Senior Project
Electronics

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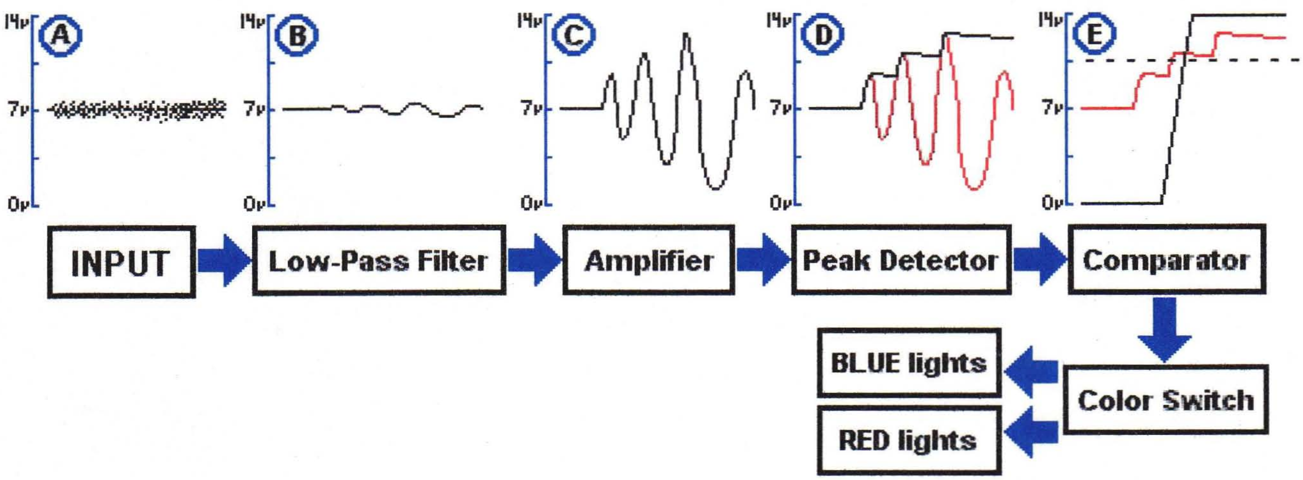
Bass Activated Lights



INPUT: The preamp output of my car stereo head unit is the input of the circuit, characterized by a full spectrum audio signal, with a max amplitude of about .25 volts, fluctuating above and below 7 volts. The Low-Pass Filter, however, required an input amplitude of at least 1 volt peak, so I cascaded an amplifier stage, with a 1:5 voltage gain, at the input of the Filter.

Low-Pass Filter: The input audio signal (figure A) contains a variety of different frequencies ranging from 20-15000 Hz. This stage attenuates the frequencies higher than 106 Hz, while slightly amplifying the desired frequencies lower than 106 Hz, with a gain of about 1.6. Notice the wave pattern in figure B.

Amplifier: The Low-Pass Filter has increased the signal to a max amplitude of 1.5 volts peak. The supply voltage (V+) is 14 volts, and because the audio is alternating current, the ground reference (sinusoidal axis) is 7 volts, allowing for a max amplitude of 7 volts peak, without distortion. This would lead one to believe that the voltage gain should be set to a ratio of 1.5:7. However, when designing a circuit of this complexity, it is helpful to leave room for adjustment, so I set the voltage gain to a max of 15, using a 15k-ohm variable resistor.

Peak Detector: This stage performs rectification of the alternating audio signal, by rejecting the negative fluctuations below 7 volts. It also smoothes out the ripples in the positive fluctuations, thus representing the level of bass, as a DC voltage from 7-14 volts. Notice figure D, upon arrival of the amplified signal (Red), the Peak Detector charges to the peak voltage, then slowly discharges a fraction of a volt, before charging back up to the peak voltage of the following oscillation.

