EE 245: Electrical and Electronic Circuits II Laboratory
Simple FSK IR Communication System

Instructor: Dr. Siavash Farzan
Robin Simpson
Sam Solano

Fall 2023

Contents

1 Introduction

As the culmination of our explorations in EE 245: Electrical and Electronic Circuits II Laboratory, this report details the design, implementation, and testing of a simple Frequency-Shift Keying (FSK) Infrared (IR) Communication System. This project, conducted over the final three weeks of the quarter, required the integration of a variety of electronic components and principles, culminating in a functional transmitter and receiver pair.

The focus of our project was threefold:

1. **555 Timer-Based Transmitter**: We designed and implemented an IR transmitter using a 555 timer IC. This component served as the heart of our transmitter, configured as an inverting hysteretic comparator. The inclusion of a Reed switch allowed us to vary the oscillation frequency of the transmitter between two distinct frequencies - 3.6 kHz and 7.2 kHz. The frequency shift was controlled by the proximity of a magnet to the Reed switch, enabling the binary selection essential for FSK transmission.

2. **Photo-Amplifier**: The receiver's initial stage involved a photo-amplifier, comprising a photo-diode (PD) and a trans-impedance amplifier (TIA). The PD converted incoming IR radiation into electrical current, which was then amplified by the TIA. Key to this stage was the careful selection of the TIA's resistor, balancing the need for sufficient gain against the constraints of our single supply voltage setup.

3. **Analog Tachometer**: The final and perhaps most intricate part of our receiver was the analog tachometer. This component consisted of a comparator to convert the incoming signal into a clean square wave, a one-shot circuit to transform this wave into a pulse-density modulated (PDM) waveform, and a low-pass filter to extract the average DC value from this PDM signal. The tachometer's role was to accurately translate the varying frequencies received from the transmitter into distinct DC voltage levels.

Throughout the project, our team engaged in rigorous preparation, including reviewing datasheets, selecting optimal components, and conducting preliminary calculations and simulations using LTspice. This preparatory work was crucial in ensuring the smooth progression from design to implementation.

2 Preparation

2.1 Implementation of 555 Timer-Based Transmitter

Primary Objective To implement and test the functionality of a 555 timer-based transmitter for Frequency Shift Keying (FSK), as delineated in Figure 1 of the lab manual.

Sub-Objectives

1. Assemble the 555 timer-based transmitter circuit according to the schematic provided.
2. Test the circuit's ability to alter its frequency output in response to changes in the state of a Reed switch.

Anticipated Outcomes

- Accurate demonstration of frequency modulation in the transmitter circuit induced by the Reed switch.

Equipment and Components

- 555 Timer IC
- Infrared (IR) LED
- Reed switch
- Resistors and capacitors as per the circuit design requirements (Two 10k Resistors, Two 10nF Capacitor (One for Signal 'Cleaning'))
- Breadboard and connecting wires
- Oscilloscope for measuring frequency response
- Power supply unit

2.2 Implementation of Photodiode Amplifier

Primary Objective To design and implement a Photodiode Amplifier for the FSK IR Communication System as per the requirements outlined in the lab manual.

Sub-Objectives

1. Design a circuit with a photodiode and a trans-impedance amplifier (TIA) to convert the light signals into electrical signals.
2. Test the circuit's ability to accurately convert IR signals of varying frequencies into corresponding electrical signals.

Anticipated Outcomes

- Successful conversion of IR signals into electrical signals with minimal noise and maximum efficiency.

Equipment and Components

- Photodiode
- Operational Amplifier for TIA (LM358P)
- Resistors and capacitors as per the circuit design requirements (Two 10k Resistors, 100k Resistor, 10nF capacitor)
- Breadboard and connecting wires
- Oscilloscope for signal analysis
- Power supply unit

2.3 Implementation of Analog Tachometer

Primary Objective To design and implement an analog tachometer as part of the FSK IR Communication System, capable of converting frequency variations into DC voltage.

Sub-Objectives

1. Design a circuit comprising a comparator, a one-shot circuit, and a low-pass filter.
2. Test the circuit's ability to accurately convert frequency variations from the FSK transmitter into proportional DC voltage.

Anticipated Outcomes

- Effective conversion of frequency variations into distinct DC voltage levels.

Equipment and Components

- Comparator IC (TLC3702)
- AC Coupling (30k Resistor, 10nF Capacitor)
- One-shot circuit components (Schotty Diode, 6.2k Resistor, 10nF Capacitor)
- Low-pass filter components (150k Resistor, 10 nF Capacitor)
- Breadboard and connecting wires
- Oscilloscope for signal analysis
- Power supply unit

