Instrumentation Lab, Physics 111A

Final Project: Transmitting Information Using Lasers

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Introduction

The purpose of our final project was to display data communication through optical transmission. We initially intended to use IR components to transmit and receive the signal however we didn't follow through on this since aiming the signal would have proven to be challenging without being able to see the signal. We used a 5 mW laser diode and the phototransistor available in the lab instead.

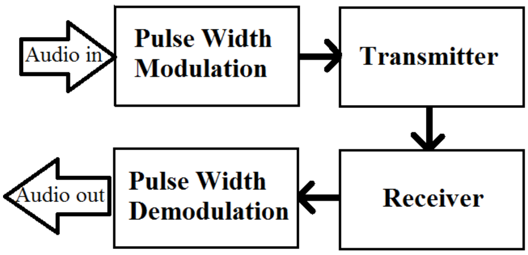


Figure 1: PWM Analog Transmission

We built a circuit that used Pulse Width Modulation to take an audio signal and modulated it with a 40 kHz variable duty cycle square wave to transmit it through pulses. PWM was new to us but relatively simple to understand, the information is encoded in the duty cycle of the square wave such that the amplitude of the input signal is proportional to the time for which the square wave is at the high or "on" value. We built a variable duty cycle circuit using a 555 timer, which was another new element of the project for us. This circuit was modulated using our audio input and sent through a laser diode. The modulated optical signal was then received at a different circuit that detected the signal and filtered the noise in a series of steps. We used a signal conditioning circuit that clipped the signal to a threshold value and also amplified it in a series of stages and demodulated it to output it through a speaker.

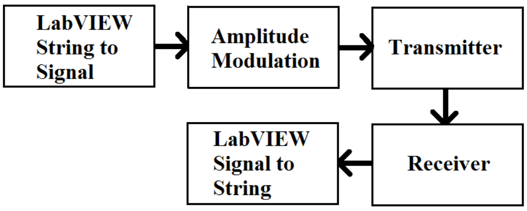


Figure 2: AM Digital Transmission

Having time left over we then built another circuit that took a digital signal as its input instead of an analog signal. We didn't have time to fine tune it so the design wasn't very robust and the programs we wrote were only able to transmit numeric strings as digital signals by converting them to boolean arrays but the design worked well and displayed data transmission through light. We designed a LabVIEW vi which converted a number string to an analog signal which we sent to an amplitude modulating circuit that emitted the signal through a laser diode. This signal was picked up by a similar but simpler receiver circuit as described above. The signal received was sent back through another LabVIEW vi that processed it and recreated the numerical string.

Pulse Width Modulation for Audio Signal

PWM Transmitter [1]

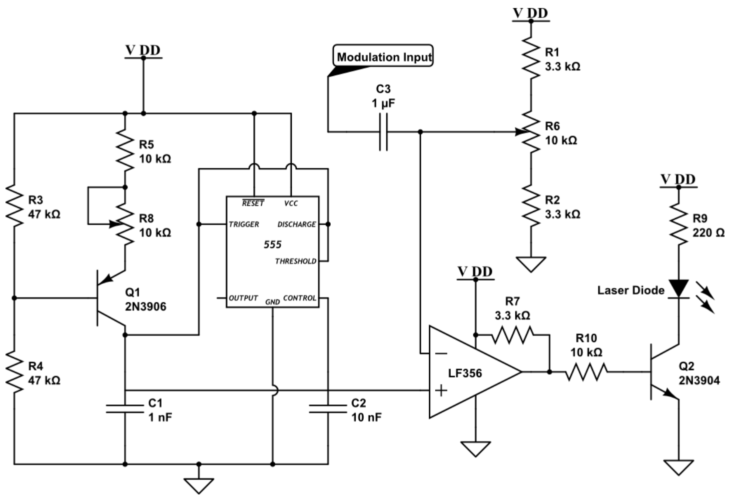


Figure 3: PWM Transmitter

In the transmitter circuit above the 555 timer is used to generate a ramp waveform, the current source at Q1 charges the timing capacitor which creates the linearly increasing ramp signal instead of the typical exponential waveform. C1 and R8 set the transmitter frequency, to generate a 40 kHz waveform we used C1=0.001 µF and adjusted the potentiometer until we saw a 40 kHz waveform. We tried powering the timer using both 9 V and 12 V, the 9 V worked well but the amplitude of the waveforms was around 5 V and that resulted in the transmitted signal being rather weak so we used 12 V instead. The resulting ramp waveform is shown below on the scope trace.

