

Tower Lights Project

by Bob Rinker

This document describes my ideas concerning some of the circuits that will be needed for the new tower lights project. Some of the circuits are rather conceptual - more components will probably be necessary to make these circuits actually work! I tried to explain how each circuit works in detail - hopefully everybody can understand my explanations. Also, BTW these are not set in stone - if you have suggestions, better ideas, etc. please share them!

Some assumptions (we need to verify some of these!) - if these assumptions are not correct, some of the details of these circuits will need to change:

- We can use existing wiring that goes from the basement wiring closet to each room. We need 6 wires (control plus return for each of the red, green and blue LEDs) for each room.
- All circuitry, except the LEDs themselves, will be located in the basement, in or near the basement wiring closet.
- There will be (no more than) three RGB LEDs in each room, connected in a series string. If more LEDs are used, the main power supply voltage will need to be increased. For fewer, the power supply voltage can be reduced.

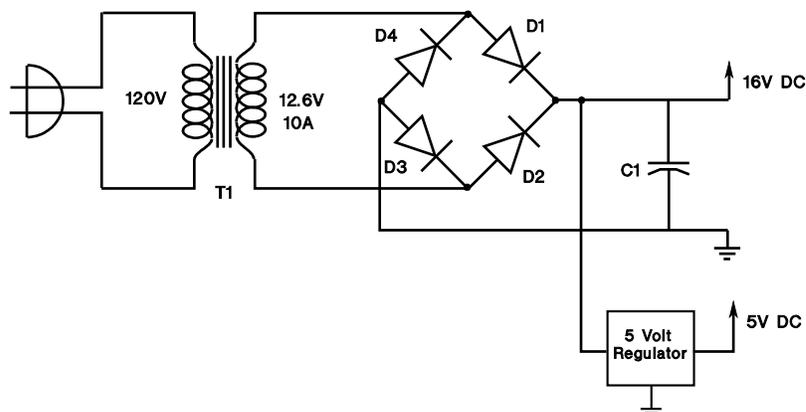
Power Supply

The power supply needs to provide enough current to supply all of the LEDs at once. There are 120 LEDs total (a red, green and blue string of LEDs in each of 40 rooms), each LED is capable of drawing 250 mA, so a total of $120 * 0.25A = 30$ Amps is needed. It might be wise to have several separate power supplies supplying the total current, rather than one large one. The diagram below shows a 10 Amp supply - four of these will be needed.

The different color LEDs each have different characteristics. At 250 mA, the Green and Blue LEDs drop approximately 3.5 V, while Red drops about 2.5 V. In order to drive a series string of 3 green or blue LEDs at 250 mA will therefore require around 10.5 V minimum, plus a couple more volts for the drive circuitry. 12 V is therefore a minimum voltage required for the circuits to operate properly. Probably 14-18 V would be better. A larger voltage will require more power dissipation - more heat sinking - in the driver transistors.

The exact voltage is not critical, as long as it is within this range, so a regulated power supply is not necessary.

An example circuit is shown below.



Transformer T1 connects to the 120 VAC power line, and reduces the voltage to 12.6 VAC. The four diodes D1-D4 form a full wave bridge rectifier, which converts the AC Voltage to a pulsating DC. Since the 12.6 VAC is its RMS (average) value, the peak of the sine wave is approximately $12.6 * \sqrt{2} = 17.7$ V, so the DC output is actually more than 12.6 V.

The circuit works as follows. The bridge rectifier consists of 4 diodes in a single package. A diode allows current to flow in one direction (indicated by the "arrow" of the diode symbol), but not the other direction (indicated by the "bar"). During the positive half cycle of the sine wave, diodes D1 and D3 conduct, and current flows into capacitor C1. The capacitor charges up to the peak voltage, except that the diodes drop some of the peak voltage, so the maximum voltage on the capacitor is around 16.5 V, rather than the 17.7 V mentioned earlier. During the negative half cycle of the sine wave, D1 and D3 stop conducting, and D2 and D4 conduct instead, which continues to keep C1 charged up. The LED circuits therefore are fed a relatively constant DC voltage.

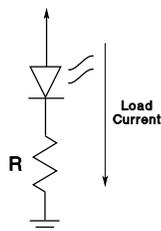
The digital chips require a fairly constant 5 V supply voltage. Therefore, a 5 V regulator chip is connected to the DC voltage. This chip contains circuitry that works to maintain a constant 5 V, even if the input supply voltage fluctuates. The digital circuitry draws maybe 200 mA total, so a standard 5 V regulator chip can be used.

