UNIT 1
INSTRUCTOR'S MANUAL

INTRODUCTION TO PROGRAMMABLE LOGIC CONTROLLERS

1. This unit has no Experiment section because it provides general information about programmable logic controllers. You may want to proceed directly to Unit 2 so that the students can apply this knowledge to their own PLC.

2. It is advisable to review the organization of this manual with the students during the first instructional session. They will need to refer to the Appendix during future units. They should also know how to locate programming information in the specific units.

UNIT 1

INTRODUCTION TO PROGRAMMABLE LOGIC CONTROLLERS

Objectives

Upon completion of this unit the student will be able to:

1. Identify the three basic sections of a programmable logic controller.
2. List several applications of a programmable logic controller.
3. Explain the advantages of a programmable logic controller over a hard-wired relay circuit.
4. Define the terms: input device, output device, input module, output module, controller.

Background

Until recently, *input devices*, such as switches and sensors, and *output devices*, such as motors, lights, buzzers and *relays*, had to be linked together permanently. These *hard-wired* circuits are electrical control systems which are constructed to do a specific job. They use mechanical relays, *timers*, *counters* and switches wired together in different combinations to create control circuits. Typical control circuits take care of jobs like turning machines on and off in an automated factory. They also turn the lights and furnaces on and off in sports stadiums and control the valves and brushes in a car wash.

Hard-wired circuits are very difficult and costly to design and build. If they ever need to be modified or replaced, they must be torn apart and rewired. Such changes are also very costly and often extremely difficult. With the *Programmable Logic Controller* (*PLC*) there are no mechanical relays, timers or counters. All of these functions are taken care of within the PLC's computer.

A Programmable Logic Controller is a device which uses a computer to turn output devices, such as motors, lights, buzzers, and relays, on and off in response to input devices, such as switches and sensors.

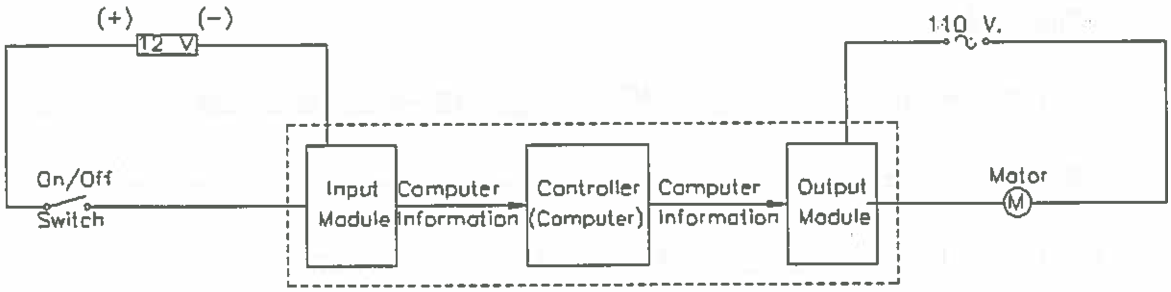
*All words and phrases printed in *italics* are defined in Appendix A: Glossary.

A typical PLC has three sections, *the input module*, the *output module*, and the *controller*, or *processor*. The input module has several electrical connections which are connected to the input devices. When electricity is supplied to a connection, the input module tells the computer that this connection has been activated. More than one connection can be activated at a time.

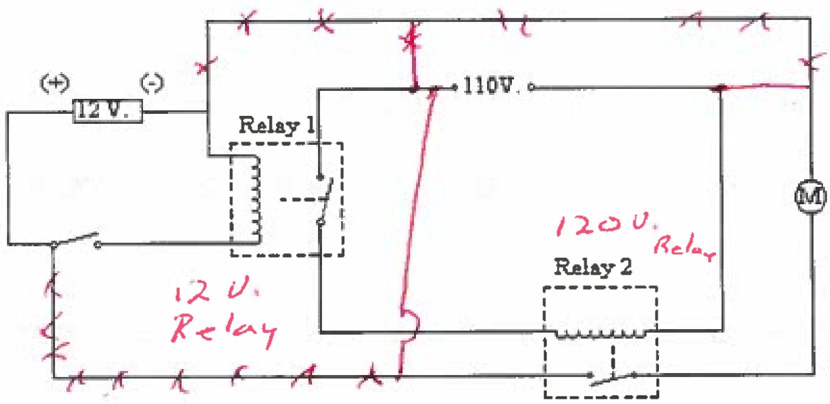
The output module contains miniature switches which, based on its *program*, the computer then tells to open or close (turn off or on), operating connected output devices. The controller is the part of the PLC which houses the computer and determines when, based on its input, an output will be activated. The computer's decisions are programmed by the PLC operator. The PLC in your system has the input and output modules and controller all in one package.

For the computer to interface with the outside world it needs a translator. This translator is the combined input and output modules. In order to modify a circuit, it is only a matter of modifying a computer program to connect new input and output devices being put to use. This process is much less expensive than modifying hard wiring. Therefore, PLCs are better to use when electrical circuits need to be changed frequently. Some examples of applications are robot control, lighting controls in stadiums, food processing controls, pumping station operation, and elevator control.

Figure 1-1 illustrates a comparison of a PLC circuit and a hard-wired circuit. Notice the two mechanical relays in the hard-wired circuit. If a different type of relay were needed, the existing relays would have to be replaced physically. In the PLC, both relays are described in the PLC's program. To change a relay in the circuit, a simple change is made in the PLC's description of the relay. No physical changes need to be made.



Relay 1 & 2 shown below exist
only as a program in the PLC controller



NOTE: All connections between components
must be made with wires.

Figure 1-1
PLC vs. Hard Wiring

To assess your understanding of the information above, please answer the Questions which follow.

Questions

1. What is a PLC?

 A programmable logic controller (PLC) is a device which uses a computer to turn output devices on and off.

2. What is the difference between a PLC and a hard-wired circuit?

 If a hard-wired circuit needs to be changed, the components must be rewired, a very expensive process. With a PLC, only the program must be modified to change the circuit operation.

3. Describe the three basic sections of a PLC.

 Input module - tells the computer that the connection from an input device has been activated or de-activated.

 Output module - contains the relays which tell output devices when to operate, based on the program.

 Controller - houses the computer for the PLC and determines, based on its program, when outputs should be activated and de-activated.

4. Give at least three examples of how a PLC might be used.

 Robot control, elevator control, lighting systems such as in stadiums, pumping station operation, food processing systems.

5. Define the following terms:

a. Input Device

Electrical device, such as a switch or sensor, used to signal the PLC input module.

b. Output Device

Electrical device such as a motor or light which is controlled by the PLC output module.

c. Input Module

The part of the PLC which signals the computer that an input device has been activated.

d. Output Module

The part of the PLC computer used to control the output devices.

e. Controller

The central part of the PLC. The computer which interprets the electrical signals from the input modules and translates the program into electrical signals to the output modules.

UNIT 2
INSTRUCTOR'S MANUAL

INTRODUCTION TO THE MB655 SYSTEM

1. Since this unit presents all of the components of the system, the students should be encouraged to examine the kit as they read the background materials.

2. Correct safety and handling procedures should be emphasized because the students will be wiring the panel during the Experiment.

3. The Experiment is designed to demonstrate to the students what types of feedback they can expect to receive from the PLC and from the panel. It also familiarizes them with the locations of specific types of feedback information.

4. The wiring used during the experiment by-passes the PLC to provide power directly to input and output devices. Be sure to examine and approve each student's wiring (Step 4) before allowing him to proceed with the Experiment (Step 4).

5. If the students have a limited background in electricity, you will need to help them understand the differences between normally open and normally closed switches and between momentary and maintain switches.

6. Built-In Applications are detailed in Appendix E.

Unit 2

INTRODUCTION TO THE MB655 SYSTEM

Objectives

Upon completion of this unit the trainee will be able to:

1. Identify the components of the Allen-Bradley MicroLogix 1000 PLC.
2. Describe the input and output devices.
3. Describe the built-in applications.
4. Describe the Built-In Applications
5. Describe handling and safety procedures.
6. Construct simple input/output connections.

Background

The Allen Bradley MicroLogix 1000 System is designed to introduce you to basic MicroLogix operation and programming. In order to accomplish this you will have to study simple electrical circuits, numbering systems, some essential mathematics and ladder logic diagrams. First you will have to familiarize yourself with the kit hardware.

The power cable for the kit plugs into any grounded (three-prong) 110-volt outlet. The grounded outlet is available at the upper edge of the controller body. The power indicator light turns on when the system is on. This light signifies that the system is operable.

NOTE: This switch should **always** be set to **OFF** before plugging in the system.

The System can be divided into six sections:

1. PLC and its components.
2. Input / Output devices.
3. Input / Output interfaces.
4. Built-in applications.
5. On Board power supply and
6. Extra Equipment.

Sections 1 through 5 are located on the panel, as shown in Figure 2-1. The extra equipment is packaged separately within the System suitcase.

