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LED Light Bank Assembly

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The goal of this module is to construct a relatively simple and inexpensive LED light bank for underwater illumination.

1.1 Background:

An LED is a Light Emitting Diode. Like a normal diode, it consists of two pieces of semi-conducting material (one P-type with positively charged particles and one N-type with negatively charged particles) bonded together to form a P-N junction. Current flows easily from the positive P-side (the anode) to the negative N-side (the cathode), but flows very poorly in the opposite direction.

Charge carriers (electrons and holes) flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, releasing energy in the form of a photon. If the change in energy level is large enough, the photon will have a wavelength in the visible spectrum and will emit visible light.

LEDs have a number of advantages that make them ideal for underwater lighting. Water absorbs different frequencies (colors) of light at different rates, so some colors (especially blue and green) are more suitable for underwater illumination. Since LEDs generate color on a specific wave length, they do not generate the visible wavelengths that will merely be absorbed by the water so they are more efficient than multiple spectrum white light. They also do not use filaments to generate light, so they lose less energy to heat generation; they tend to dim over time instead of burning out abruptly; and they have a much longer life (~ 10 years) than incandescent bulbs. The LED packaging also makes them more resistant to vibration, damage, flooding and shock than other lights and focuses the light.

LEDs do have some disadvantages. They tend to be more expensive than other lighting sources and their lifespan is related to operating temperature (overheating will cause premature failure). However, the ocean serves as a heat sink and should minimize the risk of premature failure and the increased cost is insignificant compared to the benefits.

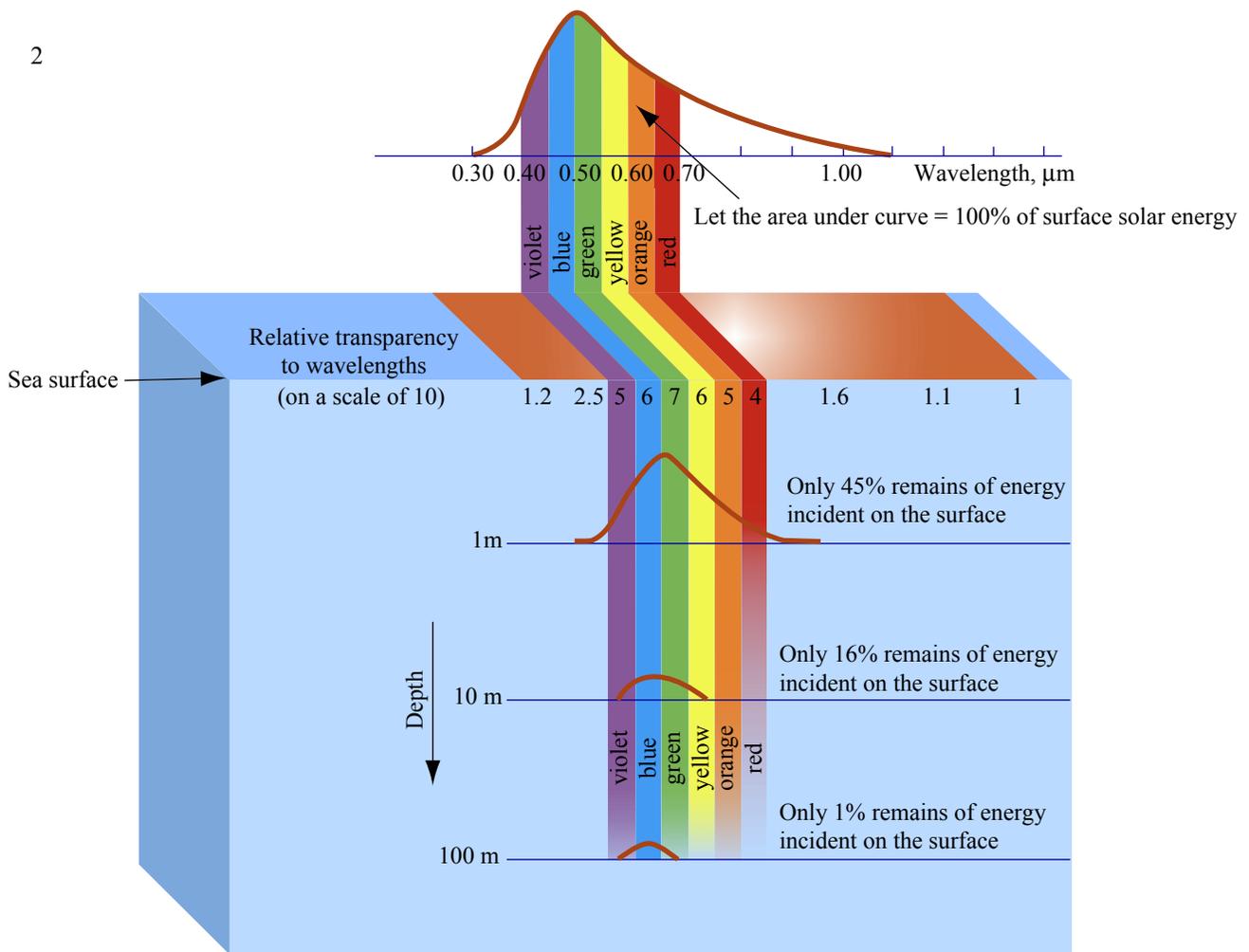


Figure by MIT OpenCourseWare.

