Wireless Optical MIDI Data Transfer

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I. Abstract

This paper will examine the use of visible light as a medium of data transmission in a practical setting. The study uses MIDI audio sent at 33 kHz from an electronic keyboard and passes it through an LED light configuration and accompanying logic to reproduce the data on a MIDI Sequencer. Signal correction including filtration of background noise is also performed for a DC noise source. The device justifiably avoids modulation and provides less than 10 µs delay to achieve a high quality wireless audio system. The spectrum of visible light is used in a low directivity to simulate practical applications of the device.

II. MIDI standard introduction

MIDI (Musical Instrument Digital Interface) was first developed in 1982 and now serves as a universal standard among manufacturers and developers of electronic musical instruments. The MIDI data consists of 8-bit packets beginning with a status byte followed by one or two data bytes. Furthermore, each byte begins with a start and stop bit, making each packet 10 bits long (8 bits of data). Table 1 shows the available formats which MIDI messages fall into.

Channel Voice	Control the instrument's 16 voices (timbres, patches), play notes, sends controller data, etc.
Channel Mode	Define instrument's response to Voice messages, sent over instrument's 'basic' channel
System Common	Messages intended to all networked instruments and devices
System Real-Time	Intended for all networked instruments and devices. Contain only status bytes and is used for synchronization for all devices.
System Exclusive	Originally used for manufactures-specific codes, such as editor/librarians, has been expanded to include MIDI Time Code, MIDI Sample Dump Standard and MIDI Machine Control

Table 1
MIDI Formats

The purpose of this project was not to develop a way to package data or to generate a new way of pushing data through a wire, but was instead focused on using a medium not usually taken advantage of in today's world. The MIDI signal was chosen due to the digital nature of the original signal. By using the MIDI signal, this project would therefore be purely hardware and

would not require the need to repackage a signal through the use of software. Another reason the MIDI signal was used was the wide distribution of MIDI devices. By building a device that could communicate a MIDI signal, the project effectively was able to take any device that has this standard and communicate through it. At the end of this project, the system was able to communicate data from a keyboard as well as a drum set. Through these tests, it is believed to be able to communicate any MIDI signal, as long as it is exactly up to the MIDI standards that are required to make it a true MIDI device.

