Design of a Personal Health Monitor Interface for Wireless, IP-based, Data Logging

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Abstract

Collaborating with the Enterprise Research Centre at the University of Limerick (UL) in Ireland, we designed, developed, and implemented a proof-of-concept glucose meter adapter that allows blood glucose level readings to be securely transmitted to a remote database via existing WiFi technology. By using open source software and embedded components, we have created a highly flexible platform that allows healthcare professionals to monitor patients in near real-time. Our device aims to simplify the lifestyle of diabetics while providing new opportunities for statistical research and analysis of diabetes.

Acknowledgements

Our project team has been fortunate to receive the assistance and guidance from a number of individuals during our stay in Ireland; some aiding in the progress of our design, some assisting with the editing and compilation of our report, and others ensuring that we have remained comfortable for the duration. What follows is a partial list of these individuals and organizations deserving of our thanks and gratitude…

Thanks go out to the entire staff of the Enterprise Research Centre (ERC) at the University of Limerick (UL) for their assistance throughout our project. Special thanks goes out to Dr. Mark Southern, our primary project liaison, for his continuous support and enthusiasm shown as we worked towards the successful completion of this project. Special thanks to John Harris for allowing us complete access to his knowledge of electrical engineering and electronics, but most importantly for teaching us how to properly manufacture printed circuit boards (PCBs) using the university's facilities. Special thanks also to Seamus Clifford for leading us through numerous brainstorming sessions at the start of the project—the sessions helped us understand our project and start moving in a positive forward direction.

Thanks to the University of Limerick (UL) for providing beautiful campus facilities for us to use, especially throughout the creation of our necessary printed circuit boards (PCBs).

We would especially like to thank Charlotte Tuohy for adopting us as part of her family, introducing us to her friends, and showing us the Irish way. Her dedication to all of us ensured a pleasant and memorable time in Ireland.

Thanks to Worcester Polytechnic Institute (WPI) and the Interdisciplinary and Global Studies Division (IGSD) for providing us with such a wonderful environment for the completion of our Major Qualifying Project (MQP). We would especially like to thank Prof. Richard F. Vaz for spending the first week of the project with us in Ireland, ensuring a smooth start both technically and logistically. We would also like to extend this special thanks to Prof. Donald R. Brown for visiting Ireland in Week 8, ensuring that we continued on that right footing through to this project's completion. Both professors also voiced their support and concern every Wednesday in our weekly teleconferences.

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Executive Summary

Throughout the developed world, the spread of diabetes in the general populace is on the rise. According to the World Health Organization (WHO), over 171 million people were afflicted with *Diabetes mellitus* (i.e. hyperglycaemia or "elevated blood glucose levels") in the year 2000. King *et al* predict a 42% and 170% increase in patients diagnosed with the disease in developed and developing countries, respectively, within the next twenty years in their 1998 article, "Global Burden of Diabetes, 1995-2025." Such an increase in diabetic patients demands technological advances to better facilitate the management, research, and analysis of diabetes in the near future.

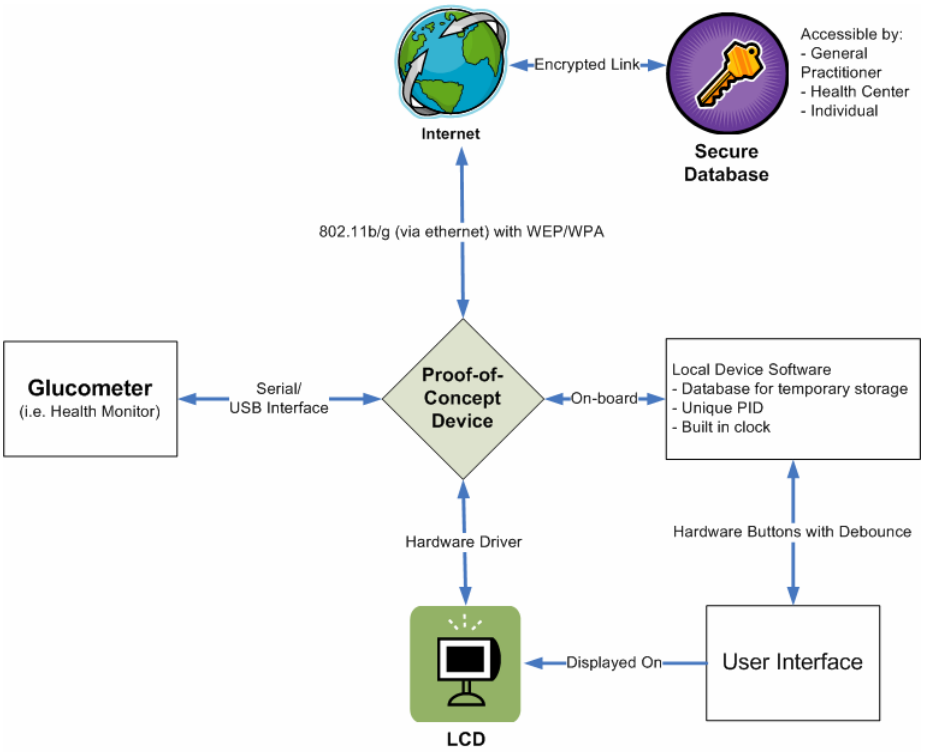
Ireland, with a population of just over four million, currently harbours over 200,000 diabetics. The Diabetes Federation of Ireland predicts that as many as 200,000 additional Irish are unaware of their affliction with diabetes ("Ireland loosing in EU diabetes battle"). The federation also claims that the number of people with diabetes in Ireland is to double by the year 2010, fuelled mainly by poor diet and the onset of sedentary lifestyles. With 10% of the total healthcare budget of Ireland—over €350.5 million—dedicated to managing expensive and preventable complications of diabetes (€210.3 million), emergency medical response and ambulatory care (€87.6 million) for diabetic patients, and towards effective management of the disease (€56 million), the need for the collection of accurate and reliable diabetic data (such as blood glucose level readings) for statistical research and analysis geared towards reducing the cost of quality healthcare for diabetics and focused upon improving the quality of life and life expectancy of those afflicted with the disease is realized (Clarke, 2002).

General practitioners advise diabetics to regularly test and record their blood glucose levels. Patients afflicted with Type I diabetes often need to adjust their blood glucose levels with insulin injections. The review of these recorded logs by general practitioners occupies time that could be better focused on providing healthcare to other patients. A device capable of collecting and organizing data from existing and soon-to-be-developed glucose meters and storing this data in a centralized database would allow for this reprioritization of general practitioner care without placing the care of their diabetic patients in jeopardy. The ability for near real time communication between patient and general practitioner could even reduce the number of check-ups required because feedback is provided more frequently to the patient by the general practitioner or healthcare professional. By storing diabetic data in a centralized database, the

foundation for the statistical research and analysis of diabetes from a vantage point previously unavailable is laid.

The Enterprise Research Centre (ERC) at the University of Limerick (UL), Ireland is interested in the creation of this personal health monitor interface. In 2005, a student research team from Worcester Polytechnic Institute (WPI), USA helped the ERC implement a proof-of-concept device that could interface with an existing glucometer, the TheraSense FreeStyle Mini. Our research builds upon the initial findings of 2005 team and aims to deliver an improved prototype, a device comprising of a short-range wireless transmitter capable of interfacing with existing glucometers, retrieving any data stored, and updating individual patient data on a remote database. Our efforts were to focus on generating useful documentation to accompany our product to enable future research teams to quickly pick-up development.

At the core of our proof-of-concept design is the OMAP5912 OSK development board, as recommended by the 2005 student research team. The figure below illustrates how the board's capability to interface with numerous external devices through different means contributes to our development platform.



System Level Diagram

Our device's hardware is comprised of four main subsections: a user input circuit, an LCD driver circuit, a wireless module, and the OMAP5912 OSK development board. Each subsystem is integral to the functionality of the product and was designed for the average diabetic. The user input is limited to three selection buttons, which control a text-based graphical user interface (GUI). We designed the LCD module to have a high level of clarity while maintaining a small size. Wireless capability is enabled though the fully integrated Airborne ABEB-10BT Wireless Ethernet Bridge. All of the software that controls this device is located on the development board, which is powered by the open source Linux operating system.

In the end, we were able to provide the Engineering Research Centre with all of the subsystems to create a working proof-of-concept device capable of interfacing with a glucose meter. Our proof of concept included a functional graphical user interface and the ability to successfully pull data from the glucose meter. Unfortunately, due to unforeseen difficulties with enabling LCD support in the operating system, final compatibility testing with our LCD was delayed. When the unit was finally connected to the system, it became apparent that the LCD itself may not be functioning within normal parameters. We were, however, able to confirm that all software was operational by making slight adjustments to use the 2005 student research team's LCD unit. Moreover, all of the documentation to recreate our development computer and recreate our proof-of-concept design has been generated and left with ERC for future development. Our research team is hopeful that research continues on this device and comes to market one day in the near future to aid the study of diabetes and, more importantly, those afflicted with the disease.

1 Introduction

Throughout the developed world, the spread of diabetes in the general populace is on the rise. According to the World Health Organization (WHO), over 171 million individuals were afflicted with *Diabetes mellitus* (i.e. hyperglycaemia, elevated blood glucose levels) in the year 2000. In their 1998 article "Global Burden of Diabetes, 1995-2025," King *et al.* use diabetes research to estimate the impact of the disease on men and women in the developing world (Aubert). They predict an increase of 42% and 170% in patients afflicted with diabetes in developed and developing countries, respectively, within the next 20 years. Such an increase in diabetic patients motivates technological advances in order to facilitate the future management, research, and analysis of this disease.

The Republic of Ireland is feeling the growing affect of diabetes on its citizens. A WHO census in 2000 reported an approximate 86 thousand Irish citizens afflicted with the disease. In 2006, the Diabetes Federation of Ireland estimated that at least 200 thousand known diabetics resided in Ireland, with approximately 200 thousand additional persons unaware that they are afflicted with the disease. In addition, there could another 250 thousand more people in Ireland considered "pre-diabetic"—that is, people who will require insulin injections if lifestyle changes are not made over the course of the next five years. With a population of just over 4 million and 17% of the population in danger of enduring a lifetime of diabetes, the collection of data from Irish diabetic patients for research and analysis could aid in determining the most efficient manor in which to deal with the disease.

Diabetic patients are advised to test their blood glucose levels periodically and in some cases use injections of insulin to maintain healthy levels of glucose in their blood. Doctors recommend that patients keep a record of blood glucose levels for review at routine examinations. The review of handwritten logbooks is time consuming for both the patient and the doctor. With the creation of a device capable of data collection and organization, and that is compatible with present and future types of glucometers, the review of data logs will be easier not only for the doctor, but for the patient as well. This device could provide physicians with a means of real time communication to pass along advice to the patient for controlling their blood glucose level. Furthermore, the device will lay the foundation both for statistical research and for analysis of diabetic patients and allow for remote monitoring of a patient's status by healthcare providers.

Few products are available for recording and graphically displaying blood glucose data digitally or sending data to remote locations. Some glucometers like the Freestyle Mini (Abbot Laboratories Ltd) can store past readings and upload data onto PCs so the user is not required to enter data manually. The GlucoMON from Diabetech, LP, is the only device found that interfaces with a glucometer and sends the information to a remote location. In 2005, a team of student researchers from Worcester Polytechnic Institute (WPI) in conjunction with the Enterprise Research Centre at the University of Limerick made significant progress towards implementation of a proof-of-concept device capable of interfacing with standard, off-the-shelf glucometers and synchronizing the stored data with an external database via a wireless network.

However, none of these programs or devices is yet capable of collecting reliable data for statistical analysis. The 2005 student research team was not able to complete the proof-of-concept device due to technical limitations of their wireless implementation and developed firmware. A few research companies are currently trying to develop devices capable of gathering data and transmitting it wirelessly to a central location, but currently no products are available for this type of action.

The goal of this project is to create a proof-of-concept device able to transmit data synchronised from a glucometer wirelessly to a remote database. Our project addresses the problem of collecting reliable data from diabetic patients for statistical analysis, while making an improvement to the lifestyle of said diabetic patient. This proof-of-concept product will be capable of gathering, transmitting, and organizing blood glucose data in a central remote location with little need of technical experience on the part of the user. The success of this proof-of-concept would not only provide the data necessary to formulate an argument for the need for real time data evaluation of all forms of health monitors, but also affirm the usefulness of wireless medical telemetry in both the Irish and world markets.

2 Project Description

The purpose of this chapter is to present the reader with the objectives of the project as well as the initial product specifications. This should aid the reader in understanding the direction of our project.

2.1 Project Objective

The following is an excerpt from the project description provided by John Harris and Dr. Mark Southern of Enterprise Research Centre (ERC) University of Limerick (UL); Appendix A1 contains the original text.

"The aim of the project is to develop and apply a wireless data transmission technology for real-time data acquisition of remote patient data in a primary care environment. Possible applications include the monitoring of diabetes, cardiovascular, asthma and chronic disease management.

The objective is to deliver a prototype wireless interface device comprising of a short-range wireless transmitter communicating over a proprietary wireless access point (WAP) updating individual patient data in a remote database over the internet. The target output is a microprocessor-based mobile RF transceiver interface" (Harris 2005).

2.2 Project Mission

Taking the above project objective, we established a project mission. Our project aims to assist the Engineering Research Centre at the University of Limerick design, develop, and implement a proof-of-concept wireless system capable of remote data monitoring and the real-time acquisition of remote patient data in a primary care environment with intent for future statistical research and analysis on said data. We will fulfil our mission by:

1. Developing a device and its firmware with prior, current and soon to be developed glucometer for data retrieval,
2. Making our device portable and use existing infrastructure (i.e. wireless) to report readings to a database system for future analysis,
3. Constructing an externally-hosted, standards-based database system for use by general practitioners and capable of supporting multiple patients while adhering to privacy concerns,

4. Designing and implementing an intuitive user interface for easy accessibility to our device's controls.

2.3 Project Specifications

Doing more research into the issues this project deals with, and through discussions with our project advisors and liaisons, we made the following determinations:

- **Proof-of-concept device**
  - The end goal should not be to have a finalized marketable product. Miniaturization and fine-tuning can happen at another time.
    - Functionality of the major subsystems is the most important aspect of this project.
  - Fit inside a metal case 45cm x 33cm x 15cm with a laptop computer.
  - Complete documentation on how to recreate results.
  - Use little to no proprietary software or hardware in the development of the device.
- **User Interface**
  - Large display
  - Clear user commands
  - Simple graphic user interface (GUI)
- **Microprocessor**
  - Ability to interface with glucometers for data transfers
  - Feedback on operations
  - Built-in memory for temporary data storage
  - Built-in clock
- **Database**
  - Secure location
  - Unique personal identification numbers
  - Easily accessible data for the user and doctor
  - Logical data organization
- **Wireless Characteristics**
  - Secure data transmission
  - High encryption level
  - Low cost – specific figures are not available as to cost, since this is a proof-of-concept device
  - Indoor and outdoor use

3 Background

In this chapter, we present a brief overview of diabetes and its impact on the world population. We then describe some of the devices used to keep control diabetes, and how medical telemetry is a key element of simplifying the life of diabetic patients. Finally, we explain how prior products and research in this field relate to our project.

3.1 Diabetes mellitus

Diabetes mellitus is a chronic disease that can be inherited (i.e. Type I Diabetes) or acquired later in life (i.e. Type II Diabetes, a.k.a. late-onset diabetes). The disease causes a deficiency in or impotency of insulin produced by the pancreas. Such a deficiency results in increased concentrations of glucose in the blood. This, in turn, can damage many of the body's systems, particularly the blood vessels and nerves composing much of the circulatory system ("Diabetes Overview"). Diabetes is on the brink of becoming a worldwide epidemic, with over one hundred million people estimated to be afflicted the disease. The fact that much of the diabetic population is unaware of their condition is also of great concern.

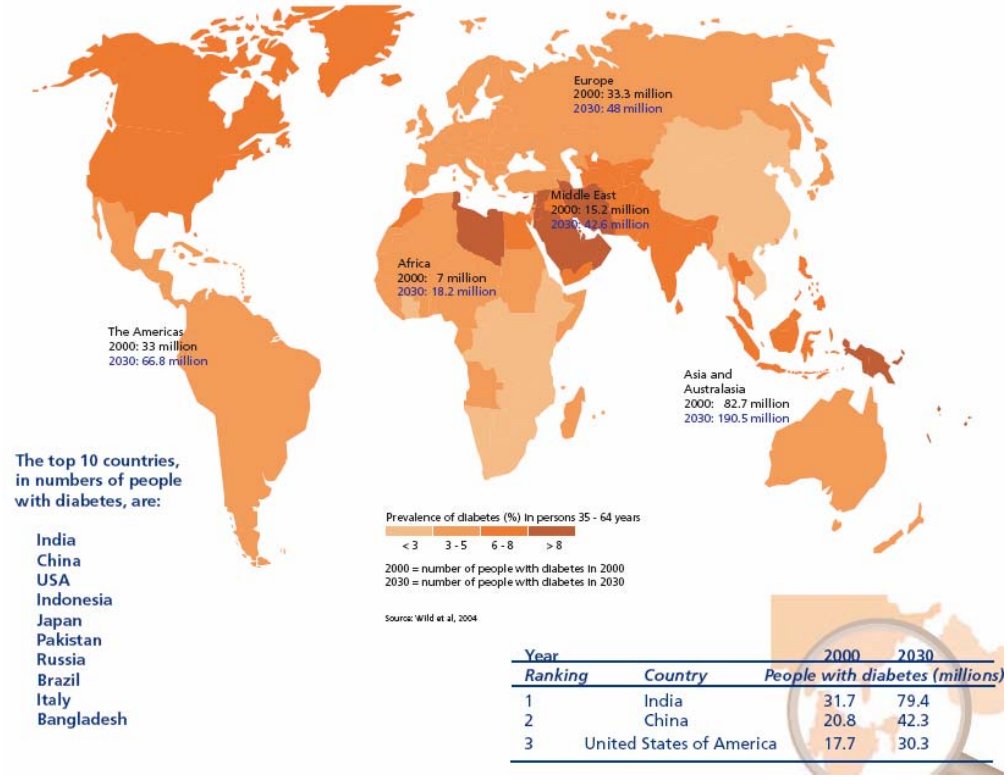


Figure 3-1: The Prevalence of Diabetes
("Diabetes: Facts & Figures")

As illustrated in Figure 3-1, diabetes is a condition that affects every nation. Diabetes mellitus occurs throughout the world, but is more common (especially Type II) in developed countries. The prevalence of diabetes is increasing the fastest in Asia and Africa, where the highest concentration of patients will likely be found by 2030 ("Diabetes: Facts & Figures").

The two main forms of diabetes are Type I and Type II. In Type I, the pancreas is unable to produce an adequate amount of insulin, and thus a person who has Type I diabetes must take insulin daily to live. Figure 3-2 illustrates and describes some of the mechanisms at work in the body of a diabetic. The symptoms of Type I diabetes usually present over a short period, although the destruction of the beta cells could have begun before any symptoms are ever noticed. Main symptoms include increased thirst and urination, constant hunger, weight loss, blurred vision, and extreme fatigue ("Diabetes Overview").

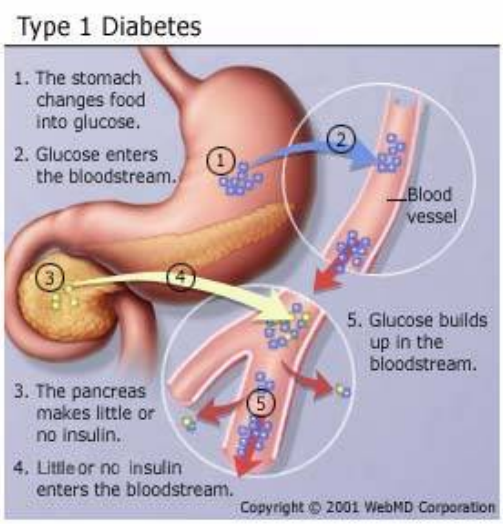


Figure 3-2: Causes of Type I Diabetes
("Diabetes Overview")

Type II diabetes is the more common form of the disease. In Type II, or late onset diabetes, the pancreas produces the correct amount of insulin; however, the body of the person cannot effectively use the insulin. Symptoms of Type II diabetes develop gradually over the course of the patient's life. The symptoms may include fatigue or nausea, frequent urination, unusual thirst, weight loss, blurred vision, frequent infections, and slow healing of wounds or sores ("Diabetes Overview"). Once this condition is recognized patients keep track of their blood glucose levels with a device called a glucometer.

3.1.1 Glucose Monitoring

To regulate blood glucose levels naturally, doctors recommend that people maintain a healthy lifestyle that includes regular exercise and a lean, well-balanced diet. In addition, diabetics need to check their blood glucose levels with the aid of testing device, such as a

Time of Test	**Goal Plasma Glucose**
Before meals	90-130 mg/dL (milligrams per decilitre)
Before bedtime snack (1-2 hours after a meal/postprandial)	less than 180mg/dL
Every three months	less than 7%

Table 3-1: Recommended Blood Glucose Range for People with Diabetes ("All About Diabetes")

glucometer. The frequency of blood glucose level checking varies between patients as it largely depends on the severity of their condition.

The monitoring of blood glucose levels at home can occur either through a invasive or non-invasive procedure. The most common method of testing blood glucose levels involves pricking a specified part of the body with a small needle, in order to draw a small amount of blood. The drop of blood is then collected on a test strip and inserted into a glucose meter. The glucose meter analyses and then numerically displays the glucose concentration level in the blood sample. Section 3.3.1 goes more in depth on the different types of glucometers on the market, from older versions to the newer versions that implement the principles of medical telemetry.

3.2 Medical Telemetry

In its simplest form, medical telemetry (or "telehealth," for short) involves delivering medicine or medical information to people from a distance ("Defining Telemedicine, Telehealth, and the Consumer"). This allows the patient to stay at home, but still be able to communicate with medical staff. Telemedicine is a subset of telehealth, which involves the implementation of information technology and of communication principles ("Defining Telemedicine, Telehealth, and the Consumer"). The research done on telemedicine includes two main parts: one deals with wireless health monitors and the other with glucometers themselves (Section 3.2.1). With this project focused on wireless collection of data from glucose monitoring instruments, we analyzed the different techniques and technologies already available for wireless collection of information for other types of health monitors.

3.2.1 Wireless Health Monitoring

Several medical institutions have begun implementing modern day technology into medical data logging - including web portals, electronic medical records, and virtual private networks (VPNs). This modern day technology improves the speed, quality, safety, and cost profile of healthcare. Figure 3-3 is an example of how wireless monitoring can work in a medical institution.

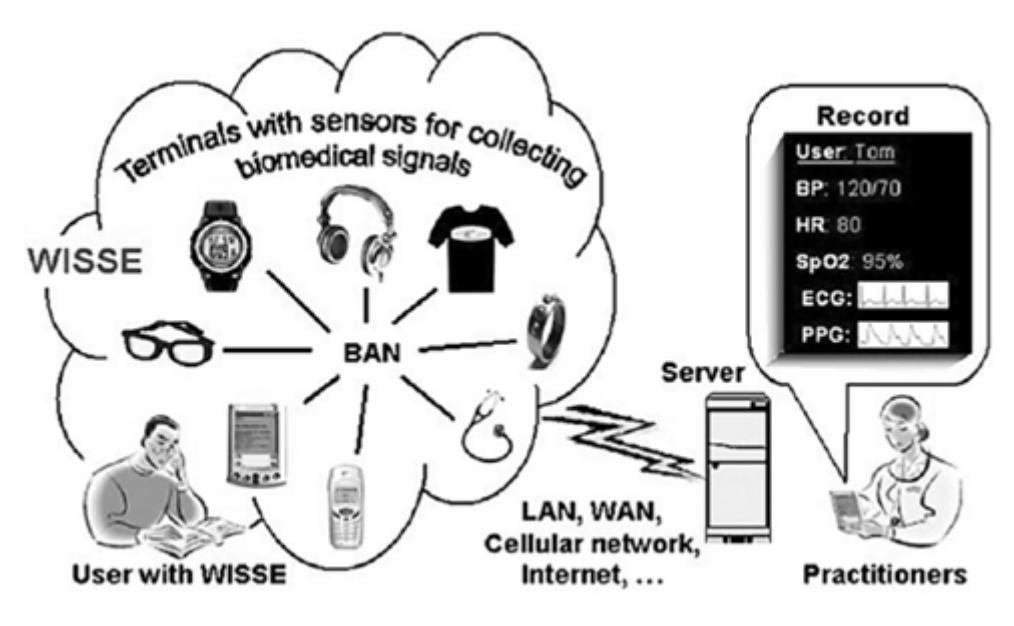


Figure 3-3: Wireless data collection
("Defining Telemedicine, Telehealth, and the Consumer")

Patients use certain sensors that transfer their data to a server where the practitioner can read and monitor their condition. This technology is an adaptation of wired technologies on traditional personal computers (PCs), which require users to work from a computer physically connected to a local network. The recently developed wireless capture of patient data reduces the need for nursing staff to sit at computers and enter basic data. Such digital solutions offer dramatic improvements over the days of paper files, chart-chasing, lengthy delays, and illegible entries. Wireless deployments have made significant improvements to the quality of healthcare, a positive impact felt both inside and outside the organization.

Increased intelligence and the lowered power consumption of the new generation of microcontrollers and digital signal processors (DSPs) make a complete new range of intelligent monitor applications possible. Further need for privacy protection and acceptance of implantable

sensors and devices require the introduction of a wireless personal network. Different applications of wireless personal area networks in telemedical environments include:

- Intelligent portable health monitors, such as:
  - ECG and
  - epilepsy monitoring,
- Intelligent control of medication delivery using:
  - wireless sensing,
  - dosing, and
  - compliance monitoring
- Breathing monitors for:
  - sleeping disorders,
  - stress monitoring,
  - biofeedback techniques, and
  - circadian rhythm analysis
- Activity monitoring using accelerometer
- Aids for disabled individuals.
- Computer assisted rehabilitation.
- Battlefield soldier monitoring.

These technologies could become an unseen part of patients' daily lives. Theoretically, a patient could simply wear and/or use a sensor with a wireless communication link that enables it to receive instructions and transmit data (usually time stamped) to a remote database ("Defining Telemedicine, Telehealth, and the Consumer"). The patient could also wear and/or use an automatic medication-dosing device with a wireless link that transmits the dosing history (dose amount and time) to a remote database.

For diabetics a remote intelligent control system could determine when a new blood glucose measurement is necessary, and use the wireless link to signal the sensor, either automatically make the measurement or request the patient make the measurement manually. Then, the data could be transmitted wirelessly to a remote database where an algorithm could recalculate the dosage level and administration timing. This new dosage schedule once received by the dosing device/recorder is either automatically administered, or the patient uses the dosing device/recorder to administer the dosage manually. The development of built in contingencies would need to coincide with the development of these technologies. For example, if the communication link were not available to deliver the new dosage schedule, the system would need to recalculate a new dosage schedule on its own and try to transmit again. A key part of this system would be the supervisory medical personnel who could access the database on a regular basis to monitor the patient measurements and dosing levels. A supervisory algorithm

would also be necessary to monitor operation of the system and alert medical personnel as needed ("Defining Telemedicine, Telehealth, and the Consumer").

Several new rehabilitation therapies could make use of such devices used by the patient in their home environment during routine activity. Using wireless communication technologies to monitor the patient and assess the effectiveness of therapy does not hinder the patient in any way. This also allows the doctors and rehabilitators to adjust the patient's regimen if necessary without having the person leave home. All of these ideas are purely hypothetical and not yet available to consumers, but are along the lines of what this project aims to make possible.

3.3 Prior Art and Research

In this section, we investigate products currently available to diabetics for control of their disease, as well as some technology with attributes previously described in section 3.3. This information indicates which customer needs are currently being filled and to what portions of the market have been saturated. Exploring and comparing these products is advantageous because of the different elements each employs. Since our project involves wireless communication and wireless transmission of data, we researched different methods of communication as well as the different elements that go into wireless communication. In 2005, a student research project from WPI worked on a very similar project and learned many lessons that will be helpful in the completion of this project.

3.3.1 Prior Art for Glucometers

A glucometer, as previously mentioned, is device used by diabetics to measure blood glucose levels. The main principles a glucometer as described on WebMD are:

1. A chemical is presented on the test strip, which on contact with glucose, produces a colour. The meter measures this colour intensity and the level of glucose present is expressed in mg/dl.
2. The other type of glucometer measures the electric current in the blood, which depends on the amount of glucose present. When blood is put on the test strip, an enzyme transfers electrons from glucose to a chemical in the test strip and the meter measures the flow of the electrons as current. The amount of current depends on the amount of glucose present and the meter produces the reading in mg/dl.

("Diabetes Overview")

Glucometers, vary in features, readability (some having larger displays or even spoken instructions for the visually impaired), portability, speed, size, and even cost. Current devices provide results in less than 15 seconds and can store the information obtained for future use.

These glucometers can also calculate an average blood glucose level over a period. Some meters also feature software kits that retrieve information from the meter and display graphs and charts of past test results ("Diabetic Meter Strips"). This software is either included in the package by the manufacturer or can be bought as an additional accessory at anytime.

Using a glucose monitor regularly has many advantages for a person living with diabetes. A glucometer enables diabetics to take care of themselves without visiting doctors and labs for tests. Instead, they can monitor their own blood glucose levels. It also promotes the well-being of the patient by allowing him/her to control the situation. Glucometers also provide a better understanding of medications taken by patients and help them alter dosages as necessary. Each glucometer has its own specialized type of test strip that only works with that type of glucometer and no other. The test strip has a code, and before any test trip can be used, the glucometer must be set to the correct code. We hope to interface our device with standard types of glucometers and provide a wireless link to send recorded data to a central database. Ideally, the product will one day be able to integrate with all types of glucometers. However, we will attempt to integrate the Free Style Mini or the One Touch Ultra to our proof-of-concept device.

Figure 3-4: FreeStyle Mini Glucometer

The Free Style Mini and the One Touch Ultra are both common types of glucose meters that the ERC had obtained for a past research project, and so were readily available for our team. Figure 3-4 above and Figure 3-5 below show the glucometers.

Figure 3-5: OneTouch Ultra Glucometer

Understanding and examining currently available glucometers will help us understand what elements of the device are important to the user. We are also interested in how the devices interface with personal computers for digital storage of glucose information. Table 3-2 shows the different types of glucometers that are available on the market.