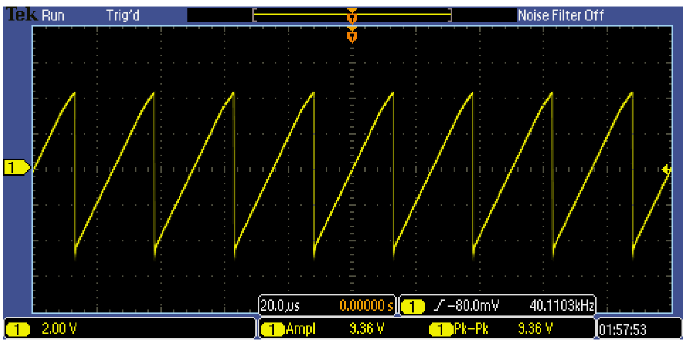


Figure 4: Variable Duty Cycle Ramp Waveform

The comparator circuit built around the op-amp sets the variable duty cycle. Before adding the modulation signal, we adjusted R6, the 10 kΩ resistor until we saw a 50% duty cycle square wave. This is the waveform that carries the modulated signal. The scope trace below shows this 50% duty cycle.

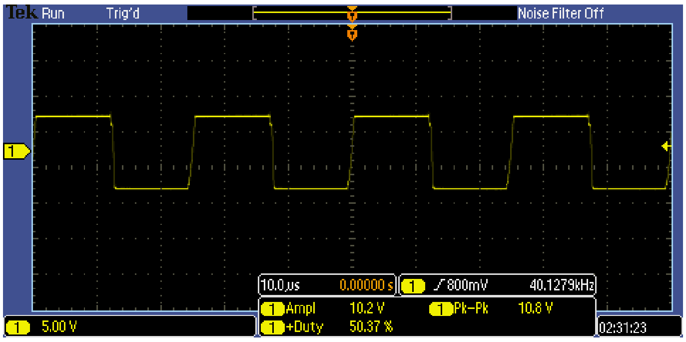


Figure 5: Variable Duty Cycle Square Waveform

Finally, the modulation signal is input to the comparator. To observe the modulation, we applied a 50 Hz sine wave to the circuit and saw the square waveform duty cycle pulsing on the scope proportionally to the amplitude of the sine wave.
The PWM output is then input to the laser diode transmitter that is built to drive high currents. The 220 Ω resistor R9 allows a maximum current of up to 19 mA through the diode which is appropriate since we found the maximum operating current of the laser diode to be 25 mA.
In order to debug the circuit, we built a simple receiver circuit with a current to voltage converter as in Lab 6, Problem 6.11 [4]. Driving the transmitter with a sine wave we were able to pick up the PWM waveform at the receiver end.

PWM Receiver [2]