Comparator: This circuit performs the simple operation of comparing an input voltage (V-in) to a reference voltage (V-ref). The 7-14 volt DC output of the Peak Detector acts as V-in, and V-ref is an adjustable 6.5-14 volts DC from a 5k-ohm potentiometer. When V-in is less than V-ref, the output is zero volts. If V-in is greater than V-ref, the output voltage quickly rises to about 12 volts. Therefore, by adjusting V-ref between 7-14 volts, the sensitivity by which the circuit reacts to the bass is adjusted. Figure E illustrates the change in the output (Black) when V-in (Red) rises above V-ref (dotted Black).

Color Switch: Now that the bass has been converted into a DC voltage, ON (12v) or OFF (0v), it can be easily used to activate the transistors controlling the lights. The lights can be deactivated by simply intercepting the signal sent to the bases of the 2N2222 transistors that control them. I used two sections of the CMOS series 4066 quad bilateral switch, one for the red lights and the other for blue, to activate and deactivate the lights, and thus change the perceived color from blue, to red, to a purplish combination of both.

RED lights: The cheapest and most efficient electronic light source would have to be Light Emitting Diodes (LEDs). Each of the four light modules hidden in the foot-space of my Grand Am, contain six high-intensity red LEDs, with 40 degree emission angles, and a continuous current rating of 20mA. There are four transistors that control the red LEDs, one for each module, consuming only 40mA due to the two parallel sets of three series LEDs in Figure 11.

BLUE lights: Each light module also contains one high intensity blue LED, consuming a maximum current of 25mA. These blue LEDs are very bright, not to mention expensive, so I designed each module with only one located in the center. There is a 2N2222 transistor for each blue LED, making for a total of eight transistor switches for the 28 high intensity LEDs in my car.

Filter out the high frequencies

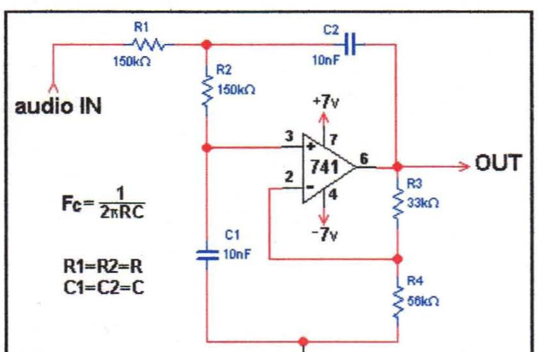


Figure 1 Sallen-Key Low-Pass Filter

I needed a simple low-pass filter that could be easily cascaded with the other stages of the circuit. So I chose an equal component, Sallen-Key, active filter, published in one of RadioShack's Engineer's Mini Notebooks. This design utilizes the abilities of the classic 741 op-amp, and requires only six discrete components. Figure 1 shows the schematic diagram of the filter.

I tuned the low cut-off frequency "Fc" to about 106Hz, with the resistor-capacitor arrangement at the input. In other words, frequencies above 106Hz will be attenuated to less than 70% (-3dB) of their original voltage. The op-amp is in a non-inverting configuration, thus defining the gain to be 1+(R3/R4) or about 1.59. The article suggested that in order to maintain stability, the gain should be left as is, which wasn't a problem for this application.

Provide a Dual-Polarity Supply Voltage

You may have noticed that the low-pass filter in Figure 1 requires a dual polarity supply voltage. When processing AC signals, it is often easier to use circuits powered by both positive and negative supplies, because they provide a consistent ground reference between stages of the signal, and therefore increase overall stability of circuit. So from the 14 volts of my car battery, I needed to establish a stable ground reference at one half the supply voltage.

