University of Canterbury

Electronics - Project One

“A Breath Alcohol Indicator”

Matt Kokshoorn & Nick Bingham

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Abstract

This report is for the University of Canterbury 'Electronics 1' course assignment carried out by Matthew Kokshoorn and Nick Bingham in the first semester of 2012. This assignment involved the design and implementation of an analogue breath alcohol sensor, or 'breathalyser'. This breathalyser was required to be within a budget of $25 and to accurately identify three discrete levels of breath alcohol. The resulting product met these requirements.

This report includes a thorough analysis of each of the functional components making up the breathalyser. This includes a computation-based simulation for each functional group, which was utilised to minimise implementation time and to identify and resolve real problems when constructing this final product. There is also an in-depth analysis of component choices.

The breathalyser itself cost a total of $24.39 which included a case and all componentry. It has adjustable breath alcohol thresholds to suit multiple countries where alcohol consumption regulations differ.

Contents

1. Introduction

Absence of knowledge of intoxication levels can pose many problems. Of particular relevance and concern here in New Zealand is the problem of drink-driving. “For drivers involved in all fatal crashes in 2006 through to 2008, 28% of those were recorded as having alcohol.” [1] Although some cases which lead to accidents are caused by deliberate disobedience of the law, in many instances people are unable to accurately guess how intoxicated they actually are – and therefore assume they are sober enough to drive when, in fact, they are not. A breath alcohol indicator, or ‘breathalyser’ is also useful for easily gauging the intoxication levels of third parties. Many cases of fatal drink-driving could have been avoided if people had the means to measure other’s intoxication level. For example, the case of *Childs v Desormeaux* [2] involved a drink driving accident following a party. The social hosts did not realise how intoxicated he was before he drove home and killed several other road-users. He could have been dissuaded from driving, or even detained, had the other partygoers been aware of his intoxication level.

The purpose of this project is to design a breathalyser capable of distinguishing between different levels of breath alcohol. The design itself requires the use of only analogue (not digital) components and to be within the budget of $25. Such constraints parallel real-world design constraints.

2. Design Description

The breathalyser requires several stages of signal processing to take the input signal (the breath alcohol level reading) and produce the desired output (an indication of that breath alcohol reading). As such, the design was broken down into the major functional groups. These were all designed in a manner such that they could operate largely independently of each other. This not only made the design process easier but also made testing and resolving problems at the implementation stage much more straightforward.

Before breaking down the breathalyser into components it was important to define the overarching aim of the project. The key goals that had to be met are as follows:
(1) The breath alcohol sensor must operate at a certain operating temperature to function correctly, and this requires sufficient time to reach the required temperature. Therefore a timer is required to identify when sufficient time has passed for the sensor to function correctly.
(2) Reaching the warm up time must be implemented in such a manner that there is a clear signal that the device is ready for use.
(3) The breathalyser must be able to identify three discrete values of breath alcohol. These correspond to low, moderate and high levels of breath alcohol.
(4) These discrete levels must be indicated in such a manner that they are clear and conclusive. This requires output values to be fixed for a reasonable time for the user to observe the results.
(5) The operational voltage of the breath alcohol indicator is required to remain constant at the chosen level of 5V. This is to remain so throughout any fluctuation in the supply voltage.
(6) The effects of noise should be minimised to increase coherence in results.
(7) The total cost of the project must not exceed the budget of $25. Also, the components must all be analogue and obtained from the University of Canterbury electronics store.

After establishing the target criteria it was possible to break the design down into the required functional groups for analysis and implementation. The key functional groups are:
- A decoupled voltage regulator to satisfy requirements (5) and (6) above.
- A timer that triggers a form of switch after a specified time when powering-up the breathalyser to satisfy requirement (1) above.
- A monostable pulse stretcher to fix the output values for a reasonable amount of time. This satisfies requirement (4) above.
- LEDs to provide essential information about heating and sensor readings to the user. This satisfies requirement (2) above.
- Suitable voltage dividers with adjustable values so that changes can be made to obtain three discrete levels and satisfy requirement (3) above.

2.1. The Voltage Regulator

Overview

The purpose of the voltage regulator is to keep the supply voltage constant. This is important, especially where substantially varying power is to be drawn from a battery (or similar) source such that major voltage fluctuations could occur in the supply voltage.

The input to the voltage regulator can be any voltage between 7V and 9V, and this value may fluctuate while the regulator is in use.

The voltage regulator must be able to maintain an output voltage of 5V at all times while the breathalyser is powered on.

Design

The initial design chosen for the voltage regulator is shown in Figure 1 below. It employs the use of an LM317 regulator and resistors to select the output voltage. The values of these resistors were chosen for an output voltage of 5V, as desired from the specifications for this block.

The final design, as shown below in Figure 2, was adjusted due to the reduced complexity and availability of the alternative option. The final voltage regulator employed the use of an MC7805 regulator as this has a fixed output voltage of 5V. A capacitor was added to decouple the output of this regulator in order to remove noise, which was found to be otherwise a significant problem.

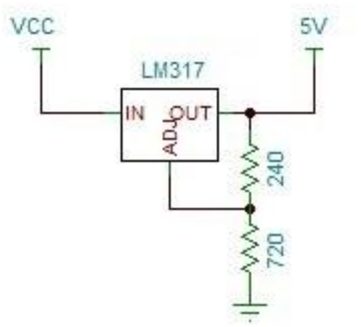

Figure 1 - Voltage Regulator Schematic (Initial)

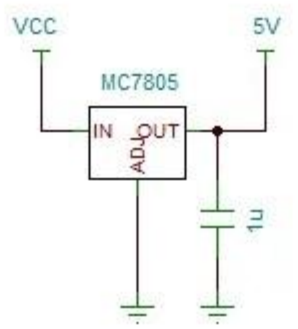

Figure 2 - Voltage Regulator Schematic (Final)

Theoretical Output - Simulation

The theoretical output of the voltage regulator (as simulated by TINA) is shown in Figure 3 below. This output is for an 8V input with a 1V amplitude sine wave to simulate possible fluctuations in input voltage. The frequency of the fluctuating input was kept at 1Hz as battery supply does not tend to fluctuate with a high frequency.

The simulation indicates that the ideal regulator block is clearly behaving as desired as the voltage remains constant at 5V for any input voltage in the required input range.

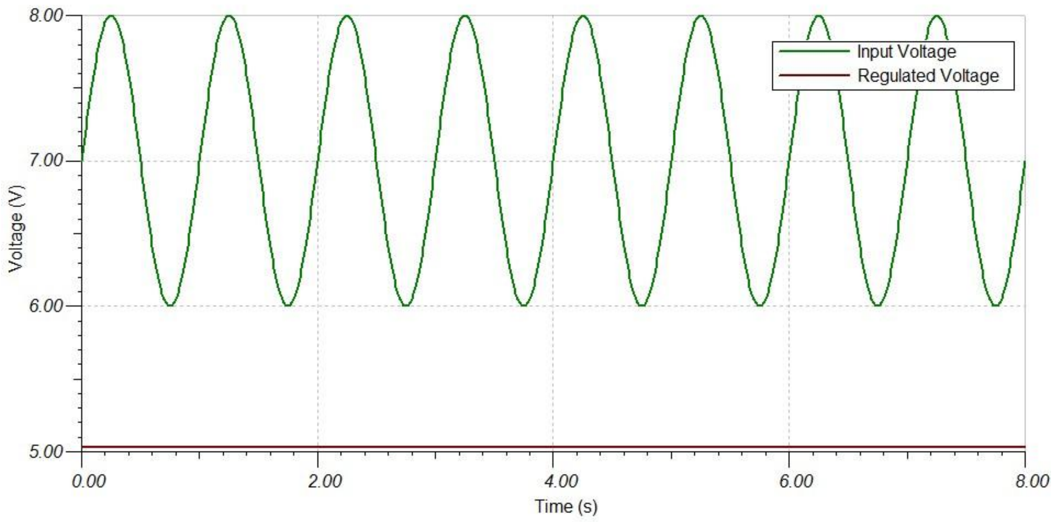

Figure 3 - Simulated Voltage Regulator Output

Practical Output - Testing

The practical output of the voltage regulator is shown in Figure 4 below. This output is for an 8V input with a 1V amplitude sine wave (5Hz). It is substantially the same as the theoretical output (it is producing a constant output of 5V for all input values in the expected range) so the regulator is functioning as desired.

