Non Exam Assessment

TASK **2**

Pedestrian Crossing

2024

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Problem description

A pedestrian crossing for a single carriageway road which is compliant with UK government planning guidelines. I am going to design a system capable of having 2 traffic lights – one for each direction – as well as an indicator for pedestrians. This system will also prevent the lights from changing instantly if a car has been recently detected at the crossing or if pedestrians have already been able to cross within a period.

Research Results

Monostable Timers

I know that I will need at least one monostable timer in my project, so I decided to research potential solutions for this.

In class we had learnt about using a resistor and capacitor in parallel as a basic monostable – as below. When learning about the RC circuit there were issues with loading that were discussed so I will investigate this during my practical investigation.

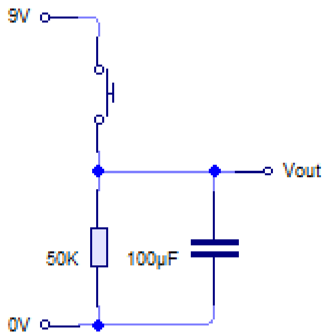

Figure 1: Basic RC Circuit

We also learnt about using a 555 as a monostable timer, this didn't have the loading issues described before but would be more expensive than using just a resistor and capacitor. It is however much simpler than the last option that I found while researching and only slightly more complicated than the basic RC solution.

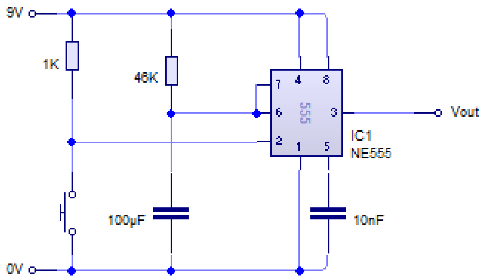

Figure 2: 555 Monostable Timer

I decided to see if there were any other options for monostable timers and learnt about the monostable multivibrator, it uses two transistors with feedback between them to produce a timer. It does still rely on RC circuits so may be subjected to the same loading problems.

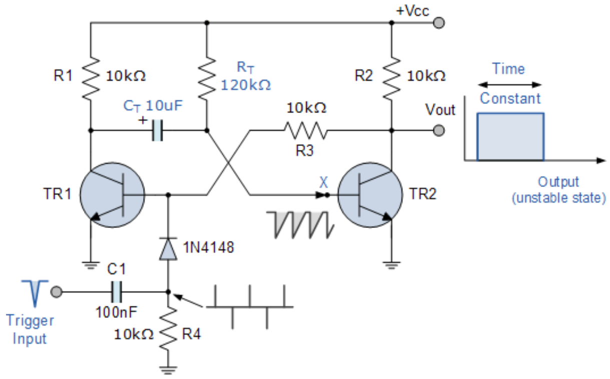

Figure 3: Monostable Multivibrator Reference

(ElectronicsTutorials, n.d.)

While this circuit may cost less than the 555 timer it is much more complicated and the time it would take to get it working would not out way the small cost benefit that using the multi-vibrator would provide.

Detecting Vehicles

Typically traffic light systems use induction loops in the road to detect vehicles approaching. This would not be practical to build within the lab for several reasons including the fact they are very sensitive, expensive to build and hard to work with; usually requiring several loops over a large area to detect vehicles. Instead, I'm going to use infrared light to detect a vehicle breaking a beam across the road.

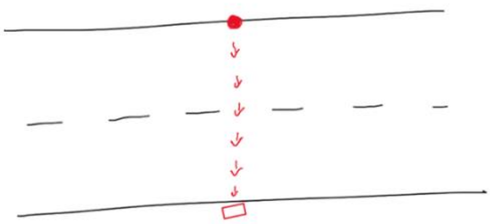

Figure 4: Example of Beam Across Carriageway

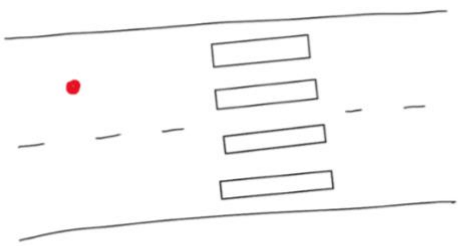

Figure 5: Example of fixed sensor embedded in Carriageway

Above are two diagrams with the different ways I could detect a vehicle using infrared light. The top diagram shows sending a beam across from one side of the road to the other to detect if the beam is broken. This would need components on both sides of the road; this could be modelled by a photo-interrupter. The other option would be using an RPR220 in the middle of the lane to detect a vehicle going over it. Using an RPR220 would make the circuit less likely to detect false readings from people in the road but if a car didn't go over it, they may not trigger it so you may need a couple per lane.

Vehicle Ride Height

In the UK vehicles must be at least 135mm above the road (SpeedyTests, n.d.), while the average for cars is between 160mm and 170mm (Anon., n.d.). This is useful if I choose to use the RPR220 approach of having sensors embedded in the carriageway to detect vehicles above them. If so I would use a value of ~165mm as that would account for all cars of average height as well as cars below that.

Traffic Light Sequence

In the UK the following sequence is used for traffic lights:

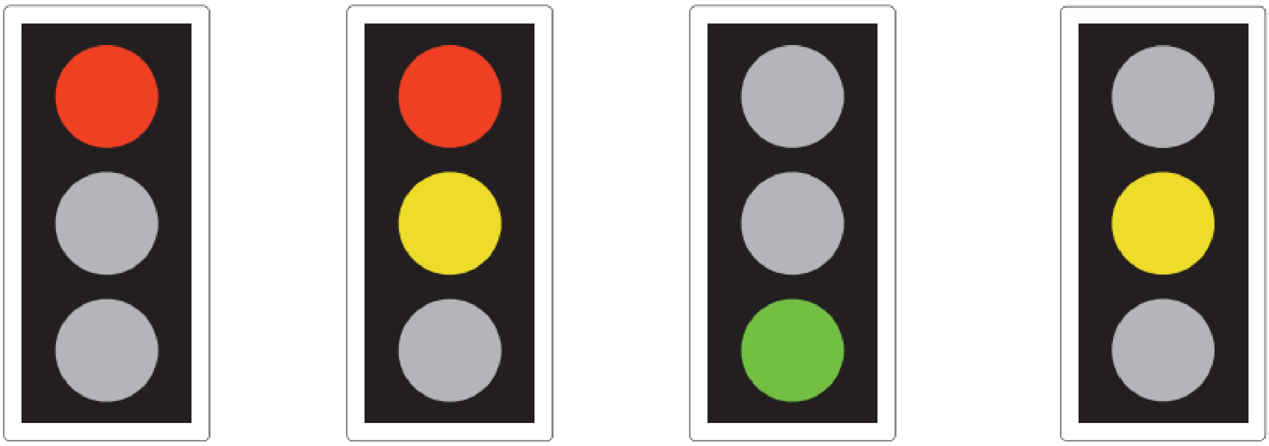

Figure 6: UK Traffic Light Sequence from Highway Code

(DVLA, n.d.)

The sequence is in the order right to left loping back round at the end. Each light has a different meaning as described in the highway code below:

RED means 'Stop'. Wait behind the stop line on the carriageway	RED AND AMBER also means 'Stop'. Do not pass through or start until GREEN shows	GREEN means you may go on if the way is clear. Take special care if you intend to turn left or right and give way to pedestrians who are crossing	AMBER means 'Stop' at the stop line. You may go on only if the AMBER appears after you have crossed the stop line or are so close to it that to pull up might cause an accident

Figure 7: Traffic Light State Descriptions

This is useful for my project as I know which order I need to display the lights in. By "default" the lights should be green allows traffic to flow along the carriageway until a pedestrian is crossing – at which point it can cycle through to red before waiting for a fixed period and cycling back to green.

Pedestrian Crossing Timings

There is extensive documentation from the Government and local authorities on how roads should be designed as well as how traffic signals should operate. Knowing this I decided to look for a "handbook" or other official documentation and found two different manuals for road design. The first is "The Design of Pedestrian Crossings" produced by the Department for Transport in April of 1995 and shows the following table,

Table 4 PELICAN CROSSINGS - OPERATIONAL CYCLE & TIMINGS

PERIOD	SIGNALS SHOWN		TIMINGS (Seconds)
	TO PEDESTRIANS	TO VEHICLES	
A	Red Standing Figure (wait)	Steady Green (proceed if way is clear)	20-60 (fixed) 6-60 (VA)
B	Red Standing Figure	Steady Amber (stop unless not safe to do so)	3 (Mandatory)
C	Red Standing Figure	Steady Red (stop, wait behind Stop line on carriageway)	1 to 3
D	Green Walking Figure with audible signal if provided (cross with care)	Steady Red	4 to 7 (in some circumstances plus 2)
E	Flashing Green Figure (do not start to cross)	Steady Red	0 or 2
F	Flashing Green Figure	Flashing Amber (give way to pedestrians on the crossing - they have priority)	6 to 18
G	Red Standing Figure	Flashing Amber	1 or 2

Figure 8: 1995 Pelican Crossings Table

(Department For Transport, 1995)

This table shows more states that are planned for my project so to simplify the figures I derived the following table:

State	Signals Shows		Timings (seconds)
	To Pedestrians	To Vehicles	
1	Red	Green	N/A
2	Red	Amber	3
3	Red	Red	1 – 3
4	Green	Red	4 – 7
5	Red	Red & Amber	1 – 2

Table 1: Pedestrian Crossing Timings

The updated version of this manual was published in 2019 as Chapter 6 of the "Traffic signs manual" again produced by the Department of Transport as shown on the next page.

Table 11-1 Sequences and timings for farside pedestrian facilities at signal-controlled junctions

Period P	Farside pedestrian signal	Vehicle signal	period duration (seconds)
1	Red	Green	Dependent upon cycle time.
2	Red	Amber	3
3	Red	Red	Minimum to clear traffic in the junction.
4	Green (invitation to cross)	Red	6-12, depending upon carriageway width and pedestrian density.
5	Black-out (clearance)	Red	3-15, may be extendable where on-crossing detection is used Where pedestrian countdown is used, this period is fixed and cannot be extended.
6	Red	Red	1-3
7	Red	Red + Amber	2

Table 11-2 Sequences and timings for nearside pedestrian facilities at signal-controlled junctions

Period P	Nearside pedestrian signal	Vehicle signal	period duration (seconds)
1	Red	Green	Dependent upon cycle time.
2	Red	Amber	3
3	Red	Red	Minimum to clear traffic in the junction.
4	Green	Red	4-9
5	Red	Red	1-5
6	Red	Red	0-30 (pedestrian extendable period)
7	Red	Red + Amber	2

Figure 9: 2019 Pedestrian Crossings Timing Tables

(Department for Transport, 2019)

This time the tables were updated to include different timing for nearside and farside allowing for a wider range of configurations. However, the values still aligned with those displayed in Table 1 from this report.

Practical investigation results

Monostable Accuracy Investigation

For my project I need to have an accurate monostable timer, to find out which is the best I researched the 3 different timing circuits I found and looked at which I could get closest to 3 seconds – the time that the system would account for a vehicle to cross the crossing safely.

First, I tested the RC solution using circuit with a variable resistor so that the load could be varied between 0Ω and 100kΩ. The circuit was setup as below with some values slightly altered due to what was available in the lab.

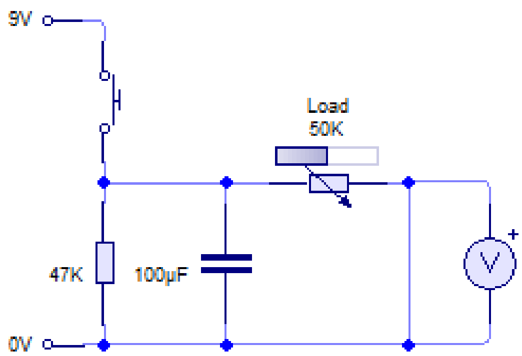

Figure 10: Loaded RC Circuit

Resistance/kΩ	Attempt	V_{out}/volts	Time High/seconds	Percentage difference
∞	1	9.09	3.43	-
	2	9.09	3.56	-
	3	9.09	3.38	-
	Average	9.09	3.46	+15.2%
1	1	8.98	~0.50	-
	2	8.89	~0.25	-
	3	8.99	~0.46	-
	Average	8.95	0.40	-86.6%
4.7	1	9.02	~1.08	-
	2	9.05	~1.06	-
	3	9.03	~0.92	-
	Average	9.03	1.02	-66%

Table 2: Loaded RC Investigation Results

The circuit was tested to see how long it produced a digital high signal for meaning V_{out} has to be greater than or equal to $1/2V_s$ [$1/2V_s = 9 * 0.5 = 4.5$v]. This should be for roughly 3.3 seconds [$T=RC$, $T=(47x10^3)(100x10^{-6})$, $T=4.7$s, $1/2V_s$ is at $0.7T$, $0.7T = (4.7)(0.7) = 3.29$].

The table shows that while the V_{out} value with a load starts the same it drops very quickly when a small load is applied. This means I'd either need to use a different timing circuit or add a buffer to V_{out} before adding a load as shown the in diagram on the next page.