3 Setup and Design

3.1 555 Timer

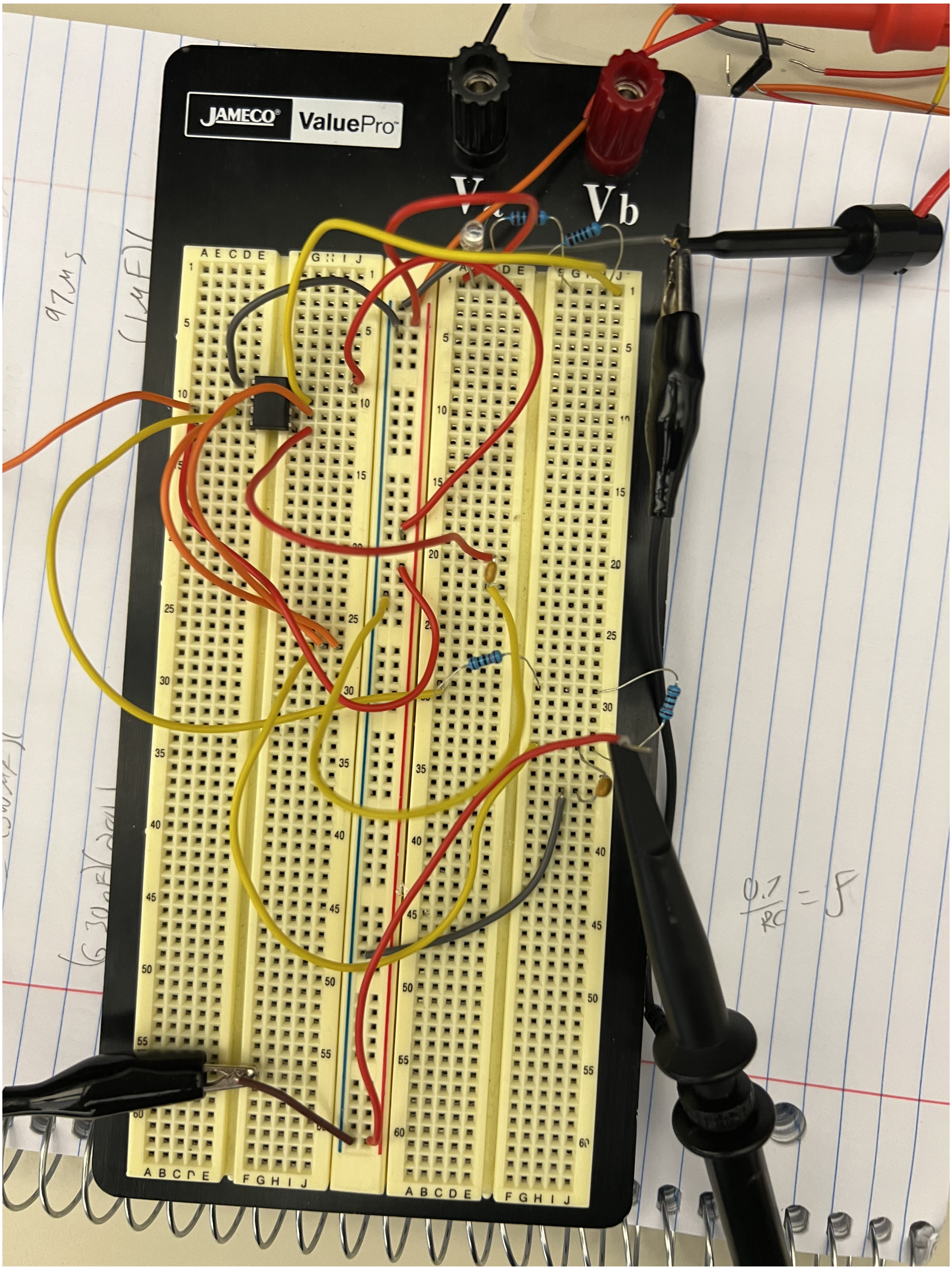

Figure 1: 555 Timer-Based Transmitter Circuit

Assembly and Analysis of the 555 Timer-Based Transmitter

Circuit Assembly and Signal Generation:

- Assembled the 555 timer-based transmitter on a breadboard following the schematic in Figure 1, using resistors, capacitors, and a 555 timer IC.
- Ensured proper configuration and connections to guarantee stability and correct functionality of the circuit.

Observation and Data Collection:

- Frequency variations in the transmitter circuit were observed and measured in response to the activation of the Reed switch using an oscilloscope.

Design Considerations:

1. **Accurate Timer Configuration:** Ensure the correct placement and wiring of the 555 timer IC according to its datasheet and the circuit design.
2. **Component Selection:** Use components with appropriate ratings and tolerances to achieve the desired frequency response.
3. **Precision in Measurements:** Utilize a calibrated oscilloscope to accurately measure frequency changes.
4. **Safety and Stability:** Always disconnect power before adjusting the circuit to prevent any electrical hazards or damage to components.

