Design of an Optical Fibre Glucose Biosensor

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Abstract

Diabetes is a growing medical problem in the world today that typically requires control of the blood glucose level of afflicted patients. Blood glucose concentration can be detected by using glucose oxidase to convert glucose in a blood sample into gluconic acid. The pH of this sample can be detected through the use of a pH indicator liquid whose colour change can be detected through an apparatus detecting the luminosity of light passed through the sample. This device would output a voltage based upon the luminosity detected. It can be more inexpensively created through the use of a carefully chosen LED and Photodiode connected with a multi-mode optical fibre. Detection can also be taken a step further by providing a rough calculation of the amount of insulin the patient should inject to normalize his/her blood glucose concentration levels. Use of a general pH indicator such as bromocresol purple would allow for the device to be expanded for the detection of other chemicals in the bloodstream. The proposed device would be an inexpensive, variable optical fibre glucose biosensor with post-processing elements to calculate suggested insulin dosage. The theory behind this device, hardware design, experimental results and efficacy are outlined below.

Key words: blood glucose concentration, glucose oxidase, gluconic acid, LED, Photodiode, multi-mode optical fibre, bromocresol purple, inexpensive, variable, insulin dosage calculation

Table of Contents

1 Introduction

1.1 Background

According to the World Health Organization, approximately 2.8% of the world population suffered from diabetes in the year 2000 [1]. Its incidence is increasing rapidly and this percentage is expected to nearly double to 4.4% in the year 2030, taking into account aging alone [1]. With the growing prevalence of diabetes in the world population, the need to treat this affliction has increased.

Currently the main treatment for diabetes is self-regulation with advice from a health care professional. Patients typically use a blood glucose meter to detect their current blood glucose concentration and then using past experience as well as advice from their healthcare professional, prepare an amount of insulin to be injected. The amount of insulin to be injected varies based upon patient sensitivity to insulin, the amount that will be consumed by the patient as well as the age and body mass of the individual involved. However, the number of visits to the family doctor by an individual with diabetes is estimated to be roughly 6.3725 visits per year or roughly one visit every 2 months [2]. This leaves a large gap in time in which the patient must rely upon personal experience and advice from their family doctor that may be outdated.

Improper injection of insulin can lead to abnormal levels of blood glucose in the patient's bloodstream which could lead to hypoglycemia if the injection made by the patient was too high or the patient may enter hyperosmolar hyperglycemia if the injection made was too low. Symptoms of these states vary on the severity of the improper dosage as well and many other patient factors. Symptoms of hypoglycemia include shakiness, sweating, confusion, irritability or paleness of the skin. Hyperosmolar hyperglycemia typically causes frequent urination, great thirst, nausea, disorientation, drowsiness and even loss of consciousness. Both complications from these diseases can be extremely dangerous to the patient depending upon what the patient is doing or where the patient is at the time. Thus it is very important for the patient to always inject the right amount of insulin to remain healthy.

1.2 Objective

The primary goal will be the design of a fibre optic glucose biosensor with post-processing directives to calculate recommended insulin dosage of the patient.

A major secondary goal would be the expansion of said device to track other chemicals/hormones that would be important for other diseases.

1.3 Approach

A glucose biosensor will be developed that will send information to a microcontroller or computer to be processed to extract the correct dosage of insulin required by the patient.

2 Literature Review

2.1 Review of Glucose Biosensors

The first blood glucose sensor was invented in 1962 by Clark and Lyons at the Cincinnati Children's hospital [3]. It used a thin layer of glucose oxidase placed over an oxygen electrode using a semi-permeable dialysis membrane. The electrode monitored the oxygen consumed by the enzyme-catalyzed reaction of glucose being converted to gluconic acid and hydrogen peroxide as outlined below [3].

$$\text{glucose} + O_2 \xrightarrow{\text{glusoce oxidase}} \text{gluconic acid} + H_2O_2 \quad (1)$$

Almost all glucose monitors can trace their origins to this electrode and meters have been developed that measure blood glucose concentration based on the products or reactants of this reaction equation. Current methods of blood glucose detection can generally be subdivided into 2 different types. The first type uses the electrochemical properties of the reactants or products in the solution to detect a voltage, which corresponds to a level of glucose concentration. The second type relies upon the reaction of the reactants or products in the outlined reaction to cause a measurable colour change. This colour change is typically detected using a laser-photodiode pair which outputs a voltage based upon the detected colour, which can be related to the glucose concentration present in the blood sample. A third type of glucose biosensor is currently in development that uses a specially developed membrane that expands or contracts in contact with glucose. The expansion or contraction of the membrane is detected with a piezoelectric sensor, allowing for quantification of glucose concentration.

Electrochemical glucose biosensors were the first type to be developed and typically rely upon the detection of oxygen and hydrogen peroxide using electrodes. These sensors required relatively high operating potentials at which many other chemical species found in the blood such as ascorbic acid, uric acids or some drugs would also be affected, possibly compromising the accuracy of the blood glucose sensor [3]. Great effort was taken to minimize the introduction of error through this problem. One solution found was to create a highly selective semi-permeable membrane which would minimize the access of contaminants to the electrode, thereby reducing the effect of erroneous chemical species [3]. Another solution was the calibration of the electrode to a voltage level low enough that interfering substances would react minimally, thereby decreasing the effect they had on detection [3]. This was typically used in hydrogen peroxide electrodes as they could be tuned to a relatively low operating potential (+0.0 to -0.20V) that ensured the contributions from other oxidizable substances were minimized [3]. First-generation devices however, were limited by using oxygen as the electron acceptor in the reaction, which is limited by its presence in the typical bloodstream.

The need to solve these many problems with early electrochemical glucose biosensors led to the development of second generation glucose biosensors which moved away from the use of oxygen as an electron acceptor [3]. These biosensors use artificially created molecules to "shuttle" electrons in the reaction, allowing for much more accurate detection of patient blood

glucose concentration. Newer electrochemical biosensors use electrode "strips" in conjunction with a small hand-held detector.

Spectroscopic glucose biosensors are the second common type of glucose biosensor [8]. These sensors rely upon dyes marking a certain product or reactant from the equation. These dyes include pH indicators such as bromocresol purple or bromocresol red, or chemical indicators such as the dye Prussian blue which detects for the presence of hydrogen peroxide. Light is shone through the tested sample (usually from a laser), into a photodiode. The photodiode outputs a voltage based upon the luminousity of the light at its sensing element. One of the major advantages of spectroscopic glucose biosensors is their lack of reliance upon the electrical properties of the chemicals being tested. This means that special films do not need to prevent contamination of the electrode, and that special electron carriers do not need to be developed. Furthermore the sensing element on a spectroscopic glucose biosensor is also not electrically related to the reaction, thus noise from the electrochemical reactions does not affect the resultant voltage from the sensor. This voltage can then be converted into a glucose concentration based upon the calibration.

A third type of glucose biosensor is currently in development that uses a specially developed membrane that expands or contracts in contact with glucose [4]. The change in size of the membrane is picked up by a piezoelectric sensor. The resultant voltage can then be converted into a glucose concentration.

2.2 Review of Sliding Scale Techniques

The second primary objective of this device is the ability to read in the information from the sensing element of this device and then convert the value received into a recommended insulin injection value. There are many important factors that must be considered when deciding the amount of insulin one must inject. These include: current blood glucose concentration, body weight, insulin sensitivity (especially in the case of type 1 diabetes), projected meal intake, age, and many other personal factors [3]. The sheer number of factors required to estimate the insulin a patient needs can make it very difficult to decide the exact amount of insulin to give to a patient. The sliding scale insulin paradigm attempts to alleviate this problem by providing a simple, standardized way to calculate the amount of insulin that should be administered to a patient based on several of the above listed factors [3], [5]. This provides a simple, easy-to-follow method of finding the right amount of insulin to administer to a patient.

While there is a clear benefit to the use of the sliding scale paradigm, there have been found to be several flaws to the original sliding scale method. The efficacy of past and present paradigms of sliding scale insulin has been questioned due to their tendency to be used as a reactive measure against hyperglycemia, which means patients are potentially treated only after reaching dangerous levels [5].

Further research into the field however, yields that while sliding scale insulin used alone may be dangerous to patient health, if combined with a fixed basal dose control of a patient's blood glucose levels can be made much safer [6], [3]. Instead of simply reacting to a patient's high blood glucose level, a basal is injected to ensure the patient's blood glucose level stays within a safe boundary. The sliding scale dose can then be used to further correct the patient's blood glucose level to normal standards.

3. Methodology

The device in development can be subdivided into two main parts: A sensing element and a post-processing element.

3.1 Biosensor Design

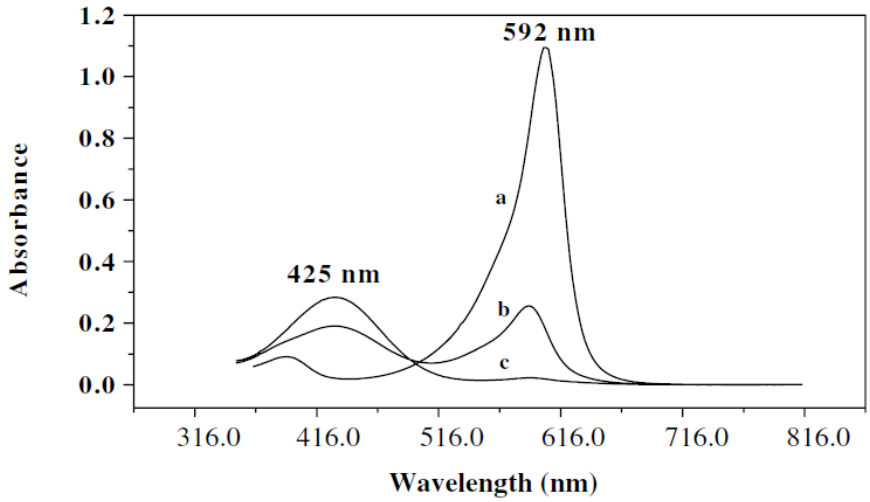
The sensing element of the device will be used to detect the glucose concentration in a sample of a patient's blood. This element would ideally follow the standard set by the International Standards Organization (ISO). According to ISO 15197 blood glucose meters must provide results within 20% of laboratory standards, 95% of the time.
A possible secondary objective of this device is to allow for the detection of other chemical compounds in the bloodstream. This would allow for the monitoring of the treatments for other diseases such as the hormone treatments for Turner's syndrome or Klinefelter's syndrome. It would thus be ideal to develop a detection mechanism that can easily be modified or converted for use in detection of other chemicals.

The post-processing element of the device would be used to calculate the proper dosage of insulin that would be required by the individual to normalize his/her blood glucose concentration. A formula or look-up-table would need to be created that would relate blood glucose level, body mass index, and other factors related to insulin sensitivity. In the ideal situation this processing would take place on the device itself so as to allow for increased portability and accessibility. However preliminary testing will be done with a computer-connected device for calibration and proof-of-concept purposes. The user interface also needs to be user-friendly as the device should be tailored for use by the average person at home rather than by their specialists.
Following the secondary objective of the sensing element, it would also be ideal to allow for this element of the device to be used for other diseases that require drug doses based upon the concentration of certain chemicals in the blood.
The design of an accurate electrochemical biosensor requires the use of doped membranes as well as specially developed electron carriers, both of which were found to be extremely difficult to create with the equipment available. A piezoelectric glucose biosensor would also be difficult to produce, as well as largely unproven. Thus, it was decided that the sensing part of the glucose biosensor would be based upon the spectroscopic method.

The general idea of the spectroscopic method is to detect the passage of light through a dyed substance. The choice of dye will affect which product or reactant is being detected in the reaction. One example of a dye that has been proven useful in this respect is Prussian blue. This dye changes from clear to blue in the presence of hydrogen peroxide and has an appreciable absorbance between 600-1000nm. This chemical however, was found to be rare and expensive to purchase.
It is also possible to use a dye to detect for the production of gluconic acid. This is most easily done using a pH indicator that changes colour based upon the pH of the solution. With higher glucose concentration more gluconic acid would be produced when catalyzed by glucose oxidase. This would lower the pH of the solution and subsequently change the colour of a

properly chosen dye. For this purpose bromocresol purple was found to be an interesting dye as it had a large visibly effective pH range from 5.2-6.8, which is fairly close to the expected range of the solution: 4-7. Research done into this dye revealed that its peak absorbance occurs at the wavelength 592 nm, very close in wavelength to the colour yellow [7]. This makes bromocresol purple (BCP) effective in the correct pH range, as well as a good inexpensive alternative to other dyes (yellow belongs to the visible spectrum and is easier to find from a lighting source than an infrared wavelength). Also, since this dye is a pH indicator, it can be used to detect many other chemicals in the bloodstream based upon their pH values when under reaction. It is for these 3 reasons that the dye to be used for the sensing element was chosen to be BCP.

Fig. 1 Absorbance Spectrum of Bromocresol Purple [7]



EW absorption spectrum of pH sensor with BCP in different pH environments ($a = 11, b = 8, c = 5$).

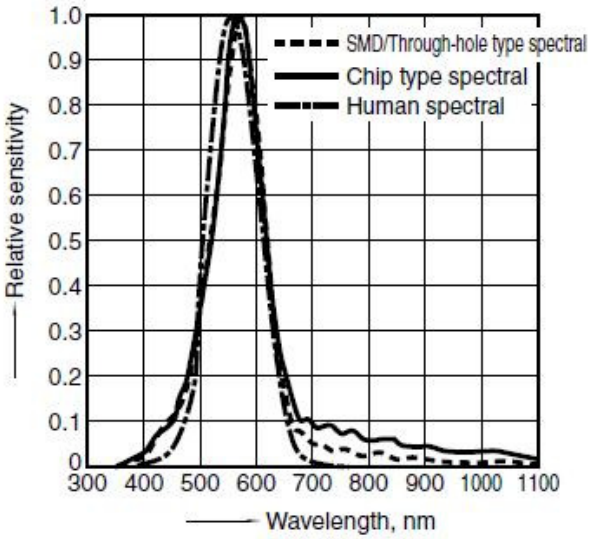
With the type of dye chosen, the next step was to choose the colour of the light source and photodiode to be used by the sensor. In order to get maximum resolvability from the detector it is important that the light source be chosen to output a wavelength of light as close as possible to the peak absorbance of the dye and that the photodiode be chosen to have a peak absorbance as close to the dye's peak absorbance as possible.