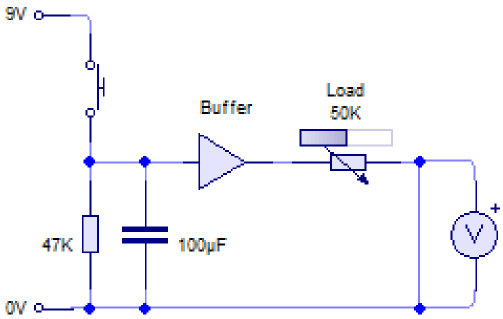

Figure 11: Loaded RC Circuit with Buffer

The buffer should remove the loading problem; however, buffers cannot produce much current so would only be able to power an LED. To power anything else e.g. Lamp/Buzzer I would need to add a MOSFET or Transistor as well. The buffer can also only produce logic high or logic low which means that the V_{load} can only be used by digital systems. You could use a voltage follower instead but this uses an opamp which has the same problems as the buffer with not producing enough current.

Resistance/kΩ	Attempt	Time High/seconds	Current/mA	Percentage Difference
∞	1	3.68	0	-
	2	3.46	0	-
	3	3.32	0	-
	Average	3.49	0	+16.2%
1	1	3.65	18.03	-
	2	2.96	17.98	-
	3	3.42	18.05	-
4.7	Average	3.34	18.02	+11.4%
	1	3.45	2.71	-
	2	3.26	2.71	-
	3	3.63	2.69	-
	Average	3.44	2.71	+14.9%

Table 3: Buffered and Loaded RC Circuit Investigation Results

As predicted, there was very little current, and the current dropped as the load was increased. The value of Vout from the buffer was slightly changed when there was a load [R_l=4.7kΩ, V_{out}=8.75v and R_l=1kΩ, V_{out}=7.58]. The buffer did remove the problem where the time was different with a load attached but the little current does mean it would be hard to use if you needed to power another component or subsystem. This also means that the monostable multivibrator is probably susceptible to the same loading problems so would need multiple buffers within it to allow for a load to be connected.

Testing the 555 circuit I was aiming for a high time of similar to the RC circuit – 3.3 seconds. This would let me compare the two more fairly. On the next page is the circuit which was built to test the 555.

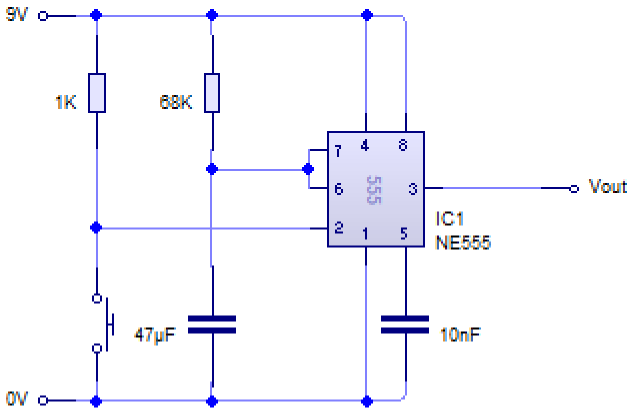

Figure 12: Loaded 555 Circuit

The load was connected between V_{out} and 0v with a voltmeter placed in parallel with the attached load.

Due to components available in the lab I had to use slightly different values for the resistor and capacitor than were calculated for the ideal 3.3 seconds, meaning that this circuit should be high for 3.52 seconds. [$T=1.1(68\times10^3)(47\times10^{-6})$, $T=3.5156$]

While the circuit it high it should produce 9v at V_{out} and I have measured the current to compare it to the output of the RC circuit.

Resistance/kΩ	Attempt	V_{out}/volts	Current/mA	Time High/seconds
∞	1	8.44	0	3.48
	2	8.44	0	3.53
	3	8.44	0	3.25
	Average	8.44	0	3.42
1	1	7.55	11.34	3.66
	2	7.55	11.35	3.79
	3	7.54	11.30	3.45
	Average	7.55	11.33	3.63
4.7	1	7.64	2.03	3.45
	2	7.64	2.02	3.56
	3	7.64	2.03	3.54
	Average	7.64	2.03	3.51

Table 4: 555 Timer Investigation Results

While the values for the current from the 555 are lower or the same here, the 555 has an amplifier inside of it allowing for current to be provided with low loads such as a loudspeaker which could be as low as 8Ω. For this reason, I am going to use the 555 circuits for my timing subsystems because they don't have any problems with loads, can provide accurate times – within the constraints of the capacitors and resistors in the lab – and are easy to build.

Infrared Object Detection

To detect if a vehicle is in the road near to the crossing so that the traffic lights aren't constantly stopping the traffic. The two options I have from my research are the RPR220 and a photo-interrupter. I wanted to test how each operates and the output at V_{out} when a "car" is covering it.

First, I'm going to test the RPR220, it requires a protective resistor for the diode and a resistor for the phototransistor to vary the results at V_{out}. I calculated the protective resistor at 693Ω idea [$R=10.4/(15\times10^{-3})$] which gave me 820Ω as an E24 value in the lab.

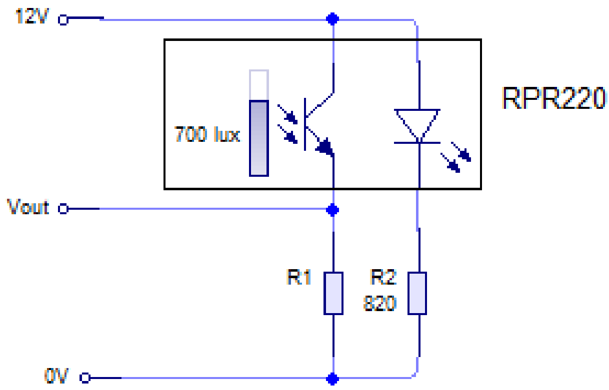

Figure 13: Phototransistor and Infrared LED Circuit

I am going to test 1kΩ, 100kΩ and 1MΩ for the values of R1 to see how Vout changes.

Resistor/kΩ	Attempt	Uncovered/volts	Covered/volts
1	1	0	0.04
	2	0.01	0.05
	3	0	0.02
	Average	0.003	0.036
100	1	1.57	11.90
	2	1.56	11.91
	3	1.76	11.91
	Average	1.63	11.907
1000	1	11.75	11.97
	2	11.40	11.96
	3	11.38	11.88
	Average	11.51	11.93

Table 5: RPR220 Investigation Results

The testing shows that the RPR220 with an 100kΩ resistor works best for my use case which would be with a comparator/op-amp so that the circuit could produce a digital value to be used by logic gates.

The other option I found when researching was a photo-interrupter (611S), it works almost identically to the RPR220 but doesn't detect anything that isn't between the prongs. This is to simulate having an infra-red beam across the road. The collector of the phototransistor cannot exceed 15ma meaning that if you need to add a load it should be buffered first as to not damage the transistor. To test this component, I have built the circuit below and passed a piece of card between the infrared-led and the phototransistor to see if it switches.

The LED needed a protective resistor which was calculated as 1.2kΩ, [$R=V/I$, $R=12/10x10^{-3}$, $R=1200$]. To account for any tolerance, I used a 1.5kΩ which should give the current through the LED as 8mA [$I=V/R$, $I=12/1.5x10^3$, $I=8x10^{-3}$] which is better as it is less than the max of 10mA.

Attempt	No Card Blocking Light/volts	Card Blocking Light/volts
1	4.53	3.77
2	4.54	3.78
3	4.53	3.78

Table 6: Initial 611S Investigation Results

The resistor value of 100k didn't work well so I decided to try 2 new values: 10kΩ and 1MΩ

Resistor/kΩ	Attempt	No Card Blocking/volts	Card Blocking/volts
10	1	3.64	3.60
	2	3.64	3.60
	3	3.66	3.60
	Average	3.647	3.60
1000	1	8.30	4.87
	2	8.31	4.88
	3	8.35	4.97
	Average	8.32	4.91

Table 7: Further 611S Investigation Results

After testing the two new resistor values, I decided that 1MΩ was the best value as it had the largest range between the card blocking the LED and the LED not being blocked.

After testing both options, I decided I would use the RPR220 as it would be easier to work with and would only detect cars in the lane it is in.

Specifications

Quantitative Specifications		
	Specification Detail	Tolerance
1	Supply voltage should be 0V and +12V	±0.5v
2a	Maximum current drawn by system should be 377mA	±2.5%
2b	Maximum power drawn by system must be 4.53W	±5%
3a	Monostable period for vehicle detection timer should be 3 seconds	±10%
3b	Monostable period for “timeout” should be 30seconds	±15%
4	Vehicles should be detected if they are within 160mm of sensor	±5mm
5	Each stage of traffic light sequence should take at least 3 seconds	+5%
6	Pedestrians should be allowed to cross for 7 seconds	±2.5%

Quantitative Specification	
1	Traffic lights should follow the British Highway Code sequence
2	Pedestrians should have a visual indication when it is or isn’t safe to cross
3	Pedestrians should have a visual indication when the system is waiting to let them cross
4	There should be a button that pedestrians can press to let them cross
5	The system should not be able to be placed in a stuck state
6	Vehicle detection shouldn’t be affected by ambient light

Justification of Specification Points

Quantitative Justifications

(1) Potential dividers within the circuit have been calculated on with the presumption that the circuit will have a 12v supply. So to ensure there isn't a knock on affect the power supply should attempt to maintain the 12v. Most components used within the circuit can support up to ±15v as a supply so the value of 12 provides enough room for tolerance either way.

(2)

a) My circuit has the following components:
   i. 4x 555 IC Draws 10mA each = 40mA
   ii. 6x 4011 IC Draws 50mA each = 300mA
   iii. 2x 4013 IC Draws 10mA each = 20mA
   iv. 1x 4510 IC Draws 10mA each = 10mA
   v. 1x 741 Op-amp Draws 2mA each = 4mA
   vi. 6x LEDs Draws 0.5mA each = 3mA

   Total = 377mA

b) Power = V * I
   = 12 * 377mA
   = 4.524W

(3) Pedestrian crossings are typically on roads with speeds between 20 and 50 mph in the UK. Since for a speed over 60 you would need a dual carriageway road which this system is not designed for. Most build up areas get a speed limit of 20 or 30 mph which is the target consumer of the system. Presuming that the pedestrian crossing is no wider than 2.5m – in the direction that cars travel on the carriageway – any car could have safely cleared the junction within the 3 seconds.

(4) As my research showed the average ride height of a car was between 160mm and 170mm and the legal minimum for vehicle ride hight is 135mm, detecting any vehicle lower than 160mm ±5mm means that most average vehicles should be detected with the only exceptions being large vehicles such as plant or agricultural equipment which pedestrians are likely to see.

(5) 3 seconds is within the allowed range for the 2019 suggested values for Traffic Signals so having the value for each period be the same time simplifies circuit construction. The length must also be **at least** meaning that if it is longer there is little to no affect. The only exception is the walking stage which should be at least 7 seconds as per specification point 6.

(6) Pedestrians should be given at least 7 seconds to cross as per The Traffic Signs manual. The 2019 version allows for 4-9 seconds placing 7 (with a suitable ±2.5% tolerance) well within those permitted values.

Qualitative Justifications

(1) The crossing is designed for use within the UK and as such should follow the Highway Code sequence of Green, Amber, Red, Red & Amber, Green so that drivers understand what the signals mean.

(2) Pedestrians are used to visual indicators – like vehicles – of whether it is safe to cross or not. They could try to read the traffic lights, but they will not be positioned in an optimal place for pedestrians. The Traffic Signals Manual from 2019 has the following example for a "pedestrian demand unit":

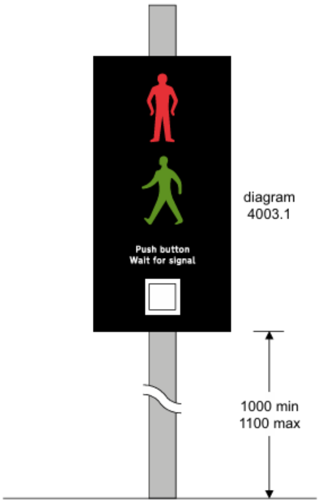

Figure 14: Pedestrian Demand Unit from the Traffic Signals Manual

(3) Pedestrians should have some way to know that the system is trying to process a crossing request the easiest way to do this is a visual indicator around/next to the button used to request a crossing, a typical design is shown below as further justification.

Figure 15: AGD964 Combined Pedestrian Signal

(4) Pedestrians need a way to request to cross at a crossing which isn't automated. i.e. vehicles are allowed to flow continuously until a pedestrian request to cross. This could be done with automated detection techniques but the easiest way that would be familiar to most people would be a push button which is then latched on as shown in Figure 15 above.
(5) When the traffic lights are turned on, they should not be able to be in a state that won't continue into a valid light pattern, this is so that the traffic lights are always directing traffic in a valid way preventing crashes or traffic problems in the case of a power-cut where power is restored automatically and not by someone manually diagnosing the circuit.
(6) Vehicles should be detected the same way when it's day and when at night so infrared light should be used as it will not be affected by the ambient light. If ambient light could affect detection, then the circuit may constantly be in a "stuck" state at night when the sensor isn't receiving the usual daylight.