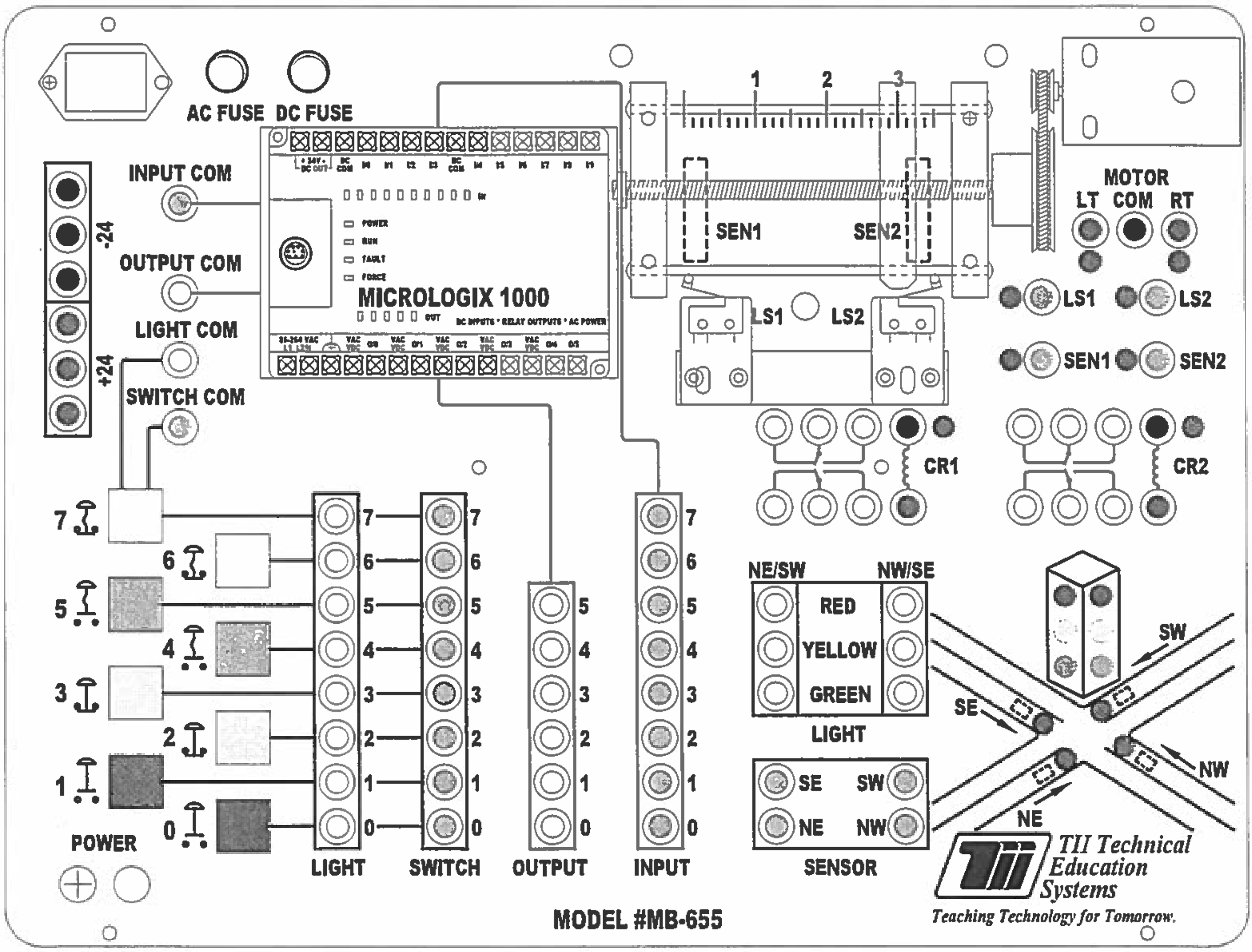


Figure 2-1
System Panel Layout

The PLC and its Components

There are ten parts to the controller of the PLC as shown in Figure 2-2. They are:

1. Input Terminals
2. DC Output Terminals
3. Mounting Hole
4. Input LEDs
5. Status LEDs
6. RS-232 Communication Channel
7. Output LEDs
8. Power Supply Line Power
9. Ground Screw
10. Output Terminals

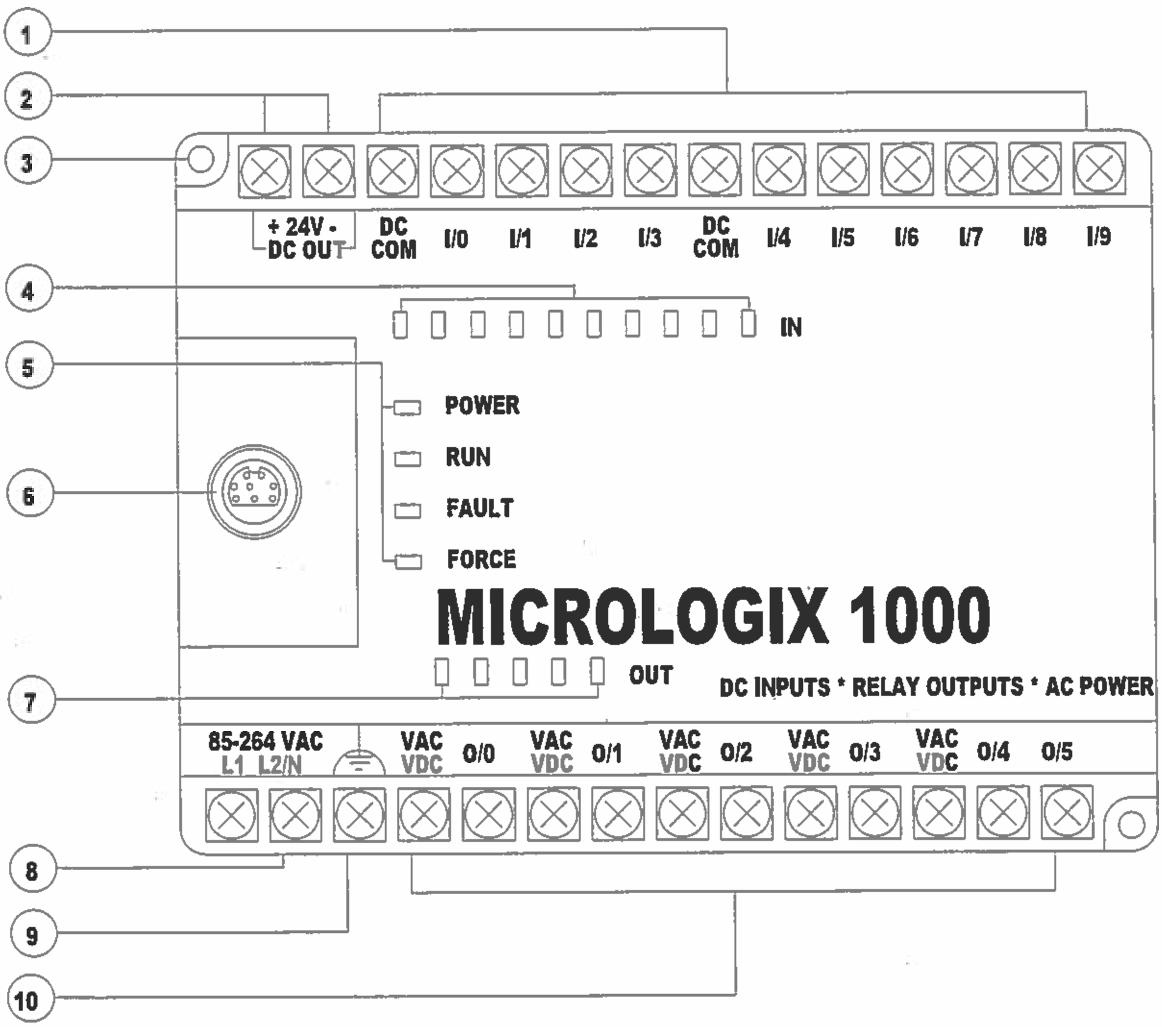


Figure 2-2
MicroLogix 1000 PLC

Diagnostic Indicator Lights

There are 4 indicator lights on the front panel of the controller. These lights illuminate as follows:

1. **Power:** The PLC is running on power supplied by an internal power supply.

2. **Run:** The unit is in run mode.

3. **CPU Fault:** When an Error has been detected in the central processing unit.

4. **Forced I/O:** One or more input addresses have been forced into on or off status.

Input Terminals

Most of the terminals along the upper edge of the body are dedicated to the input devices. There are typically 10 input terminals from I:0/0 to I:0/9. Only 8 of the 10 inputs are used in the MB655. Most of these terminals are used to connect the input devices to the input module in the controller.

Output Terminals

The output terminals are located along the lower edge of the controller body. There are typically 6 output terminals from O:0/0 to O:0/5. They are used to connect the output module to the output devices. There is a power supply terminal adjacent to every output terminal.

Input Status Indicators

These lights reflect the status, on or off, of the input devices connected to the terminal. Note that the input terminal and the input LED are identified by the same series of numbers, the addresses of the inputs in the input module.

Output Status Indicators

These lights reflect the status, on or off, of the output element of the same number in the output element of the same number in the output module. They respond only when the controller is programmed and set on RUN.

Handheld Programmer Connection (Optional)

An eight-prong circular plug is used to connect the handheld programmer to the controller. When the pendant is in use, a small door covers the connector to protect it.

EEPROM

The MicroLogix has a built in electrical erasable programmable read only memory (EEPROM). An EEPROM is a computer chip used for storing and retrieving a MicroLogix program, which cannot be removed from the controller unit.

Handheld Programmer (Optional)

The handheld programmer is the device that permits the operator to communicate with the MicroLogix's central processing unit. It is a separate unit that can attach to the PLC. It contains a set of function keys and a LCD display screen for viewing the program being entered.

The handheld programmer is connected to the controller by the programmer cable. One end of the cable plugs into the top edge of the pendant. The other end plugs into the programmer connection on the MicroLogix 1000. The handheld programmer and cable are fixed in place to allow for more comfortable use.

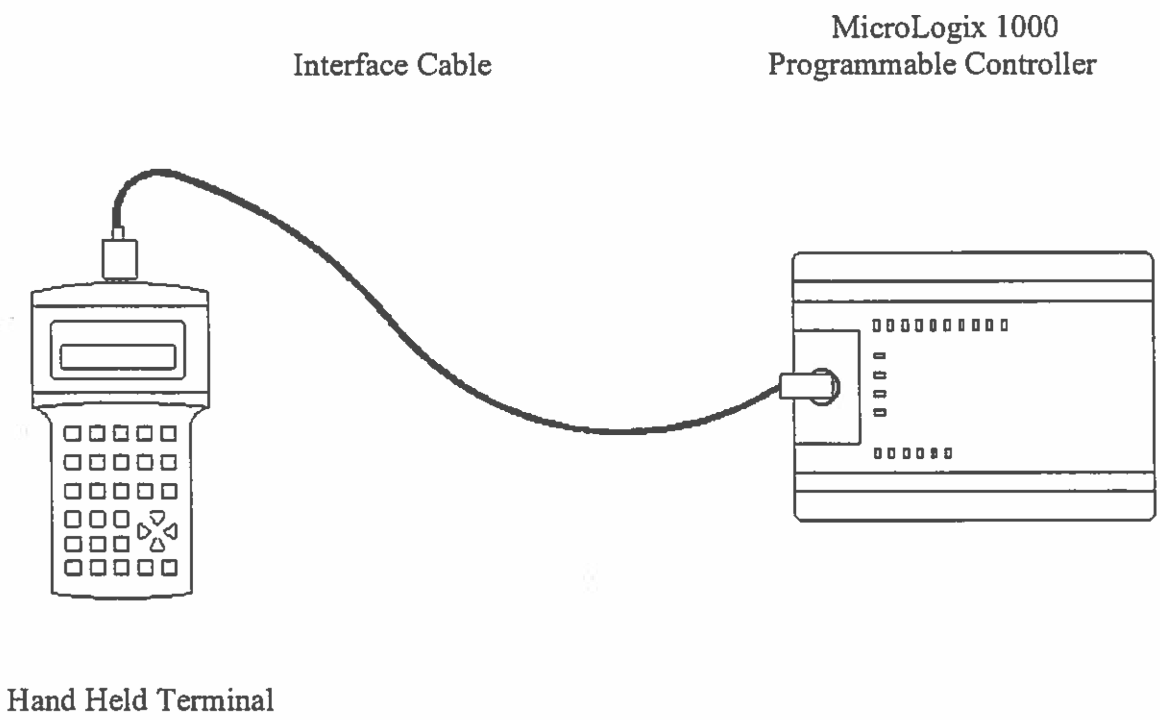


Figure 2-3
PLC Programming Pendant and Connector

Input/Output Devices

Below to the left of the MicroLogix 1000 are two rows of switches numbered 0 through 7. These switches serve as input devices for the system and are used to send signals to the MicroLogix.

There are four different types of switches on the panel. Switches 0 and 1 are *normally open momentary switches*. Switches 2 and 3 are *normally closed* momentary switches. Switches 4 through 7 are *maintain* switches. 4 and 5 are normally open. 6 and 7 are normally closed.

