

Make a High-Tech Caving Light

A Circuit Board of 37 LEDs in three groups

Cavers like light. Cavers like light so much that they carry it with them wherever they go. So, a few years ago when a new invention offered the promise of carrying more light in a smaller pocket, cavers got very excited. The invention is the white light emitting diode (LED).

This article describes how to wire together a group of white-LEDs to make an energy-efficient light useful to cavers. It speaks to those who have more experience cleaning mud from boots than clearing flux from printed circuit boards. Practical tips for soldering an electrical circuit are included. Background information describes the workings of an LED and how it differs from the tungsten light bulbs that are familiar to us. This article ends once the LEDs are soldered to a circuit board, as shown in Figure 1. Another article continues where this one leaves off; see *Mount LEDs in an El Cheapo Headlamp*.

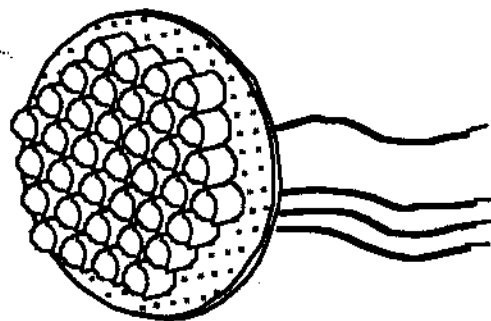


Figure 1: An array of 37 LEDs soldered onto a pre-perforated circuit board, ready for mounting into a headlamp body.

How Works an LED?

LEDs have been around for a long time. Bright LEDs have been available for a number of years. Many cavers have used key-ring sized, red or amber LED flashlights as an emergency light source or for survey point illumination. They operate, amazingly, for days on a single lithium button battery.

LEDs are so efficient because of the way they work. A traditional tungsten light bulb works by heating a tiny wire until the atoms bump into each other so violently that electrons are dislodged into higher orbits and give off light as they fall back down. By comparison, LEDs have two semi-conducting materials side by side. The one hands off an electron to the other in a very gentleman-like manner, placing it into a high orbit, where it can jump down to give off light. Energy is not wasted in the violence of heat.

This gentleman-like behavior, however, complicates things. The electron is always handed off to the same high orbit and the same color of light is produced. Brutish heat, on the other hand, knocks electrons willy-nilly to high, red- and yellow-producing orbits, as well as to even higher green- and blue-producing orbits. The result, a mixture of all colors, is white light.

A normal LED produces light of a single color. To get white light, an LED has to cheat. Surrounding the gentlemanly semi-conductors is a phosphorescent material. (Lordy, lordy what's that? And is it gentlemanly or caver-like?) Phosphorescence is the ability to absorb light of one color and re-emit another color. It's like the white powder you've seen on the inside of broken fluorescent tubes, which glows when hit by the invisible, ultra-violet light produced inside the tube. White-light LEDs are hybrid light-producers. Some of the single-color light strikes phosphorescent material which re-emits it in many colors to produce white light. By looking at a white-light LED at various angles, it is possible to see the bluish original light separate from the white phosphorescent glow. The result is a less efficient LED—some of the light is converted back to heat—but one that is useful to cavers.

It should be noted that white-light LEDs are very efficient compared to tungsten light bulbs for moderate light brightnesses. As the size of the LED array increases, there comes a point where a quality, higher voltage xenon bulb will be more efficient. I don't know where that point is, but someone who does says that cavers who like bright light would be better off using xenon bulbs. He is William Hunt, a caver in Indiana, who produces a voltage regulator for maximizing battery life with light bulbs.

That said, there is a quality of light issue. LEDs tend to produce a broad band of light as opposed to a beam. It is rather like light from a carbide lamp in that respect, however, it is much cooler in color—blue instead of yellow like carbide. If you want to illuminate a formation on the ceiling across a room, LEDs won't do it. You'll need a tungsten bulb with a good reflector behind it.

So, What's In It for Cavers?

About a year ago Henry Schneiker, a long-time caver, began marketing an LED headlamp which he designed to be the ultimate caving light. It is housed as a single unit in a waterproof, machined-aluminum case containing an unusual, almost D-sized, lithium battery. An electronic regulator maintains constant current to the array of 24 white-light LEDs, and a switch allows three power settings. It is called the Action Light and costs \$300. Not all cavers rushed into action to buy one.