Details of complete system

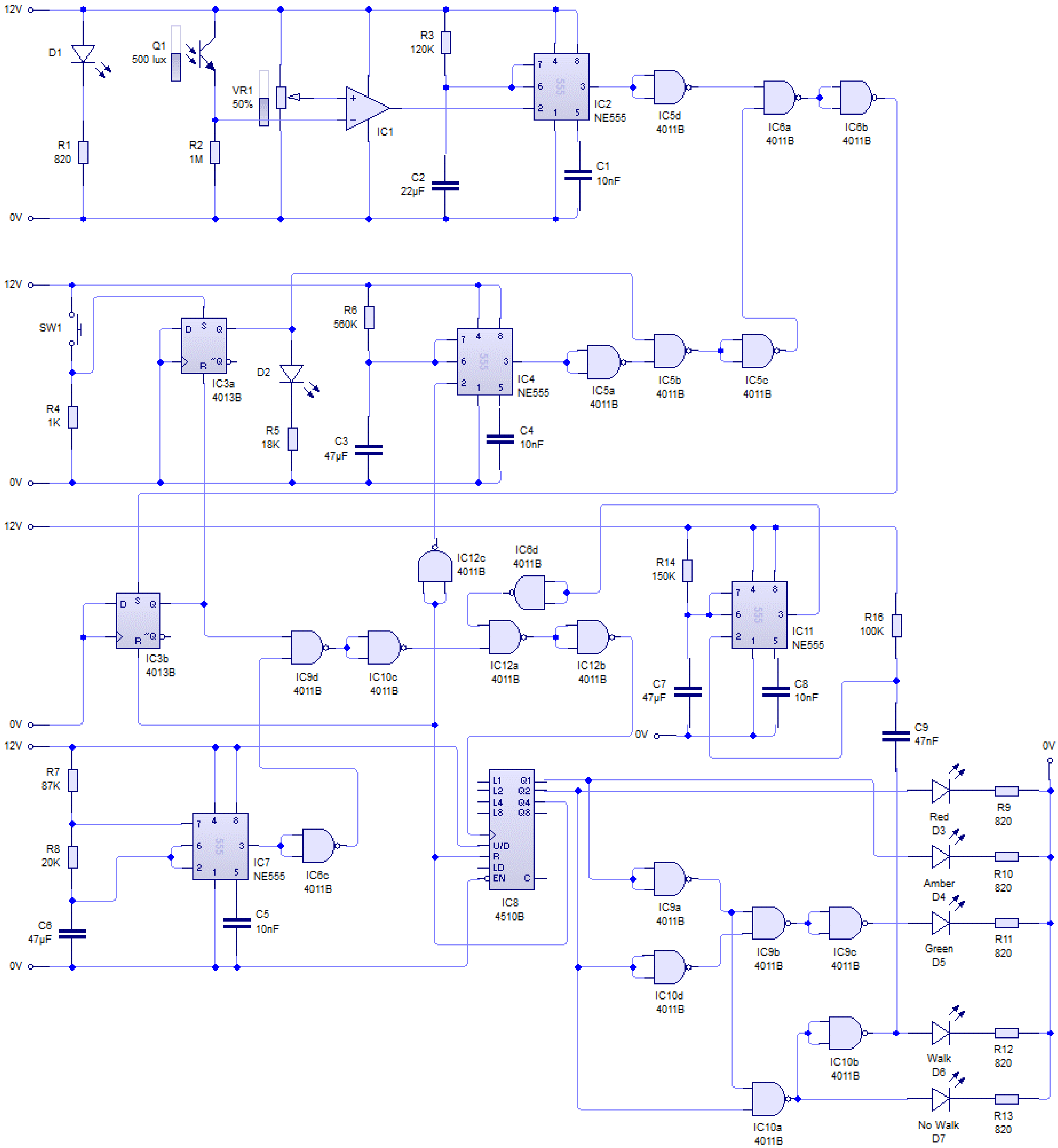

Figure 16: Full System Circuit Design

Vehicle Detection

The vehicle detection subsystem uses an RPR220 to detect vehicles moving in the lane above it. The RPR220 was selected as it had a larger range of values that could be used later to decide if there was or wasn't a car in the lane.

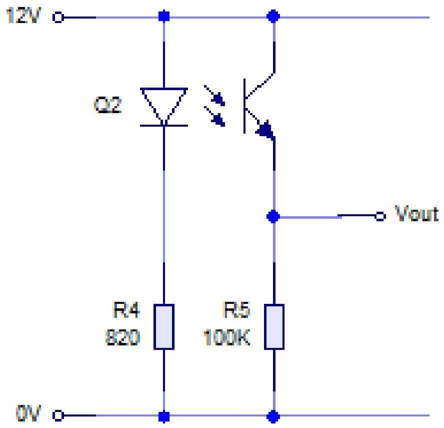

Figure 17: Vehicle Detection Subsystem

V_{out} should be a value between 0v and 12v which represents how far away an object is above the RPR220. The system shouldn't be affected by ambient light conditions as it uses infra-red.

Distance Comparator

This subsystem is used to take V_{out} from the vehicle detection subsystem and convert the analogue signal to a digital signal as to if there is or isn't a vehicle above the sensor. It has the inverting input as V_{out} from the vehicle detection subsystem and the non-inverting input as a variable resistor so that the switching point can be altered to effectively detect vehicles. Originally the inputs were as above meaning that the output of the op-amp would be high when a vehicle has passed over the sensor. However, it needed to be low to trigger the 555 Monostable timer it was connected to. To solve this, I switched the inverting and non-inverting connections to the op-amp. See the first diagram below for the original and the second diagram for the changed version.

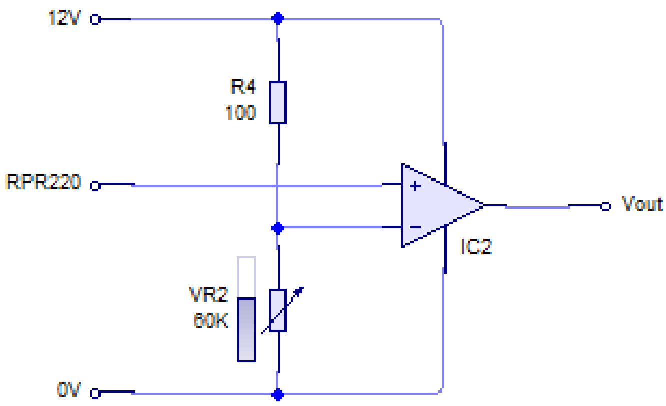

Figure 18: Planned Distance Comparator Subsystem

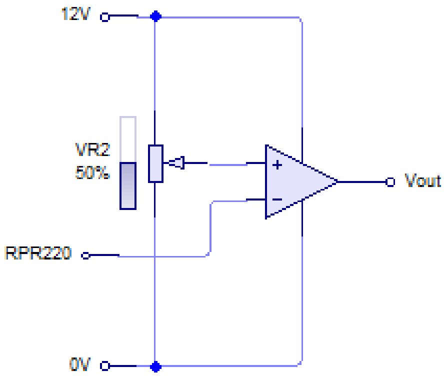

Figure 19: Revised Distance Comparator Subsystem

Monostable Timer (Car Tracking)

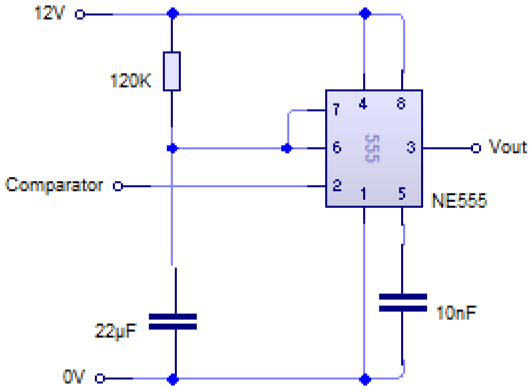

Figure 20: Monostable Timer (Car Holding Period)

This subsystem is a monostable timer to allow cars time to pass through the junction after being detected. It is made out of a 555 monostable timer and uses the voltage drop from the comparator as the trigger input. If a car is stopped over the sensor the trigger pin will be kept low and the output will be kept high; this is okay as it has the intended effect of not letting pedestrians cross when it would potentially be unsafe due to a car.

Push Button Latch

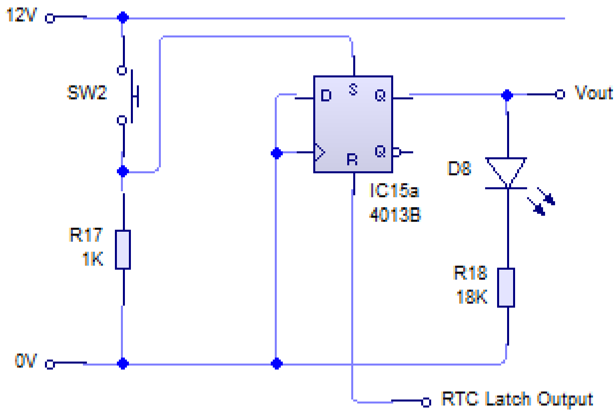

Figure 21: Push Button Latch and Indicator

This is a latch for request to cross button. It means that when a pedestrian presses the button to cross they don't need to hold it down until it is suitable to cross. When the button has been pressed the red LED will stay on with a protective resistor in place to limit the current to ~0.5mA. The Flip Flop is set by the button and then reset by the request to cross latch when the lights begin to change.

Push Button

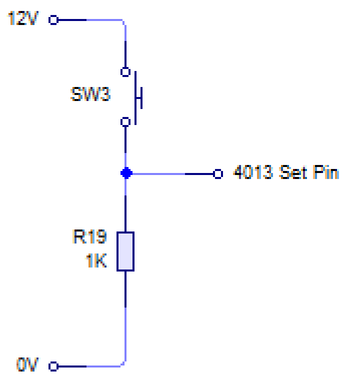

Figure 22: Push Button for Latch

The switch is pulled low so that when pressed it is taken high (12v). This switch isn't debounced as setting the Flip Flop multiple times has no effect.

Monostable Timer (Required Wait)

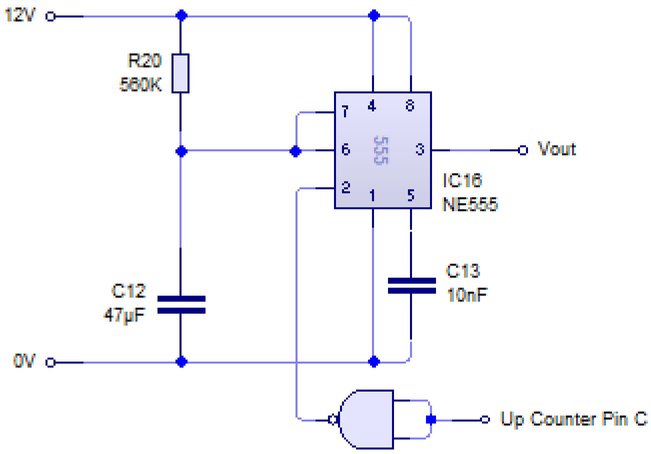

Figure 23: Required Wait Monostable Subsystem with Up Counter Interface

This subsystem is a monostable made out of a 555 to ensure lights can't change again for at least 30 seconds after the last time that pedestrians were allowed to cross. The monostable is triggered by the up-counter resetting. The up-counter requires a high input to its reset pin while the 555 requires a low pulse shorter than the monostable period so a nand gate is used to invert the pulse that resets the counter.

Request to Cross Logic

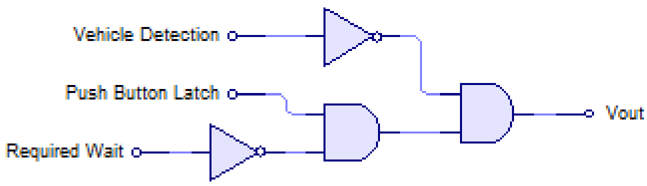

Figure 24: Required Logic for valid Request to Cross

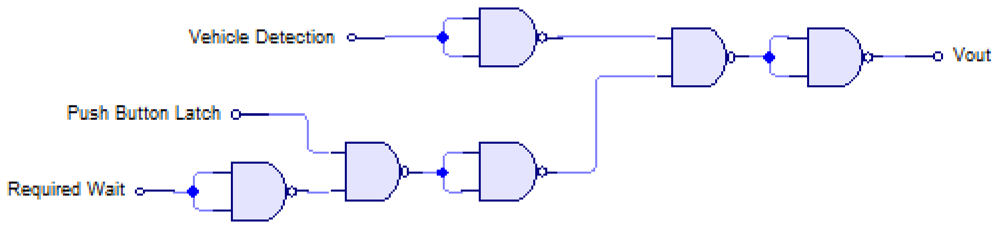

Figure 25: NAND Conversion of Request to Cross Logic

The logic required to figure out if a request to cross can be processed by the system is as follows:

$$Q = \overline{Vehicle} \cdot \overline{Required\ Wait} \cdot (Button\ Pressed)$$

Figure 26: Expression for Request to Cross Logic

It could be built out of the required logic gates but there are multiple logic systems within the circuit so to save space it was converted into only NAND gates which is shown in the second figure above.