	FreeStyle Mini	**One Touch Basic**	**One Touch Profile**	**Accu-Check Advantage**	**Accu-Check Complete**	**One Touch Ultra**
Manufacturer	TheraSense	LifeScan	LifeScan	Roche/ Boehringer	Roche/ Boerhinger	LifeScan
Sample (min)	0.3uL	10uL	10uL	4uL	4uL	1.5uL
Lot Calibration	Button	Button	Button	Chip	Chip	Button
Memory	250 tests with time & date, 14d avg.	75 Tests with Time and Date	250 tests with time & date. 14 /30d averages 15 event codes	100 with time and date	1000 with time & date multiple data management functions	150 tests with time and date and 14/30 day average
Download cap.	Yes	Yes	Yes	yes	yes	Yes
Test Time	15 sec	45 sec	45 sec	up to 40 sec	up to 40 sec	5 Seconds
Battery	Two AAAA Alkaline	Two AAA alkaline	Two AAA alkaline	Two AAA Alkaline	Two AAA Alkaline	3Volt Lithium Ion
Tests/Battery	~1000 tests	~1000 tests	~1000 tests	~700 tests	~1000 tests	~1000 tests
Auto Shut Off	2 minutes	5 minutes	5 minutes	5 minutes	3 minutes	2 minutes
Price Range	$$$	$$	$$$$	$$	$$$$	$
Size (in)/Wt.	2x3.8x1 2.1 oz	4.3x2.6x1.2 4.5oz	4.3x2.6x1.2 4.5 oz	3.6x2.3x0.6 3 oz	4.8x2.8x1.1 4.4 oz	3.1 x 2.25 x.85 1.5 oz
Comments	Very small sample size. Samples from arm. ***Coulo-metric measurement	New larger display screen. Display can be set in 17 languages	Display can be set in 19 languages. Voice synthesizer available	May add blood during first 15 seconds. Voice synthesizer available	4 languages Blood may be added to strip during first 15 seconds	Can touch test strip sample area without affecting results, alternative site testing

Table 3-2: Comparison chart for glucometer ("Diabetic Meter Strips")

Many diabetics find taking measurements painful and annoying because they must puncture their skin for a reading. This has inspired the development of alternative forms of continuous glucose monitoring systems. The MiniMed Continuous Glucose Monitoring System is a device consisting of a catheter inserted just below the surface of the skin. The catheter collects small amounts of fluid and then measures the glucose level in the blood over a 72-hour period (for more information see MiniMed.com). In 2001, the FDA approved the GlucoWatch, a watch-like device that helps people with diabetes measure their blood glucose via tiny electric currents. It draws small amounts of fluid from the skin and measures blood glucose levels three times per hour for up to 12 hours (for more information see GlucoWatch.com).

3.3.2 Prior Art for Wireless Transmission of Glucometer Data

Currently there are relatively few methods of transferring data from a glucometer to a storage device over a wireless network. Secure data logging capabilities for glucometers are exclusively though USB or RS232 to connect to a PC. One Windows Mobile based software program allows users to manually input glucose readings.

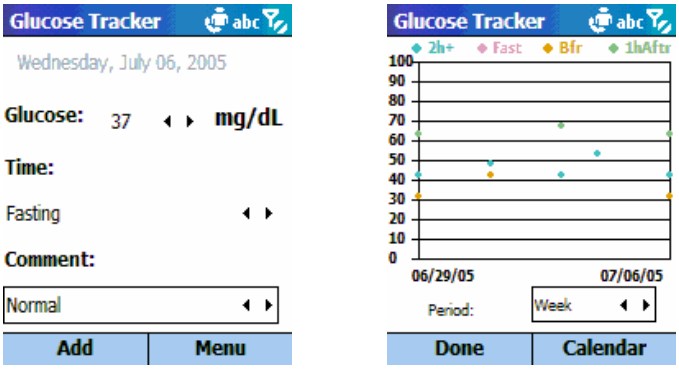


Figure 3-6: Microsoft Windows mobile glucose data logging interface ("Glucose Tracker").

This $20 software application developed by Handango is for a Windows enabled cell phone or PDA ("Glucose Tracker"). It is possible to upload the recorded information onto a PC, but there is no further functionality for sharing this information with a doctor. Since the information input manually, the risk of incorrect or fabricated data exists. In addition, the upload of the information onto a PC is a manual and sometimes complicated process requiring the user to have a good deal of technical knowledge, as well as spending extra time to upload the information.

A transmitting glucose monitoring system developed for parents to monitor their children's glucose readings is the GlucoMON. This package offered by Diabetech is a specialized glucometer and wireless technology package which requires very little thought on the user's part ("GlucoMON"). When the glucometer is placed in the package after taking a glucose reading, it automatically retrieves the data and sends it to a location predetermined by the user or administrator of the unit. It is possible to set the device to send the information to multiple cell phones or email addresses. A monthly charge is associated with this device similar to any type of two way paging service.

Figure 3-7: GlucoMON package for the wireless transmission of glucose ("GlucoMON")

This device is currently in the test stage and costs $400 to become involved with the research program not including the LifeScan® glucometer, lancer, or test strips. Diabetech offers some other products that are two-way pagers for the transfer of glucose information; however, none of these alternatives interface directly with a glucometer.

A Finnish company called eHIT, is proposing a concept product that is advertised to use existing products with Bluetooth, WLAN, or infrared capabilities to tie together a network of health monitoring systems ("Solutions"). eHit's proposal is to develop all of the software necessary for interfacing the products, however they are not interested in being part of the development of such products.

Figure 3-8: eHIT product concept diagram ("eHIT")

The concept shown in Figure 3-8 connects all of the same concepts as we are aiming for in this project. However, each of the category descriptions are quite vague, with the use of a "personal wellbeing monitoring device" and a "smart phone PDA" and the "Wellbeing Portal"

all of these elements will be integrated. The idea is to use all different types of existing wireless technology to transmit the information, and then have data storage for all of the information.

These products are the technologies available on the market for glucose data record keeping, as opposed to keeping hand written logs of the information. The Handango cell phone software does not transmit, but allows the user to carry a digital log of glucose readings. The main purpose behind GlucoMON is for families to keep track of their loved ones. There is no database service or glucose tracking software to go along with GlucoMon as of yet. The eHIT solution looks to be the product with the most similar mission to this project. However, by using only wireless enabled technology the product is restricted to people who have the means to purchase such products then configure them with the eHIT software.

3.3.3 Prior Student Research

In 2005, the Enterprise Research Centre (ERC) at the University of Limerick sponsored a student research project to develop a wireless system capable of gathering data from many different health information systems and transmitting the data wirelessly to a remote database. The system was also to include the capability to receive information and display messages back to the user regarding the analysis of the information gathered. The 2005 student team completed the project with basic functionality of the product only. They recommended a follow up project due to the potential of the product.

The 2005 student team obtained a development board in order to eliminate the need to design an entire system from discrete components. They selected the TMD OMAP5912 OSK development board for its processing abilities and versatility of expansion ports. Our research project will use the OMAP board on the recommendation of the 2005 student team although it has more processing and memory storage power than necessary for this project. After the proof-of-concept is complete, the process of miniaturization can begin by eliminating the unnecessary functionality.

One of the most important recommendations made by the 2005 student team was to be aware of lead-time on parts. Due to some long delays and time constraints nearing the end of the project, the 2005 team was forced to implement a proprietary wireless technology into their design. Two problems arose from this solution. First, proprietary technology is not desirable in a proof-of-concept design because the technology cannot be used in the final product without causing a great impact on the cost of production. The second problem arose from the

OMAP5912 OSK development board. The wireless capable USB dongle drew so much power that the board would crash after only a few seconds of operation, and the distances for successful transmissions was very short. We discovered that the USB port, which is integrated into the OMAP5912 OSK development board, has non-standard wiring and cannot support any type of WLAN technology due to the power requirements of such devices ("OSK"). Another challenge that the 2005 team encountered because of long lead times on products was with their specially designed PCB. Because the board was manufactured at UL, the pitch of the components used is limited. UL has limited technology for PCB production, which caused a problem with the ribbon cable header for the LCD selected by the team. The trouble creating the LCD driver circuit compromised the capabilities of the LCD in the end. These lessons and recommendations were taken into account as the development of this product was restarted.

The progress of the 2005 student research team at the University of Limerick illuminated many issues present in the wireless health monitor project. The concepts that were formulated were helpful in gaining a starting point; however, all the information was re-investigated and confirmed. By doing this, a much more fully developed product was produced for the Enterprise Research Centre at the University of Limerick.

4 Project Planning

In order to approach this project in a systematic manner a step-by-step plan of action was developed early in the effort. The top level Gantt chart shown in Figure 4-1 allowed for advanced consideration of tasks in relation to both the compilation of this report and the completion of the project.

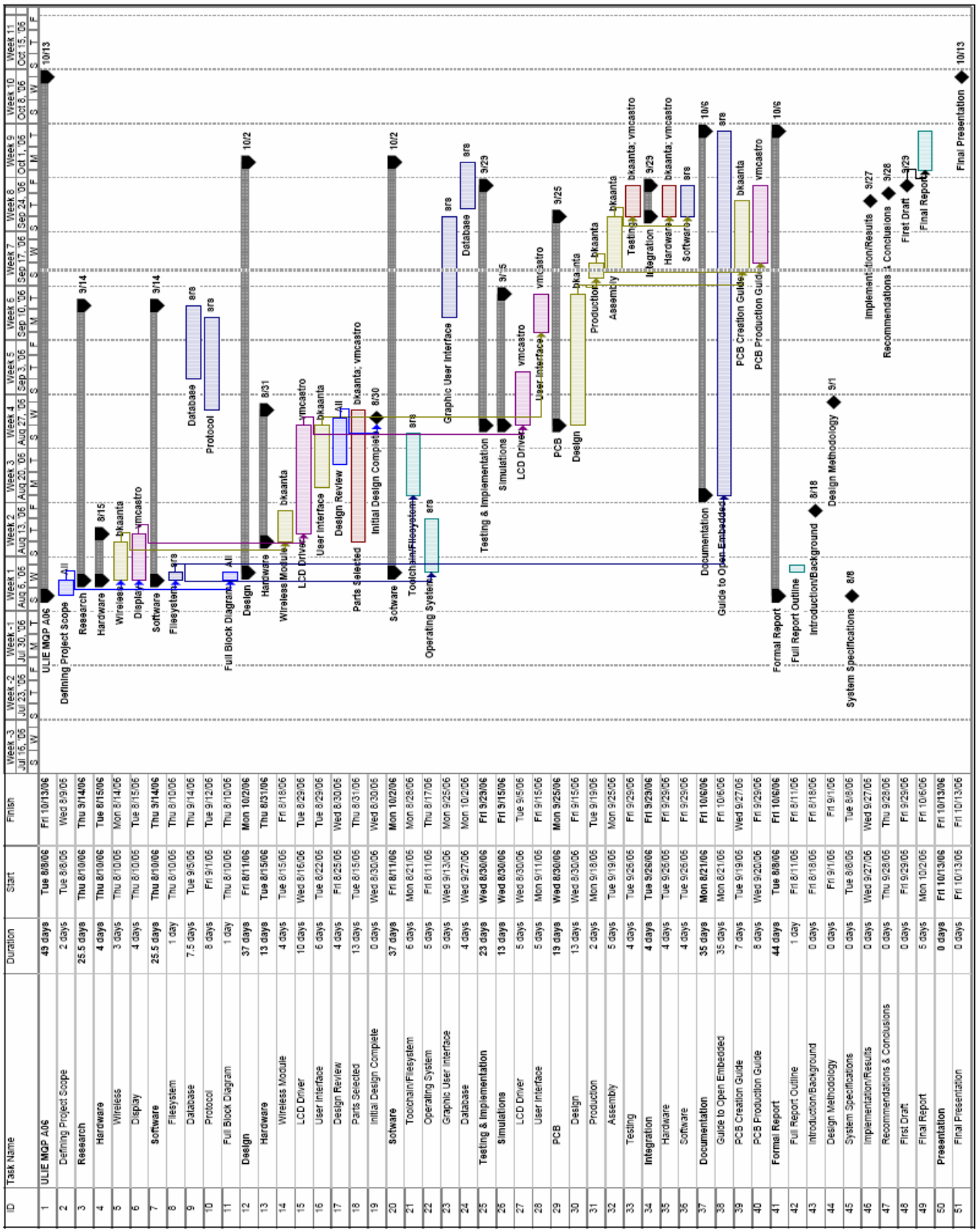


Figure 4-1: Top-level Gantt chart.

The project was divided into three main phase: research and design, implementation and testing, and integration of all the subsystems. The hardware and software components of the project were divided in the flow charts and Gantt chart in order to illustrate that parallel development took place. Integration of the systems is implicit and occurs later in one of the aforementioned stages.

Stage 1 of the project is the research and design portion that lay the foundation of the project by defining the functionality of each subsystem. This is the stage where the majority of the planning and design occurred.

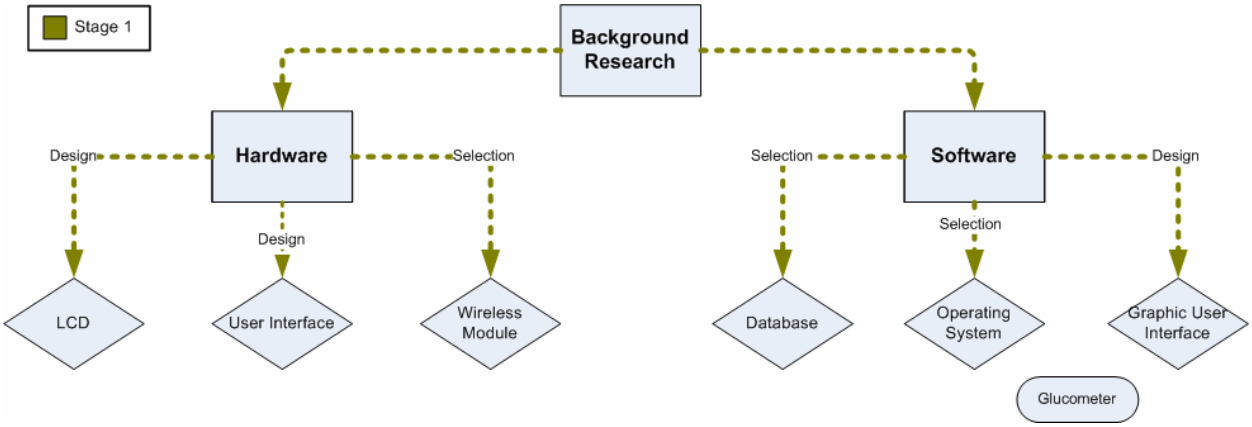


Figure 4-2: Project Stage 1 Flow Chart

Top-level diagrams and descriptions for the subsystems were created in this stage. By the end of this stage, we had a good general understand of not only the project but also the hardware and the software elements that were in the project. Based on the illustration above, Stage 1 included the following key tasks:

- Background research completion
  - Prior art
  - Customer needs
- Designing
  - LCD module
  - User interface
  - Wireless module
  - Development board operating system
  - Custom software applications
- Parts selection
  - LCD and driver
  - User interface
  - Wireless module
- Establishing of the file system on the board

Stage 2 of the project covered the individual implementation the major subsystems. Once realized, each subsystem was tested for expected values and results individually before being connected to any other part of the system. Stage 2 took the designs, plans, and ground work from Stage 1 and put them into action.

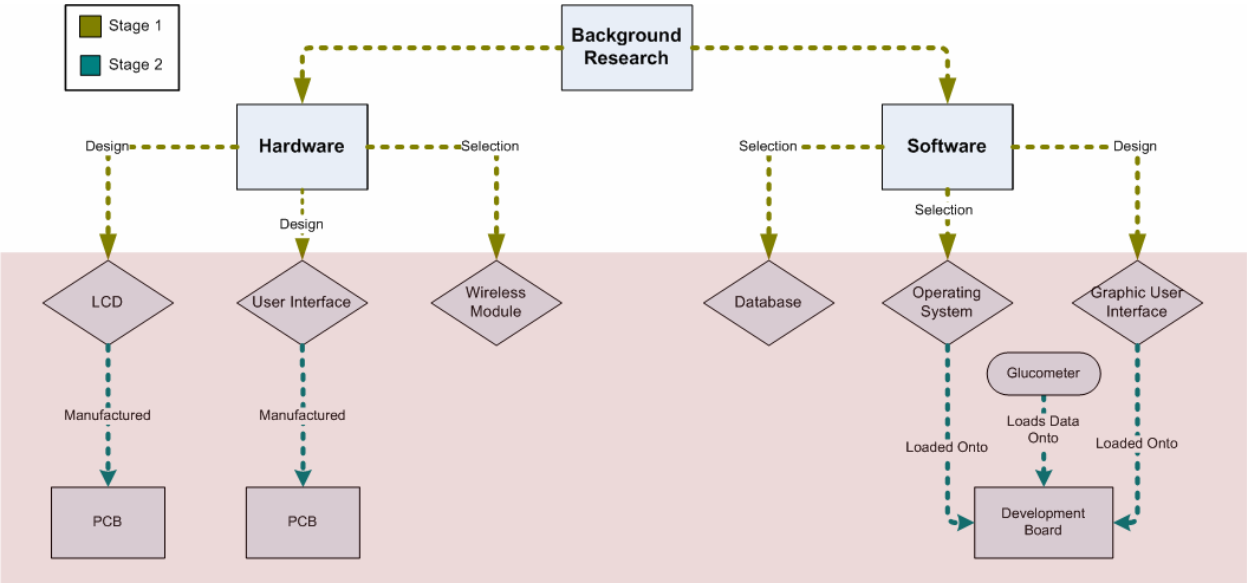


Figure 4-3: Project Stage 2 Flow Chart

As Figure 4-3 shows, Stage 2 built upon Stage 1. The actual pieces of the subsystems were built and tested. By the end of this stage, all of the major subsystems had been constructed. This stage included the following key tasks:

- Hardware manufacturing
  - Driver for LCD
  - User interface
- Hardware testing
  - Compare to simulations from design
- Operating system compiled and loaded onto the development board
- Glucometer protocol developed and functional
- Graphical user interface functional

Stage 3 of the project covered the integration of the subsystems, assuring positive connections, and testing the overall system. Taking each of the subsystems, which were designed to work together, and integrating them into one working product was the goal of stage 3.

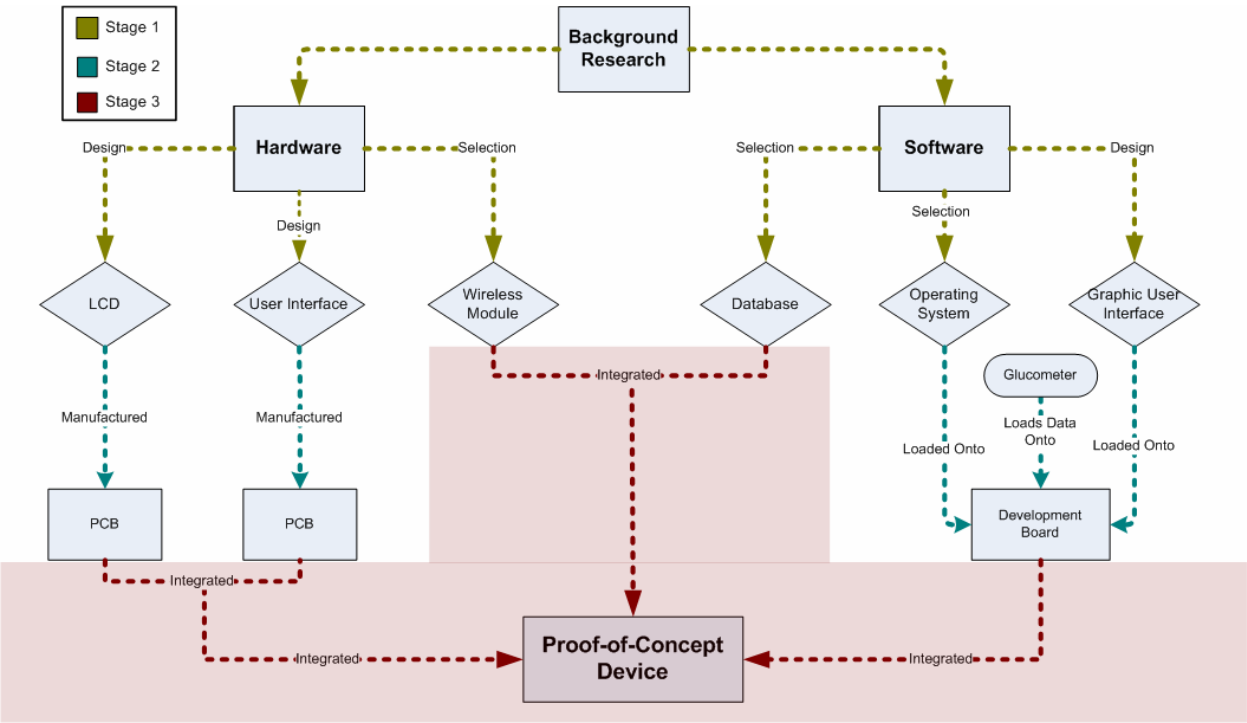


Figure 4-4: Project Stage 3 Flow Chart

At the end, with all the systems fully integrated, the end proof-of-concept device was presented. Stage 3 involved the following:

- Loading final software revisions onto the development board
- Connecting user input and LCD driver PCBs
- Upload and logging of data on device from glucometer
- Plugging wireless module into development board
  - Making wireless transmission
  - Making data entry in database
- Controlling device functions through user input
- Quality assurance

With the completion of Stage 3, the team accomplished the major goals of the project. Unfortunately, with engineering delays from both the software and hardware portions of the project, the project was not completed two weeks before the end of the project term, as had originally been planned.

5 Design Methodology

This section discusses the methods we used to design the proof-of-concept product. To complete this process the product is broken up into several different subsystems. For each of the subsystems we determine its requirements in relation to the needs of the user and our prior research. After the system requirements have been established, the subsystem is fleshed out along with some detail on how it will interface with the rest of the device.

5.1 User Interface Requirements

A user interface includes all the systems the user interacts with, and which affect how the user experiences the product. The range of customers targeted for this product includes all diabetic patients and it must be accessible for a range of people who have different technical expertise, economic standing, and life style. Designing with this large range of customers in mind, and hoping to make the product easily accessible to as many users as possible, we tried to keep the end cost low, the need for technical experience limited, and the ease of use very high. Clarity was the primary concern; we wanted to make the system self explanatory and simple to use for any level user.

5.1.1 Customer Needs

The needs of the customer should dictate how a product is developed and eventually how it comes to life. No product can be successful without a market; therefore, the customer is the most important element in the development process. Through research into the life of diabetic patients, we were able to establish the current issues diabetics experience in their everyday lives. The discussion of products currently on the market in Chapter 3 helped identify elements, which the users found pleasing, as well as the displeasing factors associated with the product. In Chapter 8, we will make suggestions for features we were not able to incorporate in the proof-of-concept, but envisioned as integral to the eventual success of the product. The division of this project's functional goals into two different groups allows for the distinction between what this project aims to complete, and the elements identified as important and should be developed later for a marketable product. The two lists are separated with elements which will be designed and implemented in the first generation proof-of-concept product presented first, and the requirements for a marketable product presented second.

Proof-of-concept Device Features

- **Clear display -** Diabetes can cause a decline in vision, so to accommodate both patients who are elderly and or have poor vision a clear display capable of large text and images will allow them to experience comfortably the capabilities of this product.
- **Simple to navigate -** The menu system must be very clear and easy to navigate without much familiarization; something that people feel like they understand immediately when they start using it.
- **Ability to receive health related messages -** The ability for doctors or health services to send feedback messages to the user is a main feature of this device. The person must be able to receive information from the internet as well as send and store information there.
- **Clear feedback about operation -** Messages such as "Transmitting Now" or "Uploading Data" will allow to user to see easily that the device is busy and not yet ready for additional inputs. These informational queues to the user allow them to know what the processor is thinking and relate to the transfer of information.
- **Secure transmission of information –** Health information must be protected by the highest level of security possible, so the highest levels of wireless security must be implemented. In addition, the database on the internet must be a secure database only accessible to those who should have access to the information.

Final Product Features

- **Portable with small form factor –** The device needs to be battery powered and its overall size should not exceed the size of a Personal Digital Assistant (PDA) and should easily fit into a coat or pants pocket without causing discomfort.
- **Unobtrusive exterior design –** The intention of this device is to make life easier for diabetics and help them blend in with the rest of society. Designing the exterior of the product to be similar in size and format to a PDA or MP3 player would achieve this goal.
- **Long battery life -** One of the main elements of this product is simplifying the lifestyle of diabetics; therefore, a long battery life is included to reduce the need to worry about whether the device will keep working or not. A "long" battery life for this type of device would be between 3-6 hours of continuous operation, because when used normally it will be turned on

for short periods of time, then it is switched off, making the device usable for multiple days without the need for recharging.

- **Easily accessible information -** The information gathered and stored by the device should be easily accessible over the internet by the user, and the doctor.

5.1.2 Display Module

The display, as the face of this product, will be the element the user interacts with the most. Our main considerations for the display are size, colour capability, brightness, and touch sensitivity. These characteristics are elements that greatly affect the user as well as limit the possibilities from a design standpoint. Though small size is an element recommended for the final product, we would like to incorporate as many of the final features into the proof-of-concept as possible without causing delays or influencing the final functionality. A small screen is one element that can be incorporated into the proof-of-concept to show that despite small screen size the text can still be clear. A screen with a diagonal dimension between 2.5" and 3.0" should be adequate to achieve this. The ability for the screen to display colour is not essential. It is the contrast that is more important visually and not the presence of different colours.

Although the implementation of touch screen technology is increasing in markets such as car audio and navigation systems, it is difficult for people who do not have previous experience with touch screens to become comfortable with this type of system. Another way to implement touch technology is to use a stylus like palmtop computers or PDAs use. This option, however, raises the complexity of the unit greatly for both the user and the designer. In addition, constant touching of the screen either by hand or by stylus generally leaves scratches and fingerprints on the screen, which causes the clarity of the device to decline along with the lifespan of the product. A simple black and white screen with a possibly coloured background to aid in clarity of a small size between 6cm and 9cm would be adequate for this application. The discussion of technical aspects of the display module can be found in section 5.2.

5.1.3 Application Layout

The application layout will influence how the user experiences the product either in a positive or negative way. If the application layout is complicated and consequently hard to understand, the user will be less likely to continue using the product. Some of the possible

methods of application navigation include text based, graphic based, and button based. In several ways, the style of the application layout dictates the necessary user input controls.

- **Text Based Navigation**
  In this style of user interface application, words queues tell the user what action is available upon selection of that option. As illustrated in Figure 5-1, the words provided in a list give the user queues to what action lays beyond that command with additional possible actions listed consequently. If arranged in a single row, the only user interactions needed are up or down selections as well as an overall selection key. This style leaves room for upgrades in both software and hardware functionality. However, problems can arise with this method if there are too many items displayed on the screen, since then the user can only view a certain number of items simultaneously.

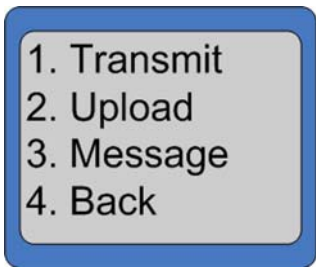


Figure 5-1: Example of a text based menu

- **Graphic Based Navigation**
  As illustrated in Figure 5-2, instead of using words to indicate actions this method uses universally understood graphics to indicate the available action. However, symbols do not always have the same meaning for every person and poor eyesight could preclude the user from comfortable use of the system. The display of the symbols occurs in multiple rows and columns. Differentiated colours aid this type of navigation; however, colour display is a feature option which was not selected in the display module section (refer to 5.1.2). In addition, only a certain number of icons can be displayed at the same time. For our project, the largest number of icons displayed would be four, since the icons need to be large enough for the user to see clearly. The input for this system would require some type of sidewise motion available, which complicates the input unnecessarily.

Figure 5-2: Example of a graphic based menu.

- **Button Based Navigation**
  A simple approach to mode selection is to provide each action available to the user its own button, which when pressed would take the user to that application. Similar to the graphic based approach, it would be necessary to provide both pictorial and text based clues for the user to indicate what action the button leads to. Although this method sounds simple and easy to

envision, for a user buttons can be confusing and frustrating. At first, navigation would be very slow because the button actions are unknown and strange.

Careful consideration of each application design method including the extra factors of the customers' needs and limitations, along with the characteristics of the display module chosen led to the selection of text based navigation. To accommodate the users who have poor eyesight the text will be large. By using a text system, commonly understood words will lead the users through the systems features. This method of navigation allows easy software upgrades and allows the user to select their preferred language. People who are not familiar with technology may not interpret symbols in the same way a technology user would, so words eliminate this barrier. It will be necessary to limit the options available and make each option as explicit as possible with few words.

5.1.4 User Input Controls

There are numerous different ways to implement controls into a device. The two viable options considered for user control on this device use either pushbuttons or a joystick. Other possibilities include a trackball corresponding to a pointer on the screen, or a stylus for a touch sensitive screen. However, those two options were eliminated due to the complexity of the hardware and software required for the integration into the system.

The ability of a joystick to house a multi-direction capable control inside a single module is favoured since it keeps the complexity of the hardware system low. However, with a text-based system this type of input provides excess functionality. A two-way joystick could be integrated into the system to be used with the application layout. We decided not to use a joystick because users may become confused when using it. In addition, we are unsure whether the OMAP OSK would accept joystick controls to the GPIO ports.

We decided to design the user inputs with buttons as the controllers. Clearly labelled buttons made to be flush with the unit casing will provide a familiar and common type of input for the device. Because there is no need for movement other than up and down, the inputs can be limited to just three buttons. Many everyday systems use arrow and selection keys, common examples are elevators and power windows in cars. For this application one button is dedicated to moving the selection bar *upwards* on the text based menu, another button is dedicated to moving the selection bar *downwards* on the menu, and a third button *selects* the desired action. The only other control necessary on the system would be a control to turn the device power *on*

and *off*. As a person carries this device with them it is necessary to have a power control that cannot be easily jostled into the *on* position. Having a toggle switch could allow for a *sleep* mode position in addition to the power *on* and power *off* settings.

