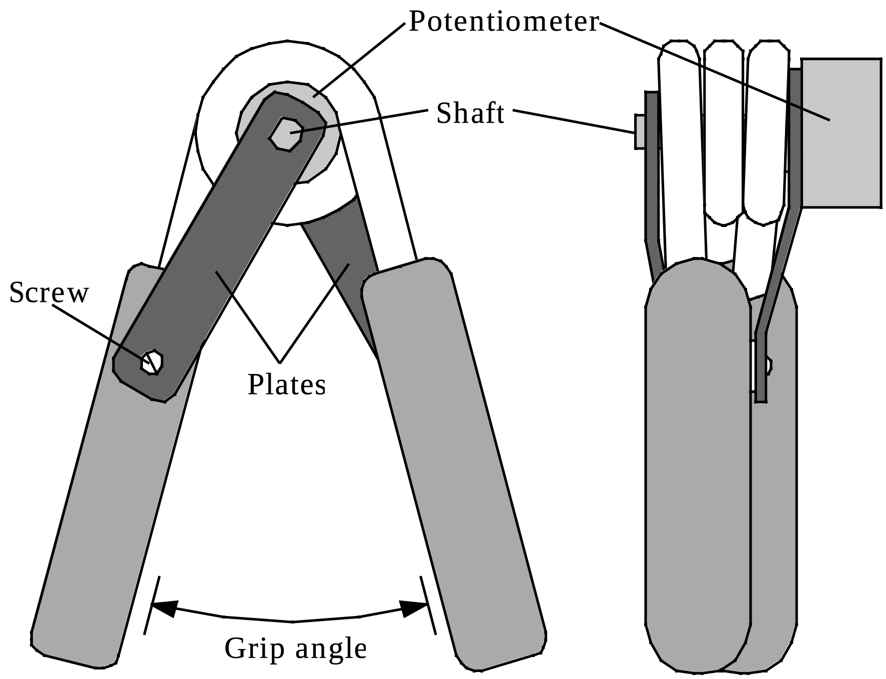


Figure 5.9 Hand gripper mounted with potentiometer

The hand grippers, shown in Figure 5.9, will be located in the Project Lab. If you prefer, you can build your own gripper potentiometer. Grippers can be purchased at most sporting goods stores (i.e., Canadian Tire, Wal-Mart, etc.). For this project, the gripper is assembled with a 50kΩ potentiometer. The potentiometer is fitted with two plastic pieces on either side of the hand gripper. The plastic can be purchased at hardware store. They can be suitably cut using a knife. The plastic pieces are fixed to the gripper with small self-threading metal screws. When the gripper is squeezed, the grip angle decreases. Decreasing this angle will either increase or decrease the resistance of the potentiometer depending on which way the potentiometer is mounted or which two of three terminals are used.

You can use the 50kΩ potentiometer from your kit instead of the gripper while building your circuit, then replace it with the gripper for your final testing.