Request to Cross Latch

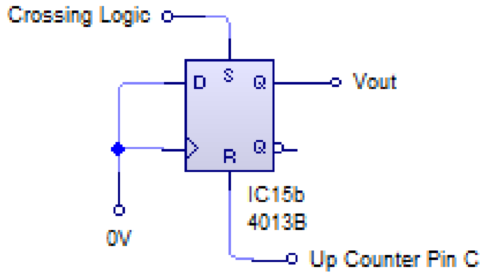

Figure 27: Request to Cross Latch

When the output from the request to cross logic is high it will set this flip flop. Once set it will then remain set to allow the clocking logic to run until the up counter is reset when this will also be reset.

Astable Timer (Counter Clock)

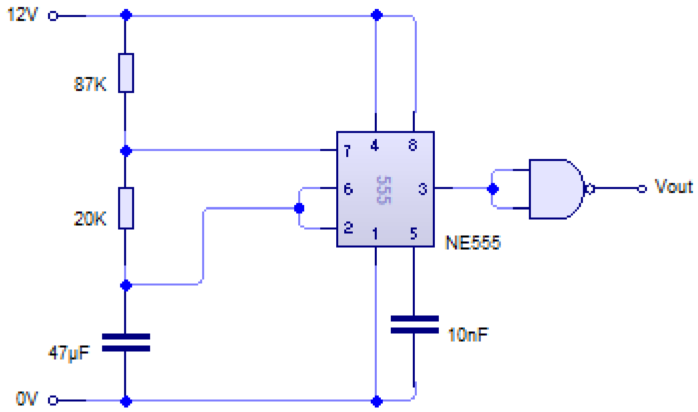

Figure 28: Astable 555 Timer with Inverter

Used as a pulse for the up counter in conjunction with the clock logic. A 555 Astable must have the high time longer than the low time, to solve this I calculated the high time to be the required low time and used an inverter to achieve the desired M:S ratio.

Monostable Timer (Crossing Period)

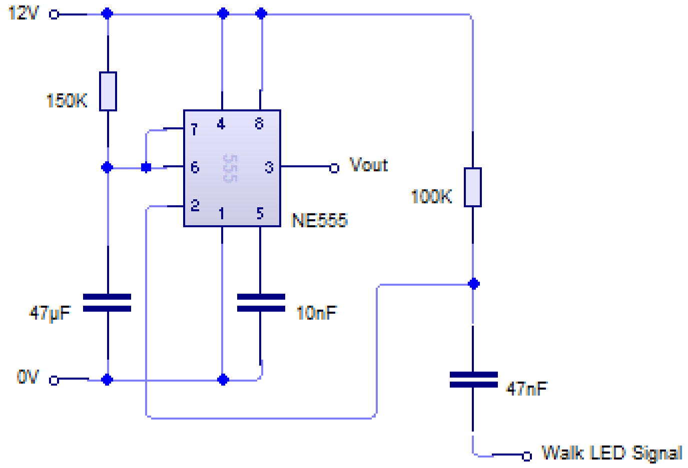

Figure 29: Monostable with Spike Generator on Trigger Pin

This monostable is triggered by the "Walk" light turning on, however a monostable needs the trigger pin to go low for shorter than the monostable period and it needs to be low not high. To solve this, I added a spike generator to the circuit so that the spike is low and not continuous while pedestrians can walk.

Clock Logic

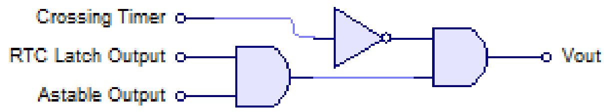

Figure 30: Require Logic for Clock

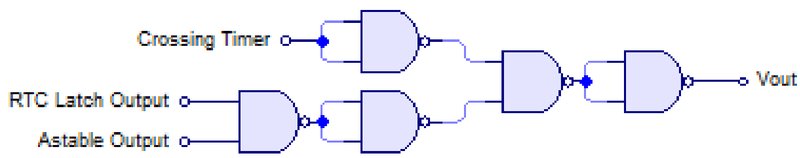

Figure 31: NAND Conversion of Clock logic

$$Q = \overline{Crossing\ Timer} \cdot ((RTC\ Latch) \cdot (Astable\ Output))$$

Figure 32: Clock Logic Expression

The clock logic is used as the input to the up counter, it combines the astable with the crossing request first so that the signal can only change when there is an active crossing request. Then as long as the "crossing timer" – time that pauses the change of state for at least 7 seconds – is not currently high the up counter can continue to clock.

Up Counter

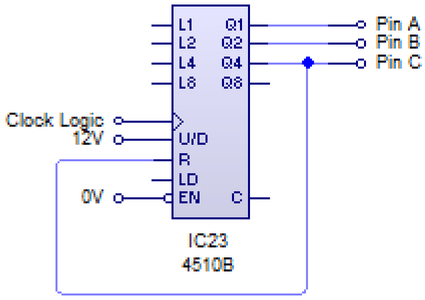

Figure 33: Up-counter with external connections shown

Used to progress though the states that the lights can hold. Pin C is connected to the Reset to loop the counter back to 0000 i.e. Green for vehicles and Red for pedestrians. The clock is from the clock logic circuit and the counter is setup as an up counter. This IC can also be used as a down counter but that functionality isn't used by my system.

LEDs & LED Logic

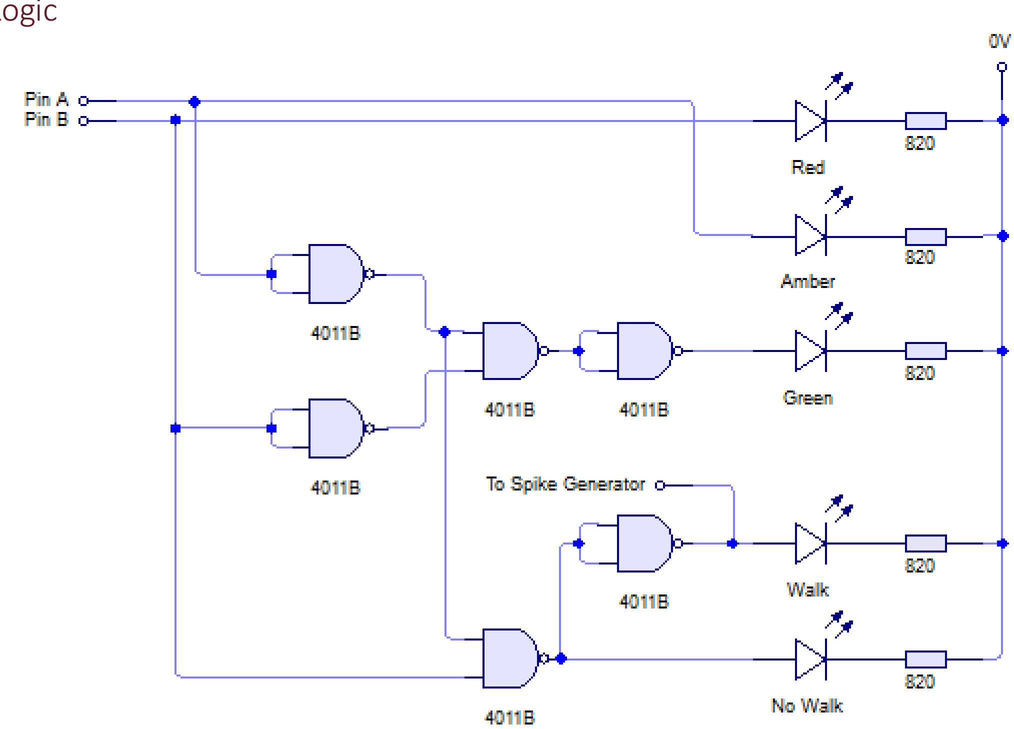

Figure 34: Logic from Up Counter and labelled LEDs

$$Red = B$$

Figure 35: Expression for Red Traffic Light

$$Amber = A$$

Figure 36: Expression for Amber Traffic Light

$$Green = \overline{A} \cdot \overline{B}$$

Figure 37: Expression for Green Traffic Light

$$Walk = B \cdot \overline{A}$$

Figure 38: Expression for Walk Indicator Light

$$\overline{Walk} = \overline{B \cdot \overline{A}}$$

Figure 39: Expression for Don't Walk Indicator Light

Above is the circuit which takes the 2 least significant bits of the up counter and displays the relevant output for that state. Below the circuit diagram are the Boolean expressions for all LEDs within the circuit. They follow the sequence set out in the specification – derived from the Highway Code's traffic light sequence.

Alternative Subsystem Solutions

Distance Comparator

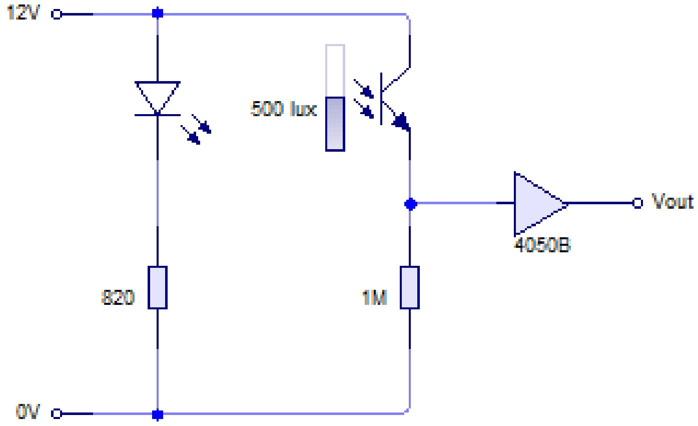

Figure 40: Alternative Distance Comparator using a 4050 Buffer IC

Instead of using a comparator I could have used a buffer to convert the analogue signal into a signal which is required for the rest of the system. A buffer can only produce V_S or V_0 since it is a logic gate, it would have a propagation delay and if the input signal was at least $0.5V_S$ then it would produce a logic 1 (high) and if not, it would produce a logic 0 (low).

Advantages:

- Less complicated since there are less components required.

Disadvantages:

- Switching thresholds cannot be configured to change the detection height.
- More propagation delay than an op-amp based comparator.

I chose to use the comparator with a potentiometer because I needed to be able to configure the high at which a vehicle would be detected and that isn't possible when using a buffer/not gate.

Astable Clock

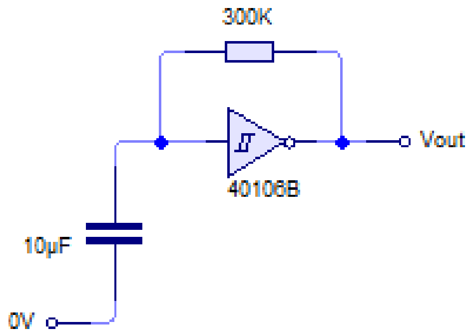

Figure 41: Alternative Astable using a Schmitt Inverter

The Schmitt astable is based on capacitor charging and discharging. If we assume the capacitor is initially uncharged then the output will be high (since it is inverting), the capacitor will then being charging through the resistor and increase Vin. Once Vin gets to the upper threshold of the Schmitt Vout will change and the capacitor will begin to discharge. This will then repeat to create an astable output. The first cycle will last longer than the others as the capacitor needs to charge up to the required threshold and will not fall to entirely empty on future cycles as shown in the graph on the next page.

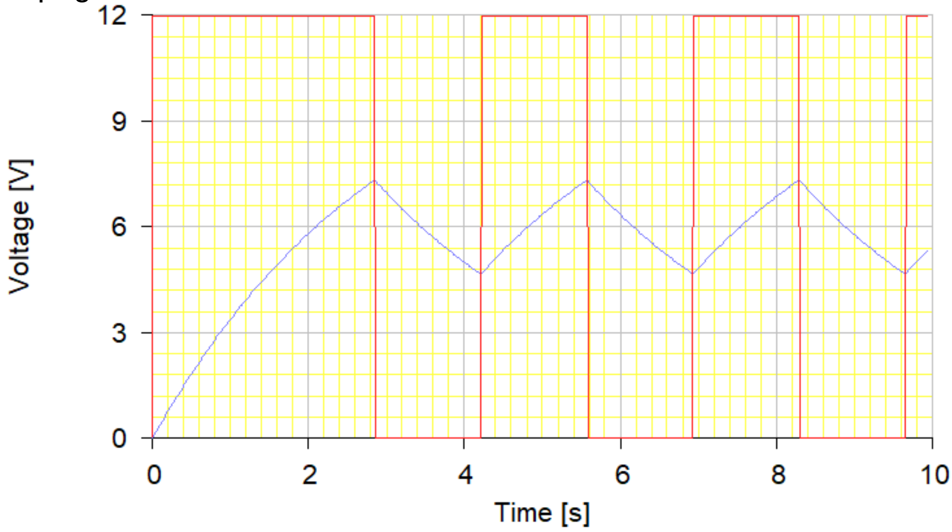

Figure 42: Sample Output from Schmitt Inverter Astable

The above graph shows the output from the astable timer – red line - with the resistor and capacitor calculated to have a time period of ~3 seconds. The blue line shows the output from the capacitor with both voltages compared to 0v. The first high period takes longer as the capacitor charges from 0v while the further pulses only go between the two switching voltages.

Advantages:

- Simpler circuit as it only needs 3 components while 555 based astable needs 2 capacitors, 2 resistors and the IC.

Disadvantages:

- Mark to space ration can only be 1:1 except for the first pulse.
- The first pulse is a non-uniform length.