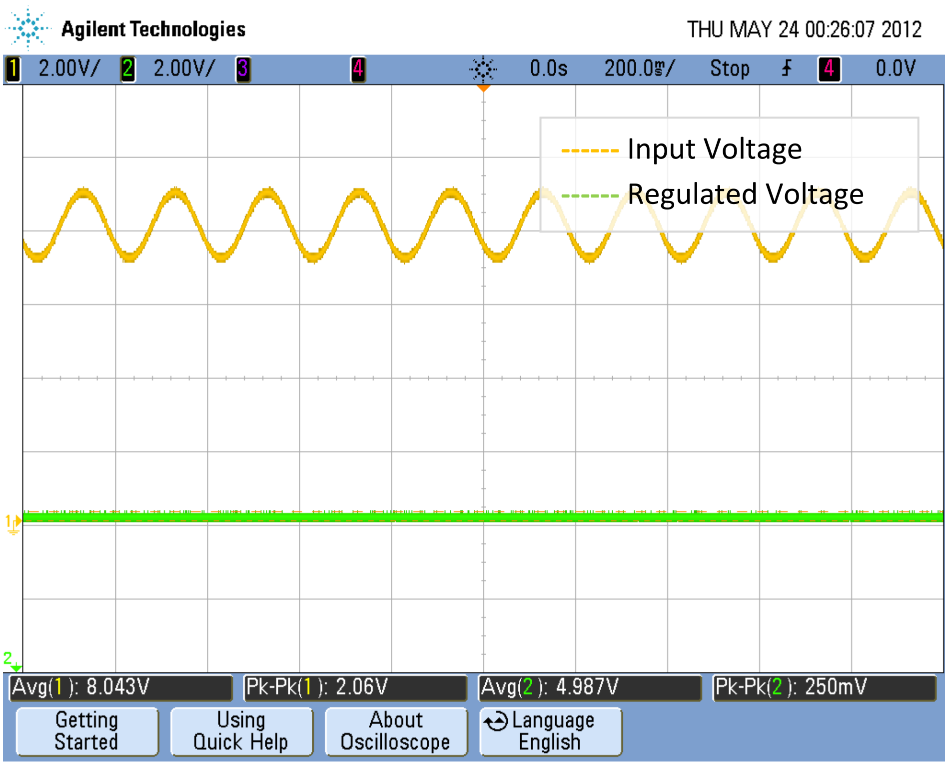

Figure 4 - Actual Voltage Regulator Output

2.2. The Voltage Dividers

Overview

The purpose of these voltage dividers is to create reference voltages for use particularly in comparators later in the circuit. The input to these voltage dividers is the regulated 5V. The output to these voltage dividers is 3V (for the timer) and three reference voltages (for the indicator LEDs) which can be varied through the use of variable resistors.

The chosen design for the voltage divider into the timer is shown in Figure 5 below. This design is the ordinary implementation of a voltage divider, designed simply to select a voltage between two reference points (in this case, the regulated voltage and ground). The resistors chosen were 460Ω, connected to the reference voltage, and 670Ω, connected to ground. These resistors gave the desired reference voltage of 3V.

The final design for the voltage dividers used to create reference voltages for the indicator LEDs is shown in Figure 6 below. The resistors chosen to connect to the regulated voltage were 680Ω, 1kΩ and 1kΩ, while variable resistors were used to connect to ground so that the thresholds could be adjusted as desired. The values for these variable resistors are currently 420Ω (for Vhigh), 210Ω (for Vmid) and 86Ω (for Vlow). These selected values for the variable resistors give reference voltages of 1.9V, 860mV and 400mV respectively, and were chosen to distinguish between the values of 2.12V (for high concentration), 1.216V (for mid concentration) and 597mV (for low concentration). These values were dictated by the voltage thresholds later in Section 2.6, where the sensor was implemented, explaining the choice of variable resistors at this stage to accommodate for a range of sensor voltages.

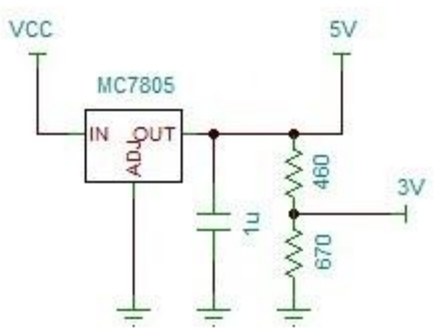

Figure 5 - Voltage Regulator and Voltage Divider for Timer

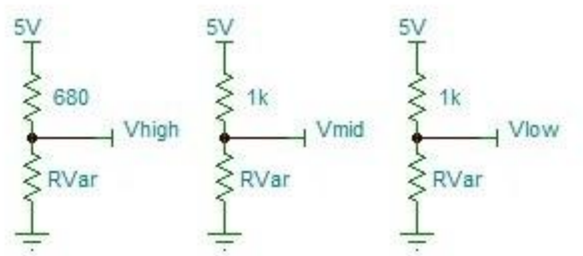

Figure 6 - Voltage Dividers for Indicator LEDs

2.3. Timer Switch

Overview

The purpose of the timer switch is to turn its output 'on' when the breathalyser is ready for use. It takes at least two minutes for the breathalyser to heat substantially enough to function properly, so the timer needs to keep the switch 'off' during this warm-up time. The input to the timer switch is a step input from 0V (when the breathalyser is switched off) to 5V (when the breathalyser is switched on). The timer switch is required to produce an output of 0V for the heating time following the step input and produce an output of 5V subsequent to reaching the required time.

Design

The initial chosen design for the timer switch is shown in Figure 7 below. It was made up of a capacitor and resistor connected to the negative input of a comparator. The capacitor and resistor were chosen such that they charge to 3V in approximately three minutes (an extra minute was chosen to minimise likelihood of errors from insufficient temperature). The comparator takes the output from the capacitor and resistor and compares it to a reference 3V. While the voltage is below the 3V threshold, i.e. prior to three minutes having been reached, the output of the comparator remains zero. When the voltage exceeds 3V after three minutes, the output switches instead to the value of the supply rail.

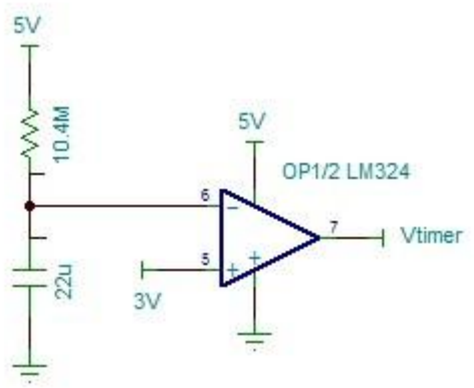

Figure 7 - The Timer Switch (Initial)

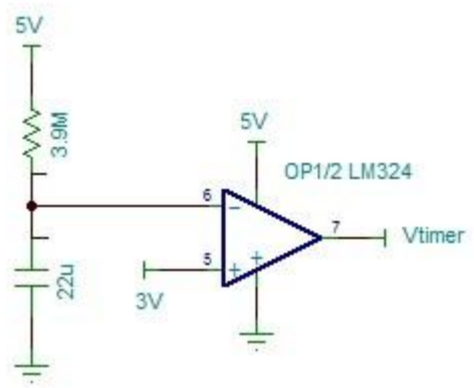

Figure 8 - The Timer Switch (Final)

Theoretical Output - Simulation

The theoretical output of the timer switch (as simulated by TINA) is shown in Figure 9 below. This output is for a simple 5V step input. This simulation indicated that the theoretical output matches what is desired as the output voltages switches to a maximum value in 180 seconds.