In order to lower costs, an LED can be chosen as the light source instead of the typical laser. It is not necessary for the light beam to travel for long distances, thus the precision and power of a laser would be wasted. The introduction of an LED as the light source also allows the use multi-mode optical fibre as the light carrier instead of a more-expensive single mode optical fibre. Multi-mode optical fibres are typically less accurate than single-mode optical fibres and are usually rated for use when less than 900m of cable is required, a value that is far exceeded by the amount of cable that will be used.

Due to availability, LEDs with wavelengths of 585nm (yellow-light) were found to be the closest match to the required wavelength. In order to maximize the resolvability of the output signal, it is important to choose a photodiode with a responsivity as close to the LED wavelength as possible. The Panasonic AMS302 photodiode was chosen as it was found to have peak responsivity at 580nm, extremely close to both the LED selection and the peak absorbance of

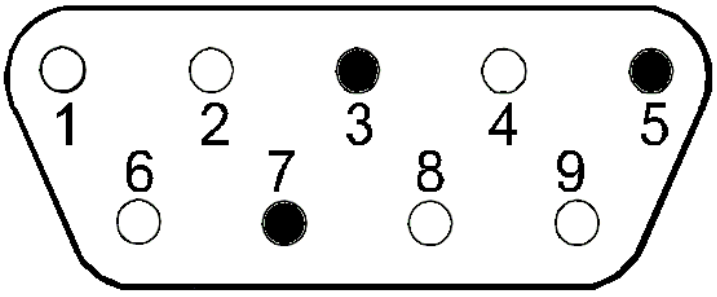
bromocresol purple. Due to the choice of an LED as the light source of the device, almost any type of optical fibre can be used to accurately transmit the light needed to the reaction platform. In particular however, a TOSLINK fiber optic cable stands out for being affordable and easily available.

Fig 2. Sensitivity Spectrum for AMS302 Photodiode



In order to transfer data from the device to the computer a microcontroller with an ADC is needed to convert the analog signal generated by the photodiode into a digital signal that can be read by a computer. This microcontroller need not be particularly fast thus it is enough to choose it based upon availability, price, operating voltage and ADC bit size. For these reasons the McMaster PIC24HJ32GP202 module was chosen. While somewhat obsolete in most computer devices, the RS232 serial connection poses as a simple way to transfer data from a microcontroller to a computer. Thus for a device prototype it will be more than adequate for use as the data transfer connector. The pin-out diagram below was used to correctly connect the needed wires for the data transfer.

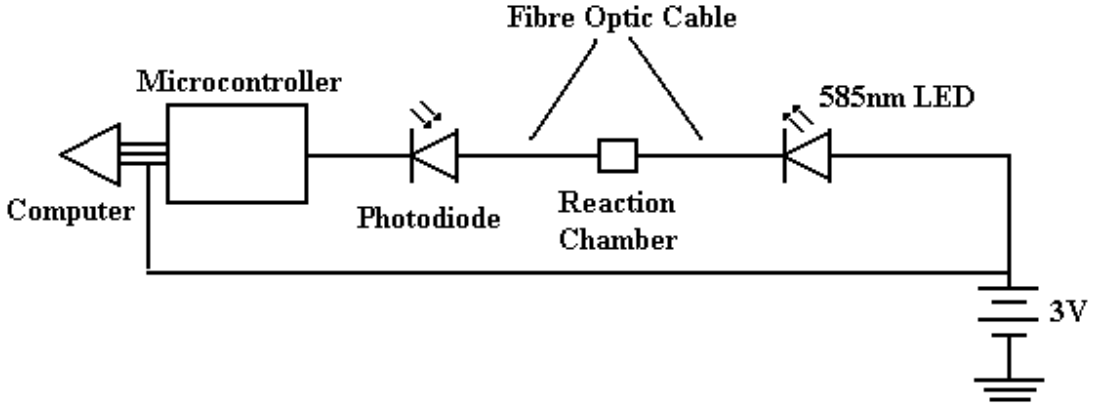
Fig 3. UART Pin-Out Diagram for RS232 Connector



3 - Transmit to PC
5 - Signal Ground
7 - +12V to Keep Serial Open

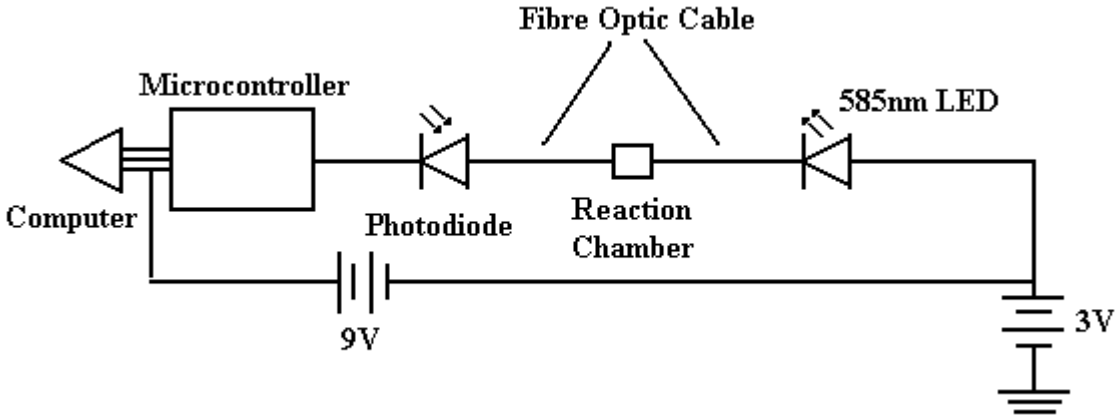
With the information at hand, the early design for the biosensor section of the device was drafted with plans to use 2 AA batteries as the power source (collectively 3V).

Fig 4. First Design of Biosensing Component



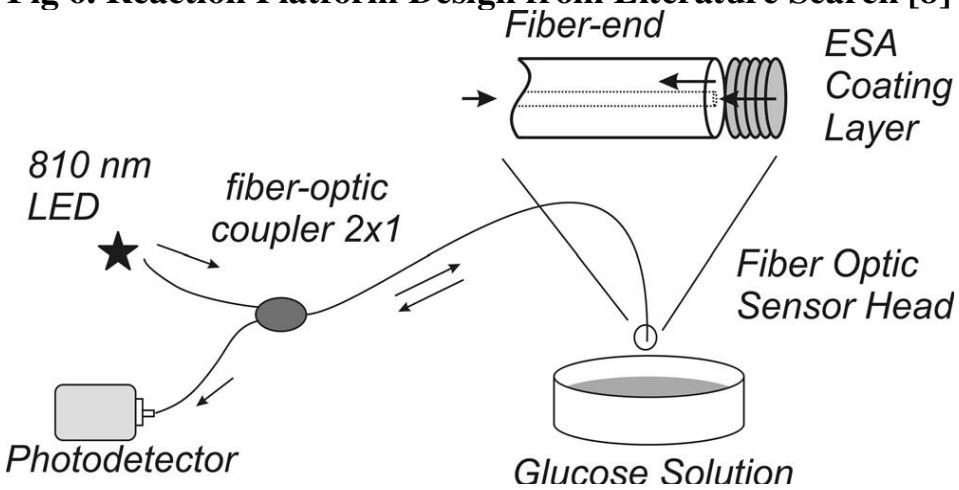
After further research into the RS232 connector however, it was discovered that 3V as the power source alone would not be enough to force the serial connection on. 12V are needed in order to keep the select bit on. Thus a 9V battery was added to the design of the circuit to create the higher required voltage.

Fig 5. Second Design of Biosensing Component



With the basic circuit designed the next step was to design the platform where the solution would be placed. The original idea was the use of 3 different fibre optic cables connected using a 2x1 fibre optic coupler or a splice similar to one of the designs found in a paper designing a glucose biosensor with the Prussian blue dye.

Fig 6. Reaction Platform Design from Literature Search [8]

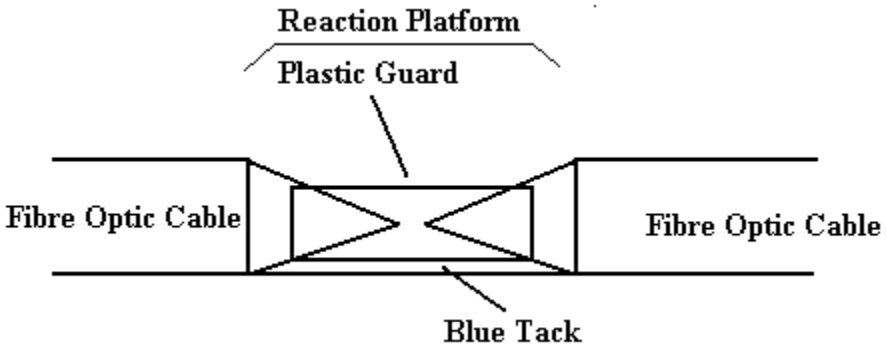


It was discovered however, that fibre-optic couplers were expensive to purchase, easily reaching 3 or 4 times the cost of the cables that would be used. Their availability and lead times were also found to be detrimental to project completion. Similarly, a splice was found to be difficult to perform with the equipment available. Thus 2 alternatives were developed for the reaction platform.

The first idea was to tie 2 fibre optic cables close together to attempt to cause the light beam to bounce from one cable to the other. Early testing with the LED alone however, found that this alternative was unreliable as very little light was reflected back to the second fibre optic cable.

The second alternative was to align the two fibre optic cables such that the beam of light would pass through the first cable, directly into the second cable. While prone to alignment and anchoring issues, it was found that this alternative was much more manageable than the first. Using blue tack, clear tape, clear plastic and cardboard a prototype platform was developed that aligned and anchored the two fibre optic cables together.

Fig 7. Reaction Platform Design

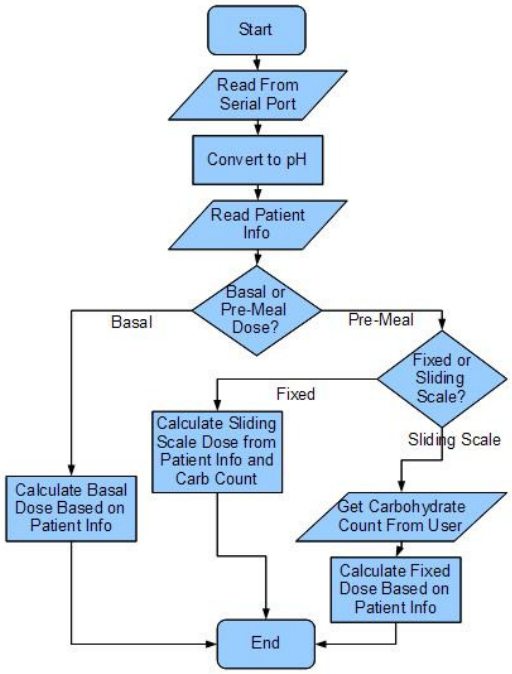


With the reaction platform and circuit designed, preliminary designs of the biosensor were completed and the biosensor portion of the device was ready for testing.

3.2 Post-Processing Program Design

The primary objective of the post-processing program requires for data to be collected from the sensing element, and using that data to calculate the patient's recommended drug dosage. In order to accomplish this, a formula or look-up-table will be needed to relate drug dosage to important attributes of the patient. Through the earlier literature search, the sliding scale insulin scheme was discovered as a means of estimating the insulin requirements of an afflicted individual.
Under the sliding scale insulin program developed for this device there are 2 different types of doses: a basal dose and a pre-meal dose. The basal dose is a fixed dose of insulin that is given to the patient in the morning and the evening that is used to keep the patient's blood glucose levels at a stable, safe amount during the day. The total dose from this basal amount is typically half the dose recommended by the patient's doctor and is given 1/3 in the morning and 2/3 in the evening. The pre-meal dose is a fixed or varying amount of insulin that is given to the patient to control his/her blood glucose level after eating. This amount varies based upon the patient's detected blood glucose concentration, projected carbohydrate consumption amount, the patient's weight, and the patient's insulin sensitivity factor.
The insulin sensitivity factor is a rough measure of the drop in blood glucose level caused by each unit of insulin taken. There are 2 rules that follow this factor, the 1500 rule that is used with short-acting insulin and the 1800 rule that is used with rapid acting insulin [3]. For simplification purposes this device assumes the use of regular short-acting insulin, which is the most common. All formulae used in the programming of this device can be found in its appropriate section in the appendix. The basic outline of the program to be designed can be seen in the flowchart below.

Fig 8. Flowchart Outlining Basic Post-Processing Program



Current post-processing design consists of a very basic text output with basic text input required by the user in order to select the functions that they want to use. Future improvements to this interface would be instrumental in improving accessibility.
An important decision for the post-processing program is the programming language that will be used. While the ideal post-processing program would be accessible to a wide audience, it is important for the program to also be able to handle the calculations quickly and accurately, while also being easy to debug and program. The preliminary programming language to be used for this was MATLAB which was chosen due to ease of the language as well as its large mathematical toolset which is useful and easy to use for many different types of calculations. Using the formulae and tables obtained from research into insulin dosage recommendations the program was designed to read input from a serial port. The functionality to read data from a text file was also added as a backup in case of poor serial port connection.
In addition to the base program, the post-processing paradigm requires 2 other text files. The first text-file labelled InChart.txt is a table that shows the amount of insulin required to control a certain amount of carbohydrates. The second text-file labelled patInfo.txt is a file that contains several important attributes about the patient including weight, patient's diabetes type (type 1 or type 2), prescribed daily insulin amount and whether the patient follows a fixed or sliding scale algorithm. These values along with current blood glucose concentration and time of day affect the insulin dosage that will be recommended to the patient.