Figure 1: Light Absorption in the Ocean (www-ocean.tamu.edu)

1.2 Theory

The LED product data sheet specifies maximum (V_{\max}) operating voltage, operating current (I_{op}), and minimum (L_{\min}) luminescence. Resistors have a resistance value (R_{resistor}) and maximum power rating (P_{\max}).

We would like to use a 24 volt battery (V_B). We know from experience that 25-30 candelas of light intensity pointing straight ahead will be sufficient for our application. Our specific LEDs require 3.6 V and 0.02 A, and supply 2500 millicandelas of luminous intensity each. Our specific resistors have a power rating of 0.25 watts. We must choose an appropriate number and configuration of LEDs and resistors to ensure sufficient voltage, current and luminescence without subjecting them to power exceeding their rating. For now we will assume that we will use M banks of LEDs in series where each bank contains N LEDs in parallel. The number and type of resistors needed in the circuit will be determined later.

Although these calculations will be performed for our specific case, they can be repeated for any combination of battery, LEDs and resistors.

1.2.1 Luminescence

The total luminescence for the light bank will be the number of LEDs in the bank ($M * N$) multiplied by the luminescence of each LED (L_{\min}).

$$L_{\text{tot}} / L_{\min} = N * M \text{ LEDs}$$

$$30 \text{ candelas} / (2500 \text{ millicandelas per LED}) = 12 \text{ LEDs.}$$

We therefore, choose 4 rows with 3 LEDs per row.

1.2.2 Voltage

The voltage required for a row of parallel LEDs is the same as the voltage required for a single LED.

$$V_{\max} * M = V_{\text{required}}$$

$$3.6 \text{ V} * 4 \text{ rows} = 14.4 \text{ V required.}$$

Since 14.4 volts is less than the 24 volts that the battery can provide, this is an acceptable number of rows.

1.2.3 Current

The amount of current that is drawn from the battery is equal to the current that is required for each row of LEDs.

$$I_{\text{op}} * N = I_{\text{drawn}}$$

$$0.02 \text{ A} * 3 \text{ LEDs per row} = 0.06 \text{ A.}$$

A standard 24 volt battery (rechargeable car or motorcycle battery for example) should easily be able to produce 0.06 A so the number of LEDs in each row is acceptable.

1.2.4 Resistance

Supplying more voltage to the LEDs than expected could shorten their lives so a set of resistors must be used to ensure that the LEDs receive only 14.4 V.

$$V_B - V_{\text{required}} = V_{\text{resistors}}$$

$$24 \text{ V} - 14.4 \text{ V} = 9.6 \text{ V}$$

The total resistance required to reduce the voltage from the battery voltage to the voltage required by the LED bank is given by dividing the voltage across the resistors by the current drawn by the LED bank.

$$V_{\text{resistors}} / I_{\text{drawn}} = R_{\text{total}}$$

$$9.6 \text{ V} / 0.06 \text{ A} = 160 \text{ ohms}$$

One single 160 ohm resistor would be sufficient to reduce the voltage from the battery to the LED banks if the resistor could dissipate the power required without melting. The power dissipated by a single resistor is given by:

$$I_{\text{drawn}}^2 * R_{\text{total}} = \text{Power}$$

$$0.06 \text{ A} * 0.06 \text{ A} * 160 \text{ ohms} = 0.576 \text{ watts.}$$

The power rating of our resistors is 0.25 watts which is much less than the required power rating, therefore a set of resistors in parallel must be used to regulate the voltage.

If the power is evenly distributed across all of the resistors, then the total number of resistors needed is given by dividing the total power required by the power rating of the individual resistors.

$$\text{Power} / P_{\text{resistors}} = N_{\text{resistors}}$$

$$0.576 \text{ W} / 0.25 \text{ W} = 2.304 \text{ resistors}$$

Since we must use a whole number of resistors, the minimum number of resistors needed is three. We will use one extra resistor for safety. Thus, $N_{\text{resistors}} = 4$.

The total resistance for N resistors in series is given by the sum of the individual resistors ($R_{\text{total}} = R_1 + R_2 + \dots + R_N$) while the total resistance for N resistors in parallel is given by the reciprocal of the reciprocal sum ($1/R_{\text{total}} = 1/R_1 + 1/R_2 + \dots + 1/R_N$). If all N resistors have the same value of resistance, the equation reduces to:

$$1 / R_{\text{total}} = N_{\text{resistors}} / R_{\text{resistor}}$$

$$1 / 160 = 4 / R_{\text{resistor}}$$

So the resistance for each of the four resistors R_{resistor} should equal 640 ohms.

