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Lab 1 Report: Signal Conditioning and Filtering

INTRODUCTION:

The goal of this lab was to create a beacon detector that would recognize a 2kHz signal and ignore a 1.5kHz signal and a 2.5kHz signal from 1 to 6 feet away. This was accomplished first by creating a circuit that detects a track wire, 2 inches away. Methods used to detect the track wire were then adapted to be used in the beacon detector, which also required that we design a band –pass filter for the 2kHz signal.

PARTS 1 & 2: Circuit Module Basics and Track Wire Detection

Parts 1 and 2 were performed simultaneously. After each piece was completed and tested, it was hooked up to the next, so when part 1 was done, part 2 was also done. The following explains each part, and how it connects to the next.

SOLENIOD/INDUCTOR:

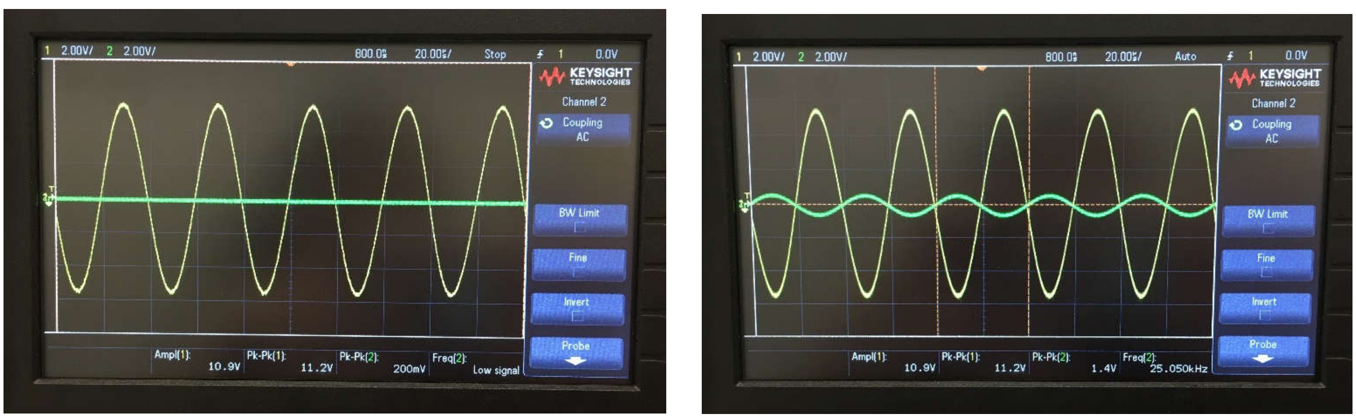

Figure 1: Solenoid Traces. The yellow trace is the signal from the test circuit and the green is the signal off the solenoid. The image on the right shows when the test circuit was held away from the solenoid, and the image on the right shows it making contact with the solenoid.

Because the availability of track wires for testing our circuits was limited, we made a test circuit by running a 500mv Vpp, 25kHz signal through a 10mH inductor. This circuit was then used to test our 10mH solenoid by moving towards and away from the solenoid. The trace that appeared over the solenoid can be seen in Figure 1. As the test circuit was moved further away from the solenoid, the amplitude of the trace decreased, and as it moved closer, the amplitude increased.

TANK CIRCUIT:

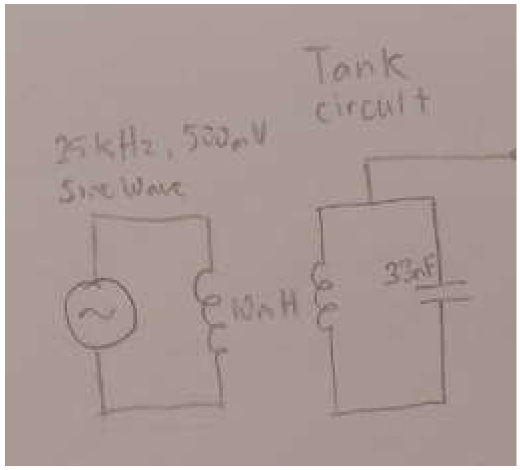

Figure 2:Test Circuit and Tank Circuit Schematic

A tank circuit was created using a 3.3nF capacitor and the 10mH inductor that was used as the solenoid in the previous step. The resonant frequency of this circuit was found to be $f = \frac{1}{2\pi\sqrt{CL}} = 27.7\text{kHz}$, close to the 25kHz of the test circuit, so the tank circuit was able to pick up the signal from the test circuit better than just a solenoid by itself , along with slightly amplifying the signal (Figure 3).

Figure 3: Tank Circuit Trace. The yellow trace shows the test circuit and the green shows the tank circuit.

