Design Review

For

Wireless Optical Piano

For ECE 397 – Individual Study

Developers

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&

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Date

February 20th, 2012

I. Detailed Electrical Design ●

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

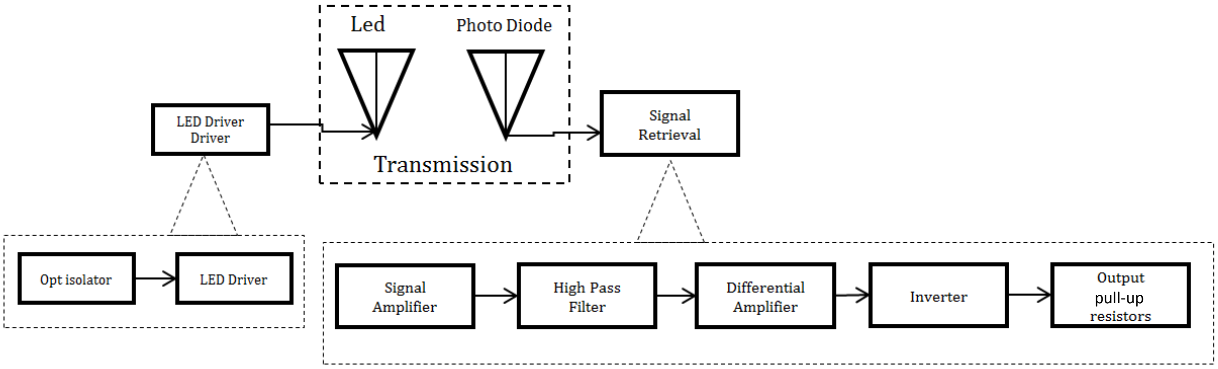


Figure 1
Block diagram of the entire project's circuitry

Optoisolator ●

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).

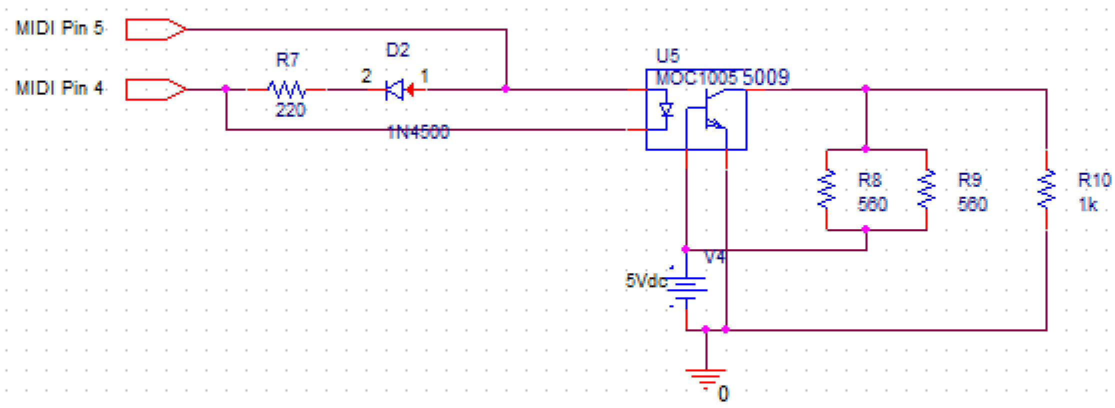


Figure 2
The Opto-isolator circuit takes MIDI pins 4 and 5 in and utilizes a MOC 5009 chip to prevent rapid changes in voltage on the output

LED Driver ●

The LED driver circuitry actually utilizes diodes in order to correct the signal from the piano and make it into something that can be sent. The LED portion of the circuitry (represented in Figure 2 as a 1 kΩ resistor) is going to be either one very powerful LED or an array of multiple LED's, based on test results.

Photodiode ●

Below, in Figure 3, the two 20kΩ resistors create a voltage drop when the photodiode is placed in parallel with the resistors.