Resistors come in discrete values so the closest value would be a 680 ohm resistor. Thus, we require four 680 ohm resistors in parallel.

1.2.5 Circuit Diagram

The resulting circuit diagram for our LED light bank will look like this:

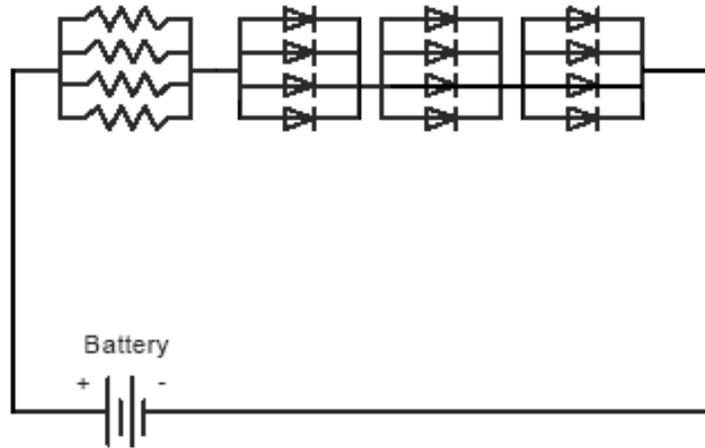


Figure 2: Circuit Diagram for LED Light Bank

1.3 Components

To build an LED Light Bank, you will need the following components:

- Power Source
- LEDs
- Protoboard to mount components
- 22 Gauge Solid Core Wire (red, black, and blue)
- Resistors

For our specific light bank, we will be using:

- A variable voltage power supply for testing
- A 24 volt rechargeable car battery for operation
- White LEDs (Jameco.com part # 1870796 or # 183231 or # 334773 get 12 per light bank)
- PCB/Epoxy Glass Protoboard (Jameco.com part # 263215, get 1 per light bank)
- 680 ohm 1/4 watt Carbon Film Resistors (Jameco.com part # 690822, get 4 per light bank)
- 22 Gauge Solid Core Wire (Jameco.com part #s 36792 for black, 36768 for blue, and 36856 for red, 100' rolls each)

1.4 Tools

To build an LED Light Bank, you will need the following tools:

- Soldering Iron with Wet Sponge
- Solder with Flux
- Wire Cutters
- Wire Strippers
- Pliers
- One Red and One Black Alligator Clip

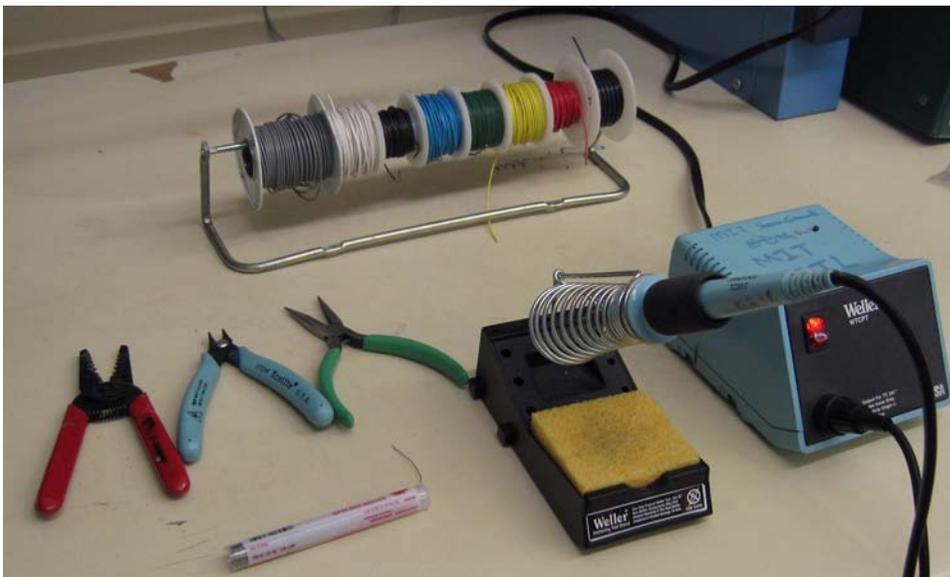


Figure 3: Tools for Building LED Light Bank

Note: Sections 1.5 and onwards, are for your reference only. We will be building a different light bank, with different number of LEDs and resistors. We will follow a similar procedure to what is described here, but the exact placement and number of components will be different. Sample, completed light banks will be available in the labs which you can use as a guide.

1.5 Assembling the Electronic Components

There are really only two parts to making an LED light board: understanding how the circuit diagram translates to the placement of components (LEDs, wires and resistors) on the protoboard and connecting (soldering) those components to the board.

