Deconstructed 555 Timer and Application Circuits for Interactive Educational Experiences

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Abstract

The Deconstructed 555 Timer and Application Circuits for Interactive Educational Experience offers interactional implementation of three fully discrete 555 Timer example circuits. The research project goal was to gain knowledge of the 555 Timer by deconstructing the device down to the component level. Three independent example application circuits, which showcase the application versatility of the 555 Timer in different modes, include Monostable, Astable, and Bistable circuits. Each mode has a hardware interface that can be used to adjust the operation of the 555 Timer allowing for a full interactive experience. The user can observe the differences in the internal working of the 555 Timer for the implemented applications. The built product is an educational and engaging interactive board which uses LEDs and OLED displays to describe the internal functionality of a 555 Timer and its application versatility. The undergraduate research concentrated on building skills in circuit design and product development.

Keywords

Undergraduate Student Poster, Electronics, 555 Timer, Experiential Learning, Integrated Circuit

Introduction

The 555 Timer integrated circuit was created in 1971, as mentioned by IEEE [1], to accomplish the simple yet surprisingly difficult task of supplying digital oscillation for electrical and computer engineers. These oscillations can be provided with a minimal number of external components applied in specific configurations with the IC. The 8-pin chip was designed with simplicity and versatility in mind, making it a widely usable IC for electronic applications. Despite its simple purpose, the internal workings of the 555 Timer can be difficult to understand given its complexity.

In 2023 a device was conceptualized to assist in the education of the 555 Timer's internal workings as well as external configurations. By deconstructing the 555 Timer into its discrete components, they were organized in a more educationally presentable way. The circuits for each external configuration, or "Mode", can be activated and interacted with to demonstrate their unique type of oscillation. To enhance student understanding, indicator LEDs and graphic displays have been strategically placed to signify analog and digital signals found inside the device.

Overview

The project was configured with the discrete 555 Timer's pins accessible through a relay board which acts as an 8-channel routing selector. The 555 Timer's pins are routed through the Relay

Board and into a circuit which houses the external components necessary for a specific mode of operation. This configuration allows the 555 Timer to be plugged into one circuit, (Mode), at a time. The Control Board is responsible for providing the logic which determines the Relay Board's connections.