While it was possible to program the sliding scale portion of the device without testing, experimentation is needed to find the function that would convert the voltage read from the photodiode into a pH value that can be used to find the blood glucose concentration. This calibration will be performed after preliminary test results are confirmed.

4 Results

4.1 Testing Limitations

Due to restrictions placed upon the project, human blood was not used in the testing stage of the device. Several alternatives were proposed for the testing material.
The first alternative considered was a glucose oxidase (GOD), glucose and water solution. This would be the most direct method of testing the blood glucose concentration as it replicates almost all the key components of a blood sample. However, glucose oxidase and glucose were discovered to be difficult to find, as well as potentially expensive.
The second alternative considered was a solution of hydrochloric acid and water. This alternative abuses the pH detection quality of the designed glucose biosensor by the simulating the end result of the glucose oxidase catalyzed reaction. By finding the pH of the solution using stoichiometric calculations it is possible to estimate the amount of glucose that would have been in the given solution had the solution actually been made from glucose and water. While promising, the pH level of pure hydrochloric acid was decided to be potentially hazardous.
The third alternative considered was a solution of water with food colouring. Food colouring would be used to simulate the colours of certain pH levels of solution, following the same idea as the previous hydrochloric acid idea. This solution would also remove the need to purchase the pH indicator agent. However, since the colour spectrum of bromocresol purple is not based on one colour (the spectrum changes from yellow to purple across the indicated pH range) this alternative is prone to inaccuracy as simulation of the required colours could be difficult with the few food colouring colours available.
The fourth alternative considered was a solution of vinegar (5% acetic acid by weight) with water. This alternative is a much safer and cheaper version of the hydrochloric acid alternative considered before. It is also useful due to the relative neutrality of a normal glucose oxidase and glucose solution as the pH of blood is relatively neutral (7.35-7.45) and glucose concentration levels are typically below 20 mmol/L.

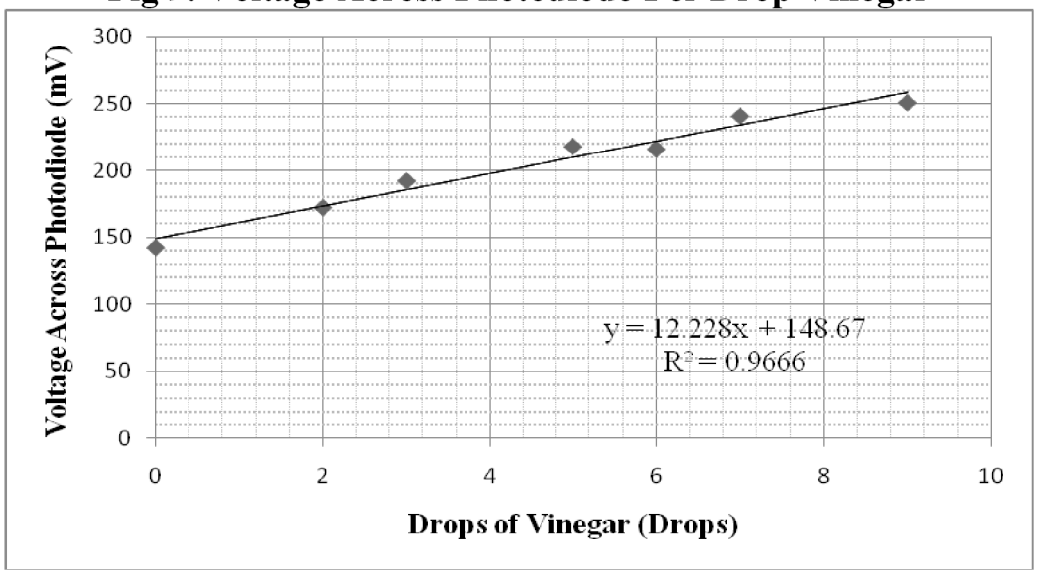
4.2 Preliminary Biosensor Test

After deliberation the fourth alternative was chosen as the testing solution. The standardized test solution was 100mL of water and a varying amount of drops of vinegar, with the final test being pure vinegar. A saturating amount of bromocresol purple was added to ensure the deepness of colour was standardized. The apparatus was set up as indicated in the diagram below with the LED and photodiode aligned with the TOSLINK fibre optic cables as straight as possible to ensure maximum possible resolvability of the test results. The unprocessed results can be seen in the chart below.

Table 1. Voltage Across Photodiode (mV)

Drops of Vinegar(Drops)	*Detected Voltage (mV)*
0	142
2	172
3	192
5	218
6	216
7	241
9	251
Pure Vinegar	269
Clear Air	281

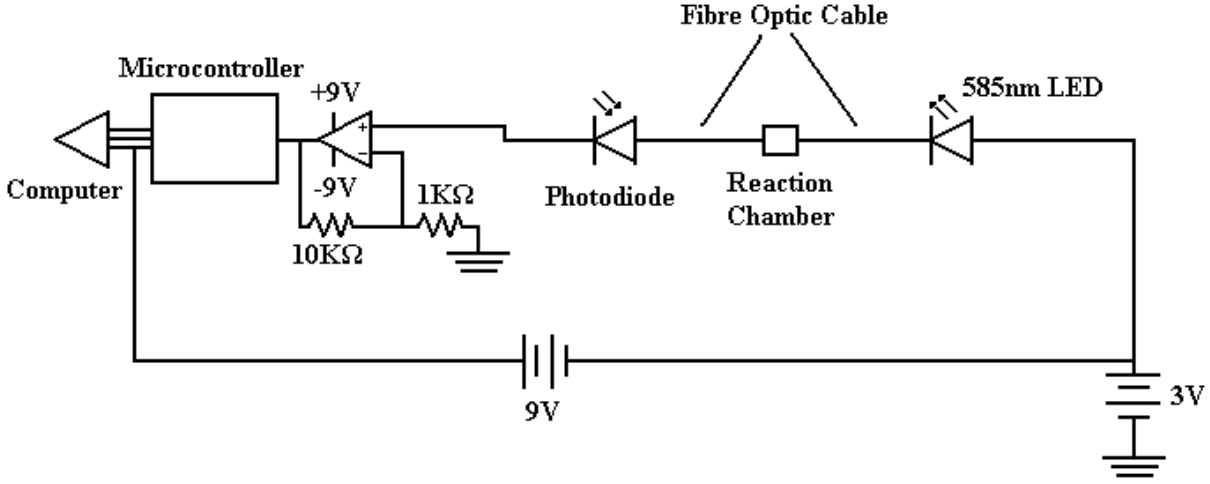
Fig 9. Voltage Across Photodiode Per Drop Vinegar



Through these preliminary results it can be seen that the voltage across the photodiode alone is fairly small. Thus an amplifier was introduced in order to allow for maximum resolvability between values. However even without an amplifier it can be seen that there is a linear relationship between pH and the voltage detected across the photodiode. This can be seen in the scatter plot with a linear trend-line seen above.

4.3 Modifications and Further Biosensor Tests

Fig 10. Third Design of Biosensor Component



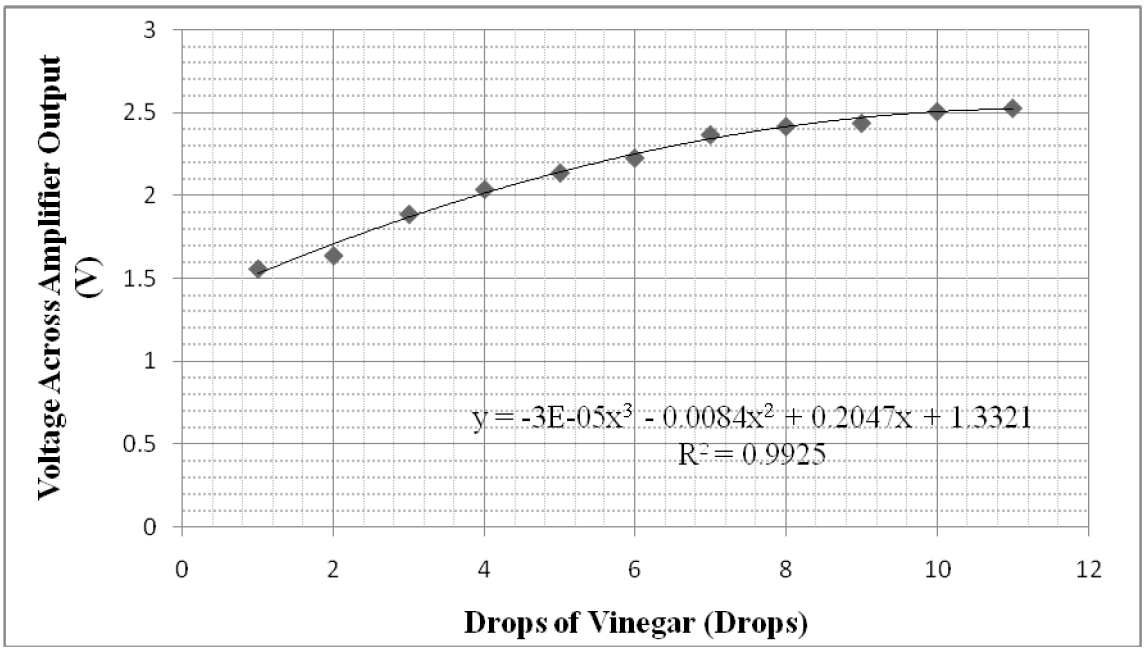
A simple non-inverting amplifier with a gain of roughly 10 (9.68 to be exact) was introduced for the second stage of the experiment. This test was done following a similar setup, using similarly prepared solutions. The tabulated results for this test can be seen below.

Table 2. Voltage Across Amplifier Output

Drops of Vinegar(Drops)	*Detected Voltage (V)*
0	1.38
1	1.56
2	1.64
3	1.89
4	2.04
5	2.14
6	2.23
7	2.37
8	2.42
9	2.44
10	2.51
11	2.53
Pure Vinegar	2.62
Clear Air	2.75

From the above tabulated results it can be seen that there is an expected upward trend in the voltage that passes through the photodetector as the solution becomes more acidic just like the first graph. However, this graph reveals a little bit more about the trend as more data was taken at the upper and lower ends of the test range.

Fig 11. Voltage Across Amplifier Output vs. Drops of Vinegar



From this data we can observe that the trend as the pH is increased in the solution may actually be a higher order polynomial (cubic shown) than the previously used linear trendline.

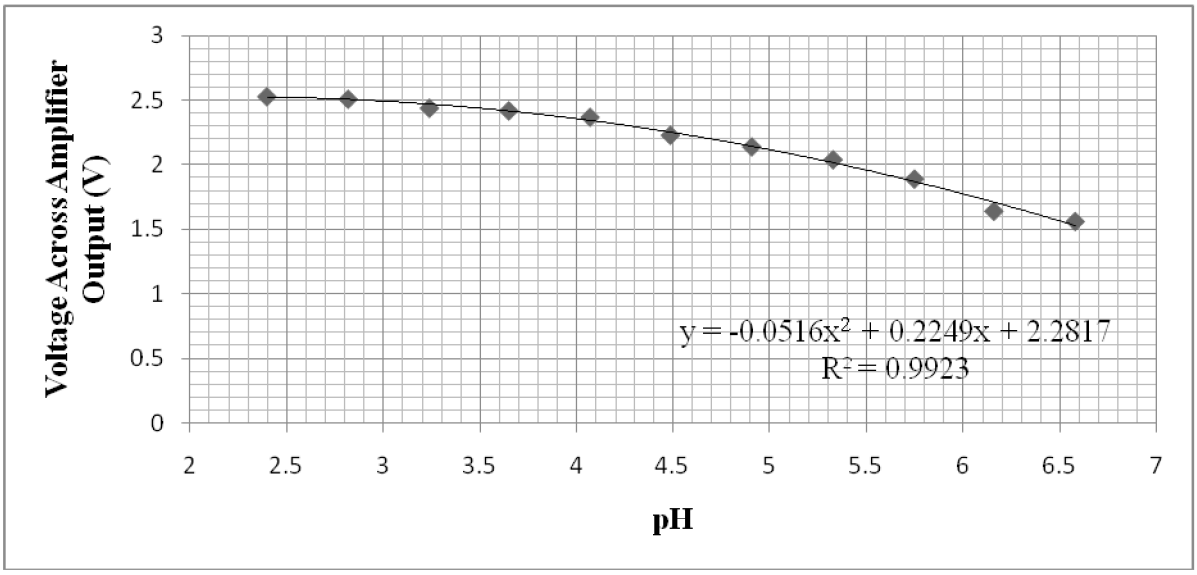
While these tables show promising data correlating acidity of the solution to voltage detected across the amplified photodiode output, the tabulated data does not directly relate pH level to voltage detected. A relationship between drops of vinegar and pH level must be found to complete the relation. The most direct method of accomplishing this would be to use an electronic pH detector to detect the pH of the solutions in question, however for the duration of the experiment a pH detector was not available, thus an alternative method was required to find the pH level. Along with the graphed data that was used to find the trends for the pH, 2 other points were taken: the voltage from a pure vinegar sample, and the voltage from a pure water sample. These 2 points can be thought to correspond to the upper and lower bounds of the pH points. The pH of plain water is estimated to be 7 while the pH of 5% vinegar was calculated stoichiometrically to be 2.4. Logically the trend of increasing pH with drops of vinegar should start off as a fairly straight-line relationship at low levels. However as more and more vinegar is added to the solution it will slowly reach the upper bound of the pH of pure vinegar. Thus it is possible to approximate the relationship as linear. The linear approximation was done by simply setting 0 drops to the pH of 7 and 11 drops to the pH of 2.4.

