Chapter 5

The Flashlight

In this chapter, we will learn the following to World Class standards:

1. **Creating a Simple Electrical Circuit**
2. **Drawing the Schematic**
3. **Specifying the Lighting Device**
4. **Selecting the Light Bulb Socket**
5. **Selecting the Battery**
6. **Selecting the Spring**
7. **Selecting the Switch**
8. **Selecting the Wire**
9. **Drawing the Electrical Assembly Drawing**

Creating a Simple Electrical Circuit

In the 21st century, a designer needs to understand how to improve their product with technical enhancements by utilizing cast or extruded components, composite materials and any form of electrical circuit. We discuss the first two enrichments to manufactured goods in the World Class CAD textbook covering mechanical design, but in this course, we will apply simple to advanced electrical circuits to give our assembly better product capabilities. As in the beginning of the electronics technology over a century ago, we will design and then build with analog electrical components, using soldering and wire to connect the various specialized parts which will allow the customer to easily control the device. As we gain experience, we will incorporate digital devices that are less expensive, smaller and may be more reliable. Digital devices do require the electrical designer to have greater expertise. In every one of our designs, we will begin with a sketch that visually shares our ideas.

In our first project, we will design a flashlight. Instruments that illuminate our way are very common in the industry and every architect, designer and engineer should be familiar with basic lighting circuitry. The main elements of a lighting circuit are the lamp, the switch, the bus and the power source. We would find our journey very difficult if we had an assignment where we would have to locate a building, automobile or piece of office equipment containing a lighting device that did not have the major components that we just listed. Over the years, incandescent lamps have been replaced with light emitting diodes (LED), analog switches with digital controls, wires with circuit board tracks, and chemical batteries with solar panels. In the example shown in this chapter, we will use those older analog parts, however if you desire to improve your design with more advanced components, the decision is entirely yours.

