# Lab 1 – Signal Conditioning and Filtering

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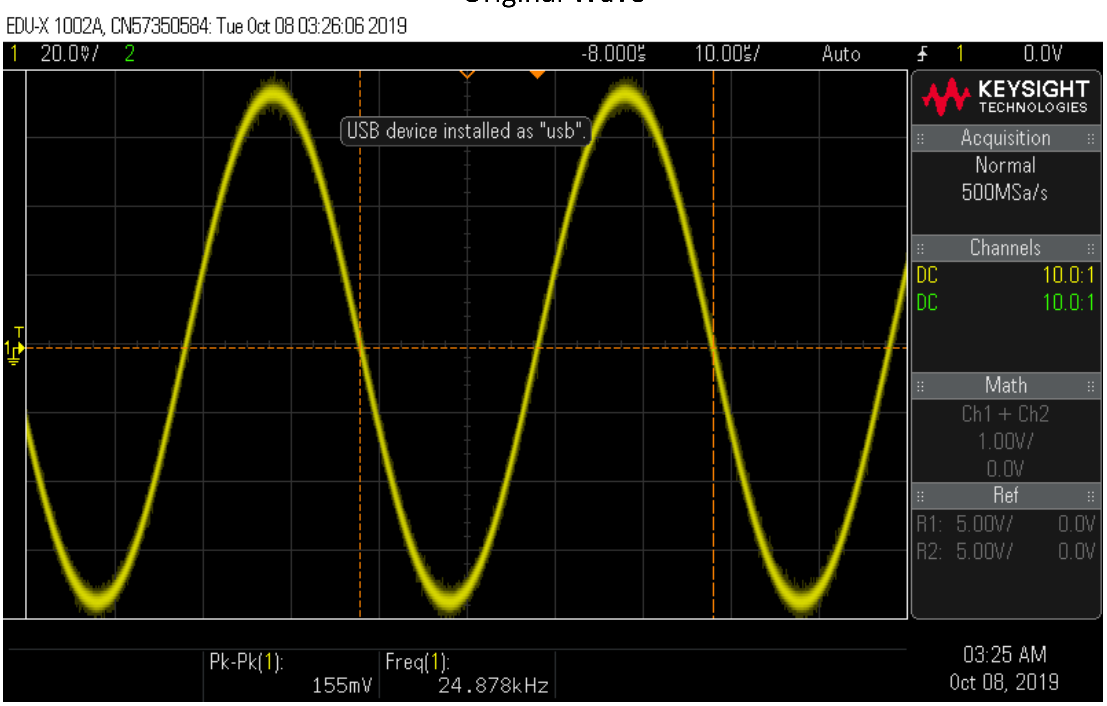
## Part 1/2 – Circuit Module Basics/Track Wire Detection

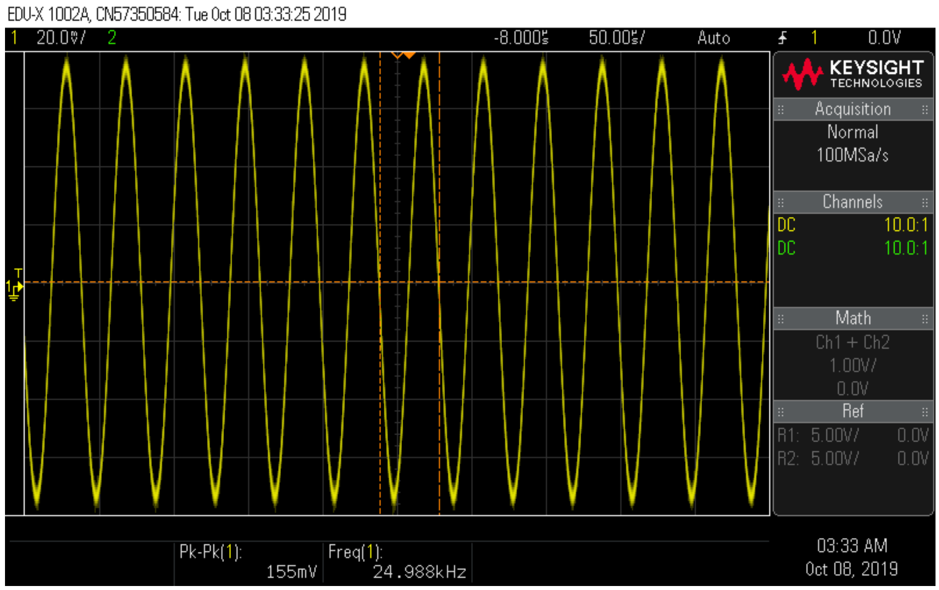
Part 1 introduces the components that will be hooked together to create the track wire detector in part 2. This emphasized the importance of designing testing individual stages of a circuit before combining them. This ensures an easier debugging experience as well as a cleaner circuit design. There are seven main components for the track wire detector circuit. These components combine to create a circuit capable of driving an LED with a high signal (2.7-3.3V) when detecting the presence of a track wire within 2 inches of the solenoid/inductor.

Solenoid/Inductor: The solenoid/inductor can turn the oscillating 24-26kHZ frequency of the track wire into an EMF. This EMF is can be used as a voltage input for the rest of the circuit. This was verified using an o-scope shown by the following trace.

Original Wave



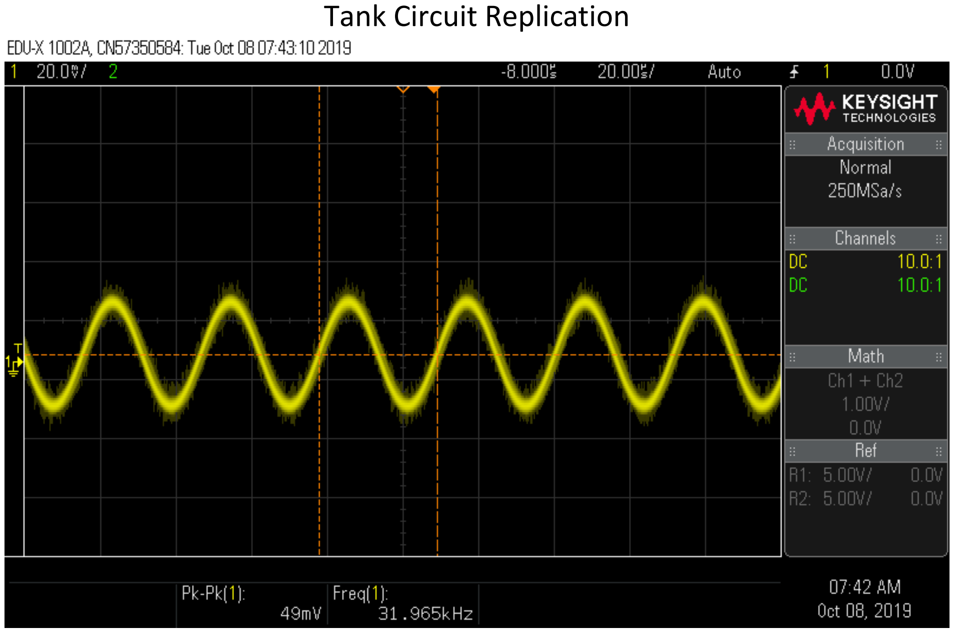
Solenoid/Inductor Replication




This replication of the wave was taken when the track wire was touching the inductor. The further away the track wire moved from the inductor, the lower the peak to peak amplitude became of the replication wave. In order to fix this gain needs to be added using the tank circuit and non-inverting amplifier.