5.1.5 Concept Renditions

With guidelines on the product's physical parameters and an idea of how the user will interact with the product, we produced a rough estimate of how the product might eventually materialize. As the design process progresses it was important for us to have an end goal in mind to keep all the systems being developed in parallel headed in the same direction.

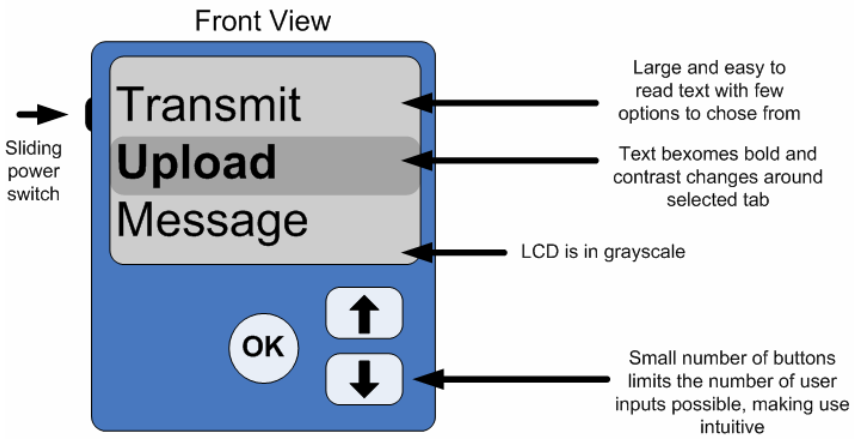


Figure 5-3: Concept rendition 1

The first generation concept model shown in Figure 5-3 integrates the straightforward three-button control system for the user input along with the text bases menu system for the user interface. The case of the device is just big enough to accommodate the LCD to keep the size of the produce as small as possible. While, the overall system is small, the text on the screen is large to accommodate any users whom are visually impaired.

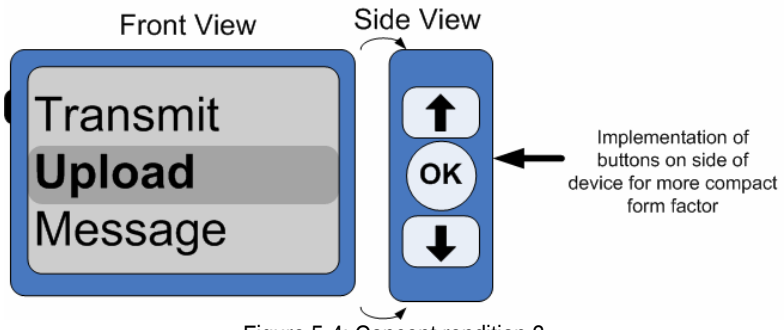


Figure 5-4: Concept rendition 2

Figure 5-4 is simply a variation on original concept with the buttons moved around to the side of the unit to reduce the overall size.

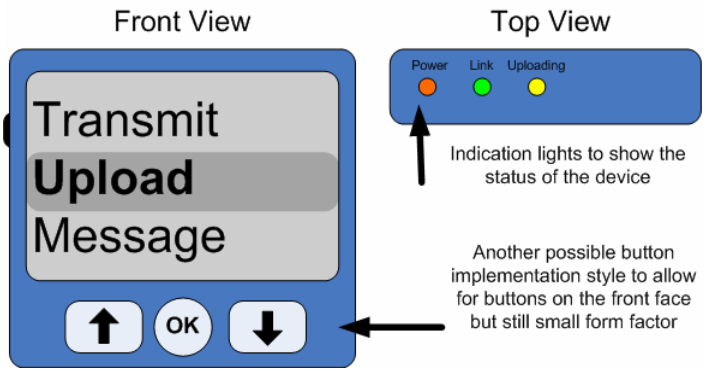


Figure 5-5: Concept rendition 3

There are many different possibilities for the button arrangement, which all three of the concept renditions illustrate. In Figure 5-5 the buttons remain on the front face of the unit; however, positioned along the length of the screen to reduce the vertical height of the device. In addition, indication LEDs are shown as a possibility for an addition to the product. These indication lights would allow the user to be sure of the devices status at any given time.

5.2 Choosing an LCD

The display specified in "Design of a Health Monitor System" by Broders *et al.* is the Sony ACX705AKM. Upon inspection of this system, we discovered problems that had arisen with the ribbon cable connector of this model of display. As a result, we decided to investigate this model as well as other display options in terms of the characteristics required by the customer. We considered both aesthetic components of the display and technical requirements of the driver circuit to choose an appropriate LCD.

Several determining factors were involved in the selection of an LCD for this project. Because diabetes patients will be the main users of this product the probability of the user having some sort of visual impairment is higher than in other products. To aid in clarity we assessed both the display area of the LCD and the image quality. The first major decision involved the colour capabilities of the device. The choice between a full colour display, black and white with integrated backlight, and a colour capable backlight for the display, though not a major factor, does affect the overall power consumption of the device. Through discussions with Dr. Southern, we decided that having a colour screen is not critical for the user's experience of the product. Dependence on colour schemes to help the user navigate the device could preclude some colour-blind patients from use of the device. These factors contributed to our decision to

put the most weight on the dot format for clarity. Table 5-1 shows the different display options for the LCDs under consideration.

	Display Area	Backlight	Dot Format	Colour
Sharp LM24022	60 mm x 42mm	LED	240x160	B/W
Sharp LM 32019T	115.2 mm x 86.4 mm	1CCFT(E)	320x240	Blue
Sony ACX705AKM	57.6mm x 38.4mm	None	242x162	512
Hantronix HDG320240	79.8mm x 60.6mm	None	320x240	Gray STN / Yellow STN / FSTN
Seiko G321EV	96mm x 72mm	Blue	320x240	B/W
Microtips MTF-T022BHNLN	33.9mm x 45.1mm	LED	240x320	262k
Optrex F-51373GNC- FW-AH	59mm x 80.3 mm	CCFL	240x320	TFT

Table 5-1: Display options for LCDs

The cable connector length and style was the next consideration taken into account. Table 5-2 shows the different dimensions of the connection cables as well as the number of pins associated with that particular module.

	Number of Pins	Number of Backlight Pins	Screen Width	Contact Location	Connection Cable Length
Sharp LM24022	18	2	13.6 mm		50mm
Sharp LM 32019T	12		16.25mm		39mm
Sony ACX705AKM	22		11.5mm	bottom	26.4 (curved)
Hantronix HDG320240	18		17mm	side	32mm
Seiko G321EV	14	3	32.5mm	Side	4.5mm
Microtips MTF-T022BHNLN	39		12mm		18.6mm
Optrex F-51373GNC- FW-AH	22	3	22mm		7.6 mm

Table 5-2: Comparison of LCD pin connections.

Though power consumption in the proof-of-concept product is not a large factor, the final product should use a low power screen. Because it will not cost extra development time to incorporate this feature, we will place emphasis on selecting a low power LCDs. Because the development of this system is ongoing with the OMAP5912 OSK, we had to keep in mind the available 3.3V supply. Choosing a display requiring a supply voltage above this level creates the need for extra control circuitry in the driver circuit. Table 5-3 demonstrates the different requirements of each LCD.

	Power Consumption	Power Supply	Minimum	Max	Average
Sharp LM24022	32mW		4V	7V	5.6V
Sharp LM 32019T	1482mW		10V	12.5V	
Sony ACX705AKM	47mW	3V	2.55V, 3.5V	3.15V, 4.2V	3V, 3.8V
Hantronix HDG320240	21mW	3V	2.75V	3.25V	3V
Seiko G321EV	45mW		4.75V	5.25V	5V
Microtips MTF-T022BHNLN	24mW		1.65V	3.3V	1.8V
Optrex F-51373GNC- FW-AH	100mW		2.7V	5.5V	

Table 5-3: Comparison of LCD power allotments.

Take special notice of the power consumption column. Some of the models clearly draw more power than would be acceptable. We eliminated all of the LCDs above 40mW, which leaves three viable models. Cost is another factor in this decision, yet because we will only purchase a single LCD for our proof-of-concept, cost is not a main consideration. The previous research

team chose an LCD that was $59; however, as illustrated in Table 5-4 prices for the modules vary as much as the modules themselves.

	Price
Sharp LM24022	39.00 USD
Sharp LM 32019T	79.00 USD
Sony ACX705AKM	59.00 USD
Hantronix HDG320240	46.14 USD
Seiko G321EV	98.35 USD
Microtips MTF-T022BHNLN	46.30 USD
Optrex F-51373GNC-FW-AH	99.15 USD

Table 5-4: Comparison of LCD prices.

It was difficult to find European suppliers for many of the LCD modules; therefore, we used Mouser, a large electronics distribution company in the USA, to validate price points.

After reviewing the possibilities, the Hantronix came out as the clear choice for the LCD in this application, as opposed to the. Figure 5-6 and Figure 5-7 contrast the Sony ACX705AKM-7 chosen by Broders *et al*. and the Hantronix HDG320240 we selected.

Figure 5-6: Front view of the Sony ACX075AKM-7.

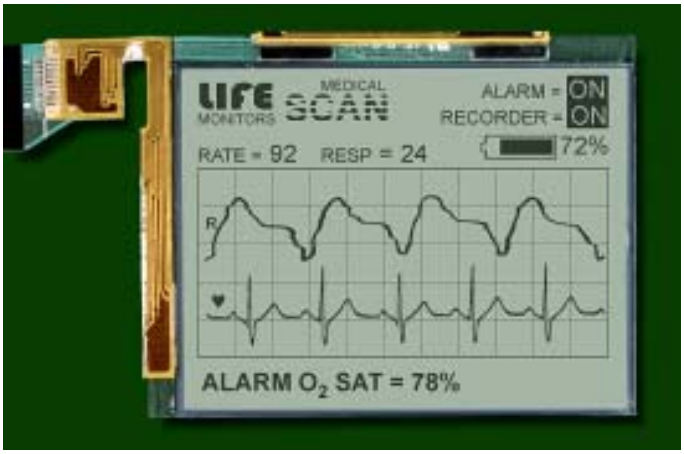


Figure 5-7: Front view of the Hantronix HG 3202040.

The Sony LCD is a colour display; however, the Hantronix provides better resolution and has a larger screen. The final determination is that users need sharper images, not necessarily images in colour. The Hantronix LCD has a large connection pitch that will make mounting the header much easier. The Sony LCD is a reflective colour active matrix display, and the Hantronix LCD is a transflective positive display, which creates a better overall display design with a wider viewing angle.

A major concern when choosing our LCD was the amount of voltage that was needed as the input. Upon first looking at the Hantronix HDG320240 datasheet, it showed an estimated 15V needed for input. Our development board can only supply a limited 4.2V or 3.3V input. We emailed several distributors and Hantronix, the manufacturer of the LCD. We received two

replies both informing us that this LCD indeed is functional at a minimum of 3V. An explanation to the discrepancy was suggested to be that the voltage included the backlight inverter, which requires more than 10V as input (Personal Communication, August 2006). Please refer to Appendix A3, for the emails received regarding the voltage needed.

5.3 Choosing a Development Board

Early on in the project, we were presented with the OMAP5912 OSK development board. Though Broders *et al.* used this board previously, we decided to re-examine the functionality of the board and assess its ability to meet the demands of the engineering project at hand. Since the end goal is to provide a device with a functional user interface, the prospect of using a fully programmable gate array (FPGA) or microcontroller (e.g. PIC) seems a difficult path to produce the intended graphical user interface and wireless communications system.

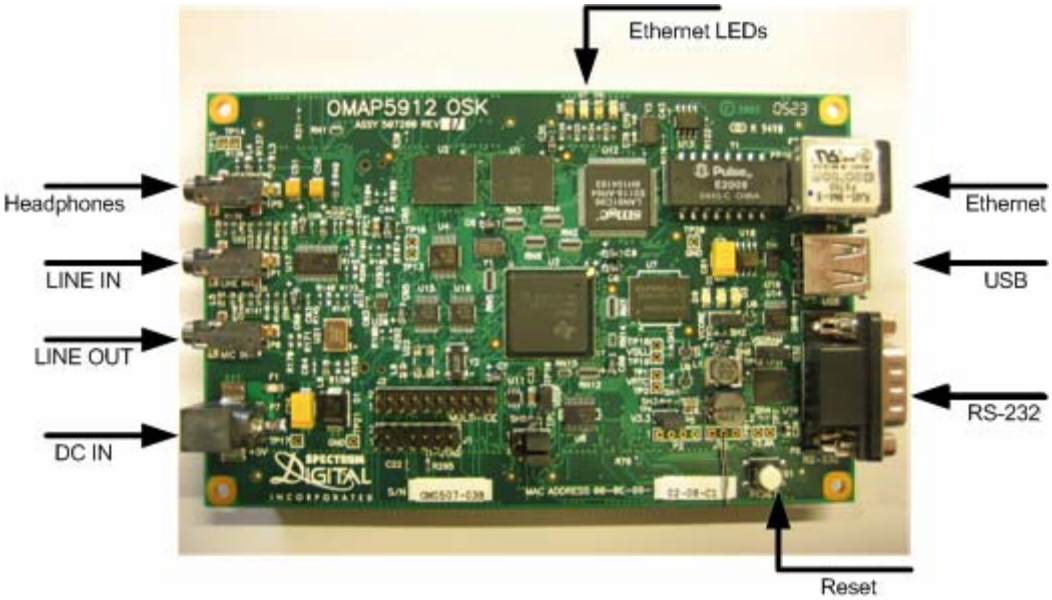


Figure 5-8: Top side of the OMAP5912 OSK with I/O ports labelled

The OMAP5912 processor, as part of Texas Instruments (TI)'s OMAP line, is marketed as a solution for portable medical devices that supports the execution of Java bytecode (an application programming option) natively and is capable of running various operating systems that would be more than capable of providing an environment able to display a graphical user interface. Finally, the processor features several standard modes of expansion--including CompactFlash, serial, USB, and standard HiRose connectors—all of which are easily removable from future iterations of the proof-of-concept device if deemed unnecessary. These factors, in combination with the realisation of our tight development timeline, allowed the project team to

confirm the OMAP5912 OSK development board as a suitable environment for the development of our interface to personal health monitors.

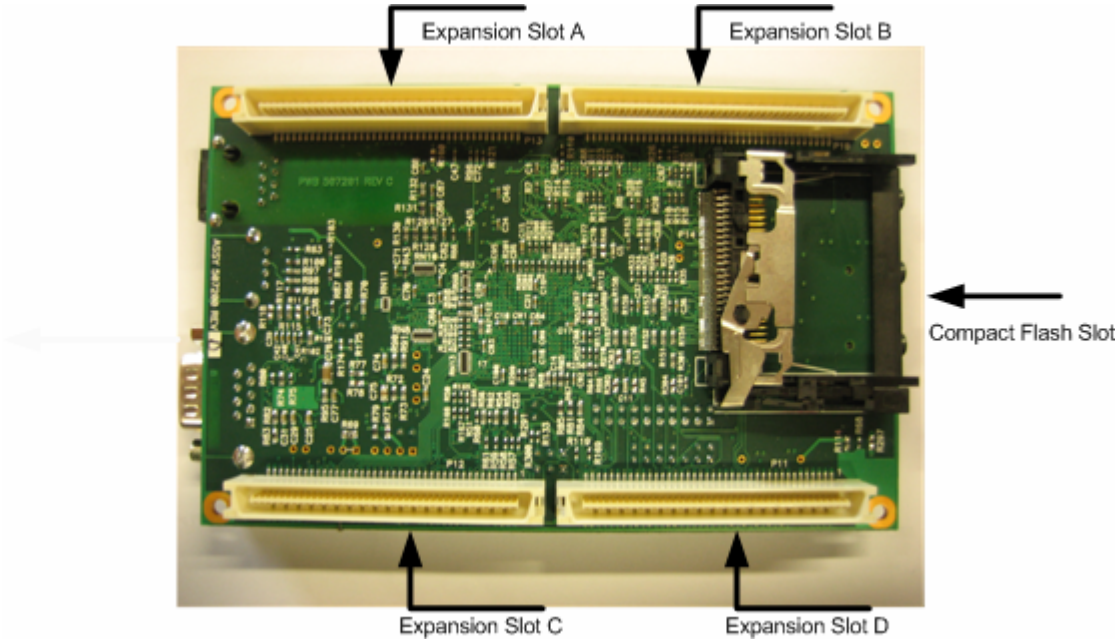


Figure 5-9: Backside of the OMAP5912 OSK with I/O ports labelled

Of particular importance on the backside of the OSK development board are the standard HiRose connectors and the Compact Flash card slot. Expansion Slot C will be our interface to the board's LCD controller and also serve to deliver signal from the buttons of our external user controls.

5.4 Software Engineering

The following sections serve to outline the design considerations and specifications followed to choose a board-specific operating system, an embedded graphics system to render our graphical user interface (GUI), and a suitable language for engineering our software.

5.4.1 Choosing an Operating System

Although the team is using the OMAP5912 OSK development board, which has considerably more on-board flash (32-Mbytes ROM) and memory (32-Mbytes DDR) than most embedded computers, we took the design perspective of a marketable product; namely, keeping the memory requirements of the device to a minimum in the interest of overall product development cost. With this in mind, we turn our attention to choosing an appropriate scalable proof-of-concept operating system.

An embedded operating system varies greatly from an operating system developed for use in a desktop or server environment. Issues not considered during normal operating system development become important to the embedded software engineer, particularly compactness of design. An embedded operating system's target is often a device with limited on-board flash and physical memory, further underscoring the need to streamline an operating system and keep its overall footprint small. Similarly, because many embedded devices operate independently of an always-on power source, efficiency of the operating system is directly proportional to battery life, the longer a microprocessor has to execute an instruction, the greater is the overall power consumption.

With that said, there are three types of embedded operating systems to choose from: real time operating systems (RTOSs), embedded Windows-based operating systems (e.g. Windows CE), and embedded Unix-based operating systems. A real time operating system is intended for devices that must operate in real or near-real time (also called "soft" real time). The effectiveness of a device needing such an operating system is gauged by how quickly a specific task can be completed. The control options on a digital thermostat, of everyday kitchen appliances, or even of mobile telephone are layered on an RTOS. Often the device is designed to act upon certain sensed data gathered from its surroundings before initiating a function. A thermostat, for example, will remain in a low power-consuming idle loop while awaiting its specific task of raising or lowering the temperature. For our personal health monitor interface, a real time operating system acting on well-defined triggers is unnecessary.

Opposing RTOSs are passive operating systems. A passive OS relies on user input for functions to occur, rather than environmental triggers. There are two forms of passive operating systems currently dominating the marketplace: embedded Windows-based and embedded Unix-based systems. Cost is a concern in our development project, not only for the development of the product, but also looking to projected costs to the end user. The licensing fees associated with Microsoft products, particularly for development with an embedded operating system (i.e. Windows CE, PocketPC OS, or Embedded Windows XP) would be large. In addition, choosing such an operating system would limit the portability of the proof-of-concept design to other processors and/or architectures.

Our options for implementation in an embedded design quickly narrowed to look upon Unix-based operating systems, from which there are literally hundreds to choose. To avoid the

licensing and vendor lock-in issues discussed previously in relation to embedded Windows-based operating systems, we have also decided to avoid Unix-based proprietary solutions. With good documentation and an active online support community available behind the GNU/Linux operating system, we decided that working with a custom-compiled GNU/Linux operating system would provide both the feature-set and small footprint for which we were looking.

5.4.1.1 Choosing a Build Environment

With the decision made to pursue an open source, custom-compiled version, of the GNU/Linux operating system, the question of choosing a software development tools becomes an issue. Development of an operating system and custom applications for an embedded environment takes place on a "development machine", usually an x86 or x86-64 based machine running a similar operating system to the device. We realized that our device would need to be a machine running a suitable Linux distribution. Further research revealed that the action of cross-compiling for an embedded device requires a cross-compile toolchain, patched to meet the requirements of the microprocessor. At the time of this writing, there are four options available for successfully building a cross-compile toolchain and development environment: using 'crosstool', using 'bitbake' with an up-to-date OpenEmbedded repository, using 'buildroot' and an updated uClib C Language repository, and finally by hand.

Getting a working cross-compile toolchain and build environment is a complicated process that can take a lot of time. Although there are relatively few applications required to get a toolchain built, not all revisions of each of the applications are interoperable or guaranteed to produce a working toolchain and/or filesystem upon setup completion. With this in mind, the path of creating a toolchain and build environment completely by hand, from source, was simply not an option for our team.

The 'crosstool' utility was the first polished application capable of constructing a cross-compile toolchain. Written by Dan Kegel in 2003, the application is capable of compiling the toolchain automatically if all the other necessary packages and dependencies are compiled and patched. The process of getting all necessary tools and ensuring they are patched correctly is a daunting task for any first-time embedded software developer that can consume lots of time. Although a more sophisticated method than the by-hand method, it still does not fit into the rapid development model. ("Building")

The 'buildroot' tool is very near to what the team requires to build a cross-compile toolchain and development environment rapidly. The application accounts for dependencies and patches that may be unknown to the user and is capable of retrieving said items to complete a build successfully. Unfortunately, the use of *makefiles* by 'buildroot' provides a level of flexibility—and complication—unnecessary for our planned device. ("Buildroot")

Where 'buildroot' does not work, an OpenEmbedded repository coupled with 'bitbake' works. The 'bitbake' application uses easily designed and parsed text files to build toolchains and applications for embedded environments. The OpenEmbedded development repository is also known for supporting many different processors and embedded architecture, providing an opportunity to move development to a different processor later with little difficulty. Finally, the active OpenEmbedded community provides a great deal of support—a feature that is very valuable when working on a rapid development project such as ours. Thus, the use of OpenEmbedded and 'bitbake' to get our GNU/Linux cross-compile toolchain and development environment up-and-running is best suited for our project team. ("OpenEmbedded")

5.4.2 Choosing an Embedded Windowing Environment

With a development board and target operating system chosen for the development of our interface to a personal health monitor, our attention turned to focus on the needs of our graphical user interface (GUI). Keeping in line with the parameters used to choose an operating system (i.e. open source, freely available) and acknowledging the need to stick to well-documented, popular solutions to adhere to our limited engineering development time, our research produced four different embedded windowing environments from which to choose: Qt/Embedded, Fast Light Toolkit (FLTK), and GTK+. In actuality, these graphical widgets will run on a windowing environment or write directly to a device's framebuffer.

Trolltech develops Qt/Embedded and its sister, Qt, which is an accepted graphical widget at the heart of the KDE desktop environment for GNU/Linux. Qt/Embedded produces output displayable on a standard windowing environment (i.e. X-Windows, Microwindows) or directly on a device's framebuffer, the latter being preferred for application development in an embedded environment. The graphical widget is not without its drawbacks, though. Trolltech has gone to great lengths to develop Qt and Qt/Embedded and, although the software is released freely, its source code remains closed to public viewing—leaving future modifications up to Trolltech. In addition to limiting the support options available to the project team during development, this

could pose a problem for future development of our proof-of-concept product—particularly streamlining efforts related to the graphical user interface. ("Qt/Embedded")

Through research, we learned the Fast Light Toolkit (FLTK, pronounced "fulltick") is designed to support three-dimensional graphics via OpenGL. Since our device is being designed with only two-dimensional graphic support in mind, increasing our overall system footprint size for support of graphical enhancements never to be used we consider to be poor engineering design; therefore, we decided against using FLTK for our GUI. ("Fast Light Toolkit")

GTK+ is a graphical toolkit released under the auspices of the GNU Project. We learned that GTK+ is suited for rapid application development as it does not restrict developers to C/C++, but allows the use of languages more suited to rapid development (e.g. Perl, Python, etc). An engineering research project by Blue Mug, Inc revealed that GTK+ development with X-Windows could produce for an embedded device. The flexibility and promise for future streamlining of X-Windows and the GTK+ environment, coupled with the support of the open source community responsible for the widget's deployment will provide the basis for our device's graphical user interface. ("GTK+)

5.4.3 Choosing an Application Design Language

With an operating system and a suitable embedded windowing toolkit selected for use on our OMAP5912 OSK development board, it became necessary to explore the possibilities for rapid application development. The team, having a background in the C and Java languages, was familiar with the complexities associated with each language. Although being an industry favourite, rapid application development in C can be slow going. In addition, error generation in C is vague and prone to memory allocation issues; thus, we ruled out the use of C for our main application design language.

Although memory management is controlled in Java, the software development kit and runtime environment is quite large and would influence our overall software footprint greatly. The ability of the OMAP5912 OSK to execute Java bytecode natively does initially seem helpful, but the potential for design problems in the still developing embedded Java toolkit and untested interaction with our chosen windowing environment provides us with enough reason to avoid using the programming language.

Further research revealed rising interest in moving the Python language to the embedded computing market. ("Extending and Embedding") Touted as being an adaptable language to

programmers familiar with C and Java, Python was a language the team was capable of learning and implementing in the short time available. In addition, the likelihood of future developers having C or Java experience is high, and would provide an easy entry point for future development. Moreover, successful research stories of embedded computing with Python—such as the experience of Carmannah Technologies Corp—and the ease with which external monitoring applications and graphics can be created, the language appears to be a well-suited match for our device. The team acknowledged the initial footprint of the Python development library may be on the large side, but with embedded adaptations of the language being developed, it did not seem unreasonable that future engineering work could be dedicated to reducing the footprint of the language's use with little-to-no difficulty.

5.5 Wireless Module

Though the wireless transceiver system is a portion of the system that the user will not see or interact with directly, this system will have a big impact the user's experience of the product. Connecting to wireless network to transfer glucometer data is one of the major goals of this project, and might seem daunting to a non-technical person, so the system chosen must be easy to use to eliminate barriers that could arise from this technically complicated portion of the system. Currently wireless networks are expanding, becoming more common and available to the general population. Along with this increase in wireless availability has been an increase in the types of wireless networks.

The technical design elements of a wireless system include hardware style, type of interface, necessary range, transmission method, amount of data transmitted, and level of encryption. There is no discussion of cell phone or two-way pager wireless technology, which we eliminated at an earlier stage of design. Dependence on a service that would require a monthly service charge is not a desirable feature of this system. The transfer of information through wireless technology allows product users mobility and freedom from entangling cords. Giving health-monitoring devices the capability to communicate with a database though wireless means is the ultimate goal of this project. This is why the technical aspects of several different types of wireless protocol were investigated, to select the technology best suited for this application.

5.5.1 Choosing a Wireless Network Type

The Institute of Electrical and Electronics Engineers (IEEE) has set forth standards for wireless protocol. Currently the three main IEEE standards of wireless communication are 802.11 commonly called WiFi, 802.15 commonly called Bluetooth, and 802.16 commonly called WiMAX. The numbers are the IEEE specification number, which set the requirements of the device for certification under that code.

As discussed in previous sections, the goal is to produce a wireless attachment for a health monitor system that requires the user to obtain very little to no extra equipment in order to use the device. This specific demand for the product made the choice of the type of wireless quite simple. Bluetooth technology is a fast growing, low power, short distance, personal area network technology. Bluetooth allows users to connect several Bluetooth capable products together almost automatically. Because the transmissions range is just a 30ft radius, it is possible to run the technology on very low power. Conversely, the developing technology called WiMax, is a new long distance wireless for use in supplanting cable internet. With a 30mi radius, WiMax can offer entire metropolitan areas with wireless network coverage. However, WiMax is not common currently and development continues in order to provide the highest efficiency possible. In 1997, IEEE released the first version of the 802.11 specification for wireless local area networks (WLAN). This standard allowed information transfer rates of 1 and 2 Mbps in the 2.4GHz unlicensed frequency bandwidth. Since that time, the IEEE 802.11 work group has come out with many different 802.11 variations and advances. Offering a transmission radius of 300ft, and a quickly developing, widespread support base, WiFi fit our criterion for the integration of wireless technology into a personal health monitor.

Another reason we selected WiFi for this application is that free access points are becoming more and more prevalent in airports, coffee shops, libraries, and hotels. Some of these access points are provided as a free service, locations around the world can be can be searched at anchorfree.com.

Figure 5-10: Example layout of a wireless system

Though Figure 5-10 shows the transmission to a WiFi tower, this most likely will not be the case. As explained previously many free access points are available to the public in metropolitan areas and this is spreading out around the world. It is possible to enable a personal WiFi network inside a home, but if the customer does not have the means to do this, it is possible to find free access points.

5.5.2 Selection of an 802.11 Specification

Within 802.11, there are several different grades of transmission. The most widely used are 802.11a, 802.11b, and 802.11g. The first standard available to the market place was 802.11b, which is the slowest and least expensive. As the new standards are released with faster transmission rates, 802.11b is becoming less common. However, 802.11g is compatible with 802.11b because they use the same 2.4GHz band for transmission. Where 802.11b can transmit at 11Mbps, 802.11g can transmit at 54Mbps. Mainly used for industrial needs, 802.11a uses the 5GHz bandwidth and is able to transmit at 54Mbps. For our application, the 802.11b/g specification works because the amount of transmitted data will be relatively small and will be compatible with the largest number of networks already in existence.

5.5.3 Wireless Security and Encryption

Another element to the 802.11 specification is the level of encryption available. Currently there are two main types of encryption available. The older of the two encryption methods, Wired Equivalent Privacy (WEP), is the standard encryption method for all technology with 802.11 specifications. WEP is meant to be just as secure as any LAN; however, by definition no wireless network can be as secure as a wired network because of the physical constraints. Radio waves can be picked out of the air without much trouble, whereas a wired

network must be plugged into to interception to be possible. Unfortunately, WEP does not offer end-to-end security despite the use of encryption to protect data. The newer WiFi Protected Access (WPA) was designed to improve upon WEP security with improved data encryption though Temporal Key Internet Protocol (TKIP). WPA can work with products that are already WEP enabled through a software update. Technical experts have expressed views consistent with the Health Insurance Portability and Accountability Act (HIPAA), which set forth guidelines on the transmission of health information over wireless networks. A HIPPA advisory from Phoenix Health Systems states that WEP security is easily cracked and for health information use, the more secure WPA method of encryption is secure enough to gain HIPPA certification.