Each of the switches has a light inside it. These lights serve as output devices and will be controlled by the MicroLogix programs.

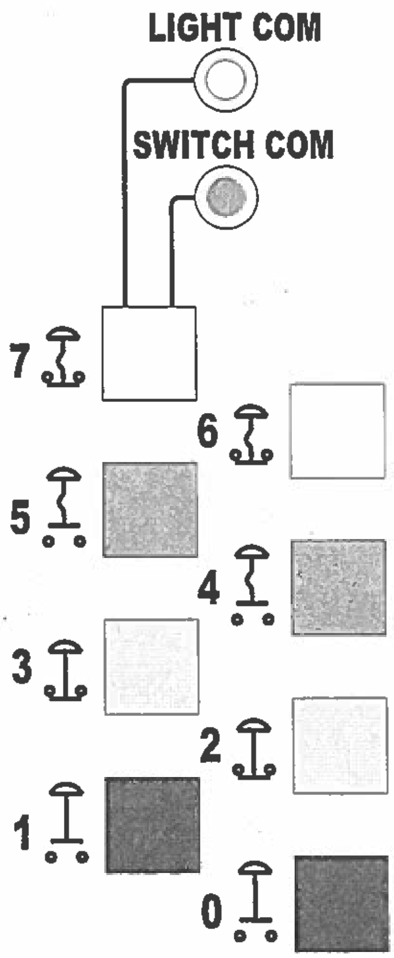


Figure 2-4
Details of Input/Output Devices on Trainer Panel

Input/Output Interface

The Input/Output interface is located in the lower middle portion of the panel. The RS-232 interface communication channel allows for easy connectivity with your programming device. There are 8 input banana jacks numbered 0 through 7. Each connector is wired directly to the input terminal with the same address on the MicroLogix 1000. Devices such as switches and types of sensors connect to these banana jacks to send signals to the MicroLogix 1000. The adjacent column contains the output connectors, six output banana jacks numbered 0 through 5. These connectors are wired directly to the output terminals with the same address on the MicroLogix 1000. When a MicroLogix program turns on an output, the connector becomes electrically charged and can be used to operate devices such as lights, motors and valves.

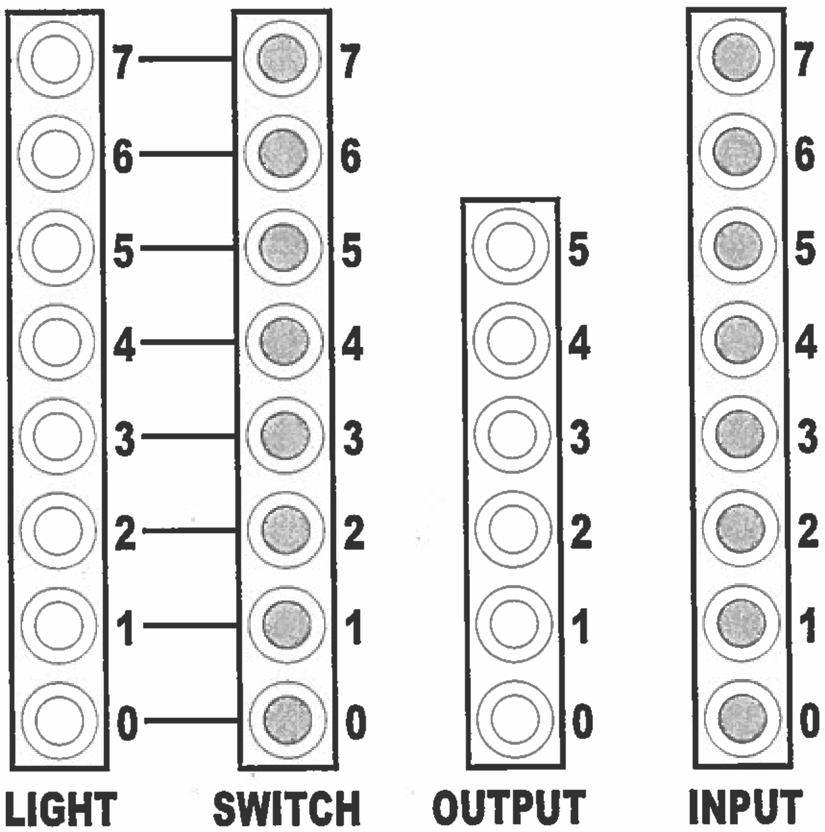


Fig 2-5
Details of Input/Output Interface on Trainer Panel

Built-In Applications

There are two built-in PLC applications located along the top and bottom right-hand side of the panel: Motor/Screw Motion and Traffic Light Intersection. These applications are designed to give the PLC user practical programming experience in controlling apparatus and devices that replicate real world situations and systems.

The Motor/Screw Motion application (See figure 2-6)consists of a DC motor operated screw mechanism with limit switches and sensors. As the moving part travels along the screw path, limit switches and proximity switches are activated. The Traffic Light Intersection (See figure 2-7) application is a silkscreened pictorial of a single traffic light controlled four-way intersection with vehicle representations available for each travel path of the intersection.

By connecting the banana jacks next to the application devices to the jacks of the PLC inputs/outputs interface with the supplied jumper wires (patchcords), an electrical wiring connection is made. When these connections are made, the application devices can be controlled through the PLC inputs and outputs consistent with the ladder logic program residing in the PLC's memory. Alternatively, the device jacks can be connected to the panel input/output lights and switches jacks for pushbutton manual operation.

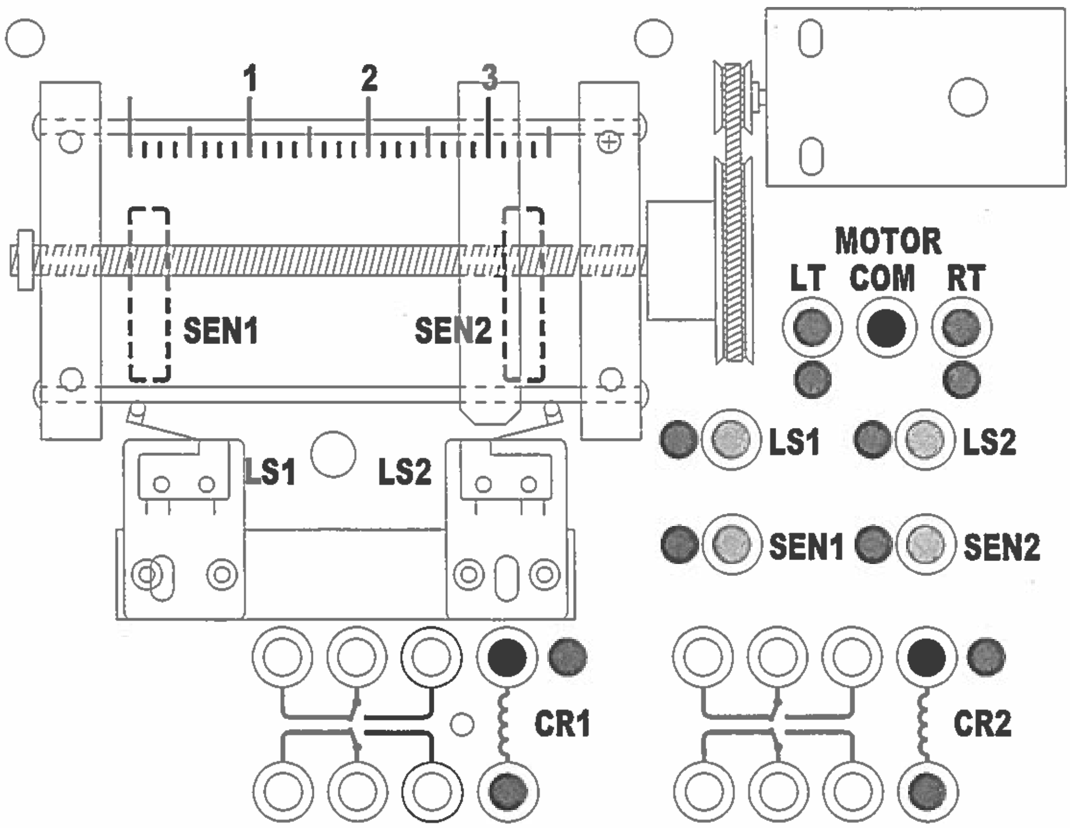


Figure 2-6
Motor/Screw Motion Application

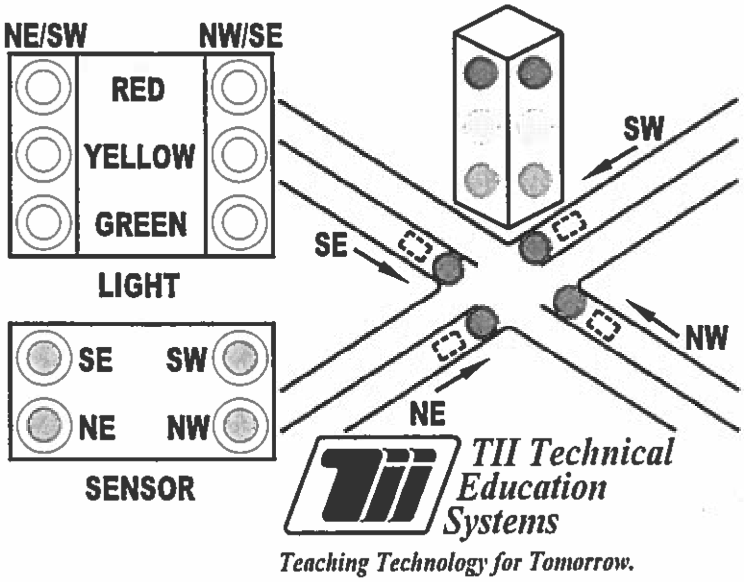


Figure 2-7
Traffic Light Intersection

On-Board Power Supply

The column of connectors on the upper left-hand edge of the panel is an external power strip (see Figure 2-8). The strip is divided in half. The lower (red) half is wired to +24 volts D.C. (VDC) and the upper (black) half is wired to –24 volts D.C. (VDC). These connectors are used for supplying power to output devices. The Allen-Bradley MicroLogix 1000 PLC controllers have their own on-board D.C. power supplies for providing power to input devices. (See Unit 5 for further explanation of D.C. power.)

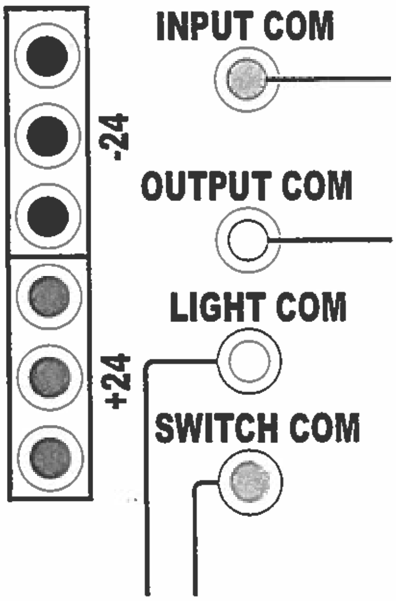


Figure 2-8
On-Board Power Supply

Extra Equipment

Jumper Wires. A set of jumper wires equipped with banana plugs is included in the System. These wires will be used to connect input and output devices to the controller through the I/O interface. The wires will be used throughout the Experiments and should be kept with the System.