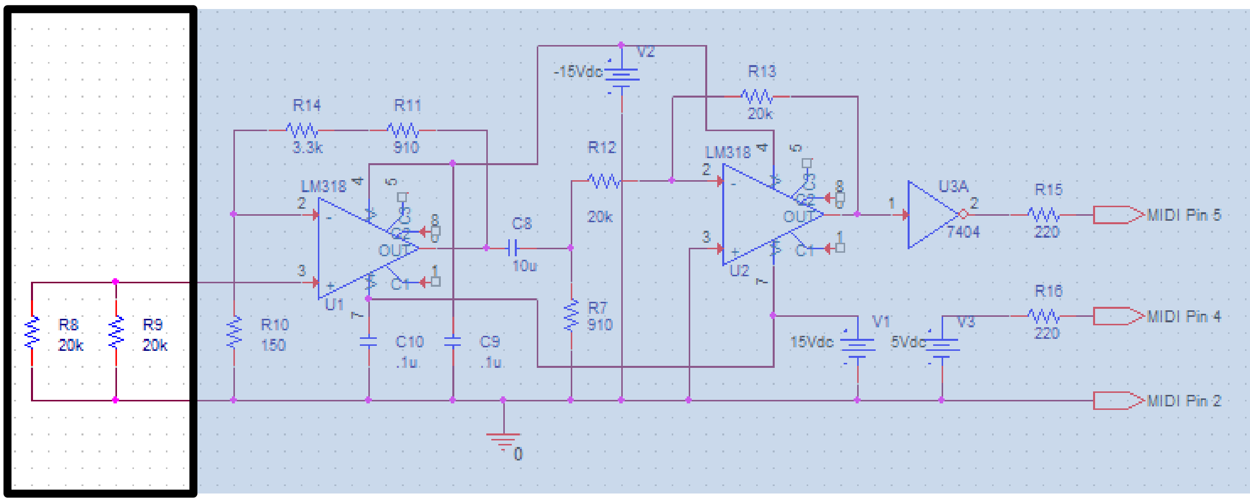


Figure 3

The photodiode forces current through the two 20kΩ resistors shown here to create a voltage drop

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).

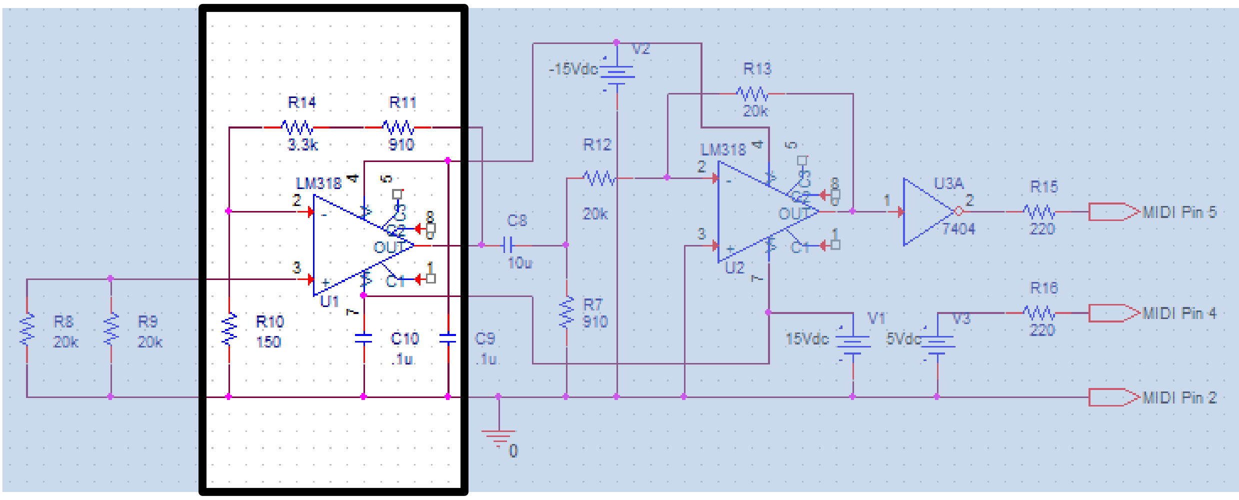


Figure 4
Amplifier circuitry

High Pass Filter ●

The high pass filter is only in this circuit to get rid of the DC offset from the ambient light the photodiode picks up. This DC offset is not something that we want to amplify, so we will most likely be changing this around a bit by using a bandpass filter before the amplifier circuitry. More is mentioned about this in the design changes section of the Design Review, and the high pass filter can be seen below in Figure 5.