I decided to use the 555 timer IC since it has a consistent mark to space ratio and allows for a mark to space ratio that isn't 1:1.

Up Counter and Logic

The up counter and it's associated logic could be replaced with a sequence generator which generates the correct sequence for the lights, below is the required sequence diagram assuming that (left to right) the bits are Red, Amber, Green:

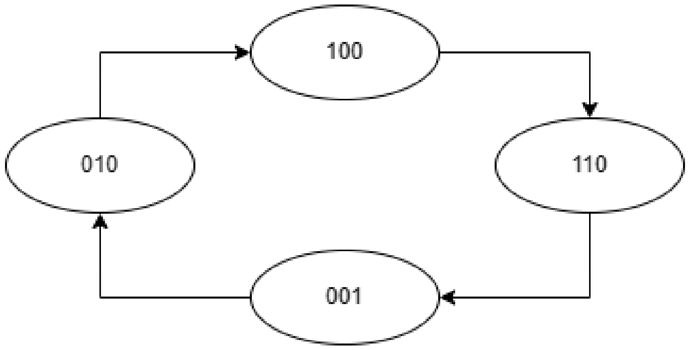

Figure 43: Sequence Diagram for Up Counter Alternative

The sequence generator will also need to account for unused states and clock them through to supported states meaning that the system would need to be clocked at startup until in the correct state. An example circuit diagram for the sequence generator is below:

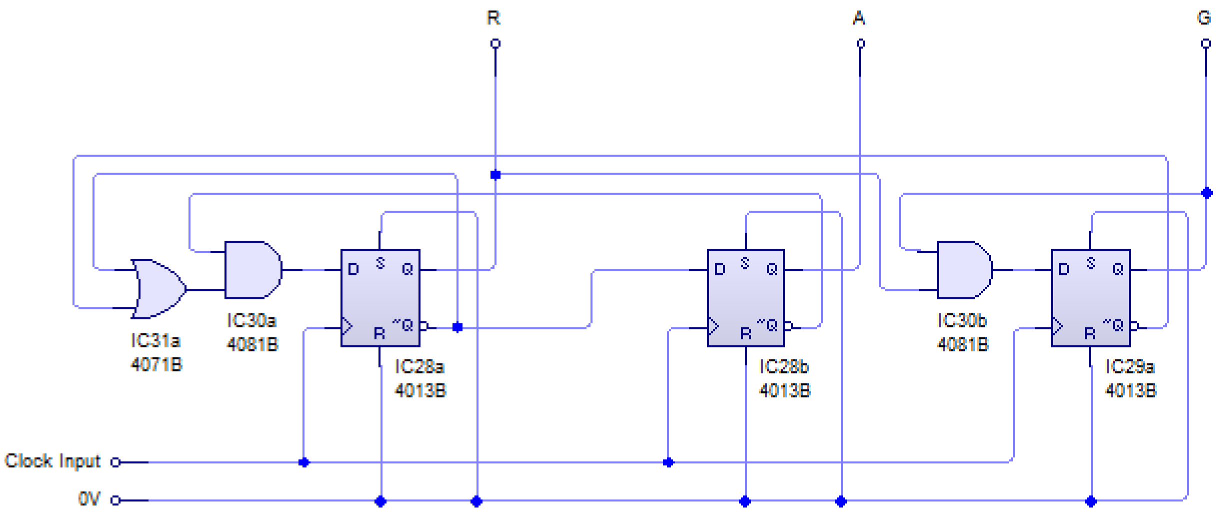

Figure 44: Sequence Generator Alternative Subsystem Diagram

The sequence generator is made of 3 flip flops which are clocked through in series by a shared clock, each time they are clocked the next value is copied in from the logic circuits and the outputs can be used to directly power the LEDs for the traffic signals.

The required working for the sequence generators logic is also included on the next page.

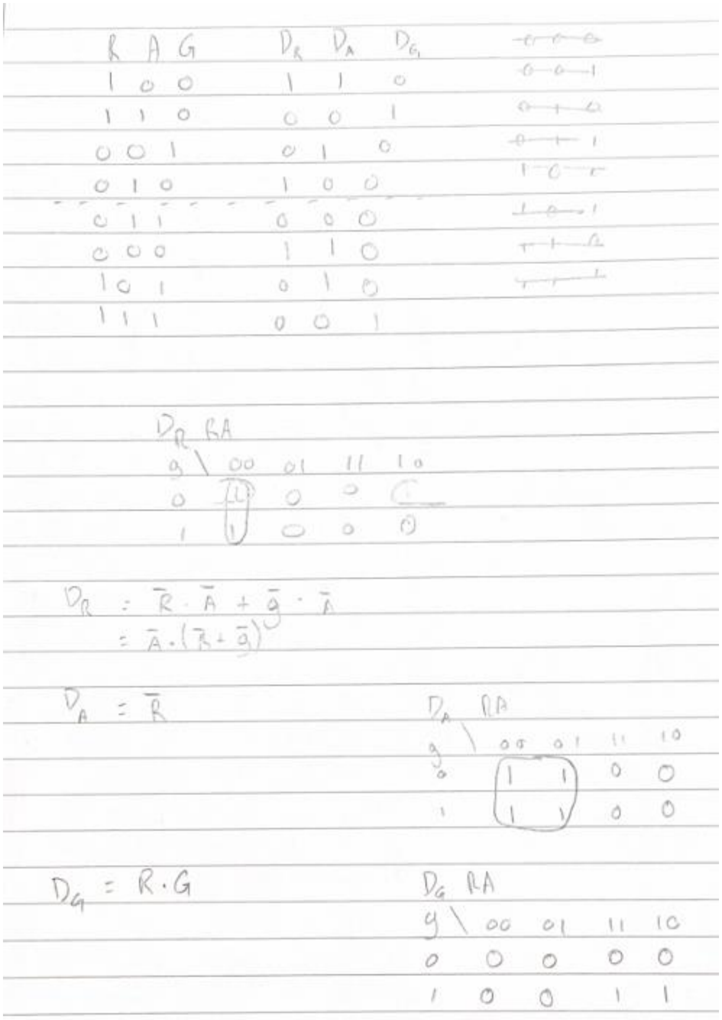

Figure 45: Working for Sequence Generator Logic

Advantages:

- Simpler interface between Logic and LEDs

Disadvantages:

- Has potential stuck states that need to be clocked through – up to 2 clock pulses – before system is ready.
- More space used because there are 2 flip flop ICs and 2 logic ICs.

Overall, using the up counter was easier since there are only 4 states, I only needed to use 2 of the outputs with the 3 (MSB) used to reset the clock and other parts of the system. Whereas additional logic is needed to reset other parts of the system when using a sequence generator.

Subsystem Testing

Distance Comparator

The system should detect a vehicle passing over the top of it at approximately 150mm to 170mm. First test didn't work as comparator didn't change at low values i.e. 0.43/0.7v, I tried adding a voltage follower but that didn't do anything to help. So, I changed the value of the resistor in the RPR220 circuit to produce larger values from 100k to 1M. Since I had a potentiometer for a variable switching height, I could pick a suitable switching threshold to maintain the appropriate 160mm switching height.

Test Number	1	2	3	4	5	Average
Inverting Input/volts	6.42	6.06	5.54	5.56	6.01	5.918
Switching Height/mm	150	149	158	165	159	156.2

Table 8: Distance Comparator Testing Results

My specification required that switching was 160mm ±5mm (155 – 165mm) the average switching height was 156.2mm which is within the allowed tolerance for my specification. Since the input voltage for switching was roughly within the same range ($\sigma^2 = 0.11$v for recoded results)[1] the switching threshold could be adjusted if when in practice the system didn't operate as desired.

Monostable Timer (Car Tracking)

Test Number	1	2	3	4	5	Average
Monostable Period/secs	3.39	3.61	3.47	3.61	3.59	3.53
Output Voltage/volts	11.28	11.28	11.28	11.28	11.28	11.28

Table 9: Monostable Timer for Car Tracking Results

Given this is used by other logic systems and the supply voltage (V_s) is 12v, the output of 11.28 is plenty within the 0.5Vs that is used by other logic ICs. The monostable period should be 3s according to the specification; the allowed tolerance is ±10% allowing up to 3.3s. Unfortunately, the recorded values are outside of the tolerance, but this isn't a major issue as it is higher than needed. If this became an issue the resistor/capacitor used within the 555 Timing subsystem could be recalculated to get closer to the required value.

Push Button and Latch

Test Number	1	2	3	4	5	Average
Output Voltage/volts	11.67	11.67	11.67	11.67	11.67	11.67
Latches?	Y	Y	Y	Y	Y	-

Table 10: Push Button Latch Results

The results table shows that the Push Button, its latch and LED perform perfectly. It successfully latches every time and provided a suitable output voltage of greater than $0.5V_s$ (6v).

Test Number	1	2	3	4	5	Average
LED Current/mA	0.55	0.56	0.56	0.55	0.56	0.556

Table 11: Push Button LED Results

The LED was provided the correct amount of current (the datasheet recommended 0.5mA) and was visibly bright enough on all 5 tests. This subsystem performed as intended.

[1] Variance for provided dataset.

Monostable Timer (Required Wait)

Test Number	1	2	3	4	5	Average
Monostable Period/secs	28.95	28.94	28.87	29.12	29.03	28.98
Output Voltage/volts	11.28	11.28	11.28	11.28	11.28	11.28

Table 12: Required Wait Monostable Results

The monostable period is 3.39% lower than the specification's required value of 30 seconds. This is within the allowed tolerance of ±15%. The output voltage is also greater than $0.5V_s$ (6v). Meaning that this subsystem performed perfectly within allowed tolerances.

The output voltage is suitable since it is greater than $0.5V_s$ (6v).

Request to Cross Logic

Test Number	1	2	3	4	5
Valid?	Y	Y	Y	Y	Y

Table 13: Request to Cross Logic System Results

After 5 testing the request to cross logic was correct each time. This meets the specification requirements of having a timeout period for crossing vehicles, previous crossings and allowing the request to be latched on for this time.

Request to Cross Latch

Test Number	1	2	3	4	5	Average
Latches?	Y	Y	Y	Y	Y	-
Resets?	Y	Y	Y	Y	Y	-
Output Voltage/volts	11.29	11.29	11.29	11.29	11.29	11.29

Table 14: Request to Cross Latch Results

The output voltage was at least $0.5V_s$ (6v) and as such a valid logic output.

On every test the 4013 was set (latched) when the Request to Cross logic became high and then remained latched until the lights had completed one full cycle through all states. This subsystem performed to its requirements.

Astable Timer (Counter Clock)

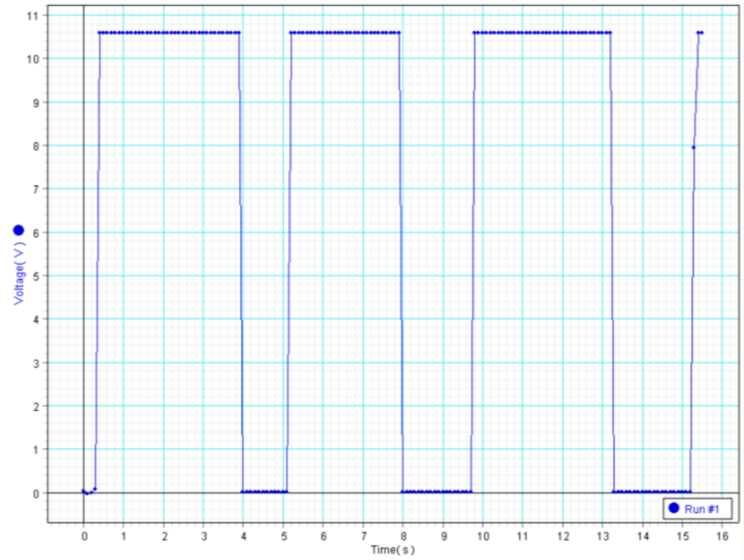

Figure 46: Astable Clock Output Graph 1

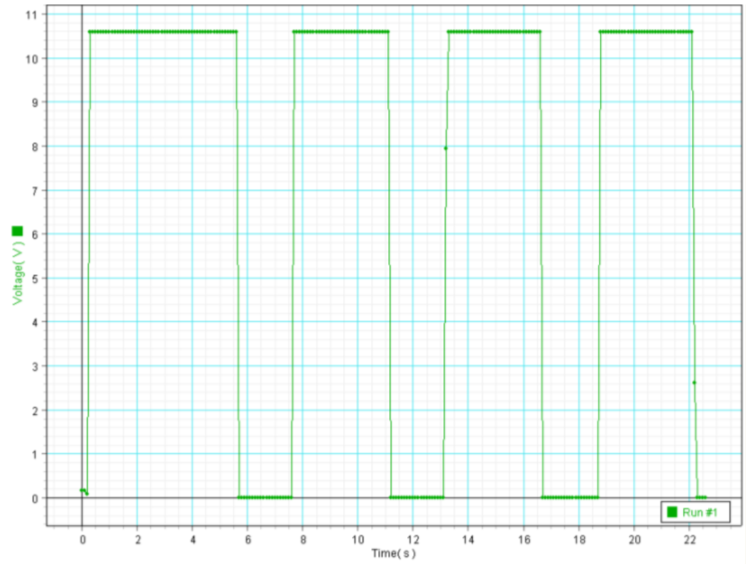

Figure 47: Astable Clock Output Graph 2

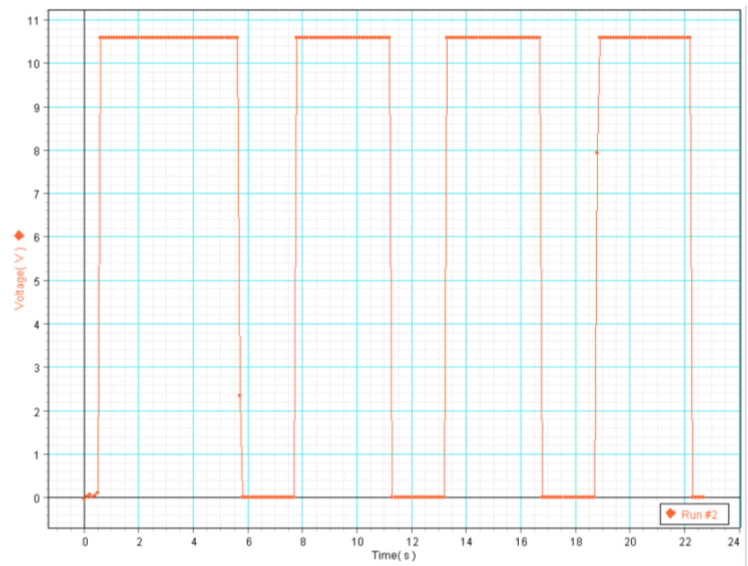

Figure 48: Astable Clock Output Graph 3

The three graphs above have been summarised in two tables below, the values are all averages over the first 3 full cycles visible within each graph.