Independent Light Bulb. A 24-volt light bulb with banana plug connectors is included for use in several experiments. You will be instructed when and how to use it.

Independent Switch. A separate normally open momentary switch with banana plug connectors is included for use in several experiments. You will be instructed when and how to use it.

Fuse

The System panel is equipped with a 1-amp fuse connected to the I/O interface. Should an improper electrical connection be made, this fuse will burn out and need replacement. If the I/O interface stops functioning, be sure to check this fuse and replace it as needed.

Handling and Safety

In order to operate the PLC System effectively, there are several handling and safety procedures that should be adhered to:

1. Keep the unit clean and dry at all times. Do not eat or drink while working with the System.
2. Always use a fully grounded (3-prong) output for your power source. Turn the ON/OFF switch to OFF before plugging in the System.
3. Check for a stored program before putting the controller into RUN mode. (This is a very important safety precaution on a shop floor.)
4. Keep fingers and objects away from the 110-volt (or 220-volt) terminals on the top left edge of the controller body (see Figure 2-2). You can get an electrical shock from touching them.
5. **NEVER** make the following connection:

Red to Black

EXPERIMENT

Purpose

To make connections using the lights and switches on the System panel.

Procedure

1. Open the System kit and check the setting of the ON/OFF switch. Set it correctly (OFF).

2. Plug the power cord into a 110-volt grounded outlet.

3. Connect a jumper wire from –24 VDC (black) to Light Common and a second jumper wire from +24 VDC (red) to Switch Common.

4. Turn on the power switch and note, which lights on the panel and controller illuminate.

   Panel - power on indicator light turns on in lower left corner.

   Controller - power indicator LED lights up on controller body.

5. Connect a jumper wire from switch connector 0 to light connector 0, as in Figure 2-9. Press and hold switch 0.

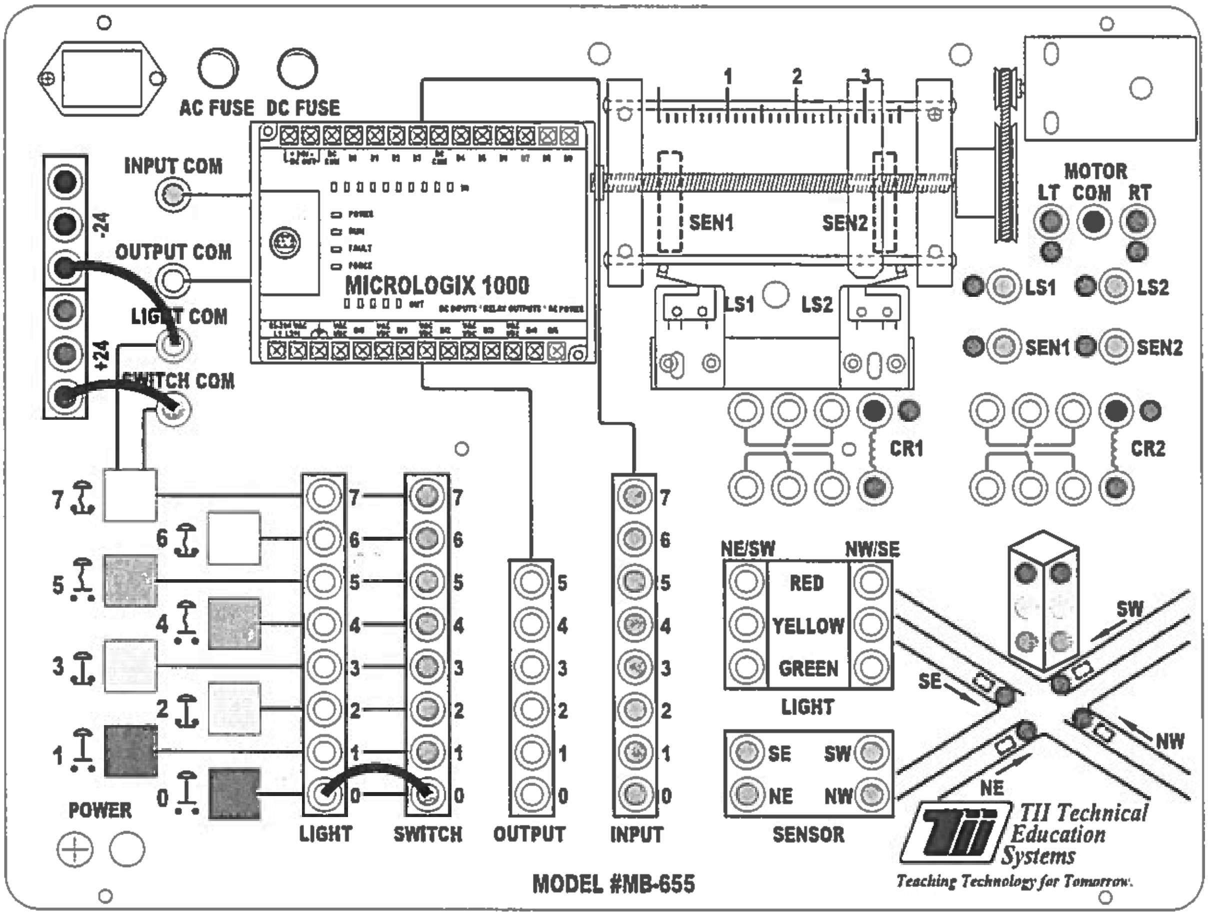


Figure 2-9
Hardware Set Up for Step 4

What changes occur on the panel and controller?

No changes occur on the controller. Light 0 turns on and stays on.

6. Release the switch.

What do you observe?

Switch 0 returns to its up (off) position. Light 0 turns off.

7. Move the jumper wire from switch connector 0 to switch connector 6. Repeat steps 5 and 6 using switch 6.

What do you now observe on the panel and controller?

Nothing happens on the controller. Light 0 comes on immediately and turns off when switch 6 is pressed. Switch 6 stays down when released.

8. Press switch 6 again.

Now what happens to the lights and switches?

Switch 6 returns to its up position and light 0 comes back on.

9. Remove the jumper wire you have been using and connect it between a +24 VDC (red) terminal and any light connector. (You will have to patch together two jumper wires.)

How do the output devices respond?

The light to which the jumper wire is connected turns on immediately.

10. Repeat Step 9 with the jumper wire plugged into a –24 VDC (black) terminal.

How do the lights respond this time?

None of the lights come on.

11. Connect the jumper wire between any light connector and switch connector 0. Test the operation of switch 0. Then test the operation of each of the other switches by moving the jumper wire from one switch connector to the next and pressing the corresponding switch. Make note of anything unusual about the way the switches operate.

There is no correct answer for this step. It is designed for the student's own use, to help him remember how each switch operates.

12. Once you are familiar with the operation of the various components on the System panel, respond to the Questions that follow.

Questions

1. What is the function of the I/O interface on the System panel?

The I/O interface is used to connect the input devices to the input modules on the PLC. It is also used to connect the output devices to the output module on the PLC.

2. Explain the functions of the status indicator lights on the PLC.

Power – PLC is running on power supplied by an internal power supply.

Run – This status indicator light indicates controller is in RUN mode (running a program).

Fault – This status indicator light indicates that an Error has been detected in the central processing unit.

Force – This indicates that one or more input addresses have been forced into on or off status.

3. What are the differences between switches 0 and 6 on the panel?

Switch 0 is a normally open momentary switch. It must be pressed before electricity flows through it. Switch 6 is a normally closed maintain switch. Power flows through it until it is pressed.

4. What is the on-board power supply used for?

The on-board power supply provides electricity for the switches and lights (output devices).

5. What is represented by the numbers on the I/O interface?

The numbers identify the address of the terminal on the PLC to which the connector is hardwired. Each number corresponds to a specific address of the same number in the input module or output module, as appropriate.

6. What applications are built in?

The Motor/Screw Motion and traffic light intersection.

UNIT 3
INSTRUCTOR'S MANUAL

SERIES AND PARALLEL CIRCUITS

1. This unit provides a review of basic D.C. circuit construction. If the students are very knowledgeable, a brief overview of background information should be sufficient. However, be sure they complete the Experiment so that they are fully aware of how series and parallel circuits function on the panel.

2. The differences between A.C. and D.C. power are introduced, but no attempt is made to teach A.C. circuitry. All Experiments depend on D.C. circuits only.

UNIT 3

SERIES AND PARALLEL CIRCUITS

Objectives

Upon completion of this unit the student will be able to:

1. Describe the three basic components of a circuit.
2. Explain the difference between A.C. and D.C. power and their uses.
3. Describe the current flow in a complete and in an incomplete D.C. circuit.
4. Draw and construct examples of series and parallel circuits.

Background

Series and *parallel* circuits are the cornerstones of electronic circuitry. The three basic components which build these circuits are the *power supply*, output devices, and input or control devices. The power supply provides a source of electric current for the circuit. Output devices use the current for various functions. Control devices direct the flow of current through a circuit. By connecting these devices together in different fashions, complex machines can be built.

Power sources fall into two categories, A.C. and D.C. A.C. stands for Alternating Current. This is the type of electrical power used in houses to run lamps, TVs, and refrigerators. It is also used for most industrial machinery. D.C. stands for Direct Current. D.C. is the type of power which comes from a battery or D.C. power converter such as in toy train sets and battery chargers. The system uses D.C. power to operate its inputs and outputs, so the focus of this unit will be on D.C. circuits.

A battery or D.C. power supply has two connections on it. These connections are called *terminals*. One terminal has a positive charge and the other terminal has a negative charge. Look at the terminal strips in the top left hand corner of the panel. The red connectors are wired to the positive terminal of the power supply; the black connectors are wired to the negative terminal.

When the positive side is connected to the negative side of a power supply, as shown in Figure 3-1, an electrical circuit is created. This connection "completes" the circuit. Electricity leaves the negative side of the power supply and flows toward the positive side. The movement of electricity moving through the wire is referred to as the current. If the wire is broken at any point between the positive and negative terminals, there is no longer a complete circuit and the current stops flowing.