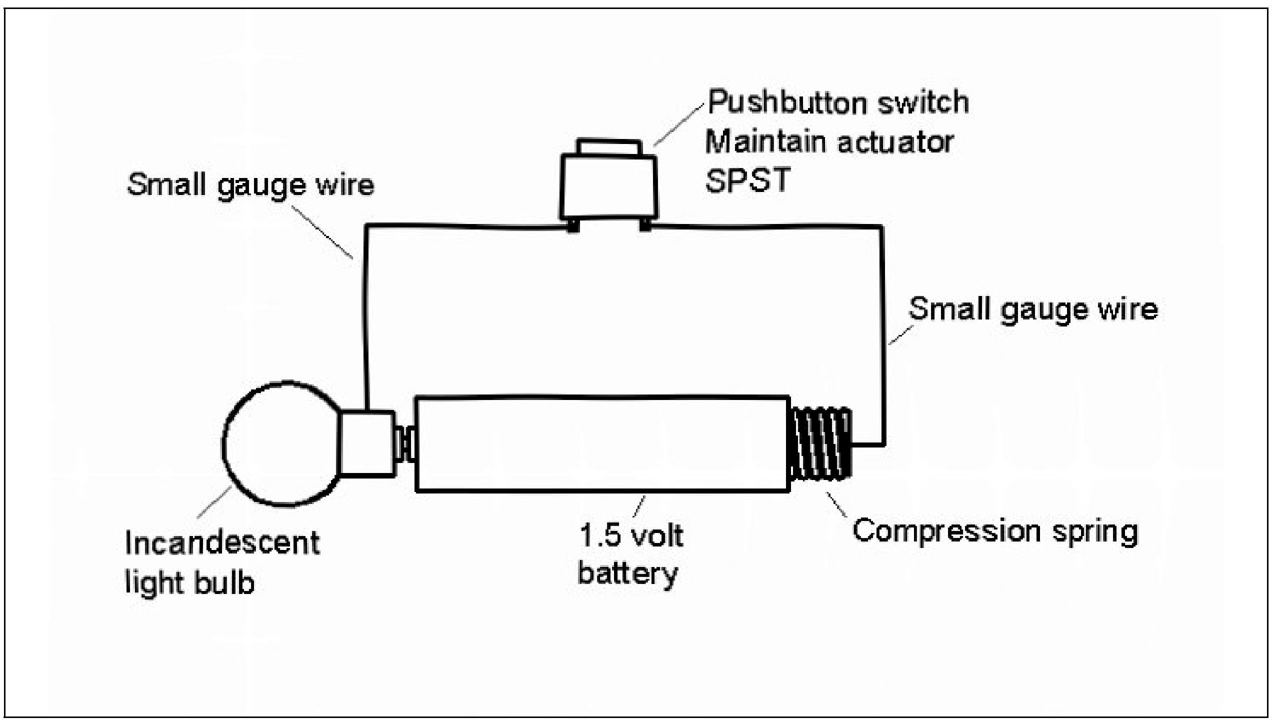


Figure 5.1 – Electrical Components of a Flashlight Sketch

Drawing the Schematic

Electrical Engineers and Designers communicate with a special language and symbols of their own and they use schematics and wiring diagrams to transmit ideas without adding the mechanical properties of the electrical device. A schematic uses industry standard symbols to display the connections and the workings of an electrical circuit. A wiring diagram begins to introduce how we are going to connect all the devices. These two drawings may sound similar but they are not. In a schematic, we may show one main power buss to supply on the rooms using a single black wire. In the actual assembly, we may have 17 separate power cables supplying the design. When the technical staff is working on a design, the schematic is the fastest tool we use to discuss the project. Only after completing the schematic and getting the document approved do we proceed to selecting parts and making the wiring diagram and assembly drawings.

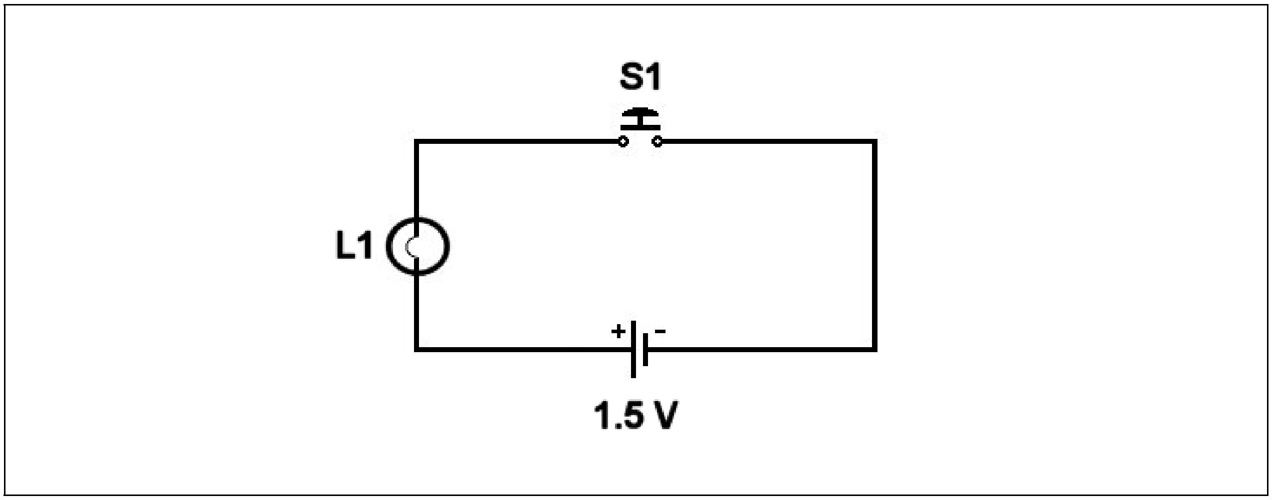


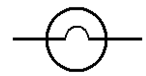
Figure 5.2 – Electrical Schematic of the Flashlight

In the simple lighting circuit, the positive side of the single cell 1.5-volt DC battery connects to the lamp, L1. The other side of the lamp connects to the pushbutton switch. We show the pushbutton switch, S1 in the normally open position and the light will be off. From the switch, S1, the bus connects to the negative side of the battery. We label the lamp and switch to identify the components clearly. In an engineering office, the electrical engineer will most likely write specific notes on the schematic that will guide us in selecting the electrical mechanisms.

*** World Class CAD Challenge 9-5 * - Draw a simple lighting schematic showing a pushbutton switch, a lamp and a battery in 5 minutes. Save the drawing as Flashlight Schematic.**

Continue this drill four times using some other ideas, such as multiple cell battery, toggle switch and more than one lamp, each time completing the drawing under 5 minutes to maintain your World Class ranking.