Table 3. Drops of Vinegar Vs. Estimated pH

Drops of Vinegar(Drops)	*Estimated pH*
0	7.00
1	6.58
2	6.16
3	5.75
4	5.33
5	4.91
6	4.49
7	4.07
8	3.65
9	3.24
10	2.82
11	2.40

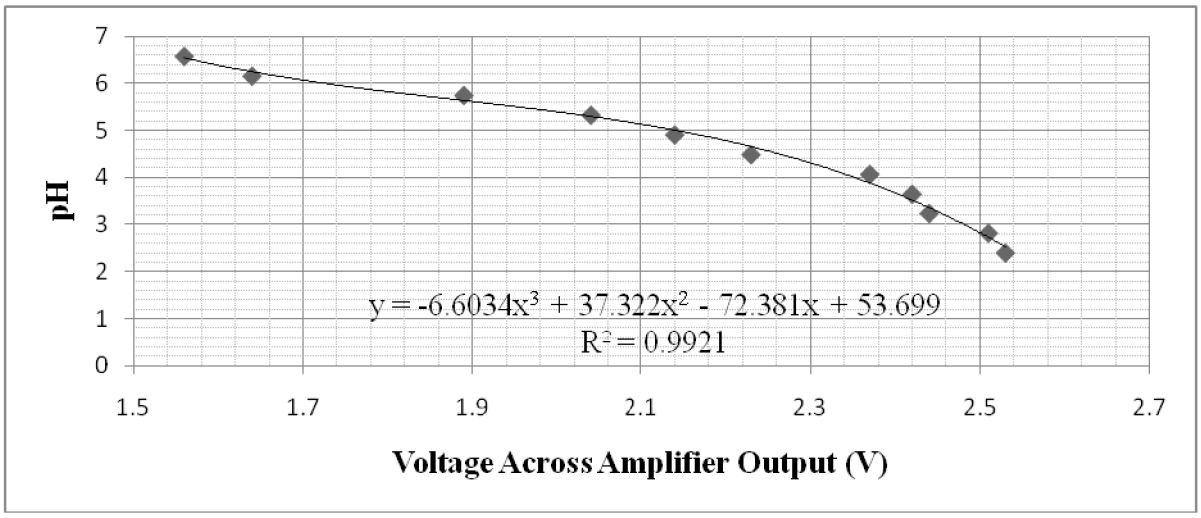
Using this relationship we modify the previous graph to compare pH to voltage instead of drops of vinegar. Again the relationship in this graph appears to be closer to a higher order polynomial than to a completely linear function.

Fig 12. Voltage Across Amplifier Output vs. pH



In order to use this data in the program, it is necessary to find the pH vs. the voltage across the amplifier, thus we modify the chart to use pH as the y-axis and voltage across the amplifier as the x-axis and find the corresponding trendline.

Fig 13. pH vs Voltage Across Amplifier Output



By finding the trend-line once again we find the correlation between the voltage of the output of the amplifier with the pH of solution being examined. This formula is used to calibrate the post-processing program in order to find the simulated glucose concentration of the solution.

4.4 Post-Processing Program Test

With the device calibrated to the LED-photodiode pair the first stage of the design is complete. What remains is to test the connection between the microcontroller and the computer and to test the post-processing program itself. The missing function converting the voltage from the photodiode to a pH level was added to complete the post-processing program. The first tests were initially to be performed using the microcontroller to PC connection using the RS232 serial cable, however it was discovered that almost all the computers accessible lacked the RS232 port required to perform data transmission from PIC to PC. Thus the results were instead read using a voltmeter connected to the amplifier added to the photodiode. Several different inputs were used in order to test the different kinds of outputs that could be generated from the biosensor.

Fig 14. Sample Output for Pre-Meal and Basal Doses with 1.93V Input

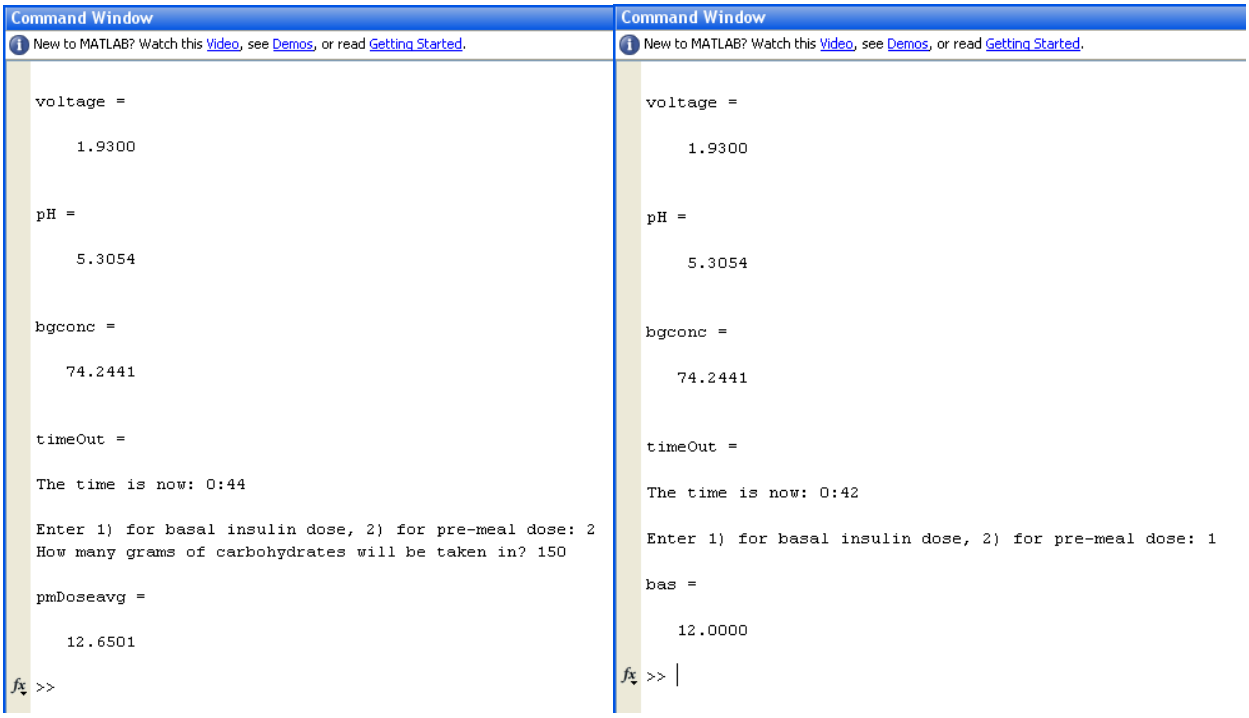
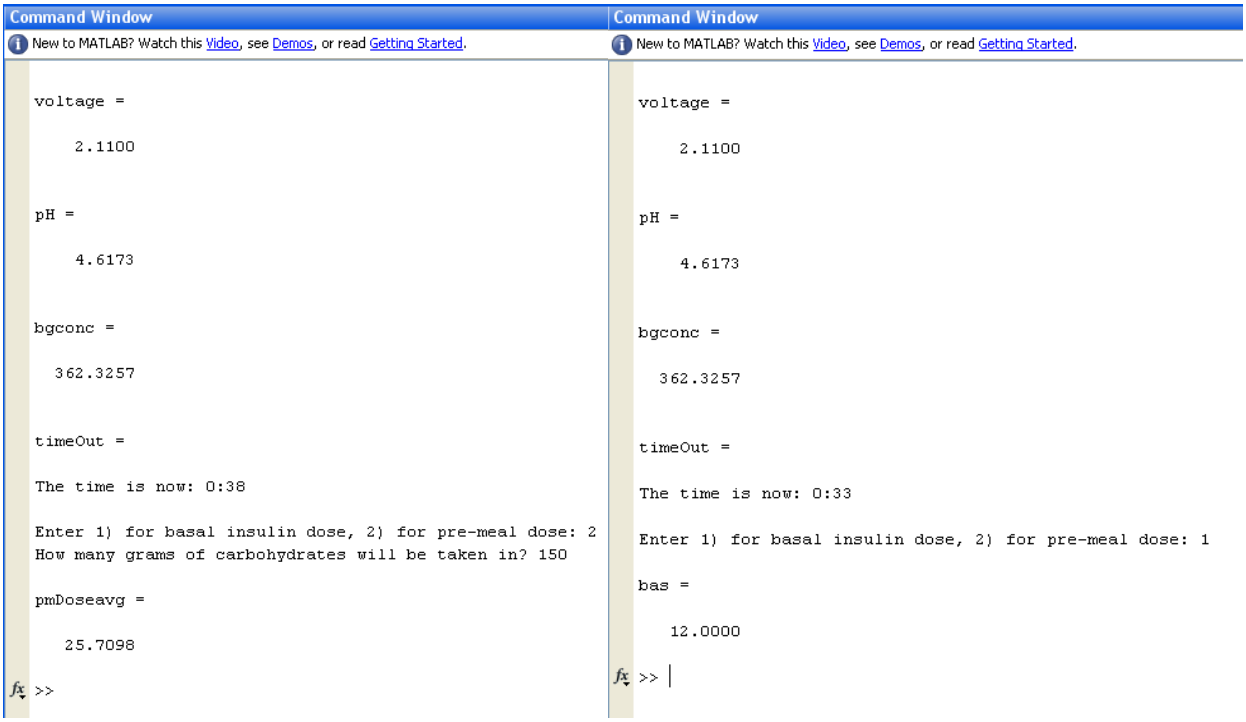


Fig 15. Sample Output for Pre-Meal and Basal Dose with 2.11V Input



5 Discussion

The results from the design of this biosensing utility have yielded promising results. All the graphs obtained from testing show that there is a relationship between the pH of an acidic solution with BCP and the voltage detected by a photodiode when an LED is shone through. This relationship was found to likely be of a high order polynomial (cubic, quintic, etc. all fit fairly well), although the linear model can still fit it closely (93.3% correlation). Also while confirmation of the final results could not be done with the tools and time at hand, the results look fairly close to what would be expected as a proper insulin dose.

During the testing of the device it became apparent that there were several flaws with some of the choices made. Probably the biggest flaw with the device was its reliance on complete alignment of all the pieces for proper function. The LED and photodiodes chosen were both found to have a relatively small field of view, roughly 1mm x 1mm and roughly 0.3mm x 0.3mm for the photodiode. Proper anchoring and alignment of the LED and photodiode to their respective fibre optic cables is essential to obtaining meaningful results, but with the small effective areas on these components it was difficult to accomplish. A small misalignment of even 0.1mm or 1 degree would change the output found at the end of the amplifier from 0.12V to 2.5V. The makeshift anchorings created to remedy this situation proved to be somewhat useful for the LED and reaction platform alignments, but the photodiode's viewing area was found to be too small to create a reliable anchor. Instead it was necessary to test every angle and position manually in order to get results.

It would have been ideal to compare the result values to results obtained from commercial glucose biosensors. Unfortunately this was not possible with the tools and time available. However, the results can still be taken as a proof that the concept of using bromocresol purple with an apparatus consisting of a proper LED and photodiode pair yields a functional pH detection device which can be used to estimate the concentration of an acidic substance.

6 Future considerations

While the device as it is now is far from complete, it has already shown promising results. Several modifications could be made to improve its performance and move it closer to reaching its original design goals.

Firstly a few design changes could be made to the apparatus to increase its efficiency. A proper housing unit for the LED, and photodiode which would connect to the fibre optic cables could be designed to enable the sensor to perform much more reliably, reducing the amount of jittering that currently needs to be done to ensure proper operation. This would help eliminate the errors caused by misalignment of the components. A proper casing for the pH detection area could be used in order to block out interfering room light, allowing for much more accurate detection of

the pH in rooms with brighter lighting. A less noisy operational amplifier for the non-inverting amplifier would also greatly aid the accuracy of the project, as well as allow for the original design plan to transfer data through the microcontroller with much better resolution. Also, calculations done after the test of the biosensor show that realistic voltages taken from the sensor should be between 1.90V and 2.11V. This is a fairly small range, thus a difference amplifier could be implemented to increase efficiency of the device.

Secondly, currently all post-processing done by the device is tied to a computer with a RS232 serial port connection. If the device is to be tied to a computer it would be ideal to support a USB or wireless connection as RS232 serial ports are slowly being phased out of use from contemporary computers. This was painfully apparent during the testing stage of the device when a computer with a serial port to perform the testing was unable to be found.
However, even more ideal would be to remove the requirement of the computer and program the post-processing directly on the device's microcontroller. This would require an extra keypad be added to the device, but it would go a long way to improving the product's portability and accessibility to the masses.

Thirdly it would likely be ideal to improve the user interface of the program to make it more accessible to patients as well as their doctors. The current program design requires the user to be able to estimate the amount of carbohydrates that they consume with each meal. While this can be extremely accurate if the patient knows the exact value, it is unlikely that a patient would know the carbohydrate count of all their meals to that degree.
Also it would be ideal to allow doctors to program the device with the average daily intake they prescribe directly. This could require the development of a better interface and/or a stand-alone program to be created instead of its current ties to the MATLAB environment.

Finally, while this device was designed with the goal of providing support to diabetes patients, it can just as easily be used to track the concentration levels of other chemicals in order to track drug delivery of other diseases. The central detection aspect of the designed biosensor was chosen as a pH detector with this versatility in mind. As long as the chemical being tracked causes a change in pH, the sensor will be able to detect this change and with proper programming, output drug administration information.

In the future a discrete, portable device not much different-looking from current glucose biosensors being used today would be the ideal. This device would have an easily accessible user interface for both doctors and patients with not just glycemic control for diabetes, but also for other track-able hormonal diseases.