SPLIT RAIL BUFFER:

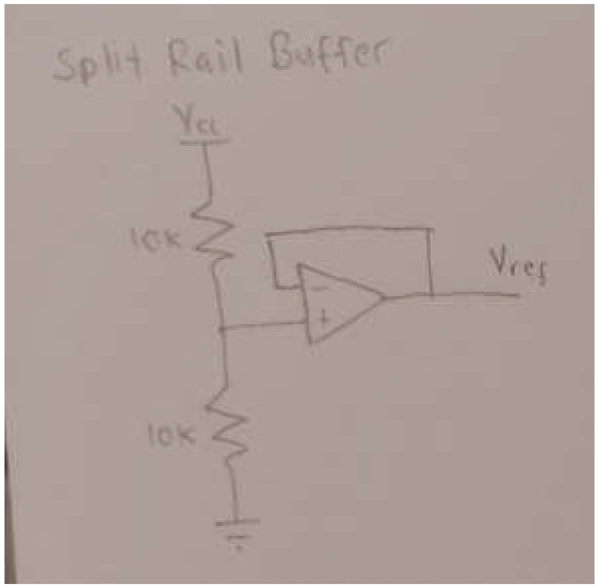

Figure 4: Split Rail Buffer Schematic

A split rail buffer was created using an MCP6004 op amp chip, two 10kΩ resistors, two 0.1μF capacitors, one as the filter capacitor and the other as the buffer capacitor to the chip. The split rail buffer used a Vcc of 3.3V and split it to 1.65V, running it through the op amp buffer so that it could be used as the reference voltage for the tank circuit and amplifier, discussed next. The voltage output was verified to be 1.65V using a multimeter.

NON-INVERTING AMPLIFIER:

The non-inverting amplifier takes input from the tank circuit and amplifies it. Initially, we built a single stage non-inverting amplifier with a gain of 2. We did this using an MCP6004 op amp chip, a 1kΩ resistor for R_f, a 1kΩ resistor for R_1, and a 0.1μF buffer capacitor, so the gain was $A = 1 + \frac{R_f}{R_1} = 2$. The reference voltage is 1.65V, taken from the split-rail buffer, so that the signal is centered at 1.65V. We took the input as the output from the tank circuit and measured the output of the amplifier on the oscilloscope (Figure 6).

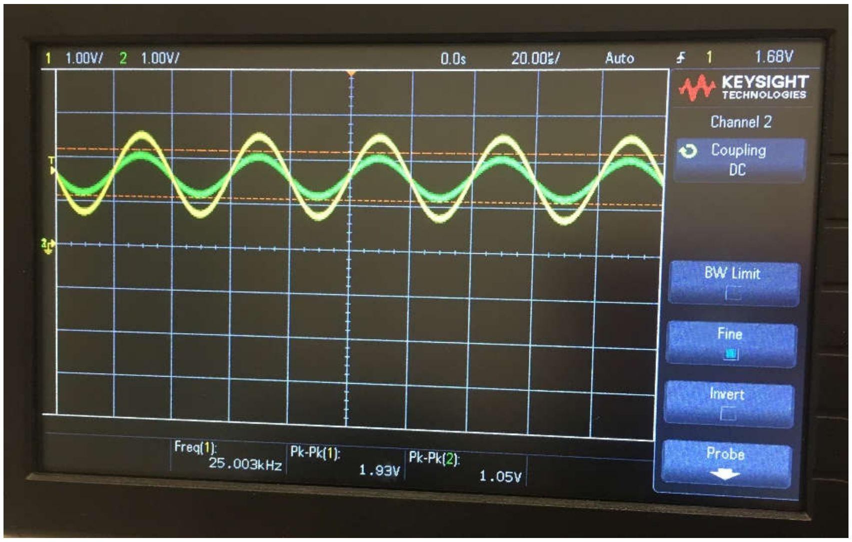

Figure 5: Trace of the non-inverting amplifier with a gain of 2. The green trace is the input and the yellow is the output.

For part 2, to achieve the gain we wanted, we used a two stage amplifier. Each stage was created using an MCP6004 op amp chip, a 10kΩ resistor for R_f, a 1kΩ resistor for R_1, and a 0.1μF buffer capacitor. Again the reference voltage for both stages is 1.65V, from the spit-rail buffer. The gain of each stage was $A = 1 + \frac{R_f}{R_1} = 11$, so the total gain was 121.

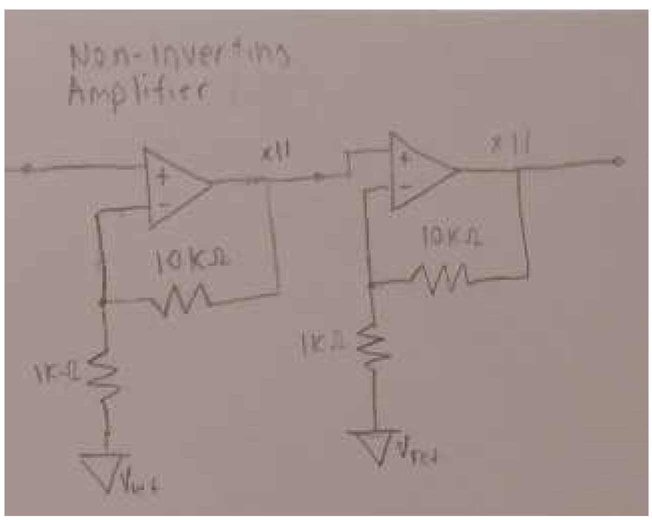

Figure 6: Two-stage non-inverting amplifier schematic

PEAK DETECTOR:

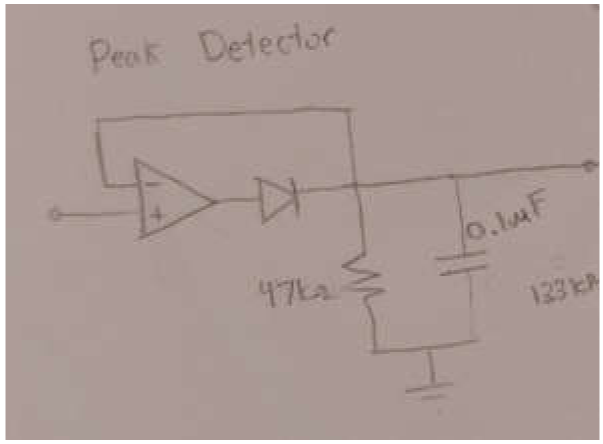

Figure 7: Peak Detector Schematic

The peak detector takes the amplified output from the amplifier and follows its voltage up to the highest point. It leaks due to the resistor, seen in Figure 7, but so long as there is a signal, the peak detector will stay high. With no signal, the peak detector will fall back to zero.

The peak detector was built using a 1N4006 diode, an MCP6004 op amp chip, a 47kΩ resistor, and a 0.1μF capacitors. There is also a 0.1μF buffer capacitor for the op amp chip. C and R were chosen to get a leakage of $\tau = RC = 0.047$s which is about 21 kHz. We wanted the time constant to be slightly lower than the frequency of the input because we wanted it to leak, but not too much smaller, because if we went to small, the peak detector output would just follow the input. The peak detector was tested using the oscilloscope (Figure 8).

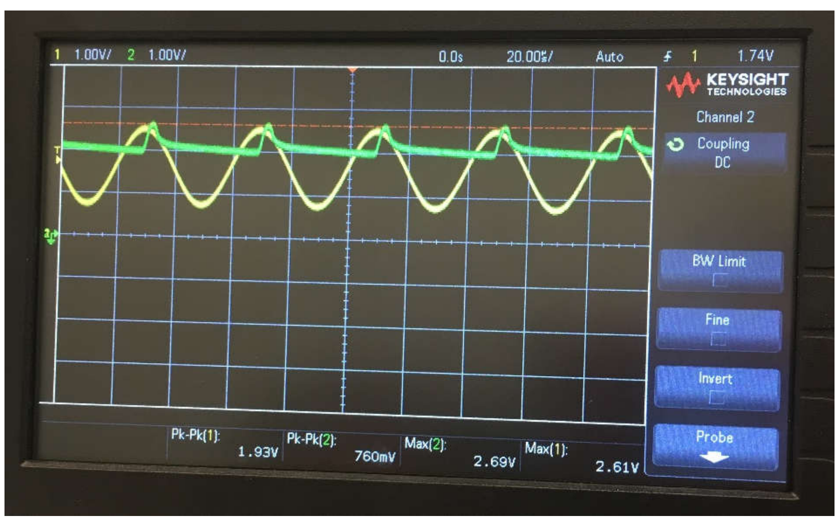

Figure 8: Peak detector trace.

COMPARATOR WITH HYSTERESIS:

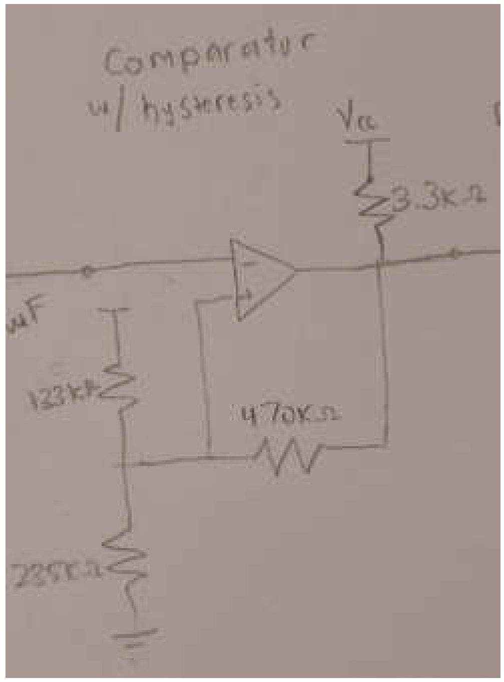

Figure 9: Comparator with hysteresis schematic

The comparator takes input from the peak detector. It is inverting so it outputs high if the input is below a threshold and low if the input is above a threshold. We chose to have the pull-up resistor to be 3.3kΩ as suggested by the lab manual. R_3 was chosen to be 470kΩ, and we determined the other resistor values (Figure 9) based on a low threshold of 1.78V and a high threshold of 2.29V, using the procedure laid out in the lab manual. We see the input and output of this stage on the LED explained next.