Specifying the Lighting Device



In almost every assembly there are ten to hundreds of smaller components and of those individual parts some are critical to the working of the design and the other parts are just present to support the important pieces. In our small lighting device, many of us will note that the illuminating object is the most important item in the assembly so therefore we should select this article first. Some of the considerations for selecting the illuminating component should be the amount of candela's produced, power required, the color of the light, the package size, durability, heat produced and sensitivity to environmental surroundings. Not every one of these criteria will carry the same weight, so we may want to determine which one of these parameters are the most important.

In the table shown in Figure 5.3, we recorded a few ideas to begin the design process. A senior designer may use a brainstorming exercise to list as many parameters about the design and encourage innovation. The project manager can add weight multipliers in the table so individuals can see what is important to the supervisor or customer. In our example, the sensitivity to the environment carries more importance than how much heat is produced. A table like this can assist the design team in making decisions without having a major design review daily or hourly.

Criteria	Data	Weight
Candela	Up to 40 lumens	4
Color	White	3
Durability	Drop test – 72 inches high	5
Power Required	One single 1.5 volt AAA, AA, C or D battery	2
Package Size	Pocket size	6
Heat Produced	5 degree Celsius temperature rise	1
Environmental Sensitivity	Waterproof	7

Figure 5.3 – Lamp Selection Criteria and Weight

In an incandescent lamp, the filament acts as a resistance to the current and will glow and emit light. Once we turn on the switch, the current will flow from the battery through the wire into the lamp and energy will be spent in producing the light. How much energy will be consumed is dependent upon the design of the lamp. It is important for the designer to compute the current flow through the wire to feed the lamp so we can select the correct battery, switch and gauge of wire. The battery that we select can sustain the light, however the more energy the light requires will drain the cell quickly.

After conducting an extensive search for 1.5 volt miniature lamps, we are going to select a 1.5 volt, 0.3-amp incandescent light bulb. The light bulb has a 10mm Edison Miniature Screw base. The filament resistance is 5 ohm and the glass of the bulb is clear. When we were searching for lamps, there are hundreds to choose. Our design circuit is simple enough to test with as many light bulbs as we wish to order, so we quickly order a common miniature lamp to test the circuit and proceed with the design.

On the incandescent light bulb shown in Figure 5.4, the base of the lamp has one of the electrical connections and the screw threads on the light bulb have the other bond in the circuit. Once we twist the bulb into the socket, we achieve both unions. The tightness of the lamp in the socket will prevent intermittent separation that we see when these types of lamps flicker. When we see lights flash on and off in a storm, the mechanical energy from the wind often cause loose electrical contacts to open and the lights or electrical device stop working. Prudent maintenance personnel and technicians will follow the manufacturer's guidelines and periodically check electrical connections for proper torque.

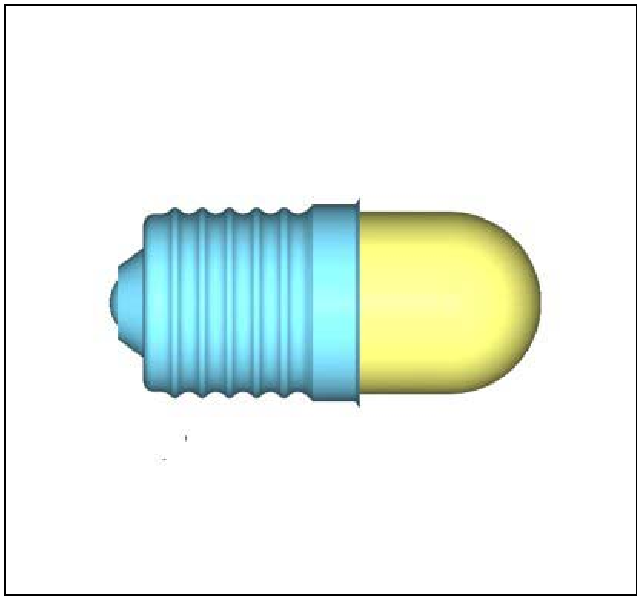


Figure 5.4 – Shape of the Light Bulb

We do want to point out that in our search for light bulbs, we see that many modern flashlight bulbs are the LED lamps that last for 100,000 hours, but require a small power supply made by the manufacturer. Building a LED light is a good project to construct when we want to create a simple circuit board that will contain integrated circuits (IC). We do not suggest using a LED lamp for a beginning flashlight project.

