Design of Speed Measurement And Detection Module

Vishwas Jasuja (B23303), Rushabh Lodha (B23495), Rohak Gupta (B23500), Taranpreet Singh (B23504)
Group 2 Project Report
EE211 - Analog Circuit Design

***Abstract*—This paper presents the design and implementation of a fully analog speed measurement system utilizing infrared (IR) sensors and NE555 timers. By positioning two IR sensors a known distance apart, the system measures the time taken by a moving object to traverse between them. A monostable NE555 timer enables a constant current source to charge a capacitor during the detected interval. The resulting voltage across the capacitor is proportional to travel time and inversely proportional to speed. A peak detector and op-amp buffer preserve this voltage for observation and measurement. An additional voltage-controlled current source and manual reset mechanism allow adaptability and manual discharge of the timing capacitor.**

I. Aim

To design and build an analog system capable of estimating the speed of a moving object using IR sensors, NE555 timers, and analog circuitry, yielding a voltage proportional to speed.

II. Introduction

Analog methods for speed measurement offer simplicity, low power consumption, and minimal processing delays. This project investigates a purely analog implementation using basic components such as IR sensors, NE555 timers, transistors, op-amps, and capacitors to measure speed through time-voltage conversion.

III. Theory

The theoretical foundation of this project is based on kinematics and electrical principles. When an object moves at constant speed between two known points separated by distance d, the time taken (Δt) is inversely proportional to speed ($v = d/\Delta t$). A capacitor charged by a constant current source produces a linearly increasing voltage according to

$$V = \frac{I\,\Delta t}{C} \tag{1}$$

where I is charging current and t is the time interval. By triggering and disabling the charging process with two NE555 monostable circuits activated by IR sensors, the voltage across the timing capacitor represents the time interval and hence is inversely related to object speed. A peak detector captures the maximum voltage, and an op-amp buffer isolates the measurement from load effects.

Key Component Pinouts and Functionality

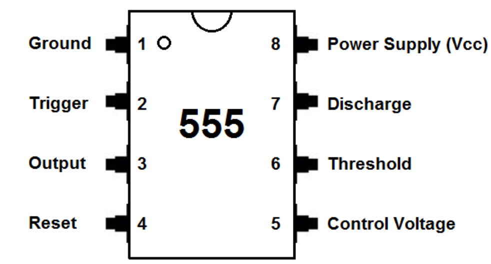

Fig. 1: NE555 Timer: An 8-pin IC used for generating precise timing pulses. In monostable mode, it outputs a high pulse of duration $1.1 \cdot R \cdot C$ when triggered.

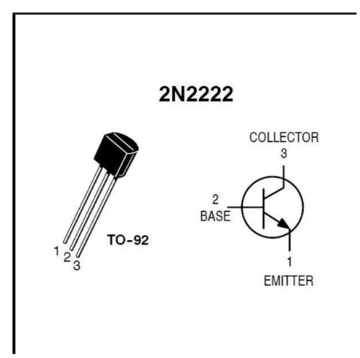

Fig. 2: 2N2222 Transistor: A general-purpose NPN transistor used here to control current flow. It acts as a switch for the constant current source.

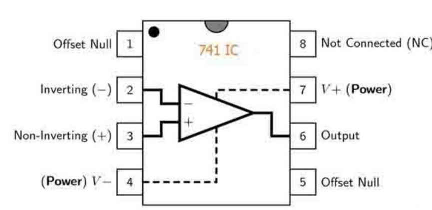

Fig. 3: LM741 Op-Amp: A basic operational amplifier used as a voltage follower (buffer) to isolate the peak detector from subsequent circuitry.

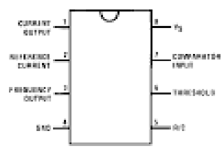

Fig. 4: KA331: A frequency-to-voltage converter IC (not used in the final implementation due to failure) that can convert VCO frequency to proportional voltage.

IV. Working Principle

The circuit operates by detecting an object passing through two IR sensors set 20 cm apart. When the first IR sensor is triggered by the motion of a vehicle or object, it sends a logic signal to the first NE555 timer configured in monostable mode. This generates a high logic pulse of approximately 1.1 seconds, determined by the time constant $1.1 \times R \times C$, with $R = 100$ kΩ and $C = 10$ μF. During this high pulse, a transistor is turned on, allowing a constant current source to charge a capacitor. The voltage across this capacitor increases linearly over time, representing the time interval the object takes to travel from the first to the second sensor.