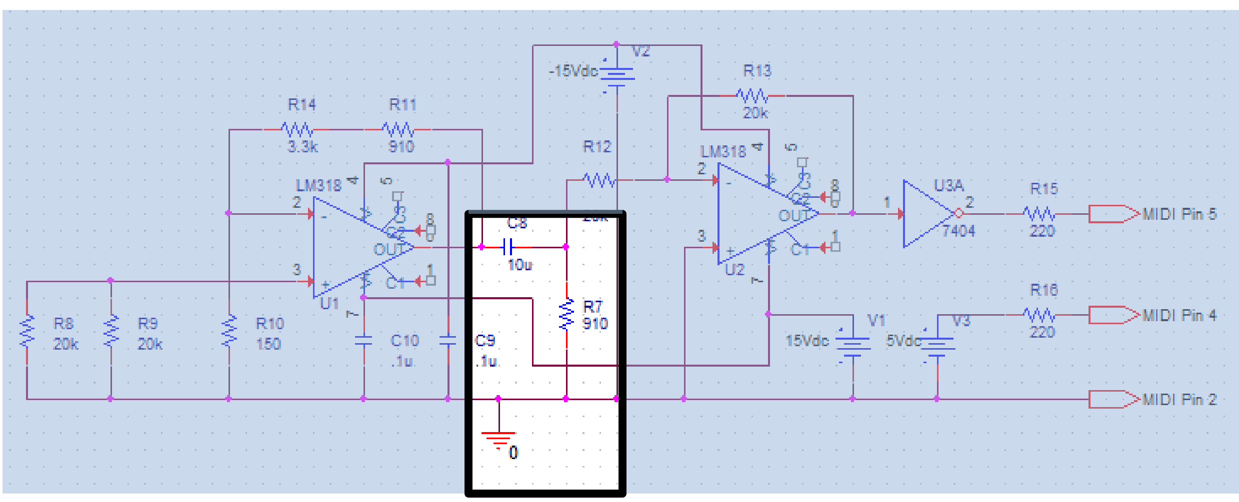


Figure 5
High pass filter

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.

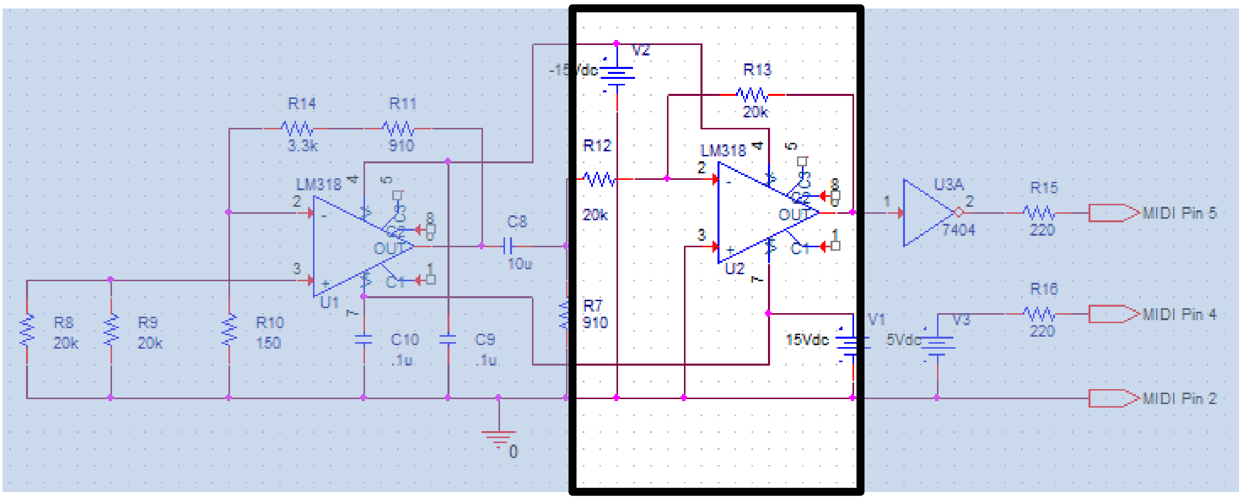


Figure 6
Differential Amplifier circuitry

Inverter

The inverter block is simply to correct the round of the 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 7 highlights this portion of the circuit.