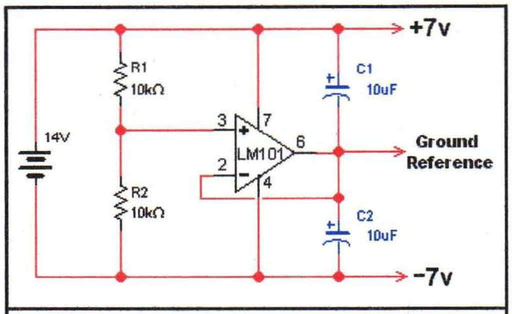


Figure 2 **Dual Polarity Power Supply**

I achieved this using the circuit in Figure 2, which I found in the July 2001 issue of "Poptronics" magazine. The output of the LM301 op-amp is tied to it's inverting input, in a negative feedback configuration. Normally, an op-amp will adjust it's output to make it's inputs equal. However, in this circuit the output has been tied to ground. So the only thing the op-amp can do now, is regulate the voltage at it's power supply pins to place the midpoint of R1 and R2 at zero volts. Since R1=R2, half the battery voltage is above ground, and the other half below. Capacitors C1 and C2 provide bypassing for the dual-polarity voltages, and also suppress undesired oscillation. This is a good method of supply voltage conversion, assuming that the difference in plus and minus currents drawn by the circuit doesn't exceed the output current capability of the op-amp.

Amplify the weak audio signal from my car stereo

As previously described in the block diagram, The low-pass filter required an input signal with an amplitude of at least one volt peak. The amplitude of my car stereo's preamp output was less than .25 volts peak. So I used the inverting amplifier in Figure 3, to raise the signal to a sufficient amplitude for the low-pass filter to process. The resistance ratio of R2:R1 has set the voltage gain to 10. The capacitors C1 and C2 are not necessary for normal circuit operation, but they serve as an added protection against direct current at the input, and guarantees no attenuation of the desired low frequencies.

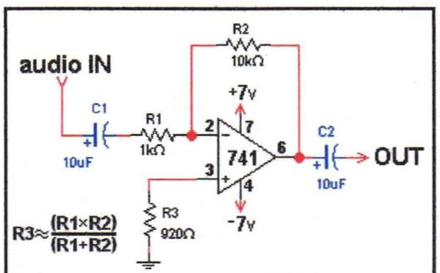


Figure 3 **Inverting Amplifier**

Amplify the output of the filter

Now that the remaining signal contains only frequencies lower than the 100Hz cut-off, it is amplified by the circuit in Figure 4. But since the peak voltage of the input signal changes with the volume setting of my car stereo, it's hard to know what to set the gain to. Also, a good rule of thumb in circuit design is to always leave room for adjustments, so I decided to make the gain easily adjustable, with the 5 k-ohm resistor R4. The gain of the dual-polarity amplifier in Figure 3 isn't easily adjusted because the value of R3 is determined by the values of R1 and R2. That is why I used the single-supply amplifier in Figure 4. Capacitors C1 and C2 are essential in the stability of the circuit, because they block the unwanted DC from being amplified. They are of reasonably high value to ensure that the desired low frequency bass is not blocked.

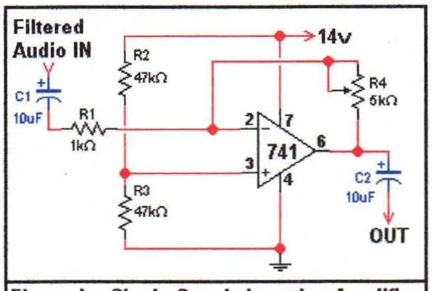


Figure 4 Single-Supply Inverting Amplifier

Rectify the amplified audio signal with a peak-detector

After the 2nd amplifier stage in Figure 4, the low-frequency audio signal has a max amplitude of 6 volts peak, fluctuating above and below 7 volts DC. The next step is to convert the audio signal into a DC voltage level that represents the intensity of the bass. This operation was achieved with the rectification circuit in Figure 5. This stage performs the function of a peak-detector, by charging the capacitor C1 to the peak voltage at the input, then discharging it at a rate set by R3 in the RC timing constant. Originally, R3 was 10 M-ohms so that the circuit could detect, and hold the peak voltage of a signal. But I lowered the value to 200 k-ohm, so that C1 could discharge between each bass "hit." As a result, the negative fluctuation (below 7 volts) at the input are ignored, and the bass is represented by a DC voltage level from 7-13 volts. The signal manipulation of this stage is best represented by Figure D of the block diagram on page 1.