Meanwhile, cavers of more modest manufacturing and marketing means, began to play with home-brewed LED caving lights. This article describes one such light.

This caver has made a compact array of 37 LEDs that fits into an inexpensive, widely available waterproof headlamp. It operates on three, internal AA batteries or with an external battery pack for longer-lasting light. It has three power settings to conserve battery life, and to get more useful light out of a slowly-dying, dimming set of alkaline batteries.

That said, I would like to add that this is not a simple, Saturday afternoon project for someone with a borrowed soldering iron. The very compactness of the 37 LEDs gives an advantage in construction to those who are near-sighted. The addition of a three-setting switch means drilling a mounting hole and adds another step of complexity. As an alternative, an array of fewer, more widely-spaced LEDs may be a better first project. It can be mounted in the same inexpensive headlamp using the internal on/off switch. Figure 6 shows a variety of simpler LED patterns to choose from. Using fewer LEDs is cheaper, saves soldering time, and permits sloppier cutting of the circuit board because there is more room between the outer LEDs and the headlamp housing. At least, read the full description of the project before undertaking it, and consider getting help from someone with more tools and experience. Consider starting this afternoon and finishing next weekend instead of this evening.

Description of the LED Array

This compact array of 37 LEDs fits onto a small perforated circuit board. (See shopping list *appendix*) The circuit design is simple enough to be formed by a few straight wires soldered to the LED leads (see Figure 3). This is a straight-forward method of connecting quite a lot of parts with a minimal amount of work.

By the way, another way to create this circuit is to make a printed circuit board. A printed circuit conducts electricity using copper foil on the surface of the board instead of wires. It can be made by drawing the circuitry on a blank, copper-coated board and then etching the board with chemicals to dissolve away the extraneous copper. Blank circuit boards for etching, however, do not have holes for insertion of LED leads. It seems to me to be more work to drill 74 holes than it is to string a few wires.

The 37 LEDs are configured in three groups (see Figure 2). The groups have 6, 10, and 21 LEDs respectively, for a total of 37. If the array were wired with three switches (as shown in Figure 3), each group could be turned on independently. This would allow brightness settings of 6, 10, 16, 21, 27, 31 or 37 LEDs. Though versatile, this seems unnecessarily complicated. Most cavers wouldn't want to fumble with three switches underground. Rather, with a single switch, it is possible to turn on 6, 16 or 37 LEDs. The wiring for such a circuit is shown in the next article which also describes mounting the array in a headlamp.

The numbers 6, 16 and 37 seem, at first, like uneven steps. The jump between 6 and 16 is much smaller than the jump between 16 and 37. They are smooth jumps in that each step is

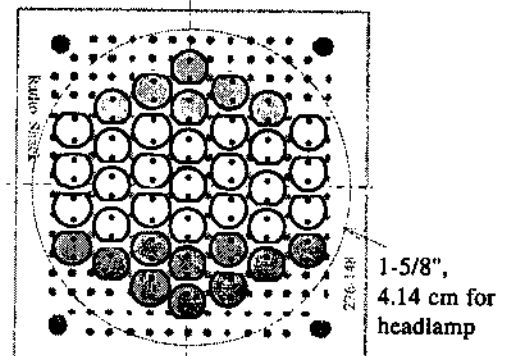


Figure 2: Front of circuit board showing position of three groups of LEDs.

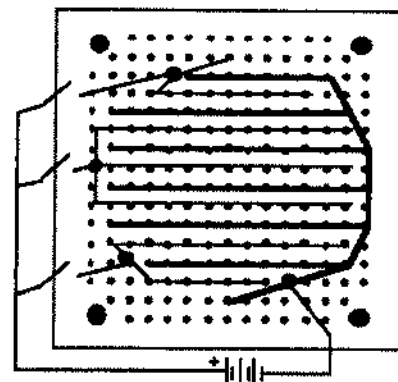


Figure 3: Back of circuit board showing wires connecting LED leads (black dots). A separate switch is shown controlling each group of LEDs. (full size)

about two-and-a-half times as bright as the previous setting. That's what our eyes need to perceive even steps of brightness.