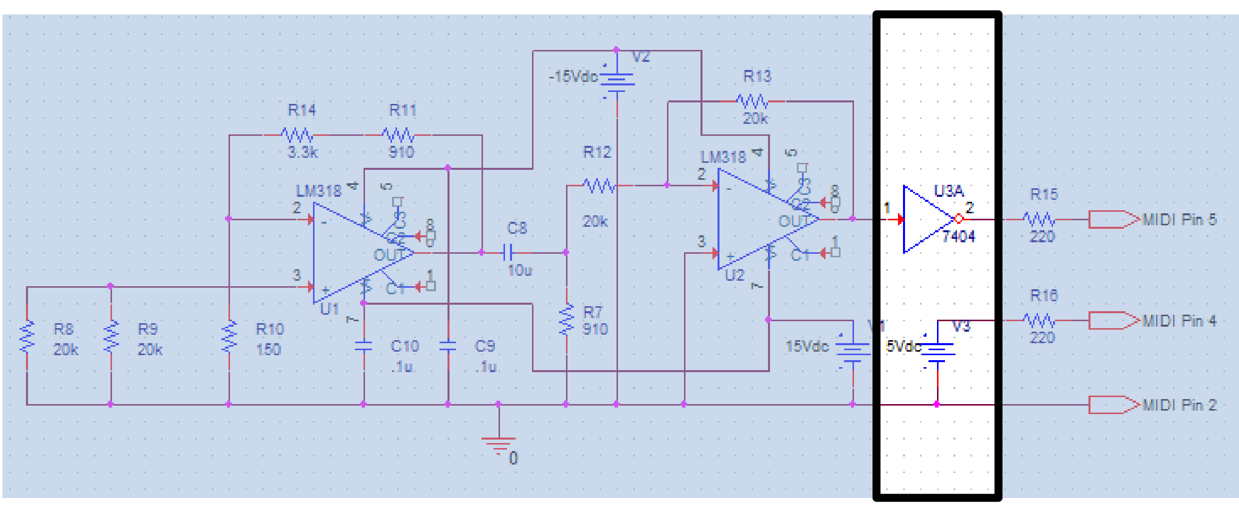


Figure 7
Inverter circuitry

Output Pullup Resistors

Two pullup 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 our receiver circuit when components are inactive.

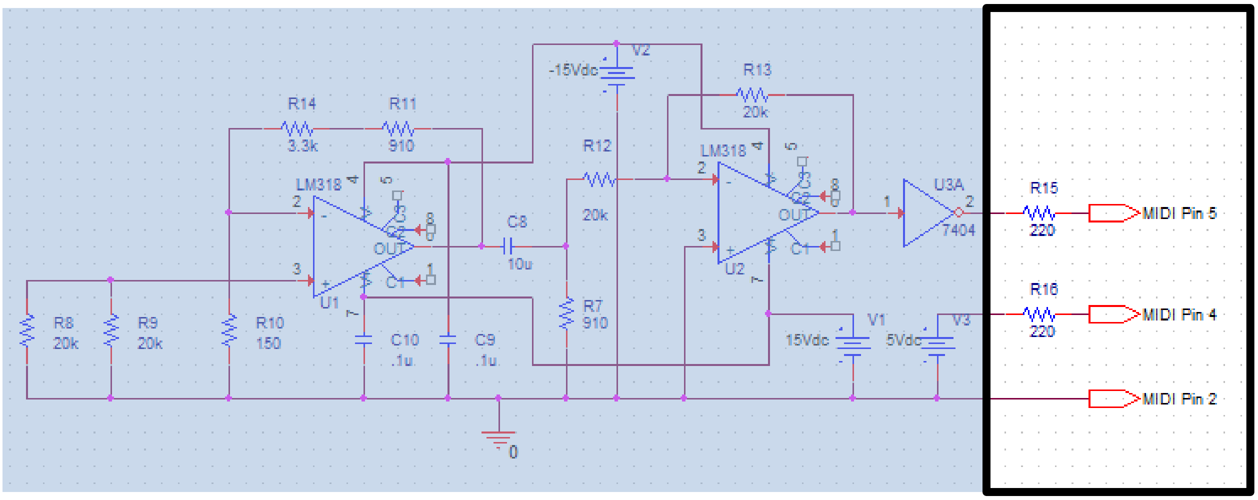


Figure 8
Output Pulldown Resistors circuitry

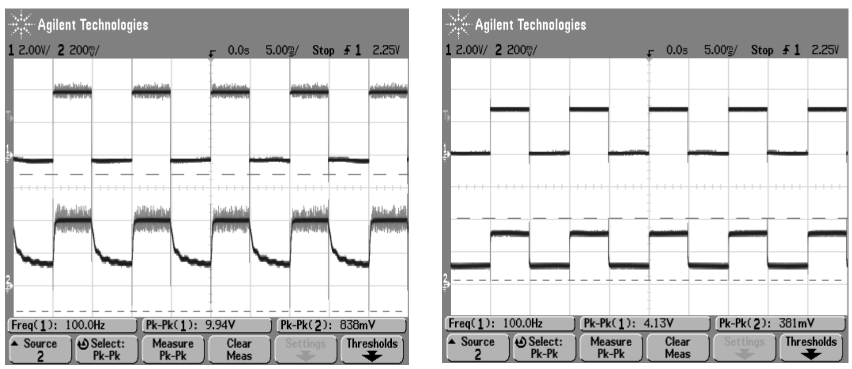
II. Design Changes from last semester's project

1. **Improve Light Source**
2. **Improve Light Received (Photodiodes)**
3. **Improve Receiver Circuit**

LED

When we worked on this project last semester, we focused on simply getting the system to work. However, the distance we were able to achieve between the LED array and the receiver circuitry was only about 160mm. That being said, we had actually purchased a much brighter LED that could ideally transmit at a much greater length, but we found it to be too slow, as seen in Figure 9. This 12 V LED was more complex that we thought after recently looking into it a bit more, with a PCB inside the shell of the light. With some different circuitry, we will be trying to achieve the greater distance through the use of this more powerful light. If this fails, however, we do have a backup light source in mind. This backup has many more LEDs in it, with each one being much brighter than the LEDs we used last semester. Through discussion with Professor Dragic, we realized that this increase in the number of LED's might not increase the distance much, but will probably just increase the area that the receiver circuit can be moved in a parallel plane to the light source without losing the signal.