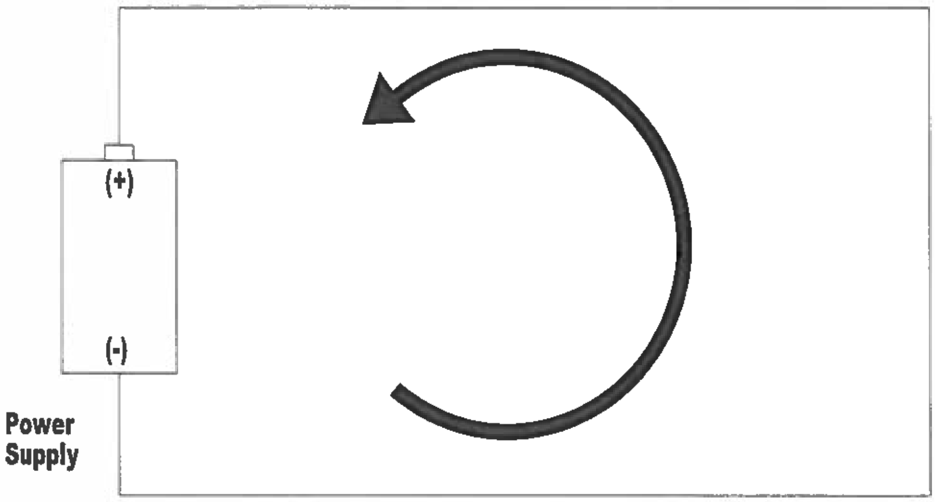


Figure 3-1
Current Loop

The circuit in Figure 3-1 is a complete circuit, but it serves no useful purpose. To construct a useful circuit, an output device must be added. An output device is any device which converts electrical energy (power) into another form. Some output devices are designed for use in A.C. circuits, others for use in D.C. circuits. Common A.C. output devices include refrigerators, household lights, motors, electric heaters, and many small appliances. Examples of D.C. output devices are car radios, battery powered and rechargeable flashlights, model trains, portable stereos, and vehicle operating lights.

As shown in Figure 3-2, an output device, often called a "load," is placed in a circuit between the positive and negative terminals of the power source. In this example the load is a light bulb. When the circuit is completed, the current is forced through the filament of the bulb on its way from the negative to the positive terminal. The current heats up the filament in the light bulb. The filament gets so hot and bright that it emits light.

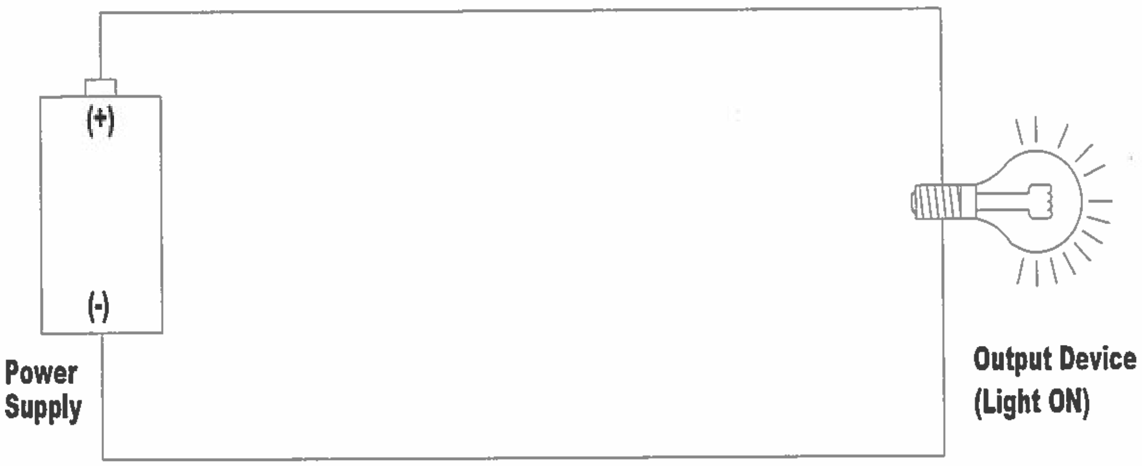


Figure 3-2
Circuit with an Output Device

The circuit in Figure 3-2 can become difficult to operate. The wire has to be disconnected to turn off the light and then reconnected to turn it back on. To make operation simpler, a control or input device can be inserted. The control device will be used to turn circuit power on and off.

The most basic form of control device is the switch. Other control devices include sensors, timers, and counters, which act as special types of switches. A control device is normally installed in a circuit between the output device and the negative side of the power source. Figure 3-3 shows the light bulb circuit with a switch installed.

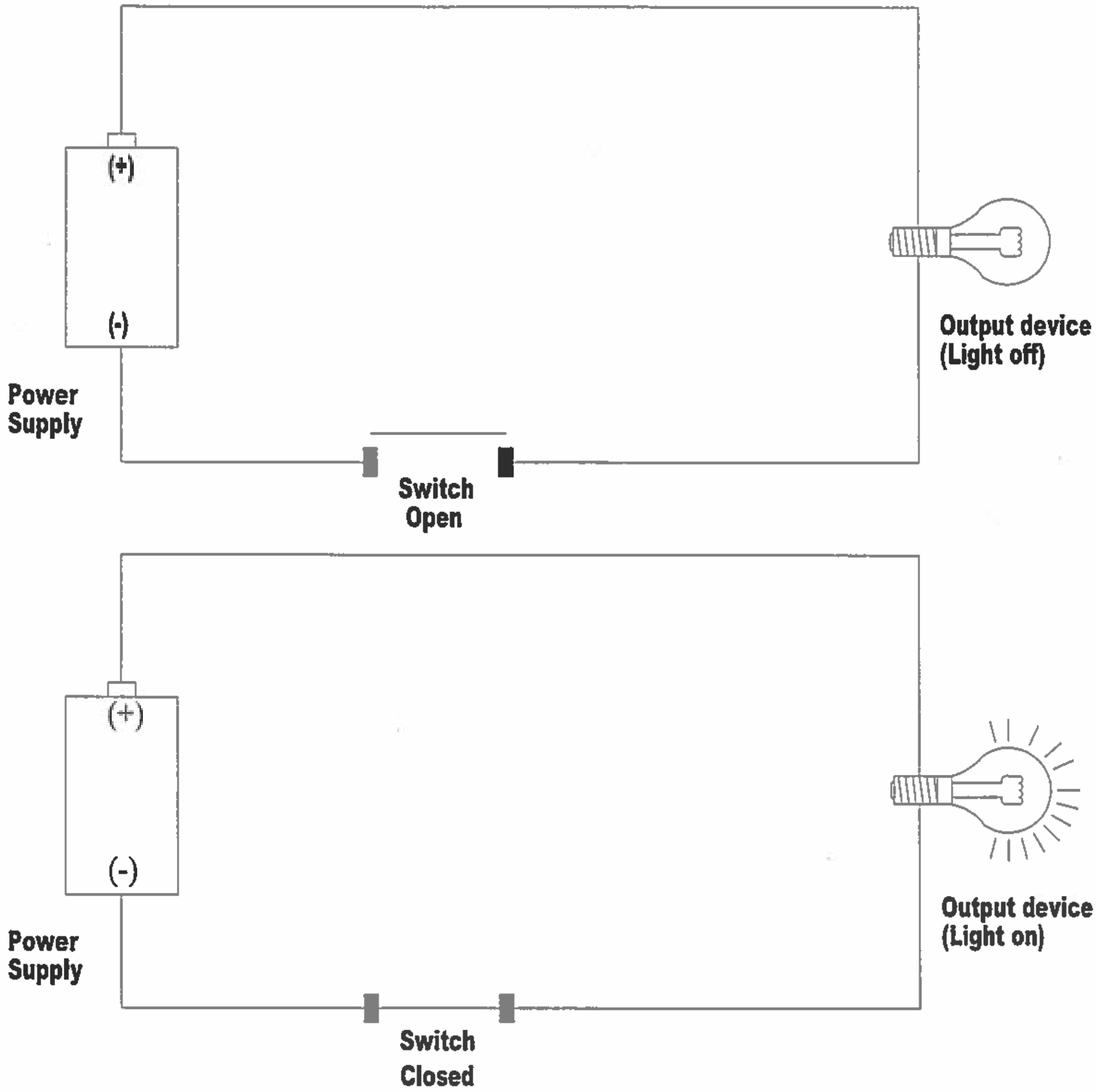


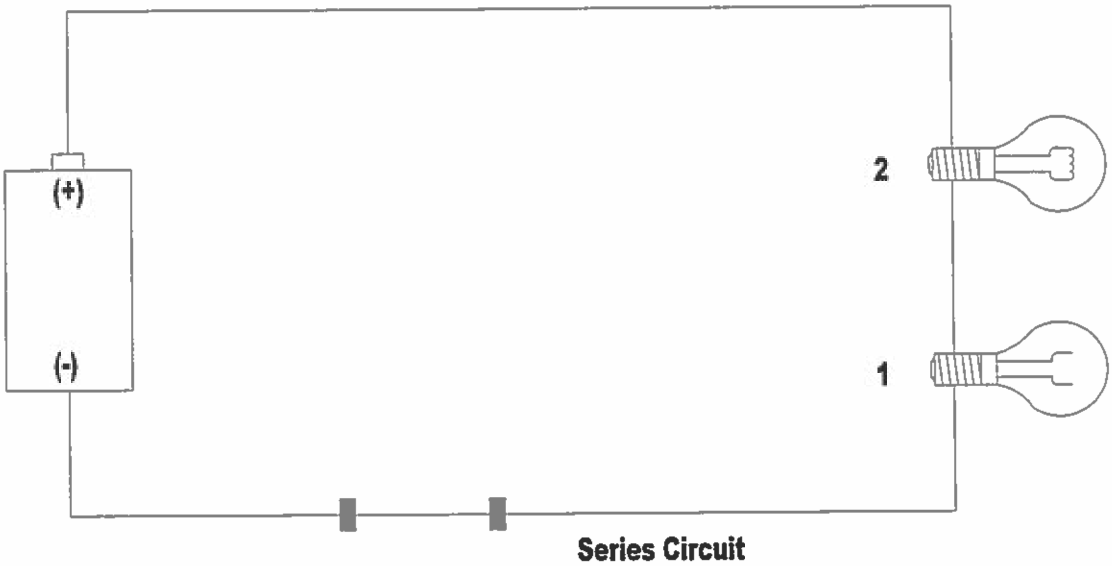
Figure 3-3
Circuit with an Output Device and a Control Device

A switch has two possible conditions or states in which it functions, open and closed. When the switch is closed it allows current to flow through the circuit and power the light bulb. If the switch is open, it breaks the flow of current, just like a break in the wire would. It does not allow a current flow, so the light stays off.

When a switch is manufactured, it can be built in either of two ways. A switch can be *normally open*, so that no current flows through it. A normally open switch must be activated to complete a circuit. Alternatively, a switch can be manufactured so that it is *normally closed*. A normally closed switch allows current to flow through it until it is activated. Once activated, the normally closed switch breaks the circuit. You have both normally open and normally closed switches on the panel.

The circuits examined so far are all series circuits. This name comes from the fact that all of the components fall in a line (in a series), one after the other. If one of the components is the series goes bad and stops operating, the current stops flowing. The whole circuit is "dead."

Another type of circuit is the parallel circuit shown in Figure 3-4. This type of circuit contains more than one path for the current to follow. If one of the components fails, the others can still operate. In the series circuit in Figure 3-4, if light 1 burns out, light 2 receives no power and cannot light up. In the parallel circuit, when light 1 burns out, light 2 continues to operate.