III. System Overview

The system can be broken up into two main parts: the LED Driver and the Signal Retrieval. This can be seen in Figure 1.
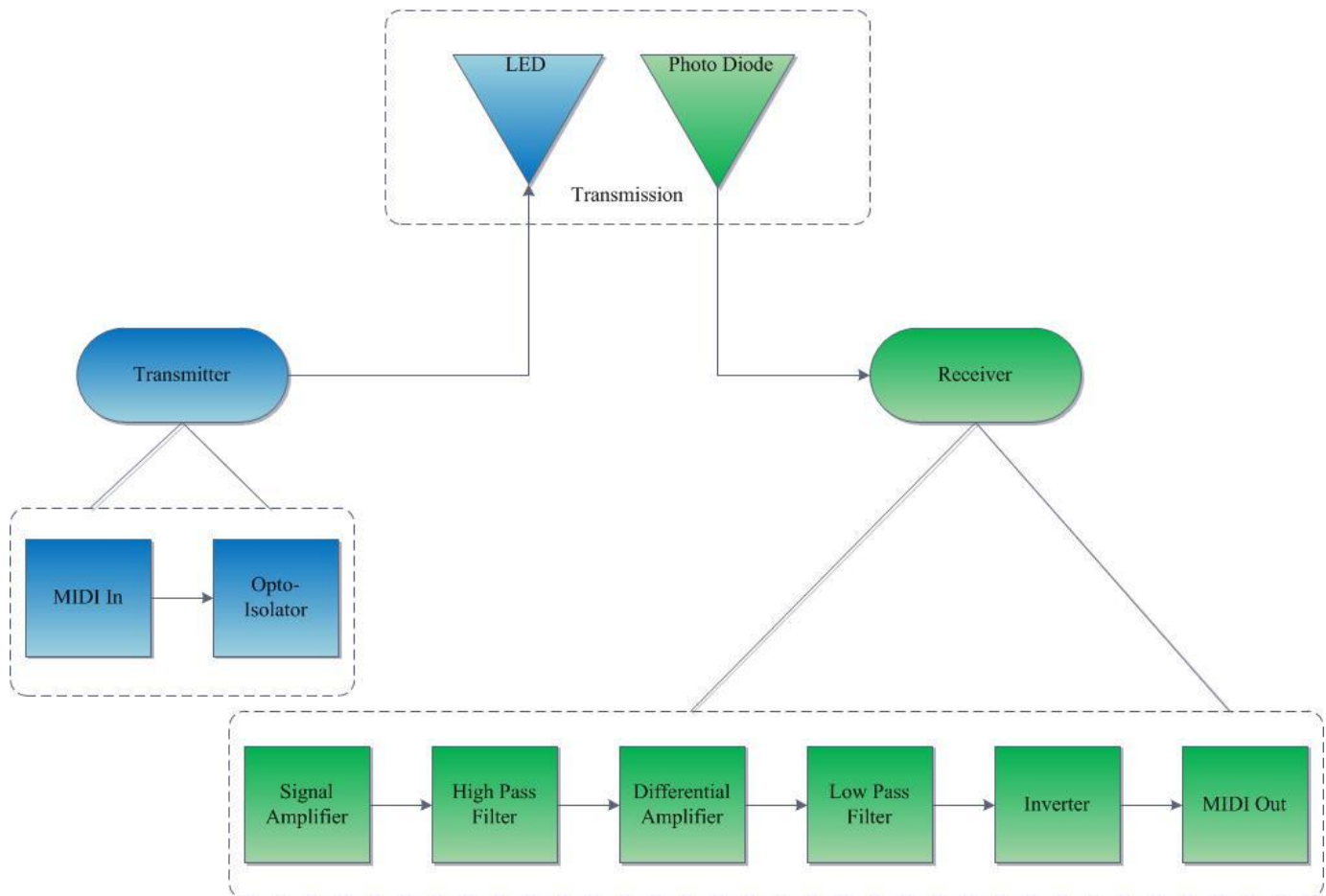

Figure 1
Block diagram of the entire project's circuitry

IV. Detailed Block Diagram Descriptions

Transmitter

The purpose of the current loop circuit in Figure 2 revolves around the MOC5009 opto-isolator chip. The opto-isolator is designed to prevent rapidly changing voltages on one side of the circuit from distorting the transmitted output. The MOC5009 chip also provides a common ground on the transmission side of the design in order to prevent ground loops. If the input is high, Pin 4 of the opto-isolator (circuit output) is connected to Pin 5 of the opto-isolator (ground) and if the input is low, Pin 4 of the opto-isolator (circuit output) is connected to Pin 6 (5V).
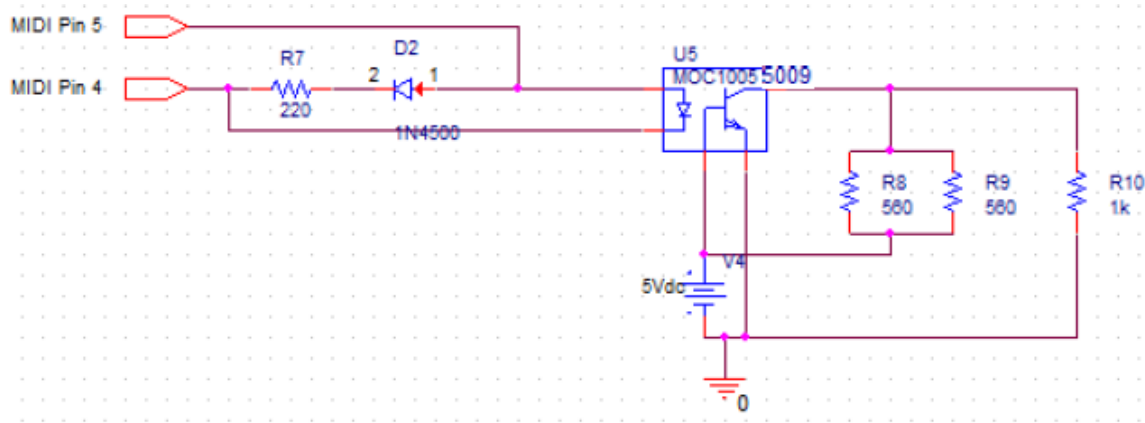