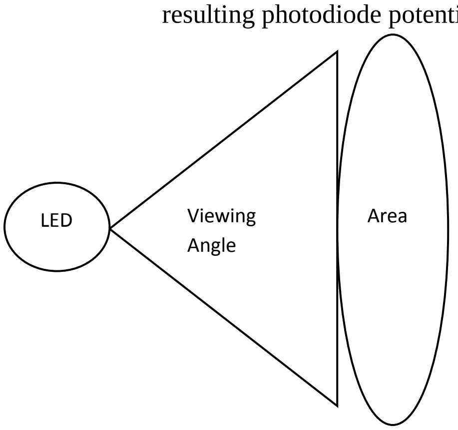
If we are in fact successful in utilizing the more powerful LED, we will be redesigning the LED driver circuitry in order to account for the 12 V requirement, as our current driver circuitry only provides 4.5 V. This circuitry will most likely be a simple three part circuit made up of a transistor, a resistor, and the LED light source. The transistor collector would be connected to a 12 V source, while the emitter pin would be connected through a resistor to ground. The base would be connected to the amplified signal, allowing the current to flow through the diode only when the input signal is high. If we were to use the new LED array, the LED driver circuitry would remain the same, as it still uses the same 4.5 V supply.



(a) (b)

Figure 9

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.



1. Obtain optimal LED viewing angle
2. Use multiple Photodiodes to cover LED are

Figure 10

Photodiode

The receiver circuitry would be essentially the same as last semester, with a few variations made to it to increase the distance it can work with. The photodiode utilized previously seemed to work just fine, with the only problem being its limited amount of current it could supply with the amount of light we were giving it. Our idea to improve this is to connect multiple of this photodiode in parallel as seen in Figure 11 in order to provide more generated current, and thus a greater initial voltage to amplify. We are unsure of how much this will slow the signal down, as we know that this will increase the RC time constant of our reception circuit. However, this is something that we expect to work well, and are going to look into testing it to achieve a greater distance of transmission.

We don't want to rely on this, though, if it doesn't seem to be getting better. We are open to trying different photodiodes, as there are many options out there that provide a much higher current output. However, we do realize that these are slower, and may not be able to be used at our 33 kHz requirement for frequency.

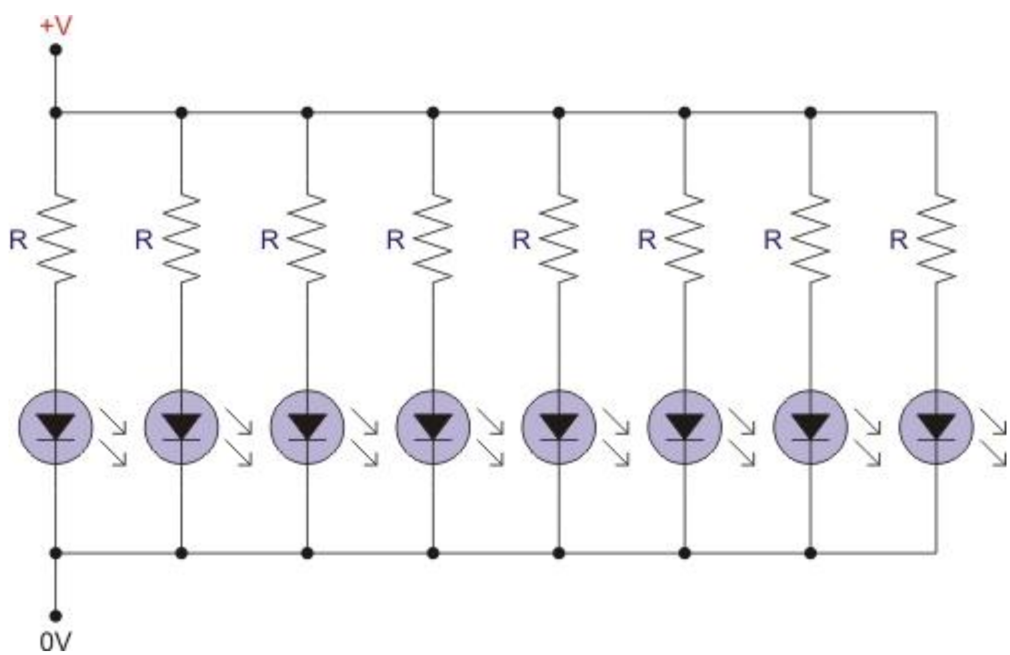


Figure 11
Photodiodes in parallel

(http://letsmakerobots.com/files/userpics/u1533/parallel_leds2.jpg)