Appendix A: Sliding Scale Insulin Formulae

Type 1 Diabetes Basal Dose Formulae
daytime low basal dose = 0.2*(patient's weight)*0.5*(1/3)
daytime high basal dose = 0.7*(patient's weight)*0.5*(1/3)
nighttime low basal dose = 0.2*(patient's weight)*0.5*(2/3)
nighttime high basal dose = 0.7*(patient's weight)*0.5*(2/3)

Type 2 Diabetes Basal Dose Formulae
daytime low basal dose = 0.4*(patient's weight)*0.5*(1/3)
daytime high basal dose = 1.0*(patient's weight)*0.5*(1/3)
nighttime low basal dose = 0.4*(patient's weight)*0.5*(2/3)
nighttime high basal dose = 1.0*(patient's weight)*0.5*(2/3)

*Note: Basal dose is 2 fixed doses of half the patient's average insulin intake given typically once in the morning and once in the evening

Fixed Pre-meal Dose
low pre-meal dose = 0.5*(patient's weight)*(1/3)
high pre-meal dose = 0.5*(patient's weight)*(1/3)

*Note: This assumes 3 meals per day

Sliding Scale Pre-meal Dose
sensitivity factor = 1500/(total daily dose)
pre-meal dose = (blood glucose concentration)/(sensitivity factor) + (carbohydrates to be consumed)/(carbohydrate factor)

*Note: Total daily dose would be given by the doctor
**Note: carbohydrate factor is taken from the chart given in program design

Appendix B: Programming Code

B.1 Post-Processing Program MATLAB Code

<ReadIn.m>

```
clc;
clear;
close all;

notdone = 1;

s = serial('COM1','BaudRate', 9600,'Parity', 'none','DataBits',8,'StopBits', 1);

while(notdone)
   TorS=input('Use Text-file(t) or Serial(s)? ','s');
   if TorS == 't'
      disp('Reading for TestIn.txt');
      PDin = fopen('TestIn.txt', 'r');
      voltage = fscanf(PDin, '%f');
      break;
   elseif TorS == 's'
      disp('Reading from serial port');
      pause(2);
      fopen(s);
      voltage = bin2dec(fread(s));
      break;
   else
      disp('invalid input');
   end
end

%calibration formula found through preliminary experimentation
pH = -6.6034*voltage^3 + 37.322*voltage^2 -72.381*voltage + 53.699;

%assume 100 ml of liquid in reaction vessel
vol = 0.1;
Hplus = 10^-pH;
%mol/L
hconc = Hplus/vol;
%convert to mg/dL, assume standard pH is 7.4
bgconc = (hconc-10^-7.4)*180.16*10*1000;
```

```
display(bgconc);

%Opens a file with patient info: weight, type of diabetes, daily dose, and
%if they take fixed or sliding scale pre-meal insulin injections
patInfo = fopen('patInfo.txt', 'r');
patrInfo = fscanf(patInfo, '%d');

%This section calculates the rough amount of insulin that should be
%injected by a patient in one day
if patrInfo(2) == 1         %if patient has type 1 Diabetes Mellitus
   low = 0.2*patrInfo(1);  %min/max insulin to be injected/kg
   hi = 0.7*patrInfo(1);
else                        %else if patient has type 2 Diabetes Mellitus
   low = 0.4*patrInfo(1);
   hi = 1.0*patrInfo(1);
end
avg = (low + hi)/2;

%Displays current time based on computer clock
c = clock;
timeOut = ['The time is now: ', int2str(c(4)), ':', int2str(c(5))];
display(timeOut);

baspm = input('Enter 1) for basal insulin dose, 2) for pre-meal dose: ');

if baspm == 1
   %This section handles basal insulin injection rates which are not affected
   %by current blood glucose concentrations
   if c(4) > 12
      baslow = low*0.5*(1/3);
      bashi = hi*0.5*(1/3);
   else
      baslow = low*0.5*(2/3);
      bashi = hi*0.5*(2/3);
   end

   bas = (bashi + baslow)/2;

   display (bas);
else
   %This section handles the amount of insulin to be injected before a meal,
```

```
   %this will be affected by current blood glucose concentrations as well as
   %the total calculated insulin to be injected daily
    tdd = patrInfo(3);          %this is the total dose of insulin regularly taken by the patient every
day

   totpmlow = low*0.5;
   totpmhi = hi*0.5;
   totpmavg = (totpmlow + totpmhi)/2;

   if patrInfo(4) == 0     %Check for fixed or sliding scale dose
      pmDoselow = totpmlow/3;   %assume 3 meals/day
      pmDosehi = totpmhi/3;
      pmDoseavg = totpmavg/3;
   else    %for sliding scale dose
      %this chart shows the avg amt of CHO each unit of insulin will cover
      %based on body weight
      inChart = fopen('inChart.txt');
      CHOChart = fscanf(inChart, '%d %d', [2 inf]);

      %look for corresponding CHO factor
      for i = 1:length(CHOChart)
         if patrInfo(1) < CHOChart(1,i);
            CHOFact = CHOChart(2,i);
            break;
         end
      end

      senFac = 1500/tdd;  %insulin sensitivity factor
      dec = bgconc-96;    %assume target 96mg/dL

      %find grams of carbohydrates to be taken in by meal
      CHO = input('How many grams of carbohydrates will be taken in? ');

        pmDoseavg = dec/senFac + CHO/CHOFact;    %add corrective dose with meal dose for
final dose required
      display (pmDoseavg);
   end
end
```

<patInfo.txt> - This file contains important information about the patient. Namely the patient's weight, diabetes type, recommended insulin intake (from doctor) and whether the patient follows a sliding scale or fixed dose paradigm for their pre-meal dose.

80
1
68
1

<InChart.txt> - This file contains information about a chart comparing the amount of insulin required to eliminate a set amount of carbohydrates based upon the patient's weight. The left side is weight in KG while the right side is the ratio of insulin units to 1g of CHO.

50 16
59 15
64 14
68 13
77 12
82 11
86 10
91 9
100 8
109 7
110 6

B.2 Microcontroller ADC C Program

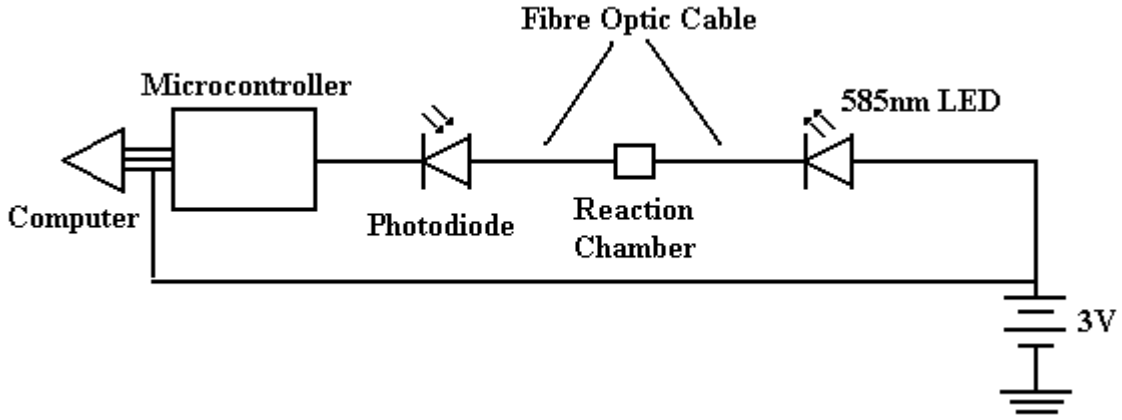
```
#include "p24hxxxx.h"

void DelayNmSec(int time);

int main(void)
{
        OSCCON = 0x33C0;
        CLKDIV = 0x0000;
        TRISA = 0xFF00;//Port A is Output
        //Initialize the ADC
        //Initializing AD1CON1
        AD1CON1bits.FORM = 0;    //unsigned integer form
        AD1CON1bits.AD12B = 0;   //10-bit ADC
        AD1CON1bits.SSRC = 7;    //autoconvert
        AD1CON1bits.SIMSAM = 0;          //no simultaneous sampling
        AD1CON1bits.ASAM = 1;    //sample immediately after last conversion
```

```
        //Initializing AD1CON2
        AD1CON2bits.VCFG = 3;     //external vref+ and vref-

        //Initializing AD1CON3
        AD1CON3bits.ADCS = 63;   //ADC Conversion Clock
        Tad=Tcy*(ADCS+1)=(1/40M)*64 = 1.6us(625Khz)
        AD1CON3bits.SAMC = 1;    //1 TAD

        AD1CHS0 = 4;                        //Connect RB4/AB4 as CH0 input
        AD1PCFGLbits.PCFG4 = 0; //Disable digital input on AN5
        AD1CSSL = 0;                        //No Scanned inputs

        AD1CON1bits.ADON = 1;    //Turn on ADC
        while(1)
        {
                DelayNmSec(100);     //Delay a few cycles before output
                while(!AD1CON1bits.DONE);
                PORTA = ADC1BUF0;        //Make output Port A
        }
}

void DelayNmSec(int time)
{
        int j;
        for (j = 0; j < time; j++)
        {
                //delay time
        }
}
```