5.2.3 Electrical Design

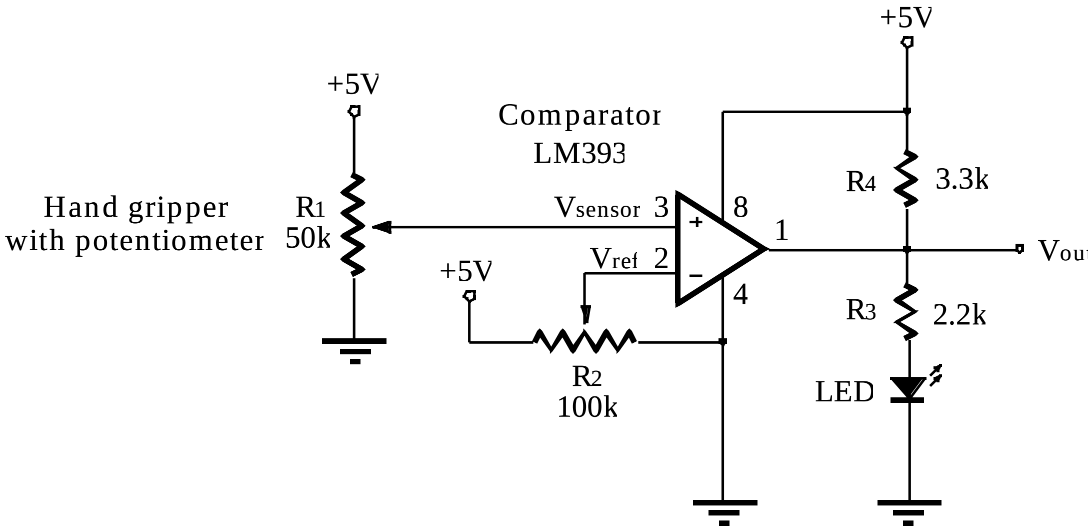


Figure 5.10 Comparator circuit for the hand grip exerciser

Squeezing the hand gripper changes the sensor voltage (V_{sensor}) at the input of the comparator of Figure 5.10. Resistor R_1 represents the potentiometer of the hand gripper. The comparator outputs a high at V_{out} when V_{sensor} reaches the reference voltage (V_{ref}). This will turn on the LED indicating that the hand gripper has been squeezed to a certain degree. Adjusting R_2 can change the amount of force needed to light the LED. Comparators usually have what is called an "open collector" output and require a "pull-up" resistor, R_4. When the output is high, approximately 2V is dropped across R_4. This leaves V_{out} = 3V. Resistor R_3 will limit the maximum current that can pass through the LED.

Build the circuit on Figure 5.10 on your prototype board located on your Board of Education (see Figure 5.11). The Stamp Board is powered by a 9V battery or by the 9V power adaptor. When the power is properly connected, the “Power LED” will illuminate. The power supply voltage is reduced from 9V to +5V by a 5V-regulator. 5V supply will be used for circuits on the Prototype Board.

Note: You must connect the +5V wires to V_{dd} and connect your ground to V_{ss}.

NEVER connect <u>any</u> wires to V_{in}.

To understand how the prototype board makes internal connections, read the Board of Education Manual. You can do this by loading the CD, choosing Documentation, selecting a topic choosing View.

5.2.4 Interfacing with the Microprocessor

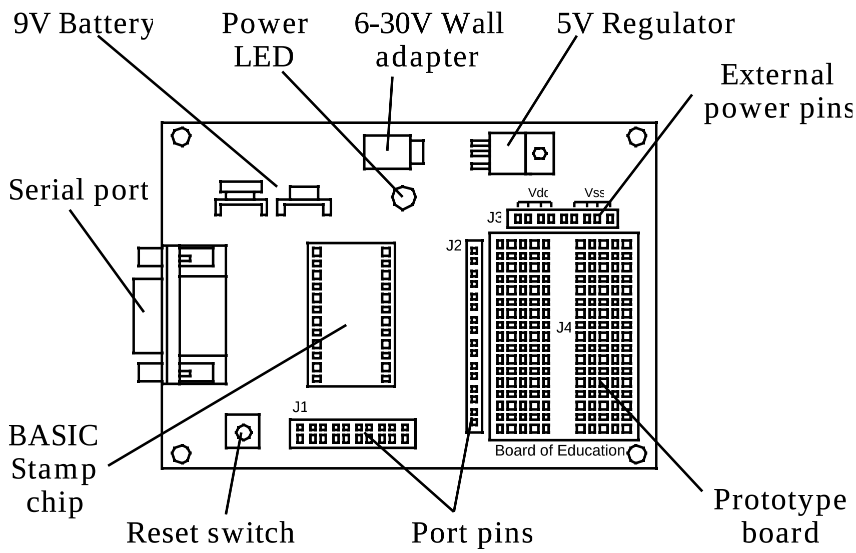


Figure 5.11 Board of Education with Prototype board

Connect and program the BASIC Stamp II computer to count the number of repetitions of the hand gripper and connect the display that count on the LCD (Liquid Crystal Display) module. Figure 5.12 shows how to connect the Basic STAMP II to the output of the comparator and to the LCD module. The output of the comparator connects to P15 of the BASIC Stamp II which you will program to continuously poll P15 for a high voltage. When the LED turns on, P15 goes high and the computer will increment the count on the LCD module. For LCD pin connections see Figure 4.3.