5.5.4 Selecting of Interface Method with the OMAP5912 OSK

With the many different connection types available on the OMAP5912 OSK there were a wide variety of interface options available. Because the end goal of this project is to provide a proof-of-concept device, and not a finished product, size is not a major concern and neither are aesthetics. In the interest of time, we decided not to design and build a complicated wireless transmission circuit. Instead, the wireless module will be a fully integrated system, which is transmission ready upon receipt and capable of interfacing with one of the many expansion slots available on the OMAP development board. Ports available for this type of module included, USB, Serial 232, Compact Flash (CF), and Ethernet 10 base-T.

The wireless transmitting module, referred to in "Design of a Health Monitoring Device" by Broders *et al.*, uses the USB port of the development board. When the developers tried to use the USB port, they discovered a problem with the amount of power being drawn from the board when this solution was implemented. The demand of power by the wireless module caused the entire board to crash after only a few seconds. The report does not mention why the USB port did not support WLAN USB key. Learning about the power constraints, the team explored alternate options. The next most viable option, which would allow for simply plugging in a module, was to use the CF slot as a wireless port. Personal Digital Assistants (PDAs) make use of CF cards. The small form factor of CF cards also made this choice practical. However, one problem with using this technology is that it is proprietary, meaning that if used in the final product we could not alter the technology in any way and it would be more expensive than using a non-proprietary system.

A Linux resource site (http://tree.celinuxforum.org/CelfPubWiki/OSK) for the OMAP5912 OSK explains why the USB port did not work for WLAN. The USB host port on the OMAP5912 development board is only for peripherals with non-standard cabling. The same resource site states that the CF socket on the development board would have the same type of problem as the USB port, and is designed to only support memory storage cards, not WLAN cards. Since most glucometers interface through either the USB or Serial 232 port, the Ethernet port is the most viable to leave those port free for data input.

5.5.5 Selecting a Wireless Module

Thus far, we have discussed the major elements involved in selecting the type of wireless module suitable for our project. With the Ethernet and Serial 232 ports as the only viable interface options, we did not limit our search to just one or the other. The security and encryption feature of the device being either WEP or WPA enabled is an important feature for the final product, but not a large limiting factor for our application. We left this feature optional because the higher encryption level can be introduced later. The wireless modules in Table 5-5 were researched and selected on the misconception that they were fully integrated systems. This table is presented as future reference for the design of a final product. These small transceivers enable embedded systems with wireless capability; however, much design work is required to support these modules. We would be forced to design a complicated printed circuit board (PCB) to connect these devices with their interface type.

	Interface	WiFi	Supply	Current	Security	Data speed	Antenna	Control	Price Point	Special
Ezurio - WISMC02BI-01	UART full RS232	802.11 b/g	3.3 - 5vdc +/- 5%	~250mA Tx Rx avg.	WEP	2 Mbps	Internal	Remote	€155	Easily switched to Bluetooth
Airborne WLNG-AN-DP101	UART full RS232	802.11 b	3.3vdc	420mA Tx 350mA Rx 75mA sleep	WEP WPA	11, 5.5, 2, 1 Mbps	1 Coaxial	HTML	€112	Low power mode Very small
Airborne WLNBETDP101	10 Base-T	802.11 b/g	3.3vdc	575mA Tx 375mA Rx	WEP WPA	10Mbps max	2 Coaxial	HTML	€112	Very small

Table 5-5: Wireless Chip Options for Embedded Design

If we had chosen to create our own embedded design the Airborne 10 Base-T wireless Ethernet bridge chip would have been selected. The small size makes it an excellent choice for integration into a future product making the form factor as small as possible while still holding all the functionality.

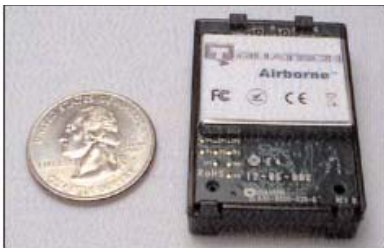


Figure 5-11: Airborne WLNG-ET-DP101

Table 5-6 shows the next evolution of options, which are fully integrated wireless chips with all the support necessary to plug them in upon arrival. These systems are much larger than the devices from Table 5-5, with have external power supplies to support the wireless capability.

	Interface	WiFi	Supply	Current	Security	Data speed	Antenna	Control	Price Point	Special
Acksys WLg-LINK-OEM-RJ	10/100 Base-T	802.11 a/b/g/h	3.3vdc	3.5W max with power saving mode	WEP WPA	11, 5.5, 2, 1 Mbps	2 HiRose UFL	Win Linux Unix	€252	Wireless repeater
Acksys WLgBRIDGE-OEM-RJ	10 Base-T	802.11 b/g	3.3vdc	3W max power	WEP	11, 5.5, 2, 1 Mbps	Internal 1 HiRose UFL	Win Linux Unix	€252	Extreme distance capability
Airborne ABDB-ET-DP101	10 Base-T	802.11 b	5vdc	2W max Power	WEP WPA w/LEAP	11, 5.5, 2, 1 Mbps	Attached 3dB	Web based	€212	Integrates chip choice

Table 5-6: Integrated Wireless Systems

All of these modules interface with other devices directly through an Ethernet port without any additional circuit design. Figure 5-12 depicts the three options presented in Table 5-6. Both of the Acksys products are open board; however, the Airborne model is in a closed case.

Acksys - WL-BRIDGE-OEM Acksys - WLg-LINK-OEM Airborne - ABDB-ET-DP101

Figure 5-12: Integrated wireless module options

Using Table 5-6 the following elimination process took place. We eliminated the Acksys WL-Bridge-OEM due to the lack of WPA encryption, of which the other devices are capable. Power consumption, though a major factor in a final product, did not affect our decision here because all three systems are powered by external sources. Originally, we hoped to keep the cost of the wireless system below €100; however, due to our short amount of development time available, the more expensive, fully integrated system was deemed the correct choice. The extra

features offered by the Acksys WLg-LINK-OEM-RJ are unnecessary for our application and driver the price of the unit above the Airborne product. The Airborne product is the least expensive of these choices while including WPA encryption security and integrates the chip chosen previously for an embedded solution. This device, is capable of interfacing with the Ethernet port of the OMAP OSK board, was a cost effective choice, and greatly reduced our development time.

6 System Specifications

In this chapter, we will present each of the four hardware subsystems of our proof-of-concept device and explain their importance as individual modules as well as their purpose in the device. We will discuss our device at the top level and then go more in depth with each of the subsystems, including descriptions of their circuitry and connectivity. Next, we give a technical background on the software element, including the operating system, the communication protocol, and the graphical user interface (GUI).

6.1 System Overview

The proof-of-concept product has four main subsystems: the user input circuit, the LCD driver circuit, the wireless module, and the OMAP5912 OSK development board. Each subsystem is integral to the functionality of the product. The main purpose of the overall system is to transmit patient data from a glucometer to a secure remote database. The data enters through the device and then wirelessly transmitted to a remote secure database. Figure 6-1 shows the anticipated flow of the data through the product. The flow and collection of data begins with the glucometer and ends when the transmission of the data occurs to the secure database via a wireless connection.

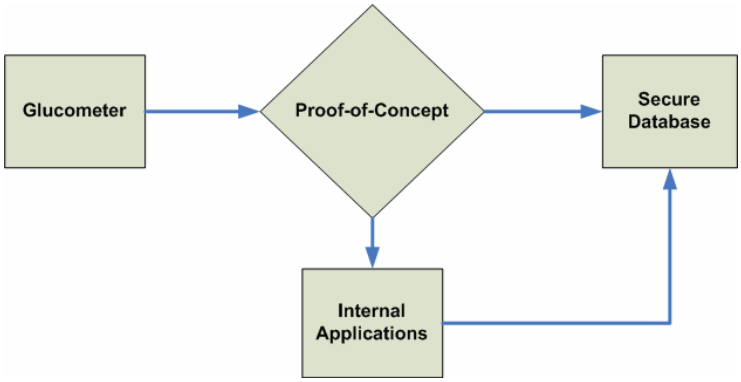


Figure 6-1: Data Transmission Flow Chart.

As seen in Figure 6-1, the data from the glucometer is passed to the proof-of-concept product that has the ability to store a limited amount of information if transmission is unavailable, or transmit the data immediately to a secure remote database. Figure 6-2 shows the top-level block diagram of the entire proof-of-concept product. This includes the integration with the glucometer as well as with the secure database.

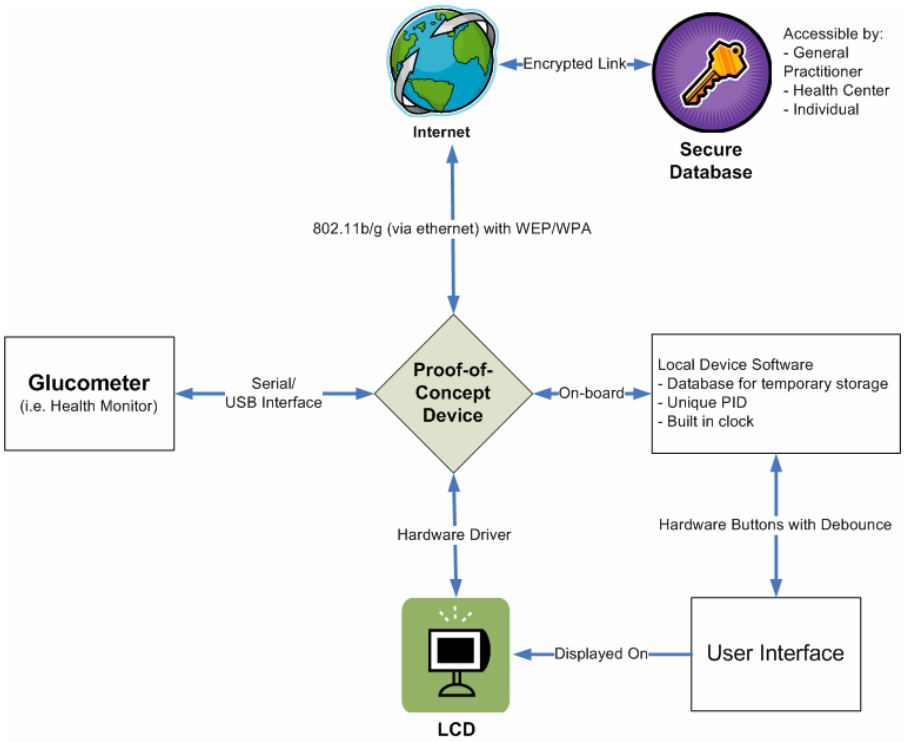


Figure 6-2: Complete System Block Diagram

The local device software drives the LCD, temporary stores uploaded data, reads user input, and couples transmitted data with a unique personal identification for each patient. Figure 6-3 shows the different modules and their methods of communication with each other. This figure also illustrates the actual components used in the design of the product.

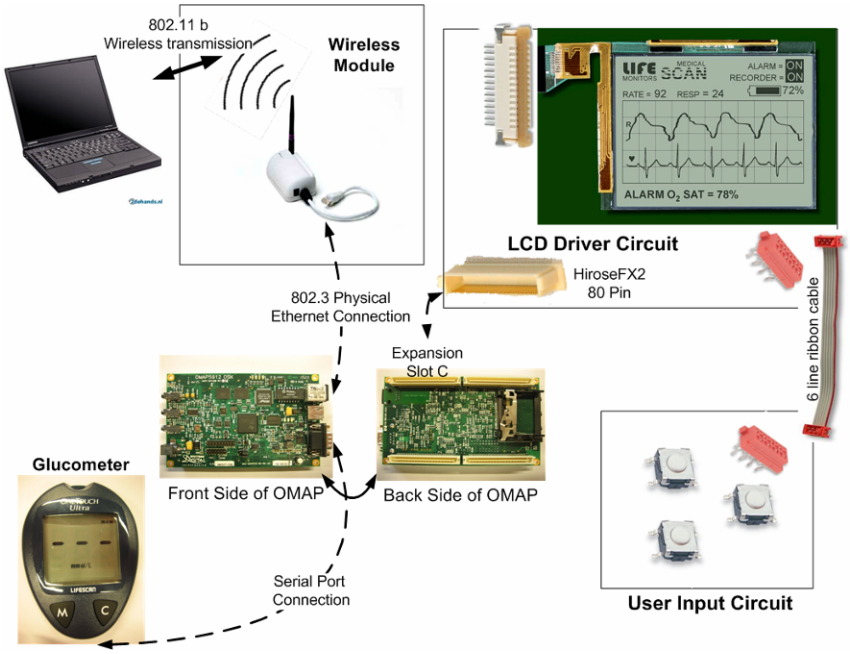


Figure 6-3: Module Integration Diagram

The user input circuit consists of three push buttons that serve for navigation through the applications. The user input connects to the driver circuit though a six-line ribbon cable that transfers power, ground, and GPIO line information. The LCD driver circuit consists of the LCD module - a Hantronix HG 3202040 – a voltage regulator, and a voltage bias configuration. This driver circuit connects not only to the user input circuit, but also with the OMAP5912 OSK development board via an 80-pin HiRose connecter, which connects to the expansion slot on the development board.

The OMAP5912 OSK development board is the centre module of the proof-of-concept device. The board's serial connector serves as the connection between the board and the glucometers. From there the custom applications begin to run and display on the aforementioned LCD module. The board's physical 802.3 Ethernet port will serve as the connection to the Airborne ABDB-ET-DP101, which is our wireless module. This wireless module will serve as a temporary non-proprietary solution for wireless connectivity. For complete part and connection details, please refer to Appendix A2.

6.2 User Input

In section 5.1 an abstract concept of the requirements for the user input was defined using the needs of the customer to design how the system should eventually manifest itself. Here that abstract concept is used to technically define what types of buttons are possible. Choosing and developing a three-button user input system allows the final product to be user friendly and intuitional. The following will describe the different type of buttons available and which are suitable for our type of application. Also included is some technical information about electrical bounce and creating a clear logic signal that the microprocessor can interpret as a change in status.

6.2.1 Input Characteristics

To select buttons with the correct working action and capabilities we looked into some switch terminology. For switches, a *pole* describes a set of contacts connected to a circuit and a *throw* describes the number of positions it .can be in to connect the circuit. The actuator is the mechanism though which the mechanical linkage is changed. Common types of actuators are toggle, rocker, and pushbutton. Another option for switches is whether they hold the placed

position once the user releases them (maintained contact) or return to the state before activation (momentary contact).

The buttons for application in this project enable the user to select between a few items on an ordered list. For this, only three keys are necessary. Two of the keys will move the selected area up or down and the third key will serve as the selection key. This type of application for a switch requires only a change in state signal. The microprocessor receives the logic for the change in state between *disconnected* and *connected* and then interprets the signal and creates a change on the visual display. We chose the momentary contact single pole single throw push button switch because there are only two states for the switch to be in and because the microprocessor is looking for the change in state alone.

6.2.2 Pushbutton Circuitry

With the action type selected, we next investigated how to ensure the logic signal sent to the microprocessor would be read clearly. In simple types of switching circuits, like this one, the switch connects the logic source either to power or to ground. To create these signals use either a pull up resistor configuration or a pull down resistor configuration.

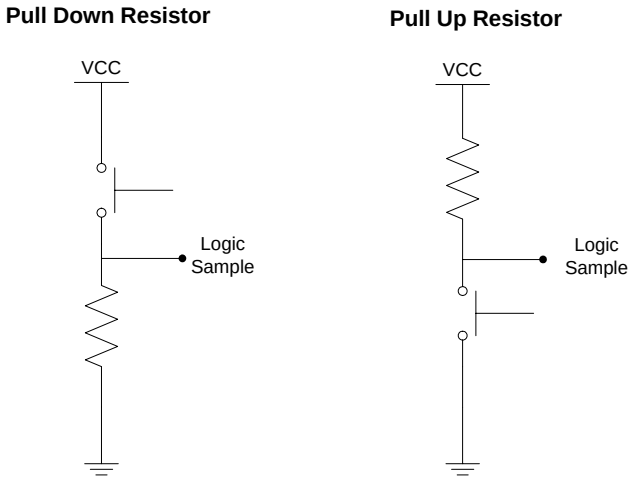


Figure 6-4: Pull down/up resistor configuration

Despite the name of the configuration, the pull down resistor provides a positive signal to the microprocessor and the pull up resistor provides a ground or null signal to the processor. In either case, the information of the constant state is programmed to the processor, and then is told to look for a change in state. Mechanical switches, however, do not make the change between states cleanly. On the other hand, they tend to make and break contact several times before

settling into the final position. The bounce time is the amount of time that the signal takes to level out after the actuator has been depressed or released.

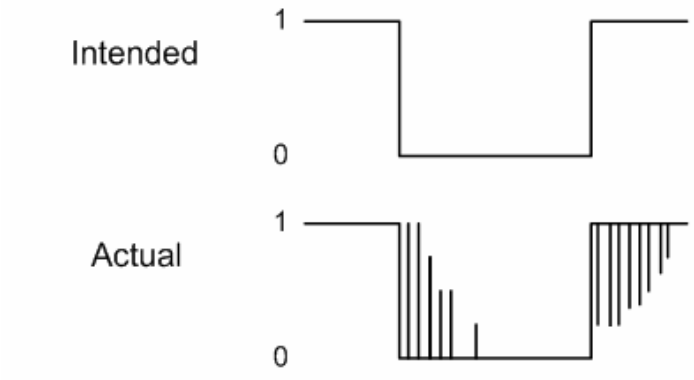


Figure 6-5: Bounce time for mechanical switches

As can be seen from Figure 6-5, the intended output is very different from the actual input that the processor receives. The bounces illustrated by Figure 6-5 could cause the processor to read switch activation multiple times when the user only touched the button a single time, and the same would be true upon release. By integrating either a mechanical circuit or a software solution for the bounces, this problem can be eliminated. One can fix this problem mechanically with a capacitor across the switch; however, this can create high current levels through the switch and leakage. By solving the problem using software, there is no electrical waste and the hardware remains as simple as possible. The simplest implementation of a software de-bouncer is to have the microprocessor count a certain amount of time before recognizing another signal.

Figure 6-6 shows the layout of the user input circuit. The OMAP development board is the source of the 3.3V input needed by the user input circuit. Choosing the pull down resistor configuration allows for the sending of a positive logic signal when the activating the button. The 10k ohm resistors are used in this circuit as suggested by Broders *et al.*

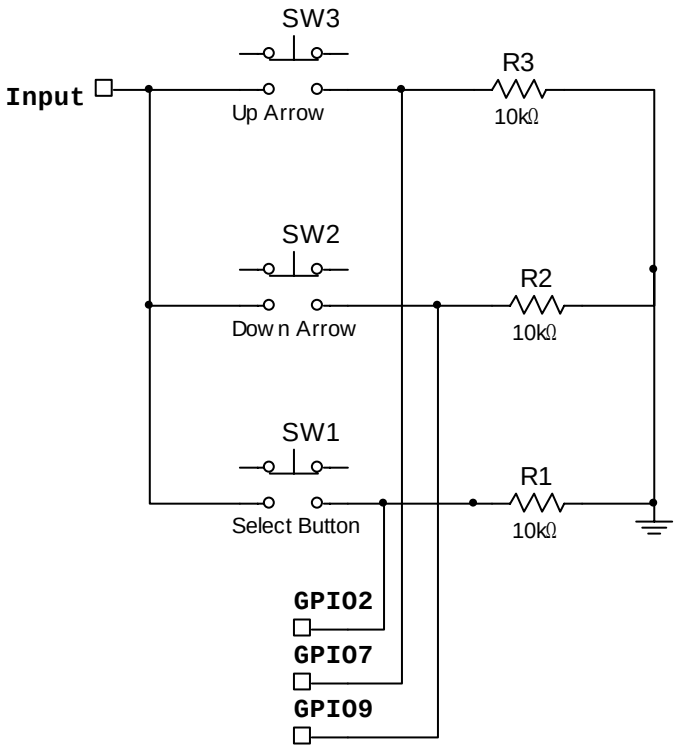


Figure 6-6: User input schematic

Depicted in Figure 6-6 is the schematic used for the user input. In the state shown by the schematic the GPIO lines will be reading a low voltage because they are simply connected to ground. However, when a switch is activated the GPIO line will register a high voltage because of the resistors, which are pulling the voltage from high on the left side to low on the right side.

6.3 Liquid Crystal Display (LCD)

This section details the portion of the product that deals with the visual interaction of the user with the product. The LCD displays the information and menu allowing the user to see their selection prior to choosing it. This section provides technical background as well as the application and design details of our LCD circuit integration.

6.3.1 Technical Background

A liquid crystal display (LCD) is a thin, flat display device made up of any number of colour or monochrome pixels (*Liquid Crystal Display* 2006). An LCD is made of two sheets of a flexible polarizing material with a layer of liquid crystal solution between the two. LCDs can differ in a variety of different ways, from their viewing modes to the type of display, and the type of technology that is used. There are three main types of viewing modes for LCDs: transmissive, reflective, and transflective. There are two types of images created by an LCD: positive mode,

or negative mode. A positive imagine displays the image darker than the background. Figure 6-7 shows a sample positive image on an LCD.

Figure 6-7: Sample of positive LCD display

This mode of operation is favoured in an application where ambient light is high and it will help with the contrast of the display, especially for a display using a reflective rear polarizer. Below are several typical Operational Mode & Viewing Mode combinations and the resulting images (assuming no backlighting which can colour the background):

- TN: Black characters on a Gray background
- STN-Green: Dark Violet / Black characters on a Green background
- STN-Silver: Dark Blue / Black characters on a Silver background
- FSTN: Black characters on a White / Gray background

(*LCD Display Modes* 2006)

A negative image displays the image area smaller than the background. When there is a backlight present and the lighting is medium to dim, you would use this mode. Figure 6-8 shows a sample negative image on an LCD.

Figure 6-8: Sample negative LCD display image

Below are several typical Operational Mode & Viewing Mode combinations and the resulting images (assuming a backlight with the specified coloration listed):

- TN: Glowing Green-Yellow characters on a light Gray background (Green-Yellow Backlight)
- STN ("Blue-Negative"): Glowing Green-Yellow characters on an light Blue background (Green-Yellow Backlight)
- FSTN: Glowing White characters on a Black background (White Backlight)

(*LCD Display Modes* 2006)

Different combinations of the LCD elements affect the type of display that is show. Table 6-1 shows the different type of LCD viewing, and their interactions with different types.

Viewing Mode	Display Description	Application Comments	Quality of Viewing with Direct Sunlight	Quality of Viewing with Office Light	Quality of Viewing with Subdued Light	Quality of Viewing with Very Low Light
Reflective Positive Image	Dark segments on light background	Not backlit. Provides best head-on contrast and environmental stability	Excellent	Very Good	Average	Poor
Transflective Positive Image	Dark segments on grey background	Can be viewed by reflected ambient light or with backlighting	Excellent No backlight	Good No backlight	Good Backlit	Very good
Transflective Negative Image	Light grey segments on dark background	Needs high ambient light or backlighting. Frequently used with colour and multicolour transflector	Good No backlight	Fair No backlight	Good Backlit	Very good
Transmissive Negative Image	Backlit segments on dark background	Cannot be read by reflection	Poor Backlit	Good Backlit	Very Good No backlight	Excellent
Transmissive Positive Image	Dark segments on backlit background	Designed for very low light conditions, yet able to be read in bright ambient lights	Good No backlight	Good Backlit	Very Good Backlit	Excellent

Table 6-1: LCD Viewing Modes
(Pacific Display Devices. 2006)

A backlight illuminates the back of a transmissive LCD. Applications requiring high luminance levels, such as computer displays, televisions, personal digital assistants, and mobile phones, use this type of LCD. The device used to illuminate the LCD usually consumes much more power than the LCD itself. The absence of a lamp significantly reduces power consumption, allowing for longer battery life in battery-powered devices; small reflective LCDs consume so little power that they can rely on a photovoltaic cell, as often found in pocket calculators.

External light reflected by a diffusing reflector behind the display illuminates reflective LCDs. This type of LCD can produce darker 'blacks' than the transmissive type. The reason for this is that light must pass through the liquid crystal layer twice. Contrast is poorer in reflective LCDs since the attenuation of the light is double.

Transflective LCDs are a compromise between both transmissive and reflective LCDs. A transflective display will look better than a transmissive display during the day, and will look better than a reflective display at night. A passive matrix display or a dual scan display consists of a row of transistors that are running across both the top and sides of the screen. With passive matrix, you are unable to see the screen unless you are directly in front of it. Generally, the display is going to be dimmer than a passive matrix.

Active matrix has transistors for each pixel, generating their own light, creating a brighter and crisp display. Because of this method used for display, multiple viewers can also view the screen. While the active matrix does have a crisp display because each pixel has its own transistor, power will drain more quickly than a dual scan.

6.3.2 Integration

Satisfying all of the constraints needed by the LCD was the next step in integrating the display into the system. Our LCD, the Hantronix HDG320240, has 18 pins, each pertaining to a particular need or constraint for the display. Table 6-2 displays the pin assignments for the LCD, which are from the Hantronix HDG320240 specification sheet.

PIN NO.	SYMBOL	FUNCTION	
1	V_L	-	Operating voltage for LC
2	V6	-	Bias voltage
3	V3	-	
4	V4	-	
5	V5	-	
6	V_{SS}	-	Ground
7	V_{SS}	-	Ground
8	V_{DD}	-	Logic Power Supply
9	FLM	H/L	Frame Pulse
10	CL2	H/HÆL	Data Shift
11	M	H/L	Liquid Crystal AC drive signal
12	CL1	H/HÆL	Data latch signal
13	INHX	H/L	1=Display ON, 0=Display OFF
14	V_{SS}	-	Ground
15	DB3	H/L	Data bus
16	DB2	H/L	
17	DB1	H/L	
18	DB0	H/L	

Table 6-2: Pin Designation for LCD

Pins 1-8 and 14 are voltage inputs. The voltages at pins 1-5 has to increment; according to the data sheet for the LCD, the voltages follow this comparison V1>V6>V3>V4>V5>V2. The design of a power circuit occurred to create this output of voltages. The specification sheet provided a sample power circuit that would satisfy the voltage conditions of the LCD. Figure 6-9 illustrates this circuit.

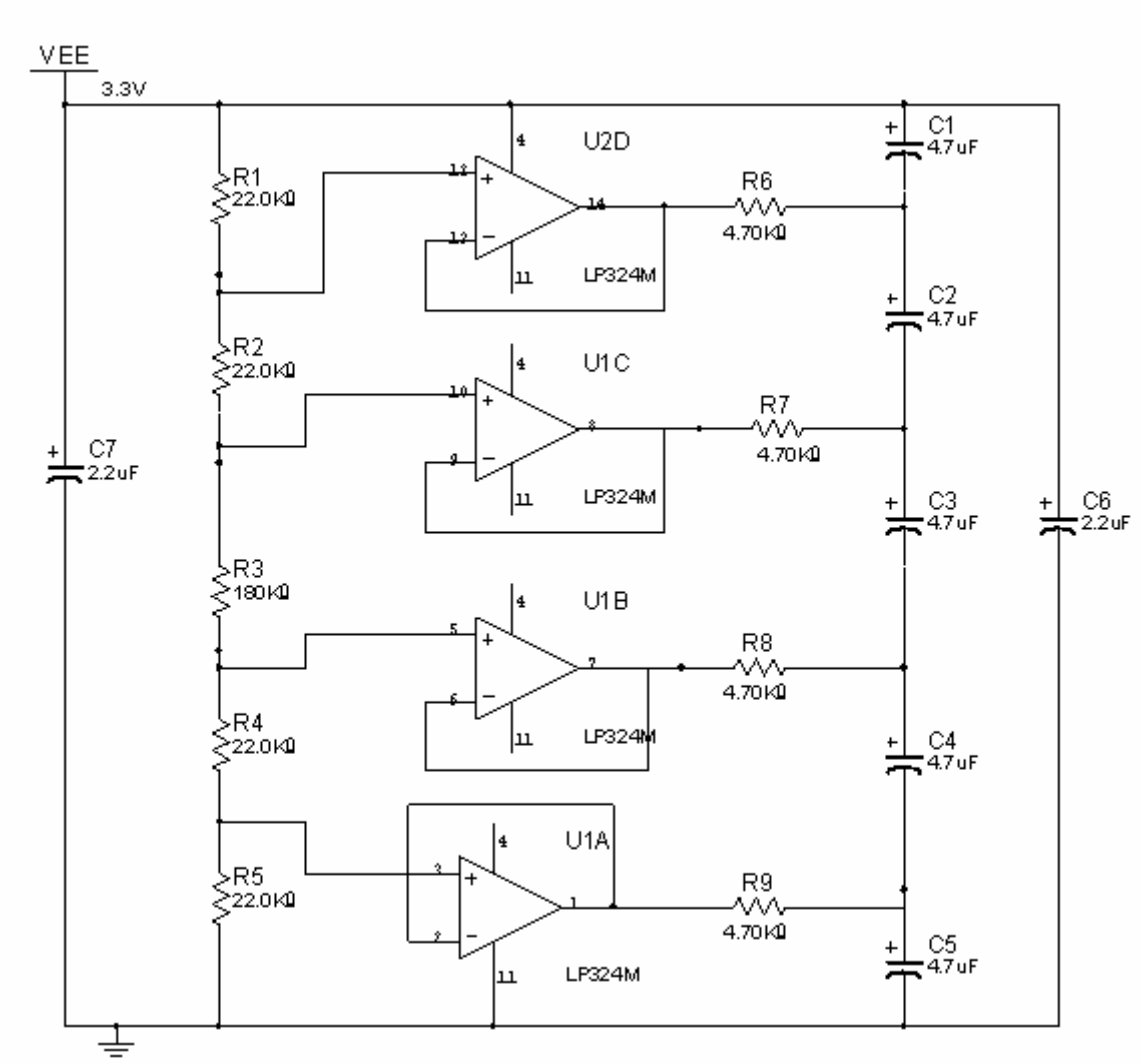


Figure 6-9: Power Circuit Schematic.

The LCD datasheet provided us with the values for the resistors, and a range of values for the capacitors. Having a basis for the values, we preformed simulations and testing in order to determine which capacitor values would be the most efficient for our circuit. The four operational amplifiers shown in the schematic are condensed into an integrated circuit, the National Semiconductor IC LP324M. Figure 6-10 illustrates the pin designations for the LP324M.

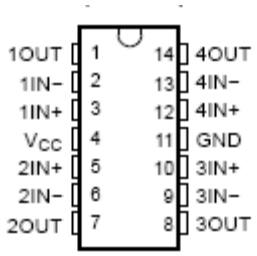


Figure 6-10: Pin Designation for LP324M.