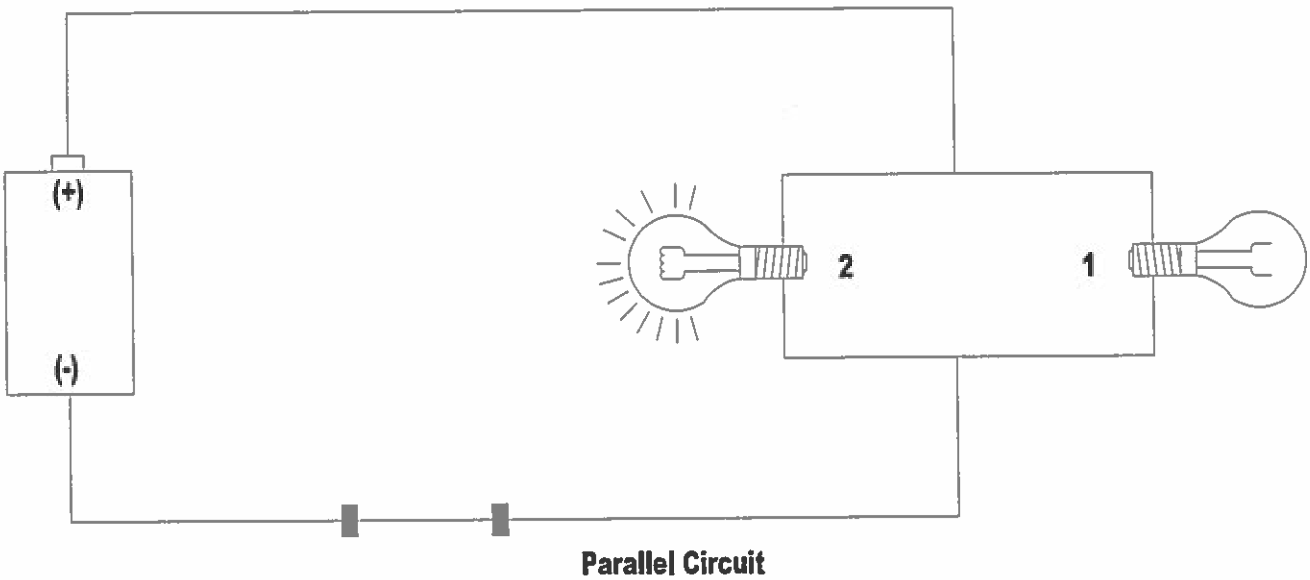


Figure 3-4
Output Devices in Series and Parallel Circuits

Control devices as well as output devices can be wired in parallel. The three switches in Figure 3-5 are wired in parallel. Closing any one of the three switches will complete the circuit and turn on the light bulb.

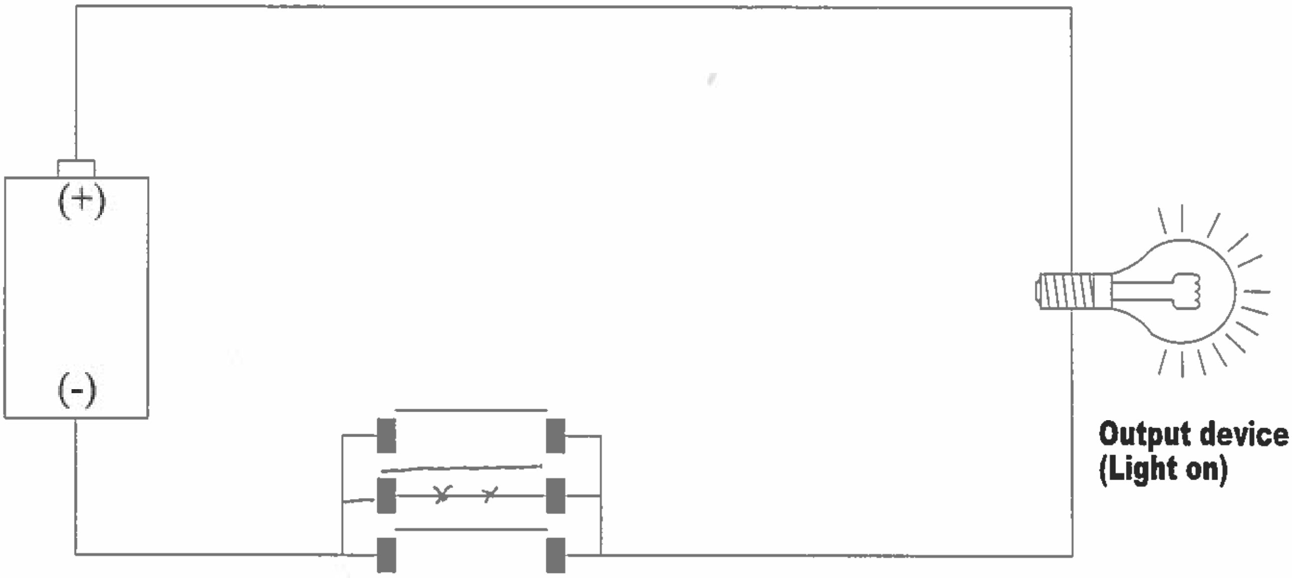


Figure 3-5
Switches in Parallel

EXPERIMENT

Purpose

To design and construct simple series and parallel circuits.

Procedure

1. Open the kit and connect it to a grounded 110 volt wall outlet.
2. Turn the power ON.
3. Using the jumper wires and the independent light bulb, construct the circuit shown in Figure 3-6.

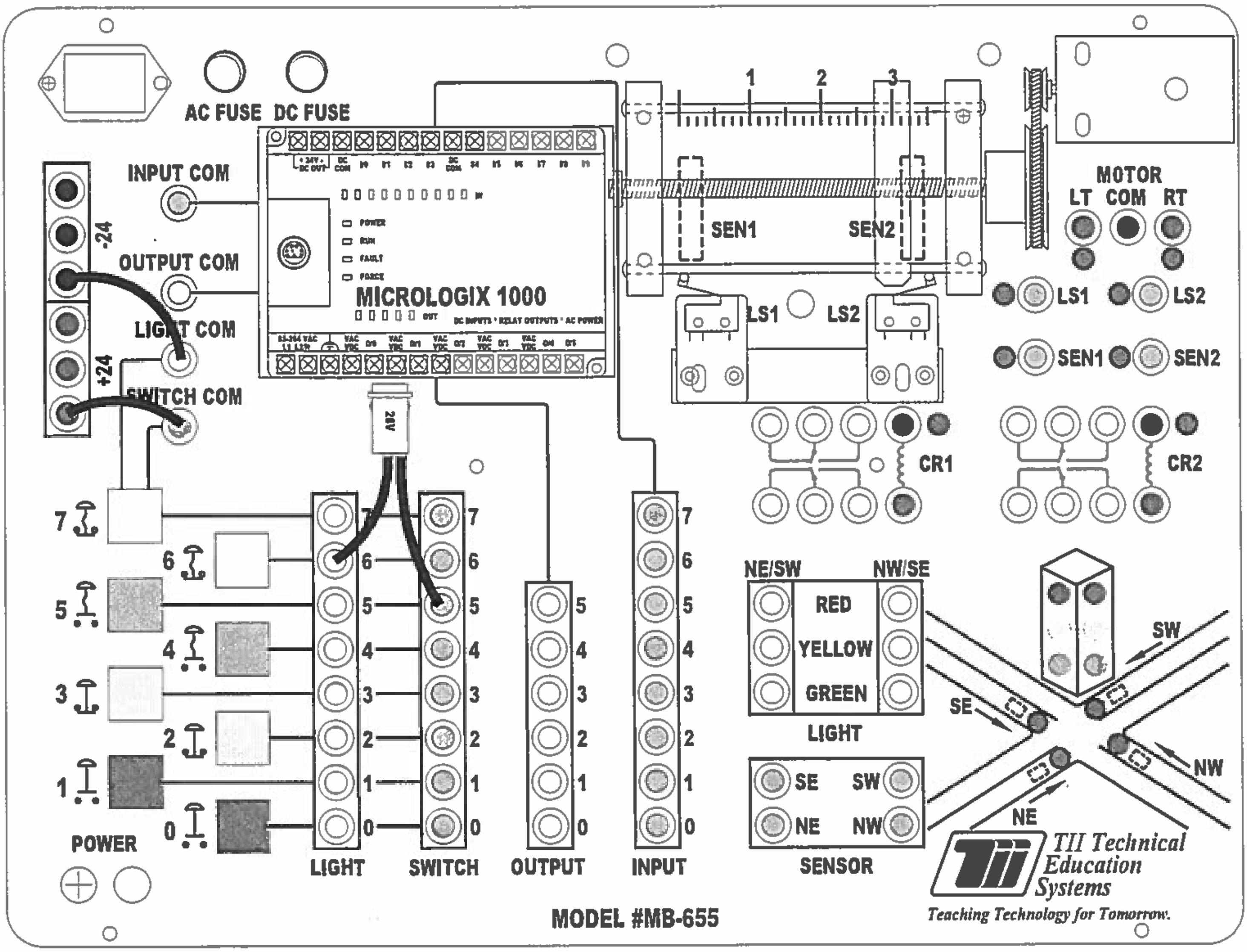


Figure 3-6
Hardware Set Up for Step 3

What type of circuit is it, and what will happen when you depress switch 5?

Two lights in series. Independent light and light 6 in series controlled by switch 5. Switch 5, when pressed, will stay in the pressed (down) position. Both lights will come on together as soon as the switch is pressed. When switch 5 is pressed a second time, it will turn off (up), turning off both lights.

4. Push the switch. (You may have to shade the lights to see if any of them turn on.)

   a. How do events compare with your predictions?

   The student should have found that switch 5 stayed depressed and light 6 and the independent light came on when switch 5 was pressed. (Note that the lights will be fairly dim, so shading them will help the student see how they work.)

   b. What will happen if you press the switch a second time?

   Both lights will go off and switch 5 will stay up once released.

5. Press the switch. What actually happens? Why?

   The lights go off because switch 5 is a normally open maintain switch. Depressed it is closed, in its "on" position. Up it is open or "off."