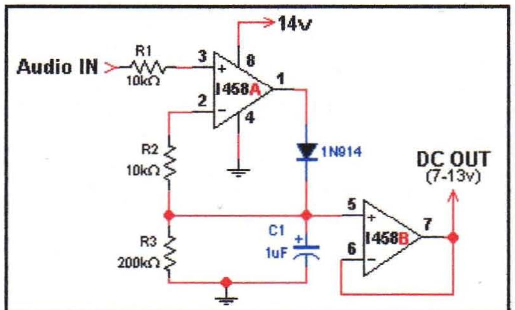


Figure 5 Peak-Detector / Rectifier

Comparator

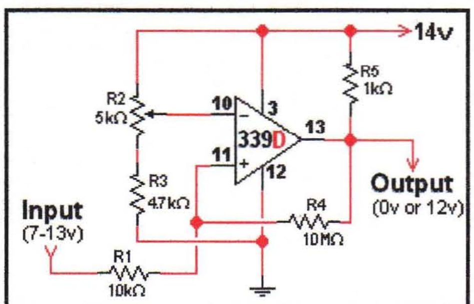


Figure 6 Positive Logic Comparator

This stage performs the function of comparing an input voltage (V-in) to a reference voltage (V-ref), The 7-13v output from the peak detecting stage acts as the input voltage, and the voltage divider formed by R2 and R3 feeds "V-ref" an adjustable 6.5-14 volts DC. The 339 comparator in Figure 6 is in a positive logic configuration, because "V-in" is at the positive input and "V-ref" at the negative input. This means that when "V-in" exceeds "V-ref," the output will change from a logic low (0v) to a logic high (12v). So by changing "V-ref" with the variable resistor R2, the LEDs can be adjusted to Always ON (V-ref = 6.5v), Mostly ON (V-ref = 8v), Hardly ON (V-ref = 11v), or Completely OFF (V-ref = 14v).

The output of this stage is used to trigger the common-emitter transistor switches that control the

LEDs. With both the Red and Blue LEDs turned on, the output of the comparator needs to supply the eight transistors with a total current of 15mA. The 339 comparator was uncomfortable with the current demand, it's output voltage decreased, along with the total current drawn by the LEDs. By lowering the resistance of R5 from 3.3k-ohms down to 1k-ohm, I was able to accommodate the current demands of the transistor switches. The only negative aspect is that when the output is low (0 volts), R5 is sinking 14mA of current, instead of the original 4mA with R5=3.3k-ohms. However, the final circuit will only be powered when my engine is running, and a current excess of only 10mA is not significant in this application.

LED Switching

As described previously, there are four transistors that control the red LEDs, and four that control the blue LEDs. By intercepting the output signal from the comparator, one could easily switch between colors. This could be managed by two SPST switches, one for blue, and one for red, mounted anywhere on the main circuit box. But I decided to hide the main circuit box under my air-conditioner, and to install a small control box in my dash for a more professional look. As a result, the two boxes were linked by a 4 foot long bundle of wire, positioned under the front dash, less than a foot from the engine. So it wouldn't be a good idea to route the comparators output through 8 feet of wire, back to the base terminal of the transistor switches, because it would amplify the electro-magnetic interference (EMI) generated by the engine. The only reasonable option was to use the switches in the control box to send a digital logic signal to a switching mechanism in the main circuit box, so that the output of the comparator doesn't leave the circuit board.