Test Number	Time High/seconds	Time Low/seconds	Total Period/seconds
1	3.10	1.67	4.77
2	3.24	1.58	4.82
3	3.15	1.53	4.68
Average	3.16	1.59	4.75

Table 15: Astable Clock Results Part 1

Test Number	Astable Frequency/Hz	Output Voltage/volts
1	0.21	11.23
2	0.21	11.23
3	0.21	11.23
Average	0.21	11.23

Table 16: Astable Clock Results Part 2

The frequency shows the values rounded to 2d.p, hence the values are all identical in this case.

The output voltage is well within the required >0.5V_s (6v) so that is not an issue for logic circuits further down the chain.

The time high calculation for this circuit was correct and fell on the tolerance for specification point 5 where the stage would have taken 3 seconds +5%. However, the time low wasn't accounted for meaning that the total time period for each stage ended up being 4.75. This could be solved by using a 1:1 Mark to Space ratio and having both the mark and space being 1.5 seconds. This also removes the need for the inverter on the output as the mark and space would be identical. This will be an improvement for the circuit but didn't have a major impact on the use case on that it wasn't fully compliant.

Monostable Timer (Crossing Period)

Test Number	1	2	3	4	5	Average
Monostable Period/secs	7.65	7.67	7.71	7.66	7.70	7.68
Output Voltage/volts	11.28	11.28	11.28	11.28	11.28	11.28

Table 17: Crossing Period Monostable Results

The monostable period is 9.71% higher than the specification's required value of 7 seconds. This is outside of the allowed tolerance of ±2.5% however the original research showed that the time is allowed to be up to 9 seconds so the average value of 7.68v is still acceptable but not optimal. This could be solved by picking resistor values that more closely get the required 7 seconds.

The output voltage is suitable since it is greater than 0.5V_s (6v).

Clock Logic

Test Number	1	2	3	4	5
Successfully Clocks?	Y	Y	Y	Y	Y

Table 18: Clock Logic Results

On 5 separate tests of the system the clock logic provided the correct output state and successfully clocked the up counter. This subsystem worked as intended.

Up Counter

Test Number	1	2	3	4	5
Corectly Counts?	Y	Y	Y	Y	Y

Table 19: Up Counter Results

On 5 separate tests the Up Counter successfully counted up from 0 to 4 before resetting itself and the other components that were connected to it. It produced the correct outputs at all 3 pins used (A, B, C/1, 2, 4) meaning this subsystem acted as it was intended to.

LEDs and LED Logic

Test Number	1	2	3	4	5
Correct?	Y	Y	Y	Y	Y

Table 20: LEDs and LED Logic Results

On each of the 5 tests the LED logic produced the correct LED pattern and the LEDs displayed the correct light pattern in the correct sequence. This subsystem acted as intended.

Interfacing

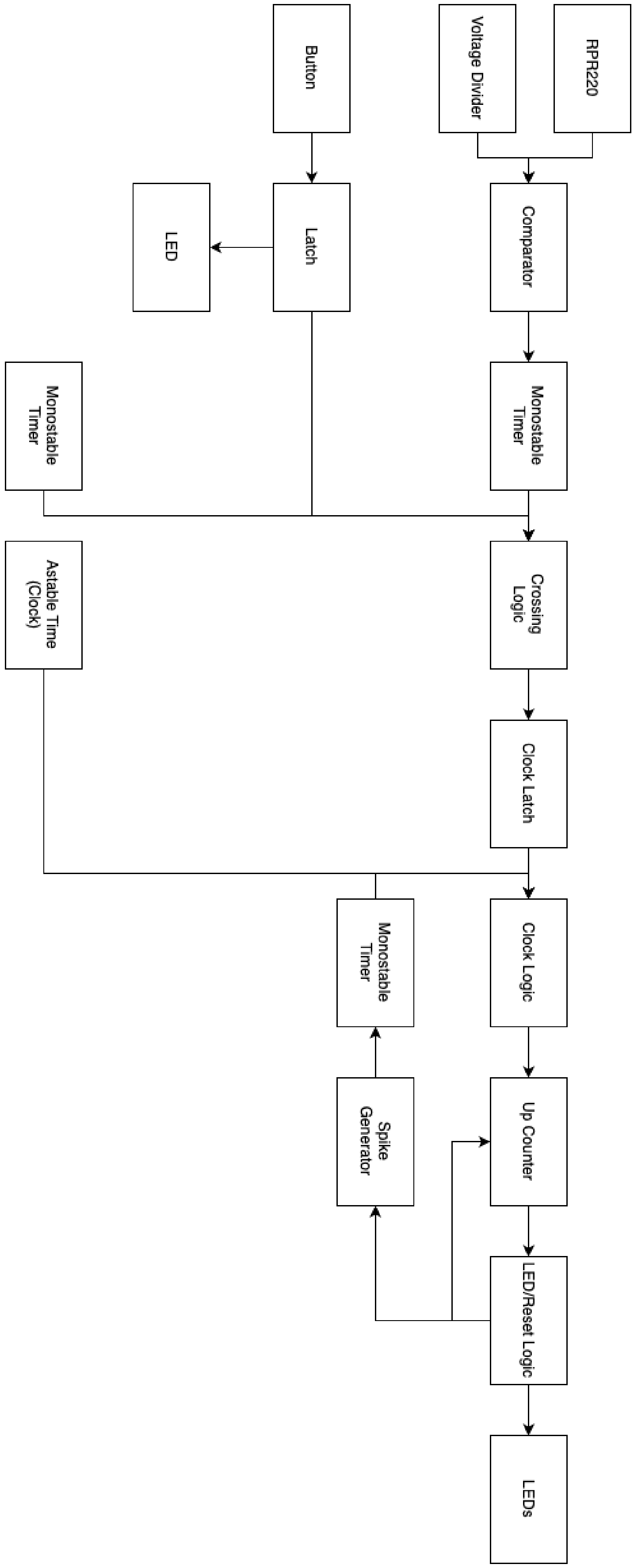

Figure 49: Full System Block Diagram

Spike Generator

The green timer – walk period – time needed to be triggered when the walk light was turned on. However, if it was directly attached it would break the timing logic as the timer would be stuck in the walk state. To solve this I used a spike generator to generate a short low pulse (less than the ~7 second monostable period) that would then allow the walk period to be longer without impacting the rest of the sequence.

Inverted Reset Signal

To trigger the timeout timer to ensure that there is the 30seconds wait between each allowed crossing period I needed to trigger a monostable from the reset pin of the up counter going high for a short time, since the pin would only be high for a short time – it came from pin C/8 of the up counter which would go low after resetting – I used an inverter to pull the trigger pin of the monostable low for a short period and trigger the timer.

User Guide

Component List

- Variety of Coloured Wire
- 1x 100kΩ Potentiometer
- 6x 820Ω
- 1x 1MΩ
- 1x 120kΩ
- 1x 1kΩ
- 1x 18kΩ
- 1x 560kΩ
- 1x 87kΩ
- 1x 20kΩ
- 1x 150kΩ
- 1x 100kΩ
- 1x 22µF
- 4x 10nF
- 3x 47µF
- 1x 47nF
- 1x RPR220
- 1x 741 Op-amp
- 4x 555 IC
- 6x 4011 IC
- 2x 4013 IC
- 1x 4510 IC
- 3x Red LED
- 2x Green LED
- 1x Amber LED
- 1x Push Button

System Description

The system should initially be in the following state:

Sub System	Initial State
Vehicle Detection	Logic Low
Request to Cross Latch	Logic Low
Required Wait Timer	Logic Low
Counter	000

Table 21: Initial System State

In the case a vehicle passes over the road the RPR220 should have an output voltage which is over the threshold set by the potentiometer and the output from the distance comparator should go low for either: the duration of the monostable period (3 seconds – 3.5 seconds in reality) or until the vehicle clears the sensor whichever is longer.

When a user wishes to cross the road, they can press the push button which has a pull-down resistor meaning it has a low output until pressed. The output from this button is connected to the set pin of the flip flop used by the push button latch. This switch isn't debounced since setting multiple times has no effect on the system.

Once the button is latched on, a red LED will be lit up so that the pedestrians know that their request is being handled. The system will then wait until the vehicle detection timer is low, there is a request from the button and the required wait timer is low. At which point a second flip flop is set which resets the first so the wating to cross LED is disabled. This connection is from the Q output of flip flop 2 (Request to Cross Latch) to the reset pin of flip flop 1 (Push Button Latch).

The astable clock produces an output with frequency 0.33Hz (in reality this was 0.21Hz), this clock signal is blocked from reaching the counter until the Request to Cross Latch has a high output, at which point the logic system performs an and between the clock output and the latch output. It is then and again with the inverse of the crossing period clock and if the output is high the up counter can clock changing to the next state. At which point there may be changes which stop clocking and the logic checks again.

When the walk light turns on, a spike generator makes a short low pulser to trigger the crossing period monostable this then delays the logic circuit for at least 7 seconds. At which point the timer output goes low again and regular clocking can resume.

As the timer counts up the LEDs are lit by a logic system which uses the two least significant bits for a modulo 5 counter.

Once the up counter gets to 100_2 (5_{10}) pin C goes high, this pin is connected to the counters reset as well as the reset for the Request to Cross latch (so that another request can be processed) since when the Request to Cross latch is set then output constantly resets the Push Button latch. It is also inverted and used to send a pulse to the monostable timer for the required wait. This depends on propagation delay since the signal will have just enough time to reset the other 2 subsystems before the counter is reset and the pin goes low.

The required wait timer is triggered when the system is reset and stops the request to cross logic from going high for at least 30 seconds (28.98 in practice). Once this timer goes low the circuit is ready to be used again.

System Guide/Tutorial

The system has two users, vehicles driving down the carriageway and pedestrians wanting to cross. For this there are 2 separate guides, please consult the guide relevant to your use-case.

Vehicle on Carriageway

When driving down the carriageway the lights will be displayed on either side of the road as shown in the diagram below.

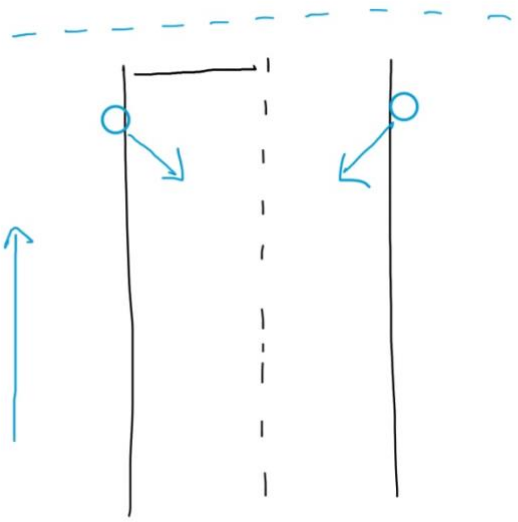

Figure 50: Diagram showing Traffic Light position and stop line

The diagram also shows the stop line – in solid black. For the purpose of the explanation is assumed you are driving in the direction of the blue arrow – i.e. down the carriageway. Two traffic lights showing the same state are in the positions marked with the circles position following the arrows towards your vehicle on the road. When driving towards the light if there are pedestrians on either side you should take care, at the point the lights begin to change from green to amber you should stop if safe to do so and if not clear the junction as soon as possible. While the light is red you should stay behind the stop lane, waiting till the light becomes green before proceeding.

If a pedestrian remains in the road you must yield to them as once a pedestrian enters the road they have priority over any traffic. You must remain behind the stop line till all pedestrians have exited the crossing and at which point provided the traffic light displays only solid green you may proceed.