Depending on the voltage requirements of the processor that is selected, we might also need a 3.3V or other source. If so, then an additional 3.3 V regulator can be included.

LED Circuits

An LED is a device that emits visible light at a certain wavelength (color). The light is created by characteristics of the semiconductor junction within the diode, not by heating as in an incandescent bulb. Like other diodes, the LED drops a certain amount of voltage as current flows through it; the voltage drop is somewhat greater in an LED than in other diodes - typical numbers are 2.5 V to 3.5 V, rather than 0.6 V for power supply rectifier diodes. The light intensity and color emitted by an LED is dependent on the amount of current flowing through it. Since the color change is an undesirable consequence, intensity is best controlled by using pulse width modulation (PWM). This means that a constant current source is the best circuit to use to drive an LED.

Before describing the constant current circuit, consider the simple LED circuit below:



The LED is connected in series with a resistor, whose value is chosen to limit the current to a safe level for the particular LED. A typical low power LED, such as one used as a power indicator on an electric device, draws a current of 20-30 mA. High power LEDs draw 150-350 mA - the ones we are currently using are designed to run at 250 mA. If the diode is connected to a fixed voltage supply, the resistor value can be calculated using Ohm's law:

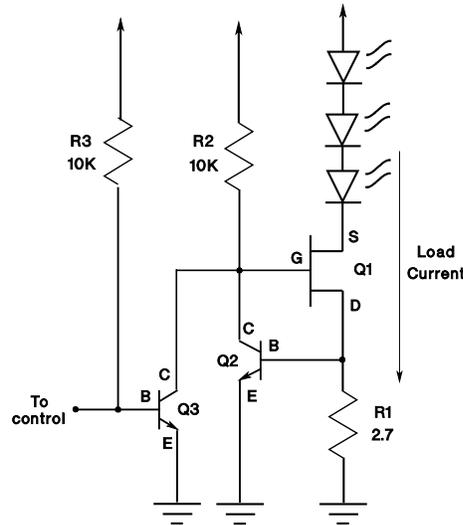
$$R = \frac{V_{supply} - V_{diode}}{I_{diode}}$$

For example, the nominal resistance required for an LED that has a voltage drop of 3.5 V, draws 250 mA, driven with a 16.5 V supply, would be 52Ω. For a string of three such LEDs connected in series (so the total series voltage drop is 10.5V), the required resistance would be 24Ω.

The tower lights project poses a couple of problems with this simple circuit. First, as mentioned earlier, the different color LEDs produce different voltage drops; in fact, even diodes of the same color

vary somewhat. Second, the tower wiring itself has some resistance that needs to be factored into the resistance calculation, and this resistance varies with the length of the wire (11th floor wires have more resistance than 2nd floor wires). Finally, we need to be able to control the diodes, turning them on and off, and controlling their intensity using PWM. For these reasons, as well as those cited earlier, we can use a constant current circuit to determine the current. These circuits will automatically compensate for the variations, and will allow for PWM.

The constant current circuit for each series string of LEDs is shown below:



The single resistor in the main current path of the simple circuit is replaced with a Field Effect Transistor (FET) Q1 and a small resistor R1. The FET acts like a variable resistor - when a voltage is present on its gate (labelled "G" in the diagram), the FET turns on. In other words, current flows between Q1's Source ("S") and Drain ("D"). When the voltage is removed from the gate, no current flows. If a small voltage is placed on the gate, a correspondingly small current flows - in other words, varying the voltage on the gate varies the amount of current that flows between Source and Drain, similar to the behavior we would get by varying the value of a resistor placed between Source and Drain.

Bipolar NPN transistor Q2 and resistors R1 and R2 determine the voltage on the gate of Q1. NPN transistors work as follows: if a current flows into the base (marked "B" in the diagram), a correspondingly larger current can flow from collector ("C") to emitter ("E"). The connection from Base to Emitter is itself a diode, and it begins to allow current to flow after the voltage between base to emitter reaches approximately 0.6 V. In this circuit, the voltage from Base to Emitter is determined by the current through R1.

