Electrical Engineering 3 Final Project Report
Discrete Logic Traffic Light System

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Introduction and Background

This project's goal was to design a stoplight system for an intersection of two one-way streets. If one of the lights is red, the other is green. After eight seconds, the green light turns to yellow for two seconds and then to red. The light remains red for eight seconds, then the second light turns green and continues the same pattern with the same timeframe.

The project was completed on a breadboard and incorporated resistors, capacitors, and diodes. We also utilized basic Boolean Logic to synchronize the two lights so they behave like stoplights in the real world.

We used two integrated circuits: the 555 timer and the 4017 decade counter. The 555 timer operates as an astable mulitvibrator by producing a continous stream of rectangular oscillations. The 4017 IC is a decade counter that has three entry ports and ten exit ports. The 555 timer produces pulses that are sent to the 4017 IC at a certain frequency. Each time the 4017 IC receives the rising edge of a pulse, it directs current to the next sequential pin number. The equation used to calculate the time that each light spends at each color comes from different capacitor and resistor values. The equation[2] defines the pulse period as
$t = (\ln(2) \times (R_1 + 2R_2) \times C$.

Testing Methodology

How We Designed the Test

We identified a significant problem with our circuit fairly early on. In the first prototype of our traffic light circuit, we set up three LEDs to act as a single traffic light. We wired four consecutive timing outputs from the decade counter to the green LED, two outputs to the yellow LED, and four outputs to the red LED, so that each LED would turn on for four seconds, two seconds, and four seconds, respectively. After connecting the circuit to power, we discovered that neither the red nor the green LED lit up at all; therefore, we decided to test the connections between the green and red LEDs and the decade counter.

Faced with these obstacles, we designed our test to compare the timing of the decade counter with the voltages being output by each of the decade counter's timing outputs to determine whether the discrepancies were related to power, timing, or flaws with the components themselves.

How We Conducted the Test

We first tested the four outputs of the 4017 decade counter that connected to the green LED of our circuit. The four outputs were connected in parallel to the green LED; in other words, all four outputs and the LED were wired together in a single terminal strip. While the circuit had power flowing through it, we used a DMM to measure the output voltage across the green LED. We found that there was no voltage difference across the green LED, and concluded that either the LED was faulty or the outputs were not correctly providing power to the LED.

For the next step in our analysis, we connected each one of the four outputs to the green LED separately and connected the circuit to power. Individually, each output lit the LED at the correct designated time interval. This test confirmed that the decade counter timing was working as expected, and that each individual output correctly produced a high voltage.

The third step in our testing analyzed the effects of the clock pulse frequency on the decade counter in an effort to determine whether a higher or lower frequency would have an effect on the current flowing through the red and green LED's. To do so, we changed the values of the resistors to produce a lower clock frequency, as shown in the 555 Timer Frequency Equation (above). We observed that the green and red LED's remained off while the yellow LED blinked at a slower rate, as expected. Using a DMM, we tested the voltage across both the green and red LED's and confirmed that no voltage was present across them. We repeated this process with a new combination of resistors for the 555 timer to produce a higher clock frequency, and observed the same results as with the lower frequency. The timing pulse frequency did not have an effect on the state of the green and red LEDs.

In the fourth step of our testing analysis, we directly altered the current flow from the decade counter to the green and red LEDs by placing switching diodes in series between the decade counter outputs and each LED. We wired four consecutive decade counter outputs in parallel with one another to flow into the each LED, effectively ensuring that current flowed solely from each decade counter output into the LED and eliminating the possibility of backwards flow of current from one output into another output of the decade counter. After connecting the circuit to a power source, we observed that the green and red LED's turned on at the correct time intervals, and used a DMM to ensure that current was indeed flowing through each LED. The setup of this particular step is shown in our final circuit schematic in Figure 1.

How We Analyzed the Test Data

In steps 1, 2, and 4 of the testing of our circuit, we collected data both visually and with a DMM. While testing the flow of current from certain outputs of the decade counter, we determined that the best method of detecting current flow was through visual stimuli - namely, observing whether an LED in a particular circuit lights up. Since our project involved LEDs as the main components anyway, this provided a simple method of determining the state of current flow through each path we tested. A DMM was used as a secondary confirmation of current flow within certain paths of our circuit, providing a more definitive and quantitative measure of the voltage from each of the decade counter's outputs and across each LED.

Step 3 of our analysis, which involved changing the pulse frequency from the 555 timer IC, required a bit more quantitative analysis. Using the 555 Timer Period-Frequency Equation,

$t = \ln(2) \times (R_1+2R_2) \times C$, we were able to produce an exact clock period for each output of the decade counter, accurately determining the length of time in which each LED would remain on.