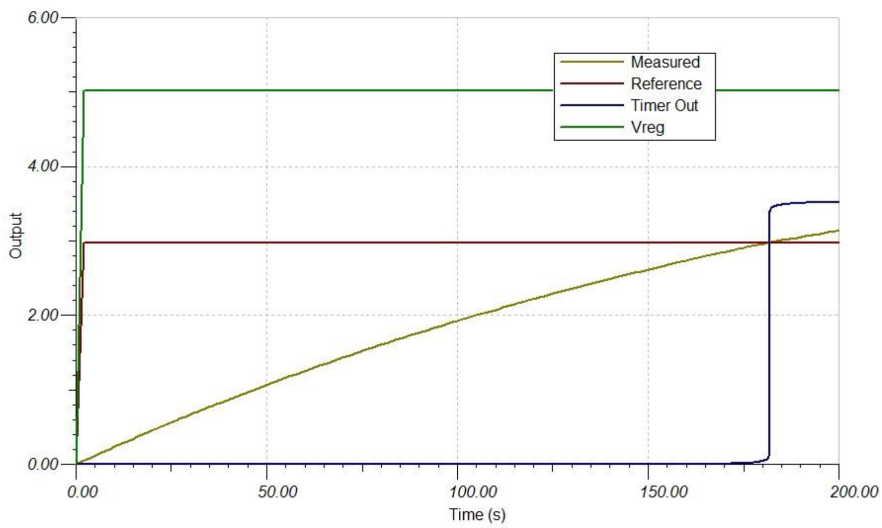

Figure 9 - Simulated Timer Switch Response

Practical Output - Testing

When the simulated model was put into practice and actually built and tested, the charge time was actually significantly longer than it was in the simulations. This may be due to a problem encountered with a practical op-amp but this was not able to be determined.

As it was desirable to keep the charge time to around 180 seconds, the actual model was adjusted empirically until the desired rise time was achieved. To do this, the resistor value was reduced significantly from 10.4MΩ to 3.9MΩ to lower the time constant. The practical output of the new timer switch is shown in Figure 10 below. This output is for a simple 5V step input. This output met the design criteria as the output voltage switches at 180 seconds.

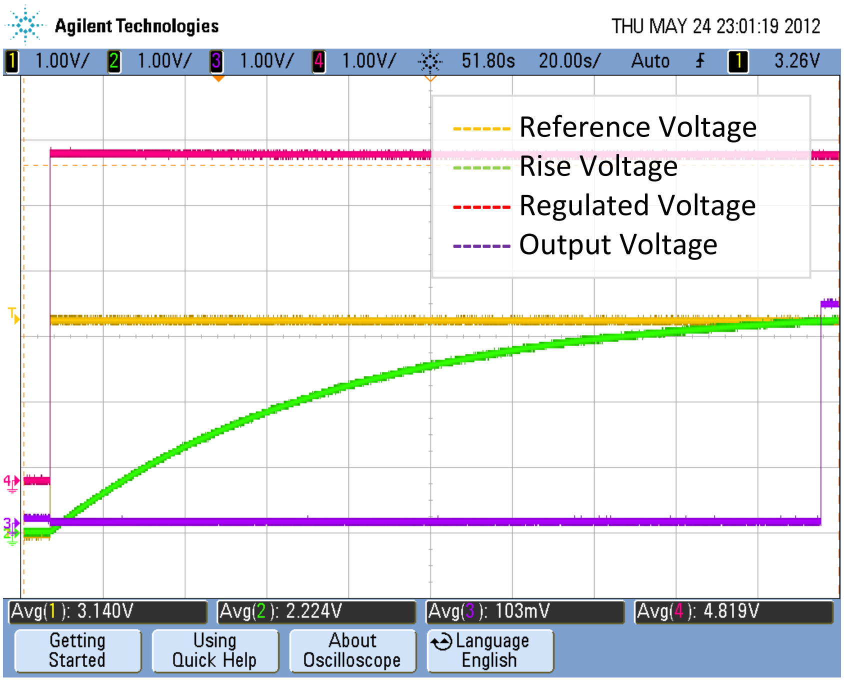

Figure 10 - Actual Timer Switch Response

2.4. Timer LEDs

Overview

The purpose of the timer LEDs is to indicate when the timer switch is turned 'on' to convey to the user that the breathalyser is ready for use. The first LED (red) should turn on when the breathalyser is powered up and the second LED (green) should turn on around three minutes later. The input to the timer LEDs is a step input from 0V to 5V. These inputs are identical, despite occurring at different times. The timer LEDs are required to turn on and remain on after they receive the 5V step input. The chosen design for the timer LEDs is shown in Figure 11 below. Both are made up of a resistor - to limit the current - attached to an LED. The resistor chosen for the green LED was of a lower value than that chosen for the red so that the 'ready' LED would display brighter.

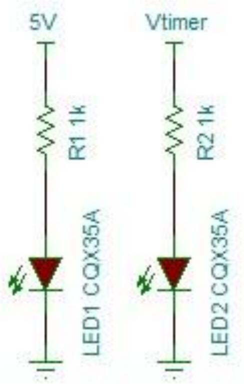

Figure 11 - Timer LEDs

Output - Simulation

The theoretical output of the combined timer switch and timer LEDs (as simulated by TINA) is shown in Figure 12 below. This output is for a simple 5V step input. This indicates that the theoretical output matches what is desired as the first LED switches on when the breathalyser is powered up, and the second LED switches on to indicate that the breathalyser is ready after 180 seconds.

Output - Simulation

The actual output of the combined timer switch and timer LEDs is shown in Figure 13 below. This output is for a simple 5V step input. This output matches the simulated output substantially so is behaving as expected. The second LED switches on at 180 seconds.