So the circuit works as follows. If Q2 is off, no current flows from Collector to Emitter, and therefore the gate of Q1 is held high via the 10K resistor R2. This high voltage on G turns Q1 on, thus allowing current to flow through the LEDs, Q1, and R1. However, as current flows through R1, a voltage appears across R1. As soon as this voltage reaches around 0.6 V, Q2 turns on, and reduces the voltage at G, which reduces the current flowing through the LEDs and R1. For the values in the circuit this occurs at a current of $I = \frac{0.6V}{2.7\Omega} = 250 \text{ mA}$. As Q1's gate voltage is reduced, it begins to limit the current, which reduces the voltage drop across R1. An equilibrium is reached, such that Q1 allows just enough current to flow through R1 to turn Q2 on just enough to produce a gate voltage on Q1 that allows just enough current to flow. This current is approximately 250 mA, and is (mostly) independent of the LED voltage drops and the supply voltage. The value of R1 determines the magnitude of the constant current.

The final part of the circuit involves Q3 and the LED control line. If the control line is high or unconnected, current flows from Base to Emitter, turning Q3 on. This removes the voltage from the gate of

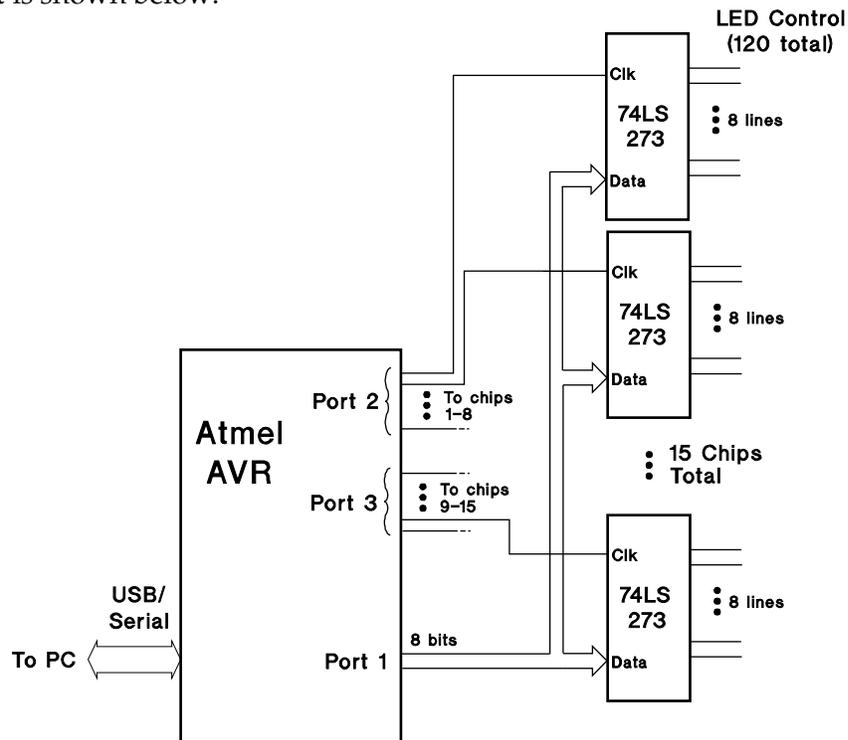
Q1, which turns Q1 and the LEDs off. If the control pin is pulled low, no current flows into the base of Q3, which turns it off, and allows the gate voltage on Q1 to function as described earlier.

Note that polarity of the control line is inverted - a "low" on the line turns the LED circuit on, a "high" turns it off.

LED Control Circuitry

The LED circuits are controlled by an Atmel AVR processor. Each of the LEDs must be controlled individually - this requires 120 separate control pins. If the processor were to drive the control circuits directly, it would require 15 8-bit ports - more than are available on any model of AVR. Thus, an external 120 bit buffer is needed - such an external buffer can be constructed from 74LS273 octal buffer chips. Each chip has 8 flip-flops; the connections include 8 inputs, 8 outputs, a Clock input, and a Clear. Fifteen chips are required to implement the full 120 bit buffer.

A possible circuit is shown below:



Three 8-bit ports are required from the AVR Processor. The 8 bits of one port are connected (in parallel) to the flip-flop inputs of all of the buffer chips. The bits from the other two ports are individually connected to the Clock inputs of the buffer chips - 15 of the 16 total bits contained in these ports are used.

In operation, the AVR processor places the first 8 control bits on the data lines, then toggles the Clock bit of the first buffer chip to latch the data into the flip-flops. It then places the next 8 bits on the data lines and toggles the Clock bit of the next chip. This process continues until all 120 bits have been latched into the buffers.