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Wakefield Robotics Ltd.

Robotics 101 Online Education

Robotics 101 – An Introduction to PIC Microcontrollers

Chapter 2 – Interfacing to Microcontrollers

2.1 Objectives

To provide the student with an understanding of basic electronic components, and how they can be interfaced to microcontrollers, so as to protect the microcontroller and increase its power-controlling capabilities.

To show the student how to read schematic diagrams, and assemble matching circuits.

2.2 Introduction

Outputs

Microcontrollers have very weak output pins. They can only provide 25 milli-amperes (mA) of current at the voltage provided to the power pin V_{DD}. In most cases, we will provide the microcontroller with +5 VDC. This is enough power to light up an LED, but not much more.

Therefore, we have to boost up the power that the output pins can control. We can do this with transistors, MOSFETs, relays, etc. This way, we can control motors, lights, buzzers, etc. In other words, we can make our microcontroller control real world things!

Inputs

In the digital mode, the input pins on the PIC microcontrollers can read high voltages (close to V_{DD}) and low voltages (close to ground). Therefore, we need to cover interface switches, so that we can tell if they are open or closed. This will require the discussion of switches and resistors. I use the digital mode with the whiskers on autonomous robots, so they can tell when they bump into things.

In the analogue mode, certain input pins on the microcontrollers can read the voltage applied to them, and convert it to 10-bit digital number. This is the number from 0 to 1024, where 0 indicates a voltage close to ground and 1024 indicates a voltage close to V_{DD}. With input pins in the analogue mode and a potentiometer, you can tell the position of the wiper and the adjusting knob on the potentiometer. This could be used as an input to control motor speed.

There is also a comparator mode for input pins. In this mode allows the voltage applied to a comparator pin to be compared with another voltage, either are reference voltage or another pin. If the applied voltage is greater than the reference voltage, then the output is a true or one. If not, it is a zero. This output is stored in a special location in the registers. I used the comparator mode to create an ultrasonic sensor. We will discuss this application later.

2.3 Introduction to Electricity

This section is going to cover what electricity is, and its basic properties: voltage, resistance, and current. I will try to use some well-known analogies to help keep the definitions clear. Okay, let's begin.

What is electricity?

There are lot's of definitions of electricity, but I would like to keep it as simple as possible. Electricity is the study of the flow of electrons in a conductor.

Electrons are negatively charged particles, which orbit around the nucleus of atoms. Electrons tend to move away from negatively charged molecules and are attracted to positively charged molecules. A conductor, is simply a material where the electrons are free to move.

Okay, lets consider an analogy. Let's consider a garden hose filled with water.

When pressure is applied to one end of the garden hose, the water will begin to flow. This is similar to the voltage that's applied to a conductor, which causes the electrons to flow.

The water flow rate is similar to current. The higher the water flow rate, the more water comes out of the hose. Current is simply the amount of electrons flowing through the conductor. The higher the current, the more electrons flow through the conductor.

As water flows through a hose or a valve, it encounters resistance to its flow. As you close a valve, the resistance increases and a water flow rate drops off. This occurs even if the pressure applied to one end of the garden hose did not change.

Similarly electrons, as they flow through the conductor, encounter resistance, which tries to slow or stop the flow of electrons. The greater the resistance, the less the current, even though the applied voltage is still the same.

Voltage (V) is specified in volts. Current (I) is given in amperes or amps. Resistance (R) is given in ohms. There is an equation that relates the three properties of electricity. This equation is called Ohm's Law.

Equation #1. *Ohms Law*

$$V \text{ (Volts)} = I \text{ (amps)} \times R \text{ (ohms or } \Omega)$$

For example, if the current flowing through a conductor is a one amp (1 coulomb/second or 6.242×10^{18} electrons/second) and the resistance in a conductor is one ohm, then the required voltage is one volt.

Therefore, if 2 V were applied to the same wire, then the current should be doubled. The current would be 2 amps.

We will use Ohms Law extensively as we proceed through this chapter.

Types of Electrical Power

Now, there are two common sources of electrical power. The first is DC or direct current electrical power. The current for DC power always flows in the same direction. This is the type of power that we get from batteries.

The second type of electrical power is AC or alternating current. The current for AC power regularly changes its direction. The current flows in one direction and the conductor, and then it turns around and moves in the other direction. This is the type of electrical power that we have in our homes and is available through the electrical outlets in the walls.

Microcontrollers need DC power. Therefore, most of our discussion in this course will involve direct-current electrical power.