Figure 2
The Opto-isolator circuit takes MIDI pins 4 and 5 in and utilizes a MOC 5009 chip to prevent rapid changes in voltage on the output

The LED driver circuitry utilizes a diode in order to correct the signal from the MIDI keyboard and create a clean square wave for transmission. The LED portion of the circuitry (represented in Figure 2 as a 1 kΩ resistor) is a powerful 12V LED with a spotlight lens to focus the light signal.

When the project first began, the focus was on simply getting the system to effectively transmit the MIDI signal through light, regardless of distance. However, the distance that was achieved between the LED array and the receiver circuitry was only about 160mm. That being said, a much brighter LED had already been purchased that could ideally transmit at a much greater length, but was found to be too slow, as seen below in Figure 3. This 12 V LED was more complex that was originally thought, as it had a PCB inside the shell of the light to monitor and filter the input power source. To fix this issue, very small but tolerant resistor (around 25 Ω with a 2 W tolerance) was included in place of this PCB that was able to handle the large amount of power that it would be dissipating. The resistor was then packaged inside of the original LED

spotlight packaging and connected in series with the LED. This enabled the LED to be supplied with a large amount of current with varying amounts of voltage across this very simple circuit.
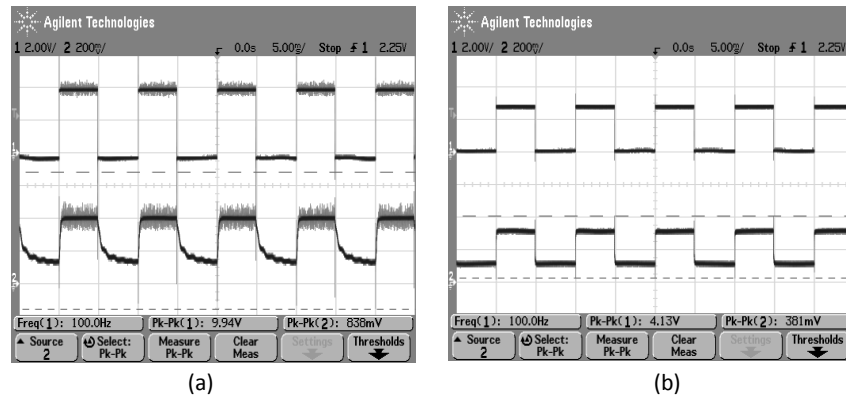

Figure 3

12V LED (a) Input to LED (top) and resulting photodiode potential (bottom). 5V LED (b) Input to LED (top) and resulting photodiode potential (bottom) shows drastic improvement in rise and fall time. Both are done driven with a 100 Hz square wave.

An idea that was also discussed was to use weaker LED's, but assemble a lot of them in an array that would supply much more light. Through discussion with Professor Dragic, a professor in optics at UIUC, the conclusion was made that this increase in the number of LED's might not increase the distance much, but would probably just increase the area that the receiver circuit can be moved in a parallel plane to the light source without losing the signal. Since distance was the main consideration, and not projection surface, this path of action was not taken.