For those who like simplicity, the array can be alternatively wired as a single group by soldering the two dotted lines shown in Figure 4. To get useful run-time for such a large array an external battery pack should be used, rather than three internal AA cells. (By the way, the three-group array itself contains a simplification. More even steps of two-and-a-half times as bright would be 6/15/37 LEDs. But 6/16/37 is easier to construct.)

Having three groups of LEDs offers two advantages. The first one is obvious. When you want more light turn on more LEDs. When you want to conserve battery power, turn on fewer LEDs.

The second advantage is not obvious but is important for getting maximum use out of alkaline batteries. Alkaline batteries die a slow and lingering death. That is, their voltage drops gradually over their lifetime. A cave passage that is lighted adequately with 16 LEDs and fresh batteries can become dim and dangerous with stale batteries. Still, there's a lot of steam in stale cells. As batteries are used and voltage drops, turn on 37 LEDs instead of 16. When you would otherwise need to change batteries, turn on more LEDs instead. Useful battery life is extended.

Increasing the number of LEDs at lower voltage works because of another advantage that LEDs have over light bulbs. They give off light just as efficiently at lower voltage as at higher voltage (within their operating range). Light bulbs, on the other hand, give off mostly heat at lower voltage and very little light. That's the yellow glow you see with dying batteries. An aging alkaline is very inefficient at producing tungsten light, but not LED light. (A disclaimer: This is true for normal LEDs. I don't know whether it holds absolutely for white-light LEDs because of their hybrid light-producing nature.)

This lingering death is a property of alkaline cells but not of NiCads or nickel-metal hydride cells. I hope to write another article on run-time that can be expected with various sizes and types of batteries using this LED headlamp.

Soldering LEDs to the Circuit Board

Circuit board is a hard composite material used to hold electronic components. It is available in a perforated version with holes one-tenth of an inch apart. This is a standard distance in electronic parts, including the distance between LED leads.

If you want to mount the LED array into a particular headlamp, the first step in construction is to cut the circuit board to size. The Eveready headlamp accepts a circuit board 1-5/8 inches in diameter. (Another article describes mounting this array into that headlamp.) Circuit board material is hard and somewhat brittle. It can be cut with strong scissors or preferably with metal snips. Perhaps "cut" is the wrong word. Boards can be "trimmed" by chipping away small chunks of material. Alternatively, actual cuts can be made with a fine-toothed hacksaw. If you have a Dremel tool, those cutting disks work well for straight cuts.

Notice in Figure 4 that the 1-5/8 inch diameter circle is not centered on a hole in the perforated board. Rather, it is centered in line with one row of holes, and between rows in the other direction. So, once the board is cut out, even though it's circular, there is a top and bottom,