In order to measure the time of each timer pulse, we timed the illumination of the yellow LED in our circuit. The yellow LED was connected to only one output of the decade counter, meaning it remained in a high state for the duration of one full clock pulse period. This provided a simple method of measuring the resulting pulse period for each resistor combination. Table 1 in the *Results and Discussion* section shows the results of this step of testing.

How We Interpreted the Data

In the first step of our testing, in which we measured the voltage across the green LED when connected to four outputs of the decade counter with a DMM, we found that 0V were flowing across the LED for the entire duration of all four outputs' pulses. Because the four outputs were connected in parallel, we hypothesized that none of the decade counter's outputs were producing a voltage pulse, or that the outputs were in some way interfering with one another and preventing electricity from reaching the LED.

We tested the first half of our hypothesis in our second step of testing, in which we wired each of the decade counter's outputs independently to an LED. When we found that each output produced a correctly-timed voltage pulse and lit the LED when independently wired, we proved that each output was functioning correctly. We therefore concluded that our problem resided with the combination of outputs, not with the individual outputs themselves, and moved into step three of our testing.

In the third step of our testing, in which we varied the clock frequency input to the decade counter, we found that the LEDs continued to fail to light under a wide range of clock frequencies. In our experimentation, we had hoped that a variance of clock frequency would reveal an issue with too low (or too high) input pulse frequencies in activating the LED, but this clearly was not the case. Because the LEDs were again connected to four outputs of the decade counter in parallel, and we had ruled out the individual failure of each output pin, we speculated that the outputs were interfering with one another in some way. Specifically, since no voltage was reaching the LED, we theorized that current was flowing out of the HIGH output and into the LOW outputs due to the potential difference between them. We decided that we needed to restrict the direction of current so that it could only flow from the output to the LED.

To restrict the current, we placed one switching diode in the forward-biased position in series from each of the decade counter's output to the terminal strip at which they were all connected. When connected to power, we found that the green and red LEDs lit up, and that appropriate voltage flowed across them. With this result, we concluded that the decade counter's outputs were indeed interfering with one another, subsequently solving our problem and allowing us to build our final circuit, shown in Figure 1.

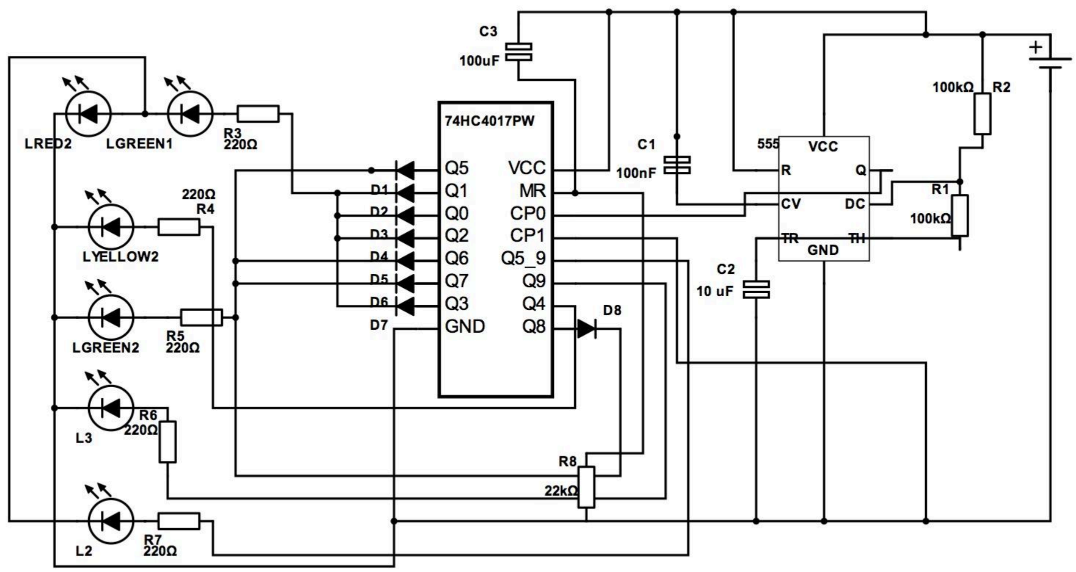


Figure 1: Final Circuit Diagram

A 555 - timer IC (right) provides a controlled input pulse of exact frequency to the 4017B decade counter (left). The 4017B decade counter then

RESULTS AND DISCUSSION

Our circuit required fairly simple test parameters for most of its operation, mainly because our main issues were with presence of current flow, which we could determine by wiring an LED to the questionable path. In fact, much of our testing was done by using this qualitative form of measurement, as described in steps 1, 2, and 4 in our testing methodology. When testing the timing system, however, we used a more quantitative approach to ensure exactness in pulse period.