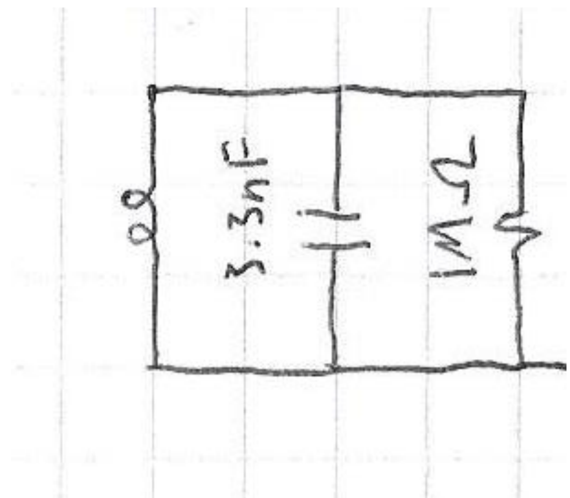
Tank Circuit: The input of the solenoid/inductor is fed into the tank circuit. The tank circuit uses the solenoid/inductor portion above and adds in a capacitor in parallel. This circuit acts as a passive amplifier. If further amplification is needed a resistor can be added in parallel as well. The higher the resistor value the lower the Q value, but the higher the gain. This is referred to a “Q-killer resistor”.

Tank Circuit Replication



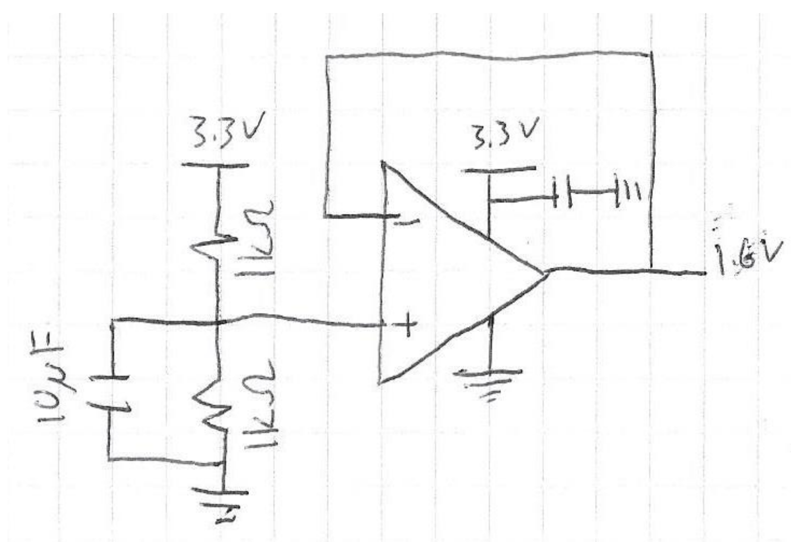
With no amplification and contact between the track wire and the circuit the peak to peak amplitude is roughly 1/3 of the original amplitude. In order to be able to see this wave at the 2 inch requirement gain was added at this stage using a 1MOhm resistor. This resistor was used because it was the largest we had available and we wanted as much gain out of this portion of the circuit as possible and were less concerned with the Q value.

Tank Circuit Diagram



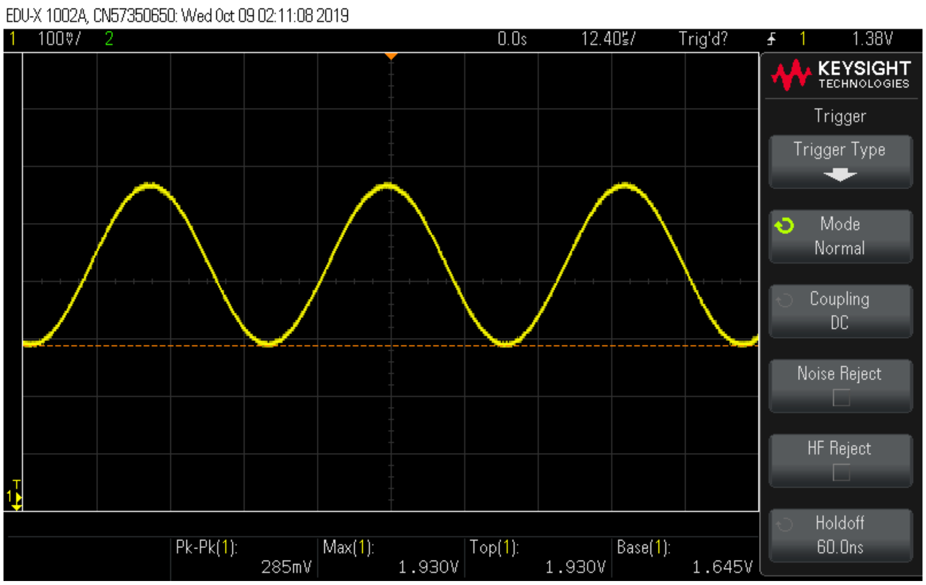

Split Rail Buffer: A split rail buffer is used to create a power rail in between the high voltage rail and the ground rail of the power supply. This is advantageous over a voltage divider the inclusion of an op-amp makes the component resilient to current draw. This application of a split rail buffer creates a 1.65V rail.

Split Rail Diagram

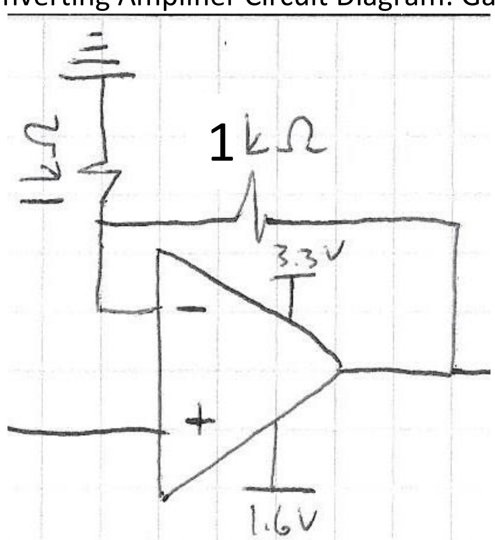


Non-Inverting Amplifier: The output of the tank circuit is fed into the non inverting amplifier. The split rail centers the wave at 1.6V. Non-inverting amplifier are advantageous in filtering circuits, such as in part 4, due to their high input impedance.  This high input impedance is important for sensors that have difficulty sourcing current. The minimum gain that can be applied using a non-inverting amplifier is 1. Thus, a non-inverting amplifier can not be used to reduce an input.  Diagrams and traces for a non-inverting amplifier with a gain of 2 can be seen below. These were used in part 1.