CAUTION! Always check the connections to V_{dd}, V_{ss} and to the display before turning on the power so that you don't damage the display or the computer.

On the CD, select Board of Education and read the Board of Education Manual pages 24 – 32. Under the Basic Stamp heading, read the Basic Stamp Manual pages 25-38 which describe how to connect the serial cable between the Board of Education and your serial port and how to install the Stampw.exe file onto your computer. The serial cable is used in the downloading of the BASIC program to the BASIC Stamp chip. When the reset switch is pressed, it will restart the execution of the downloaded program.

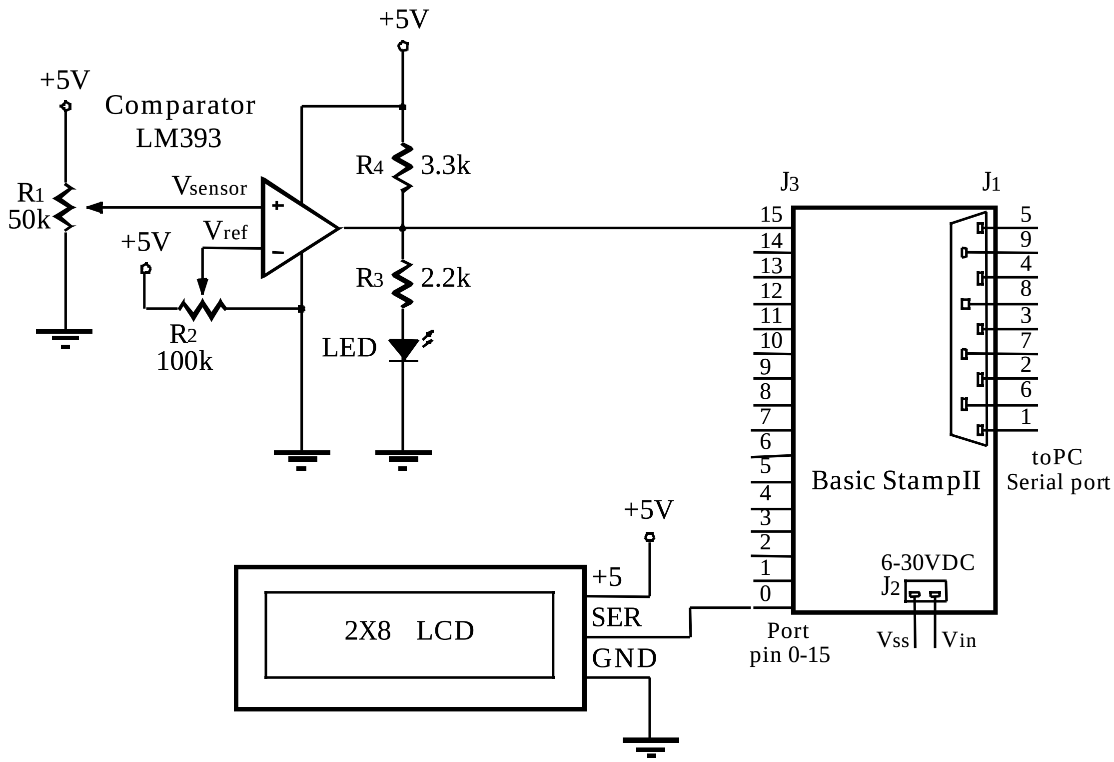


Figure 5.12 Complete hand grip exerciser schematic

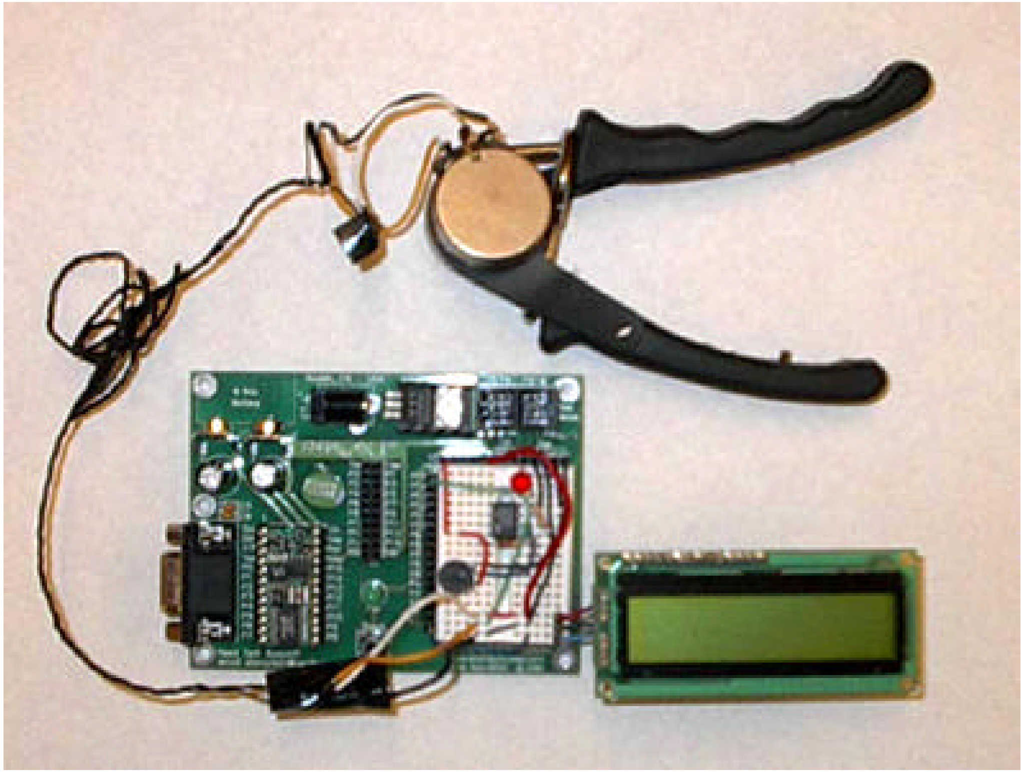


Figure 5.13 Implementation of hand gripper

The photo of Project 2 is shown in Figure 5.13.

5.2.5 Software

The program shown in Table 5.2 can be copied from the computers on the laboratory or it can be typed into a Windows or Mac computer as directed in the manual on the CD. This software program is then to be downloaded into the Basic STAMP II via the 9-pin serial cable. This program will count the number of times that the comparator goes from a low voltage to a high voltage and display that count on the LCD module.

Table 5.2 Software to operate STAMP as a counter

```
'******************** Basic Stamp Project ******************

'********************* Declare Variables *******************

'{$STAMP BS2}                          'Identifies processor type
FLAG        var     bit                'Comparator output high or low?