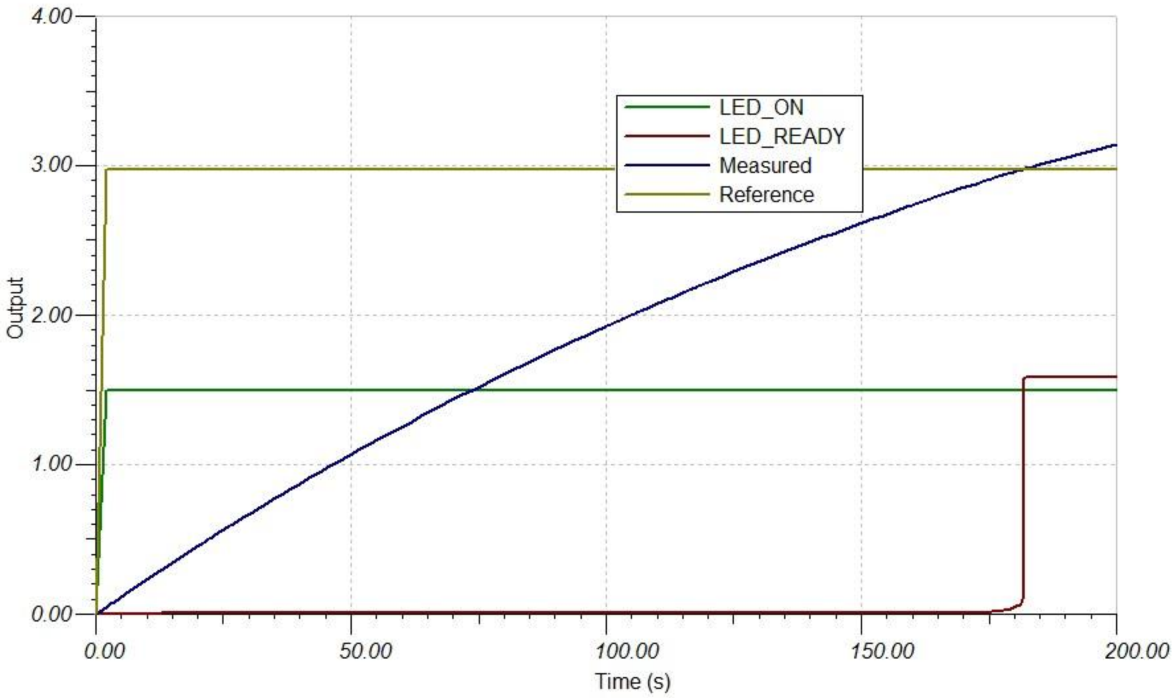

Figure 12 - Complete Timer: Theoretical LED Functionality

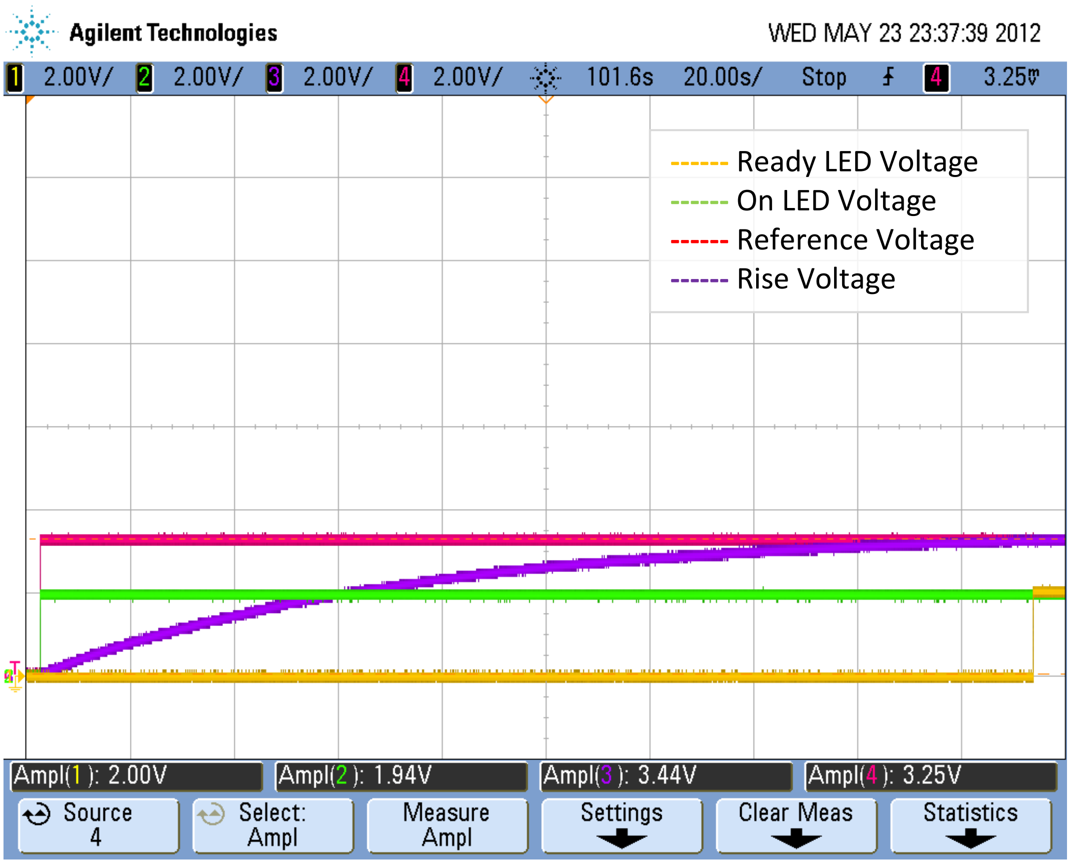

Figure 13 - Complete Timer: Actual LED Functionality

2.5. Sensor

Overview

The sensor provides all of the data for the system to process. The purpose of the sensor block is to use the varying resistance of the sensor to create a voltage indicative of the input breath alcohol reading.

Design

The chosen design for the sensor block is shown in Figure 14 below. It is composed of the sensor itself and a resistor. The sensor can be modelled as having a separate heater resistance and sensor resistance (this is shown in the diagram) [3]. When alcohol is incident on the sensor, the sensor resistance drops. With the chosen setup the sensor resistance and load resistance act as a voltage divider and hence when the sensor resistance drops, upon breath alcohol input, the output voltage increases.

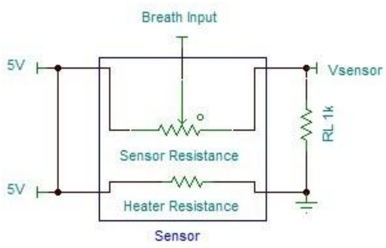

Figure 14 - Sensor

Signal Response

The measured signal response of the sensor block to three breath alcohol input values is shown in Figure 15 (extracted from Figure 27) below. This indicates that the input takes about 3 seconds to reach a maximum input reading and this maximum value increases as the alcohol content increases.

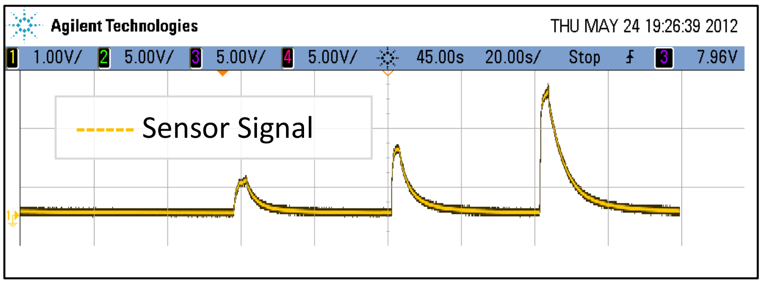

Figure 15 - Measured Sensor Responses for Increasing Alcohol Concentrations

Simulated Signal

In order to simulate this signal for circuit simulation purposes later in development, three function generators were connected in series on TINA. Each of these were made to produce a waveform approximating one of the three input alcohol levels. This simulated signal is shown in Figure 16 - Simulation of Sensor Input for Testing below.

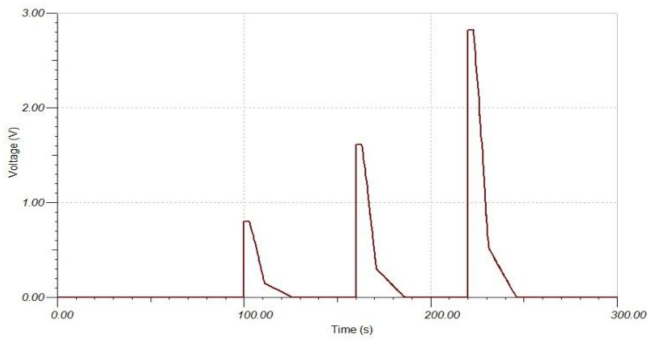

Figure 16 - Simulation of Sensor Input for Testing

2.6. Monostable Pulse Stretcher and Indicator LEDs

Overview

This is the final and largest of the functional blocks required for the fully working breathalyser and three of them are required; one for each of the indicator LEDs. The purpose of this block is to take an input from the sensor, which is fed into the comparator. This comparator is set to trigger to an 'off' state if the sensor voltage exceeds a certain threshold defined by the relevant voltage divider in section 2.2. When the comparator triggers, this in turn is set to trigger a monostable pulse stretcher for ten seconds, during which time this pulse will turn on one of the indicator LEDs.

The Comparators

There are three comparators required to implement this functional block, one for each of the threshold voltages. These were simple to implement and their implementation is shown below in Figure 17.