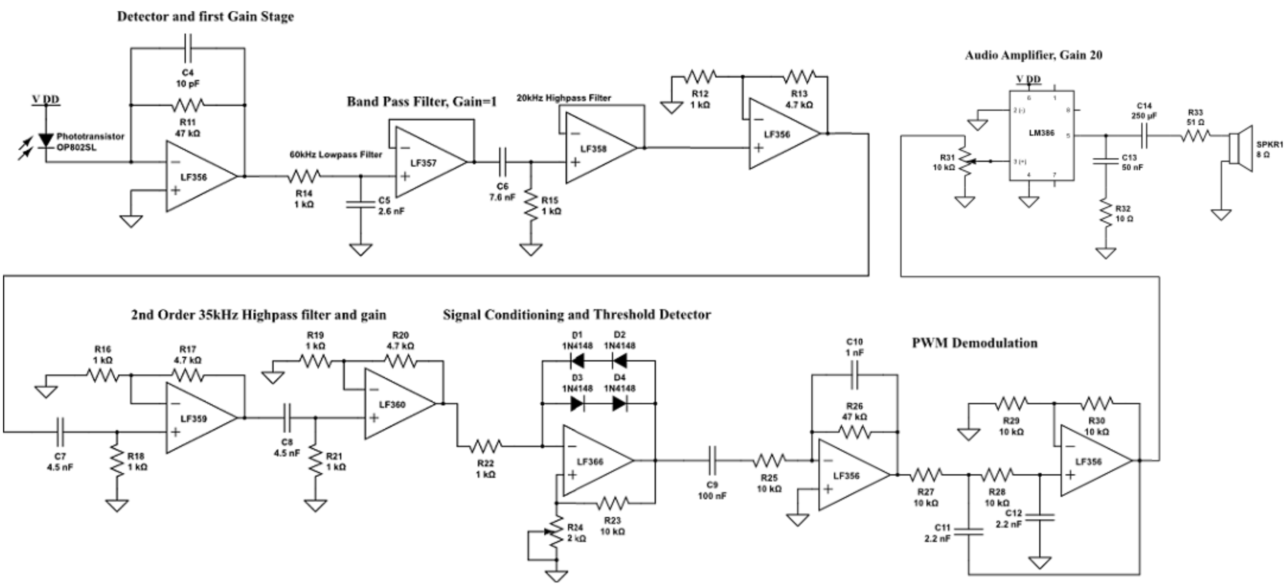
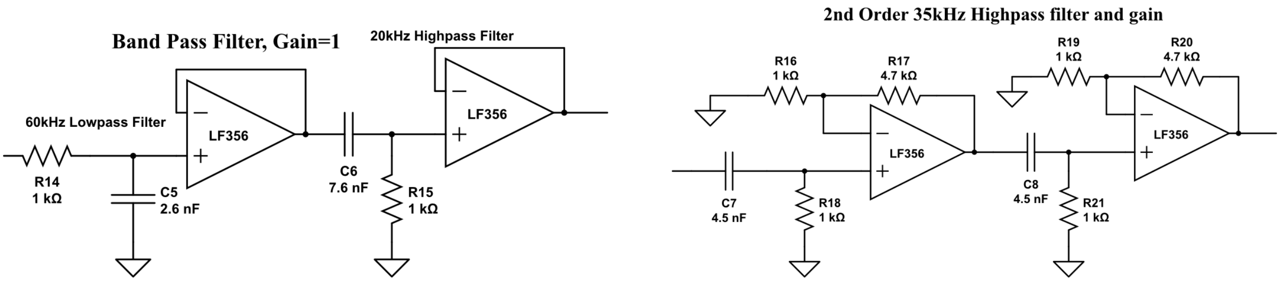


Figure 6: Complete PWM Receiver circuit

For the receiver circuit we put together the design above, starting with the first Detector and Gain Stage module. This is made of a simple current to voltage converter that uses the phototransistor to pick up the signal while also amplifying it. It is followed by some filtering and then an inverting amplifier of Gain = -4.7. We added the bandpass filter between the detector and first gain stage to remove noise.