3.2 Photodiode Amplifier and Tachometer

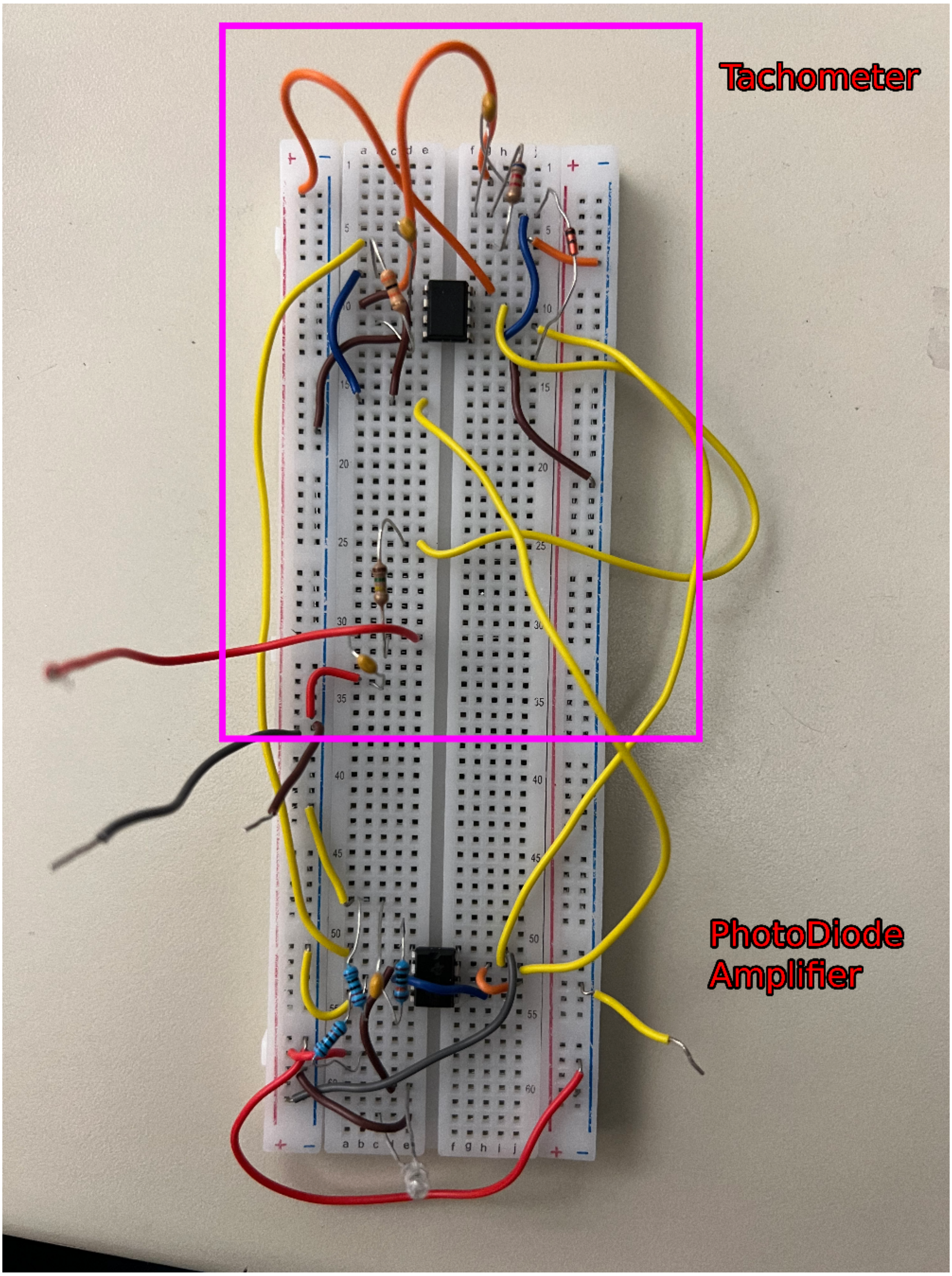

Figure 2: Photodiode Amplifier and Tachometer Circuit Design

3.3 PhotoDiode Amplifier Circuit Assembly and Signal Analysis

Circuit Assembly:

- Assembled the Photodiode Amplifier on a breadboard following the designed schematic.
- Ensured correct placement and wiring of the photodiode and the operational amplifier to achieve the desired response.

Observation and Data Collection:

- Monitored and analyzed the output signals using an oscilloscope, focusing on signal strength and clarity.

Design Considerations:

1. **Effective Trans-Impedance Design:** Selection of appropriate resistor values for the trans-impedance amplifier to ensure optimal gain and signal-to-noise ratio.
2. **Signal Integrity:** Minimizing noise and ensuring the fidelity of the signal conversion from IR to electrical.
3. **Component Compatibility:** Using components compatible with each other and suitable for handling the frequencies involved in the system.
4. **Safety and Circuit Stability:** Ensuring safe practices during circuit assembly and testing, including power management and handling of sensitive components.

3.4 Tachometer Circuit Assembly and Analysis

Circuit Assembly:

- Assembled the analog tachometer on a breadboard following the designed schematic.
- Ensured correct configuration of the comparator, one-shot circuit, and low-pass filter for accurate signal processing.

Observation and Data Collection:

- Monitored the circuit's response to frequency variations using an oscilloscope, focusing on the output voltage levels.

Design Considerations:

1. **Effective Comparator Design:** Selection of appropriate comparator IC to ensure fast and accurate signal conversion.
2. **One-Shot Circuit Configuration:** Accurate design of the one-shot circuit to generate fixed-duration pulses corresponding to frequency changes.
3. **Low-Pass Filter Efficiency:** Designing a low-pass filter to extract the average DC value from the pulse-density modulated waveform.