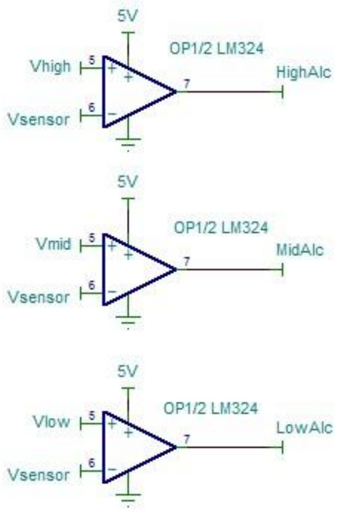

Figure 17 - The Threshold Determining Comparators

The Monostable Pulse Stretcher

All three of the comparators feed their output into a monostable pulse stretcher. These are designed to respond to a signal above a certain threshold (the threshold is used to stop the pulse stretcher triggering off noise) by outputting a constant-voltage pulse for a fixed amount of time and then returning to the other state indefinitely to await the next signal. To implement these, a differentiator is first required to create a negative spike upon comparator state change from 5V to 0V. The positive spike is filtered using a diode to prevent the pulse being stopped when the input signal turns off. This negative spike is then fed into the actual monostable multivibrator, which creates the output pulse. The implementation of this design is shown below in Figure 18.

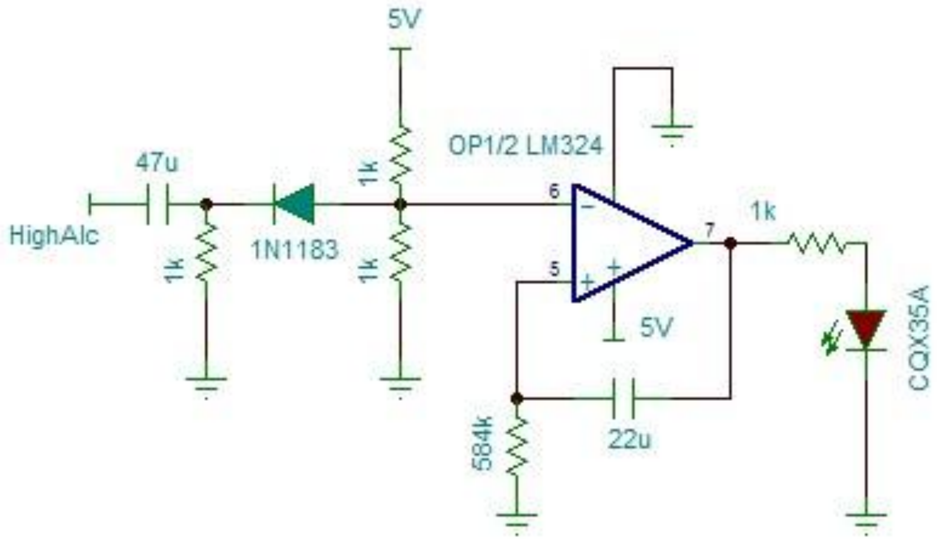

Figure 18 - The Monostable Pulse Stretcher

The Indicator LED

The final stage of the functional block is the LED itself. This takes the upper rail output of the monostable pulse stretcher as input, remaining on until this voltage drops back to zero when it turns off. The implementation of this section is shown at the end of the above block in Figure 18.

Theoretical Output - Simulation

The theoretical output of the timer switch (as simulated by TINA) is shown in Figure 19 below. This output is for a simple 5V step input. This indicates that the theoretical output matches what is desired as the output voltage switches to a maximum value in 110 seconds.

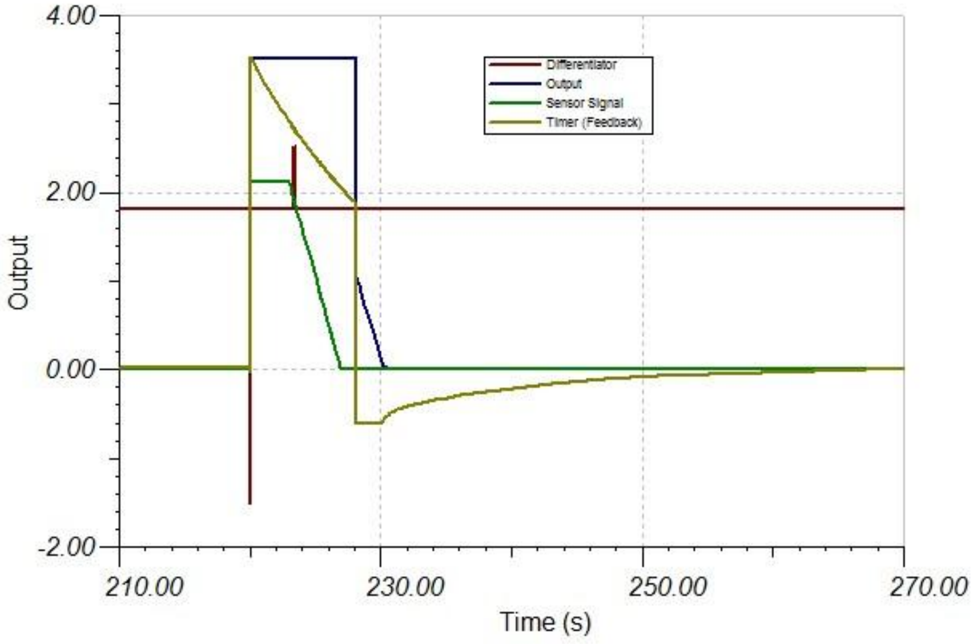

Figure 19 - Simulated Monostable Pulse Stretcher and LED Output

Practical Output - Testing

The practical output of the monostable pulse stretcher, as well as the signal at various stages of processing, is shown in Figure 20 below. This output matches, almost exactly, the simulated output and so this functional block is working as expected.

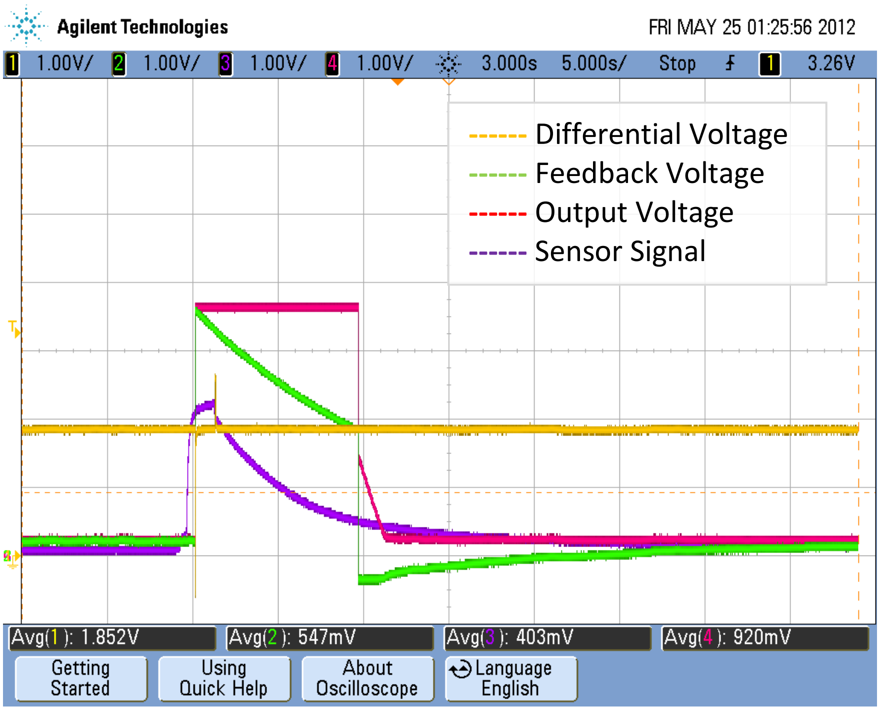

Figure 20 - The Actual Monostable Pulse Stretcher and LED Output

3. Simulation Results

The complete circuit was designed in TINA and can be seen below in Figure 21.