Next, we will select the light bulb socket for the flashlight.

Selecting the Light Bulb Socket

We will purchase an E10 miniature light bulb socket from a manufacturer. The socket has the mating E10 screw base with a solder tab coming off the base of the socket and another off the side of the socket.

In our assembly, a spring will force the battery's positive end up against the bottom of the E10 socket. That will make the first connection and for the other connection, we will need to solder a wire to the outside of the socket's threaded section. When soldering the socket, we need to clean and degrease the surface the light socket where we will join the wire. Heat the lamp socket and the wire with the tinned iron and apply the solder. We should not have an excessive amount of solder on the joint.

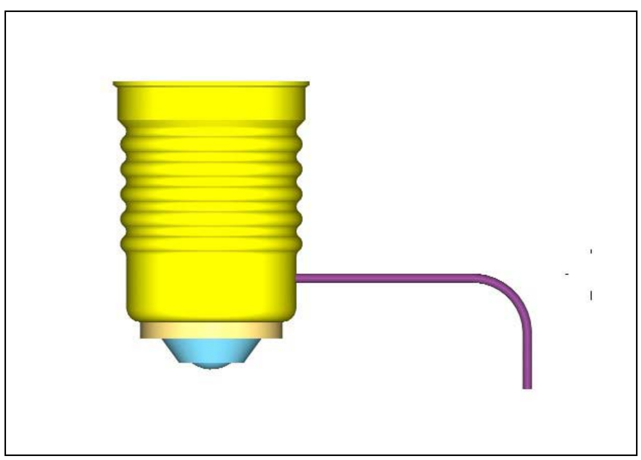
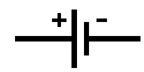


Figure 5.5 – Shape of the Socket

Selecting the Battery



Next, in our design, we will select a single 1.5-volt battery. Although we would prefer a smaller package, we will accept any common sized electrochemical cell such as AAA, AA, C or D. There are hundreds of custom battery sizes available, but the individual or their organization would have to stock uncommon sized replacements if they choose a non-standard battery.

Alkaline cells are ancient in their discovery with the oldest battery dating back over two thousands years ago. Two plates are immersed in an electrolyte, which is an acidic fluid. One plate, the cathode holds an electrically positive charge and the other plate, the anode holds an electrically negative charge. When we connect the anode and the cathode to a load like a light filament, the battery begins to drain. The acid becomes weaker and the two materials become chemically alike. Ultimately, the cell becomes so discharged that our battery cannot illuminate the lamp any longer. In the AAA, AA, C or D batteries the electrical connection is made on either end of the cell, the positive (cathode) has the dimple protruding from the end and the negative (anode) side is flat.

If we use a rechargeable electrochemical cell, the current entering the battery from the charger will restore the charge on the two plates. We are not able to recharge all batteries, and some may even explode if they are not designed for recharging. When using batteries in a design, we need to read the technical data concerning the cell, since parameters such as temperature and storage effect performance.

Our light bulb draws 30mA (0.030 amps) at 1.5 volts for a power usage of 0.045 watts. We compute the power usage by the formula shown in Figure 5.6. The battery also has a potential of 1.5 volts, so the current draw will be parameter that determines the life of the cell.

P = VA

Power = Volts x Amperage

Figure 5.6 – Power Formula

In the table below, we can compare the performance, size, weight and temperature limitations of four common size alkaline batteries.

Size	Diameter	Length	Nom. Voltage	Capacity	Oper. Temp	Weight
AAA	0.41 in.	1.75 in.	1.5 Volt	1250 mAh	0 to 130ºF	0.4 oz.
AA	0.57 in.	1.99 in.	1.5 Volt	2850 mAh	0 to 130ºF	0.8 oz.
C	1.03 in.	1.97 in.	1.5 Volt	8350 mAh	0 to 130ºF	2.3 oz.
D	1.35 in.	2.42 in.	1.5 Volt	20500 mAh	0 to 130ºF	5.2 oz.