Non-Inverting Amplifier Trace: Gain = 2

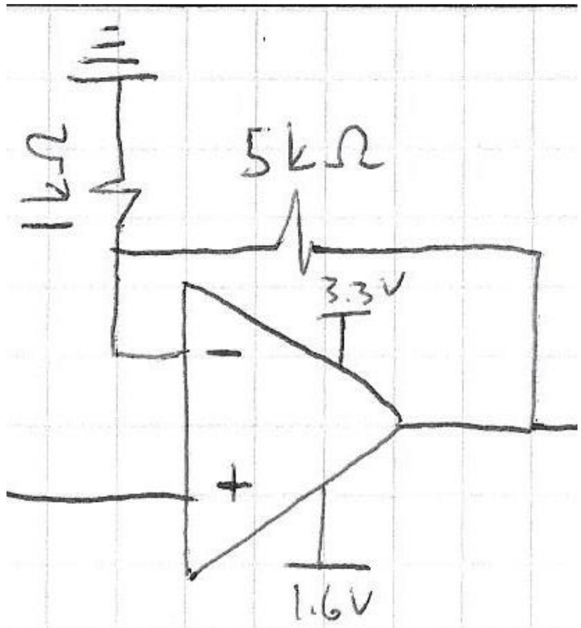



Non-Inverting Amplifier Circuit Diagram: Gain = 2



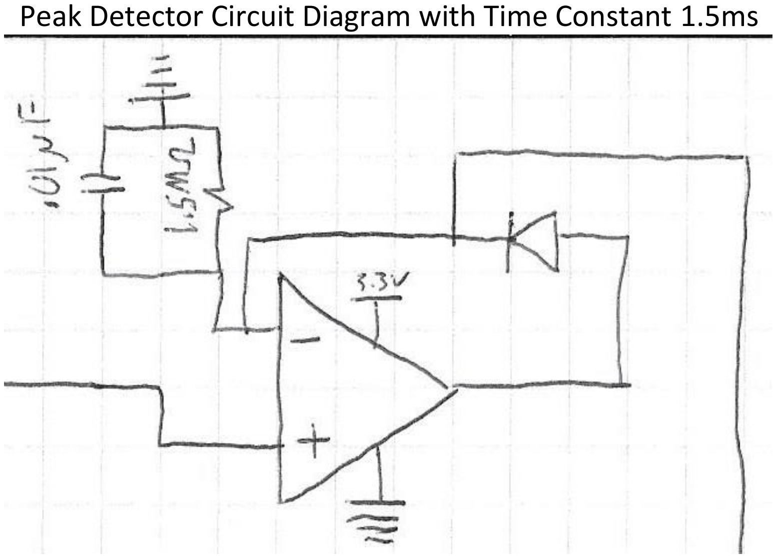
Diagrams for a non-inverting amplifier with a gain of 5 can be seen below. These were used in part 2. We chose a gain of 5 because it was the maximum gain out chips could produce. We used two of these in series to produce a maximum gain of 25.

Non-Inverting Amplifier Circuit Diagram: Gain = 5

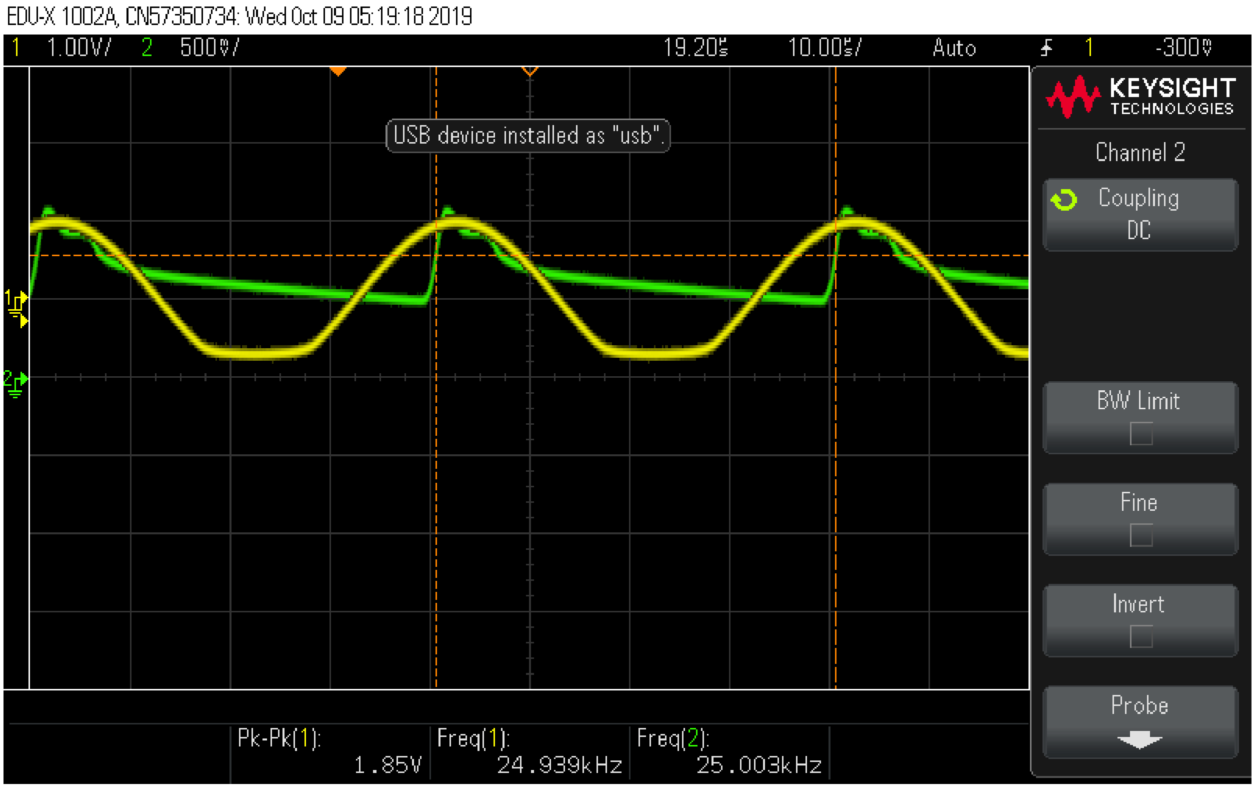



Peak Detector: The output of the non-inverting amplifier should be an amplified sine wave in a 0-3.3V range and is fed into the peak detector. A peat detector holds voltage at the highest given point on the negative end of a polarized diode for a time constant T=RC. A resistor is used to leak the current off of the diode, otherwise the peak detector will remain constantly at a high voltage and will not recognize the next peak.

Peak Detector Circuit Diagram with Time Constant 1.5ms

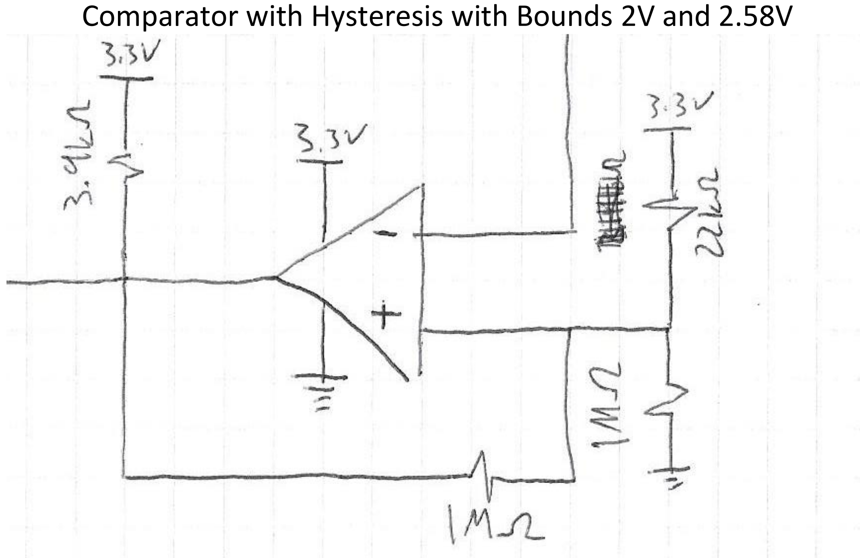


Peak Detector Trace with Time Constant 1.5ms



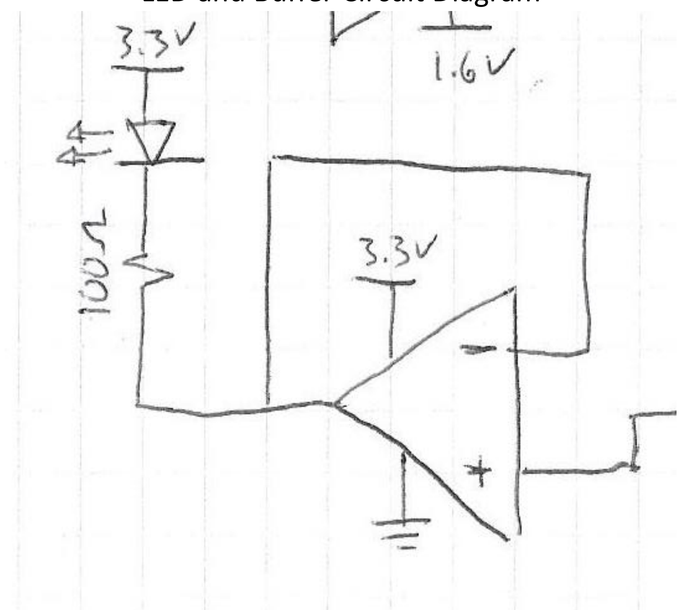

Comparator with Hysteresis: The output of the peak detector is fed into the comparator. A comparator uses hysteresis bounds to snap the output voltage from high to low depending on the input provided. If above the upper hysteresis bound the output will be high. If below the lower hysteresis bound, then the output will be low. We used op-amps for our comparator instead of the comparator chips provided. Our design can be seen below.