6. Modify the circuit to that shown in Figure 3-7.

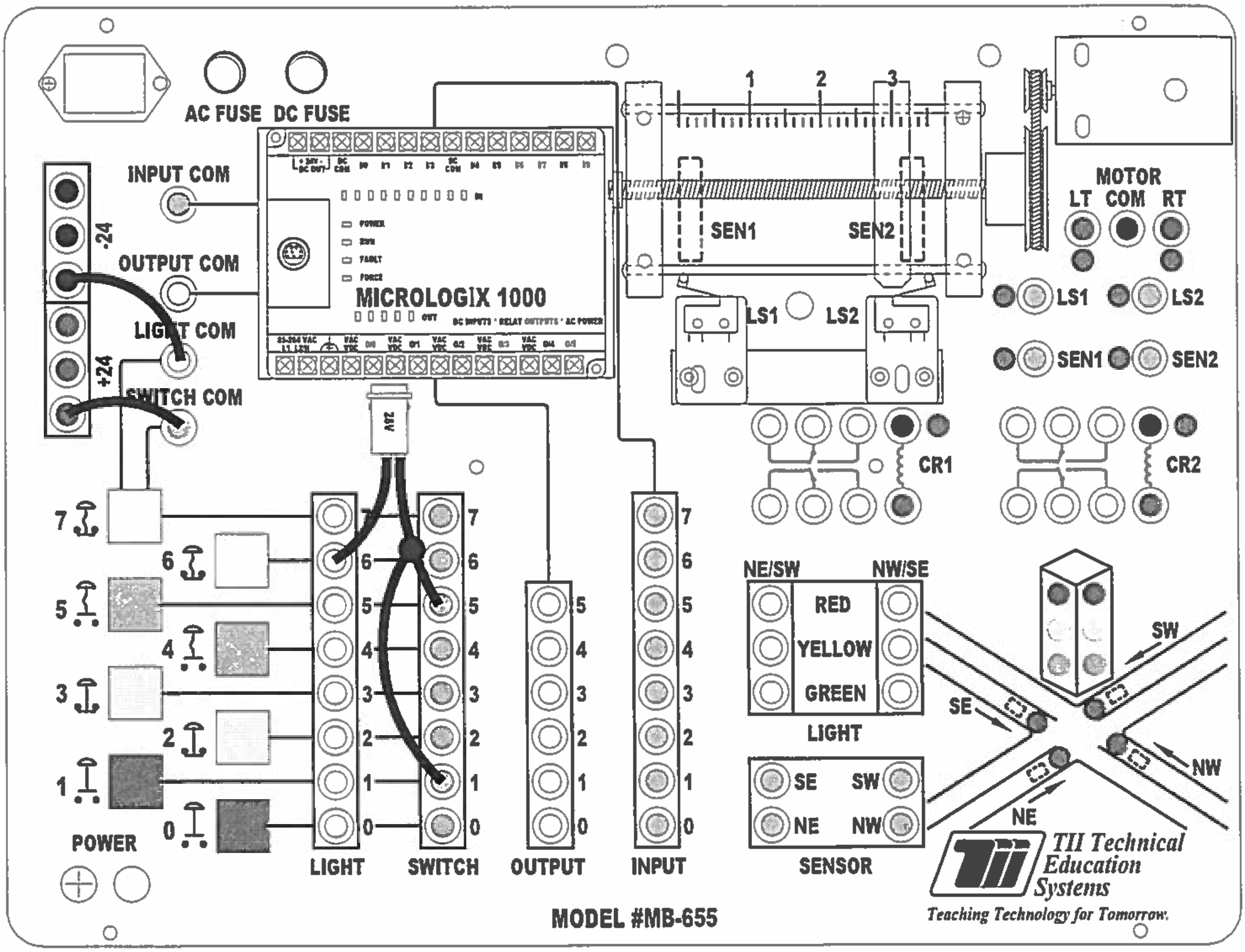


Figure 3-7
Hardware Set Up for Step 6

How will it operate? Why?

Switch 5 will continue to control the lights as it did before. Switch 1 will also control the light. Since switch 1 is a normally open momentary switch, the lights will come on when switch 1 is pressed. As soon as switch 1 is released it will return to its off (up) position and both lights turn off.

7. Press each switch and keep a record of the results in Table 3-1.

Switch Letter	Lights Come On (X)
0	
1	X
2	
3	
4	
5	X
6	
7	

Table 3-1

How do your findings compare with your predictions?

The student should explain any differences between his predictions and his findings in Step 7.

8. Remove the wire connecting the independent light to light 6. Depress each switch.

What happens and why?

Neither light comes on because the lights are in series and no longer complete a circuit.

9. Reconnect the light and remove a wire from one of the two switch jacks. Depress each switch again.

a. Explain what you observe.

Only the switch which was still connected could operate the lights. If the wire was removed from switch 1, only switch 5 could control the lights. Likewise, if the wire was removed from switch 5, only switch 1 could control the lights.

b. How do the circuits constructed for the lab compare with the circuits illustrated in Figures 3-4 and 3-5?

The first circuit (Step 3) is like the series circuit in Figure 3-4. The second circuit adds to this two switches in parallel, similar to the switches in the Figure 3-5.

10. Disassemble your circuit and set your equipment aside. If you had any difficulties, review the Background materials and try the activity again.

11. Once you have completed the Experiment, respond to the Questions which follow.

Questions

1. Describe the three basic components of a circuit.

Power supply such as a battery. Switch (or other input device) used to complete and break the circuit. Output device such as a light, which is operated by the circuit.

2. What produces a D.C. current?

Electricity from the battery or other power source flows through the wires and components of the circuit. This can only occur when all components are connected in a closed loop and the path for the electricity is complete.

3. How is a current used in a circuit?

The current is used to power the output device when the path is completed (switch closed).

4. Identify the four circuits in Figure 3-8 as either parallel or series.

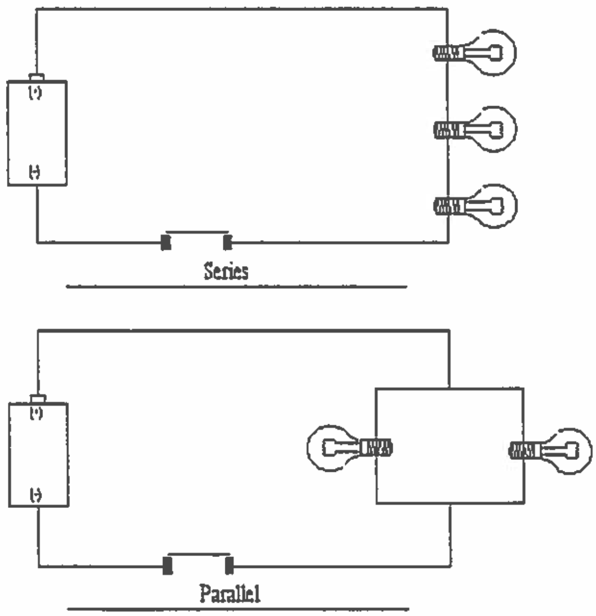


Figure 3-8

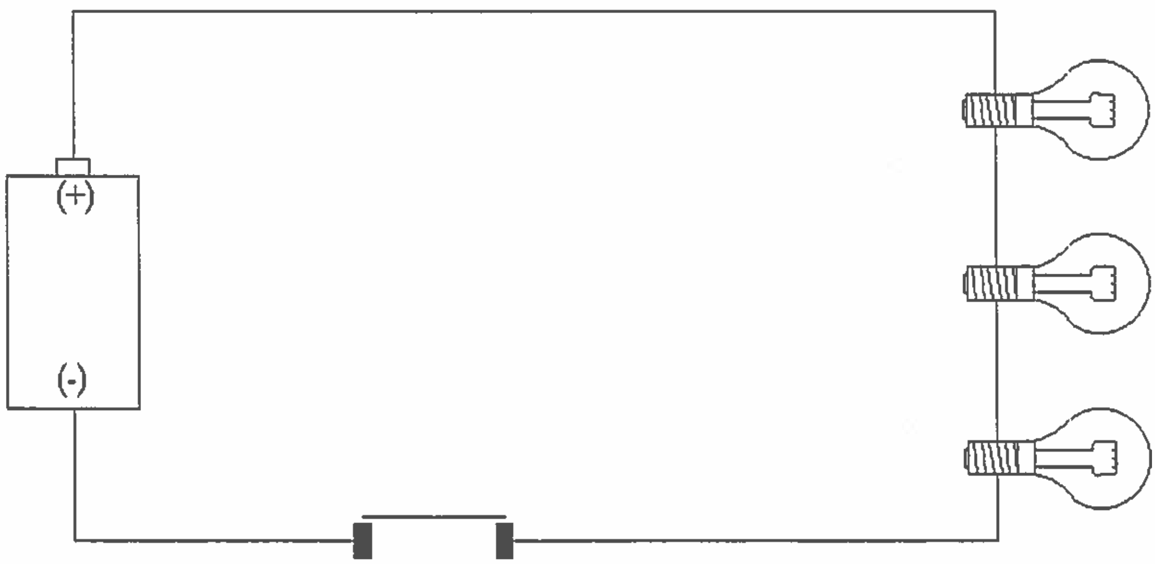
5. What is the difference in current flow in a complete and an incomplete circuit?

In a complete circuit, electricity flows through all elements in the completed path. There is no current flow at all in an incomplete circuit.

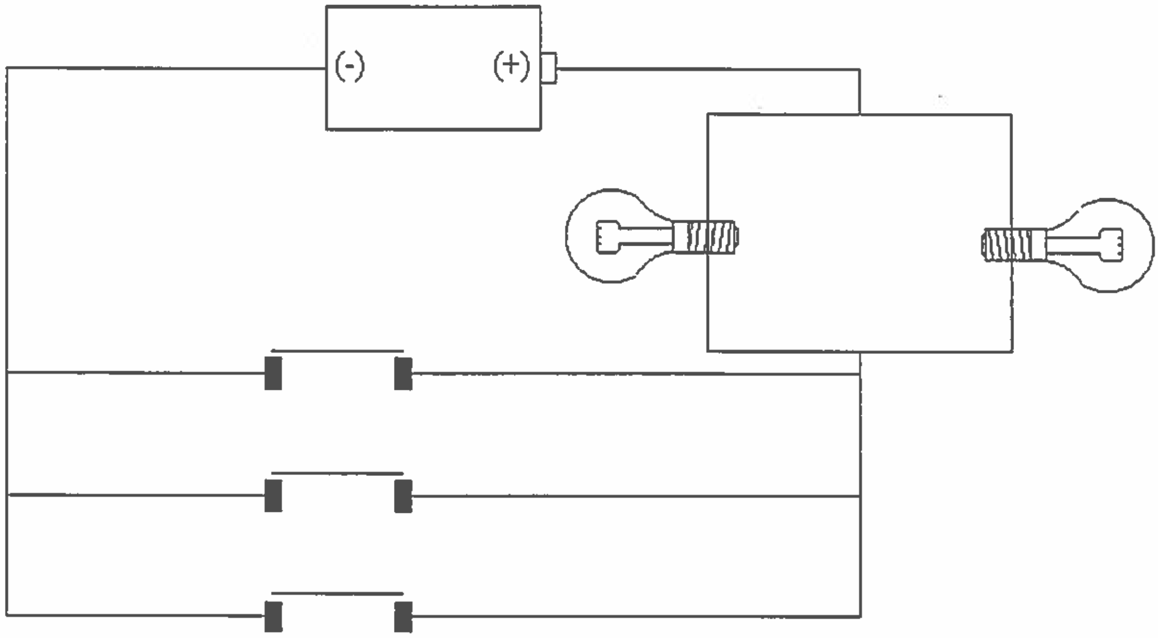
6. What are A.C. and D.C., and how are they used?

A.C. is alternating current and is used for standard household and industrial electrical power. D.C. is direct current. It is the on-board power supply, in batteries, and used for running cars. It is also the output power of battery chargers and transformers, such as those on toy train sets.