Figure 5.7 – Alkaline Battery Comparison Chart

As we can see, the standard AAA package is not designed for long life. Just slightly smaller than an AA battery, the AAA cell only has a 1250 milliamp-hour capacity. For extremely small flashlight designs, the standard AA alkaline battery is more efficient supplying 2850 milliamp-hour. Once we build our circuit, we can test all four electrochemical cells for life and generate a graph showing hours of usage and the amount of light generated. For our design, we will select the AA battery.

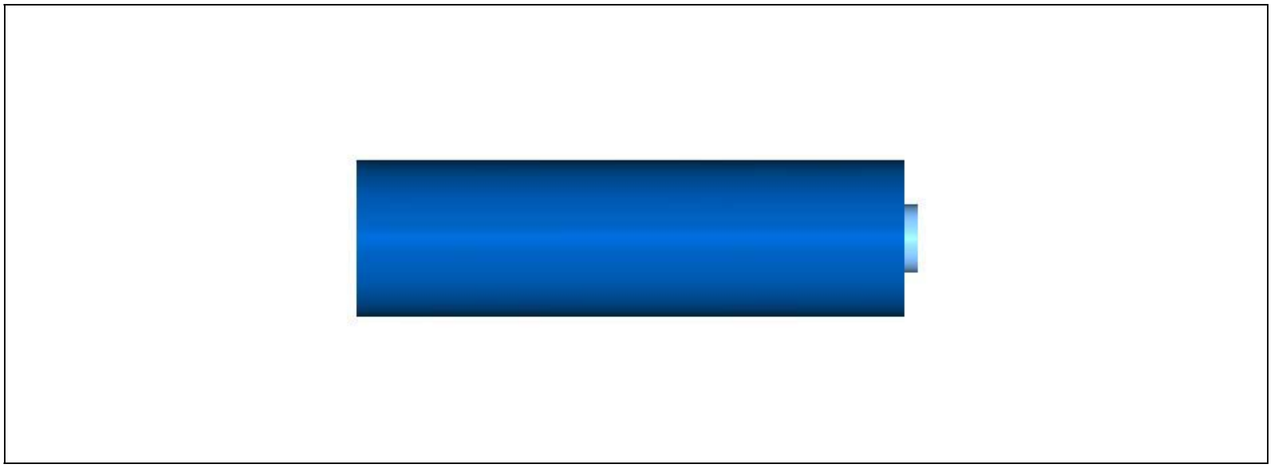


Figure 5.8 – Shape of the AA Battery

Selecting the Spring

The spring performs both a mechanical and electrical function in the design. The coils of the compressed spring will force the lamp and battery together and the material of the spring will act as a buss or wire to transmit the current from the switch to the anode (negative) end of the battery.

What materials are good conductors? The conductivity of a material is the inverse of the material's Resistivity. In the chart below, we see different materials that manufacturers use to improve conductivity. The material with the lowest resistivity is the best conductor. The substance with the best conductivity is silver, a metal that is both expensive and has a low melting point. In the list, music wire, the primary material we use in making springs is not the best conductor, but we will add nickel plating for corrosion protection and improve the conductivity at the same time.

Material	**Resistivity at 20º C**
Aluminum	$2.82\times10^{-8}\ \Omega m$
Brass	$7.0\times10^{-8}\ \Omega m$
Copper	$1.72\times10^{-8}\ \Omega m$
Gold	$2.44\times10^{-8}\ \Omega m$
Music Wire (steel)	$11.8\times10^{-8}\ \Omega m$
Nickel	$6.84\times10^{-8}\ \Omega m$
Silver	$1.47\times10^{-8}\ \Omega m$

Figure 5.9 – Material Conductivity Comparison Chart

To find the static resistivity of a metal or any material, we compute the following formula.

$$p = R \times \frac{A}{l}$$

Where p is the static resistivity measured in ohm – meters (Ωm)
R is the electrical resistance of the material measured in ohms (Ω)
A is the cross sectional area of the material measured in square meters (m^2)
l is the length of the material measured in meters

We can rearrange the formula to find the resistance R placed on a circuit by selecting any material. In most cases, we neglect to compute the resistance on a circuit from wires, but we make this computation in cases of high voltage, long distances and where energy levels are critical.