Comparator with Hysteresis with Bounds 2V and 2.58V



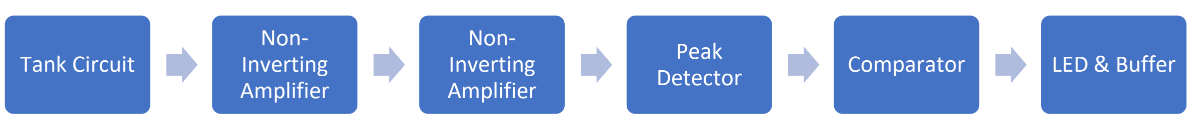
LED and Buffer: The output of the comparator is fed into the LED and Buffer. The LED is driven by the output of the comparator and used visually show the output of the circuit. The buffer isolates the LED output from the rest of the circuit. If there was no buffer, the LED would modify the hysteresis bounds of the comparator and create a inconsistent output voltage. Thus the sine wave to digital signal conversion is complete.

LED and Buffer Circuit Diagram

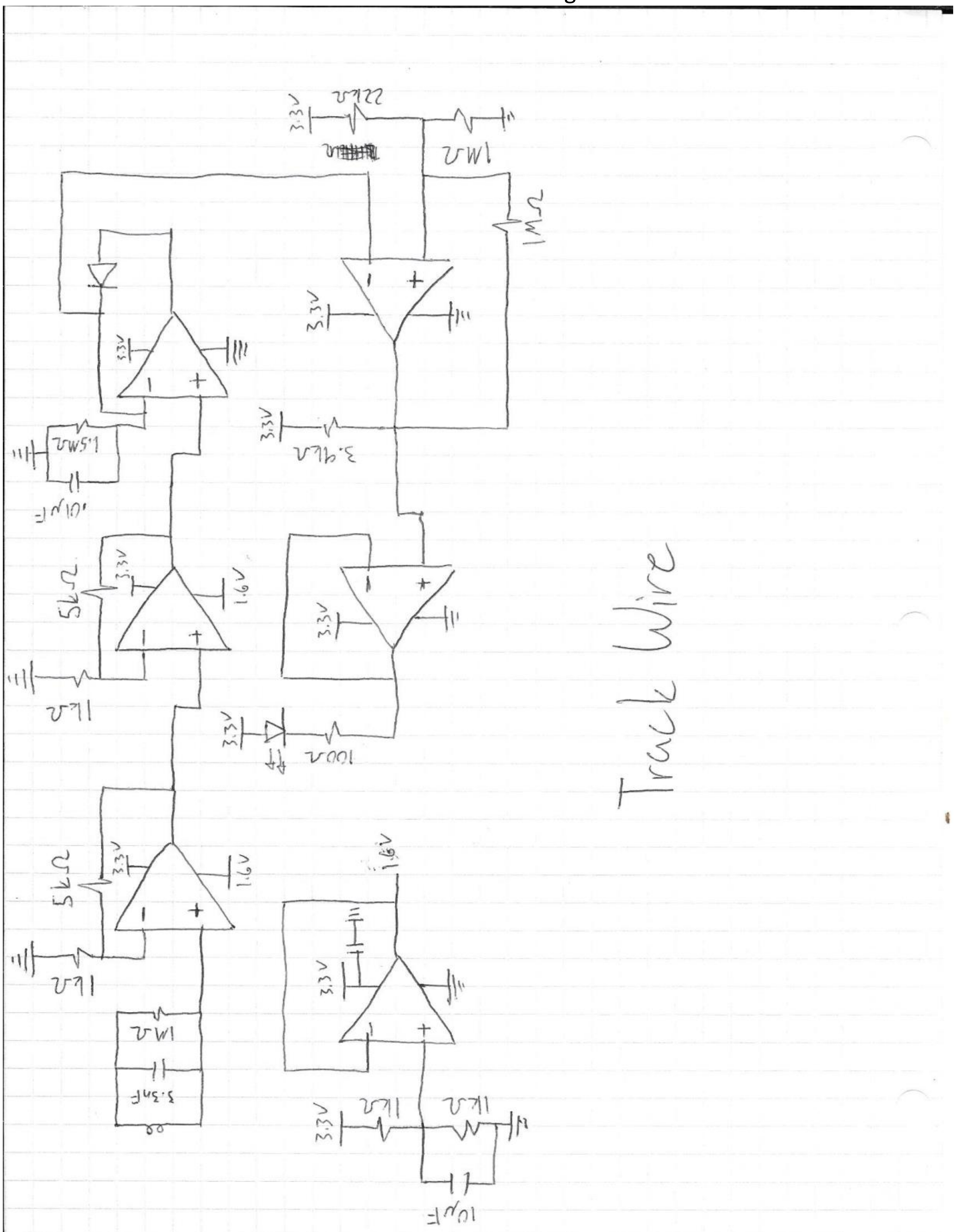



These components are connected to create the tank wire detector circuit. The flow of the circuit is shown in the block diagram below.