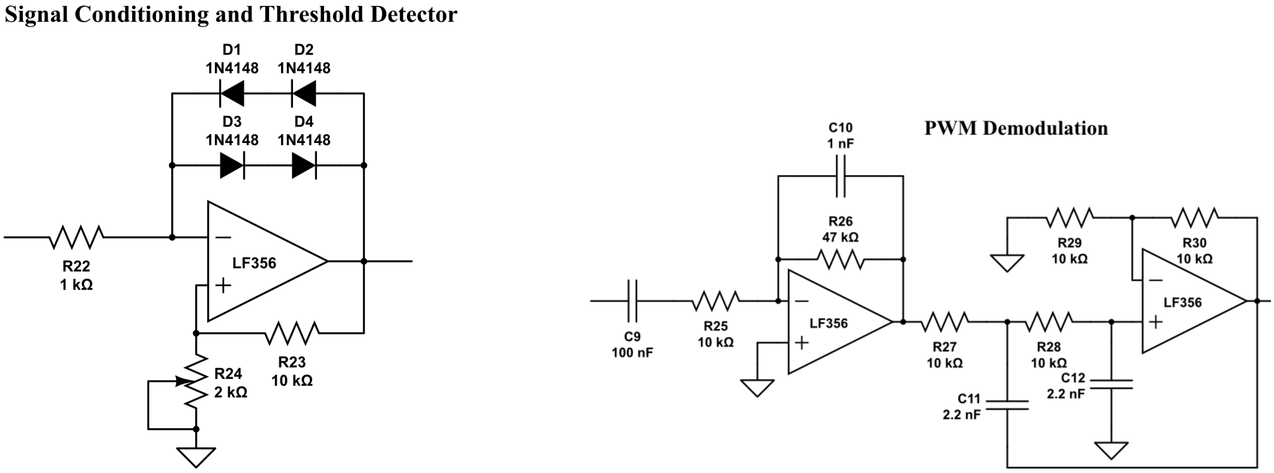


(a) Bandpass filter (b) Second order highpass filter and gain

Figure 7: Filtering

Following the detector, we included some filtering circuits. These were added after the rest of the circuit was completed because we were hearing a lot of noise through the speaker on the order of 12 kHz and 100 kHz.

The first filtering stage was a 60 kHz active lowpass filter with Gain = 1, we used R=1 kΩ and C=2.6 nF. We followed this with a 20 kHz active highpass filter with Gain = 1, we used R=1 kΩ and C=7.6 nF. These filters helped to cut out most of the high and low frequency noise around 40 kHz but there was still some low frequency, about 500 Hz noise after the band pass filter. We then added the second order high pass filter at 35 kHz that cut out most of the noise, there was also a 4.7 times gain at each stage.



(a) Signal Conditioning (b) PWM Demodulation

Figure 8: Signal Processing

Following the filtering, the signal was sent though a signal conditioning circuit. This is essentially a clipper circuit that produces a uniform amplitude above or below our reference level of 240 mV set by the potentiometer R24. The diodes clip some part of the circuit above and below the assigned threshold so that regardless of how far our laser diode is with respect to the phototransistor, we get the same high and low levels. The signal is then sent through a third order lowpass filter that removes the 40 kHz carrier pulse.