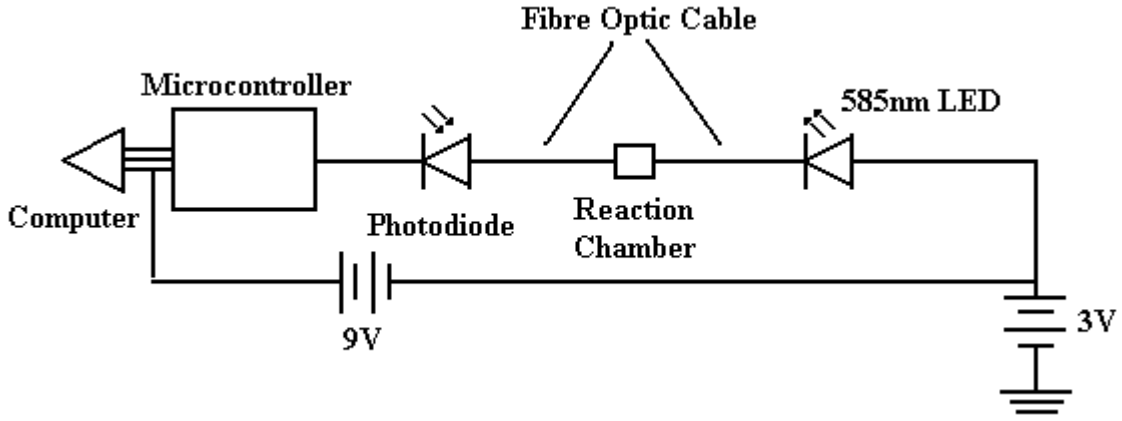
Appendix C: Design Schematics

C.1 Biosensor Designs

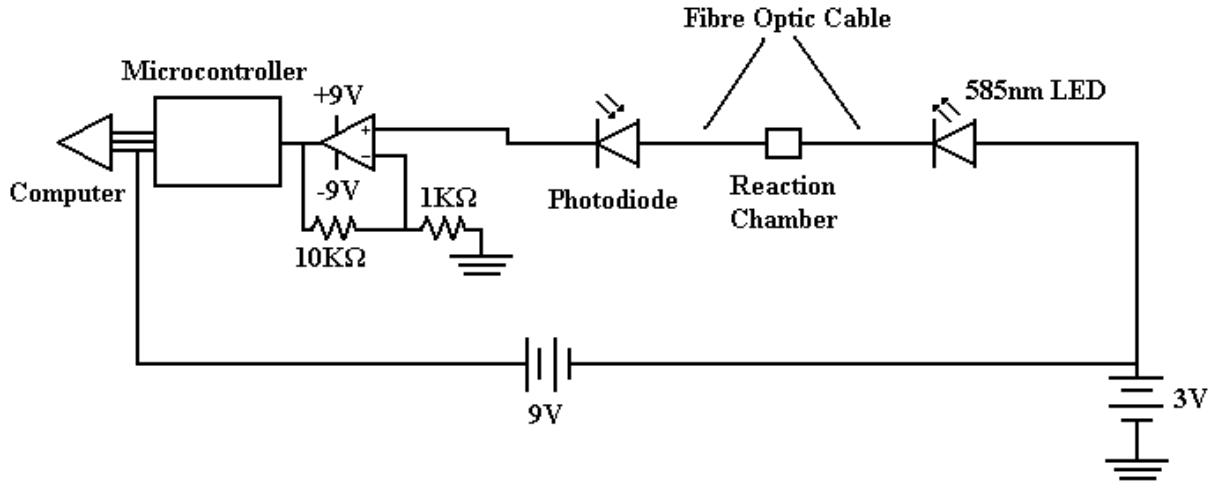
First Iteration



Second Iteration – 9V battery added to enable data transfer to PC

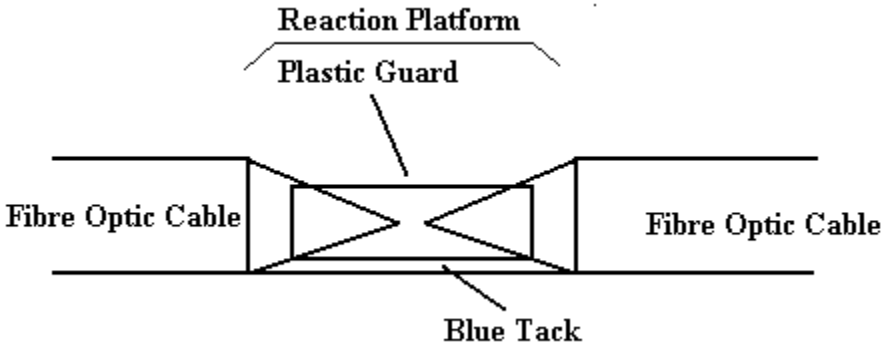


Third Iteration – Non-inverting amplifier added to boost photodiode output

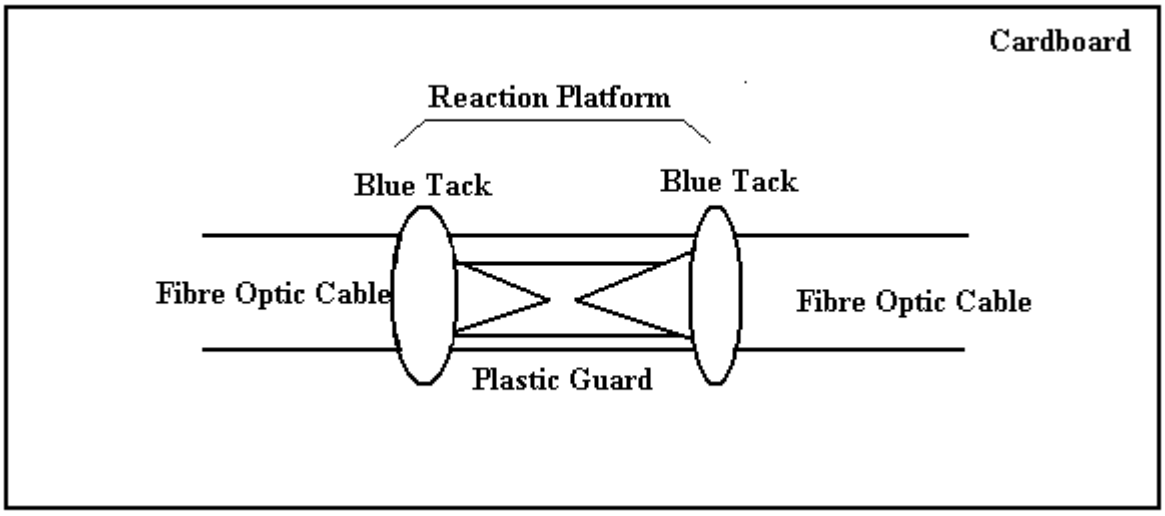


C.2 Reaction Platform Design

Reaction Platform Design – Side View

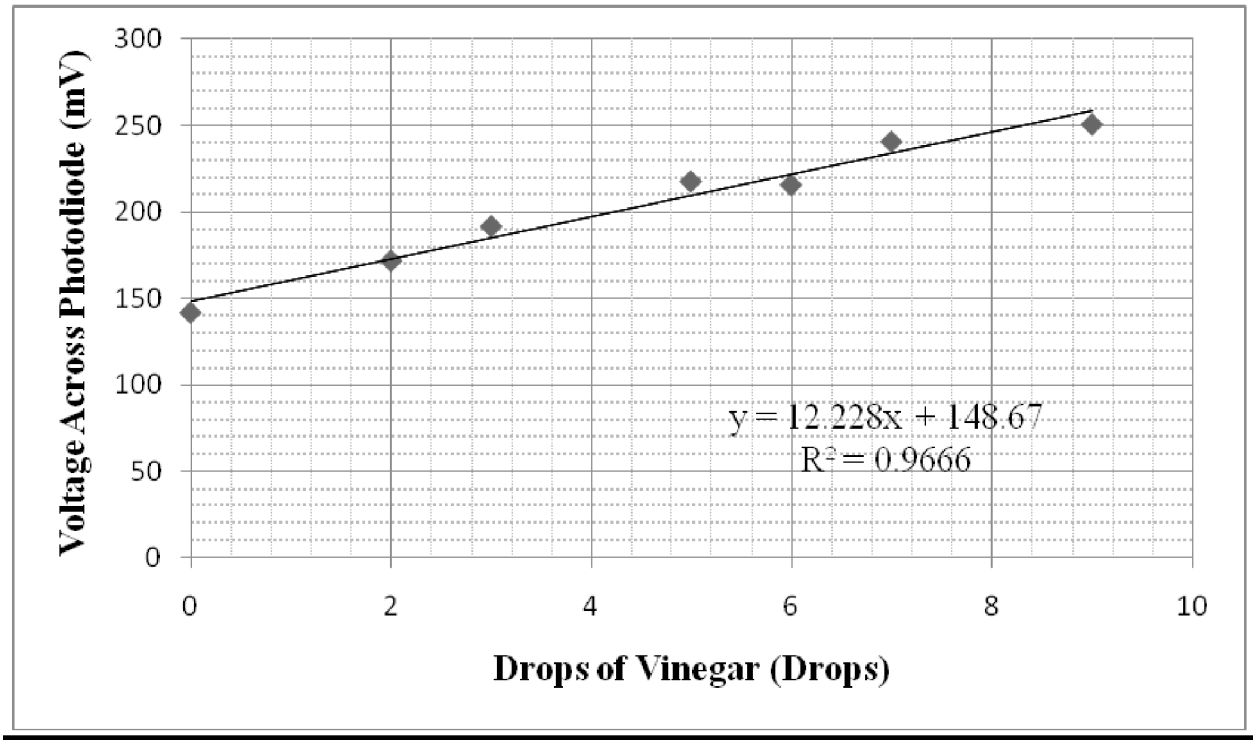


Reaction Platform Design – Top View



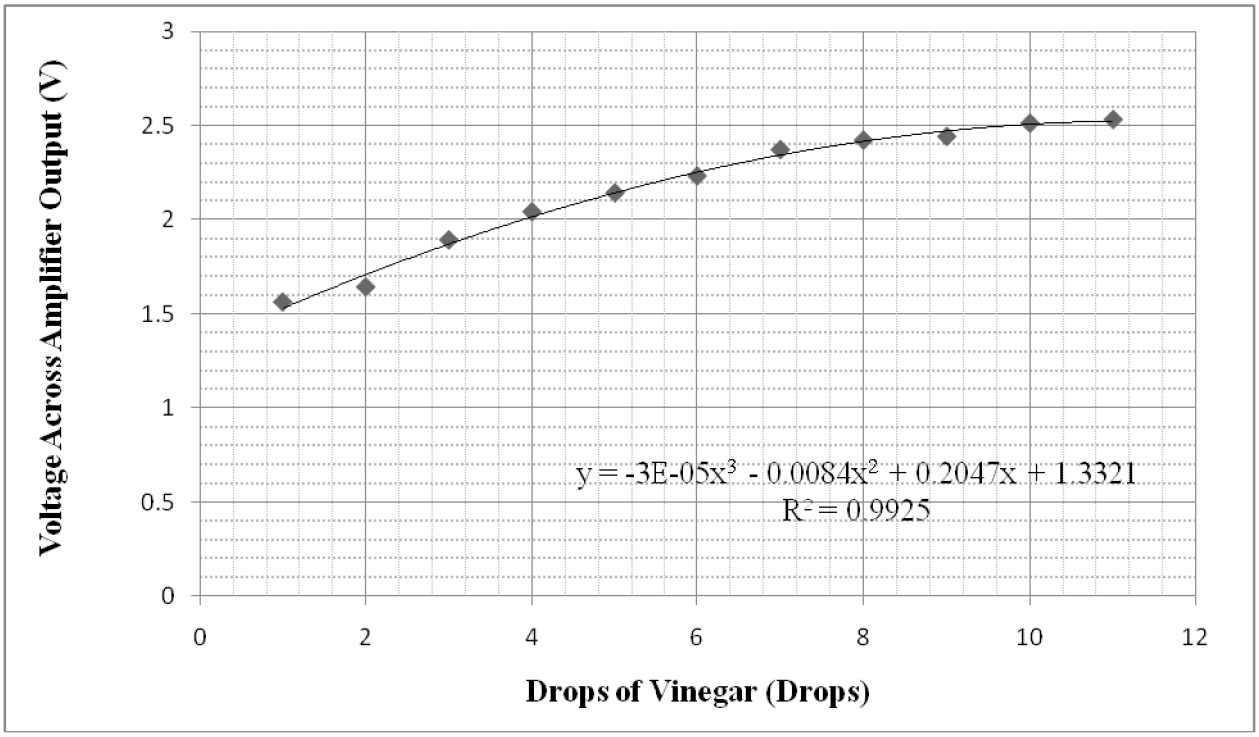
Appendix D: Resultant Graphs and Tables

Graph of Unamplified Voltage Across Photodiode



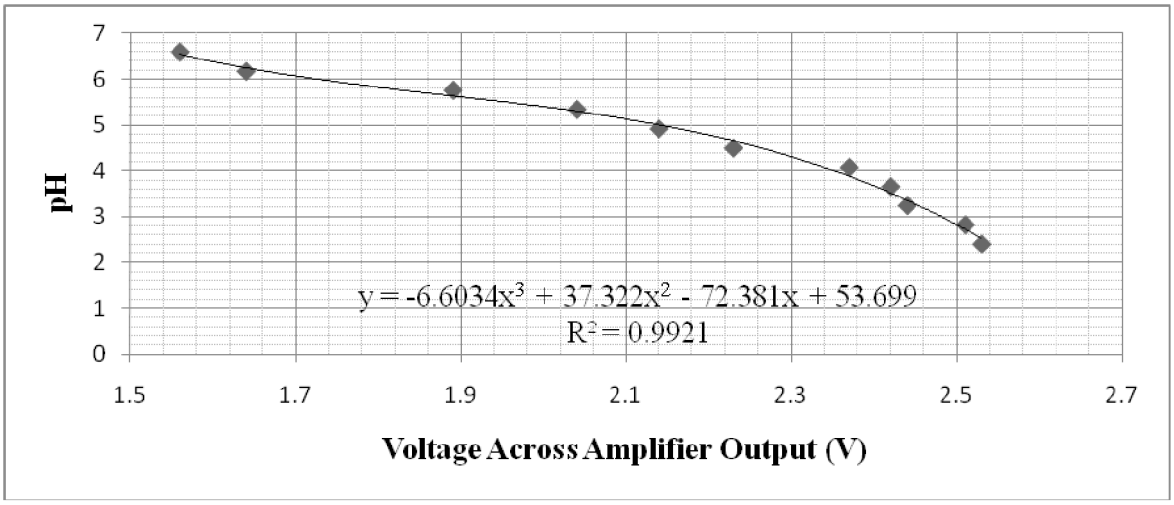
Drops of Vinegar(Drops)	*Detected Voltage (mV)*
0	142
2	172
3	192
5	218
6	216
7	241
9	251
Pure Vinegar	269
Clear Air	281

Graph of Amplified Voltage Across Photodiode



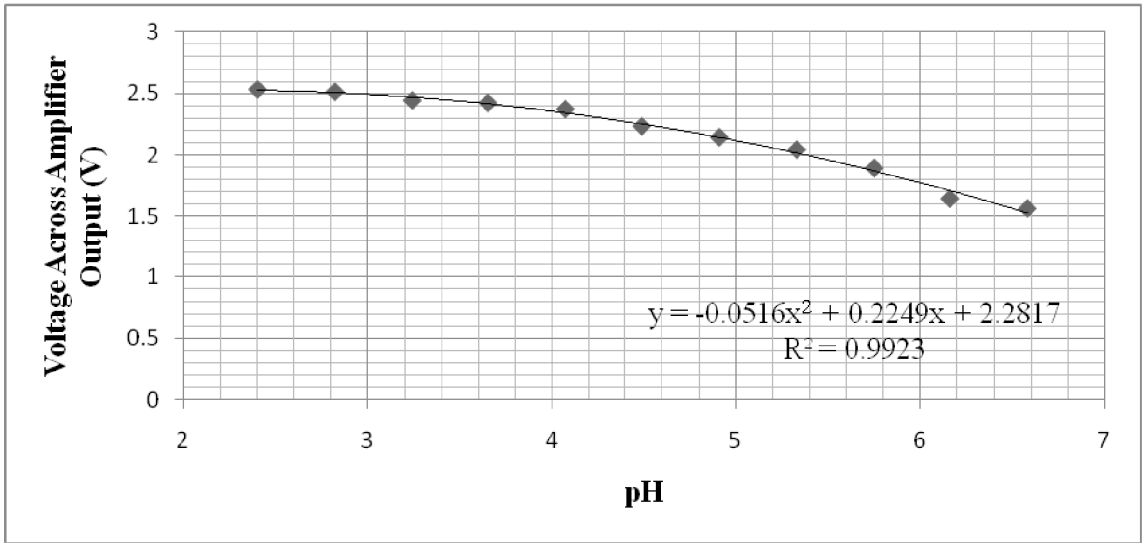
Drops of Vinegar(Drops)	*Detected Voltage (V)*
0	1.38
1	1.56
2	1.64
3	1.89
4	2.04
5	2.14
6	2.23
7	2.37
8	2.42
9	2.44
10	2.51
11	2.53
Pure Vinegar	2.62
Clear Air	2.75