The Opto-Isolator chip in use was tolerant from 5 V up to 15 V. This allowed a wide range of voltages to be supplied to the Opto-Isolator V_{cc}, resulting in a matching max output voltage. Due to this flexibility, in testing, the voltage was raised and lowered to find an optimal voltage for the sender circuit. Therefore, after this optimal voltage was found to be 12V, a power supply could be designed to match this voltage.

Receiver

Photodiode

Below, in Figure 3, the 20kΩ resistor creates a voltage drop when the photodiode is placed in parallel. Because the MIDI signal only reaches a maximum frequency of 33 kHz, not too much consideration was put into which photodiode should be used, and a simple VTP1188 photodiode was used. This provided a very small output current, but satisfied the minimum speed requirements of this MIDI signal. A voltage amplifier will be used to correct for this small output voltage from the resistor instead of purchasing a more expensive, better performing photodiode or using a slower photodiode that provides a higher voltage.
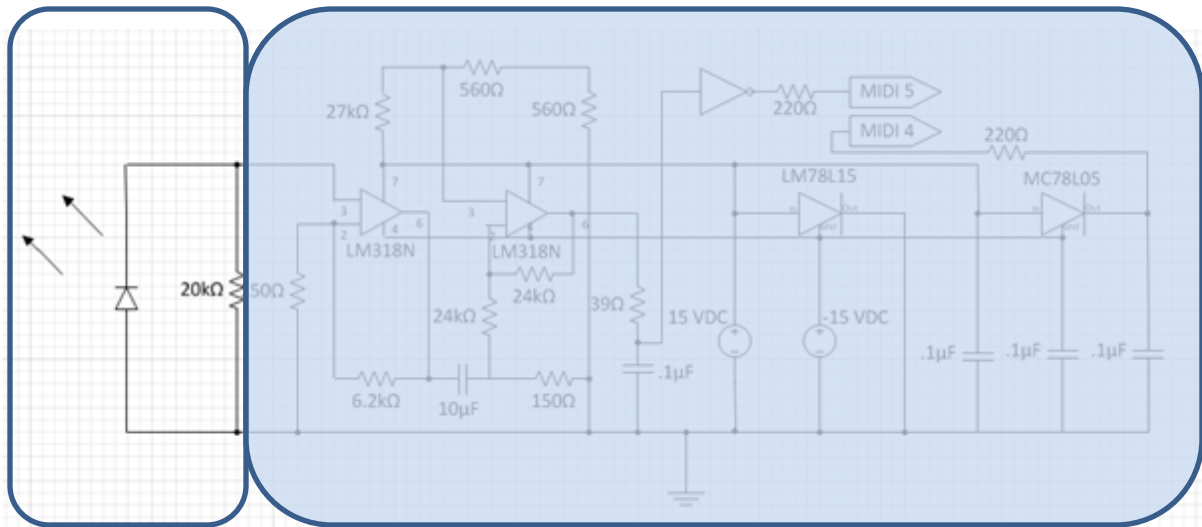
4

Figure 3

VTP 1188 Planar Silicon Photodiode forces current through the 20kΩ resistor shown here to create a signal voltage

Signal Amplifier

The signal amplifier is highlighted below in Figure 4. The purpose of this circuitry is to take the small voltage that is dropped as a result of the photodiode (no more than 200 mV) and get it up to a level that can be recognized as a MIDI device (around 5 V). A LM318 Operational Amplifier was used in this part of the circuit. The following shows the voltage amplification that occurs with this configuration that is derived from the resistor network around the OpAmp.