TOTAL       var     word               'Count of lows to highs

'******************* Initialize Constants *******************

N9600       con     $4054              'Set baudrate to 9600
```

```
I           con   254         'Instruction prefix value
CLR         con   1           'LCD clear-screen instruction
L2_C4       con   195         'Line 2, character 4 code
L2_C10      con   202         'Line 2, character 10 code

'************* Initialize Display & Variables ***************

INIT:                          'Start of program
 pause 100                     'Small delay
 serout 0,N9600, [I,CLR]       'Clear the display
 pause 1                       'Small delay
 serout 0,N9600, ["THREE MUSKETEERS"] 'Insert your names here
 serout 0,N9600, [I,L2_C4,"Count:"] 'Dislay Count:

 FLAG = 0                      'Set FLAG to 0
 TOTAL = 0                     'Set the counter to 0


'*********************** Main Program ***********************

MAIN:
 pause 100                     'Small delay for debouncing
 if in15 = 0 then OFF          'If P15 is low, go to OFF
 if in15 = 1 then ON      'If P15 is high, go to ON
 goto main                     'Loop to MAIN forever

OFF:
 FLAG = 0                      'Set FLAG to 0
 goto MAIN                     'and return to MAIN

ON:
 if FLAG = 1 then MAIN         'If flag was already 1, go to MAIN
 TOTAL = TOTAL + 1             'else increment the counter
 serout 0,n9600, [I,L2_C10]'On line 2, character 10
 serout 0,n9600, [dec TOTAL,"  "]'display the counted decimals
 FLAG = 1                      'Reset the flag to 1
 goto MAIN                     'and return to main
```