2.4 Resistors and Potentiometers

Resistors

In *Section 2.3*, we introduced resistance in conductors. Resistors are devices with a known resistance. We use resistors so that certain electrical devices do not get too much current and malfunction or overheat.

Since the majority of our circuits are going to require resisters of one form or another, we must learn how to recognize the values of common resistors. Small resistors are usually marked with four or five colored bands. We must learn how to convert the colored bands into the matching resistance. See *Table 2.1*.

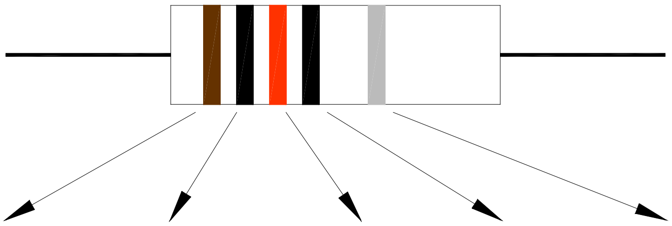
Figure 2.1 Sample Resistor

Now let us consider the resistor shown in *Figure 2.1*. This is a common resistor that we will use in many of our circuits dealing with LEDs (Light Emitting Diodes). Notice that this resistor has only 4 color bands. Now let's figure out what the resistance is for this resistor.

Start reading the color bands on the resistor from the end where the bands are tightly packed. In this case, the left end. From *Table 2.1*, we see that brown represents 1, black represent 0, and since red is the last tightly-packed band it represents the multiplier 100. Therefore, the resistance is 1 0 * 100 = 1000 ohms (1 kΩ).

In summary, read each band's color and write down the matching number to create a 2 or 3 digit decimal number. Multiply this number by the multiplier to get the matching resistance. The tolerance is given by the band separated from the others. In this case, silver means 10% tolerance.

Table 2.1 Resistor Color Code Chart



Color	Band #1	Band #2	* Band #3	Multiplier	**** Tolerance
Black	0	0	0	1 Ω	
Brown	1	1	1	10 Ω	± 1%
Red	2	2	2	100 Ω	± 2%
Orange	3	3	3	** 1 kΩ	
Yellow	4	4	4	10 kΩ	
Green	5	5	5	100 kΩ	± 0.5%
Blue	6	6	6	*** 1 MΩ	± 0.25%
Violet	7	7	7	10 MΩ	± 0.1%
Grey	8	8	8		
White	9	9	9		
Gold				0.1 Ω	± 5%
Silver				0.01 Ω	± 10%

* Band #3 is optional. It may not appear on some resistors.

** k is an abbreviation for kilo or 1000. Therefore, 1 kΩ equals 1000 ohms.

*** M is an abbreviation for mega or 1,000,000. Therefore, 1 MΩ equals 1 million ohms.

**** Tolerance is the accuracy of the manufacturing of the resistor. A 1 kΩ resistor with a 10% tolerance could have a resistance as small as 900 ohms, or as great as 1.2 kΩ.

Rather than draw a picture of a resistor every time we want to show one on a drawing, we will use the shortcut or schematic symbol for a resistor. This symbol is shown in *Figure 2.2*.

Figure 2.2 Schematic Representation of a Resistor

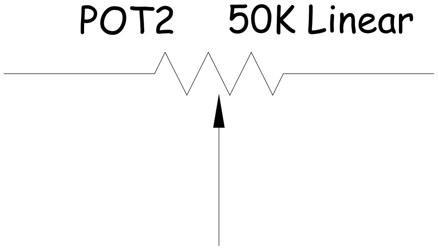
The text R5 translates as R for resistor, 5 for #5. Or, this is resistor #5. The 1K indicates that this resistor has 1000 ohms or 1 kΩ.

Now let’s consider potentiometers, a type of adjustable resistor.

Potentiometers

Potentiometers are devices with three leads. Two leads are connected to each end of a resistor of a fixed resistance. The third lead, called the wiper, is adjustable and it can move up and down the length of the resistor.

Figure 2.3 Schematic Representation of a Potentiometer



Let's consider *Figure 2.3*, the schematic symbol for a potentiometer. You can see the two leads on either end of the resistor and the wiper (the line with the arrowhead) which can move along the body of the resistor. The text "POT2", indicates that this potentiometer #2 in the circuit. The text 50K Linear indicates that this is a linear potentiometer with an overall resistance of 50,000 ohms.

There are 2 types of potentiometer tapers, linear and logarithmic. A taper is the relationship between the position of the wiper and the resistance. A linear taper means that the resistance from the left side is proportional to its distance along the body of the resistor. For instance, if the wiper is in the far left position, the resistance is zero. In the mid-position, the resistance is ½ x 50 KΩ = 25 kΩ, and at the far right position, the resistance is 1 x 50 KΩ = 50 kΩ.