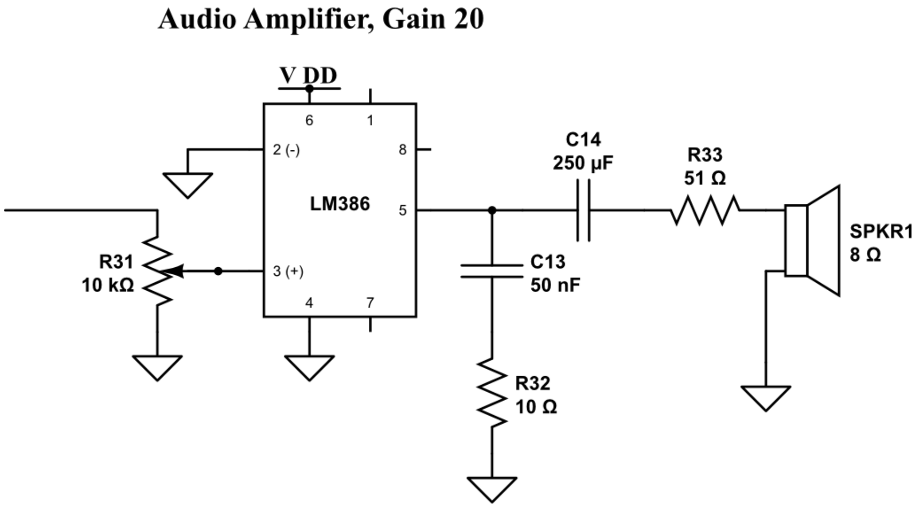


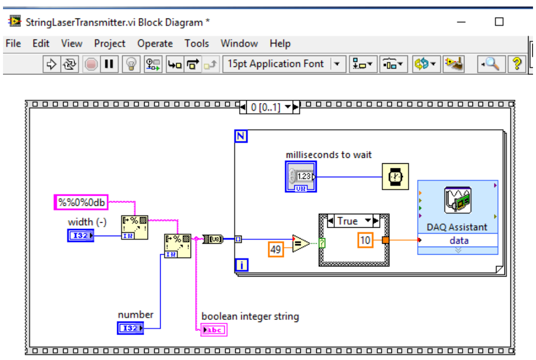
Figure 9: 20 Gain Audio Amplifier

The audio output was finally transmitted through a 20 gain audio amplifier using an LM386 as shown below. We used a series of small amplification stages initially because the resource we were using [2] mentioned Gain-bandwidth product limitations and having looked this up, we found that the gain bandwidth for LF356 is 5 MHz and using high gain could result in unintentional bandwidth clipping.

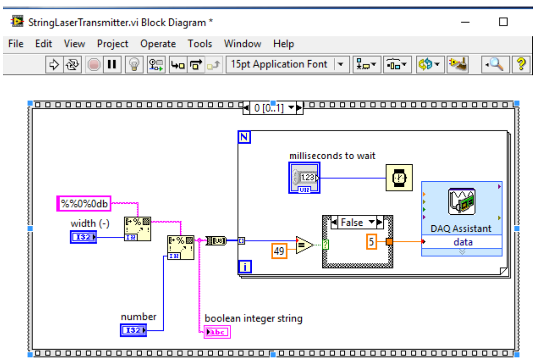
Amplitude Modulation for Digital Signal

LabVIEW String to Signal

We designed a LabVIEW vi that takes a number as a string, converts it to a byte array in which each byte has the assigned ASCII value of that string element. The vi then loops over each element of the array and depending on whether the ASCII value is 49 (corresponding to 1) or 48 (corresponding to 0), the vi commands the DAQ to put out a pulse of 10V for the logical high (1 bit) or 5V for the logical low (0 bit). This is all enclosed in a case structure which then tells the DAQ to set the output voltage back to 0 after it has looped over all the elements of the byte array. The images below show the block diagram true and false cases for the vi.



(a) String to Signal, True, Logic High



(b) String to Signal, False, Logic Low

Figure 10: String to Signal vi

Amplitude Modulator and Transmitter

We built a very simple amplitude modulator shown in figure 9. We set the bias current at 18 mA and the circuit modulates the bias current between 13 mA and 23 mA based on whether V_{in} is the logical high or the logical low. While amplitude modulation is not the best choice for transmitting data since the noise is amplified proportionally to the signal. We did not struggle with this problem because our logical high and logical low had a difference of $\Delta V = 5$ V and all the noise was on the order of 500 mV. Another issue with amplitude modulation is that it works well for very low frequency radio waves but not for higher frequency waves so our data transmission rate was quite slow. However it worked for demonstrating optical data transmission and the functionality of the LabVIEW vi's we designed. The signal output by the laser diode is then picked up by a nearby receiver.