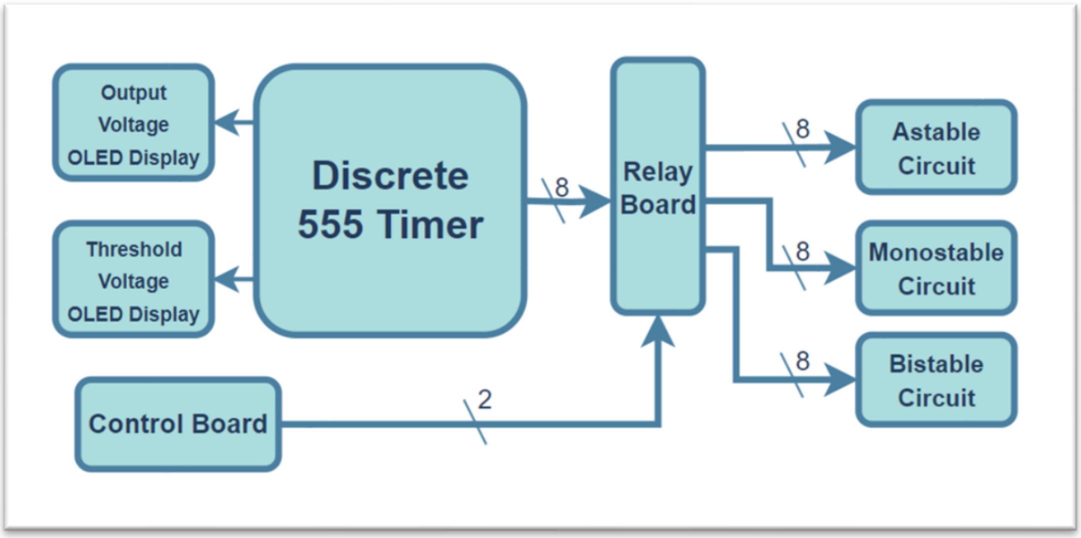

Figure 1: Project Block Diagram

Design of Discrete 555 Timer and Indicator Circuits

When building the discrete 555 timer, the NE555 configuration was referenced. This configuration was ideal because of the use of diodes and lack of dual emitter transistors. As described by Mainwaring [2], the 555 internals are split into four main components: two comparators, an SR latch and finally the output stage. The comparators use a simple transistor configuration that compares the voltages at the base emitters of Q1 and Q8 for the threshold and Q12 and Q14 for the trigger. These use the voltage divider (which the 555 is named after) as a reference for the comparators. Once one of them is activated, their output goes directly to the SR Latch. This configuration works to drive the output as well as "latch" the current state until it is reset or discharged. By the time the signal reaches the output, it is a fraction of the original input voltage. To compensate for this, the output stage includes a Darlington amplifier to drive the voltage back to its original value. Screw terminals are used to connect the discrete 555 pins to the external circuit configurations to showcase three modes of operation.

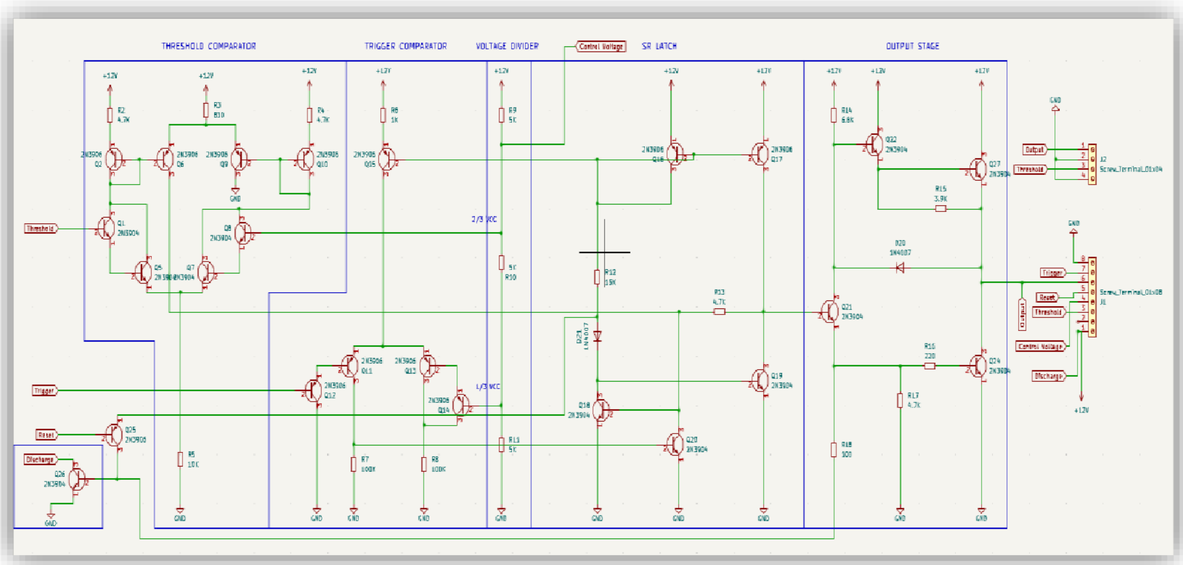

Figure 2: Discrete 555 Timer Schematic

The main goal of this project was to give students and observers a more visual understanding of the flow of electricity through the circuit. Using LEDs to indicate when certain nodes are activated can provide students with a basic understanding of the circuit during its observation. The LEDs show the activation of both comparator outputs, the SR latch inverted and non-inverted output, the discharge transistor, and the final output node. To avoid loading effects, separate op-amps were used to replicate the behavior of the 555 comparators and SR latch in real time. These op amps allow LEDs to showcase the internal operation of the 555 without disrupting the discrete 555 circuitry itself.