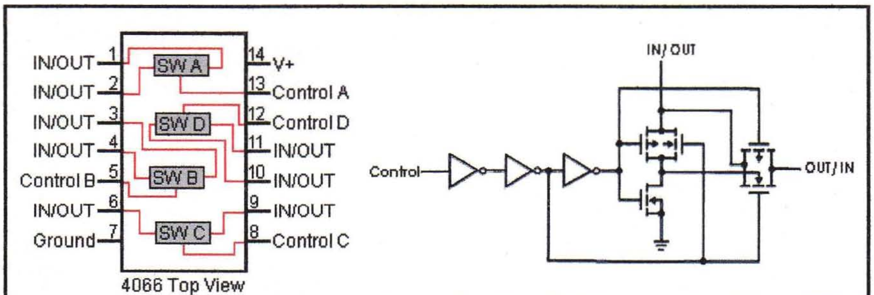


Figure 7 4066 Quad Bilateral Switch

The CD4066 integrated circuit (Figure 7) consists of four Complimentary MOSFET switches designed to efficiently control low-current signals. Each switch is either open or closed, depending on the logic signal present at it's control pin. A low logic level (0v) at the control pin opens the switch, and a high logic level (14v) closes the switch. When in the closed position, the resistance between the two "IN/OUT" pins is only 80 ohms, and when the switch is open, the resistance is nearly infinite. I used section A of the quad 4066 to control the signal going to the blue LEDs, and section B to control the red LEDs.

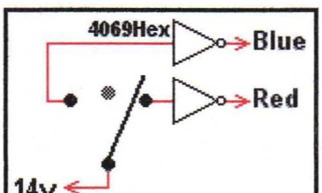


Figure 8 Color Switch

The SPDT switch in Figure 8 is located in the control box and is used to change colors. The logic signal is inverted by the CMOS series 4069, before arriving at the the control pins of the 4066 switch. This ensures that the logic signal at the control pin doesn't float between levels when the signal is switched. When the switch is positioned to the far right, the blue lights are activated, and when positioned to the far left, the red LEDs are activated. But when the switch is in the unconnected center position, the control inputs are 14 volts, so both the red and blue LEDs are on to cast a purplish glow.

LED Transistor Switches

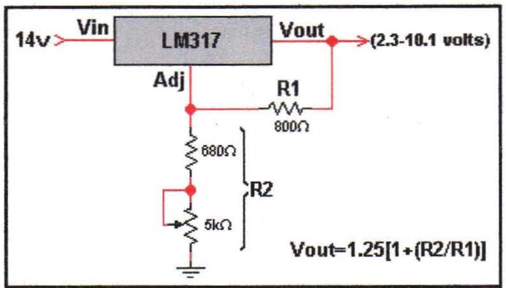


Figure 9 Brightness Adjustment

I used the popular 2N2222 transistor, in a common-emitter configuration, to perform the actual switching of the LEDs. By applying the comparator's output signal (either 0v or 10v) to the base of the transistor, the collector-emitter junction can act as a switch to control current flow. Another advantage of using transistors in this application, is that the brightness of the LEDs can be easily changed by adjusting the positive voltage at the collector. The LM317 in Figure 9 regulates it's output to a voltage determined by the ratio of resistance between R2 and R1. So by adjusting the 5k-ohm potentiometer, the output voltage can be adjusted from 2.3 to 10.1 volts DC.

As previously stated, their are four small light modules located in my car, each containing one high-intensity blue LED, and six high-intensity red LEDs. As seen in Figure 10, each blue LED is switched by a single NPN transistor. When the 10 volt input signal activates the blue LED, the current flowing through the base is limited to a about 1.2 mA by the resistor "RB." The resistor "RC" conducts approximately 95% of the total emitter current, so I set it's value to allow no more emitter current than the maximum 25mA rating of the LED.

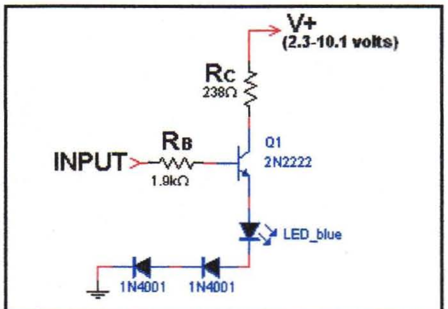


Figure10 Blue LED Transistor Switch

However, the blue LEDs had slight inconsistencies, such that some were brighter than others. So for each transistor switch, I set "RC" to a necessary value for consistent brightness of the blue light, with an average resistance of 238 ohms. The two 1N4001 rectifier diodes in Figure 10 lower the forward voltage of the blue LED, because it's voltage drop is less than that of the three red LEDs in series, so it doesn't need as much voltage to light. Without the diodes in place, the blue light could not be effectively dimmed, because the minimum of 2.3 volts at the collector would still light the LEDs.