7. Draw a series circuit that has one switch to turn on three light bulbs.



8. Draw a parallel circuit which uses three switches to turn on two lights which are also in parallel.



9. Think about electrical circuits, which have only two states, on and off. Based on what you know about circuits, why are binary numbers used in computers?

In an electrical circuit, ON and OFF can be represented by the two digits of the binary system. 0 = OFF, 1 = ON.

UNIT 4
INSTRUCTOR'S MANUAL

NUMBERING SYSTEMS

1. Several numbering systems are reviewed in this unit. Emphasis should be on the relationship of the binary system to other systems, particularly hexadecimal.

2. The Experiment consists of making conversions between numbering systems, so an Answer Key (for the Experiment problems only) is provided at the end of the unit. Use the answers to provide immediate feedback to the students about their work with number system conversions.

3. Conversions between the binary and hexadecimal systems will be used later in the manual. You may wish to have the students create their own conversion charts between the two systems. These could then be used for reference later on. (You may also wish to make a classroom conversion chart, if it is appropriate.)

UNIT 4

NUMBERING SYSTEMS

Objectives

Upon completion of this unit the student will be able to:

1. Describe the general origins of numbering systems.
2. Explain the differences between Roman, decimal, binary, octal, and hexadecimal numbering systems.
3. Identify one use for each numbering system.
4. Convert numbers between selected numbering systems.

Background

Numbering systems go back in history to the time when people invented writing. Symbols drawn in sand or soil were used to explain things to other people. Numbering systems were the means to communicate amount or quantity.

The ancient Romans used a numbering system which is still found today. *Roman numerals* may appear on the cornerstones of buildings, indicating when the building was constructed. They may be used in the front of a book to give the book's date of publication. They are sometimes used on clock and watch faces, instead of the more common *Arabic numerals*, which we all use every day. A major disadvantage of the Roman numeral system is its lack of any symbol for zero. The Roman symbols for one through ten, along with their Arabic equivalents, are given in Table 4-1.

Arabic	Roman		Arabic	Roman
1	I		6	VI
2	II		7	VII
3	III		8	VIII
4	IV		9	IX
5	V		10	X

Table 4-1
Numerals One Through Ten

Additional symbols are introduced to indicate 50, 100, 500, 1000, etc. You may have seen dates written in Roman numerals on movie title screens: MCMLXXVIII = 1978, MCMXC = 1990.

To write the symbol for 27 in Roman numerals, take from the list the fewest numbers possible to add up to 27. Put them in a row from largest to smallest. The fewest is 10 + 10 + 7. Putting the Roman equivalents in a row:

27 = XXVII

Even though 27 and XXVII look completely different, they represent the same quantity:

27 = *
XXVII = *

The Decimal System

The numbering system you use daily is the *decimal* system, where "dec" in decimal means "10." The decimal system uses the ten Arabic symbols 0,1,2,3,4,5,6,7,8,9, arranging them in different orders to represent different quantities.

Another name for the decimal system is the *base 10* system. Base 10 specifies that there are ten basic symbols used to represent quantities. There is a single principal reason that a base 10 or decimal system of counting was developed. People have ten fingers. Fingers make counting in base 10 very convenient; you carry your counting aids with you.

Numbering systems other than base 10 are used in PLCs. These systems are binary or base 2, octal or base 8, and hexadecimal or base 16.

The Binary System

The *binary*, or *base 2*, system uses only two symbols, 0 and 1, to represent quantities. All computers use the binary system to perform calculations and to talk to other computers. Computers are restricted to a two symbol system because they are only able to detect on and off electrical states. Since the heart of industrial PLCs is a computer, industrial grade PLCs use the binary system internally.

When writing a binary number, a group of either eight or sixteen symbols is usually used to represent the quantity. Each symbol or *bit* has a specific value (see Table 4-2). Starting at the far right hand end of the eight bits, moving to the left, each bit is two times the value of the bit to its immediate right. The first bit represents "1," the second bit represents "2 x 1," or "2," and the third bit represents "2 x 2," or "4." The fourth bit is equal to "2 x 4," or "8." This process continues leftward, no matter how many bits are used. Table 4-2 shows the values for each bit in an eight digit binary number. It also gives examples of several binary-decimal equivalents.

1	2	4	8
00000001	00000010	00000100	00001000
16	32	64	128
00010000	00100000	01000000	10000000

0 = 00000000
3 = 00000011
5 = 00000101
13 = 00001101
255 = 11111111

Table 4-2
The Binary Numbering System

To determine the value of a binary number, take the value of each "1" bit and add them together. The "0" bit means that its value is not used in that number. For example, the quantity represented by the binary number 01011001 can be found as follows.

1. Find the values of each of the "1" bits:

   The right most bit is a 1, and its value is 1.
   The fourth bit from the right is a 1, and its value is 8.
   The fifth bit from the right is a 1, and its value is 16.
   The seventh bit from the right is a 1, and its value is 64.

2. Add all the values together:

$$1 + 8 + 16 + 64 = 89$$

So,

$$01011001 = 89$$

Reversing the process allows conversion of decimal numbers into binary numbers. For example, converting the decimal number 19 into a binary number is accomplished as shown below.

1. Determine which binary values add up to 19:

   First, subtract the largest binary value which is less than or equal to the decimal number.

$$19 - 16 = 3$$

   Then, take the remainder and subtract the largest binary value less than or equal to it. Repeat this step as many times as necessary to get a remainder of 0.

$$3 - 2 = 1$$
$$1 - 1 = 0$$

2. List, from largest to smallest, the binary values used in the subtraction process.

$$16, 2, 1$$

3. Insert 1's in the appropriate positions in the eight bit number, leaving the remaining bits 0.

   "1" goes into the first position from the right.
   "1" goes into the second position from the right.
   "1" goes into the fifth position from the right.

$$00010011$$

So,

$$19 = 00010011$$

Because it is so difficult and time consuming for a person to work in the binary system, PLCs convert their binary numbers into other systems which operators can use more easily.

The Octal System

The *octal* or *base 8* system is very much like the decimal system, except that it uses only eight symbols, 0,1,2,3,4,5,6,7. (The symbols 8 and 9 are never used.) Table 4-3 compares the octal system to the decimal and binary systems. Because conversion between octal and other numbering systems is a complex process, it will not be addressed here.

Octal	Decimal	Binary
0	0	00000000
1	1	00000001
2	2	00000010
3	3	00000011
4	4	00000100
5	5	00000101
6	6	00000110
7	7	00000111
10	8	00001000
11	9	00001001
12	10	00001010
13	11	00001011
14	12	00001100
15	13	00001101
16	14	00001110
17	15	00001111
20	16	00010000
21	17	00010001
22	18	00010010
23	19	00010011
24	20	00010100

Table 4-3
Comparison of Octal, Decimal, and Binary Numbering Systems

The Hexadecimal System

The *hexadecimal*, or *base 16*, system uses 16 symbols, 0,1,2,3,4,5,6,7,8,9,A,B,C, D,E,F. It is used for computer software to translate long binary numbers into a more readable form, *alpha-numeric* notation. In every cluster of four binary bits, there are 16 possible combinations of 0 and 1 (see Table 4-4). Each of the 16 symbols in hexadecimal numbering represents one of these combinations. So hexadecimal translates each cluster of four binary digits into one symbol.

0 = 0000	8 = 1000
1 = 0001	9 = 1001
2 = 0010	A = 1010
3 = 0011	B = 1011
4 = 0100	C = 1100
5 = 0101	D = 1101
6 = 0110	E = 1110
7 = 0111	F = 1111

Table 4-4
Hexadecimal - Binary Equivalents

To convert a number from binary to hexadecimal, follow the process shown in the example below. The binary number 110100010000011101011100 represents a computer command.

1. Starting from the right hand end, break the number into clusters of four digits.

110100010000011101011100

1101 0001 0000 0111 0101 1100

2. Determine the equivalent hexadecimal symbol for each cluster.

1101 = D   0001 = 1   0000 = 0

0111 = 7   0101 = 5   1100 = C

3. Arrange the hexadecimal symbols in the same order as the binary digit clusters.

D 1 0 7 5 C

Thus,

$$110100010000011101011100 = D1075C$$

It is easy to see why hexadecimal numbers are so much more manageable than binary numbers.

To convert from hexadecimal to binary, reverse the process.

1. Find the binary equivalent of each hexadecimal symbol.
2. Arrange the clusters of four binary digits in the proper order.
3. Remove all spaces between the digit clusters.

EXPERIMENT

Purpose

To convert numbers between decimal and binary, and hexadecimal and binary numbering systems.

Procedure

You will try a few conversions between numbering systems. Be sure to refer to the procedures on the preceding pages when you need help.

1. Convert the following decimal numbers to binary numbers:

   37, 294, 127

   Refer to Answer Key At End of Chapter.

2. Convert the following binary numbers into decimal numbers:

11111011, 01010101, 0000001001011010

Refer to Answer Key At End of Chapter.

3. The following are IBM computer commands written in the binary system. What are their hexadecimal equivalents?

00101101010110101101000000000001
11111111000000001111010000000000
00010010000000100011101100000001

Refer to Answer Key At End of Chapter.

4. When you call up an IBM computer's list of internal commands, you get a screen full of symbols like the following. What would these look like in binary numbering?

   9401902F, 59013301, C5:5:4042E00

   Refer to Answer Key At End of Chapter.

5. Check all of your answers against those at the end of the unit. If you have any difficulties, review the background materials and try the problems again. Once you are satisfied that you understand the numbering systems, answer the Questions below.

Questions

1. Describe the most important features of each of the numbering systems you studied.

   Roman - uses combinations of letters, no zero.

   Binary - base 2, uses only 0 and 1.

   Decimal - base 10, daily use.

   Octal - base 8, similar to decimal with only 8 symbols

   Hexadecimal - base 16, uses the 10 decimal numerals plus letters A-F; easily converts long binary numbers into simpler alphanumeric codes.

2. Give at least one example of uses for the numbering systems discussed in Question 1.

Roman - clock and watch faces, buildings, copyright dates.

Decimal - everyday arithmetic.

Binary - computers.

Octal - PLC inputs, outputs and relays.

Hexadecimal - IBM computer commands, conversion of binary numbers to simpler codes.

3. Why did people develop numbering systems?

People invented numbering systems to quantify events, crops, trade agreements and the like.

4. Which type of conversion was easiest? Hardest? Why?

There is no correct response to this question. It is designed to increase the student's awareness of some of the complexities involved in computer and PLC operations.

ANSWER KEY

1. 37 = 00100101
   294 = 0000000100100110
   127 = 01111111

2. 11111011 = 251
   01010101 = 85
   0000001001011010 = 602

3. 00101101010110101101000000000001 = 2D5AD001
   11111111000000001111010000000000 = FF00F400
   00010010000000100011101100000001 = 12023B01

4. 9401902F = 10010100000000011001000000101111
   59013301 = 01011001000000010011001100000001
   C5:5:4042E00 = 11000100000001000010111000000000