LED AND BUFFER/ TRACK WIRE DETECTION CIRCUIT:

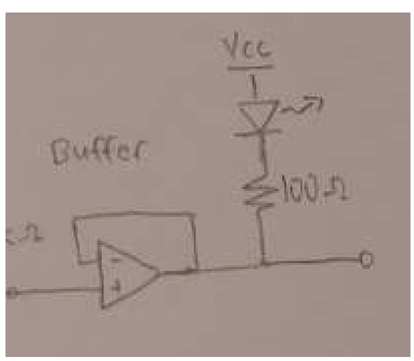

Figure 10: LED with buffer schematic

The buffer and LED take the output of the comparator and visually shows if there is a signal being detected by the entire track wire detection circuit (Figure 11). The LED is active low, which is needed because the comparator is inverting, so the LED turns on when there is a low signal from the comparator and turns off when there is a high signal from the comparator. Overall, the LED is on when the track wire is detected and off when it is not.

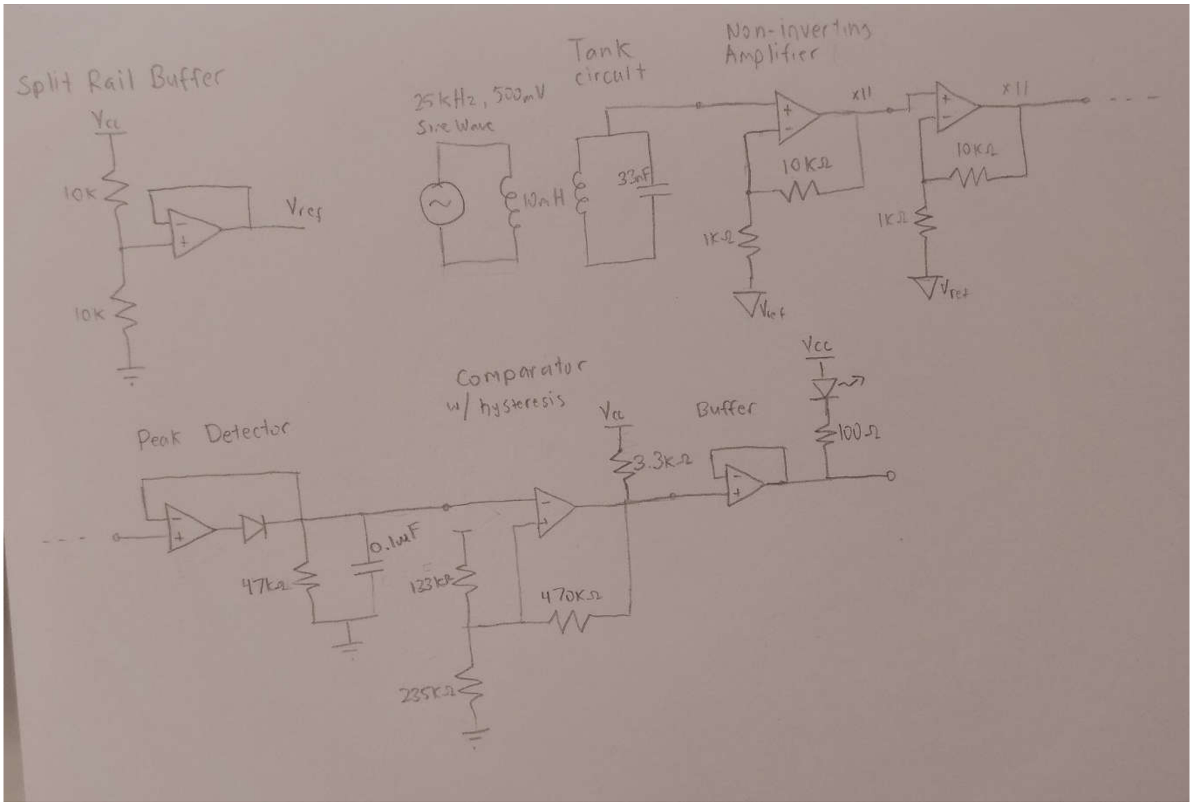

Figure 11: Complete Track Wire Detection Circuit.All op amps are powered with 3.3V to ground. There is a 0.1µF buffer capacitor on each op amp as well.

PART 3: Photo Transistor and Transresistive Amplification

In this section of the lab, we looked at the differences between three configurations for the phototransistor.

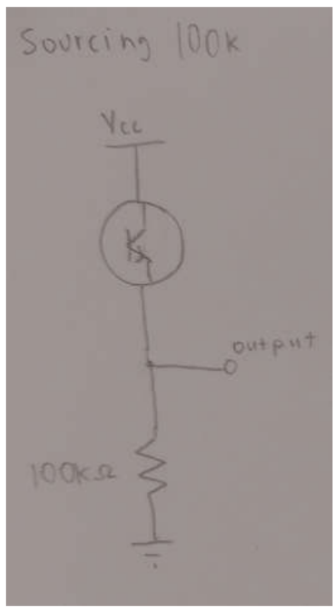

Figure 12: Sourcing configuration

The first is the sourcing configuration (Figure 12). Using a Vcc of 3.3V and a load resistor of 100kΩ to ground, the trace shown in Figure 13 was observed. Changing the resistor to 1kΩ results in the trace shown in Figure 14. The difference between the two is the magnitude of the output voltages. Lower resistance allows for higher output voltage.