Logarithmic-taper (or Audio) potentiometers do not have the same scale as a linear potentiometer. At the far right position, the resistance between the left lead and the wiper is zero. At the mid-position, the resistance is much greater than 25 kΩ. However, at the far right position, the resistance is again 50 kΩ. This type of potentiometer is usually used to control audio signals, like the volume of speakers.

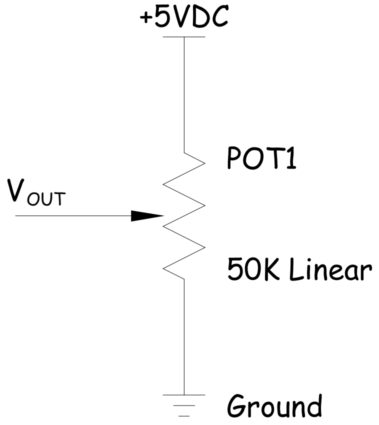
We will be using linear potentiometers throughout this course.

Potentiometers come in rotary and linear styles. A rotary potentiometer has a knob or key, which is rotated to change the wiper position. A linear potentiometer has a slide, which moves back and forth in a straight line. As the slide moves, the wiper moves with it.

Now potentiometers have 2 common applications: a variable resistor and a voltage divider. We have already discussed the variable resistor. Using just 2 leads, one attached to one end of the resistor and the other attached to the wiper, we can make a variable resistor. As the wiper position is changes, the resistance between the selected leads also changes.

The voltage divider is a little bit more complicated. If we attach a high voltage to one end of the resistor, and another lower or negative voltage to the other end of the resistor, then the voltage coming from the wiper will change with the position of the wiper. Consider *Figure 2.4*.

Figure 2.4 A Potentiometer Set Up as a Voltage Divider



From *Figure 2.4*, we can see that +5 VDC has been connected to one end of the resistor, and 0 VDC or ground has been connected to the other end. If the wiper is in the uppermost position, the voltage at the wiper will be +5 VDC. If the wiper is in the mid-position, the wiper voltage will be +2.5 VDC. If the wiper is in the lowermost position, the wiper voltage will be 0 VDC.

Later, if you decide to take the next course, I will show you how to a linear potentiometer as a position feedback device in a position control circuit – in other words, a control system application.

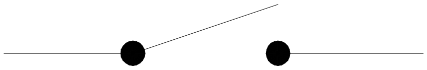
2.5 Switches

When interfacing microcontrollers with the outside world, switches can come in handy. They allow us to send signals to the microcontroller when certain real-world events occur. For example, if someone wants to get into the house, they push the doorbell button.

Switches can be classifies by the number of contacts, the number of positions, the type of switch, and whether the switch stays on after it has been pressed. Let’s take a step back and define what a switch is – at least in electrical terms.

Let’s consider a normally-open (NO) switch first. A normally-open switch, when actuated, provides an electrical conductor between two switch terminals. Let’s consider the simplest switch, a normally-open single-pole single-throw switch.

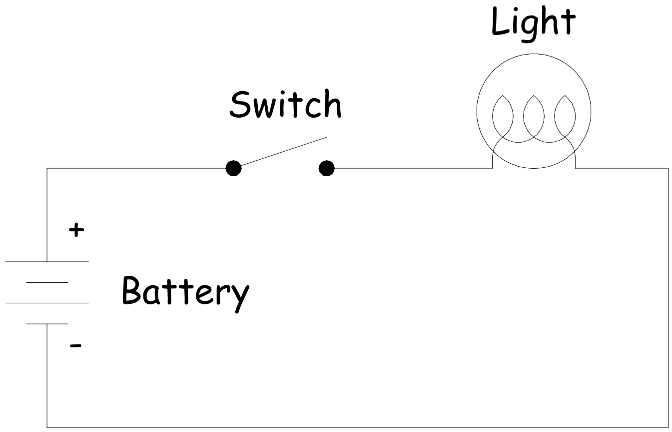
Figure 2.5 Schematic Representation of a SPST Normally-Open Switch



When the switch is not actuated, there is no electricity conducted between the terminals or connectors on the switch. When the switch is actuated, the lever comes down, making contact between the two terminals, which allow electricity to be flow through the switch.