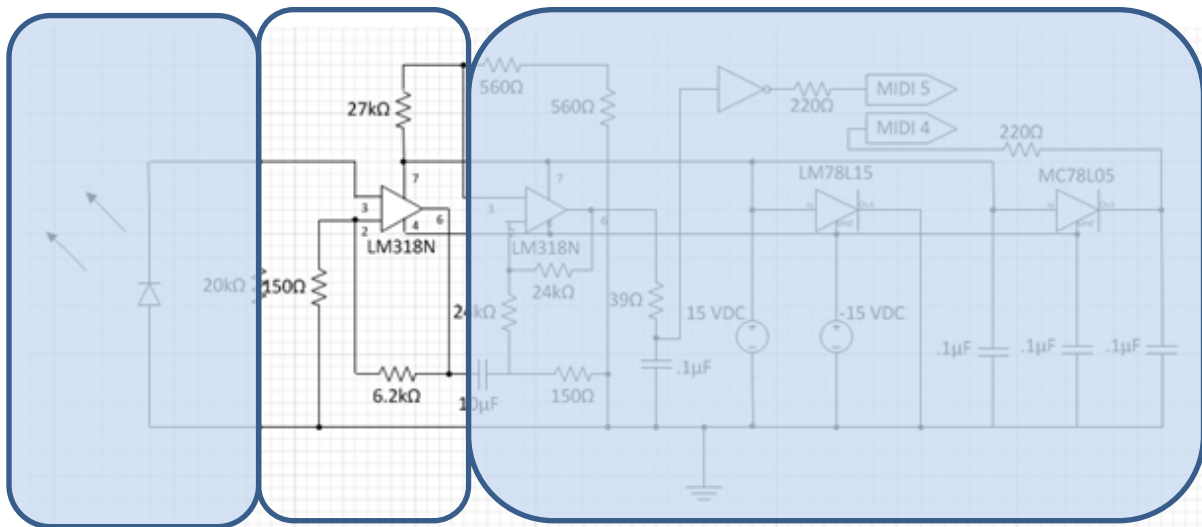$$A = \frac{150 + \ 6200}{150} = 42.33 \ V/V$$

Figure 4

Amplifier circuitry

High Pass Filter

The high pass filter's purpose is to eliminate the DC offset from the ambient light that the photodiode receives. This is connected after the voltage amplifier, although it could be used before with the same effect. However, if it is placed before, any imperfection in the amount of the DC offset removed would be amplified, whereas placing it after confirms that it will not have any DC offset amplified. A simple first order high pass filter is used from the use of a capacitor and resistor and can be seen below in Figure 5. This filter was created while making sure that the cut-off frequency was not higher than the 33 kHz frequency that is required to keep the MIDI signal. Since the only real requirement of this filter was to eliminate the 0 Hz DC offset, as well as any 60 Hz signal induced by a normal light source, the cut-off frequency was set far from the 33 kHz range, and actually stayed within the 100's of Hz range.
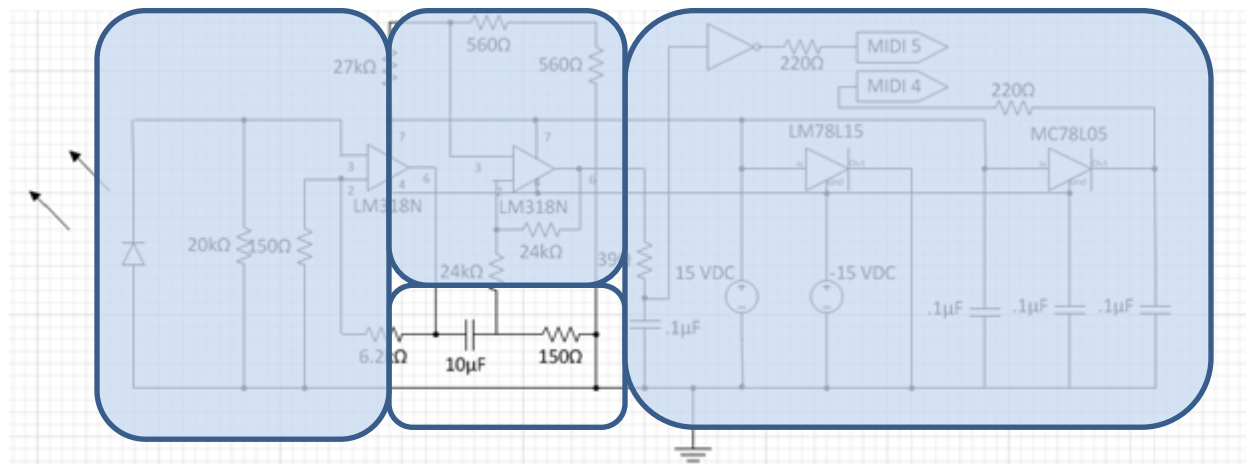
Figure 5
High pass filter