After selecting the music wire material, we learn that the force to hold the electrical connection together is dependent upon several factors, which are the conductivity of the material and the voltage being transmitted. For a nickel-plated spring, Duracell suggests that we apply 500 to 1000 grams (1.1 to 2.2 lbs) of force. The AA battery is approximately 0.5 in diameter, so we are looking a short spring about 0.375 high, 0.375 in diameter, using steel music wire around 0.0625 in diameter and can generate a maximum of 2.2 pounds in force. We are quickly able to narrow down the parameters and rapidly come up with a workable solution. As the mechanical designers narrow in on a flashlight case design, we will need to modify our electromechanical spring to fit their package.

For this spring, we will use music wire that is made from steel. The Modulus of Elasticity or Young's Modulus is the stiffness of the material and for steel; the value is 28,000,000 to 30,000,000 pounds per square inch (psi). The torsion modulus for round steel wire is between 11,000,000 to 12,000,000 psi.

We will use the following formula to find the amount of force in the spring when we compress the battery between the socket and the spring.

$$P = \frac{G d^4 F}{8 N D^3}$$

Where P is the force is pounds
G is the torsion modulus
D is the diameter of the wire
F is the deflection
N is the number of coils in the compression spring
D is the diameter of the coil

From our initial drawing, we have a compression spring diameter of 0.375 inches that has a height of 0.375 inches. When we place the battery in the case, the spring will depress 0.125 inches. The Torsion Modulus is 12,000,000 psi. If the wire diameter is 18 gauge (0.047) and the spring has 4 coils, then the maximum compression or solid height of the compression spring would be 4 times 0.047 or 0.188. Add the 0.125 depression height to the 0.188 and we find that the unloaded or full height of the compression spring has to be 0.313 inches. Our height of 0.375 will give us a tolerance window to avoid maximum compression.

Now that we have chosen our first values, we will computer the force the spring we have on the battery. The mean diameter of the spring D is the outside diameter minus the diameter of the wire, so 0.375 – 0.047 equals 0.328 inches. As we can see in Figure 5.10, our first set of numbers compute a force of 6.482 pounds. This value is well above what is required by the battery manufacturer for contact force.

$$P = \frac{12{,}000{,}000\ \text{lb/in}^2 \times 0.047\ \text{in}^4 \times 0.125\ \text{in}}{8 \times 4 \times 0.328\ \text{in}^3}$$

$$P = \frac{7.3195215\ \text{lb-in}^3}{1.129201664\ \text{in}^3}$$

$$P = 6.482\ \text{lb}$$

Figure 5.10 – Calculating the Force of the Compression Spring on the Battery

Now we will change the diameter of the music wire, which will also change the mean diameter of the spring, but all other parameters remain the same. The music wire will be 20 gauge (0.035 inches) and the mean diameter will become 0.375 – 0.035 equaling 0.34.

$$P = \frac{12{,}000{,}000\ \text{lb/in}^2 \times 0.035\ \text{in}^4 \times 0.125\ \text{in}}{8 \times 4 \times 0.340\ \text{in}^3}$$

$$P = \frac{2.2509375\ \text{lb-in}^3}{1.257728\ \text{in}^3}$$

$$P = 1.790\ \text{lb}$$

Figure 5.11 – Calculating the Force of the Compression Spring with 20 Gauge Music Wire

In the second attempt, we are between the 1.1 and 2.2-pound force that the battery manufacturer suggests for small direct current applications. The lesson we learn early in design is to begin with common sense parameters. We did not select a 2-inch diameter spring for a 0.5 diameter battery. We did not select 8-gauge music wire that is 0.162 diameter. We begin by selecting sizes that match the assembly and we set our goal from values specified by the manufacturer of the power source. If the small spring did not have enough force, what can a designer change?

We can select a material with a higher Torsion Modulus, but that is not always easy if we begin with music wire, which already has a very high value. Increase the diameter of the wire such as 0.035 to 0.047 and since this parameter is computed to the fourth power, we will see a difference in the force by the multiple of over three. Changing the distance deflected does not have a large affect but this will also increase the force. In the denominator of the formula, decreasing the number of coils by one or two will increase the force. Making the mean diameter of the spring smaller has a larger affect. So remember, wire size and compression spring diameter are made for large changes and material selection, number of coils and distance of spring depression are made to fine tune the design.

In Figure 5.12, we made a 3D compression spring with ends ground to be flat. When we build the prototype, we can determine the best method of attaching the wire. The nickel plating on the steel spring will allow for easy soldering. For round components, design a nest that will hold the part still when soldering the wire to the coil. After the wire is soldered to the spring, the spring assembly is placed in the flashlight body.