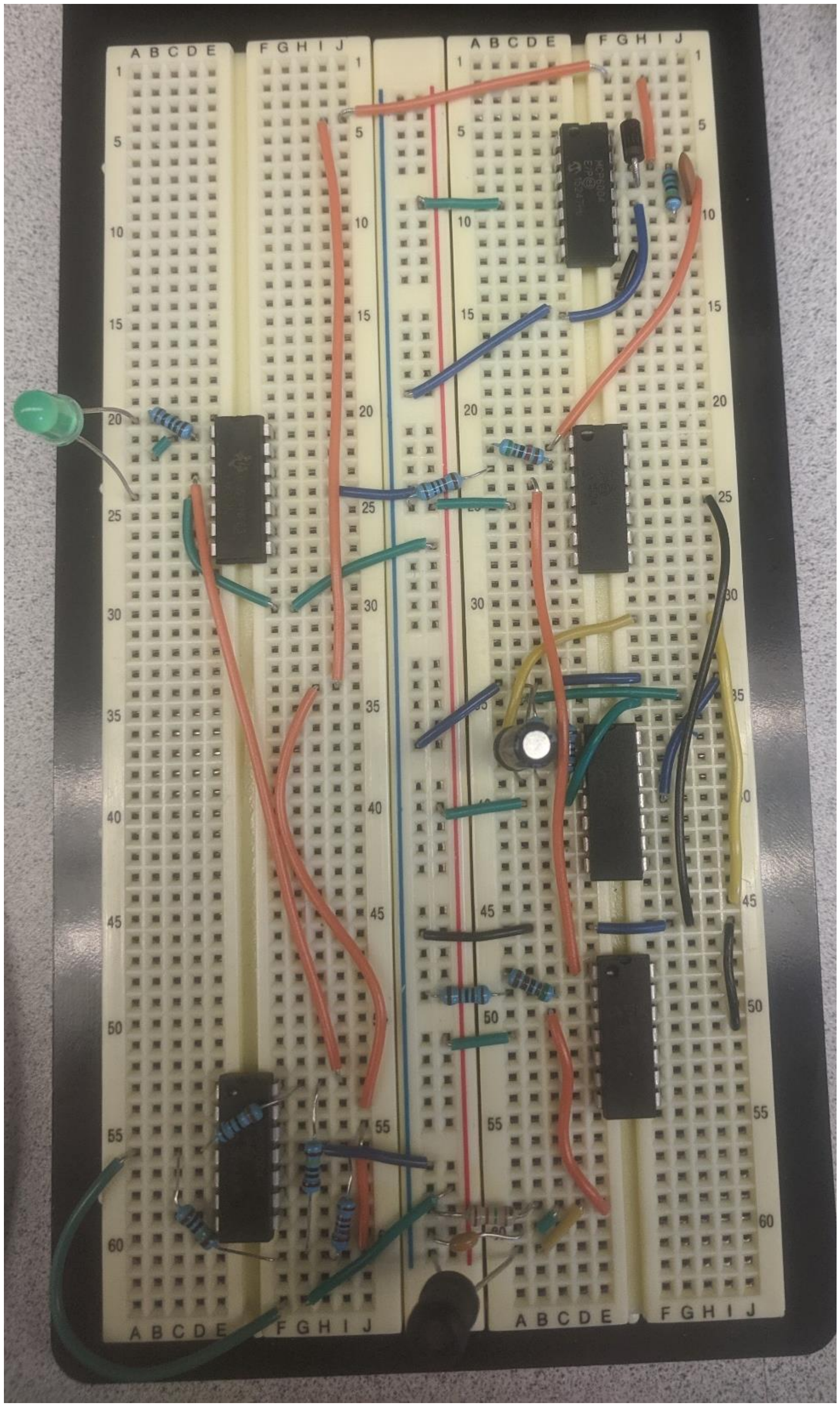
Track Wire Circuit Block Diagram



Track Wire Circuit Diagram



Track Wire Circuit Picture

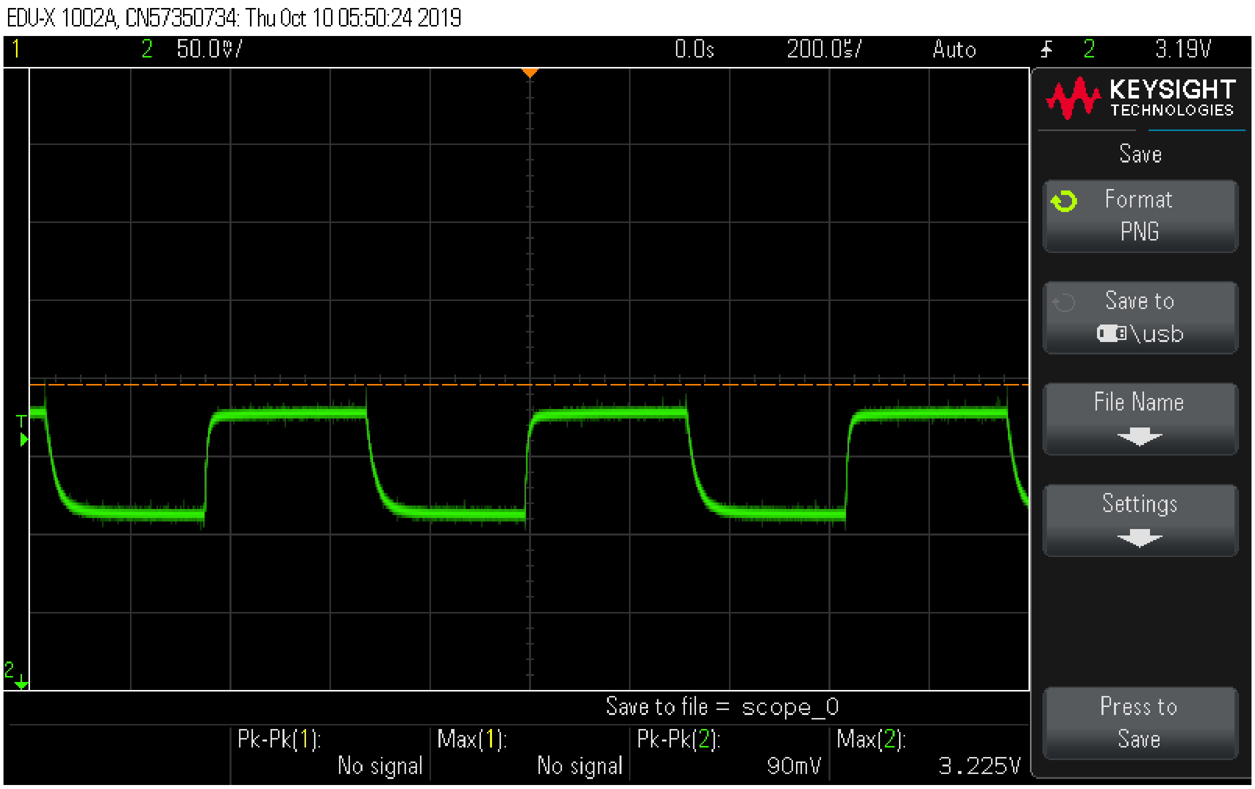


## Part 3 – PhotoTransistor and TransResistive Amplification

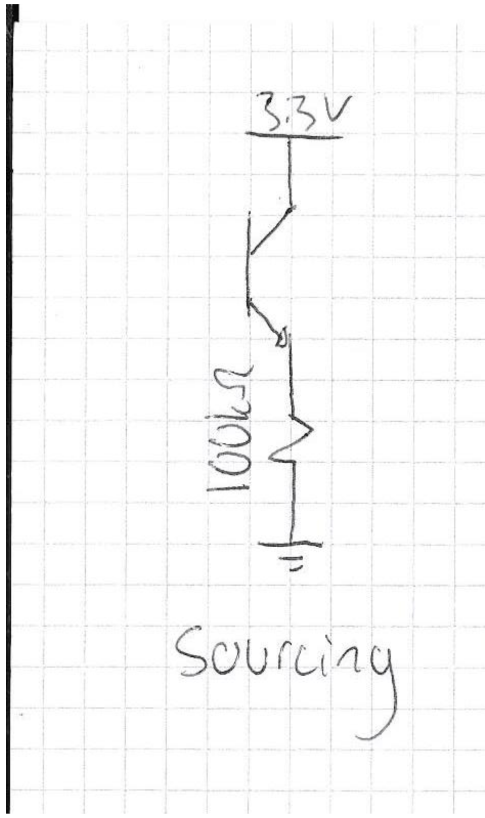
This part requires three different circuits to be built. A photo transistor in sourcing configuration, sinkning configuration and a trans resistive opamp stage with an output gain of 1V/mA.

A sourcing configuration has the collector of the photo diode to the 3.3V and a 100k resistor to ground.