Pedestrian Crossing Road

When you wish to cross the road, press the button on the post. Once your request has been acknowledged by the system a Red LED will be displayed to you. You should then watch the two pedestrian symbols, one red meaning not to cross and one green meaning it is safe to cross. When the green indicator is shown, check both ways down the carriageway and once it is safe to do so promptly cross the road.

The longest you can wait is 30seconds + 3 seconds after each car passes over. Meaning if the road is clear, you will be waiting at most 30seconds after the last crossing. If it is busy that time may be longer as each car passing over requires at least 3 seconds of clear road to ensure you can cross safely.

Circuit Layout

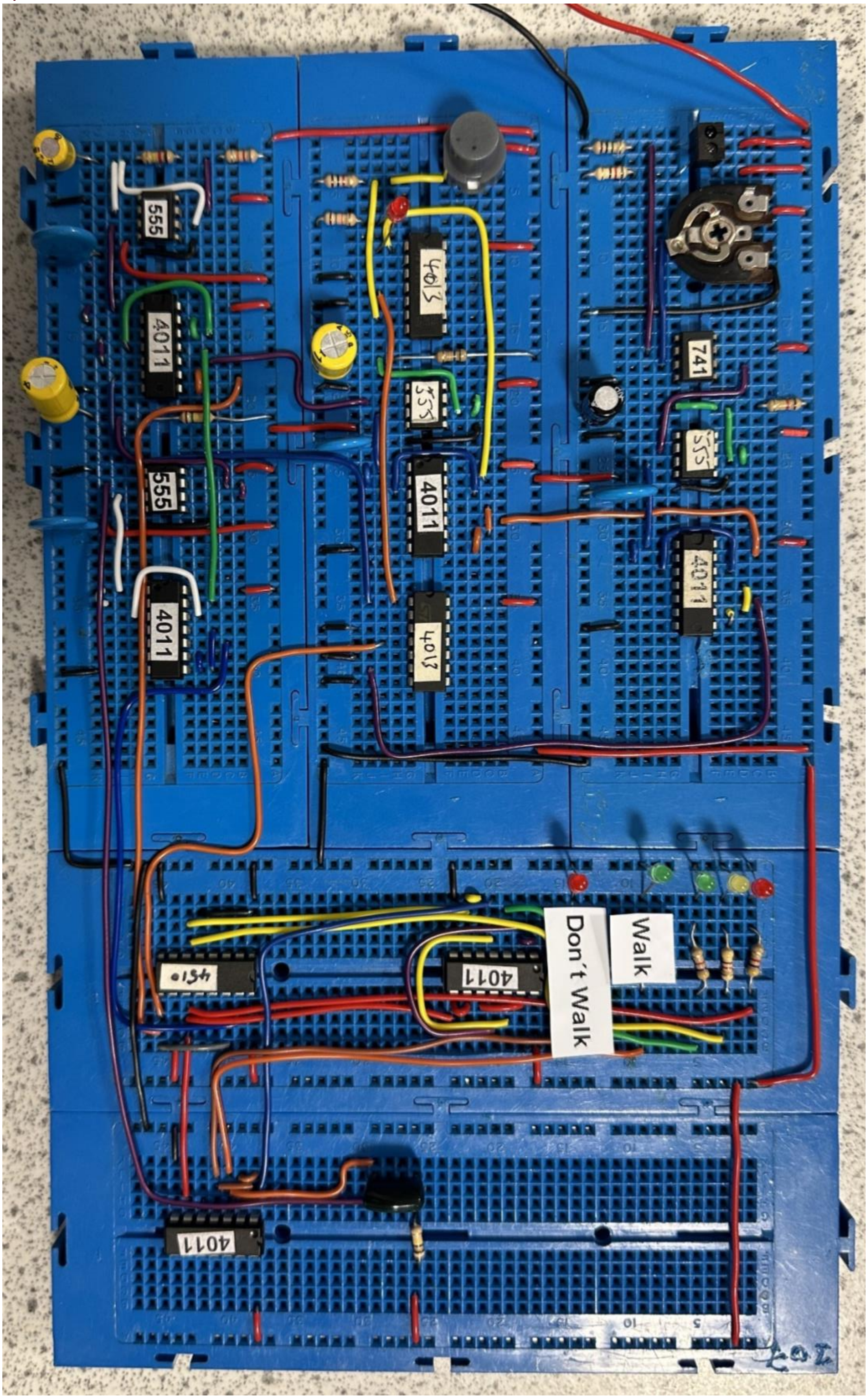

Figure 51: Fully Constructed Circuit on Breadboards

Risk assessment

Hazard	Risk & Severity	Probability	Actions Taken to Mitigate Risk
Cuts and Bleeding	When cutting wires to the correct size or using wire strippers you could accidentally cut your fingers. (Low to Moderate)	Very Low	When using scissors or wire strippers I take care that my nothing else is in the way before using them.
Liquids	Liquid could be spilt onto breadboards causing a fire or damaged components (Moderate to Severe)	Moderate	When working with components I will keep all liquids off the desk and only have a drink when safely away from the circuit.
Electrical Shocks	Exposed wires could shock me while working with the circuit (Low)	Low	I didn’t touch the circuit while connected to a power supply. I also ensured all wires had insulation and through the whole components to reduce exposed wire.

Full system test plan

Full System Test PLAN			
Test	**Quantity to be tested**	**Testing method and equipment**	**Expected test result**
1	Traffic lights follow the correct sequence when changing from Green to Red and back.	**Equipment:** • Fully constructed circuit • 12v Power Supply **Method:** Power the circuit on and ensure it has ended up in the correct initial state (Traffic lights showing Green, Pedestrian light showing Red and no light showing waiting to cross). Then press the button to request to cross, the lights should then change through the sequence of: 1. Green to Amber 2. Amber to Red The pedestrian light should go green, the light showing they are waiting to cross should go out. Then they should stay on red for 7 seconds (±2.5%) before the following sequence is performed: 1. Red to Red and Amber 2. Red and Amber to Green The pedestrian light should then go back to red as well. This should be performed at least 3 times with the circuit being powered off im-between to ensure that the circuit cannot be put into a stuck state.	Sequence accurately changes and follows the correct pattern
2	Pedestrians are given 7 seconds to cross.	**Equipment:** • Fully constructed circuit • 12v Power Supply • Stopwatch **Method:** Power the circuit on and ensure it has ended up in the correct initial state (Traffic lights showing Green, Pedestrian light showing Red and no light showing waiting to cross). Then press the button to request to cross. Once the pedestrian light goes green, start a timer. The timer should then be stopped as soon as the pedestrian light changes to red.	Pedestrians are given at least 7 seconds to cross.

		This should be repeated at least 5 times to get an accurate average.	
3	Pedestrians are given a visual indication that the system knows they are waiting to cross	**Equipment:** • Fully constructed circuit • 12v Power Supply **Method:** Power the circuit on and press the crossing button. You should see a red LED indicator turn on. It should then remain on until the pedestrian crossing light goes green, and the traffic light goes red.	Visual indication is clear and always in the correct state
4	Vehicle detection isn't affected by ambient light sources	**Equipment:** • Fully constructed circuit • 12v Power Supply • Torch • Voltmeter **Method:** Connect the Voltmeter between the output from the op-amp in the distance comparator and 0V. Measure the values of V_{out} when an object is at 160mm above and when it isn't in ambient lab lighting. Then when in darkness and a third time when a flashlight is being shone on the PRP220. This whole test should be conducted at least 5 times to take an accurate average.	System not affected by ambient light
5	Maximum current drawn and power dissipated by the system	**Equipment:** • Fully constructed circuit • 12v Power Supply • Ammeter **Method:** Connect the ammeter in series with the positive terminal of the power supply going to the circuit. Turn the circuit on and take a reading from the ammeter, turn the circuit back off and repeat at least 5 times to take an average for current draw. Then multiply this value by the maximum supply voltage (12v) to calculate maximum power dissipated.	Current should be less than 377mA and power calculated to less than 4.53W
6	Supply voltage is within 11.5v to 12.5v	**Equipment:** • Fully constructed circuit • 12v Power Supply • Voltmeter	Supply voltage ≈ 12v

		Method: Connect the Voltmeter between the top and bottom rails of the circuit – i.e. in parallel with the supply – turn the supply on and take a reading. Then turn the supply of and repeat at least 5 time to take an average. Check the average value is within 12v ±0.5v.	
7	Each stage of light sequence takes at least 3 seconds	**Equipment:** • Fully constructed circuit • 12v Power Supply • Stopwatch **Method:** Power the circuit on and ensure it has ended up in the correct initial state (Traffic lights showing Green, Pedestrian light showing Red and no light showing waiting to cross). Then press the button to request to cross; time how long it takes for the system to change between each state where each change should take 3 seconds +5% with the exception of the red state for vehicles where it should be 7seconds ±2.5%. After timing one cycle power the circuit off and then repeat the test at least 3 times to ensure there are no states which cause the test to be invalid. Take an average of the time per state across all tests and compare it to the required 3seconds +5%.	Time per stage = 3 seconds

Full system test results

Full System Test RESULTS

Test	Test Number	Sequence Correct?	Lights Displayed Correct?
1	1	Y	Y
	2	Y	Y
	3	Y	Y
	4	Y	Y
	5	Y	Y

Test	Test Number	Time to Cross/seconds
2	1	7.66
	2	7.71
	3	7.65

	4	7.00
	5	7.89
	Average	7.582

	Test Number	Clear Visual Indicator Present?
3	1	Y
	2	Y
	3	Y
	4	Y
	5	Y

	Test Number	Ambient Light Switching?		Torch Light Switching?	
4	1	Y	155mm	Y	157mm
	2	Y	147mm	Y	160mm
	3	Y	154mm	Y	159mm
	4	Y	161mm	Y	152mm
	5	Y	149mm	Y	162mm

	Test Number	Current Drawn/mA	Power Dissipated/mW
5	1	57	684
	2	53	636
	3	54	648
	4	59	708
	5	52	624
	Average	55	664

	Test Number	Supply Voltage/volts
6	1	11.79
	2	11.79
	3	11.79
	4	11.79
	5	11.81
	Average	11.794

	Test Number	Red Amber/seconds	Red/seconds	Amber/seconds
7	1	4.68	7.71	3.16
	2	8.59	7.65	9.52
	3	4.77	7.64	4.78
	Average	6.01	7.67	5.82

Full system test analysis

Full System Test ANALYSIS	
Test	
1	On all 5 tests the LED logic displayed the correct lights in the correct order, there were no stuck states as all possible states had a valid display. The lights were clear and only illuminated in valid patters. The system met this specification point.
2	The average time to cross given to pedestrians – the time that the walk light was illuminated – was 7.582 seconds. This was 8.3% higher than the specification required. The allowed tolerance was ±2.5% so the +8.3% was over 4x larger than the allowed tolerance. This didn't impact how the system worked since it allowed pedestrians longer to cross and my research showed they can be given up to 9 seconds. However, it did technically fail this specification point although there were no major affects to the system operation.
3	Each time the system was tested a clear indicator was present and has a suitable illumination to where it could be seen. The indicator was also understood by multiple people who tested the circuit as it followed the typical format of a Red LED next to the push button. The system met this specification point.
4	The system was not affected by ambient light. All test showed that the vehicle distance comparator still switched at the correct threshold. The values for switching aligned with the testing of the distance comparator and as such the system passed this specification point.
5	Average current draw is just 14.5% of the current draw calculated in the specification. This is most likely due to the fact that many components were in series and the values used to calculate the specification used the absolute maximum of each component. As such this specification point was met since the average current draw was significantly less than the maximum. The power draw was also in turn much lower than the maximum – only 14.7% of the maximum. As such the system has also met this specification point.
6	The supply voltage was comfortable within the allowed 11.5v to 12.5v range. The circuit continued to work with a supply voltage within this range and would probably work in a larger range of 9v to 15v since those are the extremes of supported voltages by many of the ICs that are used within the system.
7	The systems clocking method means that the time in each state was very unreliable. Since if it missed the clock pulse due to some form of delay it could potentially be waiting much longer than necessary. The better way to do this would have been use the monostable to disable/pause the astable timer rather than having logic to control when the signal got through from the clock.