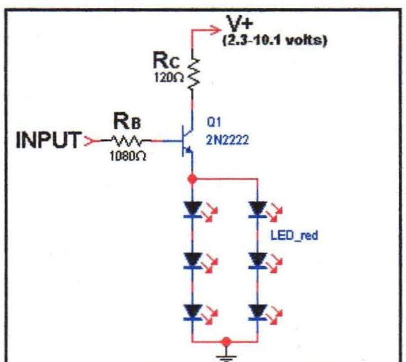
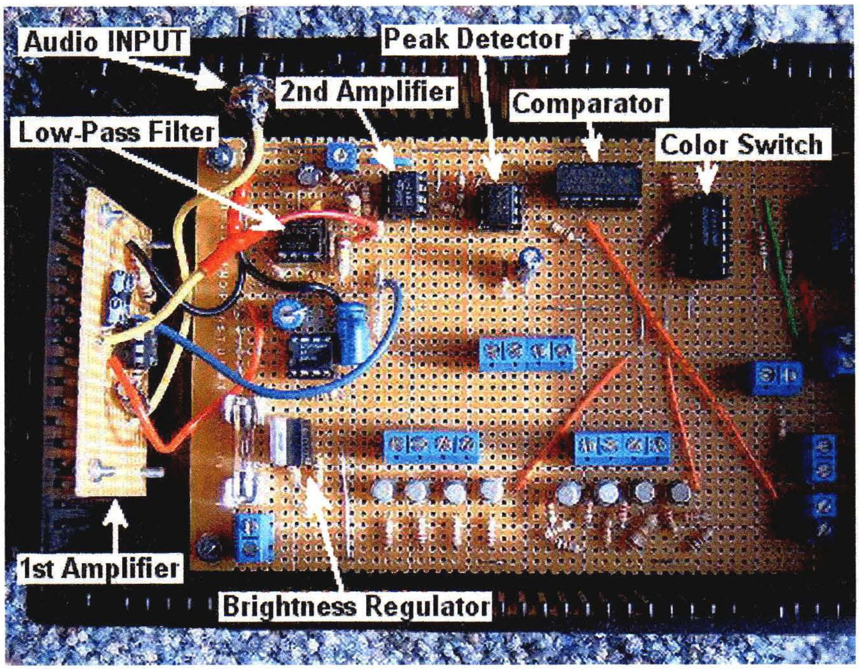


Figure 11 Red LED Transistor Switch

The high-intensity red LEDs (Figure 11) are rated for a continuous current of 25mA, so I set "RC" to allow for a total emitter current of 40mA, with each LED receiving 20mA. The resistor "RB" allows 2mA to flow into the base, because 2N2222 transistors generally work best when the base current is 5% of total emitter current. I used six red LEDs because the color red is not as bright as the color blue, and the purple combination they produce is fitting.