1.5.1 Add Jump Wires to Connect Inner and Outer Mounting Holes

Consider the empty protoboard shown in Figure 4. It has 32 rows of mounting holes. The outer five holes on the left are connected to the outer holes on the right by a thin piece of metal embedded in the board. The inner five holes on the left are connected to the inner holes on the right by a thin piece of metal embedded in the board. However, the outer holes are not connected to the inner holes. This is true for all but the first two rows which only have four outer holes and no inner holes.

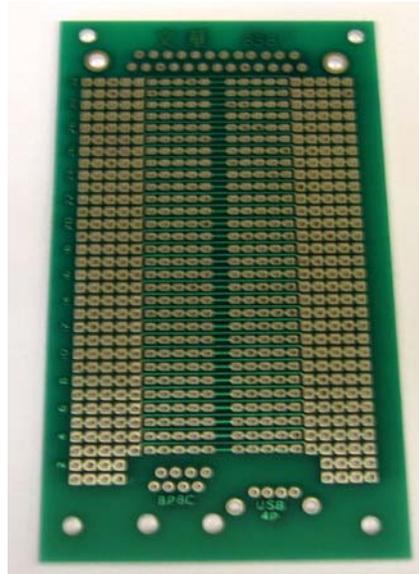


Figure 4: Protoboard

It would be very convenient if the inner and outer holes were electrically connected as this would allow us to place each set of 7 parallel LEDs in a single physical row. However, we only need 7 rows of parallel LEDs (14 rows of protoboard holes: 7 positive and 7 ground). So we will create 14 jump wires and place them on the board to create 14 evenly spaced, connected rows.

- Cut 7 pieces of black wire approximately 0.65" long.
- Cut 7 pieces of red wire approximately 0.65" long.
- Strip all 14 pieces of wire leaving approximately 0.35" insulation in the middle.
- Bend each wire in half to form a "U" shape.



Figure 5: Bent Jump Wire

- Place the protoboard so the lowest numbered row is closest to you (the numbers are located on the left hand side of the board)
- Locate row # 32 (it should be the further row away from you).
- Even numbered rows will be ground so place one black jump wire between the right most outer hole on the left in row #32 and the left most inner hole on the right in row #32.
- Turn the board over and solder both ends of the wire into place.
- Note: The insulation on wire may shrink or melt if you hold the soldering iron on the stripped ends for too long. Solder may also leak through to other side of PCB board as you solder. This is not a problem but it can push your wire out of place.
- Trim the wire leads so very little wire sticks out from the back of the board.
- Turn the board back over so you can see the black wire insulation.
- Locate row #31.
- Odd numbered rows will be positive and even numbered rows will be ground so place one red jump wire between the right most outer hole on the left in row #31 and the left most inner hole on the right in row #31.
- Turn the board over and solder both ends of the wire into place.
- Repeat this process for rows #28 and 27.
- Repeat this process for rows #24 and 23.
- Repeat this process for rows #20 and 19.
- Repeat this process for rows #16 and 15.
- Repeat this process for rows #12 and 11.
- Repeat this process for rows #8 and 7.

Your board should now look like this:

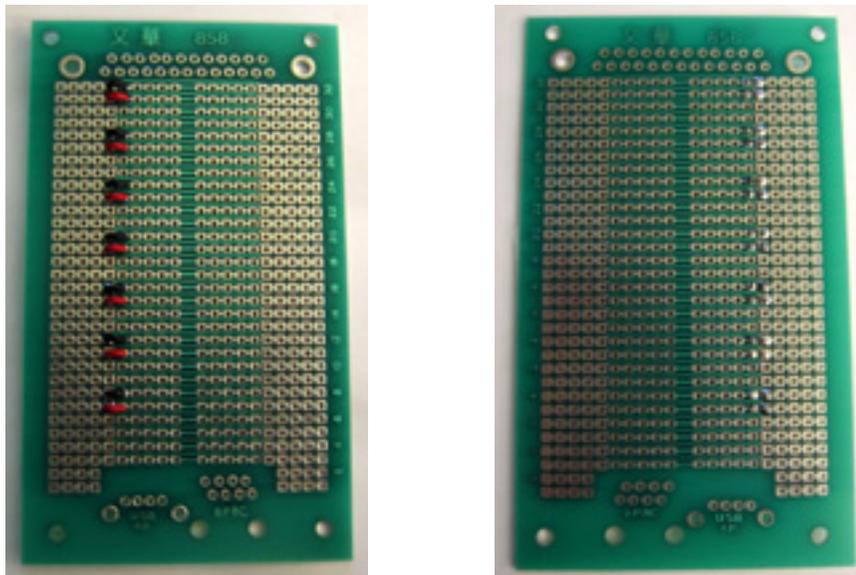


Figure 6: Protoboard with Jump Wires: Front (left) and Back (right)

1.5.2 Add Wires to Connect LED Rows Together

We now have seven pairs (fourteen rows) of mounting holes. These pairs should be connected in series. The LEDs will connect one row to another but we need to add wires to connect one pair to another. We shall accomplish this by connecting the ground row of one LED pair to the positive row of the next LED pair.