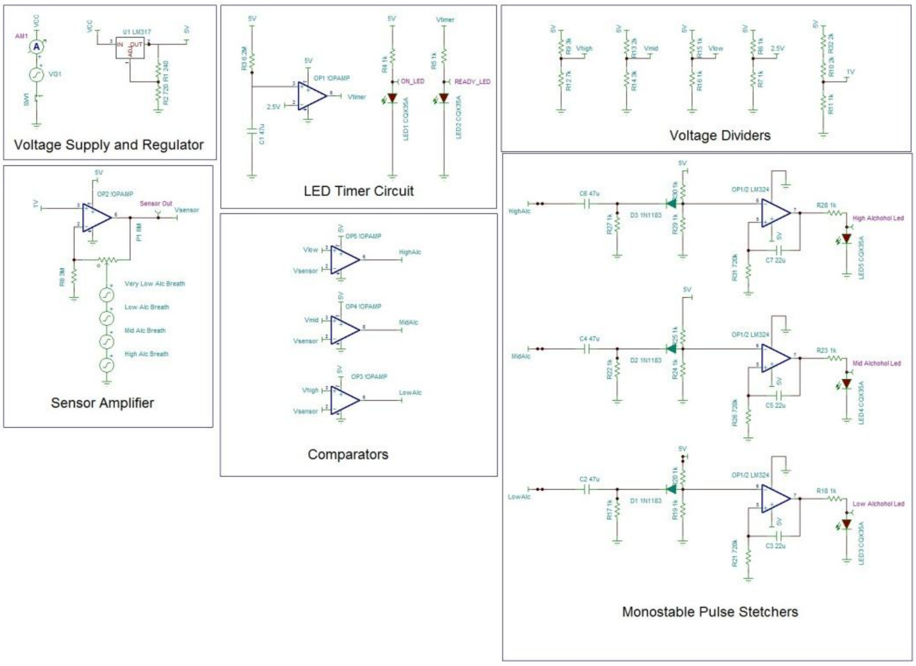

Figure 21 - Initial Circuit Design Using TINA

The circuit seemed realistic and relied on the changing resistance in the sensor to decrease the gain of the non-inverting amplifier with a 1V input, changing comparator state and therefore triggering the pulse stretchers. The simulation of this circuit can be seen below in Figure 22.
NOTE: AM1 shows current drawn from the supply.

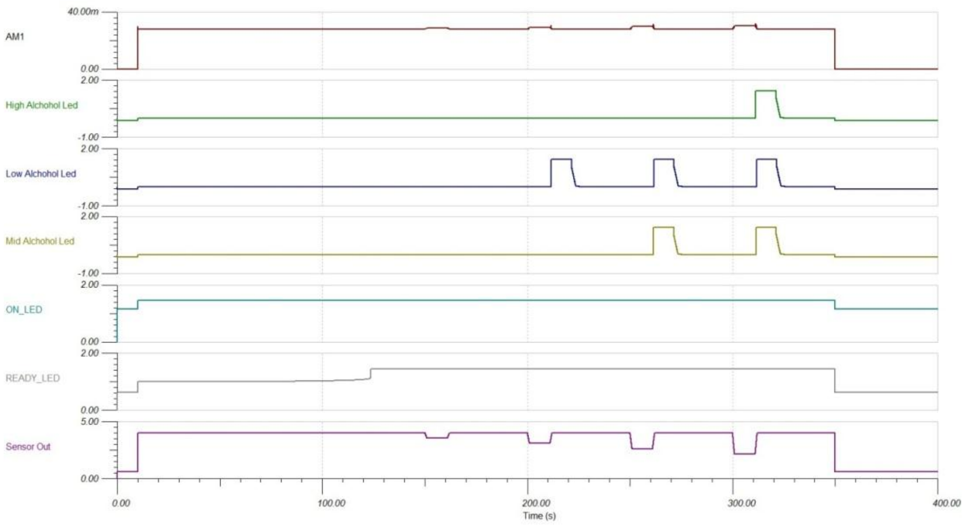

Figure 22 - Proposed Design Simulated Outputs.

Upon further investigation it became clear that the output voltage from the sensor's voltage divider was of great enough range and value to not require amplification. With this change to the design one of the voltage dividers could be removed along with the non-inverting amplifier. Additionally potentiometers were chosen so that reference voltages could be calibrated as desired after fabrication. The revised circuit is shown below in Figure 23.

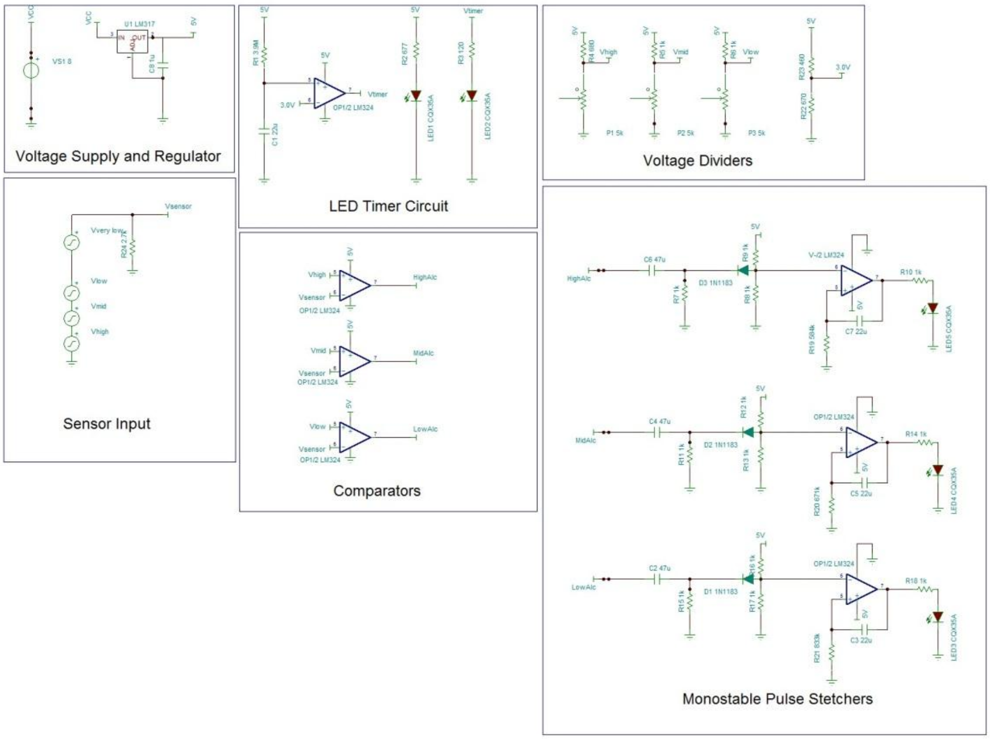

Figure 23 - Final Breathalyser Circuit Design using TINA.

This circuit was accepted as the final design and yielded the following simulation in Figure 24.