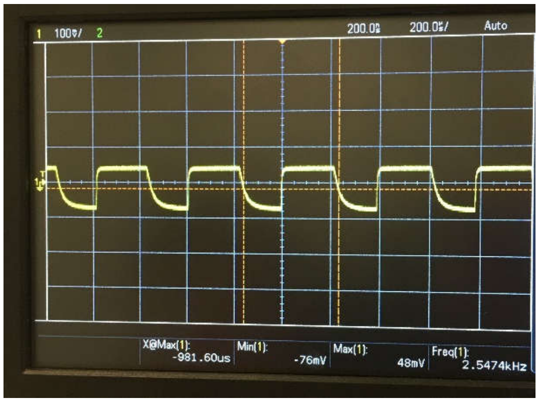

Figure 13: Sourcing with a 100 kΩ resistor.

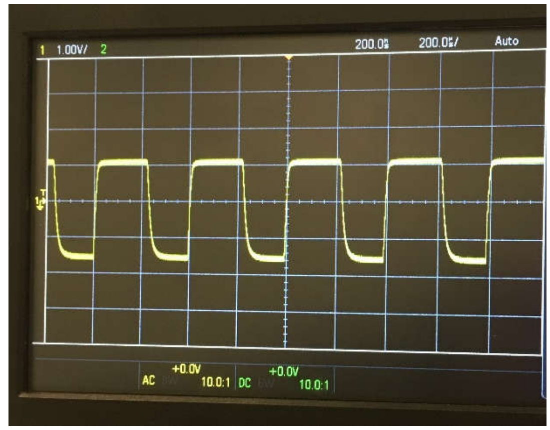

Figure 14: Sourcing with a 1 kΩ resistor.

The second is the sinking configuration (Figure 15). Again, Vcc is 3.3V. Using a 100kΩ to Vcc, the trace shown in Figure 16 was observed, and using a 1kΩ resistor, the trace showing in Figure 17 was observed. Again, the difference between the two is the magnitude of the output voltages. Lower resistance allows for higher output voltage.

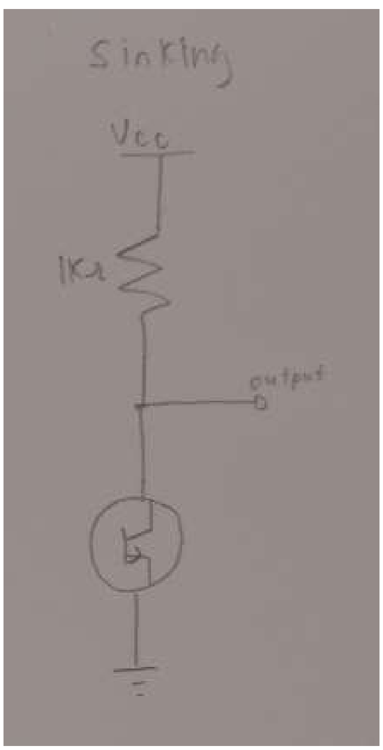

Figure 15:Sinking Configuration

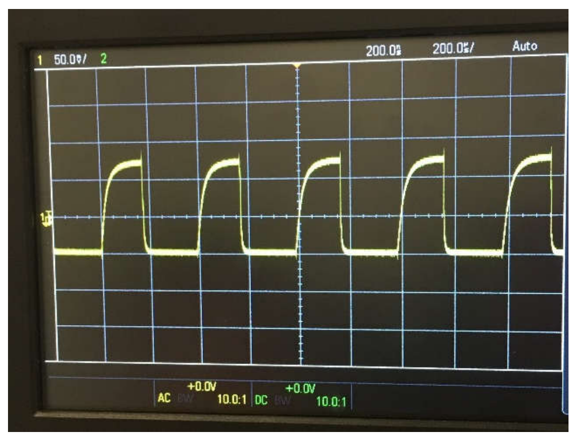

Figure 16: Sinking with a 100 kΩ resistor.

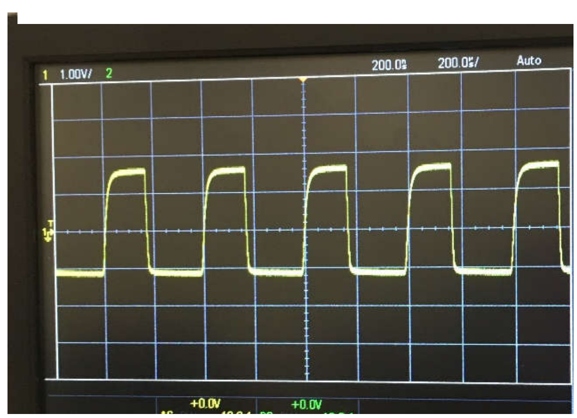

Figure 17: Sinking with a 1 kΩ resistor.