Filtering ●

One more improvement we would like to make is to utilize the amplifying circuitry much more. In order to do this, we believe that the signal input by the photodiode will need to be filtered right away to get rid of noise and the DC offset. It will then need to be amplified by a large amount in order to achieve the gain needed for the following circuitry. Next, it may need to be filtered again if our amplifier circuitry is noisy. We intend on utilizing a band pass filter, as seen in Figure 12, to be the first filter. This bandpass filter is simply a high pass and a low pass cascaded to limit both ends of the frequency spectrum we want to get rid of. This could effectively get rid of the DC offset as well as eliminating any high frequency noise on the signal that we would not want to be amplified. The frequency response of the bandpass filter shown in Figure 12 can be seen in Figure 13.

Filter Calculations

2nd Order Low-Pass Butterworth:

Transfer Function:

$$H(s) = \frac{Vout(s)}{Vin(s)} = \frac{1}{1+C2(R1+R2)s+C1C2R1R2s^2}$$

Parameters:

$$C1 = 2 * C2$$

$$R1 = R2$$

2nd Order High-Pass Butterworth:

Transfer Function:

$$H(s) = \frac{Vout(s)}{Vin(s)} = \frac{s^2}{s^2+s\left(\frac{1}{R2C1}+\frac{1}{R2C2}\right)+\frac{1}{R1R2C1C1}}$$

Parameters:

$$C1 = C2$$

$$R2 = 2 * R2$$

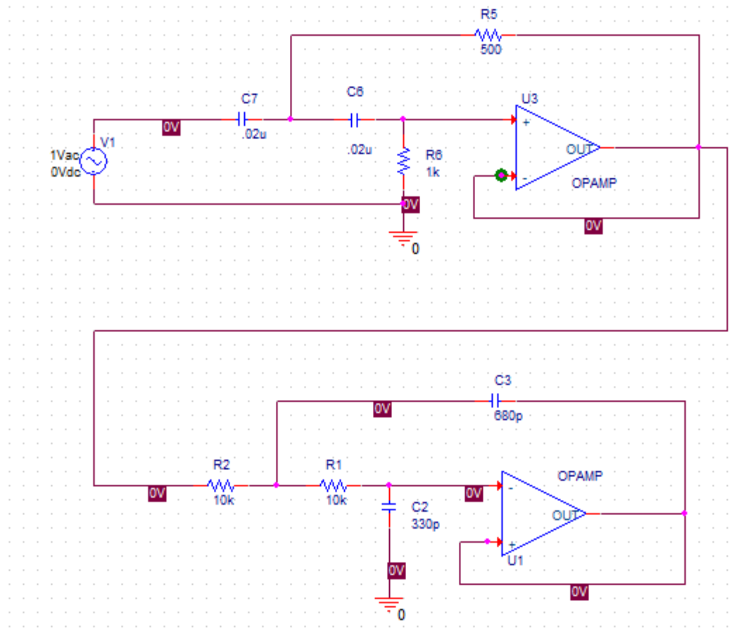


Figure 12
4th order Butterworth Bandpass filter circuit

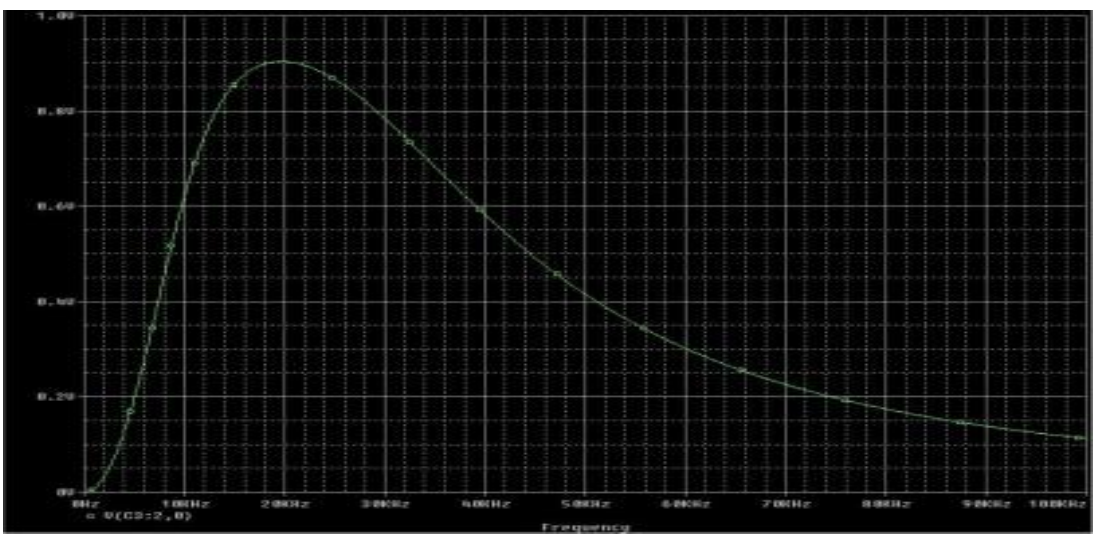


Figure 13
Frequency response of 4th order Butterworth Bandpass Filter

Transmission options

One change we will be making is the way that the LED transmits. We would like to test out inverting the signal before and after transmission in order to operate this system with practically no light visible to the human eye. This would obviously be an energy saving feature specific to our system, as the nature of the sporadic pulsing of the MIDI piano allows us take advantage of it. At 33 kHz, this random pulse wouldn't really be visible to the human eye, and would appear to be "always off".

Power Supply ●

A power supply will be implemented in order to eliminate the need for the bench voltage supply. The idea behind this is that it could be used by any wall outlet in order to bring this project even closer to being an actual product able to be used by a customer in any normal setting. This circuit will have to take a 110V AC signal and supply +15V, -15V, +5 Volts, and Ground. The circuitry to do this will simply take the 110V AC signal, convert it to 30V DC, and step it down to 15V through a 15V regulator listed in the parts list. This 15V will be utilized as the ground for our signal, with the +V and –V terminals from the DC power converter will be used as the +15V and -15V that we need. This is subject to testing, as we aren't sure if this circuit will actually work. The +5V that is required will be obtained by using the +5V regulator listed in the parts list and supplying it with the +15V. This circuit has been built and supplies the proper voltages, but has not been tested using existing circuitry for the receiver.

It is important to note that this power supply will only power the receiver circuitry, as this is expected to be stationary when in use. The sender circuitry will continue to be powered by batteries to maintain its portable nature.

Uses with other MIDI devices ●

An overall goal for EOH is to have a modular design. Although initially the project was operated using a piano signal as the source, other MIDI sources should be capable of providing similar data. We propose the stretch goal of making our device capable with a MIDI guitar as well as MIDI drum kit.

Reduced LED Driving ●

One idea that we had was to modulate the LED at less than 100% to try and reduce the change that the LED has to undergo to send the signal. If we limit the voltage change to range from 10% - 90%, we might be able to reduce the amount of lag on the fall time of the sent signal. This is something we aren't sure about, and could probably try to implement later on in the project if other steps aren't working

III. Testing and Verification

Requirement	Verification
I. Utilize a more powerful LED system to send the light without losing the 33kHz signal. a. LED is more powerful than the one used last semester. b. LED works at 33kHz. c. LED doesn't work on reduced power at 33kHz.	I. Research will be done to test out different types of LED light sources. Ones that might be used include a 12 V spotlight LED or an array of 24 high-brightness LEDs. a. Using one photodiode and the same distance from LED to PD, test voltage output across resistor attached in parallel to PD. It should be greater for both LEDs, but proceed with the one with a greater voltage. b. Take the LED with more voltage and test it with a function generator with square waves at 33kHz to make sure the signal is able to be sent. c. Make sure the PD still outputs the same voltage at 33kHz as it did at DC.
II. Utilize Multiple Photodiodes a. At a distance of 5 ft from LED, connect multiple PD's in parallel b. Start at low frequency (1kHz), obtain signal, then increase to 33kHz c. If PD cannot resolve 33 kHz decrease number of PD's	II. Connect multiple photodiodes in parallel using trial and error to find the best tradeoff between distance and frequency response a. Increase number of photodiodes until a measured voltage of around 200 mV is obtained b. Using function generator and oscilloscope, measure 33 kHz across each photodiode to see amplitude c. Obtain tradeoff between distance and frequency response by repeating steps a) and b)
III. Receiver works well at different distances. a. Receiver works at the same distance as last semester with new light. b. Receiver works at 5 ft.	III. If the receiver only works at a certain distance, it is really not commercially ready. Since a commercially ready product is one of the goals of this project, it is important to make sure that it works well at different voltage levels. a. Hold the LED 160 mm away from the PD and make sure