This is an ultra low power quad operational amplifier. The negative input pin of each operational amplifier connects to the output pins. This creates a buffer amplifier, which helps interface the impedances. Although the majority of the pins had their power input, Pin 8 requires 3V for the logic supply. However, the voltages available to us are 3.3V and 4.19V from the board. To compensate for this, we created a voltage reference circuit. We needed an integrated circuit that would take an input voltage of 3.3V and output 3V of power. National Semiconductor's LP2966 does just that. The specification sheet for the LP2966 gave a suggested way to setup the chip. Figure 6-11 shows the sample schematic taken from the National Semiconductor specification sheet.

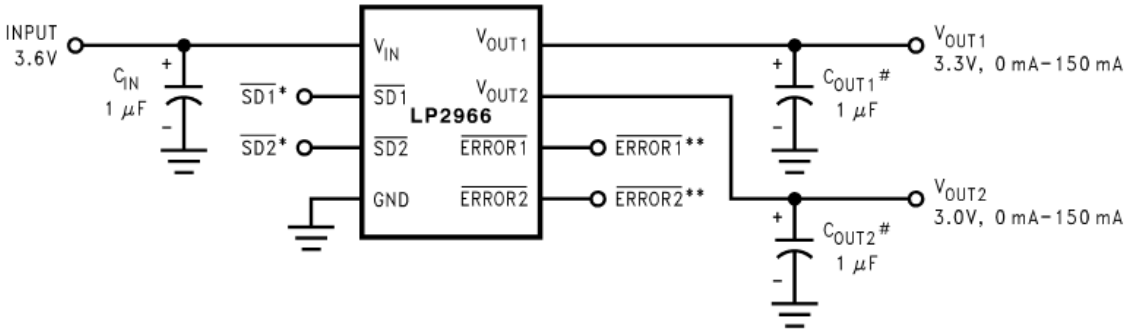


Figure 6-11: Suggested Voltage Reference Circuit

In our particular case, we do not need some of the extra features that this reference has to offer. Figure 6-12 shows our particular implementation.

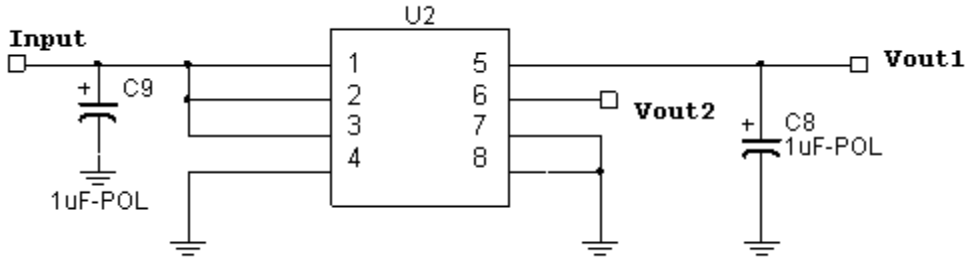


Figure 6-12: Voltage Reference Circuit

The particular chip that we chose has two output voltages, and both of them are 3V, unlike what Figure 6-11. As shown in Figure 6-12, the active low shutdown pins (pin 2) SD1 and (pin 3) SD2 are connected to the input voltage since we will not be using them. The error pins ERROR1 (pin 7) and ERROR2 (pin 8) are grounded. We will be using pin 5 (Vout1) as our 3V output, therefore we will be leaving pin 5 (Vout1).

6.4 Wireless Technology Background

This section will elaborate on some of the terminology of protocols and security types used in the wireless module. Although our wireless module is fully integrated, the different elements of wireless technology should be known as to understand the potentials of the wireless system for our proof-of-concept device.

6.4.1 Terminology

The following descriptions provide the reader with a further understanding of wireless systems vocabulary, which will be used to further explicate the system block. All of the following information can be found at http://en.wikipedia.org.

- **Open System Interconnection** (OSI) **Reference Model** – an abstract description of how communications and computer network protocol are designed. There are seven layers of which each layer using only the functions of the layer below, and exporting functionality to the layer above.
- **Media Access Contro**l (MAC) – part of the OSI network model in the data link layer. This dictates who can access physical memory at any time. Also acts as an interface between the Logic Link Control and the physical layer of the OSI network model.
- **Carrier Sense Multiple Access with Collision Avoidance** (CSMA/CA) – type of MAC protocol which senses the carrier scheme, transmits a jam signal when information is to be transmitted, waits for sufficient time then sends a data frame, if a jam signal is received after the frame has been sent transmission stops for random amount of time then is retried.
- **Transmission Control Protocol** (TCP) – part of internet protocol which guarantees that all information packets arrive and maintain original order. Ability to request a packet over again if one is lost. Where TCP is not appropriate (as in real time operations) usually, UDP is.
- **User Datagram Protocol** (UDP) – part of internet protocol where programs on networked computers can send short messages sometimes known as *datagrams* to one another. Unlike,

TCP, UDP does not provide ordering guarantees or assurance that information was received. Without checking all information, data transfer can occur much more quickly.

- **Direct-Sequence Spread Spectrum** (DSSS) – a modulation technique for signal transmissions. This method phase modulates a sine wave pseudo-randomly with a continuous string of pseudo-sine code. Each modulation is much shorter than the information bit. The receiver knows the modulation code prior to reception and is able to demodulate the signal using that same modulation code.
- **Orthogonal Frequency-Division Multiplexing** (OFDM) – a more complex modulation technique, also called discrete multitone modulation based on frequency-division multiplexing (FDM), where each frequency channel modulates with a simpler modulation. The difference from FDM is that each of the frequencies used are arranged to be orthogonal with each other, which eliminates interference between the channels.
- **Complementary Code Keying** (CCK) – an improvement over M-ary Orthogonal Keying and uses 'polyphase complementary codes. Polyphase complementary codes are codes where each element is a complex number of unit magnitude and arbitrary phase, or more specifically for 802.11b is one of [1,-1, j,-j]. The CCK modulation used by 802.11b transmits data in symbols of eight chips, where each chip is a complex QPSK bit-pair at a chip rate of 11Mchip/s. In 5.5 Mbit/s and 11 Mbit/s modes respectively 4 and 8 bits are modulated onto the eight chips.
- **Request to Send / Clear to Send** (RTS/CST) – used in communications between 802.11b and 802.11g. The transmitter sends a RTS frame. The destination replies with a CTS frame.
- **Wired Equivalent Privacy** (WEP) - uses the stream cipher RC4 for confidentiality. A stream cipher is a symmetric cipher in which the plaintext digits are encrypted one at a time, and in which the transformation of successive digits varies during the encryption. The use of the cyclic redundancy check, CRC-32 checksum, ensures the integrity of the data.
- **WiFi Protected Access** (WPA) - data is encrypted using the RC4 stream cipher, with a 128bit key and a 48bit initialization vector (IV). WPA uses Temporal Key Integrity Protocol (TKIP), which dynamically changes keys as the system is used.
- **Counter Mode with Cipher Block Chaining Message Authentication Code Protocol** (CCMP) – is an encryption protocol, which uses the Advanced Encryption Standard (AES) algorithm. In the CCMP, unlike TKIP, key management and message integrity is handled by

a single component built around AES. Data is encrypted using Counter (CTR) mode AES. One achieves authentication by using a Cipher Block Chaining Message Authentication Code (CBC-MAC).

6.4.2 802.11 b

802.11b was the first widespread IEEE wireless specification to be widely used in the consumer marketplace. Using the unlicensed medical scientific band at 2.4GHz 802.11b runs into interference from microwave ovens, Bluetooth devices, and cordless phones. 802.11b has a maximum raw data rate of 11 Mbit/s and uses the same CSMA/CA MAC method defined in the original 802.11 standard. The requirements of CSMA/CA protocol cause the actual performance of the device to be quite a bit lower, however. The type of internet protocol used also makes a difference with TCP being slower but reliable and UDP quite a bit fast but less reliable. An 802.11b device can operate at 11 Mbit/s, but as the quality of signal becomes a problem, a feature called Adaptive Rate Selection will scale transmission back to 5.5, then 2, then 1 Mbit/s. At 5.5 and 11Mbit/s, CCK is the modulation scheme, and at one and 2Mbit/s, DSSS is used. Since the lower data rates use less complex and more redundant methods of encoding the data, they are less susceptible to corruption due to interference and signal attenuation. (IEEE 802.11)

6.4.3 802.11g

802.11g works in the 2.4 GHz band (like 802.11b) but operates at a maximum raw data rate of 54 Mbit/s. 802.11g hardware is compatible with 802.11b hardware. The modulation scheme used in 802.11g is OFDM for the data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s, and reverts to (like the 802.11b standard) CCK for 5.5 and 11 Mbit/s and DSSS for 1 and 2 Mbit/s. Even though 802.11g operates in the same frequency band as 802.11b, it can achieve higher data rates because of its similarities to 802.11a. In order for an 802.11g device to transmit to an 802.11b device the RTS/CTS communication scheme must be used because 802.11b cannot see the signals which are modulated with OFDM. The process of using RTS/CTS in communications slows the process down. This problem only happens in older networks where the receiver is a strictly 802.11b device.

6.4.4 Security

The original security for wireless networks was WEP. This security encryption style does not protect very well against nodes that are inside the network, and when working with

radio waves it is hard to keep people out of the network. The major failing of this security occurs because RC4 is a stream cipher; hence same traffic key cannot be used twice. The purpose of an IV, transmitted as plaintext, is to prevent any repetition, but a 24-bit IV is not long enough to ensure this on a busy network. Using the IV in that way opened WEP to a related key attack. For a 24bit IV, there is a 50% probability the same IV will repeat after 5000 packets. To counter this, WEP2 was released enforcing a 128-bit encryption key and an enlarged IV value. However, this did not fix all the problems and it still leaves the network vulnerable to WEP type attacks.

WPA was developed to interface with all WEP enabled hardware though a simple software upgrade. Designed for use with an IEEE 802.1X authentication server, different keys for WPA were distributed to each user. One major improvement in WPA over WEP is the TKIP, which dynamically changes keys as the system is used. When combined with the much larger IV, this defeats the well-known key recovery attacks on WEP. An even more robust form of security was released early in 2005 called WPA2. WPA2, in addition to TKIP and the Michael algorithm, introduces a new AES-based algorithm, CCMP that is considered fully secure by the WiFi Alliance.

6.4.5 Wireless for Development Application

Drawing on the attributes of the previous system characteristics, the wireless module chosen for the proof-of-concept application incorporates 802.11 b technology as well as WEP and WPA security for transmissions. Although the ABDB-ET-DP101 is not an 802.11g product, it can communicate with 802.11g networks by using the RTS/CTS communication protocol. The outstanding attribute of the ABDB-ET-DP101 is the capability to interface directly with the OMAP5912 OSK development board upon arrival. The 802.3 physical Ethernet connection allows the wireless module to immediately interface with the development board leaving only software drivers to be installed before complete functionality is obtained.

6.5 Software Background and Specifications

The following text serves to illustrate the specific software requirements of the personal health monitor interface and outline the theory underlying the application design and development.

6.5.1 Pyramid of Software in Embedded Systems

The visual model of a pyramid illustrates software development in microcomputers—a complex structure completed in layers. Figure 6-13 illustrates the different levels of embedded software directly related to the personal health monitor interface. The foundation is rooted in an operating system and its library files, a middle layer consisting of both a core application and a communications protocol that must work in tandem, and finally a graphical user interface (GUI) that will act as the final layer—the capstone—of our embedded software design pyramid.

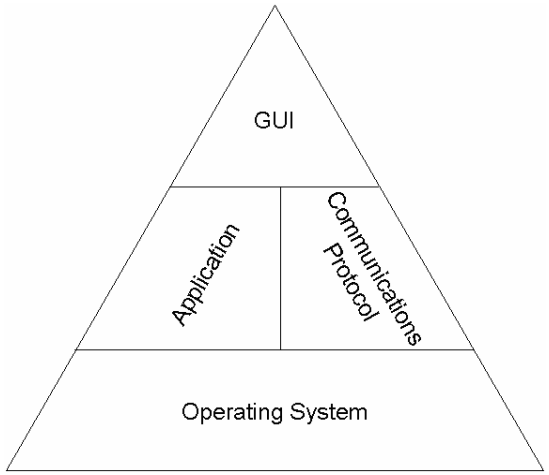


Figure 6-13: Pyramid of Software in Embedded Systems

6.5.1.1 Operating System

The OMAP5912 OSK development board lends itself for use with the Linux open source operating system. Reasons for the team's decision to use the software were previously discussed in Section 5.4. Since Linux is considered a general-purpose operating system, there are several different versions (i.e. distributions) and package types available for use. Our decision to use the OpenEmbedded project's libraries to construct our operating system base ensured that not only would we be using the latest available stable releases of all software, but also that we would be generating a kernel and root filesystem (the components that makeup a Linux operating system) that is functional.

Building an operating system for an embedded platform requires what is referred to as a *cross-compile toolchain*, specific compilers and library files configured for building software for the desired platform. In our case, the OMAP5912 processor is from the ARM9 family and our software will need to be compiled by an appropriate toolchain. OpenEmbedded is capable of producing the toolchain and build environment for the OMAP5912 OSK development board using the *org.openembedded.dev* database. The toolchain and development environment are

built within OpenEmbedded via the following command (for more detailed build info please see Appendix A5):

```
$ bitbake linux-omap1
```

The toolchain specifically consists of the following software packages:

- GNU Binutils (a collection of binary tools, including a linker and assembler),
- GNU Compiler Collection (GCC – an open source C/C++ compiler), and
- GNU C Library (gLibC – an open source, standards-focused C library),

which are used to build the packages and libraries necessary for compiling the kernel and root filesystem with the necessary patches for an ARM9 class microprocessor.

Once the toolchain has been constructed, development can move forward with the build of both the kernel and root filesystem via the following OpenEmbedded command (again, Appendix A5 reveals more detailed build information):

```
$ bitbake bootstrap-image
```

The build produces three binary image files:

- Das U-Boot (a Linux bootloader, similar to LiLo or Grub for desktops),
- Linux Kernel, and the
- Root Filesystem (in JFFS2 file format).

These three files can then be transferred sequentially via an 802.3 (Ethernet) or RS-232 (Serial) connection to the OMAP5912 OSK development board's RAM and later burned to the on-board Flash ROM. Once burned, each time the development board is powered it will call upon Das U-Boot, in the master boot record (MBR), which will boot the device via the Linux kernel and mount the root filesystem.

The total size of the build image is 1.1-Mbytes, much smaller than a typical desktop-oriented operating system build, which often can exceed a few gigabytes when packaging software is included. As the foundation of our software pyramid, not only is the operating system guilty of the largest footprint, but it is also responsible for supporting the needs of the additional layers.

6.5.2 Communications Protocol

The idea of a communications protocol—that is, a series of rules for interaction between two (or more) devices—is twofold for the development of our glucometer interface. Not only does our device use a communications protocol to transfer data to a database, but also for the

communication between itself and the glucometer. The former protocol, formally referred to as the TCP/IP protocol, is a widely accepted standard in the computing industry. Thus, native support for communications via the TCP/IP protocol finds itself in the Linux operating system. The communications link between our device and the glucometer, however, requires some "development" to start.

6.5.2.1 Reverse Engineering the TheraSense FreeStyle Mini Glucose Meter

Learning how the TheraSense FreeStyle Mini Glucose Meter interacts with its Windows-based host application was a key step in the development of our glucometer interface. Without this knowledge, there would be no method for extracting the data from the glucometer, which would—in turn—prevent us from proceeding with the delivery of this information to a database and ultimately from fulfilling our mission. The process for reverse engineering the glucometer was twofold: (1)identifying the command issued by the Windows host application to retrieve the data from the glucometer and (2) duplicating the command and its results in both Windows and our Linux development environment.

The TheraSense FreeStyle Mini is distributed with a custom application, the FreeStyle Connect Data Management System, designed to retrieve and process data from the glucometer via its RS-232 (serial) connection to a personal computer. The application will also allow the user to generate reports (e.g. standard day reports, 14-day reports, etc) based on his or her glucose readings.

Figure 6-14: Screenshot of FreeStyle Connect Data Management software.

(*Free Style Connect*, 2003)

As previously mentioned, we were primarily interested in how the FreeStyle Connect software gets the glucometer to transmit its memory contents over the serial connection to the computer. To do this, we employed the Advanced Serial Port Monitor for Windows application to "spy" on the communication of the FreeStyle Mini and the FreeStyle Connect application. The Advanced Serial Port Monitor acts as a virtual serial port, sitting between the actual serial port and any application attempting to access it. This permits the logging of any commands and/or data across the port.

Figure 6-15: Screenshot of Advanced Serial Port Monitor application.

We started by connecting our FreeStyle Mini glucometer to our personal computer via the serial port connector. Next, we opened the Advanced Serial Port Monitor application and set it to "spy" on COM1, the first serial port as named by Windows. Next, the FreeStyle connect software is opened and the "Read Meter" button is selected. The Advanced Serial Port Monitor returns the communication between the glucose meter and the Windows application. In Table X, the output is presented with comments on the left and without on the right. By default, the Advanced Serial Port Monitor application includes ASCII comments to assist the user with protocol identification. Please note that only line feeds (LFs) are displayed in the commented output, not carriage returns (CRs).

Readout with ASCII Comments	Readout without ASCII Comments
<NUL><NUL>mem	
[len=0]	
<LF>T-F360-62439 [len=13]	T-F360-62439
<LF>1.0000 -P [len=14]	1.0000 -P
<LF>Sep 20 2006 12:13:11 [len=22]	Sep 20 2006 12:13:11
<LF>002 [len=4]	002
<LF>	
<LF>105 Oct 07 2005 19:08 18 0x00 [len=33]	105 Oct 07 2005 19:08 18 0x00
<LF>120 Oct 07 2005 19:06 18 0x00 [len=32]	120 Oct 07 2005 19:06 18 0x00
<LF>0x1746 END [len=12]	0x1746 END
<LF>	

Table 6-3: Results of spying on RS-232 communication.

The first line of the commented readout, *<NUL><NUL>mem*, is the command the FreeStyle Connect software issues across the serial port to the glucometer. The lines thereafter are output by the glucose meter to the application for further processing. Equipped with this information, we could then go about deciphering which ASCII characters produce <NUL> responses in a terminal setting—that is, deciphering which characters produce no visible output when issued. Consulting an ASCII table revealed that line feeds and carriage returns produce <NUL> outputs. Confirming the findings of Broders *et al*, we learned the command *<CR><NL>mem* is responsible for clearing the line to the glucometer and having it deliver its memory contents via the RS-232 connection. This finding allowed us to arrive repeatedly at the shown output by sending the following command to the glucometer via the RS-232 connection:

Command with ASCII Comments	Command without Comments
\r <CR> [len=0]	\r
\n <CR> [len=0]	\n
mem <CR> [len=3]	mem

Table 6-4: Command to trigger FreeStyle Mini memory dump.

At this point, we now ventured to repeat the issuing of this command across the serial port on our Linux-based development machine. Using Minicom, a serial port monitoring application for Linux, we needed to make some adjustments our definition of the protocol. The Advanced Serial Port Monitor application had the ability to detect automatically the transfer parameters (i.e. baud rate, parity, flow control, etc) used by the glucose meter and the FreeStyle Connect application. Drawing from common serial port parameters and the findings of Broders *et al*, we were able to setup Minicom for communication with the FreeStyle Mini glucose meter. We confirmed that sending the same command from Table 6-4 under Linux would produce the output previously shown in Table 6-3.

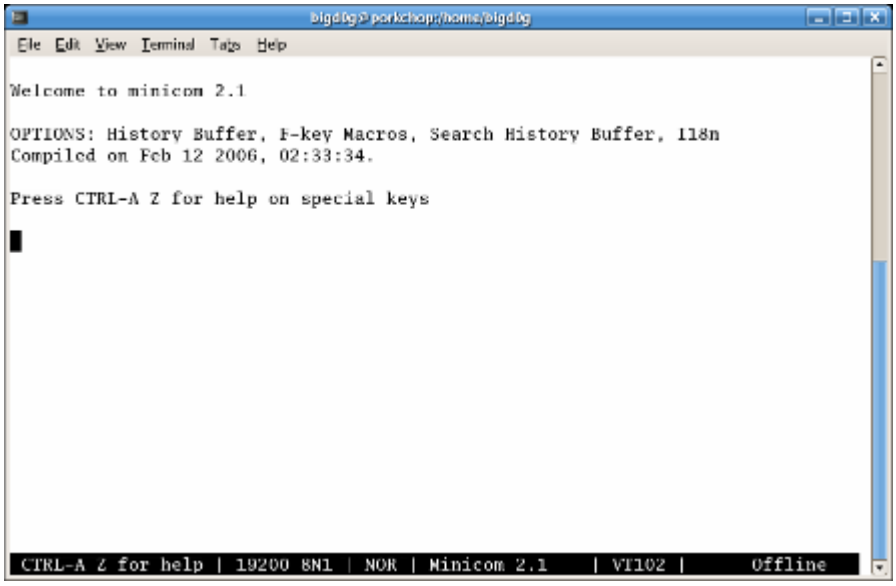


Figure 6-16: Screenshot of Minicom application.

The information learned from this reverse engineering process was applied to formulate the connection rules, or protocol, for interfacing with the FreeStyle Mini glucometer. It is our belief that this process will need to take place for each additional glucometer make/model we (or another development team) wish to interact with our interface. The defined protocol is as follows:

RS-232 Port Setup: 19,200 baud, 8 data bits, 1 stop bit, no parity, no flow control

FreeStyle Mini Protocol:

command ::= <CR> + <LF> | 'mem'

<CR> + <LF> *command*:
Device Response ::= None.
Side Effects ::= Device's serial buffer is cleared.

'mem' *command*:
Device Response ::= <LF><Serial Number><LF><Software Revision><LF><Current Date/Time>
<LF><Number of Entries><LF><LF><Log><LF>'END'
Serial Number ::= [A-Z'-'A-Z000-999'-'00000-99999]
Current Date/Time ::= [Jan-Dec' '1-31' '0000-9999' '00:00:00-23:59:59]
Log ::= 'LOG EMPTY' | <Log Entries>
Log Entries ::= <Log Entry><LF><Log Entries> | <Log Entry>
Log Entry ::= <Reading><Date/Time><EOL>
Reading ::= 000-999
Date/Time ::= [Jan-Dec' '1-31' '0000-9999' '00:00:00-23:59:59]
End of Line ::= 0x00

Side Effects: None.

Using this information, we will then be able to design an application that will download the contents of the FreeStyle Mini's glucose monitor, write the contents to a local file, and then parse the contents of the file for data we wish to send to our database. Section 7.4.2 further defines the application developed for this component of the overall design.

6.5.3 GUI and Application

The graphical user interface (GUI), in the end, will be the only component of the software subsystem that will be visible to the end user. We must design the GUI with the common diabetic in mind, while also preserving room for future upgrades and enhancements to take place easily. We accomplished this by separating the graphical user interface code and the application or "action" code.

The decision to develop with Python and GTK+ introduced a good solution to this problem: PyGTK, a GUI design package featuring the Python programming language. ("PyGTK") Moreover, PyGTK fulfils our design requirement cited in Section 5.4 to use the GTK+ windowing toolkit. Combining the power of PyGTK with Glade, a rapid development environment for user interfaces, we were able to fulfil our design goal of separating the GUI from the application code. Glade allows for the detailed creation of user interfaces, while storing the details for their creation in an Extensive Mark-up Language (XML) file. ("Glade") Calling upon the generated XML file from within our PyGTK code opens the graphical user interface and allows us to map buttons on-screen to actions. Figure 6-17 illustrates the Glade development environment on a Linux platform.

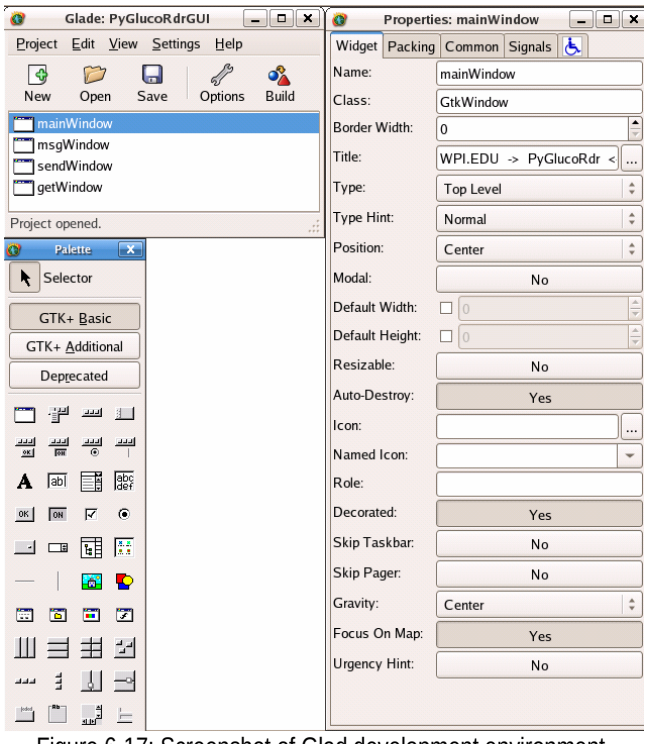


Figure 6-17: Screenshot of Glad development environment.

Our GUI needs to complete three specific functions: retrieve data from a given glucose meter, transmit data retrieved in a form suitable for capture in a standards-based database, and allow healthcare professionals to send messages to their diabetic patients using our device. Each one of these functions should take the user to a new window and allow the functionality to be completed. In addition, a method to return to the main window must be available from each menu. The flow chart in Figure 6-18 demonstrates the functionality of our proposed graphical user interface.

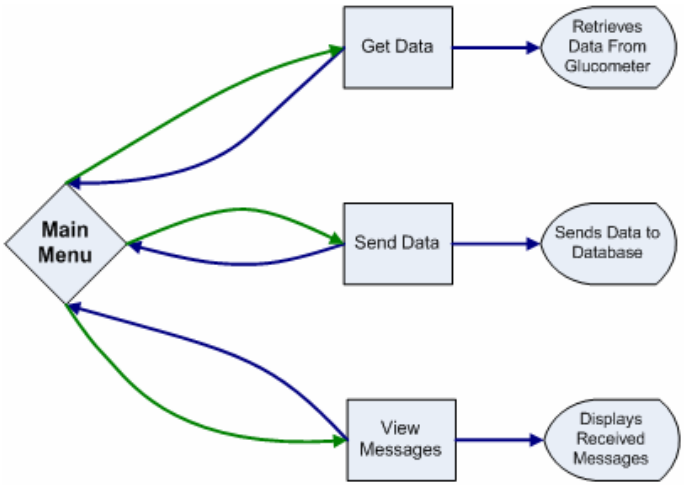


Figure 6-18: Functionality flowchart for GUI.

In addition to this functionality, the GUI must be aware of its primary user, the common diabetic patient, and their needs. In Section 5.1.4, the decision to use only three buttons (e.g. up, down, okay) will limit the ability of the user to navigate the graphical user interface if it is not designed with top-down progression in mind. Likewise, it is beneficial to have each window default to a button used often. Finally, all text of the GUI needs to be relatively large, keeping in mind that some diabetics are vision impaired.

These design requirements, in addition to the previously described functionality, are achieved by the Python application code that sits underneath the graphical user interface.

7 Implementation and Results

After designing the hardware components of the device, we began testing and integration of the different modules to create one functioning proof-of-concept device. In this chapter, we present the results of our preliminary simulations, our response to them, the printed circuit board (PCB) designs, the methods of testing hardware, and the results.

7.1 Simulation

With parts ordered and PCB creation underway, we conducted computer-aided simulations. Schematics we created using MultiSim used features from the electronic workbench that allowed us to test the circuit under particular conditions and monitor outputs as well as power dissipation. Simulation is a mathematical way of emulating the behaviour of a circuit. With simulations, it is possible to predict a circuit's performance characteristics without physically constructing the circuit or using actual test instruments. Because the LCD driver circuit combines two different sub-systems these systems were broken up into individual simulations along with the user input circuit. Each of these sub-systems interconnects, so individual testing allowed us to determine complete functionality before integration.

7.1.1 LCD Driver

The LCD driver circuit is the circuit responsible for providing several different bias voltage levels to the LCD and powering it. This complete circuit has two main portions; the voltage regulator takes an input of 3.3V and outputs a steady 3V to the LCD as VDD, and the quad op-amp provides four different bias voltages, which are proportional to one another.

7.1.1.1 Quad Op-Amp Voltage Bias Simulation

The first section of the LCD Driver is the Quad Operational Amplifier, the LP324M. One problem encountered when creating the circuits for simulation was that there would be no actual LCD connected to the circuit. Therefore, we would not know exactly how the LCD would react to the given voltages; we can only base that knowledge on what we read in the datasheet and on our conversations with Hantronix technical support staff. To validate voltages, we connected measurement probes at each of the nodes where the LCD would eventually connect as shown in Figure 7-1. This gave a sample output voltage reading for the different points at the input of the quad op-amp and the outputs. This gives us a view of the voltage flow throughout

the circuit for different input voltage levels, different resistor values, and different capacitor values.