4 Simulation

4.1 555 Timer

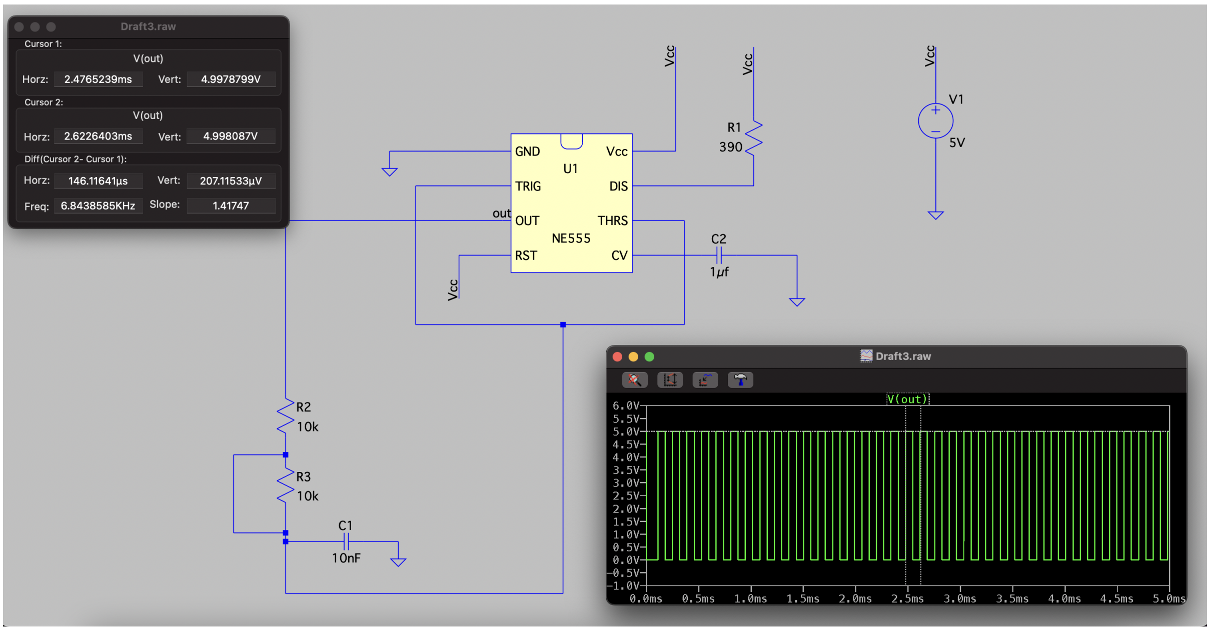

Figure 3: 555 Timer with Reed Switch Turned On

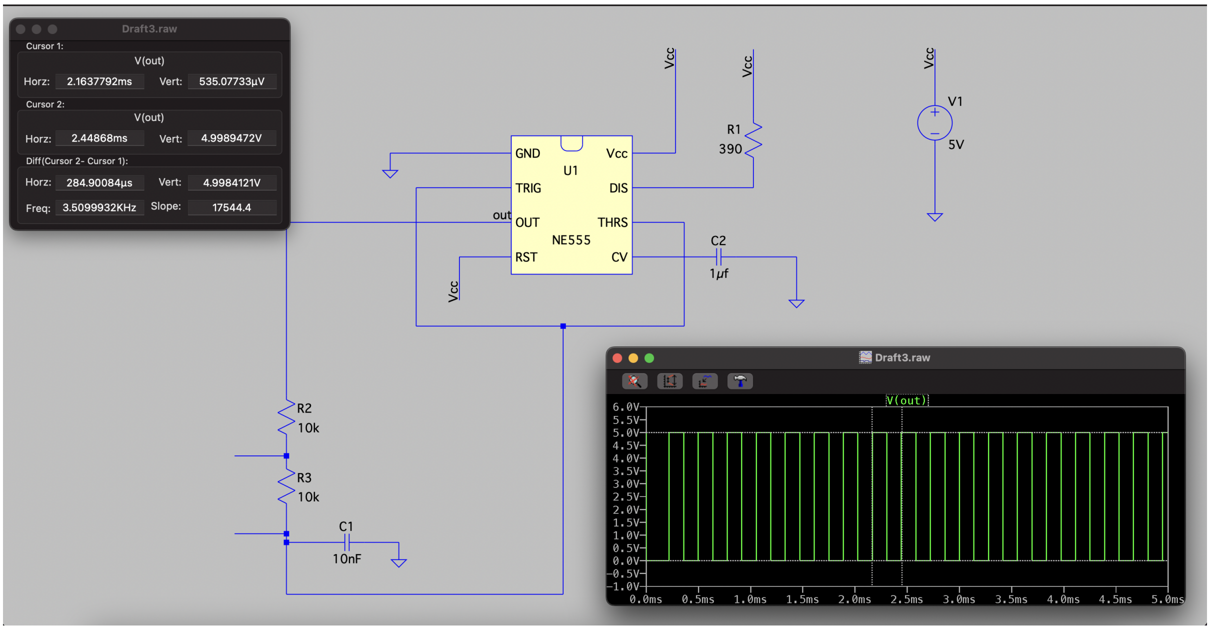

Figure 4: 555 Timer with Reed Switch Turned Off

4.2 Photodiode Amplifier

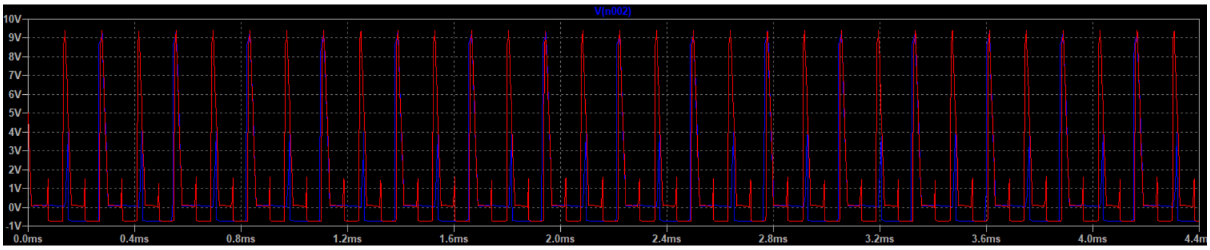

Figure 5: Observed Output from Photodiode Amplifier

4.3 Tachometer