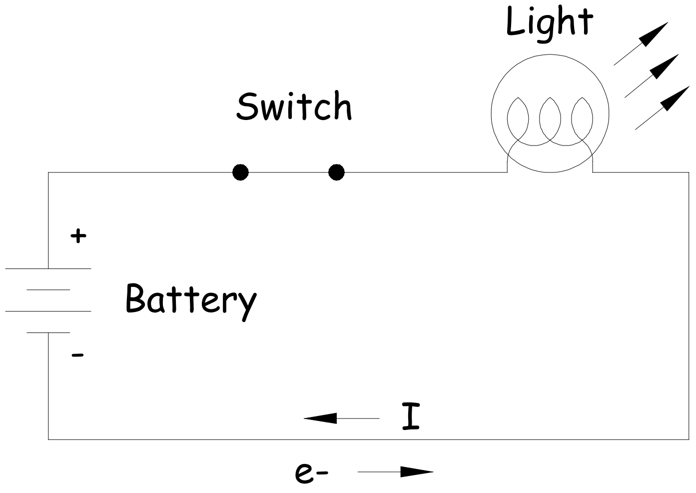
Let’s consider a flashlight as a simple example of a circuit incorporating a switch. This circuit consists of a SPST switch, a light bulb and a battery. See the schematic circuit in *Figure 2.6*. The switch is open and no current can flow. This is like a water hose which is plugged so that the water cannot flow.

Figure 2.6 Electric Circuit with Open SPST Switch



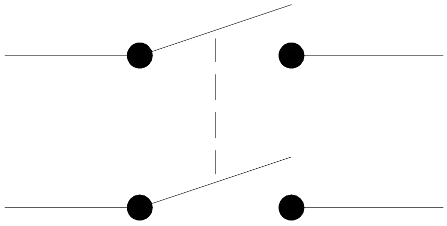
Now in *Figure 2.7,* we can see the same circuit except that the switch is closed. There is now a path for the current to flow between the positive and negative terminals on the battery. As the current flows through the light bulb, light is generated.

Figure 2.7 Electric Circuit with Closed SPST Switch



Notice that I (current) is shown flowing from the positive to the negative terminals on the battery. This is the normal convention because the early experimenters with electricity did not know what was flowing in the circuit. They assumed that the flowing particles were positively charged. The direction of flow of the electrons (e-) is from the negative terminal to the positive terminal of the battery. This is because particles of the same polarity repel and opposite polarities attract. In other words, the negative terminal repels the negatively-charges electrons and the positive terminal attracts the negatively-charged electrons.

Figure 2.8 Schematic Representation of a DPST Normally-Open Switch



Consider the schematic symbol for the DPST normally open switch, shown in *Figure 2.8*. It looks like schematic symbol for two SPST switches. However, there is a dashed line drawn between the two levers. This means that the two levers move at the same time. Therefore, both switches open and close at the same time. Since there are two switches working together, there are two or Double Poles (hence DP). Each switch can complete only one circuit, therefore it is Single Throw (hence ST).

Figure 2.9 Schematic Representation of a DPDT Normally-Open Switch

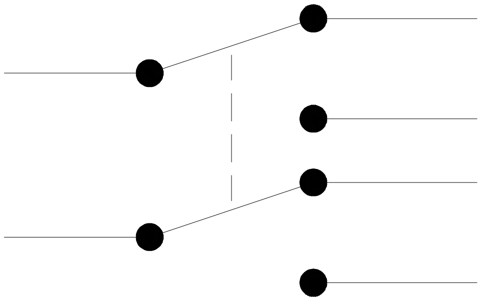
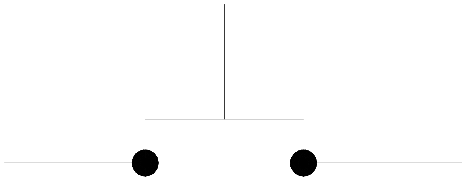


Figure 2.8 shows the schematic symbol for a DPDT switch. Here we have two switches working together (hence DP – Double Pole) and two possible circuits can be completed with the switch (hence DT – Double Throw).

Figure 2.10 Schematic Representation of a Normally-Open Pushbutton Switch



Let's finish off our discussion of switches, with a discussion about pushbutton switches. These switches are handy in applications like doorbells, robotics, and of course, microcontroller inputs.

In the case of a normally open (NO) pushbutton switch, when the switch is pressed, the switch is closed and the circuit is completed. When the switch is not pressed, the switch is open. *Figure 2.10* shows the schematic symbol for a normally-open pushbutton switch.

Figure 2.11   Schematic Representation of a Normally-Closed Pushbutton Switch

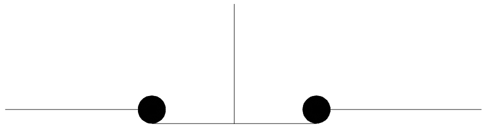


Figure 2.11 shows the schematic symbol for a normally-closed pushbutton switch. When a normally-closed (NC) pushbutton switch is pressed, the switch is opened. When the switch is not pressed, the switch is closed and the circuit is complete.