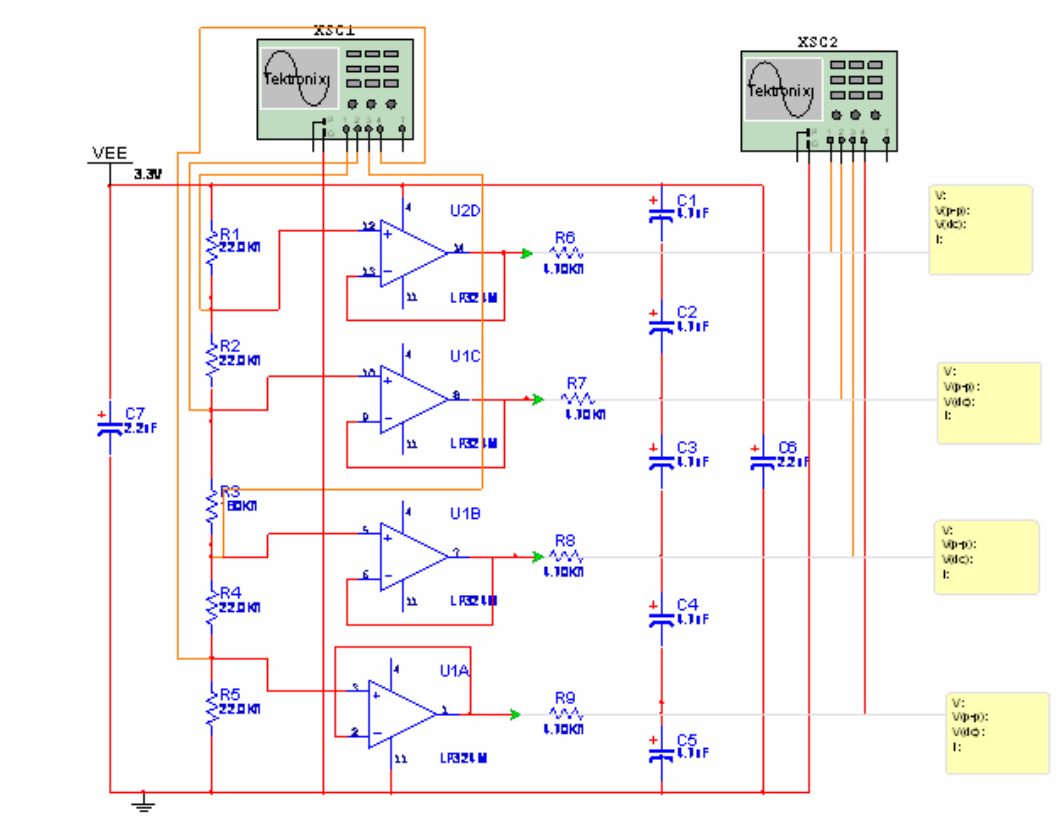


Figure 7-1: Simulation Layout for LCD Driver Circuit

Using that basic simulation layout, we could predict the expected pin outputs and input values for the LP324M. These values are shown in the table below.

Pin Number	Specification	Expected Value (V)
1	Output	0.273
2	-Input	0.273
3	+Input	0.271
4	Power	3.3
5	+Input	0.542
6	-Input	0.544
7	Output	0.544
8	Output	2.76
9	-Input	2.76
10	+Input	2.76
11	Ground	0
12	+Input	3.03
13	-Input	3.03
14	Output	3.03

Table 7-1: Predicted values for the LP324M

We simulated a DC sweep, and the results are shown in Figure 7-2.

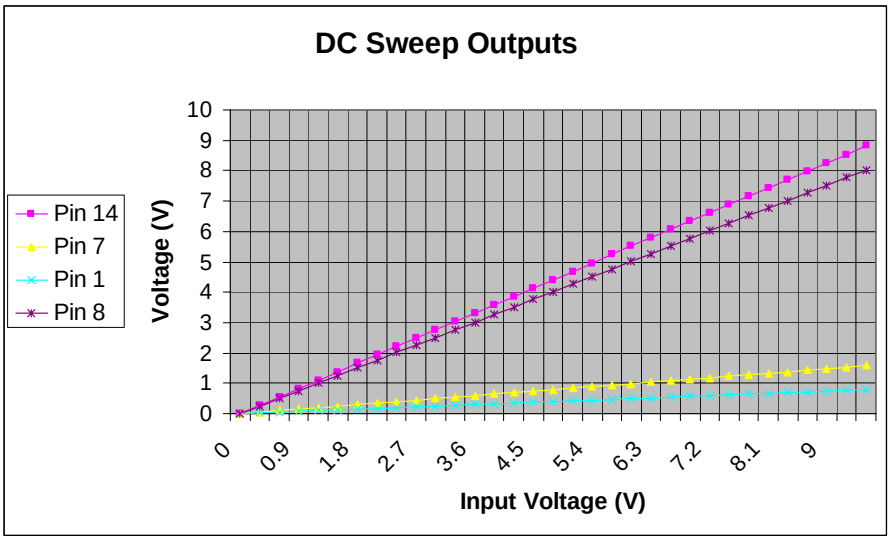


Figure 7-2: Chart of DC Sweep Outputs

Figure 7-2 shows the pin outputs of the operational amplifier when a DC Sweep was simulated. In this DC sweep, VEE, the main input voltage increases from 0V to 10V in increments of 0.3V. This chart shows the effect of such an increase on the outputs of the amplifier. As was originally expected, the outputs of the third and fourth operational amplifiers were much less than the first two. This is because the 180kOhm resistor (R3 in Figure 7-1) separates them, and is reducing the voltage at a rate much higher than the previous two 4.7k resistors. Pin 14 is the output that is the largest since it does not get much of a voltage drop between the VEE rail and the input for the operational amplifier. However, as more resistors are between in the input rail and the input for that particular operational amplifier, one notices that the input voltage decreases in comparison to pin 14.

If the purchased resistors were not within the desired range, establishing what at what resistor values the circuit would still work at would save not only time but money as well. As a result, we preformed a simulation that outputted the worst-case scenario outputs for the resistors. Appendix A6 shows the different simulation logs that were outputted and later commented. The simulations served a basis for the expected results. A problem encountered later involved the simulation program not accounting for the railing characteristics of the operational amplifier.

7.1.1.2 Voltage Regulator Simulation

In order to supply the LCD with the required 3.0V constant voltage for the input of the logic power supply, we implemented a voltage regulator into our design. We chose the LP2966

from National Semiconductor to provide us with the necessary 3.0V. This component, however, does not exist in MultiSim component library. Instead of using a similar component, which would not behave the same the LP2966, we created the component using the internal diagram shown in Figure 7-3 which comes directly from the datasheet. The components within the integrated circuit combined to form a 'box' with the respective input and output pins, and that 'box' represents the LP2966.

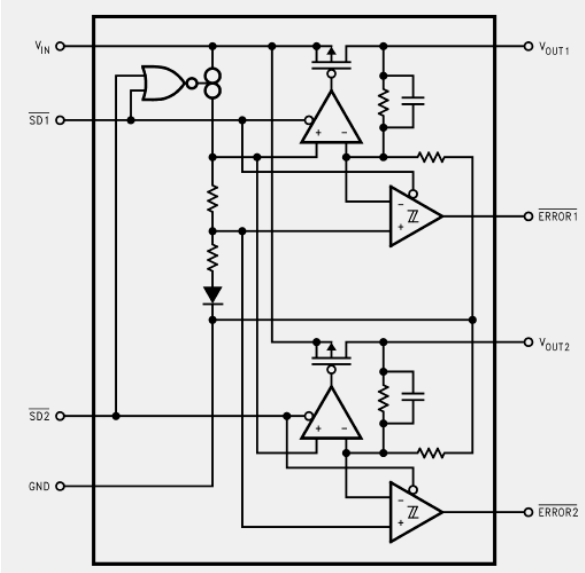


Figure 7-3: Internal Schematic for LP2966

Once the above circuit had been constructed, simulations went underway to establish the functionality of the particular parts. We connected the inputs and outputs according to guided design in Figure 6-12. We preformed a DC Sweep on the circuit, and Figure 7-4 shows the output.

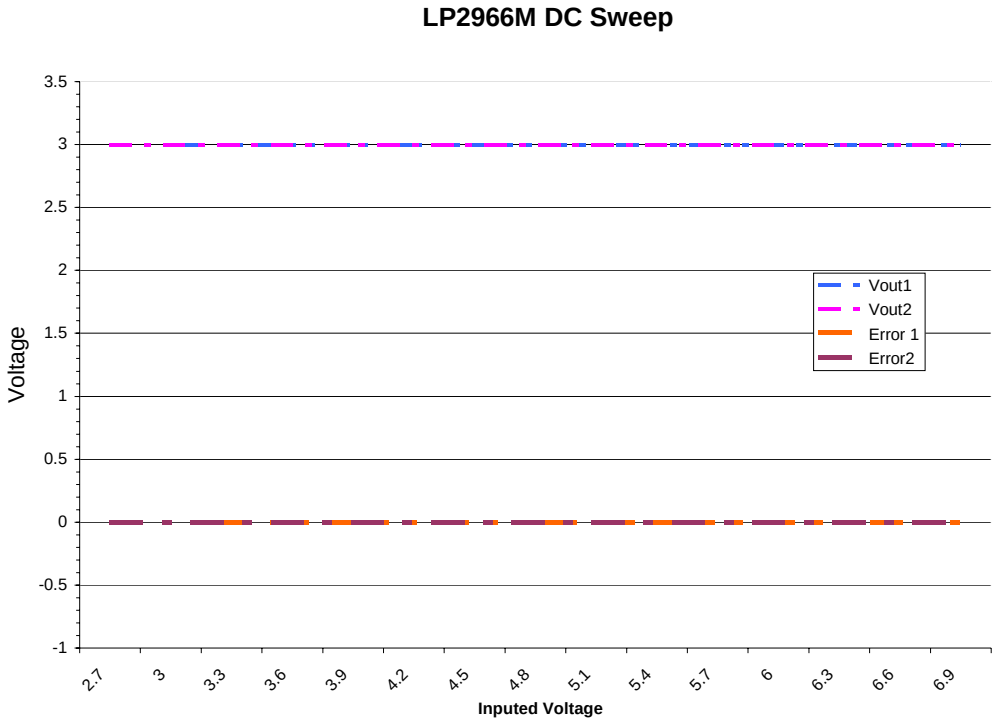


Figure 7-4: DC Sweep for LP2966M

Figure 7-5 shows the integrated circuit with the connections needed for our circuit, as well as the measurement probes in order to obtain reading. Through the measurement probes, we were able to view the same results that were outputted through the DC Sweep.

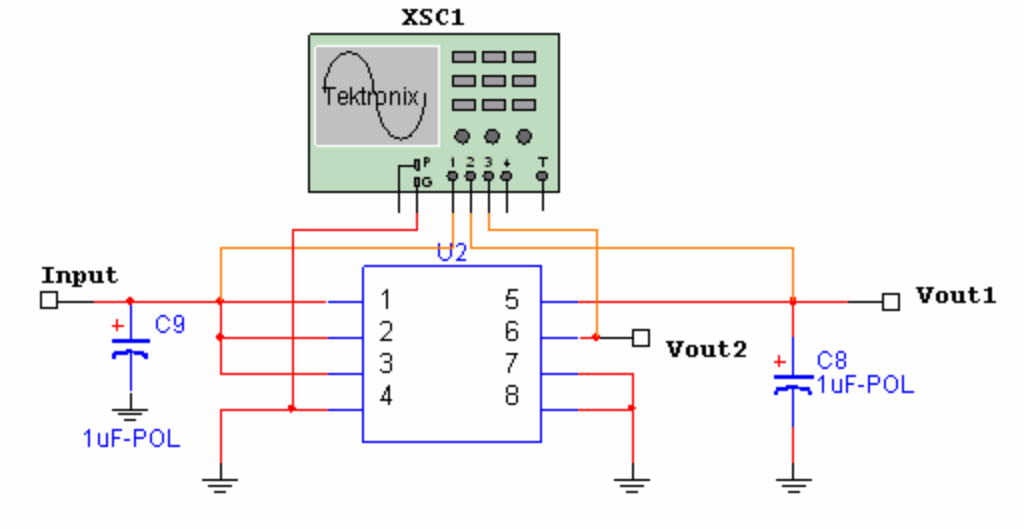


Figure 7-5: Simulation layout for voltage reference

The voltage reference did use an input of 3.3V to create an output of 3V. This configuration takes an input of 3.3V and outputs 3V at both $Vout_1$ and $Vout_2$. SD1 and SD_2 are both tied to the high voltage at V_{in}, and both $Error_1$ and $Error_2$ are tied low to ground.

7.1.2 User Input Circuit Simulation

The user input circuit takes input from the user and relays either a high voltage over a GPIO line to signal the button has been pressed, or a low voltage to signal inactivity to the microprocessor, which then causes a reaction on the LCD screen. The simulations looked for the voltage readings on the GPIO lines at the moment of activation and then the moment of deactivation. Figure 7-6 shows the user interface along with the testing equipment.

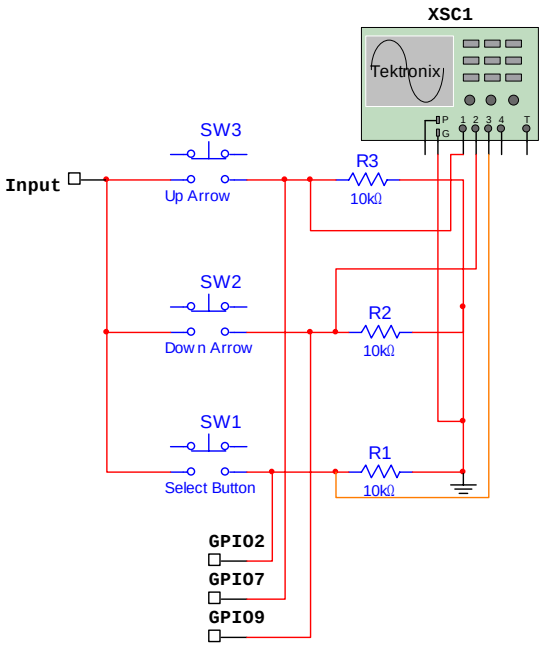


Figure 7-6: User Interface Simulation Layout

The simulations of the user interface tested single switch activation, the circuit's reactions to different combinations of buttons activations simultaneously, as well as the effect of different resistor values. The first test we conducted was to ensure that the 10K-Ohm resistor was the correct choice to implement with the circuit. It turns out that without the 10K-Ohm resistors the actual lifespan of the buttons would decrease and cause internal problems.

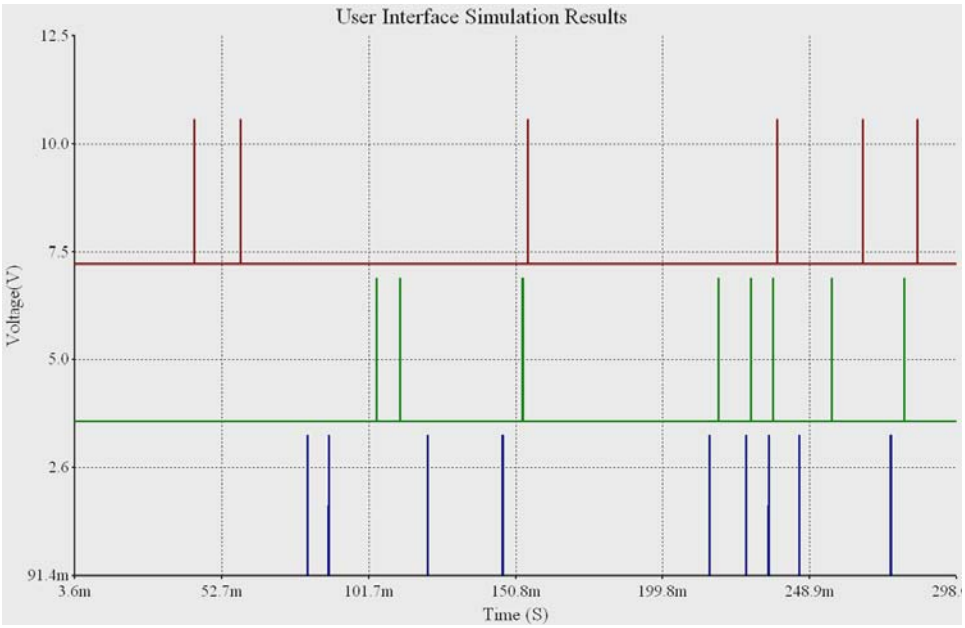


Figure 7-7: User Interface Simulation Results

Figure 7-7 shows the results of simulations, by a manual input. We manually activated the switches, thus causing a momentary spike of 3.3V. The blue line represents the up key, the green represent the down key, and the maroon represents the ok key. Different combinations of input were tried, and even multiple inputs at once.

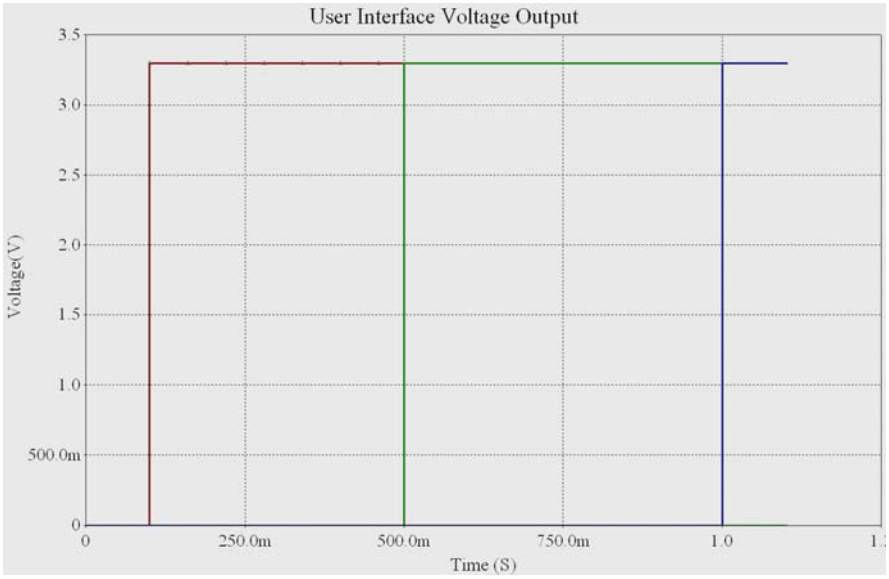


Figure 7-8: User Interface Timed Simulation Results

Figure 7-8 shows the automatic simulation script output. In this simulation one button was activated and then 500ms later the next button was activated without the deactivation of the previous button.

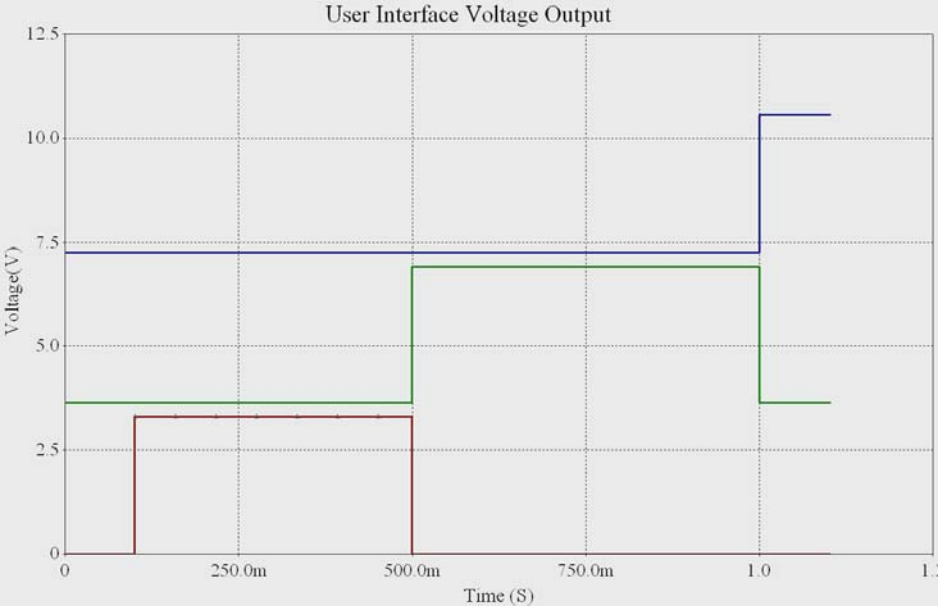


Figure 7-9: User Interface Timed Momentary Simulation Results

In this simulation, only one button can be active at a time. The output graph of Figure 7-9 does not show the graphs superimposed on one another to illustrate the deactivation characteristic of each switch.

The above-mentioned simulations provide a general overview of the functionality of the buttons. However, the interaction between the buttons and the software could not be simulated. Therefore, the outcome of pressing two buttons at the same time is still something that needs to be fixed in the software.

7.2 PCB Design

With the simulations of the circuits complete, we were confident in the circuit design as a whole and ready to layout the LCD driver and user input on printed circuit boards (PCBs). Under different circumstances, the creation of a test circuit on a solderless breadboard with gathered components occurs before transferring the circuit to a PCB. However, due to the number of connections involved for the HiRose 80 pin header for the OMAP5912 OSK and the 18-pin header for the LCD, it would have made this task very difficult and time consuming.

7.2.1 Computer Aided PCB Layout

Having very little experience in the production of PCBs we decided to try out a few different free software packages. PCBPool and Target 3000 for PCB-Production were tested and found to have little helpful documentation and non-intuitive user interfaces. We decided to use

the program called ExpressPCB. Reviews of this program acclaimed it for short start up time and helpful design tips for beginning users. In addition, ExpressPCB offers an easy online, well-priced, professional manufacturing service. Because manufacturing facilities were available at UL, we did not use this service.

The ExpressPCB software package comes with a schematic layout program called ExpressSCH. Creating the circuit schematic in ExpressSCH before starting to use ExpressPCB will help in the PCB layout because the files are linkable and the software will illuminates the connections needed between components. Figure 7-10 shows how ExpressPCB highlights the connected joints in blue as shown in the schematic of ExpressSCH.

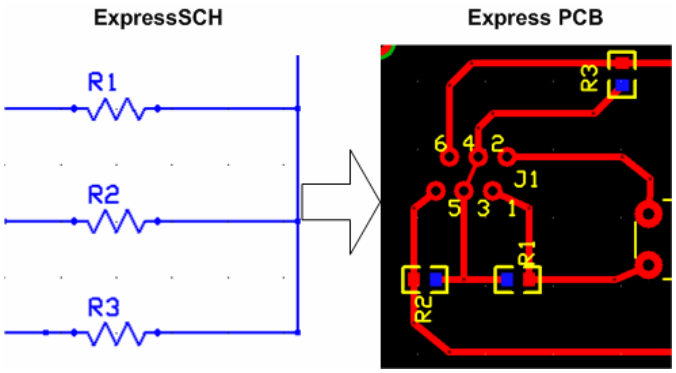


Figure 7-10: ExpressSCH and ExpressPCB linked files indicating connections

7.2.2 Component Layout

The first step towards the creation of a PCB is a compilation of the component package types. If we chose the incorrect package for a part, it may not be possible to place that part on the board in the desired location. Through-hole components are larger and easier to handle than surface mount components; however, through-hole components require holes drilled into the PCB in order to mount them. Surface mount components can very small in size, but it is possible to put many more of them in a small space than through-hole components. We selected a mixture of through-hole and surface mount components for this proof-of-concept device. Sometimes it is possible to use the through-hole components are bridges over copper traces which need to change sides of the component, also they can accommodate traces on either side of the board without drilling extra vias.

The component library in Express PCB is very limited in size. This means that the footprint of any components not in the library must be custom crafted. All of the information necessary for creating a custom footprint is contained in the components datasheet. To make the custom footprints, three main factors were involved: the pitch of the package, the width of

individual pins, and the total package size. The pitch of the component is the distance from the centre line of one pin to the centre line of the next pin, the width or size of the individual pins dictates the size of the copper pad on the PCB, and the distance from one side of the package to the other indicates the space requirements for the component. ExpressPCB provides a coordinate system in which the exact position of the cursor is displayed bottom of the screen and allows the user to input the desired coordinates for a component. By placing the first pad at the origin and entering the coordinates for each successive pad, it is possible to construct a footprint very accurately. This process took place for the 80-pin HiRose connector, the 18-pin LCD connector, and six pin micro-match ribbon cable headers. ExpressPCB lets the user specify the exact dimensions of vias and surface mount copper pads, which makes creating custom footprints relatively easy.

The first component placed on the LCD PCB was the HiRose connector because it determines where the board will be in relation to the OMAP board, so we placed it in the upper right hand corner of the board so the LCD circuit would be completely visible with no hidden components. The next component placed was the LCD connector because it determines which direction the LCD is facing. We then placed the pinned packages in the beginning in order to keep adequate distances from each other so there would be plenty of room to solder them onto the board.

We started with the default trace size of 0.25mm. This size if electrically adequate for our purposes, and if the board were being produced professionally then the traces would not be etched away; however when manufacturing a PCB in house small traces can be etched away very easily, which was a concern of ours when manufacturing our board. When the space is not critical on the PCB, it is acceptable to use large traces. The second revision on the circuit included 0.38mm traces and the third revision increased the trace size yet again to 0.51mm except at connection points to smaller surface mount part like the LCD header where the trace narrows down to 0.38mm. This larger trace size allows for a margin of error in case the board is etched for too long. This same principle applies for the via holes and copper ring surrounding the hole. We used the default size at first, but then increased it to a hole size of 0.74mm with a 2.1mm diameter surrounding copper pad. This pad size creates a comfortable buffer for the hole being drilled off centre and for over etching. We have made the holes for drilling to be 0.6mm, larger than what is required. This is in case if we drill off centre it would not damage or tear the

copper pad surrounding the hole. Copper plates the vias on PCBs when produced professionally; however, this capability is not available at UL, so a 0.6mm diameter wire is passes through the hold and soldered on either end to transfer the conductivity from one side of the board to the other. When making the traces the recommended design is to round corners and avoid right angles and sharp corners whenever possible. Rounding the corner as shown in the bottom picture of Figure 7-11 will reduce noise in the line; however, in this application, noise is not a problem, but it is better practice to round the corners on the traces.

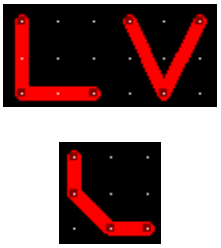


Figure 7-11: Trace examples

7.2.3 Error Checking

To ensure that the circuit came out as expected, we printed a test page of the circuit at actual size. We then placed all the components on the paper as if it was the PCB we were placing it on. Doing this, we found a few errors with our second draft PCB. Examples of mistakes had to do with:

- Package size – The quad op-amp on the first draft of this circuit had an incorrect package size and the thru hole capacitor holes were not placed far enough apart
- Pin configuration – the six line Micro-Match header pins were offset in the incorrect direction, the two tracks of the HiRose connector were not far enough apart

Shown in Figure 7-12 is the full LCD PCB circuit with top and bottom traces along with the top layer solder mask, which if professionally produced are printed on the circuit in ink. The mistakes mentioned above were corrected, and were not implemented in the figure. To get these images we printed the circuit to a PDF file from ExpressPCB.

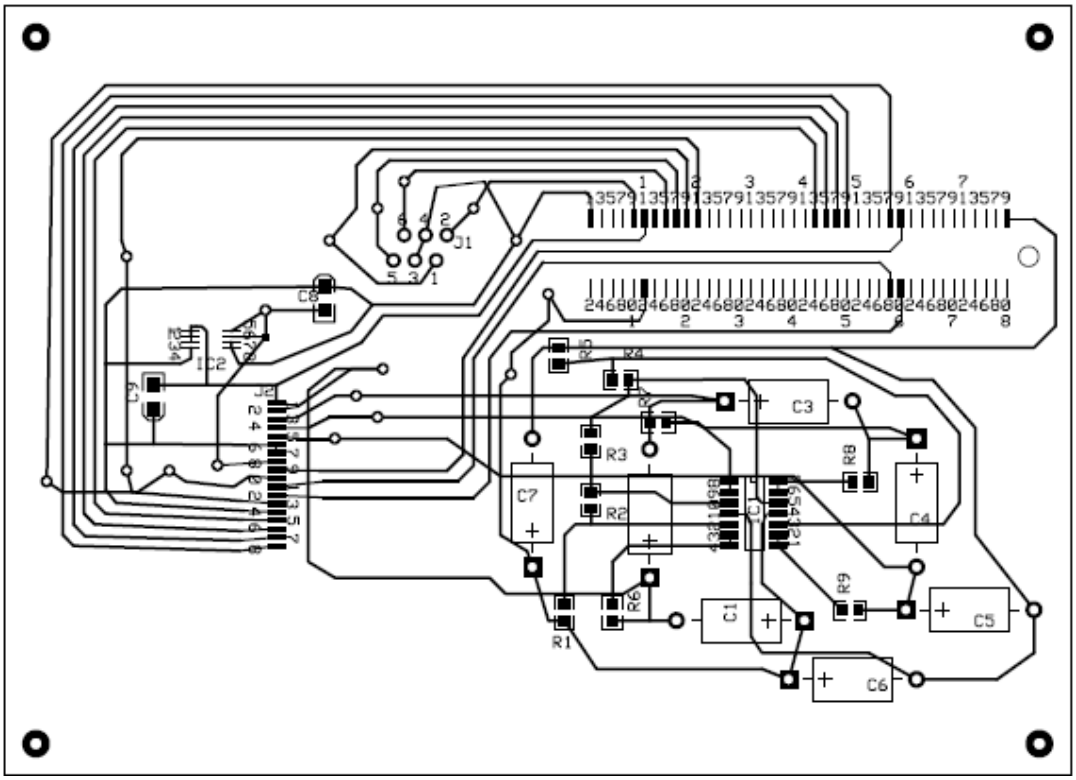


Figure 7-12: LCD PCB version two with top and bottom traces as well as solder mask.

With all of the traces on the same paper, it is hard to determine which traces are on the top side and which are on the backside of the board, so an option can be selected in ExpressPCB to show only the top copper layer or only show the bottom copper layer. Figure 7-13 is an example of printing the circuit out and placing the components on the paper to see how the layout looks. Figure 7-14 is the bottom side of the board; no components are being placed on the back so this just to note the connections.