As described above in the *How We Interpreted the Data* subsection of our *Testing Methodology* section, we originally speculated that the decade counter would only produce output voltages within certain timing frequencies, the limits of which were loosely defined in the decade counter's data sheet[1]. Using different combinations of resistors in the 555-timer circuit, as defined in the 555 timer data sheet[2], we chose resistors with various values to produce different clock frequencies.

As shown in Figures 2 and 3 below, the resistors R_1 and R_2 are responsible for controlling the HIGH and LOW times of each pulse output by the 555-timer. The decade counter receives the clock pulses and activates each of the 10 outputs in order from output 0 to output 9 (Figure 4) for one full clock period. Therefore, using the equations for HIGH[3], LOW[3], and total clock pulse period[2], we are able to calculate a range of intended pulse periods to activate the decade counter with.

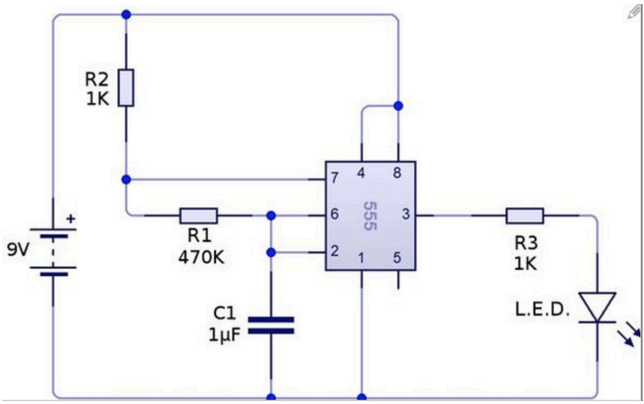


Figure 2: 555-Timer Circuit
By changing the values of R_1 and R_2, the 555-timer can produce different clock frequencies. The 555-timer frequency equation describes the calculation of frequency based on these values.