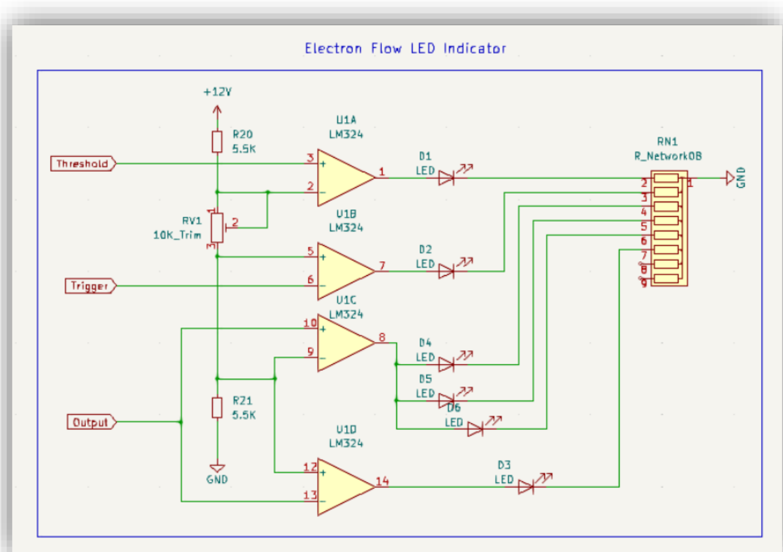

Figure 3: Drive Circuitry Internal 555 LED Indicators

Since the capacitor in the mode configuration circuits is a key component in the switching of the output for the 555 Timer, an LED bar was used to show the charging and discharging that activates the comparators when it reaches 1/3 and 2/3 VCC. A very specific IC was used to take a signal input (the threshold voltage) and compare it with internal reference voltages. Constant current drivers supply power to 9 LEDs depending on the result of the comparison. With the voltage divider being split into 3 sections, 9 LEDs give an accurate representation of the capacitor hitting the critical voltages that activate the SR Latch. These LEDs in combination with each other display a wonderful "dance" of electric potential across the vertical LED bar.

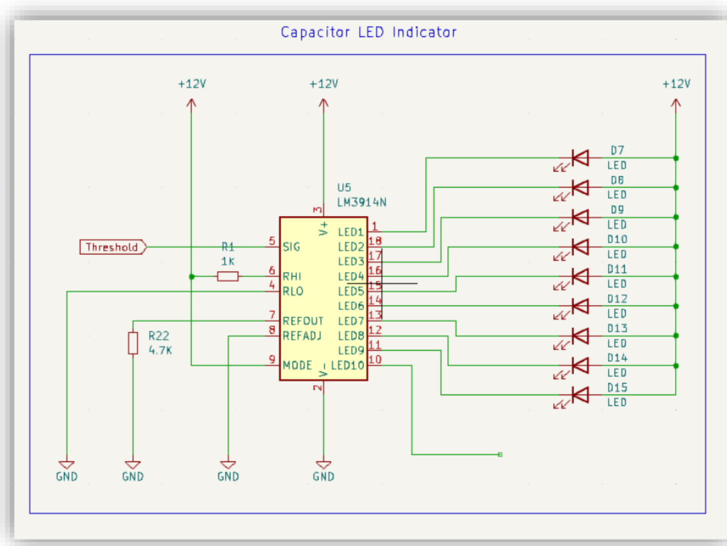

Figure 4: Threshold-Pin LED Bar Driver

External Configuration (Mode) Circuits

Three external mode circuits were designed to showcase how the 555 timer behaves in the most common configurations, or modes, as mentioned by Fahad [4]: Monostable, Astable, and Bistable. These mode circuits were built to connect to the deconstructed 555 timer just as if it were an IC built into the circuit. Each of these mode circuits has an activation button on it that will signal the Control Board to route the deconstructed 555 Timer to the circuit on which the button was pressed. Additionally, each circuit has an LED-illuminated translucent resin label that will light when that mode is active, and includes LEDs and potentiometers as needed to allow the user to control the inputs to the circuit and observe the output.

Astable mode will constantly output a square wave whose frequency can be adjusted using the potentiometer, Rpot. When activated, an LED on the board will display the resulting Astable square wave. The frequency of the square wave can be changed by adjusting the angle of Rpot.