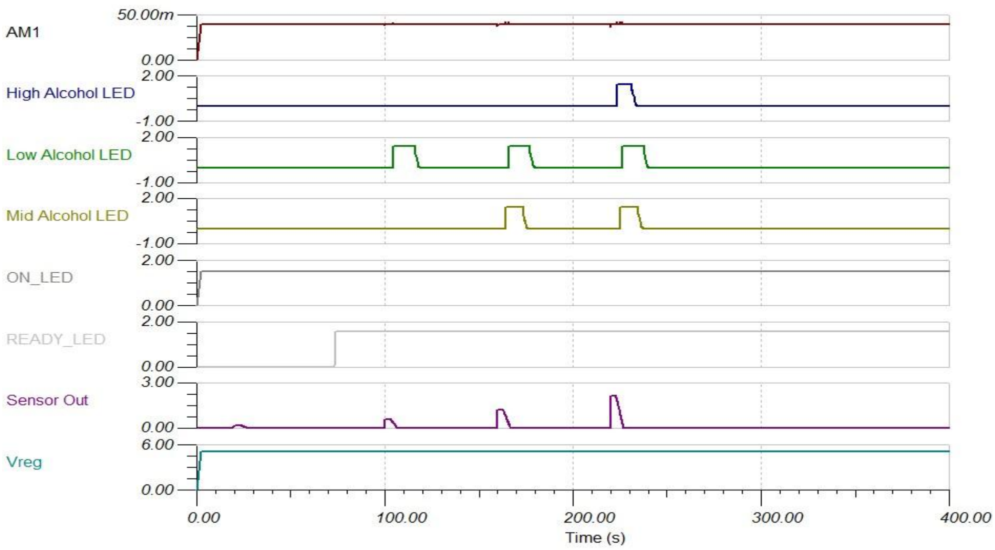

Figure 24 - Final Breathalyser Design Simulation.

4. Costs and Components

All components were purchased from the Canterbury University electronics store. The casing for the breathalyser was purchased from Jaycar Electronics [4]. The details of each item and cost can be seen below in Table 1. The total cost comes to $24.39 and is therefore within the project budget of $25.

Table 1 - Breathalyser Component Costs and Value

#	Quantity	Label	Value	Cost per unit	Total Item Cost
1	4	C1	22uF	$0.30	$1.20
2	3	C2	47uF	$0.25	$0.75
3	1	C8	1uF	$0.20	$0.20
4	3	D1	1N1183	$0.10	$0.30
5	2	LED Green	CQX35A	$0.25	$0.50
6	2	LED Red	CQX35A	$0.20	$0.40
7	1	LED Yellow	CQX35A	$0.25	$0.25
8	1	R1	3.9MΩ	$0.05	$0.05
9	1	R2	677Ω	$0.05	$0.05
10	1	R3	120Ω	$0.05	$0.05
11	1	R23	460Ω	$0.05	$0.05
12	1	R22	670Ω	$0.05	$0.05
13	1	R24	2.7kΩ	$0.05	$0.05
14	1	R4	680Ω	$0.05	$0.05
16	14	R5-R18	1kΩ	$0.05	$0.70
19	1	R21	833kΩ	$0.05	$0.05
20	1	R20	671kΩ	$0.05	$0.05
21	1	R19	584kΩ	$0.05	$0.05
22	1	U1	MC7805	$1.00	$1.00
23	2	Vero Board	2 Linear Inches	$2.00	$4.00
24	2	LM324 Quad Pack		$0.85	$1.70
25	1	Case		$2.49	$2.49
26	1	MQ-3 Breath Alcohol Sensor		$5.00	$5.00
27	2	IC Socket		$0.15	$0.30
28	3	Potentiometer (Pot)		$1.70	$5.10
				Total Cost:	$24.39

5. Development

Before the implementation of the circuit commenced on the Vero board, the circuit was developed on a breadboard to ensure that our simulations were indeed giving a reliable breathalyser circuit. This took a considerable amount of time. However, it did confirm that the design performed as expected. The complete breadboard circuit can be seen in Figure 25.

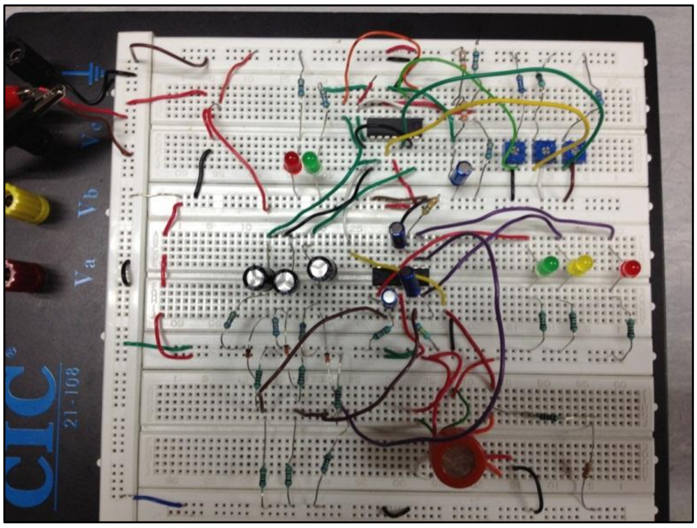

Figure 25 - Breath Alcohol Indicator Breadboard Prototype.

The next step of development involved the planning, placement and soldering of each component onto the Vero board. This was carefully planned out beforehand and required particularly careful consideration to avoid incorrect connections and short circuits. The final design was able to fit onto a 5cm by 12cm board as shown in Figure 26.

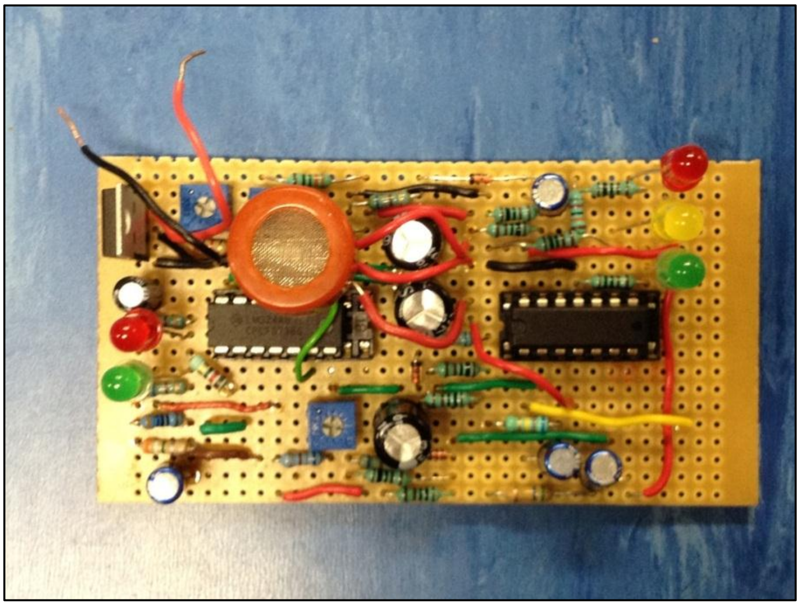

Figure 26 - Breath Alcohol Indicator Vero board Final Design.

6. Test Results

As expected the circuit functioned very similarly to the simulated design. The test results that can be seen below in Figure 27 show the response of the LEDs to three, successively stronger, breath alcohol inputs. The green line represents the green LED that corresponds to a low alcohol per volume input, the pink line corresponds to a mid alcohol per volume input and the purple line a strong alcohol per volume input.

The only apparent issue that can be seen with our test results is that the monostable pulse stretchers require some recovery time for them to generate a full ten second pulse again. This will require the user to exercise a small delay between each use of the breathalyser to achieve full LED duration. While this error can cause the LED duration to be lower, it will still come on with an appropriate alcohol per volume input therefore the overall mode of operation is not affected.