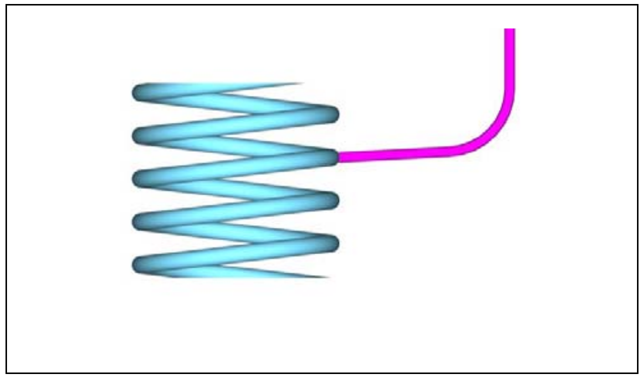
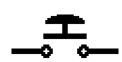


Figure 5.12 – Compression Spring

When working with spring assemblies, do not allow the team or organization that made the part or sub assembly to put multiple coiled parts in a single container together before transporting to final assembly. All of the coils and wires will twist together and we will have a technician uncoiling parts before putting them into the flashlight case. Spring manufacturers can use egg crate dividers to keep parts separate before shipping them to their assembly destination.

Selecting the Switch

We will choose a single 12-volt DC, 50 mA tactile switch that will be mounted below a waterproof cover in the flashlight body. A tactile switch has a very flat profile and we can mount a device like this one on a printed circuit board.



In our design, we will have a nest in the plastic flashlight body, which will hold the tactile switch in place. After inserting the switch, we will solder the two wires coming from the lamp socket assembly and the other from the spring assembly. We will mount the switch in a recess in the plastic and then snapping a flexible material over the recessed area, giving the assembly a watertight seal. The material will be supple enough allow an individual to depress the maintain contact on the switch. The first action is one push and the light is on and the next push and the light is off.

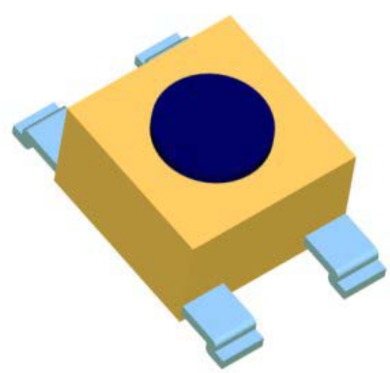


Figure 5.13 – Tactile Switch

Manufacturers design switches for different purposes. Our switch is a power switch and the incandescent lamp's load on the circuit is different than just signal traffic. We want to be sure that the DC voltage of the switch is rated for our use and the maximum amperage will not be exceeded. However, designers with experience know that a large switch, such as one designed for larger AC applications will not likely have quality contacts for the lower voltage applications. Many times larger devices will not perform adequately for smaller voltages.

Selecting the Wire

The lamp draws 0.03 amps of current, so we can predict that our nominal current is to be the same in the wire. There are many types of conductors that we can choose, but first we will classify them.

In a wall of a house or in an electrical device like a microwave or computer, we use insulated wire. Some of the time that cable is made up of multiple strands of smaller gauge wire which allow the bus to bend around corners easily. In other cases, the wire is solid copper. We use aluminum wire to transmit high voltage electricity over long distances since the material is lighter than copper by one third. In a small assembly like the flashlight, we will use solid, non-insulated wire in a plastic case. If the flashlight case was made from metal, we would have to purchase a single conductor cable with plastic insulation, so the wire would not short out on the metal case.

For assemblies made to work in simple commercial products, we would mostly likely select a PVC (polyvinylchloride) insulation that can withstand temperatures from

We will use a 24-gauge wire from the American Wire Gauge chart. The copper conductor is 0.0201 inches in diameter and the wire can safely carry 0.58 amps of current. Sizing the copper conductor to small will allow the current to transfer from one end of the assembly to the other, but the temperature in the case will increase from the cable carrying the maximum load. In certain designs, like with communication inputs and outputs,

Drawing the Electrical Assembly Drawing

After making each part drawing to purchase or to have manufactured, we create an electrical assembly in our CAD software package. In the assembly drawing, we just concentrate of those components that we are required to design. The only component that a mechanical designer or engineer may design in this problem is the spring. Most electrical designers and engineers are quite capable of designing springs that conduct electricity.