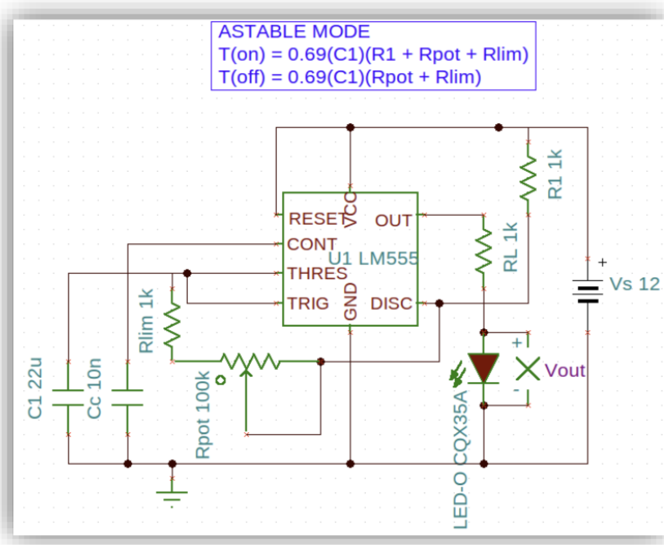

Figure 5: Astable Mode Electrical Schematic

Monostable mode, or “one-shot” mode, delivers a single square pulse when the Trigger pin is grounded by pressing the button, SW1. The length of this pulse is adjusted with the potentiometer Rpot. When the trigger button is pressed, the monostable circuit will illuminate a nearby LED to indicate the length of the pulse.

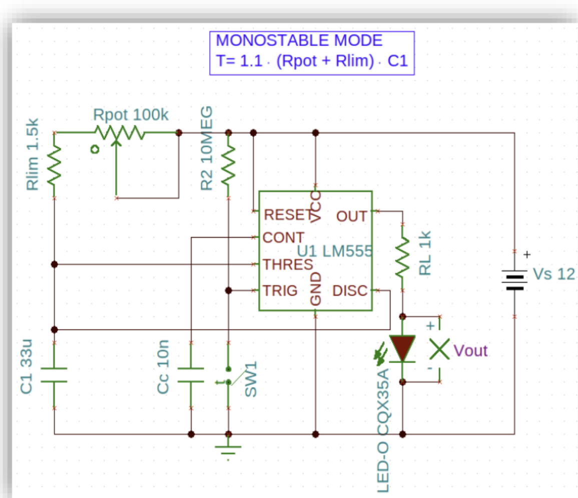

Figure 6: Monostable Mode Electrical Schematic.

Bistable mode uses only the SR latch contained within the 555 Timer. There are two buttons to set and reset the latch, and two LEDs indicating the status of the latch. This is a modification of a typical bistable configuration, which was prone to errors during prototyping. This modified configuration works much better. It eliminates the use of the 555 pin 4 being used to reset the SR-latch and instead uses both comparators to set and reset the internal latch. The disadvantage is that the modified configuration uses more resistors than a typical configuration.

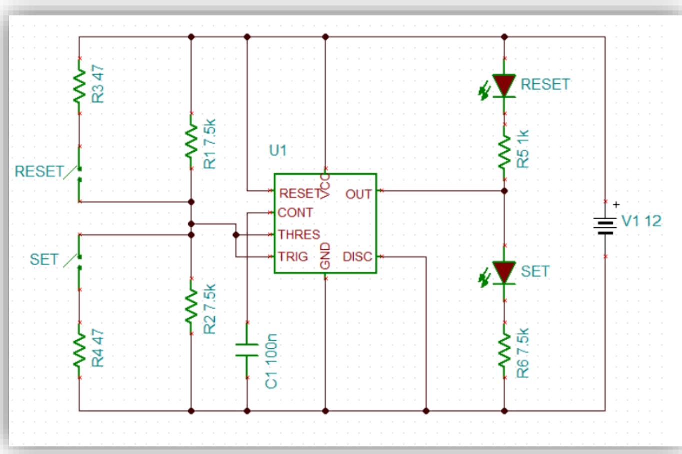

Figure 7: Bistable Mode Electrical Schematic.

Design of Controls Circuit for Project Interface

The digital signals received by the relay board must be of a certain pattern to route the 555 Timer's pins to the correct location at the correct time. The buttons to activate each Mode were momentary, so some form of memory had to be implemented to store the currently active mode and keep the necessary relays energized. Additionally, since the mode boards had individual activate buttons, it was possible someone could press 2 or 3 buttons at the same time leading to incorrect or undefined relay routings. The Control Board was developed to facilitate proper memory and filtering of the activation buttons and store the most recently selected Mode.