- Cut 6 pieces of blue wire approx. 1" long
- Strip all 6 pieces of wire leaving approximately 0.65" insulation in the middle
- Bend the wire near each stripped end and then in half to form a "U" shape
- Locate rows #28 and 31.
- Place one end of the wire in the rightmost hole of the outer right set of holes in row #28 and the other end of the wire in the rightmost hole of the outer right set of holes in row #31.
- Turn the board over and solder both ends of the wire into place.
- Trim the wire leads so very little wire sticks out from the back of the board.
- Turn the board back over so you can see the red, black and blue wire insulation.
- Repeat the process for rows #24 and 27.
- Repeat the process for rows #20 and 23.
- Repeat the process for rows #16 and 19.
- Repeat the process for rows #12 and 15.
- Repeat the process for rows #8 and 11.

Your board should now look like this:

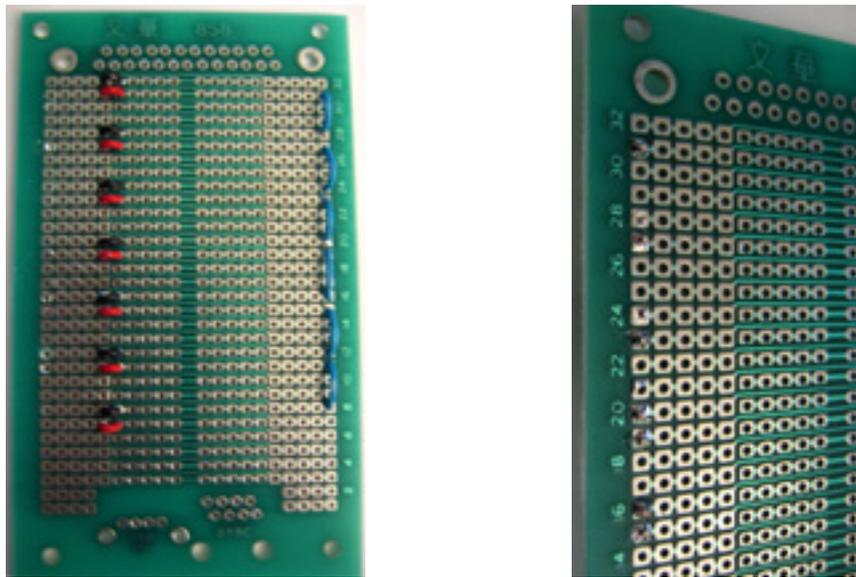


Figure 7: Protoboard with Row Connection Wires: Front (left) and Back (right)

1.5.3 Add the Negative Lead

We must add a negative lead for the light bank so we may connect the circuit to the battery or power supply.

- Cut 1 piece of black wire approx. 4" long
- Strip the wire leaving approximately 3.75" insulation in the middle
- Locate rows #32
- Place one end of the wire in the rightmost hole of the outer right set of holes in row #32.
- Turn the board over and solder the wire into place.
- Trim the wire lead so very little wire sticks out from the back of the board.

1.5.4 Add one row of LEDs

Recall that LEDs are diodes and only work in one direction. Most LEDs have a longer electrical lead and a shorter electrical lead. Typically, the longer lead is positive and the shorter lead is negative. The longer positive lead must be placed in the mounting hole on the positive row and the shorter negative lead must be placed in the mounting hole on the negative or ground row.

- Turn the protoboard over so you can see the solder connections from the previous steps but not the colored wire insulation.
- Obtain one LED.
- Locate rows #31 and 32.

- Place the longer (positive) LED lead in the leftmost hole of the left outer set of holes in row #31.
- Place the shorter (negative) LED lead in the leftmost hole of the left outer set of holes in row #32.
- Turn the board over and solder both LED leads into place.
- Turn the board back over so the LED bulb is facing you.

We would like to place one LED every three columns of mounting holes. (We would like two mounting holes between each LED.) So:

- Obtain another LED.
- Place the longer lead in the fourth leftmost hole of the left outer set of holes in row #31.
- Place the shorter lead in the fourth leftmost hole of the left outer set of holes in row #31.
- Turn the board over and solder both LED leads into place.
- Continue placing LEDs every third hole until all seven LEDs in the first row have been placed and soldered.