As the object reaches the second sensor, it triggers a second NE555 timer. This timer outputs a short pulse which activates another transistor. This second transistor diverts the base current of the first transistor to ground, effectively switching off the constant current source and freezing the capacitor voltage. This voltage thus represents the time interval Δt between sensor activations.

The voltage is then passed through a peak detector to capture the maximum value and an op-amp buffer to stabilize the output and reduce loading effects. To further process this signal, the output voltage was amplified and used to control the frequency of a third NE555 in astable mode. This created a voltage-controlled oscillator (VCO), where higher voltages resulted in lower frequencies. The resulting frequency was intended to be fed into a KA331 frequency-to-voltage converter, which would output a voltage inversely proportional to Δt and directly proportional to speed. However, due to the malfunction of the KA331 IC, this part could not be tested successfully.

A. Object Detection and Pulse Generation

The first IR sensor (IR1) detects a passing object and triggers the first NE555 timer in monostable mode, generating a high pulse of duration $T = 1.1RC$. This pulse duration determines how long the constant current source remains active.

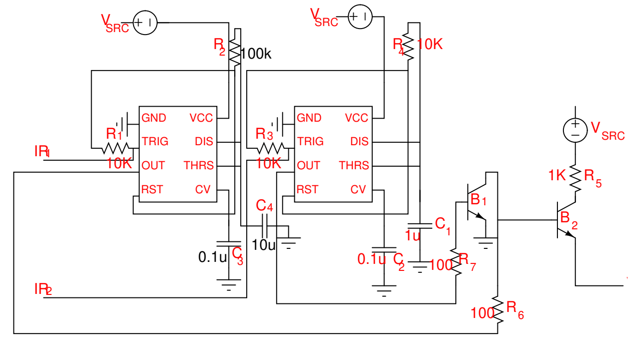

Fig. 5: XCircuit Simulation: Object Detection and Pulse Generation

B. Constant Current Charging and Voltage Capture

During the high output pulse, a 2N2222 transistor sources a near-constant current into the timing capacitor. When the second IR sensor is triggered, a second NE555 monostable outputs a short pulse that deactivates the constant current source, freezing the capacitor voltage that corresponds to the time interval.

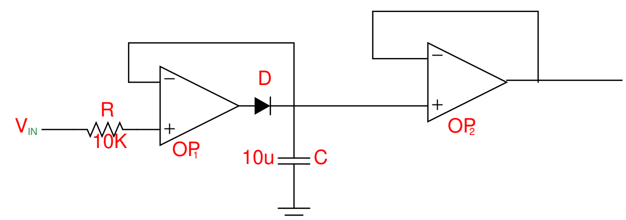

Fig. 6: XCircuit Simulation: Peak Detector and Op-Amp Buffer Stage

V. LTspice Simulation: Need for Peak Detector and Buffer

Simulations in LTspice demonstrate that without a peak detector and buffer, the capacitor voltage decays due to leakage and load effects. Figure 7 shows the voltage plateau during constant-current charging and subsequent decay when the charging stops.

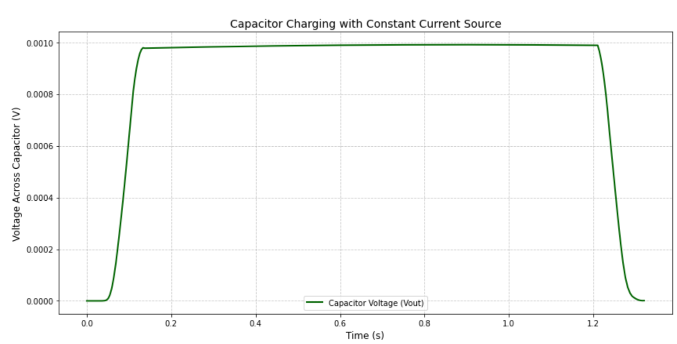

Fig. 7: LTspice Simulation: Voltage Plateau and Decay Without Buffer

VI. Design of Voltage-Controlled Current Source and Reset Button

A precision op-amp-based current source was designed to improve linearity of charging. A manual push-button was added to reset (discharge) the timing capacitor between measurements. The schematic is shown in Figure 8.