Compared to the sourcing configuration, the reaction time of the sinking configuration on the upswing is lower, resulting in the curve seen in the traces. Conversely, the reaction time on the down swing is slower for the sourcing configuration.

The final configuration is the transresistive configuration (Figure 18). This configuration keeps the voltage across the phototransistor constant and swings the output around the reference voltage, which is 1.65V in this case, taken from the split rail buffer built in part 1. The output voltage in this configuration is determined by the current from the phototransistor because the voltage from the collector to the emmitter is held constant. The output voltage can be seen in the trace shown in Figure 19, and is more quickly responsive on the up and down swings when compared to the two other configurations. This configuration is also beneficial because we can change the gain. The gain used here is 1V/mA and is achieved with a 1kΩ resistor.

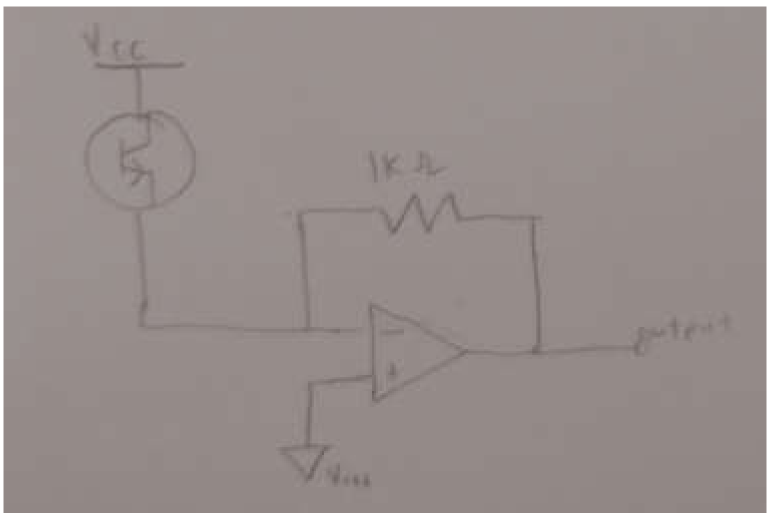

Figure 18: Transresistive configuration

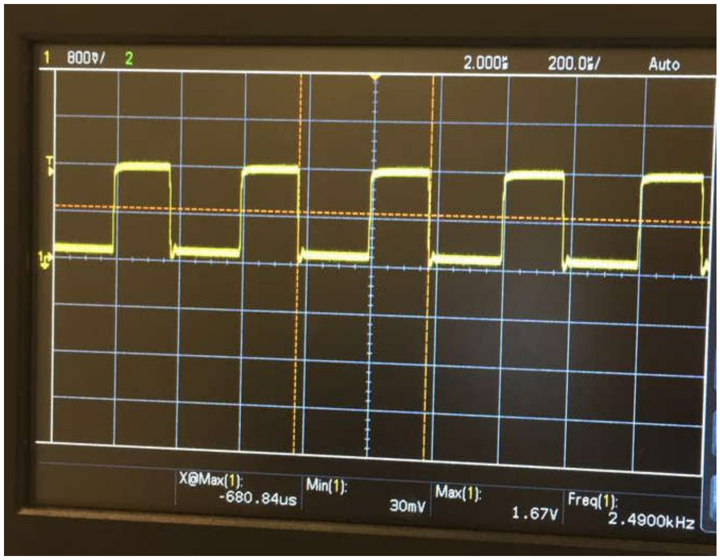

Figure 19: Transresistive configuration trace

<u>PART 4:</u> Beacon Detector

For this portion of the lab, we built a beacon detector that was designed to recognize a 2kHz signal and ignore a 1.5kHz signal and a 2.5kHz signals within a 1ft to 6ft range.