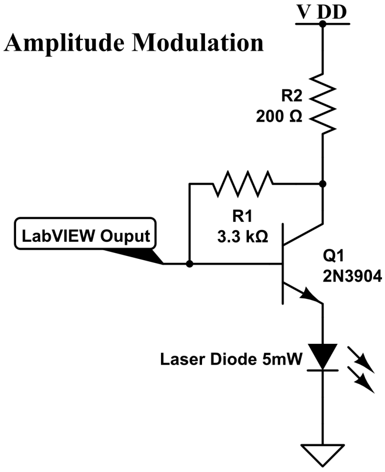


Figure 11: Amplitude Modulation

Digital Signal Receiver

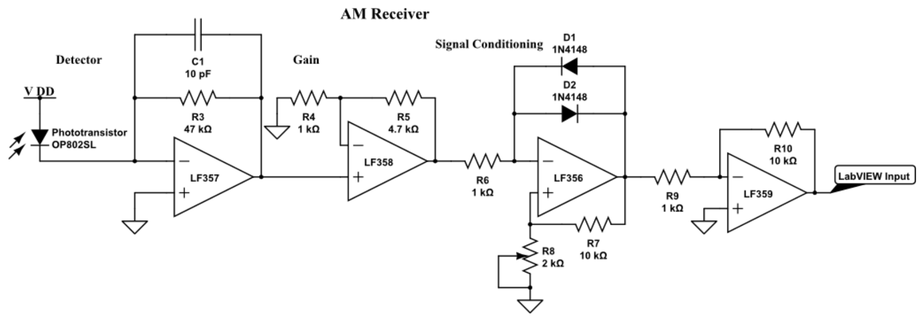


Figure 12: Receiver Circuit

The receiver circuit is made up of a current to voltage converter using the phototransistor OP802SL followed by an inverting amplifier of -4.7 gain. This signal then goes through a signal conditioning circuit that clips the amplitude to make it constant for varied distances between the transmitter and receiver. Lastly, the signal goes through gain = 10 inverting amplifier. The output from this circuit goes back into the DAQ to the next LabVIEW vi that demodulates the signal to recover the numerical string.

LabVIEW Signal to String

The block diagram below shows the true case for the vi that recovers the numerical string from the analog signal input (the false case simply appends a 0 instead of a 1). This vi takes in the output from the receiver, it starts measuring data when the voltage reaches a threshold which we set at 1 V. We used a sampling rate of 15 kHz and set a 50 ms delay in the transmitter vi before it changed the pulse level. Accordingly, the DAQ took 750 samples for every 50 ms. We indexed the for loop so that the first relevant data point that was sampled was the 325th sample and it took a sample after every 750 sample points so that the relevant data points fell around the midpoint of each pulse on average. For a pulse between 6 V and 9 V, the vi appends a 1 to an array and for a pulse between 1 V and 6 V the vi appends a 0 to the array. It then loops over each element of the array, turns it from a number to a numeric string and concatenates the string to recover the original number that was transmitted.

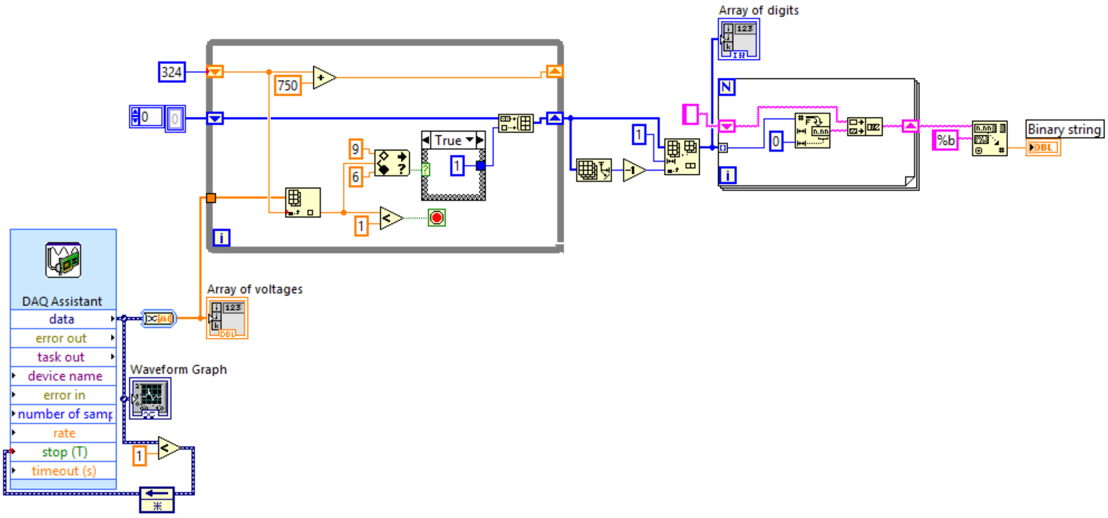
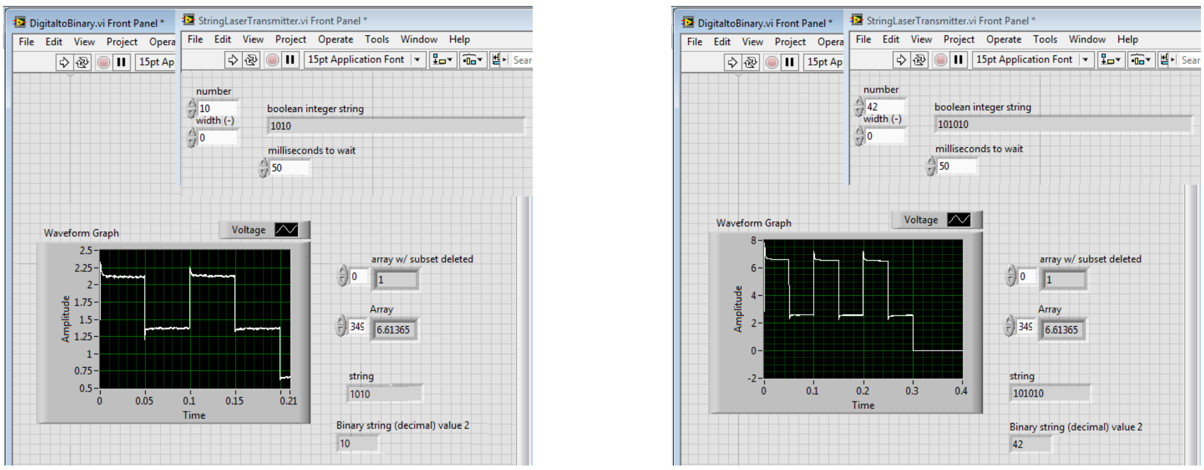