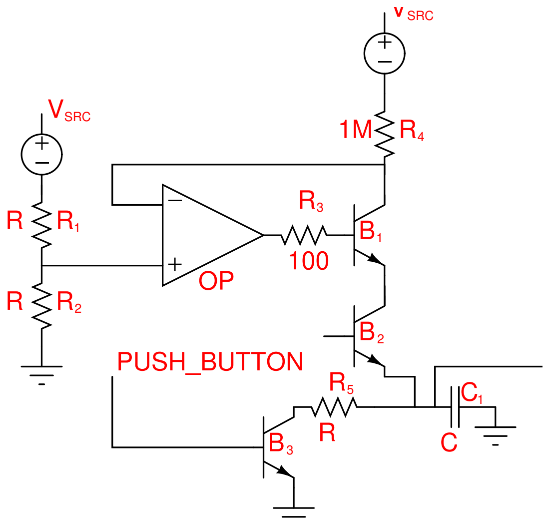

Fig. 8: Voltage-Controlled Current Source and Reset Button Schematic

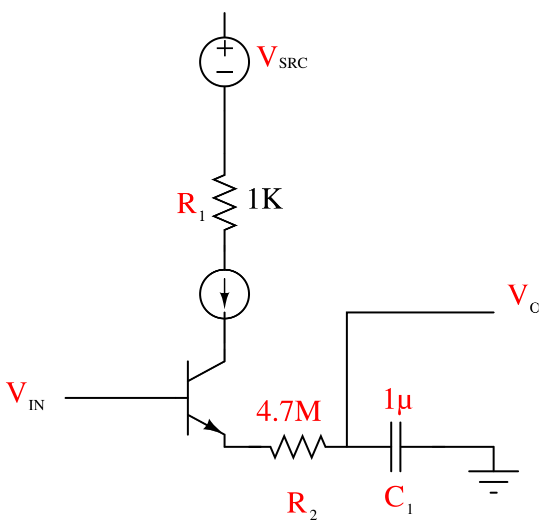

Fig. 9: simplified schematic of current source and charging capacitor

VII. Physical Implementation

All sub-blocks—object detection, pulse generation, constant current charging, peak detection, buffer, voltage-controlled current source, and manual reset—are integrated into the final system. Images of the assembled breadboard setup are shown in Figures 10–12.

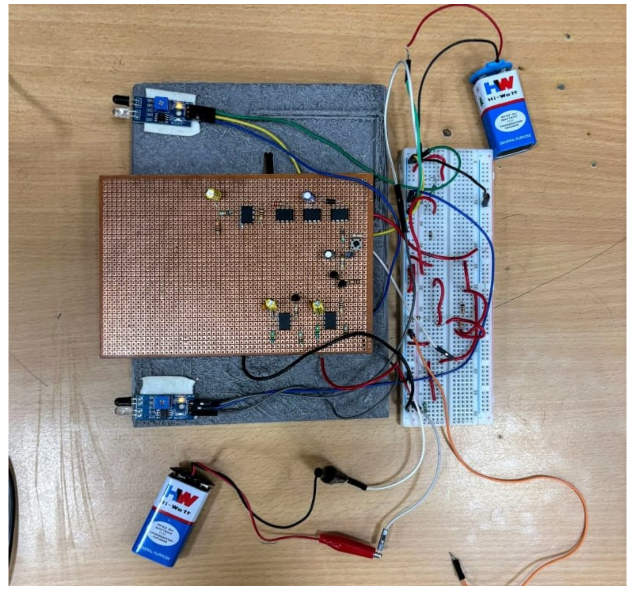

Fig. 10: Physical Implementation: Overall Circuit

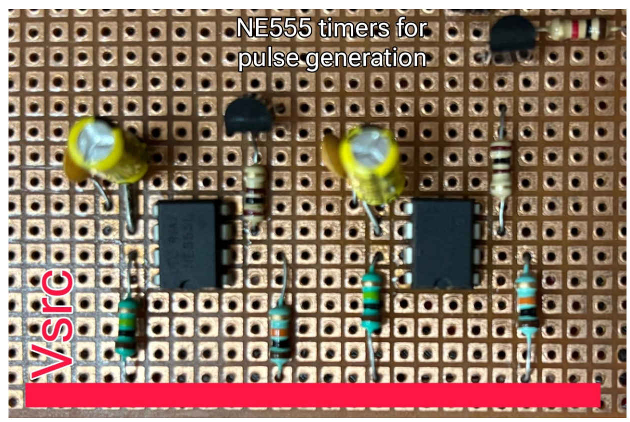

Fig. 11: Physical Implementation: Pulse Generation Circuit (555 Timers)