Souring Configuration Trace

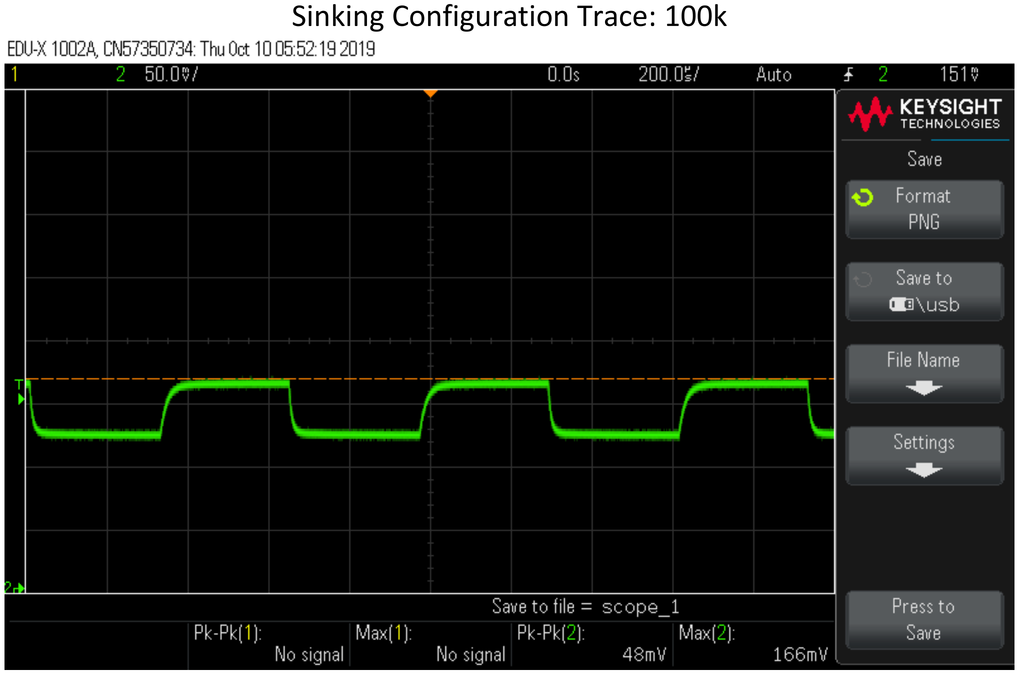


Sourcing Configuration Circuit Diagram: 100k

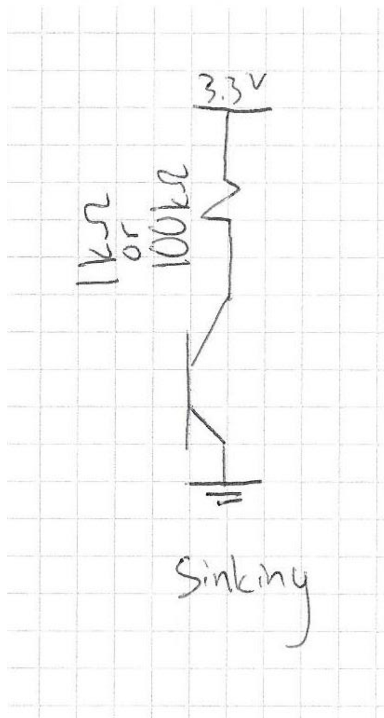



The sinking configurations have the collector of the photo diode to the ground and a 100k or 1k resistor to 3.3V.

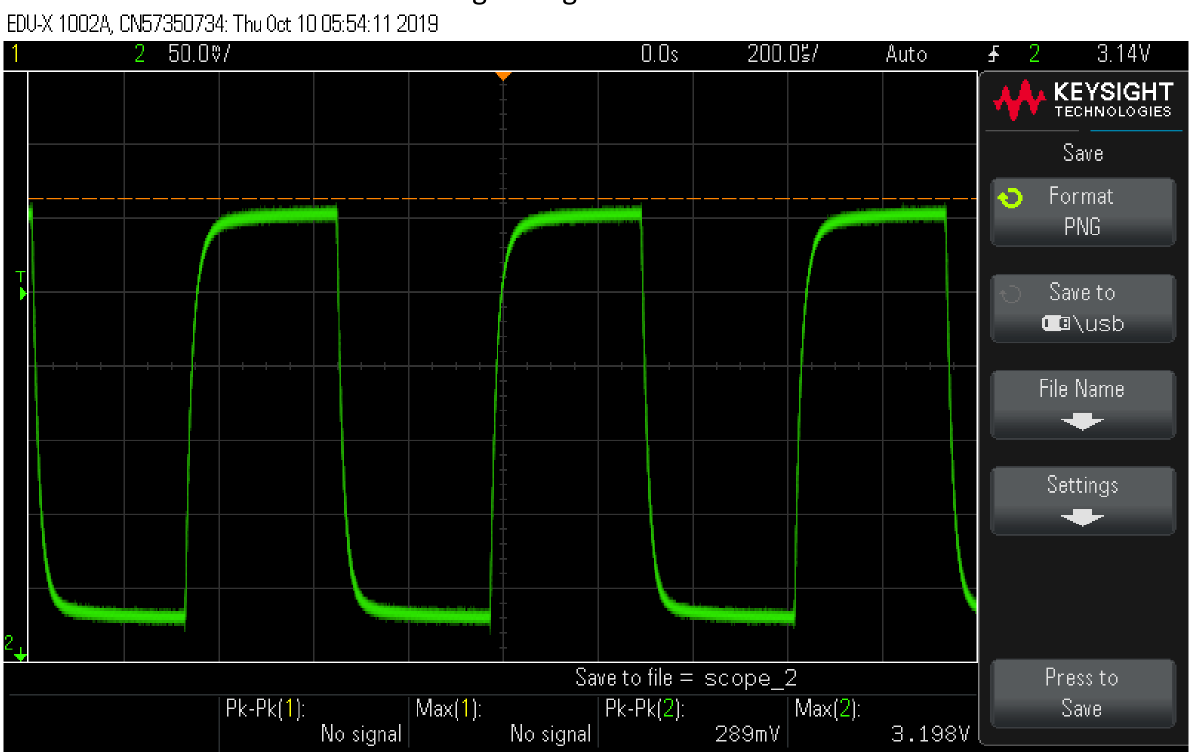
Sinking Configuration Trace: 100k



Sinking Configuration Circuit Diagram: 1k/100k

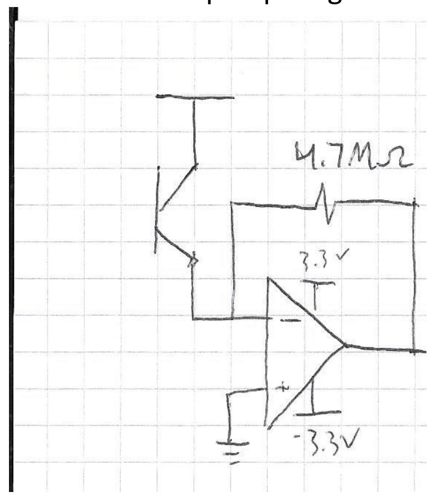



Sinking Configuration Trace: 1k



The transresistive opamp stage has an output gain of 1V/mA and a constant voltage across the phototransistor of 1.6V.

Transresistive Opamp Stage Trace

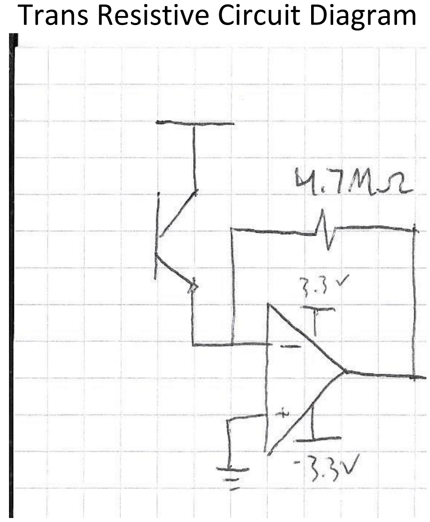



## Part 4 – Beacon Detector

Part 4 requires the design of a full beacon detector. This beacon detector will be capable of filtering out 1.5 ad 2.5 kz waves, while amplifying and detecting 2kHz waves ±5 ° and from 1 to 6ft of the photo transistor signal. When a 2kHz wave is detected an output should take place in the form of a stead LED. The beacon detector consists of three main stages in order to go from a shifting sine wave to a LED indicator.

Input Stage: The input stage started with a mechanical shielded. This shielded ensure that the ambient lights in the room do not interfere with the beacon signals traveling to the photodiode. The photodiode then feeds into a trans resistive circuit to amplify the signal enough to be fed into the filters.