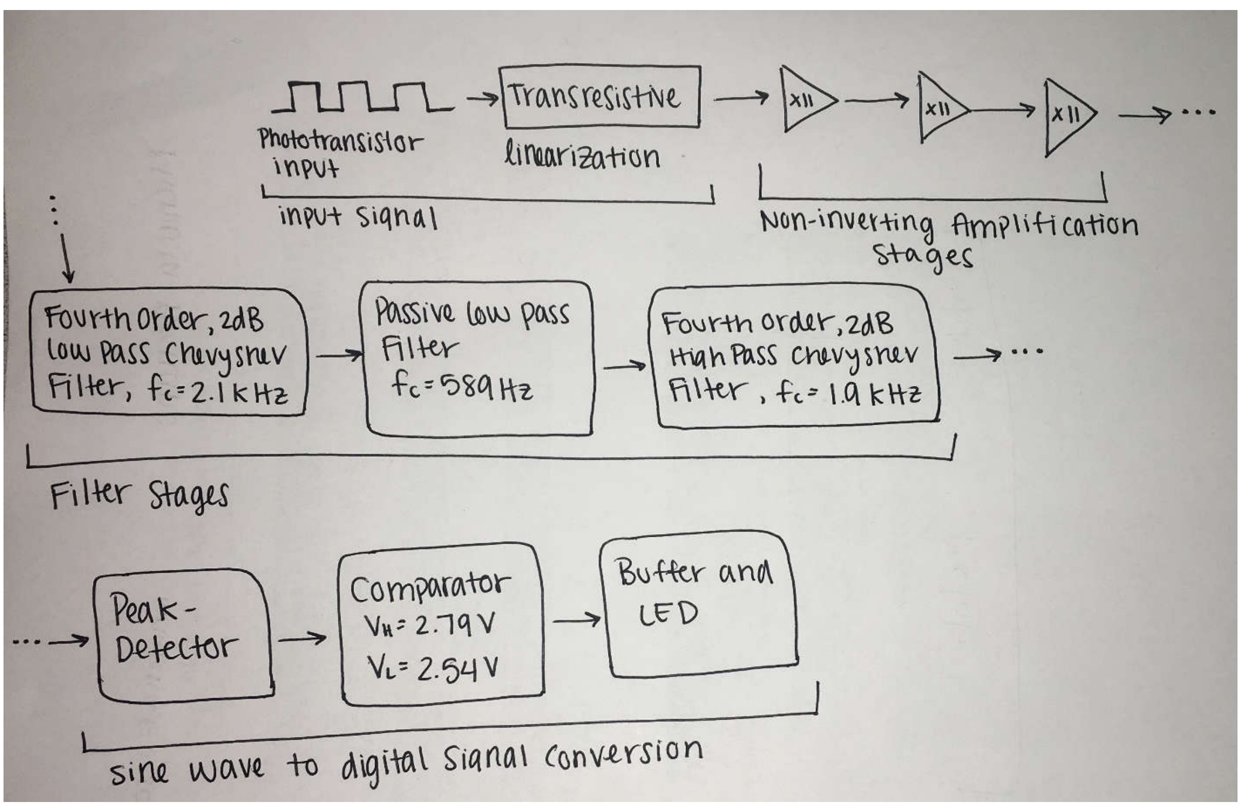

Figure 20: Beacon Detector Block Diagram

To start, an active low pass and an active high pass filter were designed. We decided to use a fourth order, 2dB Chevyshev filter for both our low pass and high pass filters. We chose Chevyshev because of its response time. We needed a large fall-off before and after our 2kHz signal, and, in the end, we did not care about what the signal was, just that it was present, so rippling in the pass band was not an issue.

Initially when designing the filters, we chose cutoff frequencies of 2.1kHz for the low pass and 1.9kHz for the high pass. Using the procedure laid out in the CKO textbook, the resistor and capacitor values for the filters were as follows:

1st Order Low Pass: $R_1 = R_2 = 16.09k\Omega$, $R_3 = 9.24k\Omega$, $R_4 = 10k\Omega$, $C_1 = C_2 = 0.01\mu F$

2nd Order Low Pass: $R_1 = R_2 = 7.86k\Omega$, $R_3 = 17.82k\Omega$, $R_4 = 10k\Omega$, $C_1 = C_2 = 0.01\mu F$

1st Order High Pass: $R_1 = R_2 = 3.9k\Omega$, $R_3 = 9.24k\Omega$, $R_4 = 10k\Omega$, $C_1 = C_2 = 0.01\mu F$

2nd Order High Pass: $R_1 = R_2 = 8.07k\Omega$, $R_3 = 17.82k\Omega$, $R_4 = 10k\Omega$, $C_1 = C_2 = 0.01\mu F$

However, while debugging, it was observed that the fall-off around 2kHz was not as quick as desired, so for the 2nd order low pass filter, R_1 and R_2 were changed to $15.6k\Omega$, and for the 1st order high pass filter, R_1 and R_2 were changed to $4.2k\Omega$, pushing the cutoff frequencies closer to 2kHz, resulting in an increased attenuation of the 1.5kHz and 2.5kHz signals.

The next step was to add an amplification stage before the filter (Figure 20). To get the beacon detector to see a signal 6ft away, we used three non-inverting amplifiers, each with a gain of 11, to give a total, non-inverted gain of 1,331.

After the initial filter stages were created and the amplification added, it was observed that when the output of the low pass Chevyshev filter was plugged directly into the input of the high pass Chevyshev filter, the overall filter did not act as a band pass filter as expected. The problem was that the amplitude of the signal out of the low pass filter was railed due to the massive amplification applied before the filter stages, as well as a small gain from the active low pass filter, so the high pass filter was seeing something closer to a square wave than a sine wave. This caused the high pass filter to fail. To fix this, a passive low pass filter with a cutoff frequency of 589 Hz was added between the two active filters so that the input to the high pass was a sine wave. A cutoff frequency far below the desired 2kHz was chosen to attenuate the signal. This completed the filter stages (Figure 20).