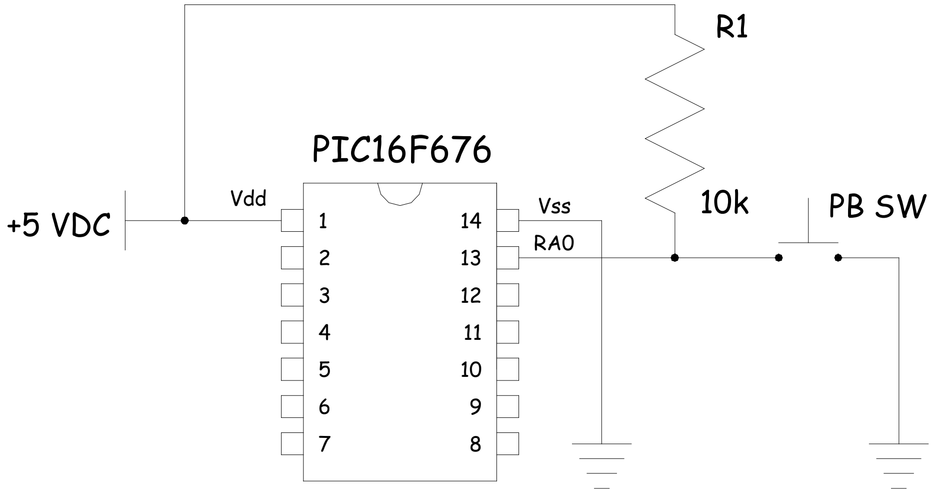
This finishes out discussion about how switches work.

2.6   Reading Switches

Now that we understand the basics about switches, we can learn to apply them as inputs to microcontrollers.

First, let's consider the normally-open pushbutton switch as an input for the PIC16F676 microcontroller. Let us use the switch as an input on Port A Pin 0.

Figure 2.12   Schematic Circuit of a Switched Input with Pull-Up Resistor



An important rule when interfacing switches to a microcontroller is that the input pin must always be connected to voltage. The input pin cannot be left "floating" or not connected to a voltage either high or low. If an input pin is left floating, it could eventually build a large enough voltage that it can be permanently damaged.

Let's examine the circuit shown in *Figure 2.12*. When the pushbutton switch is not pressed, the voltage going in to Port A Pin 0 is high – close to V_{DD}. This will show as a one in the Port A Bit 0 register. When the push button is pressed, the voltage going to Port A Pin 0 is low – close to ground (V_{SS}). . This will show as a zero in the Port A Bit 0 register.

The pull-up resistor plays a very important role. If it did not exist, then when the switch was closed, there would be a direct short between the positive and negative terminals of the power supply. That is not good.

Let’s have a look at how to set up the microcontroller program.

First, we have to set up several registers.

```
CMCON = 7               ‘ Turn off the comparators
ANSEL = 0               ‘ Turn off the analogue-to-digital converters
TRISA = %00000001       ‘ Set Port A Pin 0 as an input, the rest as outputs
PORTA = 0               ‘ Set all pins of Port A low
```

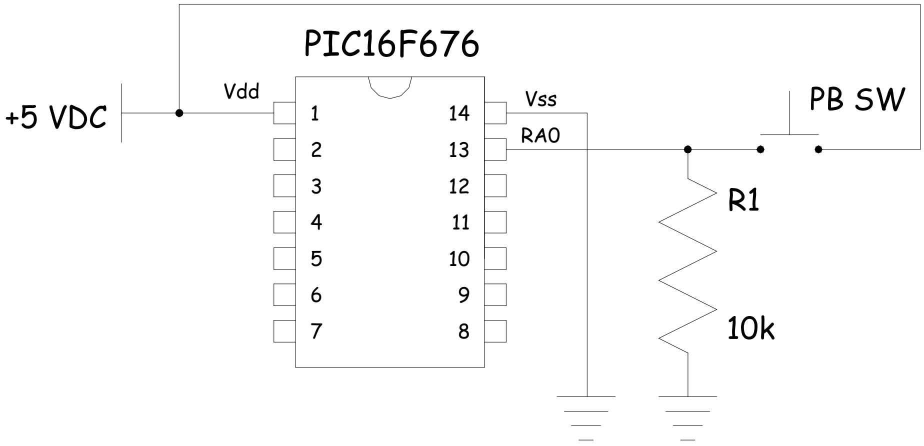
Take a close look at the registers that are being initialized. These registers show up at the beginning of almost every microcontroller program for the PIC16F676. The comments to the right of the register commands, briefly explain the purpose of the register.