Figure 13: Signal to String vi, True case

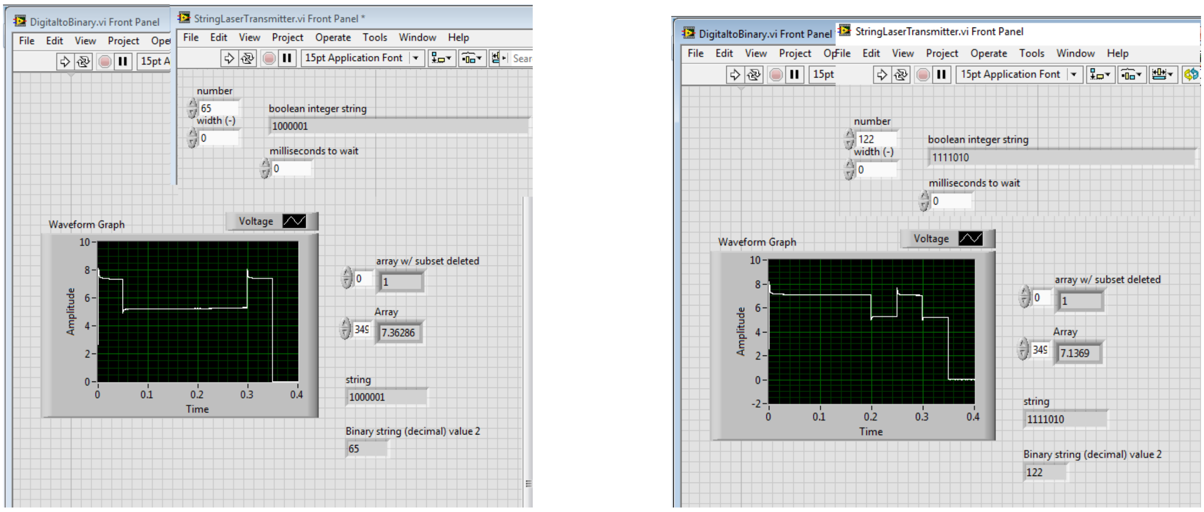
Digital Transmission Application

The images below show the front panels for both the LabVIEW vi's and show the functionality of the circuit. The signal being sent out is converted to an analog square wave that is picked up by the receiver as shown in the waveform graph and processed to return the numeric string.



(a) String 10 transmission (b) String 42 transmission

Figure 14: LabVIEW vis functionality



(a) String 65 transmission (b) String 122 transmission

Figure 15: LabVIEW vis functionality

We extracted the data from the waveform graphs and the table below sums up the relevant indexes that were processed by the vi for the strings 42, 65 and 122 corresponding to the appropriate binary digit.