After the filter stages, the signal then went through a sine wave to digital conversion (Figure20). The first stage of this was the peak-detector. This was the same circuit as used for the peak-detector in parts 1 and 2 of this lab with a $100k\Omega$ resistor to get a time constant of 1kHz. The output of the peak-detector then went into the input of a comparator. The comparator was inverting, like it was in parts 1 and 2, so the low threshold of 2.54V results in a high signal, and the high threshold of 2.79V result in a low signal. Finally, the output of the comparator is fed through a buffer and an active low LED, so when the 2kHz signal is present, the LED lights up and the 1.5kHz and 2.5kHz signals are ignored. This finished the beacon detector circuit (Figure 21).

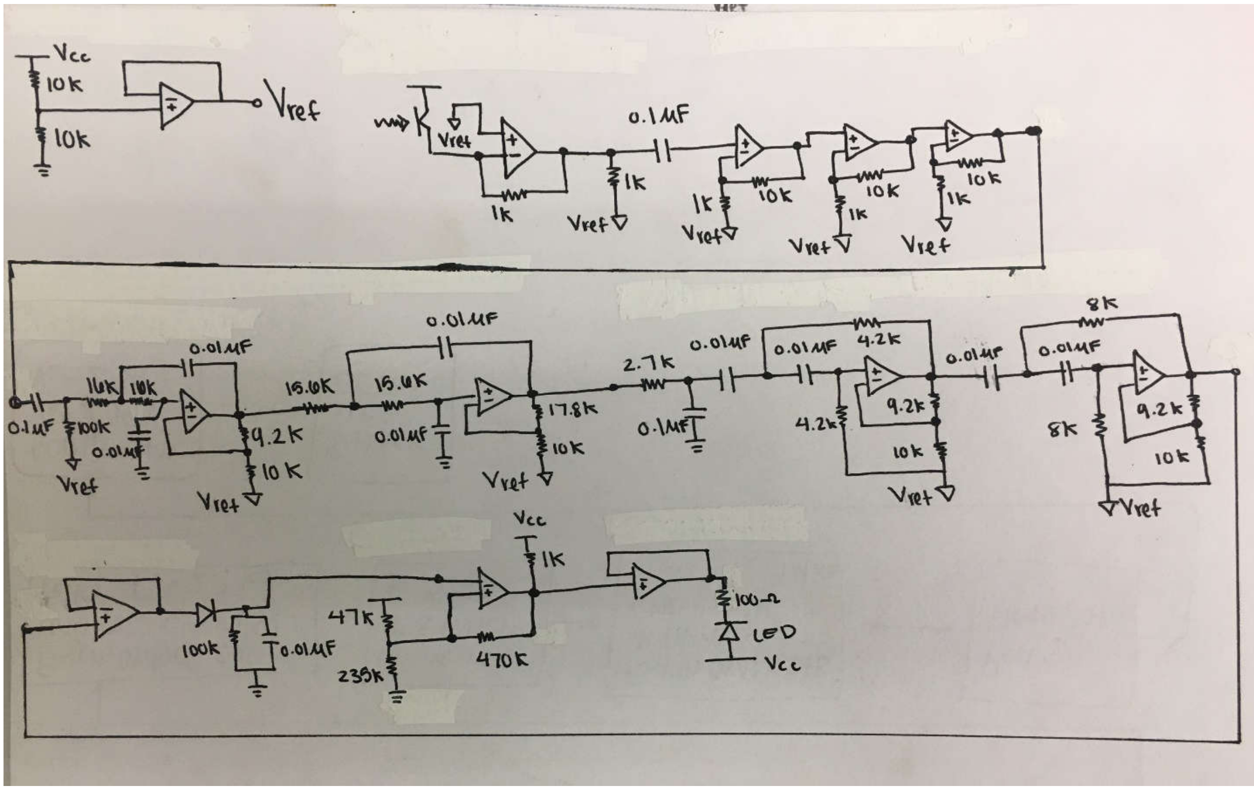

Figure 21: Complete Beacon Detector Circuit. The split-rail buffer from the track wire detector was replicated to be used as V_{ref} for this circuit. Each op amp is powered from 3.3V to ground with 0.1µF buffer capacitors.

CONCLUSION:

In the end, building a beacon detector and track wire detector familiarized us with filtering methods and methods to convert sine wave signals into digital signals. This lab also presented an opportunity to improve our hardware debugging skills. After each component was built, testing it to see if it worked, finding out what the problem was and how to fix it took the most effort. For parts 1 and 2, debugging the peak detector and comparator was where the most time was spent. For part 4, improving on the initial Chebyshev filters took the most time. This really helped our understanding of filters.

Summary and Time Tracking

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Time Spent out of Lab	Time Spent in Lab	Lab Part - Description
		Part 0 – Prototyping Circuits Basics
		Part 1 – Circuit Module Basics
		Part 2 – Track Wire Detection
		Part 3 – Phototransistor and Trans-resistive Amplification
		Part 4 – Beacon Detector

Checkoff: TA/Tutor Initials	Lab Part - Description
	Part 0 – Prototyping Circuits Basics
MC	Part 1 – Circuit Module Basics
MC	Part 2 – Track Wire Detection
CV	Part 3 – Phototransistor and Trans-resistive Amplification
CV	Part 4 – Beacon Detector
PV	Prelab

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BK	prelab