5.3 Parts

ELEC 199 Project Course Parts

Parts assembled as a kit (approximate cost $300).

- Basic Stamp II Education Kit
- LCD display, 2 X 16 Characters
- Digital Multi-meter
- 50k Potentiometer
- 100k Potentiometer
- Comparator
- Red LED
- 1k Resistor
- 5.7k Resistor
- Long nose pliers
- Wire stripper
- Tool Box
- DB-9M to DB-25F adapter
- Beam scale with force sensor FSR-400 by Interlink Electronics

Additional subsystem is supplied by the ECE Department:

- Hand grip with mounted 50k potentiometer

Table 5.3

Component	Specifications
Hand grip	
Comparator IC	LM383N
LED	5mm (Red)
Battery	9V
LCD Module	www.stampsinclass.com
BASIC Stamp II	www.stampsinclas.com
Potentiometers	50kΩ & 100kΩ
Resistors	Variety
Capacitors	Variety
Force Sensor	FSR – Inter-Electronics
Multimeter	Range, M830 BUZ
Hinge	1" wide
Wooden Plates	20x3 / 2x1 / 2"

6. Useful References and Internet Recourses

Books

1. Scott Edwards, *Programming and Customizing the Basic Stamp Computer*, McGraw-Hill, 1998, USD34.95

2. Basic Stamp Manual Version 1.9 by Parallax (www.parallaxinc.com)

Internet Sources:

http://www.howstuffworks.com/

· How Car Engines Work
· How Web Pages Work
· How Cell Phones Work
· How CDs Work
· How Jet Engines Work
· How Telephones Work
· How Web Servers Work
· How Diesel Engines Work
· How Television Works
· How Toilets Work

http://www.cln.org/

Welcome to the Community Learning Network WWW home page. CLN is designed to help K-12 teachers integrate technology into their classrooms. We have over 265 menu pages with more than 5,800 annotated links to free resources on educational WWW sites -- all organized within an intuitive structure.

http://www.cln.org/searching_home.html

Search Engines and Subject Directories

http://webhome.idirect.com/~jadams/electronics/,

Welcome! This website allows you to browse the subject of ELECTRONICS. If you are just starting the journey of learning electronics, I hope you'll make use of the simple nature and graphical content of this site. Feel free to look around. Don't worry -- there are no tests at the end of the day.

http://www.cln.org/themes/electronics.html

Electronics (Circuitry) Theme Page

Below are the CLN "Theme Pages" which support the study of electricity and electronics CLN's theme pages are collections of useful Internet educational resources within a narrow curricular topic and contain links to two types of information. Students and teachers will find curricular resources (information, content...) to help them learn about this topic. In addition, there are links to instructional materials (lesson plans) which will help teachers provide instruction in this theme.

http://ourworld.compuserve.com/homepages/Bill_Bowden/

A small collection of electronic circuits for the hobbyist or student. Site includes 93 circuit diagrams, links to related sites, commercial kits and projects, newsgroups and educational areas. Most circuits shown here can be built with common components available from Radio Shack or salvaged from scrap electronic equipment. Almost all of the circuits have been built and tested and are believed to perform as described. However, possible mistakes may be found. New items are shown in red color.