Differential Amplifier

The purpose of the Differential Amplifier is to take the DC filtered signal and create the proper Ground to +5V signal that can be read by the inverter chip. Without this circuitry, the inverter input would be at Ground for a logic high and at -5V for a logic low. Since both of these voltage levels would be read as a logic low, the signal will not make it to the output, and the MIDI sounds would not play. Figure 6 highlights the Differential Amplifier circuitry. The equation used in this circuitry is approximately

$$V_o \sim V^+ - V^-$$

where V^+ is pin three that is taken from the resistor network. This network creates a specific voltage that allows the circuit to provide a DC bias for the signal, since this input is the base voltage that the actual signal is subtracted from that comes in on V^-.

Figure 6
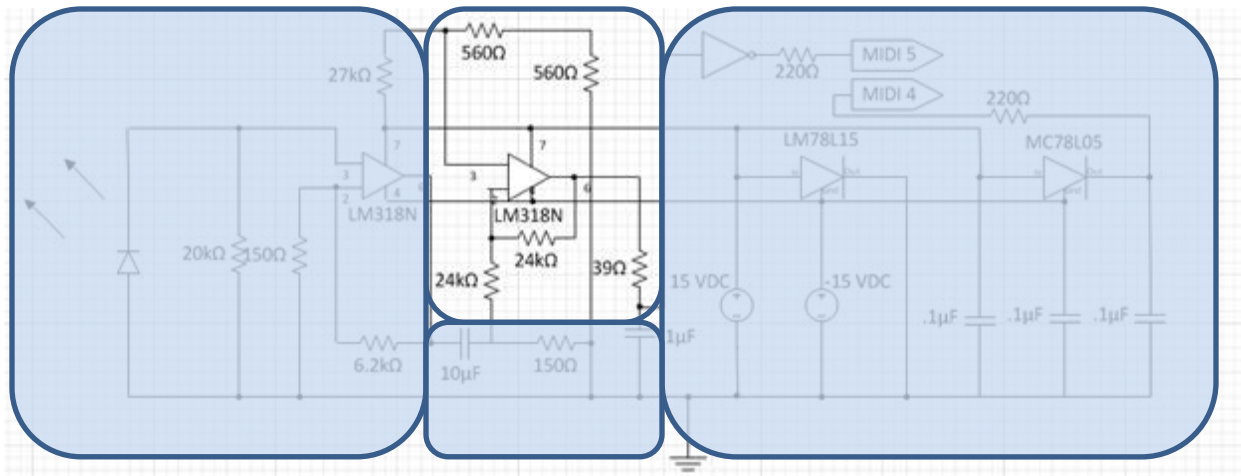Differential Amplifier circuitry