The control board takes parallel input from the 3 independent Mode via the Activate Connections outlined in the left side of figure 8. These signals are immediately routed to a 3:8 binary decoder. The decoder ensures that only one button's signal can pass through at a time. If two or more button signals are sensed, the decoder allows no signal to pass. If a single activate button is pressed, the signal passes through the 3:8 decoder and is then distributed to some diode OR gates and SR latches. Depending on which of the three signals passed through, the signal will either set or reset the appropriate SR latches. These SR latches will store and hold the correct combination of signals to send to the Relay Board.

These SR latches constructed out of NOR gates inherently have an unknown initial value at turn on. For this reason, a "Startup Reset" circuit, composed of a resistor and capacitor, was implemented to force the SR latches into the Astable configuration on startup. The resistor and capacitor simply force a low state on the Astable activation signal, as if the button were being pressed, for a few milliseconds as the power to the circuit ramps up. This ensures that when the project is powered up, the SR latches default to a known mode and do not accidentally enter an undefined or random state.

In addition to facilitating the logic from activate buttons to relay boards, the control board is also used for power regulation and distribution for the entire project. The 12V DC can be connected through a DC barrel jack compatible with an AC adapter, or screw terminals were made available for connection to a laboratory power supply or battery. A 5v rail was created using a linear regulator to supply logic level voltage to the decoder and NOR IC.

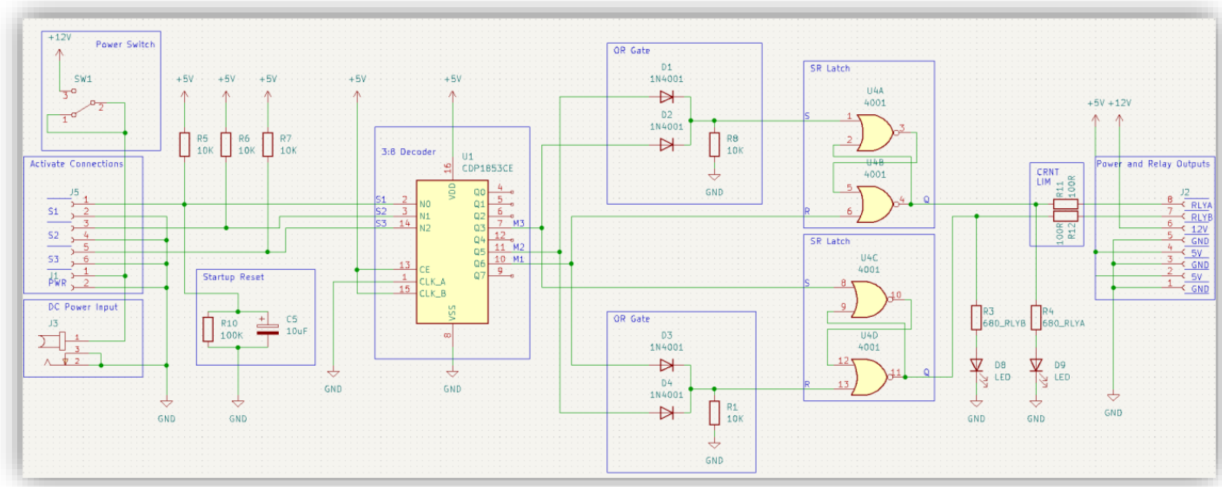

Figure 8: Control Board Logic Circuit.

OLED Waveform Display

Important graphical displays were included to assist in viewing some of the analog voltages present in the project. Although a level-indicator LED bar was included on the 555 Timer to monitor threshold voltage, the OLED boards offer an oscilloscope-like view of the waveforms as a function of time. One OLED Board displays the 555 Timers output pin. The output pin of the 555 Timer is meant to be a digital output and therefore a square wave will always be present as the output swings between saturated and off. The other OLED Board is connected to the threshold pin of the 555 Timer. This pin houses the analog voltage signals which the 555 Timer's internal comparators are always monitoring.

In the Astable and Monostable operations of the 555 Timer this pin is connected to a charging or discharging capacitor. Because the voltage across the capacitor is a slow triangle-like change, it is interesting to be able to witness this on the time domain OLED display. Both displays have a potentiometer which allows their update rate to be increased or decreased in speed; this acts like adjusting the time-base of an oscilloscope.