It may be a bit tricky to place and solder the LEDs near the jump wires. Trimming the leads of the jump wires to be as close to the protoboard as possible will help. Your board should now look like this:

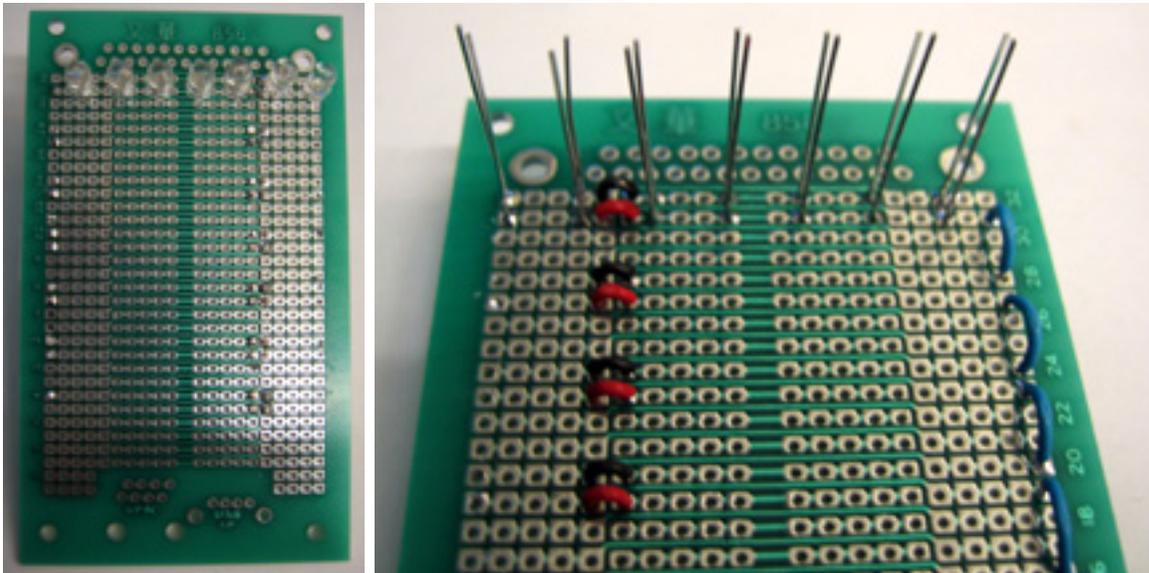


Figure 8: First Row of LEDs: Back (Left) and Front (Right)

1.5.5 Test one row of LEDs

There are two primary goals for testing the first row of LEDs: to determine if the LEDs were placed in the correct orientation and to determine if the electrical (solder) connection was made.

The orientation of the LEDs can be checked by visual inspection. Turn your protoboard so the LED bulbs are facing downwards and the leads are facing up then look at the protoboard from the side (figure 9). All of the longer leads should be in a single line and all of the shorter leads should be in a single line. If any are out of place, they will have to be de-soldered and replaced in the correct orientation.

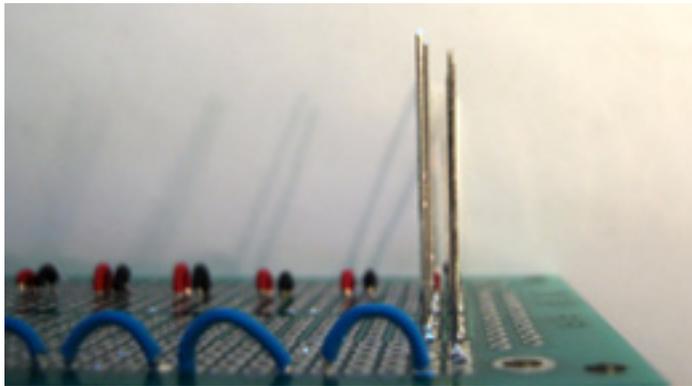


Figure 9: Side View of First Row of LEDs

The electrical connection must be verified by running a current through the existing circuit. Recall that each row of LEDs in parallel requires the same amount of voltage as a single LED. So to test the row of LEDs, you must supply 2.6 V and no more.

To test the first row of LEDs:

- Locate the positive (longer) lead of the leftmost LED (furthest away from the long negative protoboard lead) and place a red alligator clip on it (figure 10a).
- Located the long negative protoboard lead and place a black alligator clip on it (figure 10b).
- Locate a variable power supply or a battery capable of supplying 2.6 volts and 0.14 amps.
- Connect the red alligator clip to the positive terminal of the power supply or battery.
- Connect the back alligator clip to the negative terminal of the power supply or battery.

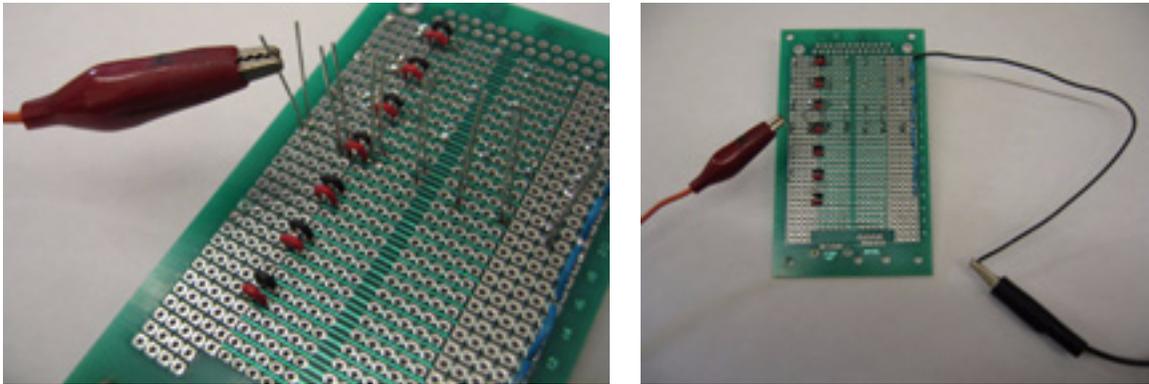


Figure 10: Testing the First LED Row. Positive Lead (right) and Negative Lead (left)