Now in our main program, we can check to see if the pushbutton switch was pushed.

```
IF PORTA.0 = 0 then
        ‘ the pushbutton switch has is pressed
ELSE
        ‘ the pushbutton switch has is not pressed
END IF
```

When the pushbutton has been pressed, the voltage to the input pin is low, and Bit 0 of Port A will be a zero. The IF statement checks to see if Port A Bit 0 is low, and performs the commands between the IF and ELSE. If the Port A Bit 0 is high, then the IF statement performs the commands between the ELSE and END IF.

Figure 2.13 Schematic Circuit of a Switched Input with Pull-Down Resistor



Now let’s consider a similar circuit with a pull-down resistor as shown in *Figure 2.13*. When the pushbutton switch is not pressed, the voltage going in to Port A Pin 0 is low – close to ground. This will show as a zero in the Port A Bit 0 register. When the push button is pressed, the voltage going to Port A Pin 0 is high – close to V_{DD}. This will show as a one in the Port A Bit 0 register.

The registers are initialized exactly the same as before, but the IF statement in our main program works a little different.

```
IF PORTA.0 = 1 then
        ‘ the pushbutton switch has is pressed
ELSE
        ‘ the pushbutton switch has is not pressed
END IF
```

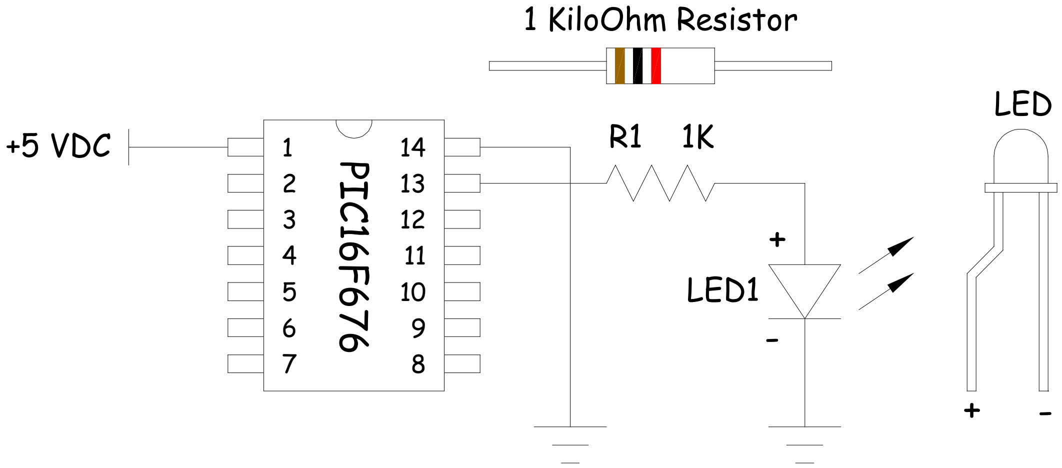
Enough of switches, let’s move on to LED’s.

2.7 LEDs

Light emitting diodes, commonly called LEDs, are very popular because they use so little power. Basically, LEDs are just tiny light bulbs that fit easily into an electrical circuit. But unlike ordinary incandescent light bulbs, they don't have a filament that will burn out, and they don't get very hot. They are illuminated solely by the movement of electrons, in a semiconductor material.

When interfacing LEDs to our microcontroller, we have to make sure that we have selected the correct biasing resistor. Otherwise, the LED or the microcontroller output pin, can be damaged. A typical LED can handle 20 mA of current and a microcontroller output can provide 25 mA of current.

Figure 2.14 Schematic Circuit of a PIC16F676 Output to an LED



Let’s consider *Figure 2.14*. Here Port A Pin 0 is connected to an LED through a biasing resistor. If the output pin provides +5 VDC, then what is the current flowing through the LED. Well to start with, the LED as a 1.6 V drop. This means that 1.6 of the 5 volts provided is lost as the current flows through the LED. Let’s look at the mathematics.

Recall: $V = I \times R$ Ohm’s Law

Rearranging the equation:

$$I = V / R$$

The voltage drop over the resistor, is equal to the total voltage minus the voltage drop over the LED.

$$V_{RESISTOR} = V_{TOTAL} - V_{LED} = 5 - 1.6 = 3.4 \text{ volts}$$

The current flowing through the resistor and hence also the LED can be found from the following equation:

$$I = V_{RESISTOR} / R_{RESISTOR} = 3.4 \text{ volts} / 1000 \text{ ohms} = 0.0034 \text{ amperes}$$

Therefore, the current flowing through the LED is 3.4×10^{-3} amperes or 3.4 mA (milli-amperes). This current is well within the allowable current for this LED.