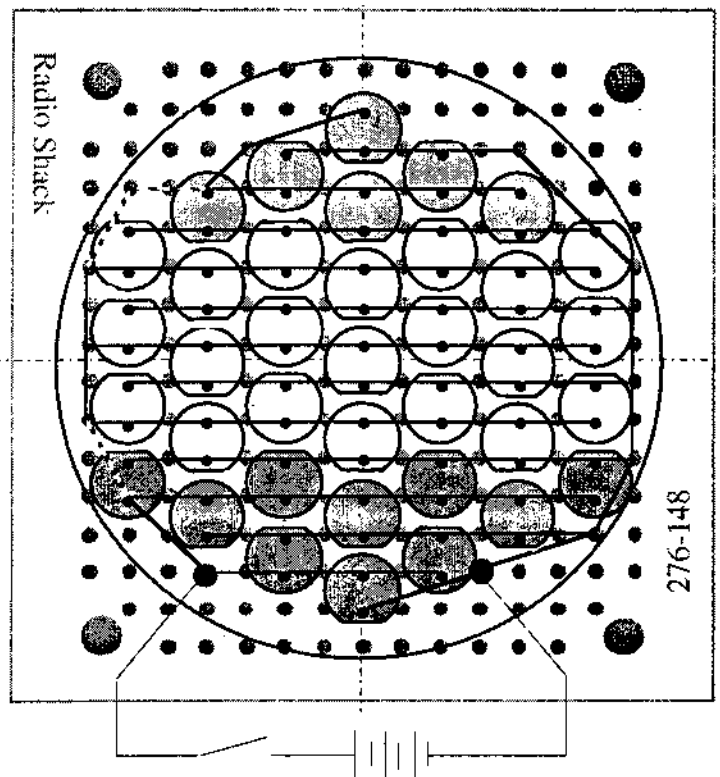


Figure 4: Detailed view of circuit board. Note the orientation of LEDs as indicated by the flattened side. LEDs are shown wired as a single unit due to the addition of two wires shown as dotted lines. Note that the center of the enclosing circle falls between two perforations.

and a left and right. Keep this in mind when inserting the first LEDs. Figure 2 is full-sized and can be cut out and used as a pattern if desired. (Line up the holes on the pattern and circuit board — not the edges. Some of the Radio Shack circuit boards have more rows of holes than others!)

Most perforated circuit boards have rings of copper foil around the holes. Before soldering anything to the circuit board, these should be cleaned of grease and tarnish so that solder sticks to them. Fine steel wool works well for this purpose. (Be sure to clean off any stray, electrically-conductive, steel fibers.)

LEDs are most easily soldered into place one horizontal row at a time. Insert the leads through the holes from the non-copper side. When inserting LEDs, it must be remembered that there is a positive lead and a negative lead. The longer lead is positive and must be attached eventually to the positive end of the battery, the one with the nipple. Also, the plastic top of the LED has a flat side molded into it near the negative lead. Figures 4⁴5 show this flat side best. Be careful to insert the LED into the circuit

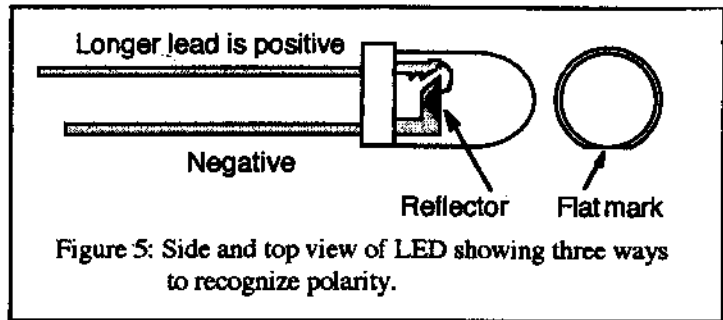


Figure 5: Side and top view of LED showing three ways to recognize polarity.

board with the correct orientation. Note in Figure 4 that the first column of four LEDs has the flat side up. The next column of five has them pointing down, and so on. This allows one straight wire to touch the positive leads on two adjacent horizontal rows of LEDs. Similarly, the next straight wire touches the *negative* leads on the *next two* adjacent horizontal rows, and so it goes. This is key to the simple circuit with few wires that is shown. Working from the top down (or bottom up) the first horizontal row has 1 LED, the second 2, the third 3, the fourth 4, the fifth 3 again, and so it goes.

Here's a complicating factor. The white-light LEDs I obtained were just slightly too big to fit the pattern shown. The little rim at the base got in the way. (The red LEDs I had on hand for testing the pattern worked just fine.) It's not hard to rub the rim across a file a few times to remove it, even a fingernail file, but it must be done to each LED, which takes a little time. File down the rounded side so it looks like the flat side and you can't tell the positive lead from the negative lead except by length.

With a row of LEDs in place, turn the board over and run a bare wire in a straight line touching each LED lead as shown in Figure 3. Solder the wire to each lead that it touches. Solid (non-stranded) wire is best for this purpose. It must be bare (non-insulated). The wire should not be too thick because there's not a lot of room. Furthermore, the wire won't be perfectly straight which leaves even less room. To solder, touch the hot soldering iron to the wire and LED lead first, then bring in the fine wire solder to touch all three until it flows onto both the wire and the lead (and preferably onto the copper foil on the circuit board as well). Heat should not be applied for more than about five seconds or there's a danger of damaging the LED. All of this is a little bit tricky. With your third hand hold the wire so it stays in contact with the LED lead.