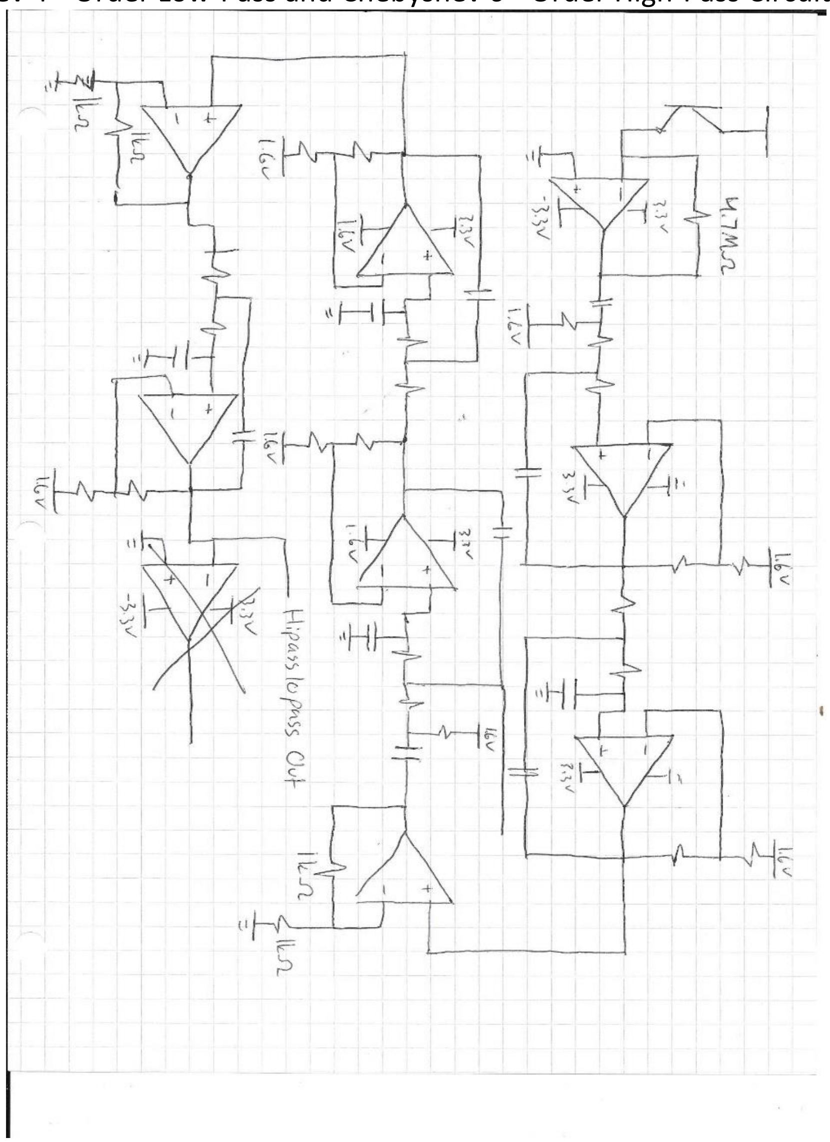
Trans Resistive Circuit Diagram



Filter Stage: Our filter stage consists of a 6th order high pass and 4th order low pass Chebyshev (the order of which does not matter) followed by two narrow band pass filers.

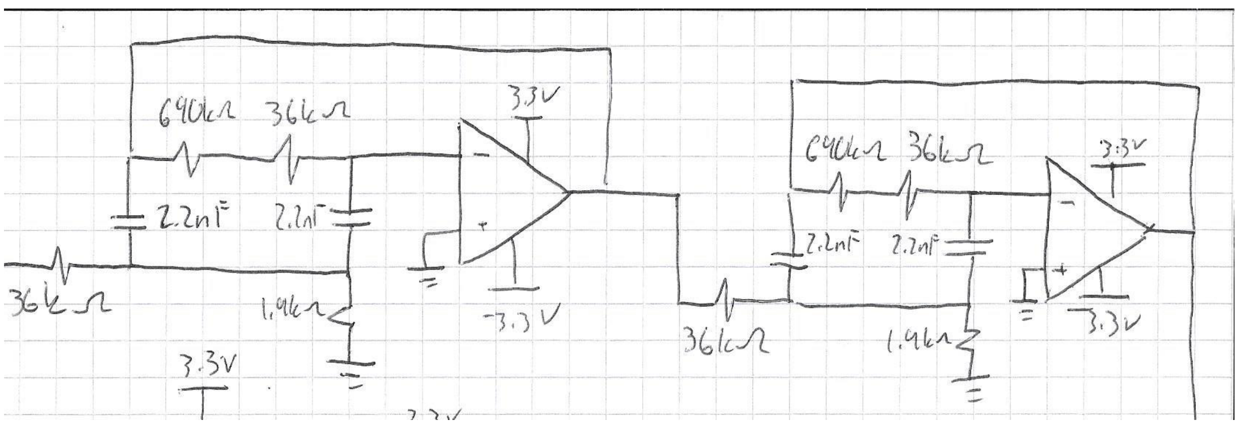
We built the Chebyshev low-pass 4th order filter with a cutoff frequency of 2.2kHz. The reason we chose 2.2kHz was to avoid the Chebyshev ripple effect at 1.5kHz as much as possible. We did notice that the Chebyshev filters work is a little unorthodox by amplifying the passing the signal and doing little attenuation of the desired cutoff frequency. Then we built a Chebyshev high-pass 6th order filter with a cutoff frequency of 1.8kHz to once again avoid the ripple effect at 2.5kHz. These filters worked fantastically but did not give the required level of attenuation needed. The 1.5kHz and 2.5kHz maximum amplitude at 1ft were greater than the 2kHz amplitude at 6ft.

Chebyshev 4th Order Low-Pass and Chebyshev 6th Order High-Pass Circuit Diagram



So, we knew we added more filters. However, instead of adding more Chebyshev filters we decided to try narrow band pass filters instead as they are easily built, replicated and we have already filtered out most of our signal using our other filters. We set the cutoff frequency to 2kHz. After these filters we achieved the final attenuation needed to successfully create the rest of our circuit. These filters also provide a gain of 10 for each filter. This allowing for easy debugging at the end of the filter stage due to the easy readability on the o scope.