Amplified Voltage vs. pH

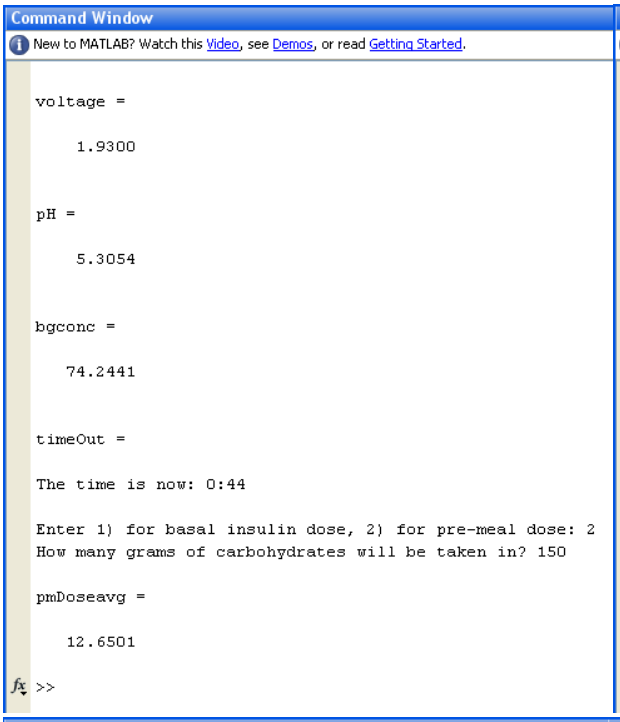


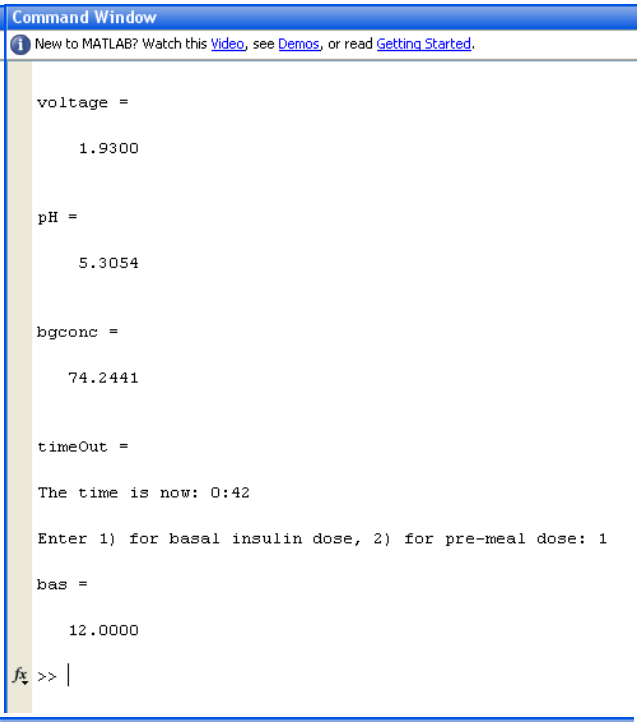
pH	*Detected Voltage (V)*
7.00	1.38
6.58	1.56
6.16	1.64
5.75	1.89
5.33	2.04
4.91	2.14
4.49	2.23
4.07	2.37
3.65	2.42
3.24	2.44
2.82	2.51
2.40	2.53

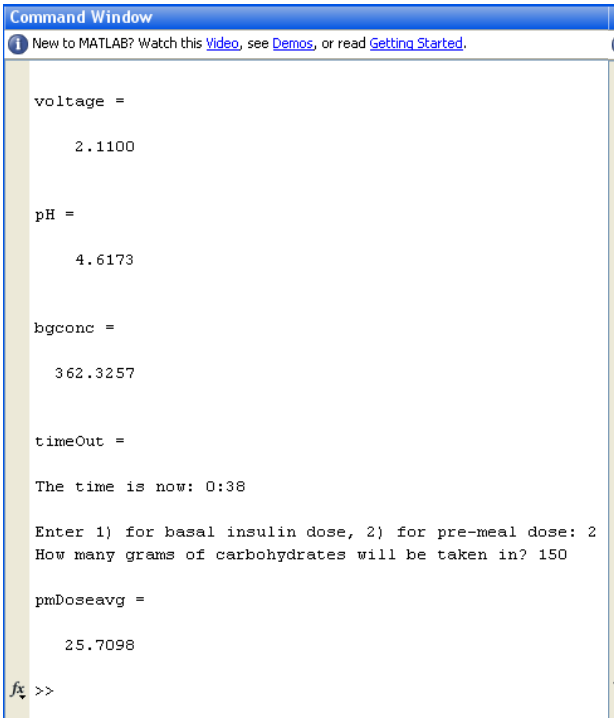
pH vs. Amplified Voltage

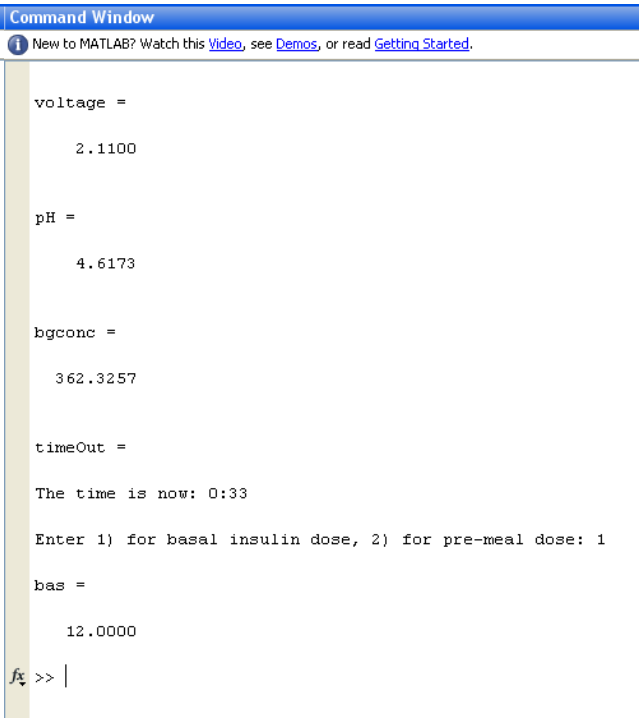


Sample Outputs









Appendix E: Component and Material Data Sheets

E.1 Microcontroller Data Sheets

E.1.1 Port Registers

TABLE 4-16: PORTA REGISTER MAP FOR PIC24HJ32GP202

File Name	Addr	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	All Resets
TRISA	02C0	—	—	—	—	—	—	—	—	—	—	—	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	001F
PORTA	02C2	—	—	—	—	—	—	—	—	—	—	—	RA4	RA3	RA2	RA1	RA0	xxxxx
LATA	02C4	—	—	—	—	—	—	—	—	—	—	—	LATA4	LATA3	LATA2	LATA1	LATA0	xxxxx
ODCA	02C6	—	—	—	—	—	—	—	—	—	—	—	ODCA4	ODCA3	ODCA2	ODCA1	ODCA0	0000

Legend: x = unknown value on Reset, — = unimplemented, read as '0'. Reset values are shown in hexadecimal.

TABLE 4-17: PORTA REGISTER MAP FOR PIC24HJ32GP204 AND PIC24HJ16GP304

File Name	Addr	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	All Resets
TRISA	02C0	—	—	—	—	—	TRISA10	TRISA9	TRISA8	TRISA7	—	—	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	079F
PORTA	02C2	—	—	—	—	—	RA10	RA9	RA8	RA7	—	—	RA4	RA3	RA2	RA1	RA0	xxxxx
LATA	02C4	—	—	—	—	—	LATA10	LATA9	LATA8	LATA7	—	—	LATA4	LATA3	LATA2	LATA1	LATA0	xxxxx
ODCA	02C6	—	—	—	—	—	ODCA10	ODCA9	ODCA8	ODCA7	—	—	ODCA4	ODCA3	ODCA2	ODCA1	ODCA0	0000

Legend: x = unknown value on Reset, — = unimplemented, read as '0'. Reset values are shown in hexadecimal.

TABLE 4-18: PORTB REGISTER MAP

File Name	Addr	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	All Resets
TRISB	02C8	TRISB15	TRISB14	TRISB13	TRISB12	TRISB11	TRISB10	TRISB9	TRISB8	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	FFFF
PORTB	02CA	RB15	RB14	RB13	RB12	RB11	RB10	RB9	RB8	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	xxxxx
LATB	02CC	LATB15	LATB14	LATB13	LATB12	LATB11	LATB10	LATB9	LATB8	LATB7	LATB6	LATB5	LATB4	LATB3	LATB2	LATB1	LATB0	xxxxx
ODCB	02CE	ODCB15	ODCB14	ODCB13	ODCB12	ODCB11	ODCB10	ODCB9	ODCB8	ODCB7	ODCB6	ODCB5	ODCB4	ODCB3	ODCB2	ODCB1	ODCB0	0000

Legend: x = unknown value on Reset, — = unimplemented, read as '0'. Reset values are shown in hexadecimal for PinHigh devices.

TABLE 4-19: PORTC REGISTER MAP FOR PIC24HJ32GP204 AND PIC24HJ16GP304

File Name	Addr	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	All Resets
TRISC	02D0	—	—	—	—	—	—	TRISC9	TRISC8	TRISC7	TRISC6	TRISC5	TRISC4	TRISC3	TRISC2	TRISC1	TRISC0	03FF
PORTC	02D2	—	—	—	—	—	—	RC9	RC8	RC7	RC6	RC5	RC4	RC4	RC2	RC1	RC0	xxxxx
LATC	02D4	—	—	—	—	—	—	LATC9	LATC8	LATC7	LATC6	LATC5	LATC4	LATC4	LATC2	LATC1	LATC0	xxxxx
ODCC	02D6	—	—	—	—	—	—	ODCC9	ODCC8	ODCC7	ODCC6	ODCC5	ODCC4	ODCC4	ODCC2	ODCC1	ODCC0	0000

Legend: x = unknown value on Reset, — = unimplemented, read as '0'. Reset values are shown in hexadecimal.

E.1.2 ADC Registers

Table 16-10: ADC Register Map

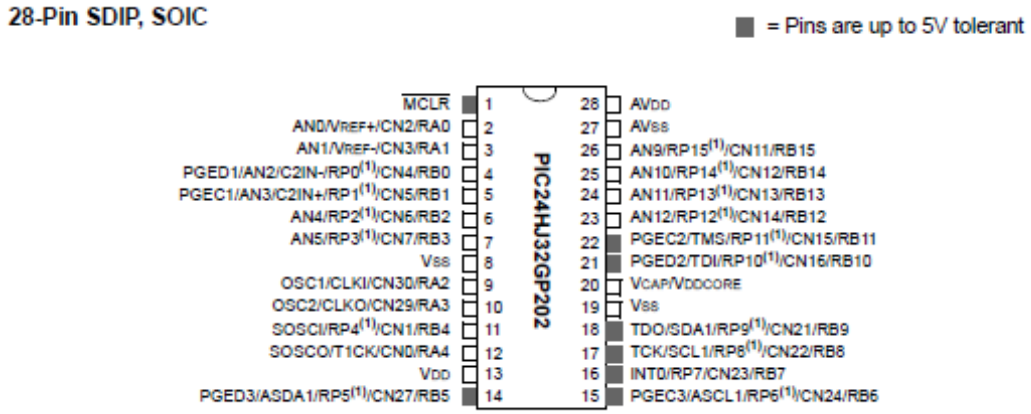
File Name	ADR	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset States
INTCON1	0080	NSTDIS	—	—	—	—	—	—	—	—	DIV0ERR	DMACERR	MATHERR	ADDRERR	STKERR	OSCFAIL	—	0000
INTCON2	0082	ALTIVT	DISI	—	—	—	—	—	—	—	—	—	INT4EP	INT3EP	INT2EP	INT1EP	INT0EP	0000
IFS0	0084	—	DMA1IF	AD1IF	U1TXIF	U1RXIF	SPI1IF	SPI1EIF	T3IF	T2IF	OC2IF	IC2IF	DMA0IF	T1IF	OC1IF	IC1IF	INT0IF	0000
IFS1	0086	U2TXIF	U2RXIF	INT2IF	T5IF	T4IF	OC4IF	OC3IF	DMA2IF	IC8IF	IC7IF	AD2IF	INT1IF	CNIF	—	MI2C1IF	SI2C1IF	0000
IEC0	0094	—	DMA1IE	AD1IE	U1TXIE	U1RXIE	SPI1IE	SPI1EIE	T3IE	T2IE	OC2IE	IC2IE	DMA0IE	T1IE	OC1IE	IC1IE	INT0IE	0000
IEC1	0096	U2TXIE	U2RXIE	INT2IE	T5IE	T4IE	OC4IE	OC3IE	DMA2IE	IC8IE	IC7IE	AD2IE	INT1IE	CNIE	—	MI2C1IE	SI2C1IE	0000
IPC3	00AA	—	—	—	—	—	DMA1IP<2:0>			—	AD1IP<2:0>			—		U1TXIP<2:0>		4444
IPC5	00AE	—	IC8IP<2:0>			—	IC7IP<2:0>			—	AD2IP<2:0>			—		INT1IP<2:0>		4444
ADC1BUF0	0300	ADC1 Data Buffer																uuuu
AD1CON1	0320	ADON	—	ADSIDL	ADDMABM	—	AD12B	FORM<1:0>		SSRC<2:0>			—	SIMSAM	ASAM	SAMP	DONE	0000
AD1CON2	0322	VCFG<2:0>			—	—	CSCNA	CHPS<1:0>		BUFS	—		SMPI<3:0>			BUFM	ALTS	0000
AD1CON3	0324	ADRC	—	—	SAMC<4:0>							ADCS<7:0>						0000
AD1CHS123	0326	—	—	—	—	—	CH123NB<1:0>		CH123SB	—	—	—	—	—	CH123NA<1:0>		CH123SA	0000
AD1CHS0	0328	CH0NB	—	—	CH0SB<4:0>					CH0NA	—	—	CH0SA<4:0>					0000
AD1PCFGH	032A	PCFG31	PCFG30	PCFG29	PCFG28	PCFG27	PCFG26	PCFG25	PCFG24	PCFG23	PCFG22	PCFG21	PCFG20	PCFG19	PCFG18	PCFG17	PCFG16	0000
AD1PCFGL	032C	PCFG15	PCFG14	PCFG13	PCFG12	PCFG11	PCFG10	PCFG9	PCFG8	PCFG7	PCFG6	PCFG5	PCFG4	PCFG3	PCFG2	PCFG1	PCFG0	0000
AD1CSSH	032E	CSS31	CSS30	CSS29	CSS28	CSS27	CSS26	CSS25	CSS24	CSS23	CSS22	CSS21	CSS20	CSS19	CSS18	CSS17	CSS16	0000
AD1CSSL	0330	CSS15	CSS14	CSS13	CSS12	CSS11	CSS10	CSS9	CSS8	CSS7	CSS6	CSS5	CSS4	CSS3	CSS2	CSS1	CSS0	0000
AD1CON4	0332	—	—	—	—	—	—	—	—	—	—	—	—	—	DMABL<2:0>			0000
AD2BUF0	0340	ADC2 Data Buffer																uuuu
AD2CON1	0360	ADON	—	ADSIDL	ADDMABM	—	AD12B	FORM<1:0>		SSRC<2:0>			—	SIMSAM	ASAM	SAMP	DONE	0000
AD2CON2	0362	VCFG<2:0>			—	—	CSCNA	CHPS<1:0>		BUFS	—		SMPI<3:0>			BUFM	ALTS	0000
AD2CON3	0364	ADRC	—	—	SAMC<4:0>					—	—	ADCS<5:0>						0000
AD2CHS123	0366	—	—	—	—	—	CH123NB<1:0>		CH123SB	—	—	—	—	—	CH123NA<1:0>		CH123SA	0000
AD2CHS0	0368	CH0NB	—	—	—		CH0SB<3:0>			CH0NA	—	—	—		CH0SA<3:0>			0000
AD2PCFGL	036C	PCFG15	PCFG14	PCFG13	PCFG12	PCFG11	PCFG10	PCFG9	PCFG8	PCFG7	PCFG6	PCFG5	PCFG4	PCFG3	PCFG2	PCFG1	PCFG0	0000
AD2CSSL	0370	CSS15	CSS14	CSS13	CSS12	CSS11	CSS10	CSS9	CSS8	CSS7	CSS6	CSS5	CSS4	CSS3	CSS2	CSS1	CSS0	0000
AD2CON4	0372	—	—	—	—	—	—	—	—	—	—	—	—	—	DMABL<2:0>			0000