It's a good idea to practice all this without endangering the lives of your expensive white-light LEDs. You can buy an assortment of 20, mostly red, LEDs at Radio Shack for a couple of bucks and extra circuit board is even cheaper. Consider them expendable. Here are some hints. You need something to hold the circuit board in place so your soldering iron doesn't push it across the table. There are soldering vices for this purpose, complete with magnifying glass. But vice grips or even a couple of clothes pins and some books can help position the circuit board. To help hold the wire in place the end can be bent and inserted through an empty hole in the circuit board in line with the leads being soldered. Fine wire can be woven above and below alternate leads, like making a basket, so that the springiness of the wire holds it in place. However, this tends to bend the LED leads or skew the LEDs themselves. That brings up the question of what keeps the LEDs from falling out once the circuit board is turned upside down. Taping components temporarily into place is generally suggested. My method was to dab a tiny drop of super glue onto the bottom of each LED before inserting it. After several minutes each row of LEDs was firmly fixed to the circuit board. The first minute can be used to double check that no LED is inserted backwards. Practice getting the solder to flow within about five seconds. When it doesn't, back off and go to the next lead while the first one cools so you can try again.

All of this technique is useless if you can't see. Have a strong light on your workspace. If you're not blessed with nearsightedness, a pair of strong, generic reading glasses from the drugstore or discount

store can help. A jeweler's visor is ideal. A magnifying glass will work if you have a fourth hand. Leave the long leads on the LED as you solder. They act as a heat sink to help cool the LED faster. Remove them with wire cutters when you're done. It's a good idea to check each row of LEDs after it's soldered. Hook up two batteries to the positive and negative wires to check that the whole row lights up. This may detect an LED installed backwards or one you have destroyed with too much heat, early on, when it's easier to fix. Plus, it's very rewarding to see the glow.

Notice in Figure 4 that all of the negative leads are connected to a common wire on the right. The positive leads are connected on the left, but in three separate groups. Use the ends of the straight wires that connect each row to loop around and join the wire two dots below it. Solder the connection.

The soldering is almost done. Just four more wires need to be connected to the circuit board. They will connect the LED array to batteries and a switch. While you used bare, solid wires for the circuit board, now you need insulated, stranded wires several inches long. The stranded wire is more flexible and doesn't break as easily when flexed. Figure 4 shows larger dots where these connections are made. The positions shown are rather arbitrary. Connection can be made anywhere along the same wire. Insert the end of a stranded wire into an empty hole next to a solid wire on the circuit board and solder them together. (First remove insulation from the end of the stranded wire.) I positioned the connecting wires to lay pretty flat and to all point clockwise. This lets the wires coil into place when installing the circuit board into the body of a headlamp.

Power It Up

Now we need a power source. White-light LEDs are rated at 3.6 volts. Three alkaline batteries have a voltage of 4.5 volts. Although this is too high and LED manufacturers say that this will damage LEDs by causing premature dimming, cavers just ignore this advice because they have found that it works. Alternatively, three NiCad or nickel-metal hydride (NiMH) batteries have a voltage of 3.75, quite close to the LED's rated voltage. The disadvantage is that they don't last as long as alkalines. Many cavers find that three C-cells is not too much weight to carry on the back of the helmet and lasts a reasonable amount of time with an LED array. The Petzl Mega comes with such a battery pack.

Figures 3 and 4 include wiring diagrams for battery hookup. That long-short-long line symbol represents three battery cells. That open-gate-looking symbol represents a switch. Figure 3 illustrates how each group of LEDs can be controlled by a separate switch, however, this is not recommended for actual hookup. For now you can twist together the loose ends of the three positive wires and connect them to the positive tip (nipple end) of three batteries linked end to end. Connect the negative wire to the butt end of the last battery and ... "Let there be light." A switch is not even necessary—take away battery, out goes light.

Any sized battery cells can be used, AAs, Cs, Ds, they all have the same voltage. Larger cells just last longer. I hope to write another article telling just *how much* longer.

The best way to hook up the three groups of LEDs is with a special switch with three settings. It is a double-pole, double-throw (DPDT), center-off switch. Center position is low power (6 LEDs); left is medium power (16 LEDs); right is high power (37 LEDs). The next article describes installing this LED array into a common, widely available, inexpensive headlamp using such a switch.