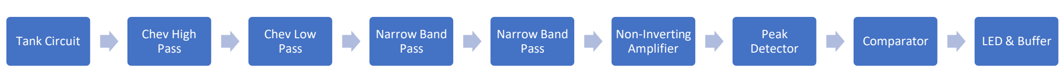
Narrow Band Pass Circuit Diagram

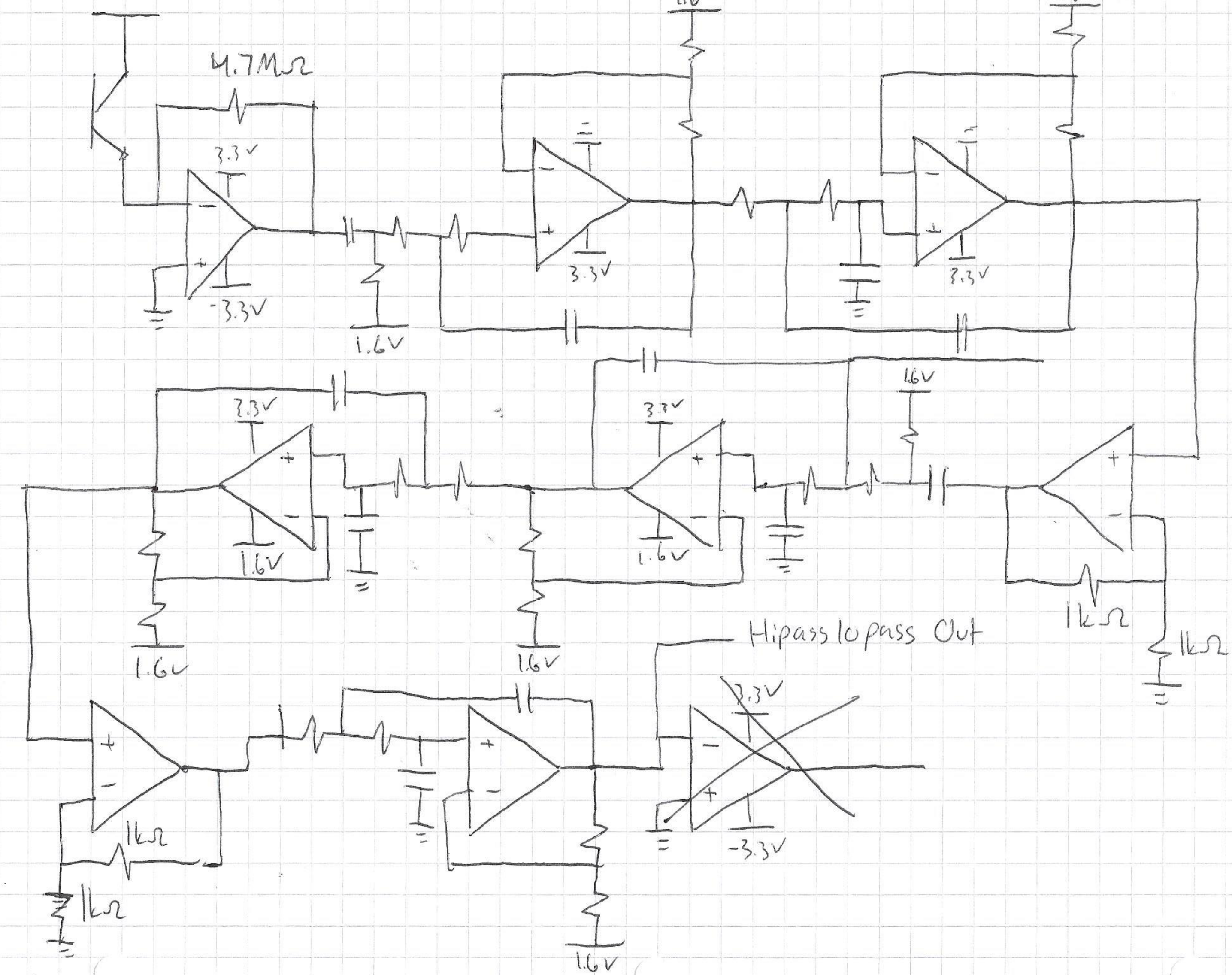



The Filter stage then feeds into the sine to digital stage.

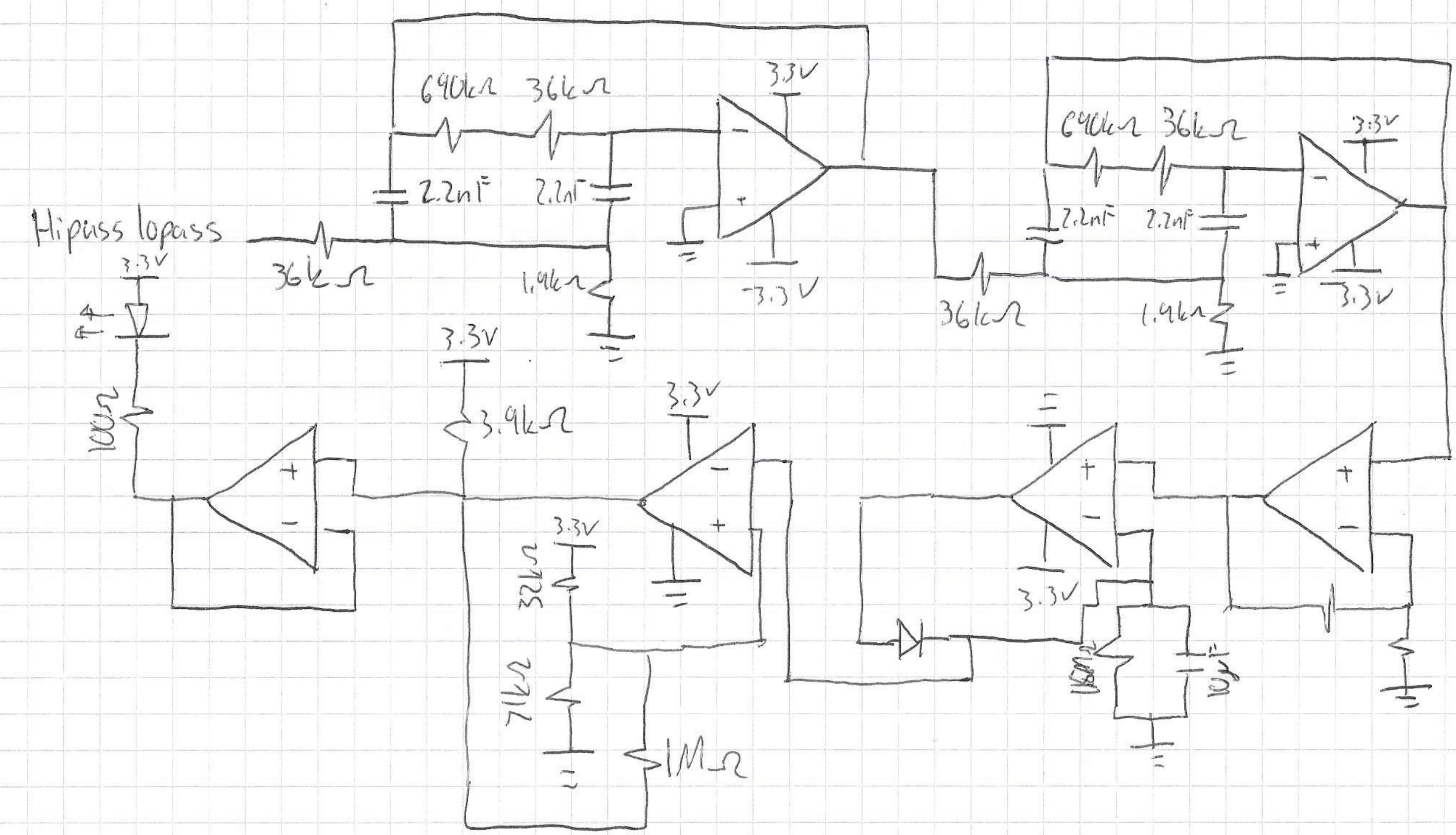
Sine to Digital Stage: The sine to digital stage follows the same path as that in the part above. Updated resistor values will be found in the full schematic below.

A full circuit and block diagram can be found below.





4.7MΩ
3.3V
-3.3V
1.6V
1.6V
3.3V
1.6V
3.3V
3.3V
1.6V
3.3V
1.6V
1.6V
3.3V
1.6V
1.6V
1kΩ
1kΩ
Hipass lopass Out
3.3V
-3.3V
1kΩ
1kΩ
1.6V


Hipass lopass
3.3V
100Ω
36kΩ
690kΩ
36kΩ
2.2nF
2.2nF
1.9kΩ
3.3V
-3.3V
3.3V
3.9kΩ
3.3V
3.3V
32kΩ
71kΩ
1MΩ
36kΩ
690kΩ
36kΩ
2.2nF
2.2nF
1.9kΩ
3.3V
-3.3V
3.3V
160mΩ
10μF

## SUMMARY AND TIME TRACKING

| Time Spent out of Lab | Time Spent in Lab | Lab Part - Description |
|---|---|---|
| 0 hrs | 1 hr | Part 0 – Prototyping Circuits Basics |
| 0 hrs | 6 hrs | Part 1 – Circuit Module Basics |
| 0 hrs | 12 hrs | Part 2 – Track Wire Detection |
| 0 hrs | 1 hr | Part 3 – Phototransistor and Trans-resistive Amplification |
| 0 hrs | 36 hrs | Part 4 – Beacon Detector |

Tony Li Prelab

| Checkoff: TA/Tutor Initials | Lab Part - Description |
|---|---|
| ZP | Part 0 – Prototyping Circuits Basics |
| ZP | Part 1 – Circuit Module Basics |
| CD | Part 2 – Track Wire Detection |
| Tony Li | Part 3 – Phototransistor and Trans-resistive Amplification |
| CD | Part 4 – Beacon Detector |

Peter Eskraus

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| Tony Li | Part 3 – Phototransistor and Trans-resistive Amplification |
| CD | Part 4 – Beacon Detector |
| [illegible] | Prelab |