Legend: u = unknown

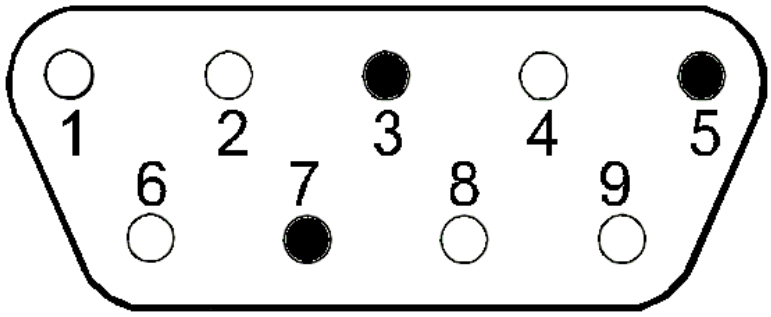
Note: All interrupt sources and their associated control bits may not be available on a particular device. Refer to the device data sheet for details.

E.1.3 Microcontroller Pin Diagram

*note microcontroller is slightly different from this, but still uses the same general pin-out



E.2 UART RS232 Pin-Out Diagram



3 - Transmit to PC
5 - Signal Ground
7 - +12V to Keep Serial Open

E.3 Photodiode Datasheets

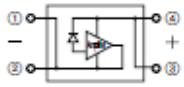
Panasonic
ideas for life

Cadmium-free sensor with spectral response Chip type ideal for brightness adjustment of mobile device displays

LIGHT SENSOR
NaPiCa

• SMD type

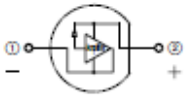
L 2.0mm .079inch
W 3.2mm .126inch
H 1.0mm .039inch



①② Anode
③④ Cathode

• Through-hole type

5.0 mm dia.
.197 inch dia.
(Surface of resin)

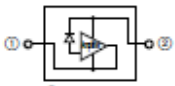


① Anode
② Cathode

• Chip type

New

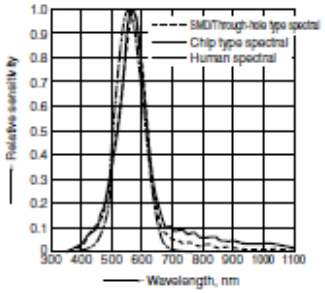
L 1.25mm .049inch
W 2.00mm .079inch
H 0.55mm .022inch



① Anode (–)
② Cathode (+)

FEATURES

1. Built-in optical filter for spectral response similar to that of the human eye.



2. Photocurrent is proportional to illumination. (linear output)
3. Uses environmentally friendly silicon chips.
4. Lead-free.
5. Lineup of 3 different shapes
- SMD type for easy automatic mounting
- Lead type same as CdS cell (photoconductive cell)
- Chip type that achieves miniaturization

TYPICAL APPLICATIONS

SMD and Through-hole types

1. Brightness detection for LCD backlight control for LCD devices (LCD TVs, car navigation systems, and mobile PCs).
2. Brightness detection for circuits in residential lighting, lighting for security, and automatic lighting for bicycle.
3. Household applicances (day/night energy savings for air conditioners and electric hot water pots, etc.)
4. Brightness detection for wall clocks (radio clocks).

Chip type

1. Brightness detection for LCD backlight control for compact mobile devices (mobile phones and PDAs).
2. Brightness detection for controlling the keypad backlight in mobile phones.

RoHS Directive compatibility information
http://www.mew.co.jp/ac/e/environment/

TYPES

Packing quantity: Tape and reel package SMD type: Inner 3,000 pcs., Outer 3,000 pcs.
Tape and reel package Through-hole type: Inner 2,000 pcs., Outer 2,000 pcs.
Baggage package Through-hole type: Inner 500 pcs., Outer 1,000 pcs.
Tape and reel package Chip type: Inner 3,000 pcs., Outer 3,000 pcs.

Type (shape)	Photo current	Part No.	
		Tape and reel package	Baggage package New
SMD type	260 μA*	AMS104Y	—
Through-hole type		AMS302T	AMS302
Chip type	20 μA*	AMS402Y	—

Notes: *Ev = 100 lx (Ev: Brightness, Fluorescent lamp is used as light source)
Tape and reel package is standard packaging style for SMD and chip types. ("Y" and "T" at end of part number indicate packaging type.)

Light Sensor (AMS1, 3, 4)

RATINGS

1. Absolute maximum ratings (Ambient temperature: 25°C 77°F)

Item	Symbol	AMS104/AMS302	AMS402	Remarks
Reverse voltage	V_R	−0.5 to 8 V	−0.5 to 6 V	—
Photocurrent	I_L	5 mA	1 mA	—
Power dissipation	P	40 mW	6 mW	—
Operating temperature	T_{opr}	−30 to +85°C −22 to +185°F	−30 to +85°C −22 to +185°F	Non-condensing at low temperatures
Storage temperature	T_{stg}	−40 to +100°C −40 to +176°F	−40 to +100°C −40 to +176°F	Non-condensing at low temperatures

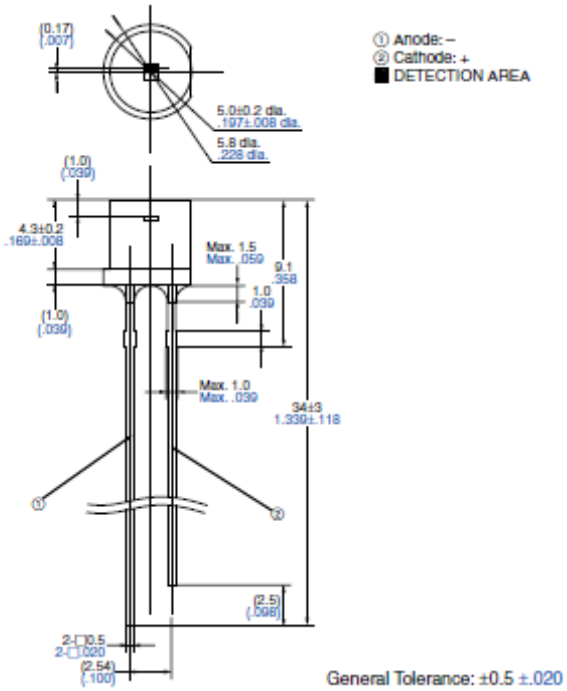
2. Recommended operating condition

Item		Symbol	AMS104/AMS302	AMS402	Remarks
Reverse voltage	Minimum	V_R	1.5 V	1.5 V	—
	Maximum		6 V	5.5 V	

3. Electrical and optical characteristics (Ambient temperature: 25°C 77°F)

Item			Symbol	AMS104/AMS302	AMS402	Condition
Peak sensitivity wavelength		—	λp	580 nm	560 nm	—
Photocurrent 1		Minimum	I_{L1}	9.1 µA	0.7 µA	AMS104/AMS302: V_R = 5 V, Ev = 5 lx*1 AMS402: V_R = 3 V, Ev = 5 lx*1
		Typical		13 µA	1 µA	
		Maximum		16.9 µA	1.3 µA	
Photocurrent 2		Minimum	I_{L2}	182 µA	14 µA	AMS104/AMS302: V_R = 5 V, Ev = 100 lx*1 AMS402: V_R = 3 V, Ev = 100 lx*1
		Typical		260 µA	20 µA	
		Maximum		338 µA	26 µA	
Photocurrent 3		Typical	I_{L3}	500 µA	35 µA	AMS104/AMS302: V_R = 5 V, Ev = 100 lx*2 AMS402: V_R = 3 V, Ev = 100 lx*2
Dark current		Maximum	I_D	0.3 µA	0.05 µA	AMS104/AMS302: V_R = 5 V, Ev = 0 lx AMS402: V_R = 3 V, Ev = 0 lx
Switching time	Rise time	Typical	t_r	8.5 ms	1.2 ms	AMS104/AMS302: V_{CC} = 5.0 V, V_O = 2.5 V, R_L = 5 kΩ
	Fall time	Typical	t_f	8.5 ms	1.2 ms	AMS104/AMS302: V_{CC} = 3.0 V, V_O = 1.5 V, R_L = 5 kΩ

2. Through-hole type



① Anode: −
② Cathode: +
■ DETECTION AREA

General Tolerance: ±0.5 ±.020

E.4 Bromocresol Purple MSDS

Health	1
Fire	1
Reactivity	0
Personal Protection	E

Material Safety Data Sheet
Bromocresol purple MSDS

Section 1: Chemical Product and Company Identification

Product Name: Bromocresol purple

Catalog Codes: SLB3298

CAS#: 115-40-2

RTECS: Not available.

TSCA: TSCA 8(b) inventory: Bromocresol purple

CI#: Not available.

Synonym: Phenol, 4,4'-(1,1-dioxido-3H-2,1-benzoxathiol-3-ylidene)bis[2-bromo-6-methyl-
Phenol, 4,4'-(3H-2,1-benzoxanthiol-3-ylidene)bis[bromo-6-methyl-, S,S-dioxide

Chemical Name: Bromocresol Purple

Chemical Formula: C21-H16-Br2-O5-S

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call: 1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Bromocresol purple	115-40-2	100

Toxicological Data on Ingredients: Not applicable.

Section 3: Hazards Identification

Potential Acute Health Effects: Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available.
MUTAGENIC EFFECTS: Not available.
TERATOGENIC EFFECTS: Not available.
DEVELOPMENTAL TOXICITY: Not available.
Repeated or prolonged exposure is not known to aggravate medical condition.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention if irritation occurs.

Skin Contact: Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: Not available.

Flash Points: Not available.

Flammable Limits: Not available.

Products of Combustion: These products are carbon oxides (CO, CO2), halogenated compounds.

Fire Hazards in Presence of Various Substances:
Slightly flammable to flammable in presence of heat.
Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Slightly explosive in presence of open flames and sparks.
Non-explosive in presence of shocks.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder.
LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: As with most organic solids, fire is possible at elevated temperatures

Special Remarks on Explosion Hazards:
Fine dust dispersed in air in sufficient concentrations, and in the presence of an ignition source is a potential dust explosion hazard.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not breathe dust. Keep away from incompatibles such as oxidizing agents.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection: Safety glasses. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Powdered solid.)

Odor: Odorless.

Taste: Not available.

Molecular Weight: 540.24 g/mole

Color: Purple. (Light.)

pH (1% soln/water): Not applicable.

Boiling Point: Not available.

Melting Point: 240°C (464°F)

Critical Temperature: Not available.

Specific Gravity: Not available.

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not available.

Solubility: Insoluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Excess heat, incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals:
LD50: Not available.
LC50: Not available.

Chronic Effects on Humans: Not available.

Other Toxic Effects on Humans: Slightly hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects:
Skin: May cause skin irritation. Low hazard for usual industrial handling.
Eyes: May cause mechanical irritation. Low hazard for usual industrial handling.
Inhalation: May cause respiratory tract irritation.
Ingestion: Ingestion of large amounts may cause gastrointestinal tract irritation. Expected to be a low ingestion hazard.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may

arise.

Toxicity of the Products of Biodegradation: The products of degradation are more toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Bromocresol purple

Other Regulations: EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
This product is not classified according to the EU regulations.
Not applicable.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 1

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves.
Lab coat.
Dust respirator. Be sure to use an

approved/certified respirator or
equivalent.
Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/11/2005 11:27 AM

Last Updated: 11/06/2008 12:00 PM

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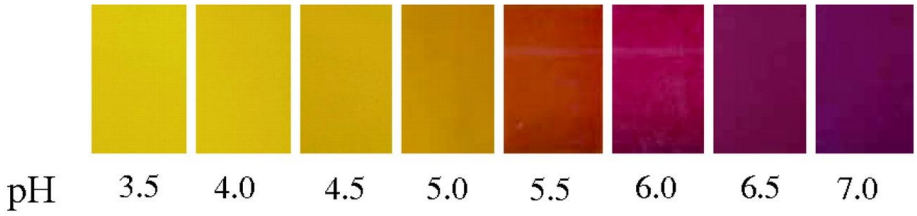
E.4.a Bromocresol Purple Spectrum



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