	music is still able to be played through the speakers. b. Hold the LED 5 ft. away from the PD and make sure music is still able to be played through the speakers.
IV. Power supply properly delivers a steady +15V, -15V, +5V, and GND a. Take in 110V AC voltage from wall outlet. b. Make sure that DC voltage converter creates a proper +15V from the wall outlet power c. Confirm that the voltage regulators and inverters actually convert the +15V to the other required voltages.	IV. The wall outlet will supply a AC to DC converter with power, from which the voltage will be stepped down. Testing will be done with a Digital Multimeter in order to confirm voltages. a. Check voltage being supplied into the converter with the Digital Multimeter and confirm 110V AC. b. After converter, use the Digital Multimeter to probe the output to confirm +15V. c. Use Digital Multimeter to probe each voltage output. Use load resistors across them to make sure the system still works when loaded.
V. MIDI piano is able to be played and heard a. Make sure the photodiode is receiving the correct signal b. Confirm that the signal is correctly coming out of the inverter circuitry c. Listen to the music ***Note: For stretch goal repeat for MIDI guitar and MIDI drums	V. The overall goal of this project is to be able to play piano wirelessly through light. When each step is finished, this is the proper way of testing the final design before use. a. Use an oscilloscope reading across the photodiode in parallel with the resistors in order to see if the signal is correct. Run/Stop can be used on the oscilloscope to capture the correct frame. b. Again, use an oscilloscope in order to capture the signal after the inverter to make sure that the signal is correctly being sent out of the receiver. c. Audibly listen for the music and make sure that actual notes being played at different levels translate into sound.
VI. Audio Delay a. Confirm that the delay is such	VI. It is important with this device to minimize delay. As is with anything

that a human will not detect it b. Obtain a value for the amount of delay in the system	that can be played for performance value, delay would hamper an artist's ability to perform. a. By playing the piano, have different subjects attempt to notice the delay, and record their reactions. b. By using an oscilloscope with probes at the MIDI input and MIDI output, quantify in microseconds the actual amount of delay.

IV. Schedule

Week Of	**Task**
January 30	Submit RFA online
February 6	Improve light source; Order parts
February 13	Test Array of Photodiodes; PSpice Modeling
February 20	Design Review
February 27	Filter & Amplify Signal upon Receiving
March 5	EOH Exhibit
March 12	Self-Contain Project Using Only Wall Outlet
March 19	Spring Break
March 26	Mock Up Demo/Presentation
April 2	Stretch Goal – Multiple Instruments
April 9	Eagle; Submit Board Request
April 16	Begin to Write Final Paper
April 23	Demos and Final Presentation
April 30	Turn in Final Paper, Lab Notebook, Checkout
May 7	Exams End

Proposed Work Distribution:

Alex Crisci: PSPICE Modeling, Voltage Regulation, Parts Ordering, Construction, Testing, Eagle

Evan Schrock: Filtering, Power Distribution, Parts Ordering, Construction, Testing, Eagle

V. Cost Analysis

Parts

Description	For	Price	Quantity	Total
VTP 1188 Planar Silicon Photodiode	Convert light signal into current	$5.00	4	$25
LED Light		$30.00	1	$30.00
Resistor	Transmission/Receiver	$0.02	30	$0.60
Capacitor	Transmission/Receiver	$0.05	20	$1.00
Diode	Transmission/Receiver	$0.05	10	$0.50
MIDI Keyboard	Signal Source	$250.00	1	$250.00
LM318 OpAmp	Amplify Signal	$1.00	1	$1.00
Opto-Isolator	Isolator Source from Transmitter	$1.00	1	$1.00
7404 Inverter	Receiver	$1.00	4	$4.00
PCM Based MIDI Sound Module	Receive/Interpret MIDI Signal	$460.00	1	$460.00
Bose Speakers	Project Sound	$50	2	$100
MIDI Cable	Connect MIDI Keyboard to Light Source; Connect Receiver to MIDI Sound Module	$10.99	2	$21.98
MC78L15CP	+15 Voltage Regulator	$0.67	1	$0.67
LM78L05	+5 Volt Regulator	$0.23	1	$0.23
30 V Power Supply	Wall AC to 30 V DC	$72.77	1	$72.77
			Total	$968.75

Labor Costs

LABOR	
Employee	Labor
Alex Crisci	10 hrs/week x 2.5 x 12 weeks x $40/hr = $12,000
Evan Schrock	10 hrs/week x 2.5 x 12 weeks x $40/hr = $12,000
TOTAL	$24,000

Total Costs

Parts	$968.75
Labor	$24,000
Total	$24,968.75

VI. 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.