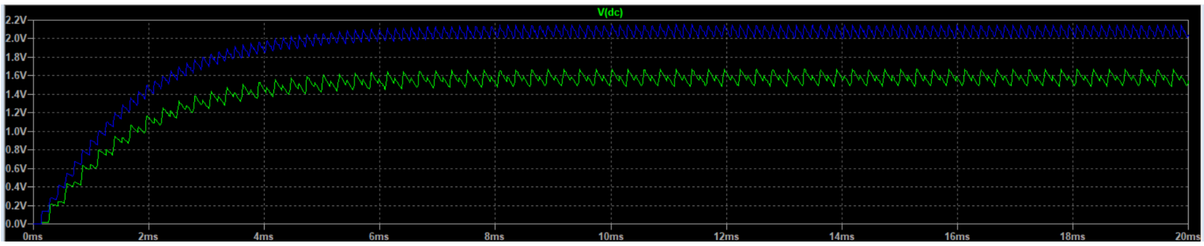

Figure 6: Observed Output from Analog Tachometer

4.4 PDA and Tachometer

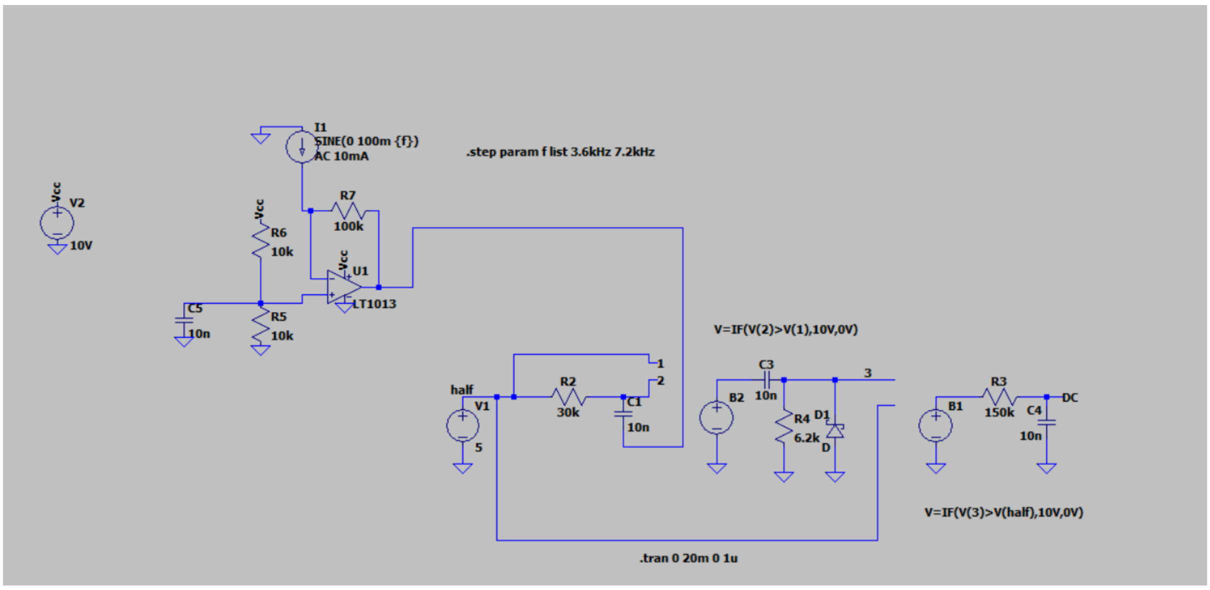

Figure 7: Combined Circuit

5 Physical Results

5.1 Combined Circuit

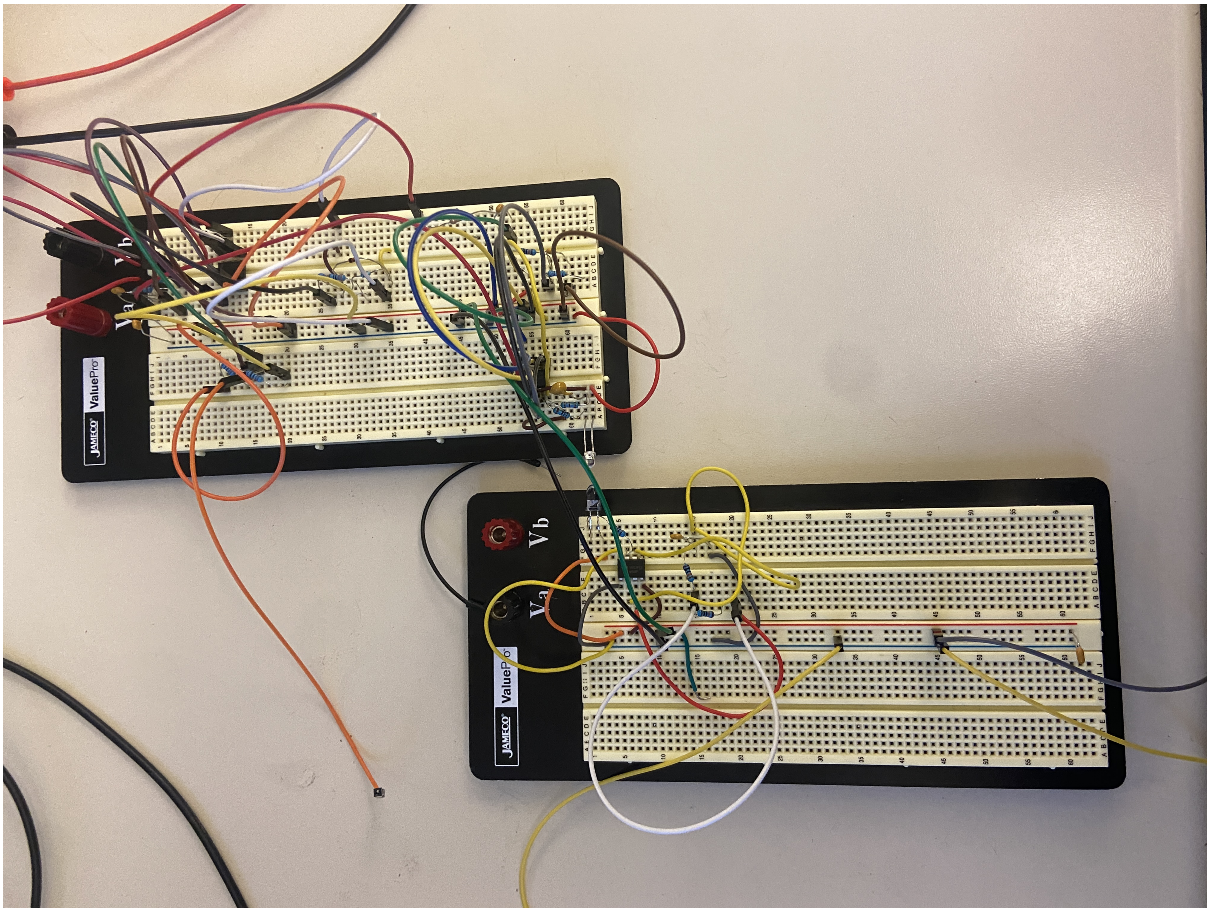

Figure 8: Combined Circuit [Receiver on the Right with Tachometer]