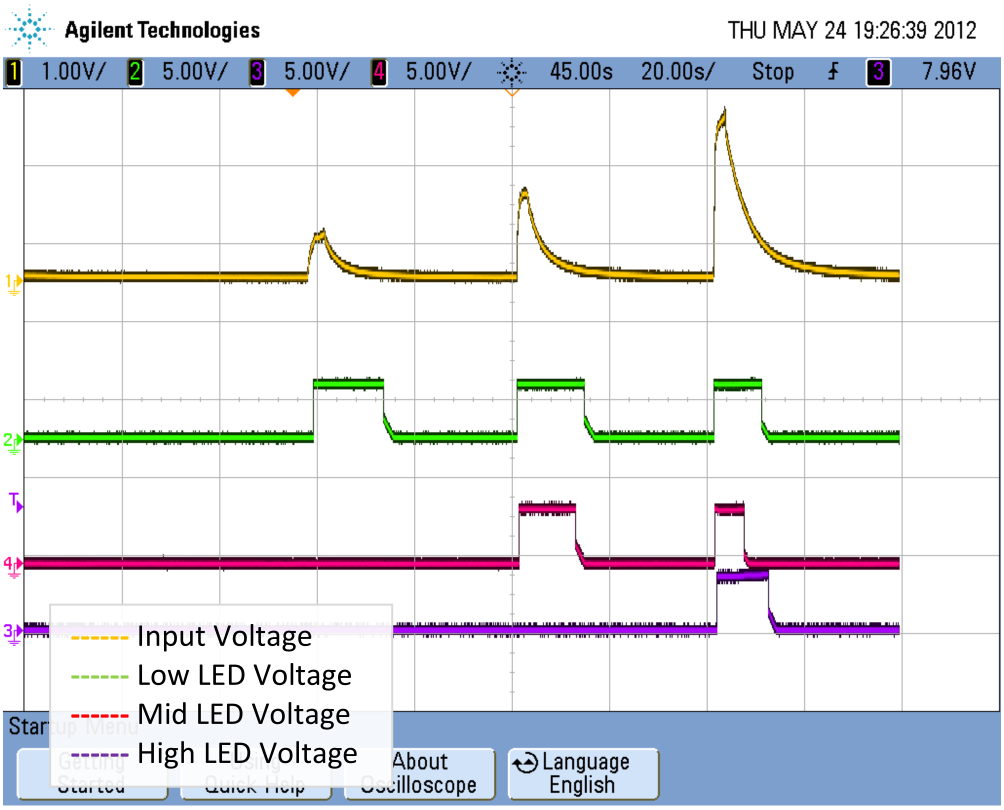

Figure 27 - Tests Results of Completed Circuit on Vero Board showing LED responses.

7. Discussion

In general the breath alcohol indicator was a success. The main attributes required of the breathalyser, as outlined at the start of Section **Error! Reference source not found.**, were all met. It featured a decoupled voltage regulator and a timer set to trigger the ready LED 'on' after three minutes of wait time. There were also monostable pulse stretchers set up to trigger at certain sensor voltages (which could be chosen by setting the variable resistors to appropriate values), and these pulses would trigger corresponding LEDs to provide information back to the user.

As all these requirements were satisfied, the board was a success on the grounds of its functionality – it satisfied all the design specifications to some degree. However, there are plenty of areas of improvement to be made. One instance of this is the occasions where it appears arbitrary component values were chosen, and some of these need to be analysed in more detail if the breathalyser is to be improved. For example, the 2.7kΩ resistor was empirically chosen because it gave the range of results that were desired. However, there are more preferable techniques to select this resistor, based on the desired balance between the voltage range and the voltage offset. Graphs showing how changing the output resistance affects the voltage range and offset for a series of sensor resistances would give a better indication of what output resistance to choose for the application.

Another issue that was encountered was the pulse length on the LEDs sometimes lasting for a shorter time than desired. However, this is a problem that is easily solved by adding extra protection against positive spikes in the differentiator. As the diodes used in these differentiators are not ideal, the spike can still be too large and cause the comparator in the monostable multivibrator to reset, ending the pulse length early. This does not particularly impede the functionality of the circuit but should be fixed nonetheless. This could be fixed either by using an improved diode or by increasing the time constant of the pulses so they maintain a high voltage for longer to avoid the positive spike. However, this defect was discovered too far through the design process to rectify.

One of the better ideas that came out in the design of the breathalyser was the use of the variable resistors. These were used to select reference voltages for the comparators going in to the monostable pulse stretchers, so they could be adjusted to make the threshold better positioned for the discrete input breath alcohol values that had to be detected. Not only was this a convenient setup for achieving this purpose, but it was also a great setup for potential application across multiple jurisdictions. Different countries have varying alcohol regulations, and thus different requirements and expectations of products such as breathalysers, so the ability to reduce or increase the thresholds for 'low,' 'mid,' and 'high,' is an invaluable tool if the product was to be marketed worldwide.

One of the aims that was also pursued was that of making the device portable. In particular, this was done by trying to minimise the size of the Vero board used. A smaller Vero board naturally meant that a smaller case could be used to house the device, making the product more plausible as a portable breathalyser. However, while this was achieved to some extent there is certainly room for improvement, especially if the product were to go into production. One particular way that the size could be reduced would be through the use of a PCB to improve the ability to design the layout of components in an efficient manner. Vero boards are not only hard to layout as there is little software support for this, but they are generally more difficult to manufacture. The size could also be reduced by using surface mount components – particularly resistors, which take up a substantial part of the board on the current model.

For this interest in portability it is particularly important to note the power consumption of the breathalyser. This is one of its major problems as it is power-intensive. This draws away seriously from this possible application; large amounts of power cannot be easily sourced from small batteries and so making the breathalyser portable is not plausible without serious power consumption improvements.

Assuming a 9V source, the heater current is calculated by:

$$I = \frac{V}{R} = \frac{5}{33} = 0.1515A$$

The power drawn from the 9V supply by the heater is therefore given by:

$$P = IV = 0.1515 \times 9 = 1.3636W$$

The total current drawn by the circuit (as measured) is $0.21A$, equating to $1.89W$ of power used by the whole circuit – hence three quarters of the power drained is because of the heater.

A 9V lithium ion battery pack contains up to 1.2Ah of power supply, meaning that this model's battery life is given by:

$$t = \frac{1.2}{0.21} = 5.7h$$

The calculations immediately above indicate that a 9V Li battery could last 5.7 hours running the breathalyser without needing replacement. While this may seem substantial and may be a workable breathalyser model, it is important to note that to purchase two rechargeable 600mAh 9V batteries and a charger would cost more than $50.00 US [5] – which would triple the cost of the breathalyser, and therefore make the low-cost breathalyser model collapse. Even non-rechargeable 9V batteries, which would not work well due to their relatively quick speed of use, cost around $10 NZ [6]. Hence the best solution would be to reduce the power consumed. This could be done by exploring alternative sensor options as the vast majority of power is lost through the inefficiency of the breath alcohol sensor.

In determining commercial application of the breathalyser, it is important to normalise what value ranges the LEDs will display; i.e. it is important to convert these thresholds into mg/L of alcohol in the air. This can be approximated using a sensitivity characteristic graph similar to the one on the MQ-3 datasheet [7]. However, that particular graph cannot be used for this breathalyser as it only matches a load resistance of 200kΩ.

The MQ-3 is particularly affected by temperature and humidity, as can clearly be seen from the datasheet [7]. In order to make this less vulnerable to these environmental factors in the future, sensors close to the MQ-3 should be included to measure the ambient temperature and humidity and provide some counterbalance to the problems that these pose. The budget was not enough to include sensors in the current model. However, it is one area that those making improvements to the model in the future would want to consider, as it can cause problems with the readings if it is not accounted for. The only real guard on this breathalyser was the three-minute wait time to let the sensor heat up. Although this solution worked relatively well for the budget, this still may not be the best solution, so this should be further assessed.

8. Conclusion

Overall the breathalyser was a success. It satisfied the requirements to a good standard and was within the budget. Although there are many improvements that could still be made, many of these are not able to be done within the budget or without using alternative manufacturing techniques, such as using PCBs and surface mount components to reduce the size of the board. The breathalyser project also showed that this particular model was implausible for marketing and selling, but with more engineering to improve the overall product it could potentially become a low-cost, marketable product.

9. References

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