Notice the sketch of the actual LED shown in *Figure 2.14*. The long leg of the LED is called the anode, and it must be connected to the positive side of the power source. The short leg of the of the LED is called the cathode, and it must be connected to the negative side of the power source. If the pins of the LED are not connected to the correct polarities, no current will flow.

Now let's consider the necessary microcontroller program to illuminate our LED. First, we have to set up several registers.

```
CMCON = 7               ‘ Turn off the comparators
ANSEL = 0               ‘ Turn off the analogue-to-digital converters
TRISA = %00000000       ‘ Set all Port A pins as outputs
PORTA = 0               ‘ Set all pins of Port A low
```

To turn on the LED, we simply add this line to the main program:

```
PORTA.0 = 1
```

To turn off the LED, we can use this line:

```
PORTA.0 = 0
```

Hey, this is starting to look like fun. Let's see if we can drive something a little bit bigger than an LED.

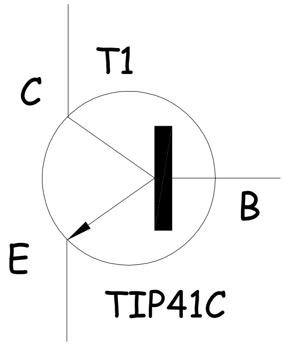
2.8 Transistors

At this time, we are going to examine a simple NPN transistor. Specifically, the TIP41C transistor.

A transistor can be used to help control larger DC voltages. However, the microcontroller, the transistor, and the driven device must all share the same ground (negative supply). Care must be taken when assembling these circuits, or permanent damage may occur to some or all of the components.

Let's have a look at *Figure 2.15*. Here, we are looking at a schematic symbol representing NPN transistor. Noticed that the transistor has three leads: B (Base), C (Collector), and E (Emitter). The base will be connected to the output pin from a microcontroller through a biasing resistor. The emitter is connected directly to ground (negative power supply terminal), and the collector is connected to the negative terminal of the device being driven.

Figure 2.15 Schematic Representation of a NPN Transistor



Okay, this sounds very complicated. Let's consider how the NPN transistor works.

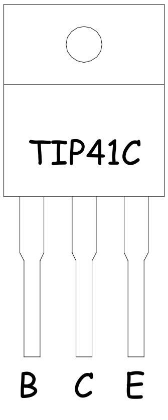
When the microcontroller output pin goes high, current flows through the resistor to the base of the transistor. This current continues through the transistor to the ground. The current is normally designated as I_{BE}, as it flows through the base to the emitter.

When a current flows between the base and emitter, another current is allowed to flow between the collector and the emitter. This current is designated I_{CE}, and it's the current that runs the other device. The ratio of the output current (I_{CE}) over the input current (I_{BE}) is called the gain of the transistor.

Transistor Gain: $H_{FE} = I_{BE} / I_{CE}$

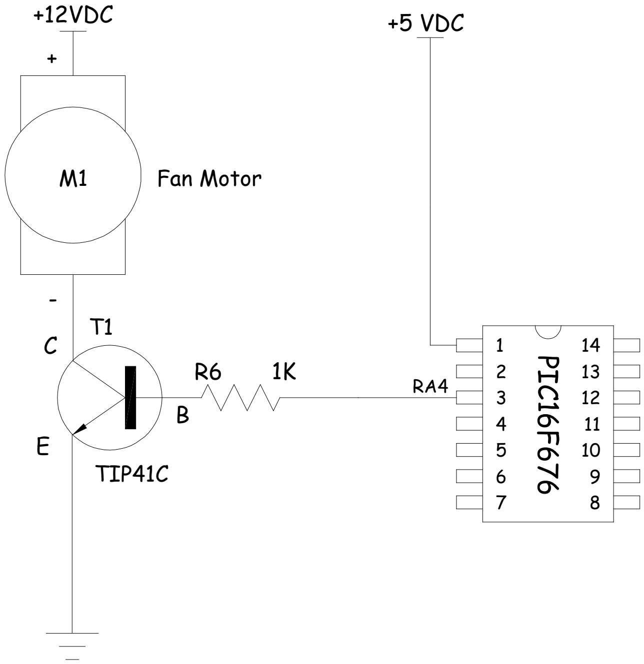
The output current is higher than the input current, so the transistor is said to act as an amplifier. We will the transistors in their saturated mode. This means that they will be either off or on fully.