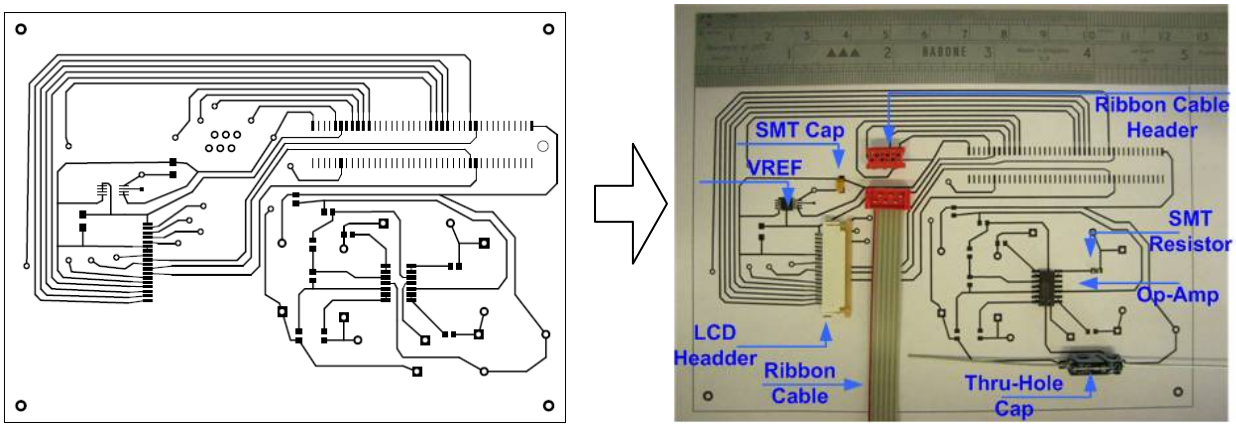


Figure 7-13: Topside of LCD driver circuit PCB version two with components

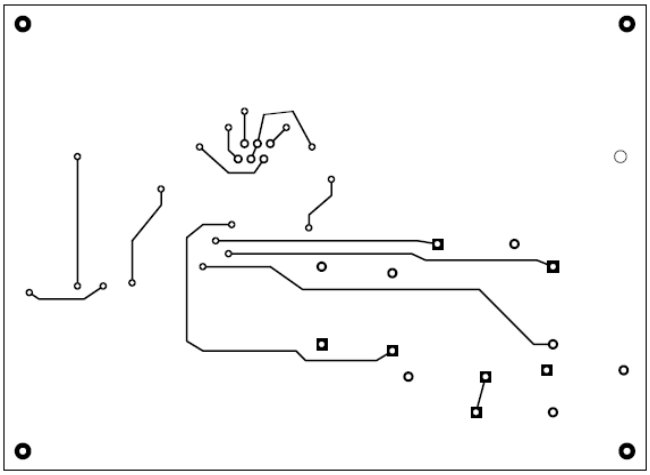


Figure 7-14: Backside of LCD driver circuit PCB version two

The user input PCB is a much simpler circuit, but it was still important to lay out all the components to ensure they fit in their footprints and did not interfere with each other.

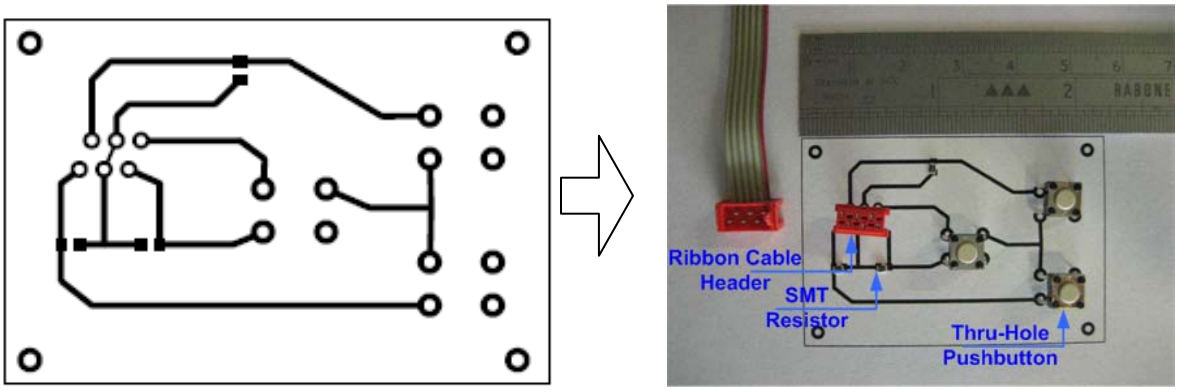


Figure 7-15: User input PCB Design and layout with components

One main problem occurred with this circuit. The Micro-Match ribbon cable header is a thru-hole component; normally this would not be a problem, but the plastic casing around the header makes it so soldering to the pins on the top side of the board is not possible. Fortunately, the simple nature of this circuit allowed for the transferring of all the traces to the bottom side of the board. Both the buttons and the ribbon cable header are thru-hole so they will remain on the top side of the board, but the resistors and the traces will be on the underside.

7.2.4 Finalizing the PCB Design

After three major revisions and one round of manufacturing to find additional errors, the PCBs were ready for final construction. Figure 7-16 and Figure 7-17 show the finalized designs for the PCBs. Included in these are all the changes described previously and an additional change for a hardware interference problem encountered after the first round of manufacturing.

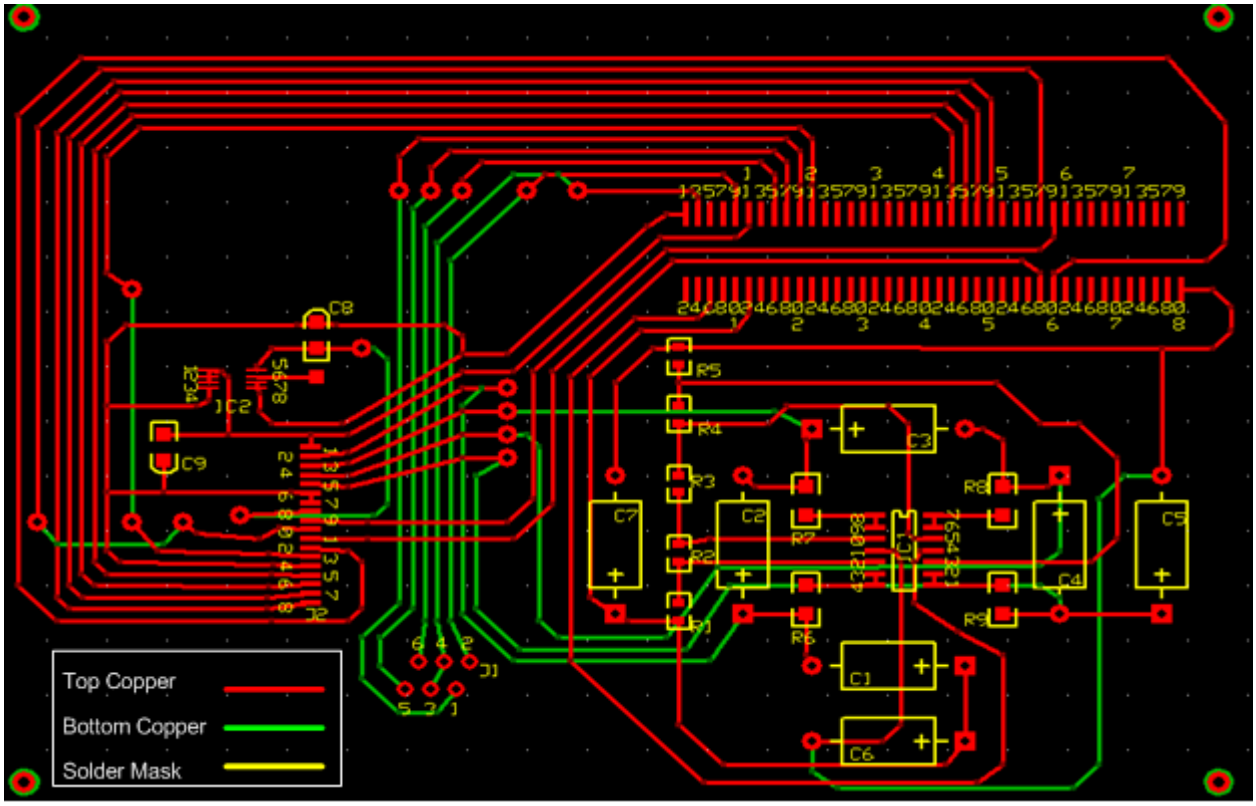


Figure 7-16: LCD PCB as seen in ExpressPCB

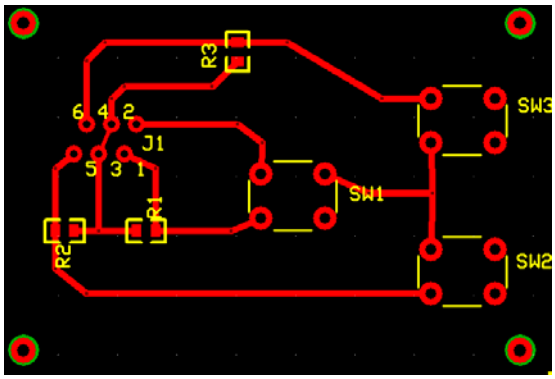


Figure 7-17: User Input PCB as seen in ExpressPCB

If we were going to have these PCBs professionally manufactured, this would be the point when we would have sent them off to the manufacturers. For in house production, the top layer copper and bottom layer copper traces are printed onto transparent paper individually. Because there is only a single side to the user input circuit, only one transparency needs to be printed out for this circuit. The LCD PCB circuit uses both sides of a double-sided PCB so both sides must be printed out, and then to make sure the sides are lined up the two transparencies are stapled together. This step can cause problems. If stapled with the wrong page, on the top, the whole circuit can come out as a mirror image and will not work with the integrated circuits pin

outs. In addition, the page must exactly line up so the vias line up and transferring of conductivity occurs from one side of the board to the other. If all of this is correct, the circuits are ready for manufacturing. For more information about the manufacturing of PCBs, please see Appendix A7.

7.3 Testing

The hardware testing we completed was a multi-step process. Upon receiving all the parts, we measured the value of each resistor and capacitor to ensure it was within expected value range. After manufacturing, the PCBs and soldering the components on we tested each individual part once again, to ensure none of the components had been damaged while being soldered. A detailed inspection of the both the LCD PCB and user input PCB was conducted under a magnifying glass to check for possible shorts between pins or traces. Unintentional shorts were removed by using a razor knife. We commenced testing by checking voltages, currents, and outputs at key nodes and comparing observed values to the expected values obtained through simulations.

7.3.1 Development Board

Before connecting the newly constructed to the OMAP5912 OSK, we tested the outputs of expansion slot C. Checking the outputs before connecting the PCBs let us know that the expected signals and power actually are making it to the PCBs in the expected locations. Pins 1-4 of slot C are ground and tested at a voltage of 0.00V confirming ground. Pins 5-8 are VDC, but have a specific expected value of 4.2V; our measurements established VDC at 4.19V. Pins 9-12 are to provide our circuit with 3.3V, and the measured value confirmed this at 3.31V. The confirmation of these values shows the inputs to the PCBs to be within the expected ranges.

7.3.2 LCD Driver

The LCD Driver circuit has two main subsystems. One is a voltage reference, and the other is the quad operational amplifier, which provides current stabilization for several bias voltages required by the LCD. These are completely separate and do not rely on each other in any way. They connect to the LCD header, and do not draw from the same power source.

7.3.2.1 Voltage Reference

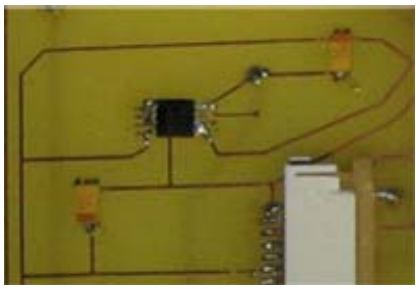


Figure 7-18: Voltage regulator

The LP266 dual output voltage regulator supplies a constant reliable 3V for the LCD logic power supply. The input line for this device comes from pin 11 of the HiRose connector, which is a 3.3V power terminal. This input lines actual value is 3.33V, which is within tolerance, and close to the 3.3V used for simulations. Though this device is a dual output, only one of the outputs is used; the other remains disconnected. We measured the output of pin 5 ($Vout_{1)}$ as 3.01V. This same voltage was recorded at VDD pin 8 of the LCD connector confirming a solid connection between the regulator and the connector.

7.3.2.2 Quad Operational Amplifier

The LP324M quad operational amplifier regulates the current for a series of bias voltages provided to the LCD. Figure 7-19 shows the schematic this section of the driver circuit, along with component, pin, and nodal identifiers. It also shows terminating location of each line in the LCD connector.

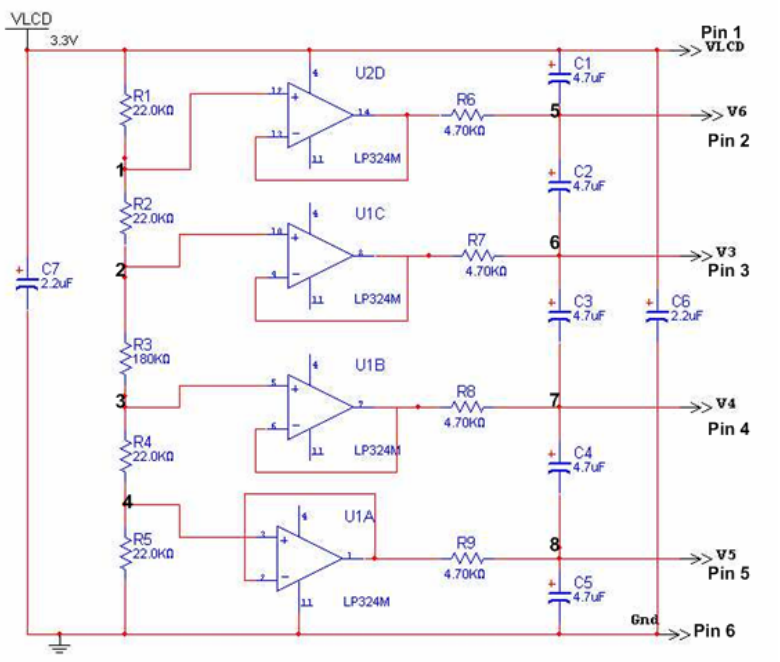


Figure 7-19: Full Descriptive Schematic for LP324M

Each resistor was tested individually to ensure continuity and value. Table 7-2 shows the expected and actual resistor values.

Resistor	Expected Value (kΩ)	Recorded Value (kΩ)	Percent Accuracy
R1	22	21.99	0.05
R2	22	21.95	0.23
R3	180	179.11	0.5
R4	22	21.935	0.3
R5	22	21.99	0.05
R6	4.7	4.71	0.21
R7	4.7	4.702	0.04
R8	4.7	4.702	0.04
R9	4.7	4.965	5.64

Table 7-2: Measured Resistance and Expected Values

With correct resistor values, the voltage drops over each of the resistors should be as expected, so we checked the inputs and outputs knowing that there should be no problems with the resistors. Measurements represent values found directly at the pins of the quad op-amp for inputs and outputs; Table 7-3 shows all 14 readings.

Pin Number	Specification	Expected Value (V)	Actual Value (V)	Difference (mV)
1	Output	0.273	0.281	0.8
2	-Input	0.273	0.28	0.7
3	+Input	0.271	0.274	0.3
4	Power	3.3	3.336	3.6
5	+Input	0.542	0.547	0.5
6	-Input	0.544	0.553	0.9
7	Output	0.544	0.553	0.9
8	Output	2.76	2.63	-13
9	-Input	2.76	2.63	-13
10	+Input	2.76	2.778	1.8
11	Ground	0	0	0
12	+Input	3.03	3.055	2.5
13	-Input	3.03	2.61	-42
14	Output	3.03	2.61	-42

Table 7-3: Actual and Expected Pin Values for LP324M

The output voltages at pins 14, 8, 7, and 1 were expected be decreasing voltages, but the voltages at pins 14 and 8 did not follow the expected values. These incorrect voltage values can cause the LCD not to work. The op-amp is rated to have up to a 2mV drop from the input to the output so all other readings are within tolerance. The problem so far has been isolated to the op-amp chip; all of the external circuitry so far has checked out to be as expected. The first option that we considered was that one of the four op-amps inside the quad op-amp is faulty, specifically U2D as labelled in Figure 7-19. To test this theory, we inputted voltage to pin 12 is to pin 10 as well. By shorting out R1 and directly connecting the input of R1 to the input of R2,

the voltage is passed to R2 and the output of at pin 8 should now mimic that of pin 14 if U2D is fully functional. Figure 7-20 is a picture of the experiment set up.

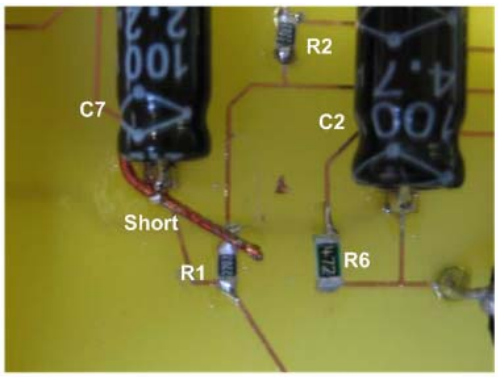


Figure 7-20: LP324M Functionality Test 1

Once it was set up accordingly, we connected the development board as the power source as before. At node 6, there was a voltage of 2.45V, which was observed at V6 previously. The result shows the U2D to be functional as far as U2C showed the same output when given the same input.

As an additional test, we raised the voltage of VCC from 3.3V to 4.19V. This was done by severing the connection (see Figure 7-21) from pin 12 of the HiRose connector and connecting that line instead to pin 6, which supplies 4.2VDC as in section 7.3.1.

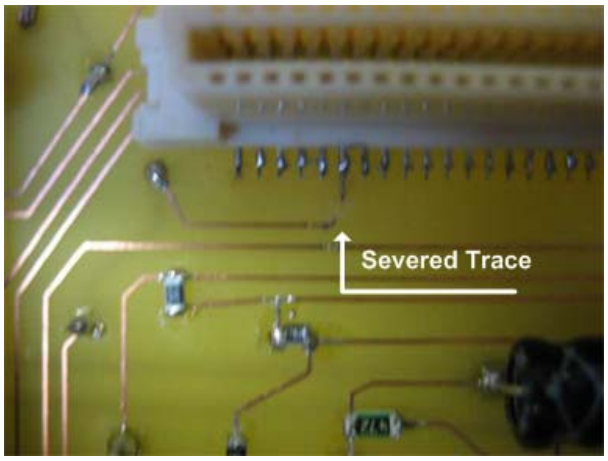


Figure 7-21: Severed HiRose Trace

Using a wire connection from pin 6 to the trace used for both powering the op-amp and as the input value to R1. Once we plugged the LCD PCB back into expansion slot C, we noticed similar behaviour occurring at the new voltage level. The input voltage of the op-amp at pin 4 now measured 4.19V along with the input to R1 and a drop to 3.839V at node one. However, the

op-amp output at pin 14 being 3.3V showed that this problem was indeed railing and not just a lack of power problem.

By raising the power up voltage of the op-amp in small increments, and replacing the 3.3V input to R1, we viewed the railing characteristics of the LP324M. We cut the connection between the op-amp's pin 4, which is the power pin, and C1. Once separated we powered the op-amp with an external power source at pin 4 and connected the ground to the board ground, this setup allowed for small adjustments of power up voltage over a range of values.

Supply (V)	Pin 4 (V)	Pin 14 (V)
5V	5.03	3.06
4.5	4.52	3.06
4.19	4.21	3.06
4.1	4.12	3.061
4	4.02	3.062
3.9	3.06	3.06
3.8	3.83	3.24
3.7	3.72	3.14
3.6	3.61	2.76
3.5	3.52	2.6

Table 7-4: Op-amp railing characteristic

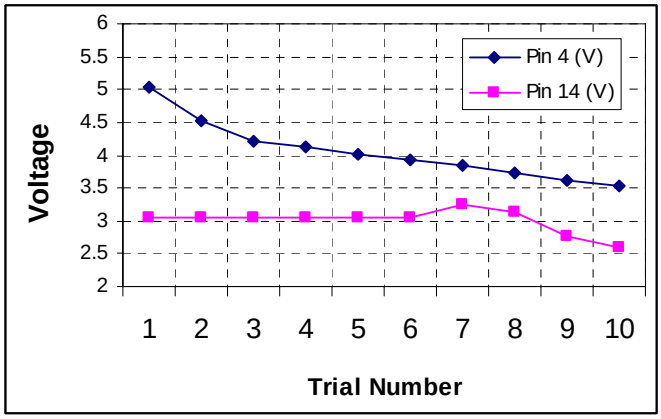


Figure 7-22: Op-amp railing characteristic chart

The 10mV increments give a good picture of the railing characteristics of our op-amp. Below 3.9V the op-amp does not have a reliable follower output for 3.3V; after 3.9V, however, the voltage follower worked well.

Based on the results we transferred the op-amp power to the OMAP board's VDC or 4.19V line, which provided adequate voltage. Figure 7-23 shows the short term solution, which was in a later revision of the LCD driver, circuit PCB.

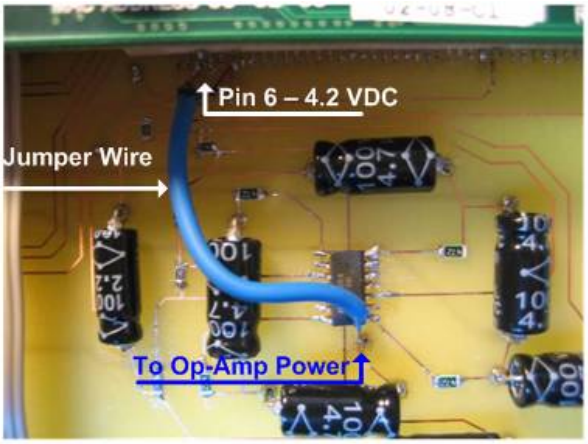


Figure 7-23: Temporary Solution for LP324M

With this jumper cable, our circuit was functional, and testing continued on the next portion of our PCB. Figure 7-24 shows the updated schematic for the driver circuit, showing pin 4 with an input of 4.19V.

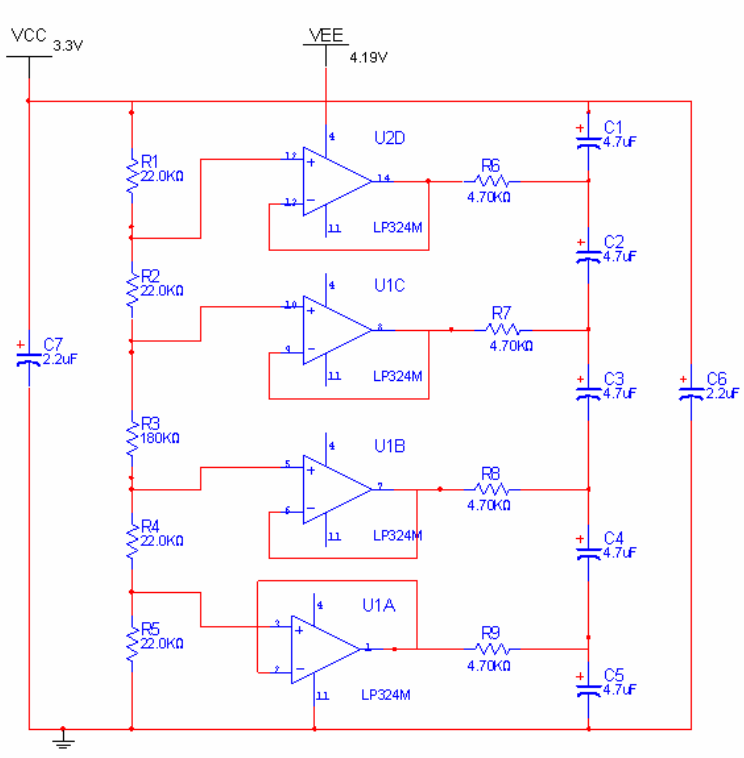


Figure 7-24: Update LCD Driver Circuit

7.3.3 User Interface

For this small circuit, testing included the power transfer over the ribbon cable and the logic change of the pushbuttons. The pushbuttons connect to the GPIO lines with pull down resistors. Therefore, when the switch is closed there will be a logic high signal. When the

buttons were not activated the signal was 0V, and when activated, the buttons reach an output voltage that ranged from 2V to 3.4V. This change will be adequate for the OMAP board to recognize a change.

Debouncing hardware is not part of this system, but was planned for the software. The buttons being used are supposed to have a bounce time of 5 milli seconds or less, and this behaviour should be viewable on an oscilloscope. With the user input circuit powered by the OMAP board and an oscilloscope connected to one of the buttons we observed the bounce characteristics of our buttons. On single shot mode the scope starts, taking measurements after a target value is obtained. Interestingly the buttons displayed bouncing characteristics infrequently. Figure 7-25 is an example of a bounce obtained on the release of the button.

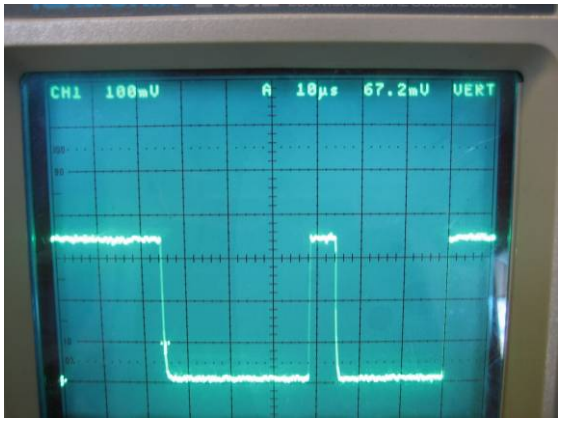


Figure 7-25: Example of bounce on user input pushbuttons

Even Figure 7-25 did not display bad bounce characteristics, though there is a second trigger value. Some type of buttons can bounce 50 or more times before coming to a consistent value.

7.4 Software Implementation

The following sections serve to outline how each of the components of the previously described pyramid of software in embedded systems was developed and implemented in our proof-of-concept interface for personal health monitors.

7.4.1 Operating System Implementation

Although OpenEmbedded was able to create our cross-compile toolchain and an initial version of the embedded Linux kernel, it lacks two features vital to our proof-of-concept; namely, frame buffer support and software to recognize our user interface controls. Frame buffer support is easily enabled in the kernel's configuration file (please see Appendix A4 for our

kernel configuration file). To meet the needs of some LCDs, code alteration may be required of the files 'lcdc.c' and 'omap_fbuffer.c' in '../drivers/video/omap' of the kernel source code.

The General Purpose Input/Output (GPIO) lines that our buttons use are controlled by the source file 'gpio-switch.c' in '../arch/arm/plat-omap' of the Linux kernel source. The appropriate lines simply need to have their attributes modified such that when one of our buttons is pressed the action maps to an appropriate key that you would find on a standard keyboard. For our purposes, we selected the up/down arrows and the 'Enter' key to map to our buttons, as appropriate. Please see Appendix 8 for the full code of 'gpio-switch.c' where our modifications are clearly commented and detailed.

With these changes made to the kernel source files, the kernel is compiled with the following commands:

```
$ make
$ arm-linux-objcopy -O binary vmlinux vmlinux.bin
$ gzip -f -9 vmlinux.bin
$ mkimage -A arm -O linux -T kernel -C none -a 0x10008000 -n "OE Linux Kernel 2.6.18-omap" -d
vmlinux.bin.gz uImage.bin.gz
$ rm vmlinux.bin.gz
```

The resulting compressed kernel image (e.g. 'vmlinux.bin.gz') can be moved to the development board, and later copied to the device's flash along with its respective root filesystem, as compiled by OpenEmbedded and discussed in Section 6.5.1. Please consult Appendix A5 for the detailed procedures followed to copy the developed kernel and root filesystem to the OMAP5912 OSK.

7.4.2 Protocol Implementation

Building upon the findings of Section 6.5 and the "Serial Programming Guide for POSIX Operating Systems", we were able to formulate a script, written in C, which could successfully open a serial connection with defined parameters, issue the command to have the FreeStyle Mini glucose meter send its data, and record the sent data to a plain text file. We tested the script on our Linux development computer and then compiled it for use on our development board using the tools OpenEmbedded had helped create in the following command:

```
$ arm-linux-gcc -g -Wall FreeStyleMini.c
```

The full source, with descriptive comments, to our script is found in Appendix A8. It serves as a template for the other scripts that will be developed as the library of supported glucose meters increases for our device.

7.4.3 Implementation of GUI and Application

The main application window to PyGlucoRdr – the Python Glucometer Reader – consists of three buttons: a get data button, a send data button, and a check on messages button. Each button is mapped with PyGTK code to open its respective window. The text on all of the buttons has been kept large to facilitate the use of this device by those suffering from visual impairment. Figure 7-26 further illustrates the style the main window was constructed in and the functionality of each of the three buttons.

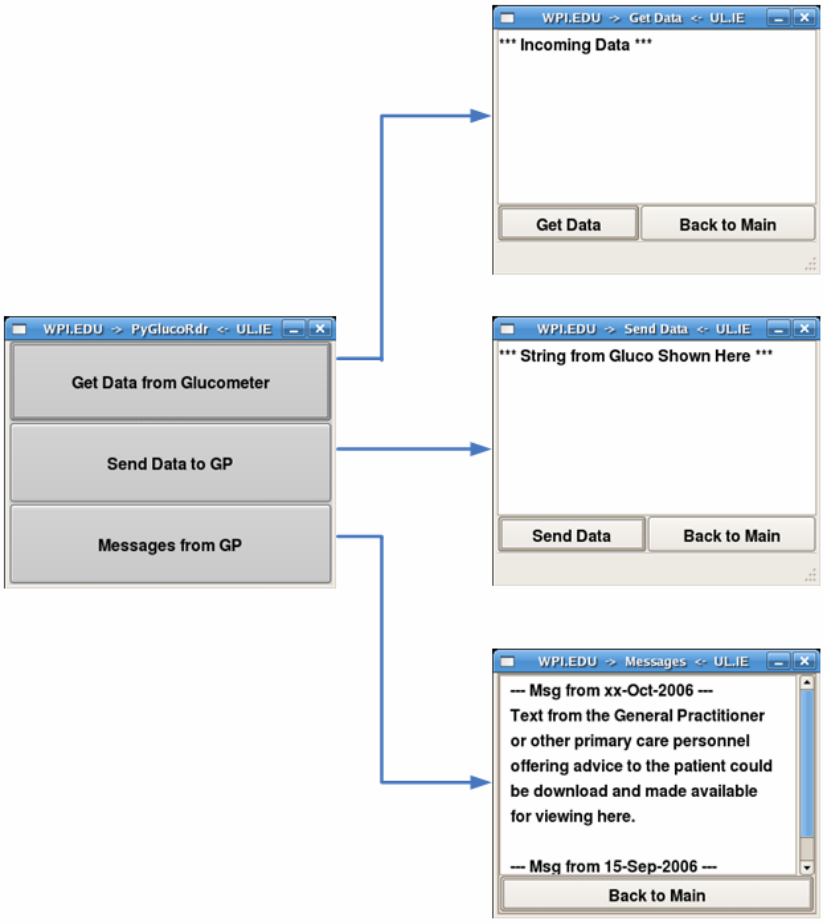


Figure 7-26: Graphical User Interface Functionality Diagram

As previously mentioned in section 6.2, the first of the three main buttons is used to open the window that will pull data from a given glucometer. As shown in Figure 7-27, the button

opens a window that greets the user with two additional options: retrieve the data from the glucometer, or return to the main menu to select a different option. If the button to retrieve the data is pressed, the underlying Python code calls the glucose meter protocol code to get the data from the glucometer and write it to a local file. If, however, the user selects the "Back to Main" button, the window is destroyed (i.e. closes and frees its memory use) and the user is returned to the main window to select another task.