Low Pass Filter

One limiting factor was not the gain of the voltage amplifier, but the quality of signal that was being amplified. In addition to the high pass filter that was being used to eliminate the DC offset from the photodiode, a low pass filter was used to correct the noise on the actual signal. By implementing a low pass filter right before the correction of the signal at the input of the inverter circuitry, it effectively got rid of any chance of extra noise in the transitions of the final output. Also, by cleaning up this signal, the circuit was effectively able to use a smaller signal (or greater distance from the photodiode), which helped accomplish the overall goal of increasing transmission distance. This can be seen below in Figure 7. As with the high pass filter, careful considerations had to be made in order to make sure that the 33 kHz MIDI signal was not filtered out from this circuitry. This meant that the cut-off frequency of the circuit had to be above 33 kHz.
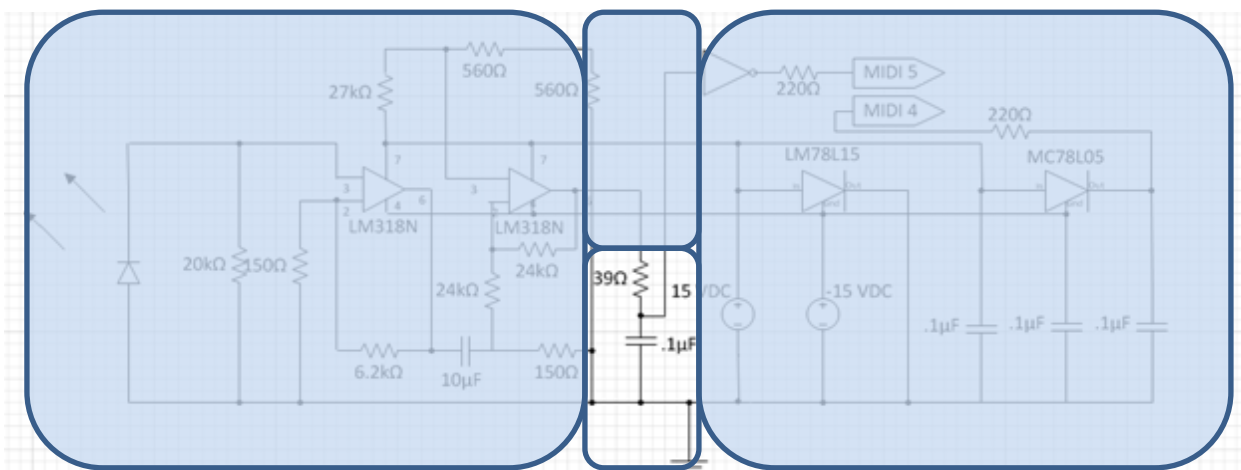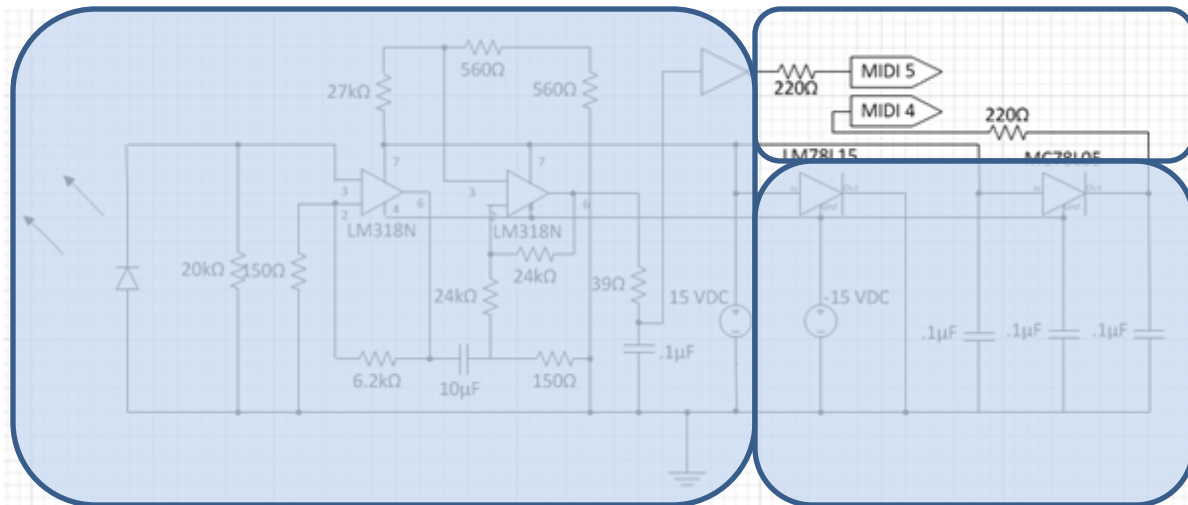