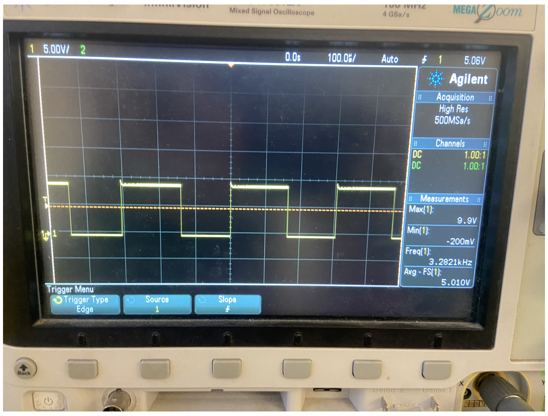

Figure 9: 3.6khz Timer

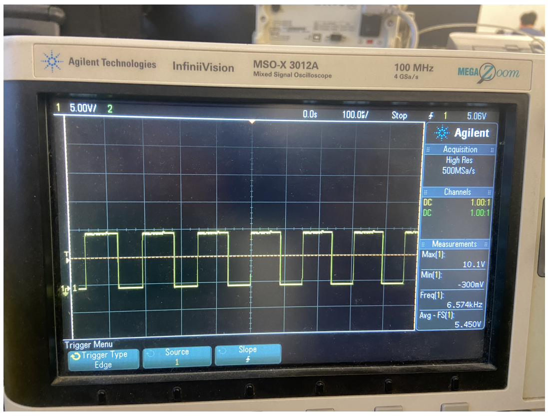

Figure 10: 7.2khz Timer

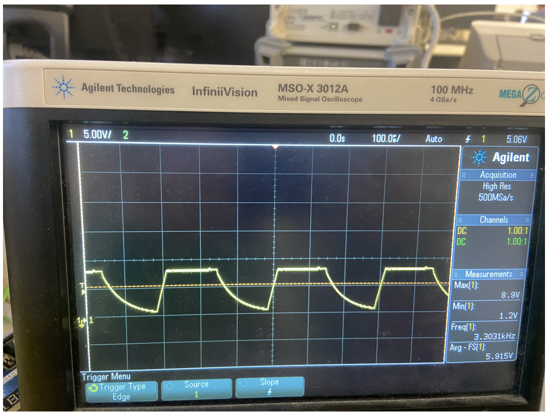

Figure 11: 3.6khz Receiver Out

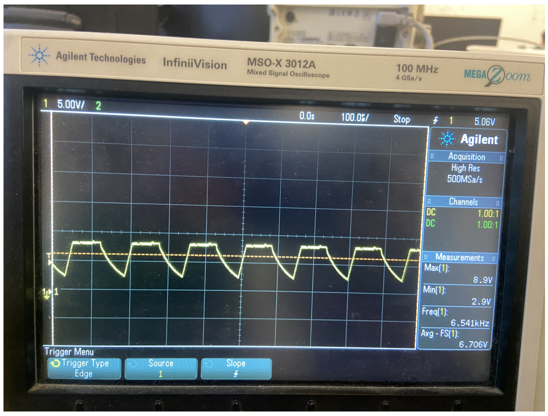

Figure 12: 7.2khz Receiver Out

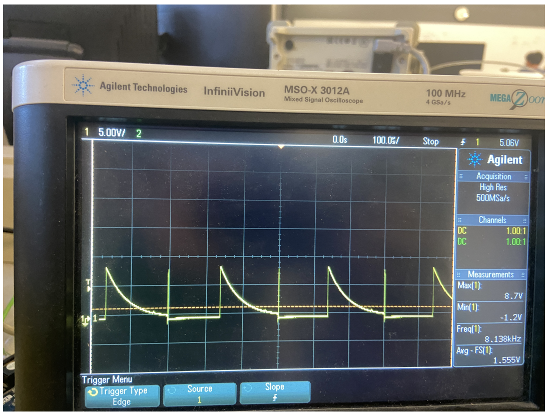

Figure 13: 3.6khz Comparator Oneshot Input

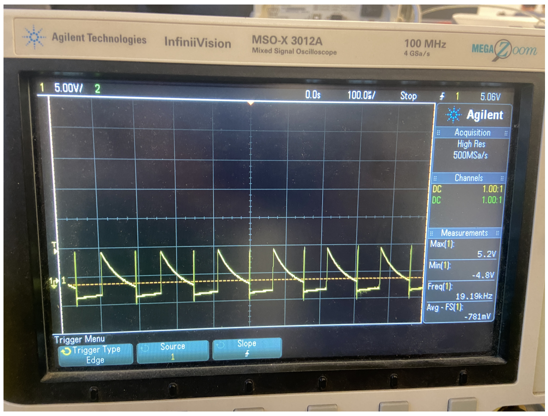

Figure 14: 7.2khz Comparator Oneshot Input

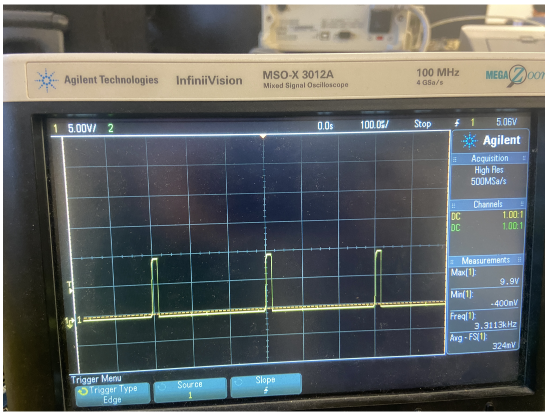

Figure 15: 3.6khz Oneshot Out

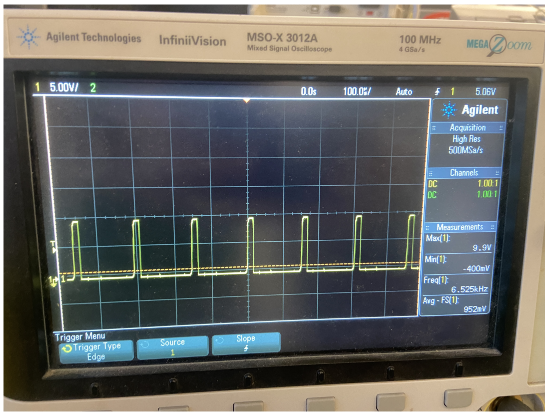

Figure 16: 7.2khz Comparator Oneshot Out

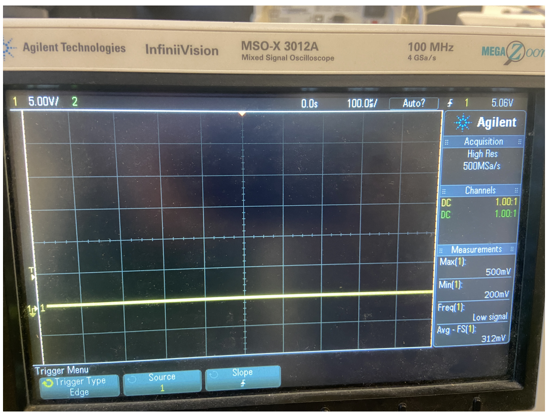

Figure 17: 3.6khz Out

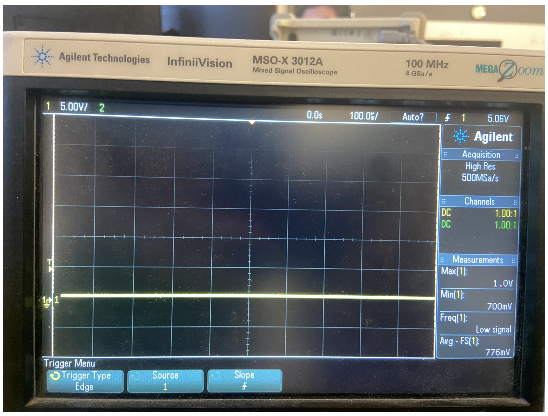

Figure 18: 7.2khz Out

6 Calculations and Derivations

6.1 555 Timer

Given the pulse time formula for a 555 timer in astable mode:

$$T_{pulse} = 1.1 \cdot R \cdot C$$

and the frequency formula

$$f = \frac{1}{T_{pulse}}$$

we calculate the resistor values needed for specific frequencies.

Assuming a capacitor value of $10\,nF$ (C = $10 \times 10^{-9}\,F$), we find the resistor values for frequencies of 7.2 kHz (with the switch on) and 3.6 kHz (with the switch off).

With Switch On (7.2 kHz)

For a frequency $f = 7.2 \times 10^3\,Hz$, the resistor value R is given by:

$$R = \frac{1}{f \times 1.1 \times C}$$

$$R = \frac{1}{7.2 \times 10^3 \times 1.1 \times 10 \times 10^{-9}}$$
$$R \approx 12.6\,k\Omega$$

With Switch Off (3.6 kHz)

For a frequency $f = 3.6 \times 10^3\,Hz$, the resistor value R is given by:

$$R = \frac{1}{f \times 1.1 \times C}$$

$$R = \frac{1}{3.6 \times 10^3 \times 1.1 \times 10 \times 10^{-9}}$$
$$R \approx 25.3\,k\Omega$$