The OLED Boards each utilize an Arduino Nano as the main controller. The low-profile Arduino module, when used according to an interfacing tutorial written by Damirchi [3], can communicate with a miniature OLED display. The Arduino features the voltage regulator and analog to digital converters necessary to run the OLED Boards. The OLED Boards feature an envelope circuit on the 12V input to help filter and eliminate any noise from the rest of the project. The diode located in the envelope circuit also ensures that USB power to the Arduino during programming does not attempt to power the entire project through the 12V bus.

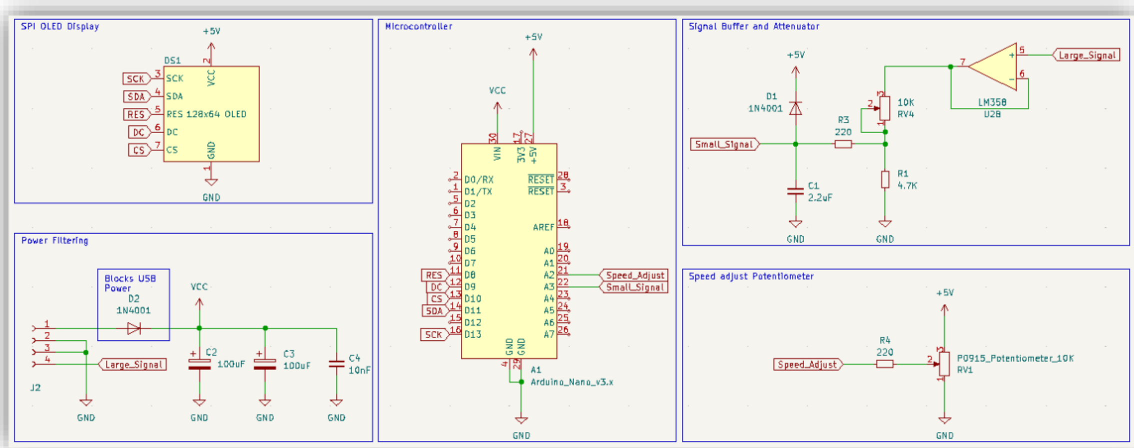

Figure 9: OLED Board Schematic.

The voltage signal which each OLED Board monitors first enters the signal buffer and attenuator section outlined in figure 9. An operational amplifier is used as a buffer to create a large input impedance to minimize loading on the 555 Timer circuit. The signal is then scaled by an adjustable voltage divider, and noise is filtered through an RC circuit before reaching the Arduino's ADC pin. The voltage divider is required to scale the input voltage down to an appropriate level for the Arduino to measure.

Conclusion

Figure 10: Fully Completed Project

In conclusion, the device was successfully used to demonstrate the 555 Timer in a convenient, educational, and user-friendly manner. The project resulted in a great piece of lab equipment that exceeded expectations in performance and reliability. The practical knowledge gained by overcoming the project's challenging design and construction will surely be put towards future academic and professional projects.

Acknowledgments

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References

[1] Santo, Brian. "25 Microchips That Shook the World." IEEE Spectrum, IEEE Spectrum, 16 Jan. 2024, spectrum.ieee.org/25-microchips-that-shook-the-world.

[2] Mainwaring, Geoff "Reon From Zircon," et al. "555 Timer IC - Working Principle, Block Diagram, Circuit Schematics." How To Mechatronics, 17 Feb. 2022, howtomechatronics.com/how-it-works/electronics/555-timer-ic-working-principle-block-diagram-circuit-schematics/.

[3] Damirchi, Written by Mohammad. "Interfacing 2.42 Inch OLED SPI/I2C Display Module with Arduino." Electropeak, 9 Jan. 2022, electropeak.com/learn/interfacing-2-42-inch-oled-spi-i2c-display-module-with-arduino/

[4] Fahad, Engr. "Types of Multi-Vibrator: Astable, Monostable and Bistable Vibrator." Electronic Clinic, 3 Jan. 2024, www.electroniclinic.com/types-of-multi-vibrator-astable-monostable-and-bistable-vibrator/

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