If you're anxious to go caving now, the circuit board works just fine, as is, duct taped to helmet or forehead.

—Wayne Bockelman

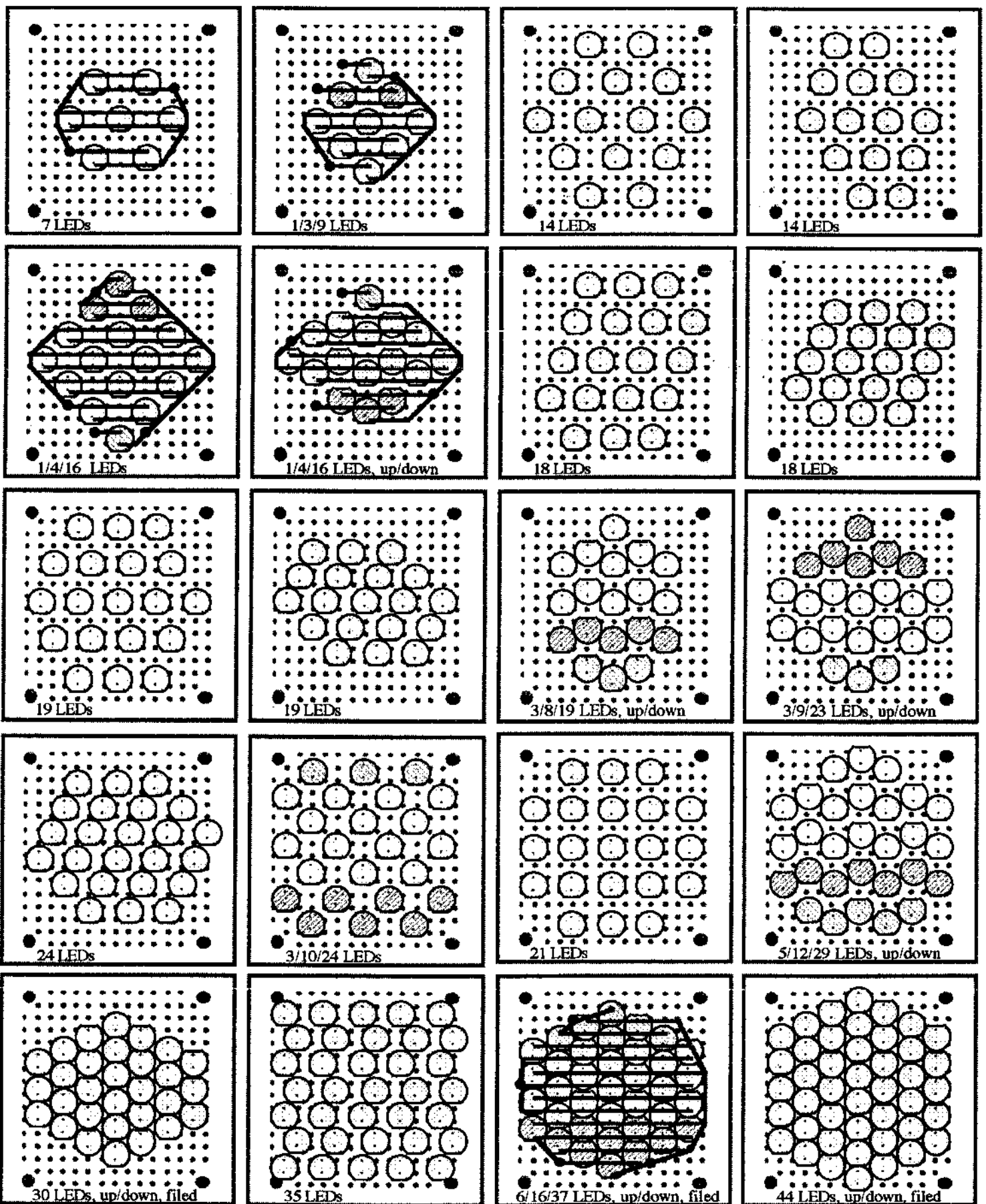


Figure 6: A variety of LED array patterns that fit on a stock, perforated circuitboard.