All of the LEDs in the row should glow green (their normal operating color). If any LEDs are not lit, double check their electrical connections for improper or incomplete soldering and re-solder if necessary. If none of the LEDs are lit, double check to make sure that the power supply is indeed supplying 2.6 V and then move the negative lead from the negative protoboard wire to the negative terminal of the last LED. If this works, then the problem is with the negative protoboard wire.

1.5.6 Cut the Leads for the LEDs

Once you have completed testing of the first row of LEDs and have corrected any problems there may be, you may cut the leads for all of the LEDs in the row. Be sure to hold the LED lead with your fingers or with pliers while cutting it. This will prevent the lead from flying through the air (and hitting people or equipment) after cutting.

1.5.7 Add the Rest of the LEDs

You are now ready to add the other six rows of LEDs.

- Repeat steps 1.5.4 through 1.5.6 for rows #28 and 27.
- Repeat steps 1.5.4 through 1.5.6 for rows #24 and 23.
- Repeat steps 1.5.4 through 1.5.6 for rows #20 and 19.
- Repeat steps 1.5.4 through 1.5.6 for rows #16 and 15.
- Repeat steps 1.5.4 through 1.5.6 for rows #12 and 11.
- Repeat steps 1.5.4 through 1.5.6 for rows #8 and 7.

Be sure to test after each row using the positive lead of the LED on the newest row furthest from the negative protoboard and the protoboard lead itself, increasing the voltage by 2.6 volts every time you add a row. Don't cut the LED leads until you are sure that all of the rows currently on the board are functioning properly.

Your board should now look like this:

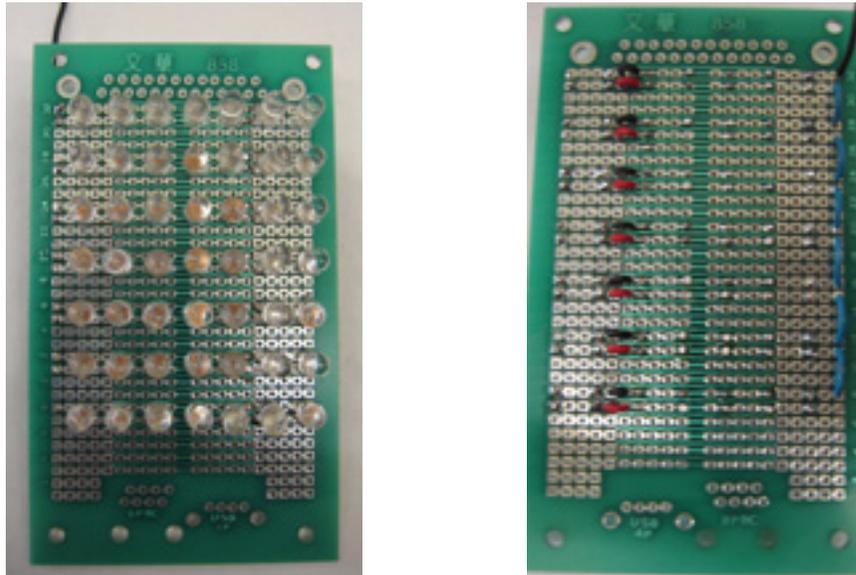


Figure 11: All Rows of LEDs: Back (Left) and Front (Right)

1.5.8 Add two more jump wires

All of the soldering work with the LEDs is now completed but we still must add our resistors to the circuit. Again, we would like to have all of our resistors in parallel located on the same physical row of the protoboard so again we will place jump wires across the inner and outer sets of mounting holes to electrically connect them.

- Place the protoboard so the colored wire insulation is facing you.
- Locate row # 4.
- Place one black jump wire between the right most outer hole on the left in row #4 and the left most inner hole on the right in row #4
- Turn the board over and solder both ends of the wire into place.
- Trim the wire leads so very little wire sticks out from the back of the board.
- Turn the board back over so you can see the colored wire insulation.
- Locate row #3.
- Place one red jump wire between the right most outer hole on the left in row #3 and the left most inner hole on the right in row #3.
- Turn the board over and solder both ends of the wire into place.
- Trim the wire leads.

1.5.9 Add one more blue wire

Similarly, we need to connect this row of resistors to the first row of LEDs, so we will need to add one more blue connecting wire.