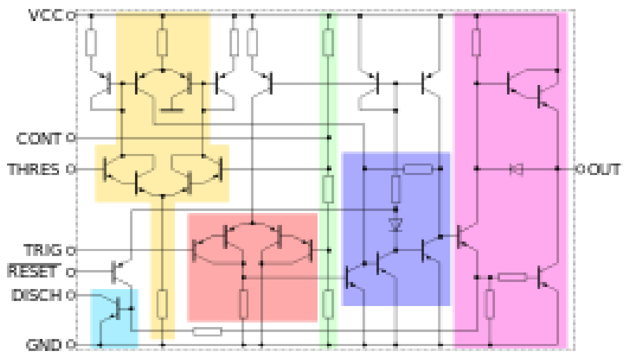


Figure 3: 555-Timer Schematic

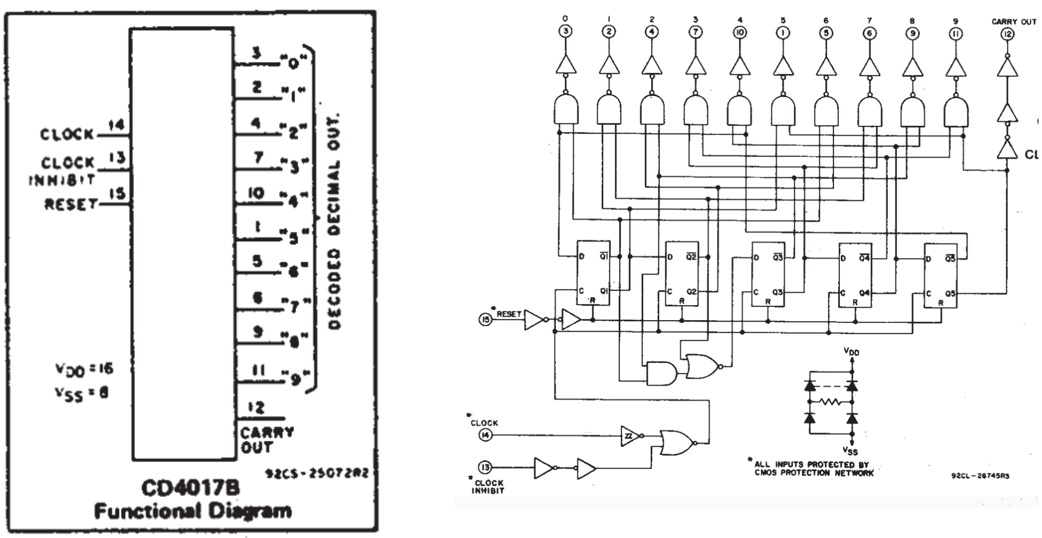


Figure 4: 4017 Decade Counter Functional Diagram and Internal Schematic
The functional diagram (left) shows the order of pulse outputs from the decade counter IC. The decade counter consecutively activates a HIGH pulse on each of the pins, from the order of Output 0 to Output 9, for a length of time defined by the total period of the input clock pulse.

The equations for HIGH and LOW times for each pulse can be found using the following equations[3]:

HIGH Time: $\ln(2)(R_1 + R_2) \times C$ LOW Time: $\ln(2)(R_2 \times C)$

TOTAL Period: $t = \ln(2)(R_1 + 2R_2) \times C$

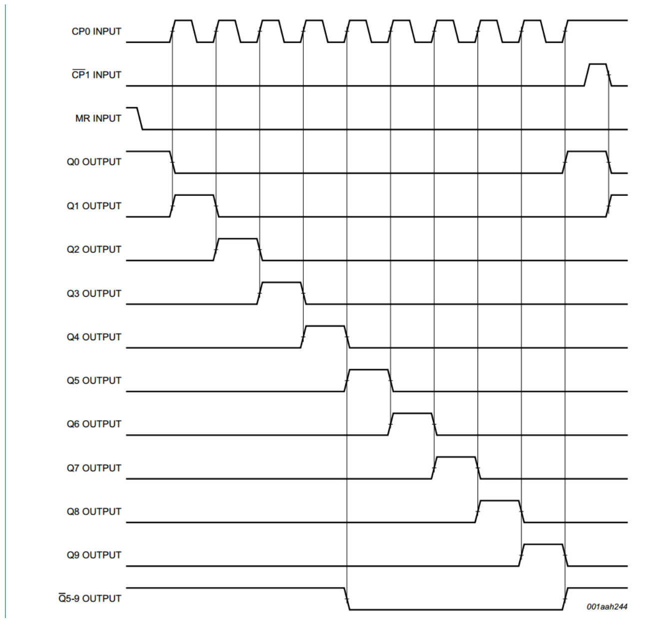


Figure 5: Clock - Decade Counter Pulse Relationship
The clock input pulse is shown as the highest signal in Figure 5. The HIGH and LOW times of the period can be altered by changing the resistance values in the 555 circuit appropriately, as shown by the 555-timer equations above. Also shown is the consecutive nature of the decade counter's outputs. As shown in the pulse diagram, each of the outputs, from 0 to 9, is shifted from LOW to HIGH voltage on the rising edge of the clock input, then shifted from HIGH to LOW on the next rising edge, effectively acting as a series of flip-flops.

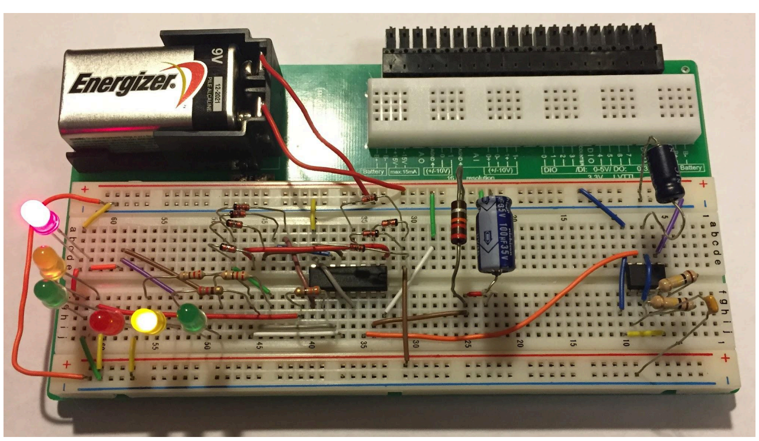
Using the total period calculation, we designed three main pulse experiments with various resistors. The total illumination of the yellow LED was measured as the total clock period because it was connected to only one of the output pins of the decade counter, so it lit up for one full pulse period that was equal to the total clock period of the 555-timer. We timed the illumination of the yellow LED using a stopwatch; however, this opened the possibility of human error in accurately starting and stopping the timer. To combat this human error, we applied an uncertainty of ± 100 milliseconds to every measurement of the LED's illumination. This uncertainty was agreed upon by estimating the maximum delay in the stopwatch user's button pressing. The results of our test are shown in Table 1 (A 10µF capacitor was used in every combination).