Figure 2.16 Sketch of as Actual T!P41C NPN Transistor



Now, let's consider the circuit shown in *Figure 2.17*. Port A Pin 4 is used to control the transistor driving the DC motor. When the output from Pin 4 is high and current is flowing between the base and the emitter, a higher current will flow between the collector and the emitter. In the case of the circuit shown in *Figure 2.17*, the current flowing between the collector and the emitter, can even come from a different power supply with a higher or lower voltage. In this case, we are using a +12 volt power supply to power of the motor and a +5 volt power supply to power the microcontroller.

Figure 2.17 Schematic Diagram of a Microcontroller-Driven DC Motor



This concludes our discussion on NPN transistors.

2.9 Schematic Symbols and Circuit Diagrams

Well, in this chapter, we have been using schematic symbols to create circuit diagrams that represent components in our electronic circuits. They may not represent the actual look of the devices, but they provide us with enough information to physically create the circuits.

In summary, we have come across schematic symbols for the following devices: resisters, transistors, LEDs, switches, lights, batteries, the positive power supply terminal, and the ground. See if you can find examples of schematic symbols for each of these devices in this chapter. I will also provide a summary of the schematic symbols.

The symbol that I use for the PIC16F676 microcontroller is a representation of the actual device configuration. In other words, it looks like the actual microcontroller. I chose this is a symbol, because it is easier for the students assemble circuits when they see this representation.

In the labs associated with this course, all the circuits are provided in the schematic format. Therefore we have to learn how to convert schematic circuit into an actual circuit. We will be using electronic breadboards to assemble our circuits.

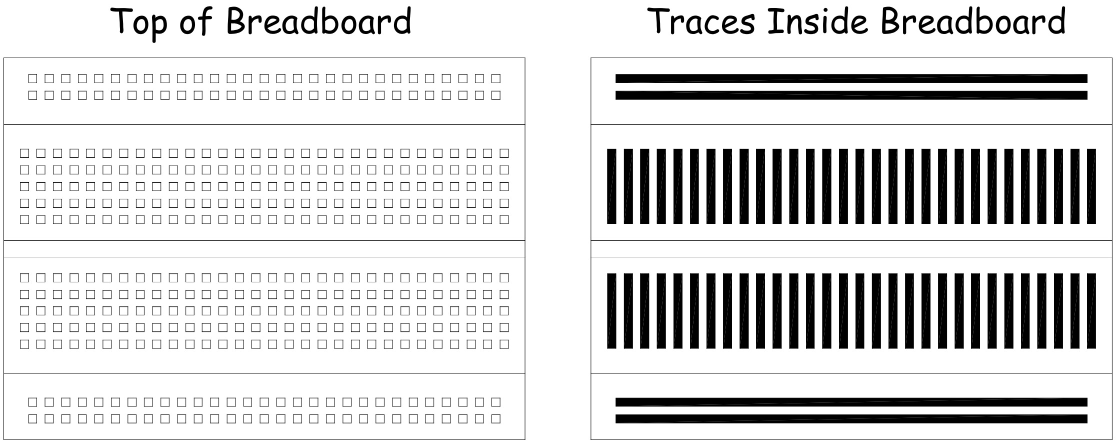
2.10 Breadboarding Electronic Circuits

Out circuits will be constructed using actual electronic components, electronic breadboards, and solid core wires to connect the pins together. First of all, let’s examine an electronic breadboard.

The electronic breadboard allows us to create temporary circuits by inserting electronic components into the pin receptacles (holes in the top of the breadboard). The breadboards are constructed so that the pins in the central section are connected in rows perpendicular to the length of the board. Power strips, along the outside of the boards, are connected along the length of the board to distribute power where necessary. An empty strip along the center of the board electrically separates the pins on DIP *(dual-inline pins)* devices, such as the microcontrollers.

22 or 24 gauge (AWG) sold-core wire is used to make the connections between the pins on the electronic devices. Rolls of wire and wire cutters/strippers are available from any electronics store. Cut the wire to the desired length using wire cutters and strip about 1/8" (3 mm) of the jacket off the wire at each end. Push the bare wire into the breadboard receptacles. Use the color of the wire jacket to help indicate its purpose. For example, red for positive voltage and black for ground.

Figure 2.18 Lay Out of An Electronic Breadboard



I hope, with the information provided in this chapter, you have an idea of the steps involved in interfacing microcontrollers to the real world. I would recommend attempting the labs assembled in *Robotics 101L - A Laboratory Manual for Robotics 101*.