Thus, to achieve a frequency of 7.2 kHz, a $12.6\,k\Omega$ resistor should be used when the switch is on. To achieve a frequency of 3.6 kHz, the total resistance should be $25.3\,k\Omega$ when the switch is off. This can be accomplished by adding an additional $12.7\,k\Omega$ resistor in series with the $12.6\,k\Omega$ resistor.

However, we used $10\,k\Omega$ resistors instead due to the LED Resistor and CV capacitor for the 555 timer. Our simulations show that the frequency checks out, but when tested on the breadboard, the levels don't match.

6.2 Photodiode Response to 3.6 kHz and 7.2 kHz Frequencies

Given the PD204-6C/L3 photodiode's specifications, particularly its response to light at 940 nm wavelength, we analyze its behavior when exposed to 3.6 kHz and 7.2 kHz frequencies.

Photodiode Current at Given Frequencies The photodiode generates a short-circuit current (ISC) of $10\,\mu A$ under standard test conditions (1mW/cm^2 at 940 nm). When exposed to the FSK signals at 3.6 kHz and 7.2 kHz, we assume that the photodiode current will fluctuate around this value depending on the IR intensity.

Trans-Impedance Amplifier (TIA) Output Using $R_{TIA} = 100\,k\Omega$, the TIA converts the photodiode current to a voltage. For the photodiode current of approximately $10\,\mu A$, the output voltage is:

$$V_{out} = I_{PD} \times R_{TIA} = 10 \times 10^{-6} \times 100 \times 10^{3} = 1\,V$$

Bias and Filter Circuit

The TIA is biased at half the supply voltage (5 V) using R_{B1} and R_{B2} of $10\,k\Omega$ each. The low-pass filter, formed by the $10\,nF$ capacitor C_B and the bias resistors, stabilizes this bias voltage. The cutoff frequency of this filter is approximately 3.18 kHz, which is below the frequency of the IR signals, ensuring stability against supply noise.