Improvements

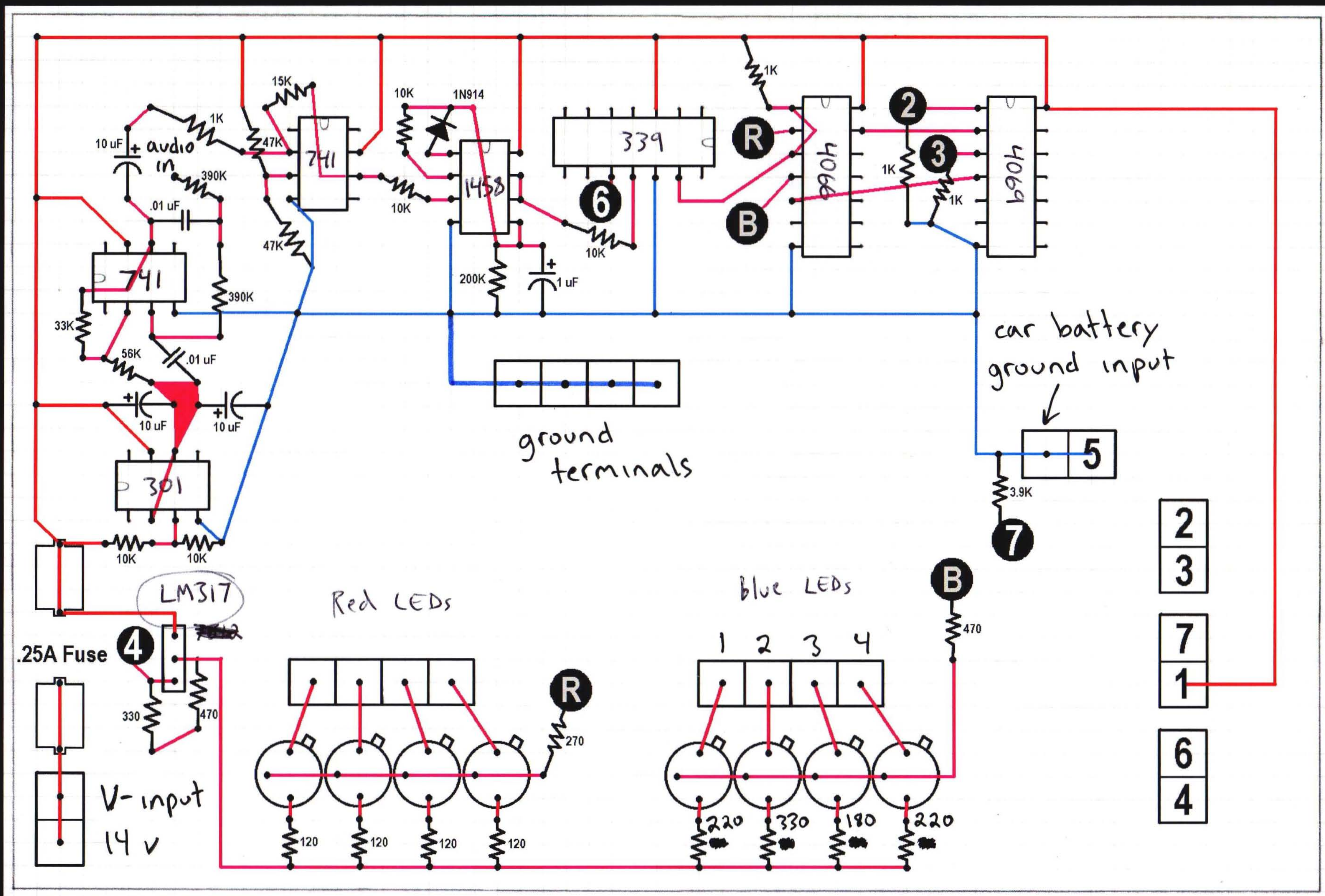
The circuit is powered by the 14 volt combination of both my car battery and alternator. This is not necessarily a stable supply voltage, because it contains a lot of the Electro-Magnetic Interference. By filtering out the undesired radio frequency noise, the overall sensitivity of the circuit would increase. The LM317 adjustable voltage regulator or a simple 12 volt regulator, could significantly reduce the noise of the circuit, assuming it could handle the 250mA demand.

I used a plastic enclosure for the main circuit instead of metal, because it was easier to work with. I wasn't even thinking about noise reduction. An advantage of using a metal enclosure is the protective force-field that it creates when tied to ground (0v). This simple method would shield the sensitive circuitry within the box, from the most of the engines EMI, thus improving the circuits performance.

These small adjustments would improve the sensitivity of the circuit, allowing for smooth operation of the lights at lower volume levels. However, the EMI does provide the cool effect of activating the lights when my engine runs at high RPMs.

Conclusion

I enjoyed every aspect of engineering this project, and it has helped me to perfect my electronic problem solving skills. However, I could not have reached my current level of technological competency without the knowledgeable guidance of my electronics teacher, Mr. Doug Ripka.



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301
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car battery ground input
ground terminals
5
3.9K
7
LM317
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4
330
470
Red LEDs
Blue LEDs
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270
120
120
120
120
220
330
180
220
V- input
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