- Cut 1 piece of blue wire approx. 1" long
- Strip the piece of wire leaving approximately 0.65" insulation in the middle
- Bend the wire near each stripped end and then in half to form a "U" shape
- Locate rows #4 and 7.
- Place one end of the wire in the rightmost hole of the outer right set of holes in row #4 and the other end of the wire in the rightmost hole of the outer right set of holes in row #7.
- Turn the board over and solder both ends of the wire into place.
- Trim the wire leads.

1.5.10 Add resistors

Now we will add the resistors. Recall that we are using five 220 ohm resistors in parallel. If you are unsure that your resistor has the correct resistance value, using an online resistor calculator like the one found at: <http://www.webcalc.net/calc/0231.php>

Each resistor is slightly longer than an LED and thus the distance between the two leads is larger. Leaving one row between leads is insufficient but staggering the leads so that the lead on line #3 is four holes away from its corresponding lead on line #4 is enough.

- Place one end of the first resistor in the 7th hole from the left on row #3 (this is the hole immediately to the right of the jumper wire).
- Place the other end of the first resistor in the 10th hole from the left on row #4.
- Turn the board over and solder both ends of the wire into place.
- Trim the resistor leads.
- Repeat the process for hole #10 on row #3 and #12 on row #4
- Repeat the process for hole #11 on row #3 and #14 on row #4
- Repeat the process for hole #13 on row #3 and #16 on row #4
- Repeat the process for hole #16 on row #3 and #19 on row #4

1.5.11 Add positive lead

Finally, we must add the positive lead which will bring electricity from the battery or power supply to our light bank.

- Cut 1 piece of red wire approx. 4" long
- Strip the wire leaving approximately 3.75" insulation in the middle
- Locate rows #3

- Place one end of the wire in the rightmost hole of the outer right set of holes in row #3.
- Turn the board over and solder the wire into place.
- Trim the wire lead.

Your board should now look like this:

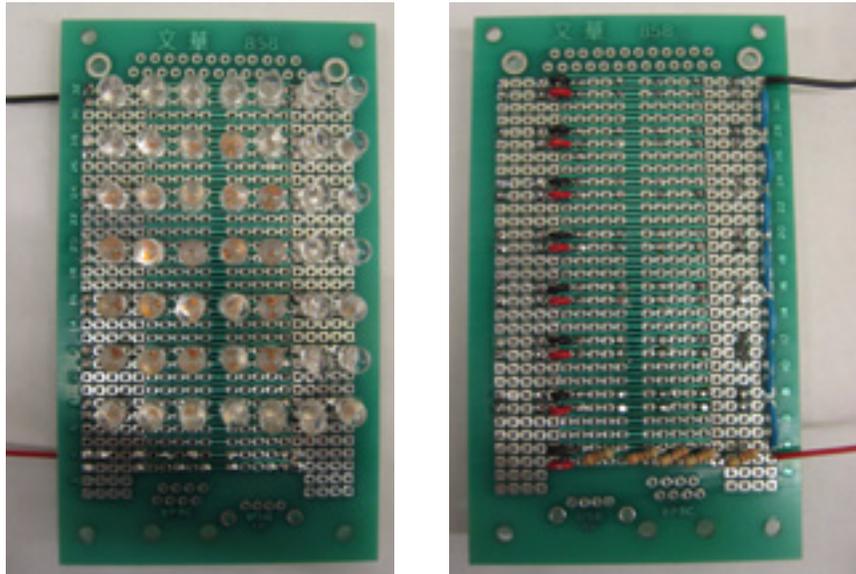


Figure 12: Completed Light Bank with Resistors: Back (Left) and Front (Right)

1.5.12 Test the Light Bank

If all went well, you should now have a fully functional light bank. To verify this:

- Place a red alligator clip on the positive lead on row #3.
- Place a black alligator clip on the negative lead on row #32.
- Locate a variable power supply or a battery capable of supplying 24 volts
- Connect the red alligator clip to the positive terminal of the power supply or battery.
- Connect the back alligator clip to the negative terminal of the power supply or battery.
- Make sure that every LED is brightly lit and the appropriate color.

Your board should now look like this:

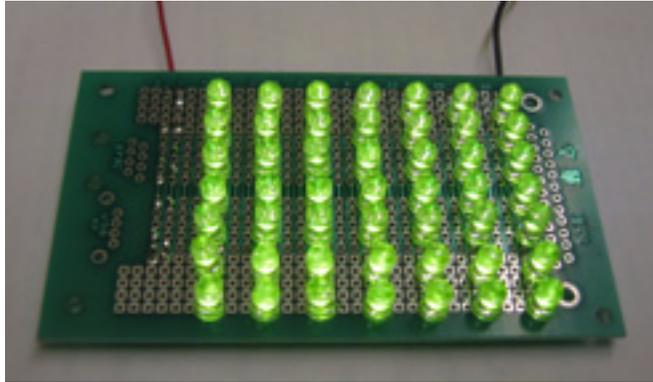


Figure 13: Working LED Light Bank