System Evaluation

Comparison of planned circuit with actual circuit

Subsystem Name	Required Function	Actual Performance
Vehicle Detection	Detect objects above the sensor and vary V_{out} to show the distance. There should be a significant change between the sensory being completely covered and uncovered.	The RPR220 distance detection subsystem had a wide range of values at V_{out} which allowed the comparator to accurately compare distance
Distance Comparator	Given the input from the vehicle detection subsystem the comparator should output a low logic value if a vehicle/object is within 160mm of the sensor.	The distance comparator detected vehicles at heights of approximately 156.2mm this was a suitable value as it still detects even the lowest vehicles. It could have been improved by having a higher detection threshold, but the subsystem did meet the specification.
Monostable Timer (Car Tracking)	When a vehicle has been detected the timer should keep the output for 3 seconds or for as long as the vehicle is over the sensor whichever is longer.	The monostable timer for vehicle detection did stay on for 3.5 seconds which was larger than the required 3 seconds but didn't have an adverse impact on performance.
Push Button & Latch	There should be a button that can easily be pressed by a pedestrian and is latched on till the circuit allows them to cross.	When the button was pressed the latch was set which displayed the LED and the latch remained set until the system processed the request to cross. This subsystem performed correctly.
Monostable Timer (Required Wait)	The circuit shouldn't let pedestrians cross every time they press the button so this timer should ensure that pedestrians wait at least 30 seconds. It should be triggered when the counter resets. And have a high output for the duration of the monostable period.	The required wait timer had an average monostable period of 28.98 seconds, this is within the 30 seconds ±15% tolerance. It was triggered successfully by the inverted reset signal from the counter, so the interfacing worked as intended. The subsystem performed as required.
Request to Cross Logic	Taking in the push button latch, vehicle detection timer and required wait timer it should be a logic 1 when the circuit should process a request to cross.	The request to cross logic worked, I know this since pressing the button while the system hasn't had a crossing yet with your hand on the RPR220 holding the circuit to wait, removing your hand then allows the crossing. Also, after a successful crossing there is the wait for 30

		seconds. As Such the subsystem worked as intended.
Request to Cross Latch	The latch should stay high once the Request to Cross logic goes high and remain high until the counter resets. It should also reset push button latch.	This subsystem worked since the clocking was allowed, the red waiting LED was also switched off showing that the output from this latch went high and once the counter reset it stayed in the correct state. This subsystem worked as required.
Astable Timer (Counter Clock)	The astable timer should have a frequency of 0.33Hz and clock through each state except for the ‘Red’ vehicle and ‘Green’ pedestrian state which should be 7 seconds.	The astable had a frequence of 0.21Hz. The high time was the required 3 seconds however the low time wasn’t accounted for. This was tested using a data logger and showed this subsystem needed its resistor values changed to meet its specification. This subsystem should be changed/fixed.
Monostable Timer (Crossing Period)	A monostable timer which has a period of 7 seconds. It should be triggered by a low spike from the spike generator when the walk LED is turned on.	The spike generator produced a low spike which triggered the monostable timer. This timer had a period of 7.68 seconds which was higher than allowed. This did not meet its specification but is a valid value from my research. This subsystem should be improved.
Clock Logic	Provide a clock – high signal – to the counter when there is a valid request to cross, the astable is high and we aren’t in the crossing period.	The clock logic gave the correct output since the counter clocked at the correct points. However, it was unreliable due to its design. While this subsystem did meet its specification it should be redesigned.
Up Counter	The up counter should perform as a modulo 5 counter and clock on the rising edge of the clock logic signal.	The counter went from 0 to 5 inclusive and once at 5 reset itself and the other components the relied on this pin. I know this subsystem worked since the LEDs were in the correct states and ended at the correct point, ‘Green’ traffic light and ‘Red’ walk light.
LEDs & LED Logic	This logic system should take the output from the 2 least significant bits and display the correct LEDs based on the current position in the sequence. The LEDs should also be Red, Amber and Green and suitable visible to pedestrians and vehicles.	The LEDs were suitable visible to both vehicles and pedestrians. The logic system took in the two least significant bits and correctly represented each state. This subsystem worked as intended.

Effects of differences between planned and actual circuits

The actual circuit is very similar to the planed circuit with one major difference being the clock for the counter is not fully stable. It has varying periods based on other factors such as the point the astable is when the crossing period monostable ends. This factor does mean that the system is not perfect, but the built circuit does have all individual timing periods within tolerance. Below are a few more minor differences between the planned and actual circuit.

(1) Car Timers monostable period is ~3.5seconds instead of 3seconds this has little to no impact on pedestrians and zero effect on vehicles.
(2) The planned and actual circuit current consumption and power dissipation are vastly different. This is not an issue as the circuit was designed to support the larger maximum current.
(3) The astable period is 1.5x the original planned period since the low time wasn't accounted for within the calculations. This is a planned improvement and can be fixed by changing the resistor values to have a 1:1 Mark to Space ratio with each being 1.5 seconds.
(4) The crossing period was 7.68 seconds instead of 7 seconds. While this didn't have a major impact on the circuit it should be fixed to have a more stable crossing period. This could be solved by picking a resistor value which gets a period closer to 7 seconds.

Fitness for purpose

The system meets most of its specification points within their allowed tolerances and provides a pedestrian crossing system which is compliant with UK regulations. The system would allow a pedestrian to safely cross the road as well as not impeding the suitable flow of traffic. The LEDs were suitable bright to be seen by pedestrians. The system also supported driving multiple Traffic lights in the case that multiple were needed for a full installation.

Limitations and Modifications

Clock Period is too long

The clock period was 1.5x longer than the intended 3 seconds. This is a limitation of the system since it means the lights are in a state for longer than required. The system also has an unstable clock since the logic can mean that the up counter misses a clock pulse, to fix this the system can use logic to disable the astable instead of using logic to filter out clock pulses. The redesigned clock circuit is below:

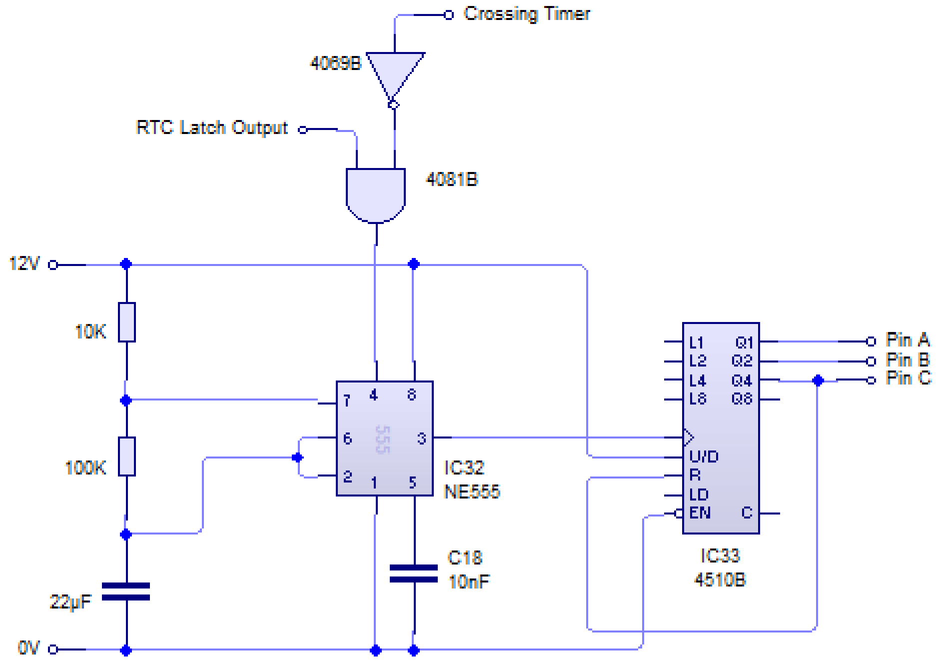

Figure 52: Revised Clock and Clock Logic

This new clock has the following characteristics:

High Time/seconds	1.67
Low Time/seconds	1.52
Total Period/seconds	3.19
Frequency/Hz	0.31

Table 22: Revised Clock Characteristics

The changes would make the clock more reliable as well as simplifying the circuit design. It will also bring percentage difference from the desired 3seconds down from approximately 97.1% to 6.3% which is much closer to the allowed tolerance value of +5%.

Visually impaired wouldn't be able to use the system

Visually impaired users would not be able to use the system since it only has visual indicators that it is safe to cross, this could be solved by having a buzzer and an additional astable which is active while the walk LED is. An example for the proposed changes is:

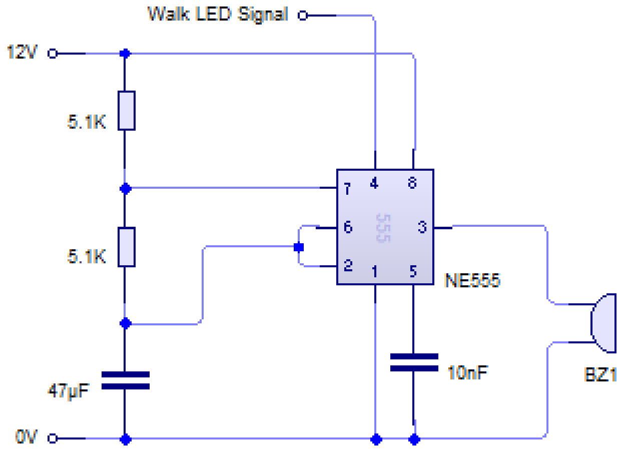

Figure 53: Proposed Subsystem for Visually Impaired

The astable has the following characteristics and would be active while the walk signal is so that buzzer is powered for the same time as the visual indicators.

High Time/milliseconds	332.22
Low Time/milliseconds	116.11
Total Period/milliseconds	448.33
Frequency/Hz	2.0025

Table 23: Proposed Clock Characteristics for Buzzer 555 Astable

This solves the limitation that visually impaired cannot using the crossing safely.

Constant traffic wouldn't allow for any crossing

If there is constant traffic across the crossing at a period such as rush hour then there would be no way for pedestrians to ever cross. This could be solved by having an additional timer meaning that after a fixed period e.g. 60 seconds the vehicle detection subsystem no longer has an effect on the request to cross logic.

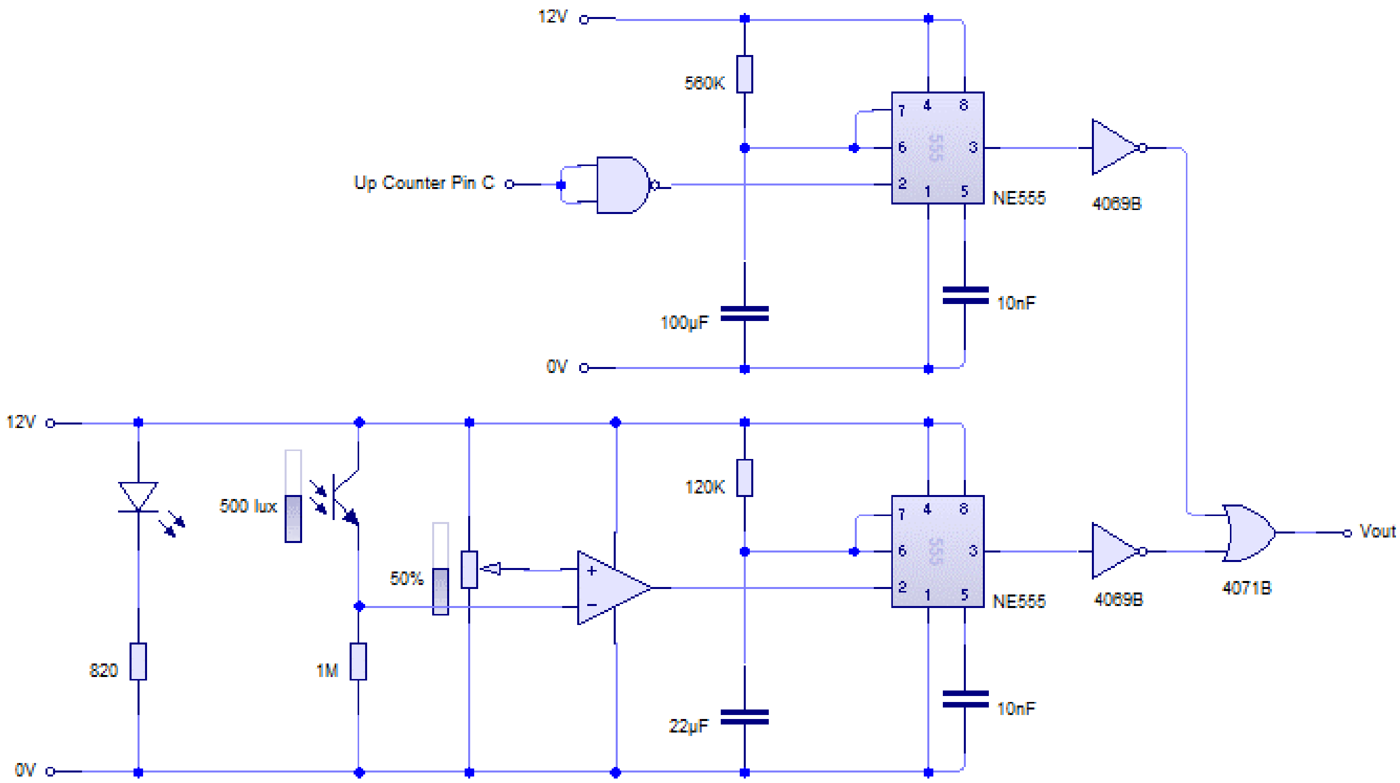

Figure 54: Revised Vehicle Detection Subsystems

The modifications required to allow for crossing even when there is constant traffic is to add a new timer (with monostable period 61.6 seconds) along with the following logic,

$$Q = \overline{(Vehicle\ Detected)} + \overline{(Maximum\ Wait\ Timer)}$$

Figure 55: Revised Vehicle Detection Logic

This additional logic means that after the 61.6 second monostable period the vehicle detection subsystem becomes redundant since the OR gate allows the inverted maximum wait signal through to the rest of the logic system. This would mean that pedestrians must wait at least 30 seconds and at most 60 seconds between times the system allows a crossing signal through.

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Figures and Tables