In the electrical assembly, we show each part carrying current. The Bill of Material (BOM), which we place typically in the upper right corner of the drawing, shows all of the items in the assembly. Numbered callouts refer each item to the Bill of Material. The drawer is responsible for gather all the construction notes for the assembly and putting them on the drawing sheet. Remember, on new drawings; only use 50% of the available space on the sheet. We need to leave room for details and revision, which are always made during the course of the product's design life.

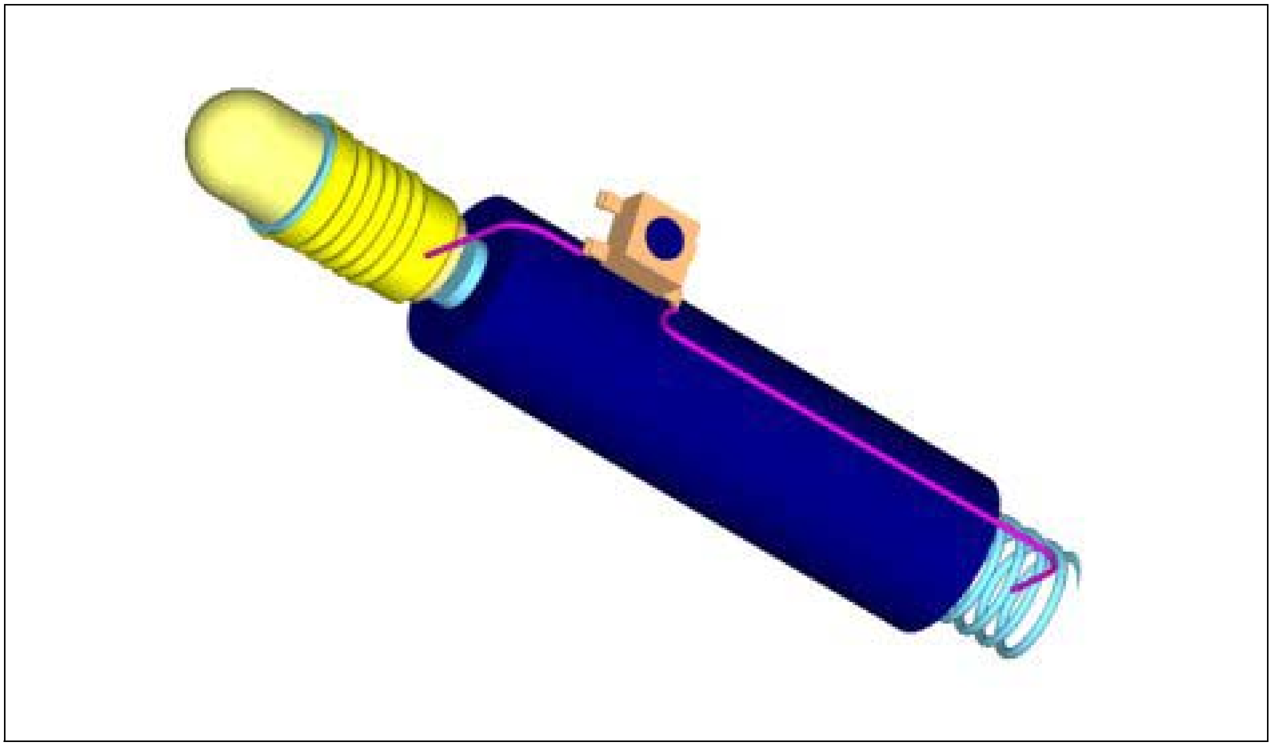


Figure 5.14 – Electrical Assembly

In Figure 5.14, we show each individual components in a three dimensional model. Our challenge in this chapter is to learn the basics of a simple lighting circuit.

*** World Class CAD Challenge 9-5 * - Draw an electrical assembly of the flashlight assembly in 120 minutes. The assembly will have a 1.5-volt DC cell, an incandescent light bulb in a socket, an on-off switch, wires and a spring to maintain contact between the battery and the lamp assembly.**

Continue this drill four times using some other ideas, such as multiple cell battery, toggle switch and more than one lamp, each time completing the drawing under 120 minutes to maintain your World Class ranking.