Photodiode Capacitance and Frequency Response The total capacitance of the photodiode (C_t) is 10 pF. At the operating frequencies of 3.6 kHz and 7.2 kHz, this capacitance may impact the response time and overall bandwidth of the photodiode. However, given the relatively low frequencies and the rise/fall time specification of 10 ns, the photodiode is expected to respond adequately to these frequency changes.

Overall System Response The combination of the TIA, photodiode, and filter circuitry should enable the system to effectively detect and convert the IR signals at 3.6 kHz and 7.2 kHz into corresponding electrical signals with minimal noise and distortion. The TIA's output voltage will vary in accordance with the intensity of the received IR signal, allowing for effective frequency-shift keying (FSK) communication.

6.3 Stage 1: Comparator

The comparator stage is designed to convert an analog input signal into a digital square wave. Key calculations involve determining the hysteresis required to prevent noise-induced false triggering.

Hysteresis Calculation

- Assuming a threshold voltage V_{th} and a hysteresis voltage V_{hys}, the upper and lower trigger levels are calculated as:

$$V_{upper} = V_{th} + \frac{V_{hys}}{2}$$

$$V_{lower} = V_{th} - \frac{V_{hys}}{2}$$

Time Constant

In this section, we analyze the AC coupled comparator, focusing on the time constant t_1 in relation to the period $T_{3.6}$ of 3.6kHz.

$$\begin{gathered}
t_1 \text{ must be larger than } T_{3.6}\text{:} \\
T_{3.6} = RC \\
\text{With } R = 500\,k\Omega \text{ and } C = 1\,nF, \\
T_{3.6} = 0.000367 \text{ seconds} \\
\text{Given } t_1 = 0.0005 \text{ seconds,} \\
\text{Condition is satisfied as } t_1 > T_{3.6}.
\end{gathered}$$

6.4 Stage 2: One-shot

The one-shot stage generates a pulse for each transition of the input signal. The duration of this pulse is controlled by an RC network.

Pulse Width Calculation

- For a given resistor R and capacitor C, the pulse width T is approximately calculated as:

$$T = 1.1 \times R \times C$$

- This formula allows us to set the pulse width by choosing appropriate values of R and C.

Time Constant

Here, we discuss the comparator based one-shot circuit. The focus is on ensuring t_2 is less than half the period of $T7.2$.

$$\begin{gathered}
t_2 < \tfrac{T7.2}{2} \\
\text{For } T7.2 = 138.8\,\mu s, \\
\tfrac{T7.2}{2} = 69.444\,\mu s \\
\text{Choosing } R = 2k\Omega \text{ and } C = 22nF, \\
t_2 = 0.000044 \text{ seconds} \\
\text{This satisfies the condition, } t_2 < \tfrac{T7.2}{2}.
\end{gathered}$$

6.5 Stage 3: Low-pass Filter

The final stage averages the pulses to produce a DC voltage level. The cutoff frequency of the RC filter is crucial for smooth output.

Cutoff Frequency Calculation

- The cutoff frequency f_c of an RC low-pass filter is given by:

$$f_c = \frac{1}{2\pi \times R \times C}$$

- By selecting suitable R and C, the filter can be tuned to the desired frequency range, balancing responsiveness and smoothness.

Time Constant

The low pass filter's performance is assessed by comparing the time constant t_3 with the period $T_{3.6}$.

t_3 must be significantly larger than $T_{3.6}$:
With $T_{3.6} = 138.8\,\mu s$,
and selecting $R = 150k\Omega$ and $C = 10nF$,
$t_3 = 0.0015$ seconds
This is substantially greater than $T_{3.6}$,
confirming the filter's appropriateness.

7 Discussion

555 Timer Based Circuit

After testing our circuit and ensuring the correctness of component values, circuit design, and signal paths, we observed that the output frequencies were twice the calculated values. Instead of achieving trigger levels of 3.6kHz and 7.2kHz, we measured 7.2kHz and 14.4kHz. The discrepancy may be due to inaccuracies in our calculations or a potential need for additional components in the control. Despite this, the circuit functions as expected, with the circuit acting as a square wave generator because of the 555 timer acting as an inverting hysteretic comparator combined with an RC circuit. The Reed switch's state changes the circuit's signal path to either skip or add a resistor when in the presence of a magnet, the state change then changes the time constant of the circuit, which then changes the output between the two trigger levels, so the reed switch's state effectively controls the blinking rate of the LED. A hypothesis we have is the CV capacitor not being implemented in our breadboard design which affects the values and response.

Photodiode Amplifier Circuit

The Photodiode Amplifier circuit, a crucial part of our FSK IR Communication System, has been tested and validated. We observed that the circuit efficiently converts IR signals into electrical signals, maintaining signal integrity. The trans-impedance amplifier played a vital role in amplifying the current generated by the photodiode, converting it into a measurable voltage. This voltage fluctuates in accordance with the intensity and frequency of the IR signals, which is essential for the FSK system's operation. Our design considerations, focusing on component selection and circuit stability, proved effective in achieving the desired outcomes. The results confirm our hypothesis and design choices, marking a successful implementation of the Photodiode Amplifier in the FSK IR Communication System.

Analog Tachometer Circuit

The Analog Tachometer circuit, as an integral part of our FSK IR Communication System, has been thoroughly tested and validated. Our findings indicate that the circuit effectively translates frequency variations into corresponding DC voltage levels. The precision of the comparator and one-shot circuit in generating pulse-density modulated (PDM) waveforms, and the efficiency of the low-pass filter in extracting the average DC value, played pivotal roles in achieving accurate results. The circuit's performance aligns with our initial design objectives, marking a successful step towards the completion of the FSK IR Communication System.