Figure 7
Low pass circuitry

<u>Inverter</u>

The inverter block is simply to correct the round off of the square wave signal. Due to the high speed of our circuitry, the photodiode tends to round the edges of the square wave that are sent by the LED. Throughout the circuit, the amplifier and filters also add to this rounding effect. By taking advantage of the voltage thresholds for "ON" or "OFF" on the inverter chip, the rounded signal is reformed into a very sharp square wave. This causes a tiny bit of delay, but is nothing that can really be noticed by humans when listening to the system. Figure 8 highlights this portion of the circuit.

This portion of the receiver circuit is crucial for the MIDI signal to be recreated. In order for any MIDI device to recognize a MIDI signal, the signal has to be digital. If there was any rounding, the system receiving the signal would be confused and would most likely not understand what was being transmitted. The inverter effectively creates an output of a very sharp squared-off wave, as well as provides a solid 5V peak output with respect to earth ground, which is very important as well.

Figure 8
Inverter circuitry

<u>Output Pull-up Resistors</u>

Two pull-up resistors are used on the output of the receiver circuit/input to PCM based sound module in order to define the input state when no signal source is connected. Using these resistors before sending a signal to the sound module ensures a similar voltage between the voltage source level and the receiver circuit when components are inactive. Figure 9 highlights this output to the MIDI sequencer.

Figure 9
Output pullup resistors circuitry

Power Supplies

In order to accomplish our goal of eliminating the need for a bench voltage supply, it was necessary to find a way to supply the voltage from a simple wall outlet. To do this, different methods were used for the receiver and sender circuits.

For the sender circuit, an AC adapter that supplied a 12 V signal with a 1.5 V from peak to peak was utilized. A 10μF capacitor was used to bridge the signal and eliminate any AC signal. The resulting signal gave around 14 VDC that was used to power the sender circuit with the light source.

For the receiver circuit, both +15V and -15V were needed for the operational amplifiers, along with a +5V supply for the logic chip in the circuit. To do this, a DC converter that supplied a V+ and a V- with a 30V differential was used. V+ went to the input of a +15V regulator chip, and V- was supplied to the ground of the regulator. The output of this +15V regulator was then at the halfway point of these two voltages. This output was then connected to earth ground, which forced the V+ to +15V and the V- to -15V. To get the +5V supply, a +5V regulator chip was used with +15V connected to the input and earth ground connected to the ground pin. The output was then +5V with respect to the ground of the rest of the circuit. From this configuration, the circuit that required amplification and signal correction the MIDI signal was able to be powered.

V. Ethical Considerations

The Wireless Optical Piano steers clear of many, if not all, of the ethical issues found in IEEE Code of Ethics. It is important to emphasize ethical issue #7, which states, "to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others." Although wireless music data transmission via light has not been fully developed to our knowledge, we must credit Harold Hass' TED talk for inspiring the

idea of wireless data transmission of an everyday light bulb. The Wireless Optical Piano is a project that is unrelated to all other issues including bribery, injuring others, health and welfare of the public, etc.

VI. Conclusion

The purpose of this project was to create a consumer-ready wireless optical MIDI interface for use with any device that communicated via this IEEE standard. Throughout the course of this project, a MIDI keyboard and a MIDI drum set were successfully used to transmit data. While using a piano, a successful connection could be confirmed through not only the ability to play notes, but through the ability to change instruments and settings (pedal sustain, etc.) on the piano and forcing the change on the MIDI sequencer on the receiver end.

More work could be done to further this project by using modulation to eliminate a lot of the interference effects that were seen while the project was in use. Sometimes, under certain lighting conditions, the circuit seemed to receive too much noise, and the MIDI signal was lost in the system. With a proper modulation scheme, the carrier wave could effectively bypass the ambient light noise without adding too much circuitry to the existing circuit.

VII. References

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