String	Index	Time/s	Amplitude/V	Binary
42	324	0.021461	6.62172	1
	1074	0.071449	2.59649	0
	1824	0.121436	6.56814	1
	2574	0.171424	2.58487	0
	3324	0.221411	6.52972	1
	4074	0.271399	2.54904	0
65	324	0.021461	7.36673	1
	1074	0.071449	5.19787	0
	1824	0.121436	5.21175	0
	2574	0.171424	5.23564	0
	3324	0.221411	5.23467	0
	4074	0.271399	5.29245	0
	4824	0.321386	7.3974	1
122	324	0.021461	7.14045	1
	1074	0.071449	7.09816	1
	1824	0.124769	7.07815	1
	2574	0.171424	7.09106	1
	3324	0.221411	5.27083	0
	4074	0.271399	7.07105	1
	4824	0.321386	5.22499	0

Table 1: Voltage values for some strings

Conclusions

The analog signal circuit worked well as demonstrated during our project presentation. We implemented a lot of circuits and debugging techniques that we learned in this class and it was very satisfying when the circuit first started functioning. There were definitely some improvements that could be made. Firstly, the hardware could have been better, the 5 mW laser diode doesn't have a very long range but it worked up to only about 12-15 inches away from the receiver. I believe this was a result of the difficulty in pointing the laser directly at the phototransistor so that it collected all the information transmitted. We could have built a case to improve on this. In addition to this we could have done some additional signal processing and amplification to further improve the signal quality. There was some low frequency noise and the clipper circuit could have been fine tuned some more to insure that the amplitude of the received PWM waveform remained truly constant.

The digital signal circuit demonstrated the purpose we built it for such that we transmitted digital data through a laser and successfully recovered it but there was a lot of room for fine tuning. Firstly, the design wasn't robust; our data transmission rate was very slow since we used amplitude modulation and the data type we could transmit was very limited. AM is not great for laser transmission, an improvement could be to use LabVIEW to encode the binary string through pulse width modulation and pick up this signal using the receiver we built. The data type could be expanded by allowing conversion between all ASCII values to byte values. In addition signal conditioning on this circuit was not great, we can see in the table of measurements in the last section that the logical high and logical low amplitudes were not constant for each measurement meaning the distance between the transmitter and receiver was definitely playing a role in the amplitude of the waveform.

All in all, this class has been a highly illuminating learning experience. I went from knowing nearly nothing about circuits, except that you can't drive an LED without a resistor, to having some valuable knowledge such that I am now confident in my ability to design some basic to intermediate circuits. I look forward to working on my own personal projects and seeing how I can expand on my knowledge from this class.

References

[1] **Rodwell, Mark, Dr. *Lab4, Infrared PWM Transmitter*. UCSB, ECE 2C, 2009. PDF.** *http://www.ece.ucsb.edu/Faculty/rodwell/Classes/ece2c/labs/Lab4_2C_2009.pdf*

[2] **Rodwell, Mark, Dr. *Lab5, Infrared PWM Receiver*. UCSB, ECE 2C, 2009. PDF.** *http://www.ece.ucsb.edu/Faculty/rodwell/Classes/ece2c/labs/Lab5_2C_2009.pdf*

[3] **Rodwell, Mark, Dr. *Lab5b, Infrared PWM Receiver*. UCSB, ECE 2C, 2009. PDF.** *http://www.ece.ucsb.edu/Faculty/rodwell/Classes/ece2c/labs/Lab5b_2C_2009.pdf*

[4] **Fajans, Joel, Dr. *Lab 6 - Op Amps I*. Instrumentation LAB. University of California, Berkeley, n.d. Web. 06 May 2017.** http://instrumentationlab.berkeley.edu/Lab6.

[5] **Fajans, Joel, Dr. *Lab 8 - Op Amps III*. Instrumentation LAB. University of California, Berkeley, n.d. Web. 06 May 2017.** http://instrumentationlab.berkeley.edu/Lab8.