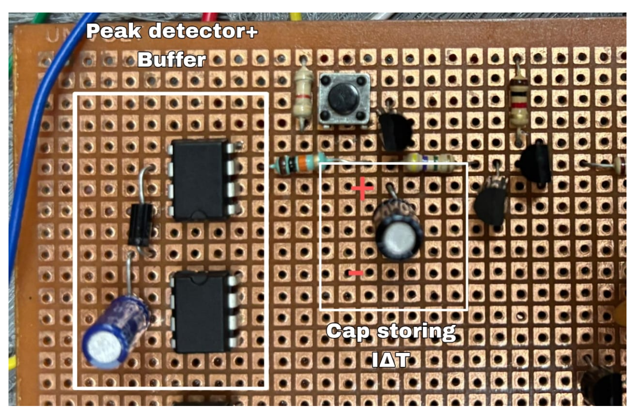

Fig. 12: Physical Implementation: Capacitor, Peak Detector, and Buffer

VIII. Results and Observations

The circuit was tested with objects moving across both IR sensors placed 20 cm apart. The IR sensors successfully triggered the NE555 timers, producing the expected monostable pulses and enabling charging of the timing capacitor through the constant current source.

The voltage across the capacitor increased proportionally with the time interval between the two sensor activations, validating the core time-to-voltage conversion principle. However, the relationship was not perfectly linear due to imperfections in the constant current source and minor leakage in the capacitor. This nonlinearity introduced small deviations in the measured voltage for equal time intervals.

The peak detector and buffer circuits were partially effective in retaining the peak voltage. While the buffer provided isolation and reduced load effects, some voltage decay was still observed over a span of a few seconds, which could affect accuracy if readings were delayed.

At higher object speeds, inconsistencies in IR sensor triggering were observed. This was attributed to the limited response time and alignment sensitivity of the sensors, which reduced the reliability of pulse generation at short time intervals.

In the advanced implementation, a KA331 frequency-to-voltage converter was integrated to convert VCO output frequency to a voltage directly proportional to speed. Despite receiving correct input signals from a function generator, the IC produced no output, leading to the conclusion that the KA331 was defective. Consequently, this stage could not be tested in hardware.

These practical limitations highlight the challenges of building a fully analog system with discrete components, especially in terms of sensor reliability, component tolerances, and retention of analog values over time.

IX. Applications

This analog speed measurement system offers several practical applications:

- **Highway Traffic Monitoring:** Cost-effective speed detection in areas lacking digital infrastructure.
- **Industrial Conveyor Systems:** Real-time monitoring of conveyor belt speeds without microcontrollers.
- **Robotics:** Localized speed feedback for mobile platforms using purely analog circuitry.
- **Educational Demonstrations:** Hands-on teaching of analog signal processing, kinematics, and timer IC operation.

X. Conclusion

The analog speed measurement system demonstrates how standard components like NE555 timers, transistors, op-amps, and capacitors can provide a voltage output proportional to object speed without digital processing. Addition of precision current sources and manual resets enhances repeatability and linearity.

References

[1] CircuitBread, *555 Timer - Introduction to 555 Timers*, Available at: https://www.circuitbread.com/tutorials/555-timer-1-introduction-to-555-timers

[2] Circuits DIY, *Frequency to Voltage Converter using KA331 IC*, Available at: https://www.circuits-diy.com/frequency-to-voltage-converter-using-ka331-ic/

[3] All About Electronics, YouTube Channel. Available at: https://www.youtube.com/channel/UCBkOVp1Cqz4MR0LYR8vKpZg

[4] Analog Devices, *LTspice Simulation Manual*, Available with LTspice installation or from: https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html

[5] Behzad Razavi, *Fundamentals of Microelectronics*, 2nd Edition, Wiley, 2013.