Resistor Values	Calculated Pulse Period	Measured Pulse Period (Yellow LED)	Red/Green Illumination
2 x 20 k***Ω***	0.42 s	0.4 ± 0.1	No
2 x 100k***Ω***	2.08 s	2.1 ± 0.1	No
2 x 500k***Ω***	10.40 s	10.4 ± 0.1	No

Table 1: 555-Timer Period Experimentation
The total period of each pulse can be found using the equation shown above, which is dependent upon the values placed in the 555-Timer circuit. A 10μF capacitor was used in every iteration. The results of three separate resistor combinations are shown. The total illumination time of the yellow LED was measured due to its connection to only one output of the decade counter.

The results of our timing of the yellow LED were consistent with the calculated values of resistance for each resistor combination, meaning our experiment was conducted accurately; however, it appeared that the variance of the clock pulse period did not have an effect on the illumination of the red and green LED's. We therefore interpreted this particular experiment's results to mean that the output pulse period of each of the decade counter's outputs can be accurately altered, but that the operation of the decade counter itself is unaffected. Instead of continuing to explore very small and very large pulse periods, though, we decided to move on in our experimentation and come back to this topic later if it presented additional challenges.

The next and final step in our testing investigated the interference of the decade counter's outputs with one another when wired in parallel. In this step, we simply added wired switching diodes from each of the decade counter's outputs to its respective LED in an effort to control the direction of current flow from output to LED. This process is described in detail in the *How We Interpreted the Data* subsection of the *Testing Methodology* section. The use of diodes turned out to be the final solution to our project, and after incorporating them in the circuit, we were able to build our final working model. The circuit diagram and physical layout of our final project are shown below.



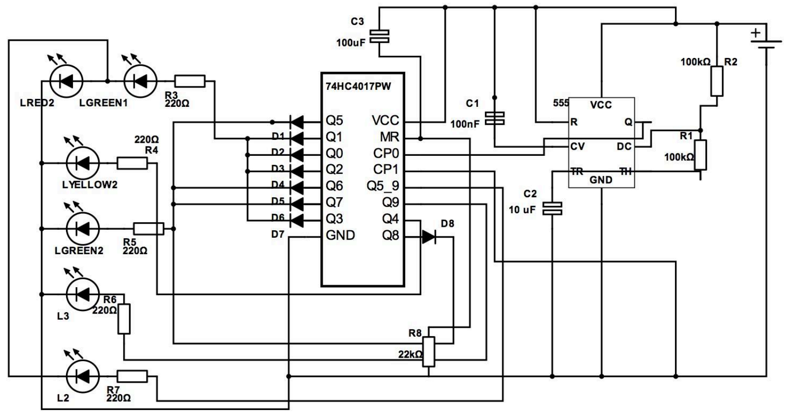


Figure 6: Final Circuit Diagram and Layout
The final layout of our project on a breadboard is shown above, mirroring the final circuit diagram shown below. In both images, the 555-timer circuit is on the right side of the circuit, the decade counter is positioned in the middle, and the LED system is positioned to the left.

CONCLUSION

Our design completely met our expectations as we set up the two traffic lights to work in synchronization. We ran into some difficulty in causing the green light to light up along with synchronizing the other traffic light. However, once we set up the diodes in the circuit, it began working. In this project, we learned that a group should always plan out their project completely before starting because one can never know what difficulties the group could run into if you do not plan and estimate the time of the entire project. We did not plan out the synchronization of the two traffic lights and the abundant amount of time it would take us. This resulted in us spending a lot of time in the last few days trying to complete this step. We could improve in the future by making the traffic light more realistic by providing a short, one second gap after the first light turns red and before the second light turns green. This would reduce the risk of car accidents for cars running late yellow lights.

An extension of this project if we had more time would be to create a 4 way traffic light for two way streets. Another extension could be to create a more efficient traffic light which controlled traffic based on light sensors under the road that turned the appropriate light green based on which road cars were present on. This would require significantly more time and more complex logic as four traffic lights would have been needed along with extra diodes and light sensors.

ILLUSTRATION CREDITS

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4. “Figure 5: Clock-Decade Counter Pulse Relationship”: Texas Instruments, and Harris Semiconductor. *CD4017B, CD4022B Types CMOS Counters/Dividers*. *4017B, 4022B Types (Rev. C)*. Texas Instruments, Feb. 2004. Web.

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