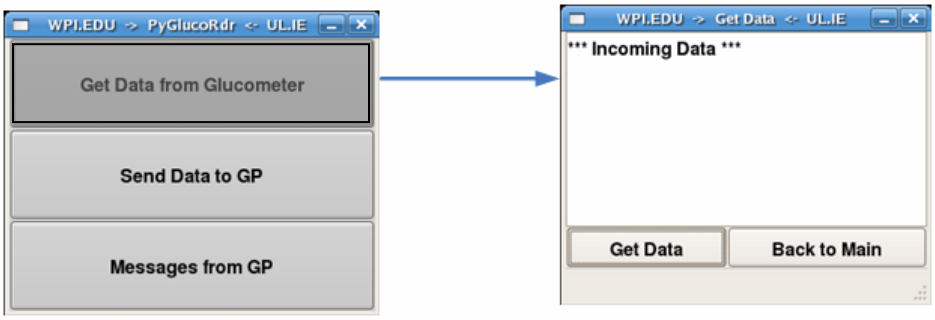


Figure 7-27: Screenshot of PyGlucoRdr's main window and Get Data window.

The second of the three main buttons opens a window dedicated to allowing the user to send the glucose meter data to the database via the supplied wireless link. Again, when pressed as in Figure 7-28, the button opens a window that gives the user two options: send the data to the database, or return to the main menu. If the user selects the send button, the data file is parsed and transmitted to the database. Again, if the "Back to Main" button is selected, the window frees its memory and closes, returning the user to the main window for further task selection.

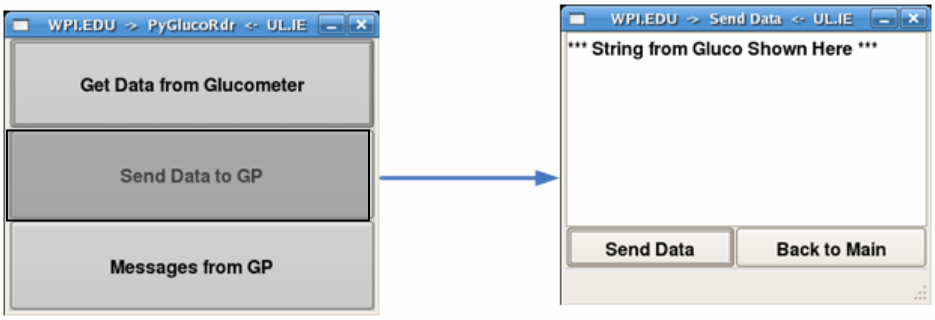


Figure 7-28: Screenshot of main window and Send Data window.

The third button of the main menu opens a window that will display any messages received from a health care professional. Figure 7-29 shows how the window is implemented and the option that the user has to return to the main window to select additional tasks.

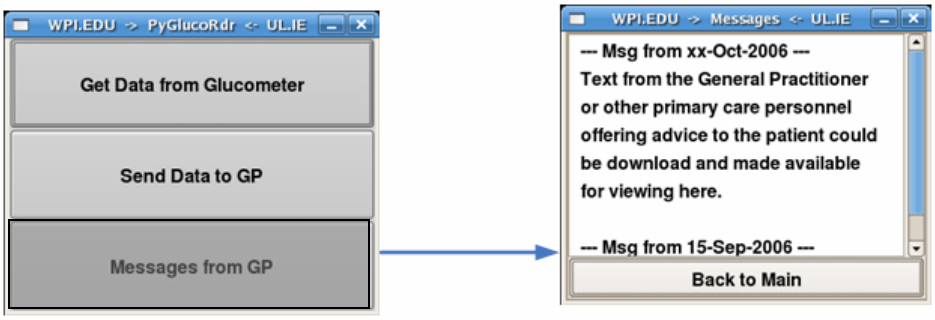


Figure 7-29: Screenshot of main window and Messages window.

This last bit of functionality is beyond the scope of our proof-of-concept, as it would require the development or adaptation of some form of message transmission similar to that of e-mail. It is also necessary to determine how the messages would be received by the device--either checked for or received when readings are transmitted to the database or as a separate process. These recommendations—and others—are discussed further in Chapter 9.

7.4.4 Database Implementation

The MySQL database creation requires both the server and client software to be installed on our Linux development computer. Both are easily installed in Fedora Core 5 with the following commands:

```
# yum install MySQL*
```

With the server and client software downloaded and installed, it is necessary to run the server (or MySQL daemon) before attempting to create/access the database with the following command:

```
$ /etc/rc.d/init.d/MySQLd start
```

Our database is tailored to meet the needs of our proof-of-concept and will require additional data fields to be created and automatically populated in future revisions. Please see the Code appendix for the MySQL code necessary to re-create our database.

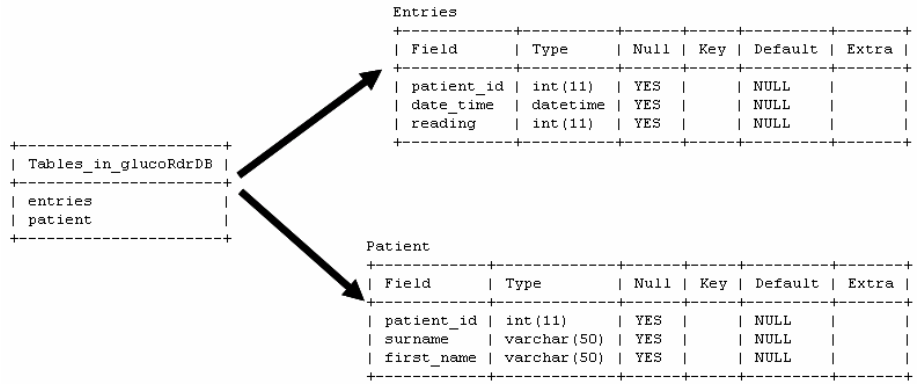


Figure 7-30: Tables in glucoRdrDB.

Our simplified database design, depicted in Figure 7-30, focuses on providing the basic table design. The two tables, 'patients' and 'entries', share a common field 'patient_id'. The 'patient_id' field currently represents an 11-digit, randomly generated number unique to each patient. This identifier would be unique to the patient and programmed into our proof-of-concept device on their behalf. Moreover, the identifier allows the two tables to exist separately—even in separate databases—while still providing a means for linking the data to the patient. This "separateness" of data and identity would allow for statistical analysis of data collected over the long term—the analysis of information in the 'entries' table—while still providing a means for health care professionals to look at the "big picture" on an individual basis when necessary—the analysis of the 'entries' table and an entry from the 'patient' table.

7.5 Wireless Module

When our wireless module, the Airborne - ABDB-ET-DP101, arrived we immediately began testing. Due to the proxy system set up at the University of Limerick, we were limited to testing the module with our personal wireless system at home. We plugged the Ethernet cable that came with the module into our Ethernet port, disabled our existing wireless card, and we were wirelessly connected to the internet. This established that our wireless module worked. We continued streaming music from the internet using the module for approximately 2 hours without disruptions.

7.6 LCD Troubleshooting

The following section serves to outline the difficulties encountered in getting the LCD up-and-running after frame buffer support was successfully enabled in the operating system

kernel. In addition, further experimentation techniques are offered to isolate the LCD's operational malfunction.

7.6.1 LCD Module Malfunction

The LCD driver circuit generates all of the expected values at this point; however, we have not been able to get it to reliably display. All of the bias voltages are in the range we expected and all of the lines from the LCD to the OMAP development board are as specified. Currently, there is no response from the Hantronix LCD when is it hooked up to the LCD driver circuit and plugged into the OMAP board, even when a command to fill all data lines with information is give. It seems that the board is simply not turning on at all. There are still several hardware possibilities for the Hantronix LCD not functioning.

7.6.2 LCD Module Malfunction Possibilities

1. VLCD is not at the correct level:

Upon first looking at the Hantronix HDG320240 datasheet, it showed an estimated 15V needed for input. Our development board can only supply a limited 4.2V or 3.3V input. We emailed several distributors and Hantronix, the manufacturer of the LCD. We received two replies both informing us that this LCD indeed is functional at a minimum of 3V. An explanation to the discrepancy was suggested to be that the voltage included the backlight inverter, which requires more than 10V as input (Personal Communication, August 2006). Please refer to Appendix A3, for the emails received regarding the voltage needed.

2. The correct signals are not being sent to the LCD:

Originally, we had a hard time determining which lines on the OMAP5912 OSK to connect to the Hantronix LCD. Several of the inputs are named using a different convention than the development board uses. The lines we had trouble with on the LCD are pin9 FLM, pin10CL2, pin11 M, and pin12 CL1. According to a Hitachi site, that has a glossary related to LCDs the following terminology can be used interchangeably. ("Display Product: Product Information").

46 What is the 'M' signal ?	The 'M' signal is a square wave of 50% duty which is used by the LCD to switch the polarity of the display driver voltage to ensure there is no DC component applied across the LC cell. Some LCD's generate this internally and some require it to be supplied
47 What is the FLM signal ?	First Line Marker. The signal is required at the start of every display frame. Other names for this signal can be: FRAME, Vertical sync, YD.
49 What is the CL1 signal ?	Data latch signal. Other names for this signal can be: LP, Horizontal sync, Load, Line clock.
50 What is the CL2	Data shift signal. Other names for this signal can be: Clock, XCK, Shift clock, Pixel clock.

signal ?	

Figure 7-31 Selection of table from Hitachi giving LCD terminology ("Display Product: Product Information").

We found several other references for the FLM signal being also the vertical synchronization signal, and M being the AC signal. We did not find the other terms defined in other resources.

3. OMAP5912 OSK not configured correctly for 4bit data

The OMAP development board is set up to drive a 16bit colour LCD from factory settings. However, this setting can be changed along with all of the other parameters of the LCD controller. Because this element of the project was completed so late in the term, we did not have enough time to test changing the settings on the pixel clock, the size, or changing the settings to the 4bit data setting.

4. LCD is blown or is not getting the correct ON command:

This is a possibility for the following reason also found at the Hitachi site, on the same table as the other definitions.

54 Why is the Power On/Off sequence important ?	It is important to achieve the correct timing to ensure that the LCD does not become damaged especially when switching ON. The basic requirement is to ensure that the display is not enabled without the supply and timing signals being present. For the ON t

Figure 7-32 Selection of table from Hitachi giving LCD terminology ("Display Product: Product Information").

Originally, we had the ON/OFF pin of the LCD connected to a GPIO line on the development board. However, when the software developer determined it would be complicated to hold that GPIO line high for extended periods of time, we simply re routed the wire and connected the ON/OFF to a 3.3V line. The theory behind this action is that a high signal would always be sent to the LCD and therefore we would not have to worry about turning it ON/OFF. This could have blown the LCD.

7.6.3 Experiments to Reveal Problem

We have conducted a few experiments on the LCD circuit to try to reveal the problem with the circuit. As a measure in caution, the first step to every experiment is a re-checking of the bias voltage levels. Once we confirm bias voltages, we continue with the experiment.

1. DC on Data Lines

We severed three of the four data lines so we could manually place DC voltage on the lines at different levels. The measured level supplied to these lines by the OMAP board is 1.2VDC. Once the lines were severed, we used an external voltage supply to vary the DC voltage on lines 15, 17, and 18 of the LCD, between 1.2V and 3.3V. No reaction was generated from this experiment.

2. Pixel Loading

We tried using a command to load all of the control data lines on the development with junk, just so every data line would be pulled high in some way. This command was tested on the LCD and driver from the 2005 student research team, and it produced the result of all the pixels receiving and displaying some type of information. When this same test was done with the Hantronix LCD and corresponding driver there was no response.

3. Connection Failure

There is a possibility that all of the signals are correct, yet the information is not making it to the LCD because of some connection malfunction. This experiment has very little scientific value; however, it was conducted anyway. Using a small piece of left over PCB, we attempted to connect the LCD outside of its connection header. By lining up the contacts on the LCD's ribbon cable with the surface mount connection on the outside of the header casing, we pressed the ribbon cable contacts onto the header surface mount pins. One time the LCD produced a response of black lines going across the screen. This result did not reoccur again after repeated attempts.

7.6.4 LCD Module Solution

To allow testing of the latest version of the software with frame buffer support we used the LCD module developed by the 2005 student team. This LCD and driver were proven to work with the OMAP5912 OSK board during the 2005 project term. The use of the past team's LCD and driver circuit allowed for confirmation that the current software revision does support loading a display onto an LCD.

8 Recommendations

The final deliverable of our project was the development of a proof-of-concept device. Modifying our device will turn the proof-of-concept into a marketable product. More than one generation of this product will be necessary to produce before it is market ready. To address this, we have formulated recommendations for both the next generation health monitor interface, which will build on and modify our final product; as well as recommendations for the final marketable product.

8.1 Proof-of-concept Recommendations

Our proof-of-concept device accomplished most of the objective set out for us by the Enterprise Research Centre. However, we recommend the following modifications be made to our device in order to demonstrate what this type of product is truly capable of.

- **Display:** We recommend a study on the optimum screen size for diabetic users with impaired vision. The Hantronix LCD described throughout this report ended up not functioning, but its selection for visible clarity remains important to our device.
- **Wireless module:** The integrated Airborne ABDB-ET-DP101 Wireless Ethernet Bridge is not a proprietary product, so it may be disassembled and re-engineered as necessary. The Airborne module was selected partially because of the transceiver chip used in the system and its potential for being used in embedded applications. We recommend designing a system to integrate this chip into the embedded system. Some type of control will need to be either programmed or designed into this system so it does not consume power when its services are not required. The system should be designed to turn on for a period long enough to search for a network, make any necessary data transfer, and then power down.
- **Battery powered:** While using the OMAP development board and the integrated wireless system, making the device battery powered is not feasible. However, as the development goes further, we recommend that the system's power needs be monitored closely to maximize battery time.
- **Programming:**
    - **Ability to receive health related messages –** Two-way transfer of information is not enabled on our device. We recommend that this capability be developed and that a history of at least 10 messages be kept for the user to review. The messages should

be categorized by date *sent* instead of the date *received* to ensure different headings for the messages.

- **Clear feedback about operation** – We recommend there be a clear indicator for the user as to the status of the device. As illustrated in the concept drawings of the product in Chapter 5, LEDs could be implemented on the device to alert the user there has been a change in status of the device. Another option is to display messages such as "Transmitting Now" or "Uploading Data" on the screen; these would serve the same purpose.
- **Database** – The database currently is a basic MySQL application. We recommend that this database be bolstered, and backed up with a more secure application because the medical information it contains should be secure. PostgreSQL could be used as the back end of the MySQL application to make it more secure.

8.2 Final Product Recommendations

The following recommendations are suggested for implementation, as the product is getting ready for the market. These developments are likely to come into account only when the device is fine-tuned for market.

- **Development board:** The OMAP5912 OSKis a good platform for the development of this type of product, but it does contain many features unnecessary for our embedded device. We recommend that these unnecessary subnets be removed, leaving only those necessary to control the device.
- **Message alert:** When a new message is received, it would be helpful display an icon in the corner of the screen to alert the user to the presence of a new message.
- **Casing:** We recommend that the final device not exceed the size of a Personal Digital Assistant (PDA) so that it fits in a person's pocket comfortably. The casing should have smooth edges and avoid having connectors that protrude from its casing.

Connection to glucometer: We recommend the development of a new form of interfacing with the glucometer. Currently, glucometers interface with the OMAP board through the serial port. The data output connection on most common glucometers is a simple stereo plug; by integrating a stereo plug connection into the device the bulky serial port component can be eliminated.

9 Conclusion

The final system presented to the Enterprise Research Centre fulfils most of our project's original missions and objectives. Referring back to Chapter 2, our research aimed to assist the Enterprise Research Centre at the University of Limerick design, develop, and implement a proof-of-concept wireless system capable of remote data monitoring and the real-time acquisition of remote patient data in a primary care environment with intent for future statistical research and analysis on said data. We will fulfil our mission by:

1. **Developing a device and its firmware with prior, current and soon to be developed Glucometers for data retrieval,**

   We were able to develop a device that downloads data from the TheraSense FreeStyle Mini glucose meter. Our application then takes that data and parses it in order for it to be sent to the database, and places it in the appropriate columns. We have left documentation on the methods behind creating the protocol for interfacing with different types of glucose meters.

2. **Making our device portable and use existing WiFi infrastructure to report readings to a database system for future analysis,**

   Our device meets the needs of our sponsors in regards to portability. Our device fits into a case, in which it can be transported for demonstrations. The type of wireless network used, IEEE 802.11b, is common in public areas, and is a service that is becoming more and more widespread.

3. **Constructing an externally-hosted, standards-based database system for general practitioner's use and capable of supporting multiple patients while adhering to privacy concerns,**

   We used MySQL to create a small example database. We did not create an interface for the general practitioner to use when accessing the database. The privacy concern has not yet been addressed.

4. **Designing and implementing an intuitive user interface for easy accessibility to our device's controls.**

   Our device features an intuitive text based graphical user interface. The software smoothly integrates with the designed user input circuit, which consists of three tactile pushbuttons. The low number of controls available to the user is easy to handle and control.

Our research team produced several "how-to guides" that are provided in the Appendix of this report that will aid the next team of researchers in making significant forward progress without the need to re-explore work completed by our research team. The "Guide to Open Embedded", provided in Appendix A5, is specifically intended to allow future software engineering get a development computer up-and-running in a relatively short period.

It is our hope that our proof-of-concept device will be a solid base upon which future researchers can develop a market-friendly product. The future of this product could:

1. **Aid in diabetic research,**
   This device will provide an opportunity for data collected to be used in further statistical research and analysis.
2. **Help general practitioners monitor their diabetic patients in near real time,**
   This device will help general practitioners make changes to their patients' treatment plan easier, and provide suggestions and recommendations as to what things the patient should or should not be doing.
3. **Simplify blood glucose monitoring for diabetic patients.**
   As a result of this device, there will be no need to maintain logs of their levels. Furthermore, the frequency with which diabetics equipped with this device will need to meet with their general practitioner may be reduced as the communication abilities of this device are used.

We hope that the Enterprise Research Centre at the University of Limerick finds our research, documentation, and developed proof-of-concept device useful and a good starting point for the development of a market-friendly device.

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A1 Project Description

Scope

The aim of the project is to develop and apply a wireless data transmission technology for real-time data acquisition of remote patient data in a primary care environment. Possible applications include the monitoring of diabetes, cardiovascular, asthma and chronic disease management.

Objective

The objective is to deliver a prototype wireless interface device comprising of short-range wireless transmitter communicating over a proprietary wireless access point (WAP) updating individual patient data in a remote database over the internet.

A microprocessor-based mobile RF transceiver interface, with the following facilities:

- RS-232 and USB interfaces for connection to various Glucometers (and over which firmware may be optionally uploaded)
- Built-in clock for real-time data logging with access to the Rugby atomic clock transmission (60 KHz) for accurate calibration.
- Programmable ID
- Built-in memory for extensive data storage
- Large LCD display
- Eight user-interface buttons (with debounce, etc.) directly interfaced to the microprocessor to enable functionality to be assigned through software.
- Bluetooth transceiver module interfaced to microprocessor.

Outline of Phases

Possible phases may include, but are not confined to, the following:

Phase 1: Design of interface circuitry to digitally interface with a proprietary Glucometer to record and store routine glucometer data in memory.

Phase 2: Design of a circuit to drive Bluetooth transceiver for data transmission to wireless access point.

Phase 3: Develop microprocessor-based software to control overall functionality and protocols of the user interface, RS-232 and USB connections.

Phase 4: Develop related software to interface securely between the interface device and the Internet based database. This should utilize internationally recognized encryption.

Phase 5: Design and integrate clock, memory storage and unique ID configuration for each patient's unique interface device.

Phase 6: Design and construct a database using commercially available software (e.g. Microsoft SQL, MySQL, etc for storage of patient-related data)

General Requirements

- Issues of noise and co-channel interference should be considered in the design of the RF circuitry (transmitter and receiver).
- The interface device components can be based on commercially available components.
- The proposed system must incorporate a rechargeable battery-circuit and power consumption minimization should be prominent in the system design.
- Through-Hole Technology may be used to build 'breadboard' prototypes, but Double-sided Surface-Mount technology (SMT) should be used to build the final circuitry, especially for the "interface device", where miniaturization is important.

Other Consideration and Options

- System expansion should be taken into consideration and components specified should incorporate at least a 25% increase in functionality (e.g. by provision of redundant I/O pins on microprocessor chip, etc).
- The database application must support significant scalability.

A2 Complete Parts List

Below are the parts used for the circuits. The part reference numbers refer to the way they appear on the PCB.

A2.1 LCD Driver Circuit

Part Reference	Description
R1	RESISTOR_SMT, 22.0K-SMT
R2	RESISTOR_SMT, 22.0K-SMT
R3	RESISTOR_SMT, 22.0K-SMT
R4	RESISTOR_SMT, 22.0K-SMT
R5	RESISTOR_SMT, 180K-SMT
R6	RESISTOR_SMT, 4.70K-SMT
R7	RESISTOR_SMT, 4.70K-SMT
R8	RESISTOR_SMT, 4.70K-SMT
R9	RESISTOR_SMT, 4.70K-SMT
C1	CAP_ELECTROLIT_SMT, 4.7uF-SMT
C2	CAP_ELECTROLIT_SMT, 4.7uF-SMT
C3	CAP_ELECTROLIT_SMT, 4.7uF-SMT
C4	CAP_ELECTROLIT_SMT, 4.7uF-SMT
C5	CAP_ELECTROLIT_SMT, 4.7uF-SMT
C6	CAP_ELECTROLIT_SMT, 2.2uF-SMT
C7	CAP_ELECTROLIT_SMT, 2.2uF-SMT
U1	OPAMP, LP324M
U2	REGULATOR, LP2966
J1	6 Line ribbon connector
J2	LCD Connector
	HiRose Connector

A2.2 User Interface Circuit

Part Reference	Description
R1	RESISTOR_SMT, 10K-SMT
R2	RESISTOR_SMT, 10K-SMT
R3	RESISTOR_SMT, 10K-SMT
SW1	SWITCH, PB_DPST
SW2	SWITCH, PB_DPST
SW3	SWITCH, PB_DPST
J1	6 LINE RIBBON CONNECTOR

A2.3 Parts Ordering Information

Farnell Total =	€ 53.69
Total with tax =	**$64.43**

Vat Tax @20% $10.74

	User Input Circuit				
	Button	**Ribbon Cable**	**Headers**	**Resistors**	**PCB**
PF Part Number:	1499270	3784381	148519	9332391	141303
Manufacturer:	OMRON	TYCO	TYCO	MULTICOMP	KELAN
Manufacturer Part Number:	B3F-1000.	1483351-1	7-215079-6	MC 0.1W 0805 1% 10K	141303
Number of units	6	2	10	50	1
Price per Unit Euro	0.75	1.05	0.63	0.03	12.26
Total Price	€ 4.50	€ 2.10	€ 6.30	€ 1.50	€ 12.26

	LCD Driver Circuit				
	IC	**2.2uF Cap**	**4.7uF Cap**	**22k Res**	**180k Res**
PF Part Number:	9486941	9418644	913285	9332820	9332731
Manufacturer:	National Semiconductor	MULTICOMP	MULTICOMP	MULTICOMP	MULTICOMP
Manufacturer Part Number:	lp324m	LV2R2M2AB-0513(E)	913-285.	MC 0.1W 0805 1% 22K	MC 0.1W 0805 1% 180K
Number of units	4	10	10	50	50
Price per Unit Euro	1.37	0.145	0.152	0.03	0.03
Total Price	€ 5.48	€ 1.45	€ 1.52	€ 1.50	€ 1.50

	4.7k Res	**LCD connector**	**Voltage Regulator**	**1uF Cap**
	9333266	1079942	3024349	967233
	MULTICOMP	MOLEX	National Semiconductor	MULTICOMP
	MC 0.1W 0805 1% 4R7	522071885	LP2966IMM-3030	MCCTA104M035
	50	2	4	5
	0.03	1.46	2.04	0.6
	€ 1.50	€ 2.92	€ 8.16	€ 3.00

Distributor Number	**Part No.**	**Manufacturerer (MFG)**	**MFG Part No.**	**Unit**	**Sub**	**S+H**	**Total Cost**
1-800-552-170	LP324M-NDD	National Semiconductor	LP324M	0.64	0.64	31	37.0
1-800-552-170	H2252-ND	HiRose Electronics Co. LTD	FX2-80S-1.27SV	5.42	5.42		
817- 804-3898	HD320240	Hantronix	HDG320240	59.00	59.00	24.77	83.7
353-91-840838	ABDB-ET-DP101	QuaTech	ABDB-ET-DP101	206.92	206.92	10	216.9
Monitary Units are in Euro Digikey products quoted together		**Conversion Rate** 1 USD = 0.782				**Total**	**337.7**

A3LCD Correspondences

These are correspondences between ULIE A'06 team member Vanessa Castro and two separate sources, concerning the voltage listed in the Hantronix HDG320240 LCD datasheet. The information contained in these emails details that the datasheet has a misprint in the driving voltage level (VLCD). On the datasheet, the necessary VLCD is around 15V, but this appears to be a misprint, and the true value should be around 3V.

A3.1 Correspondence with Mouser Electronics

From: vanessa.beck@mouser.com [Vanessa.Beck@mouser.com]
Sent: Tue 8/22/2006 9:59 AM
To: Castro, Vanessa M
Cc:
Subject: FW: Technical Question regarding LCDs
Attachments:

Hello Vanessa,

Yes, you should be fine using the Hantronix.

The specification sheet lays people astray. It works with a minimum of 3V.
My only reasoning behind the misprint is that Hantronix is steering people to purchase the backlight inverter, which does require more than 10V of input.
If you require further information, or to place an order, please contact me.
VANESSA BECK
MOUSER ELECTRONICS
800-298-5076 EXT 2033
VANESSA.BECK@MOUSER.COM
TECHNICAL SUPPORT

-----Original Message-----
From: Castro, Vanessa M [mailto:vmcastro@WPI.EDU]
Sent: Tuesday, August 22, 2006 5:37 AM
To: jennifer.burns@mouser.com
Subject: Technical Question regarding LCDs

I am interested in finding out more information about this LCD Module -
Hantronix HDG320240. What is the minimum voltage input that the LCD would work on?
I am going to be using a development board which supplies 3.3V and 4.2 V.
Would I still be able to use this LCD?

Any information you can send me will be greatly appreciated.

Thank you!

Sincerely,
Vanessa Castro

A3.2 Correspondence with Solar Technologies

From: George Lim / Solar Technologies [georgel@lcdsolar.com]
Sent: Thu 8/17/2006 2:59 PM
To: Castro, Vanessa M Cc: Subject:
RE: Inquiry from Information Search page HDG320240 Data Sheet Requested | Display Electronics Requested
Attachments: HDG320240 (Device Specification).pdf(826KB)

Dear Vanessa. Attached is the data sheet you requested.
This particular LCD does work on 3V.The data sheet is incorrect. Based on my

communication with Hantronix, and customer reviews, it works on low power

circuits. If you require any more assistance, or to place an order, please

contact me.

Thank you,

George S. Lim
Solar Technologies, Inc
Tel 949-458-1080
Fax 949-458-1081
Email: georgel@lcdsolar.com
www.lcdsolar.com

-----Original Message-----
From: vmcastro@wpi.edu [mailto:vmcastro@wpi.edu]
Sent: Thursday, August 17, 2006 4:15 AM
To: sales@lcdsolar.com; solar_stuff@yahoo.com
Subject: Inquiry from Information Search page HDG320240 Data Sheet Requested | Display Electronics Requested

Below is the result of your feedback form. It was submitted by
(vmcastro@wpi.edu) on Thursday, August 17, 2006 at 07:14:57
---

referer: http://www.lcdsolar.com/index.htm
page_name: http://www.lcdsolar.com/verify_info.php
form_name: verify_info

A4List of Connections

From HiRose Connector

HiRose Pin	Designation	18 Pin LCD	Other connection	Designation
1	GND	6,7,14	.-C8, J1p4, -C9	UIgnd
9	3.3v		J1p2	Uipow
11	3.3v	1, 8 via C9	IC2p1	Vref Vin
12	3.3v		R1, +C7, +C6, IC1p4	Vref Vin
15	GPIO7		J1p6	Sw3up
17	GPIO2		J1p5	Sw1ok
19	GPIO9		J1p1	Sw2down
21	GPIO12	13		GPIO
43	LCD.P2	15		DB3
45	LCD.P4	16		DB2
47	LCD.P6	17		DB1
49	LCD.P8	18		DB0
57	LCD.PCLK	10		Dshift/PCLK
58	LCD.AC	11		M/AC
59	LCD.VSYNC	9		FLM/VSYNC
60	LCD.HSYNC	12		Dlatch/HSYNC
79	GND		.-C5, -C6, R5, IC1p11	

LCD Header

18 Pin LCD	Designation	HiRose Pin	Designation	Other Connection
1	VL (3.3v)	11	3.3v	
2	V6		Bias	.-C1 / +C2
3	V3		Bias	.-C2 / +C3
4	V4		Bias	.-C3 / +C4
5	V5		Bias	.-C4 / +C5
6	VSS/ GND	1	GND	.-C9 / p14
7	VSS / GND	1	GND	.-C9 / p14
8	VDD (3.0v)		V2 out Vref	Pin 7 Vref
9	FLM / VSYNC	59	LCD.VSYNC	
10	DATA SHIFT / PCLK	57	LCD.PCLK	
11	M / AC	58	LCD.AC	
12	DATA LATCH / HSYNC	60	LCD.HSYNC	
13	INHX ON/OFF	21	GPIO 12	
14	VSS / GND	1	GND	.-C9 / p6
15	DB3	44	LCD.P3	
16	DB2	43	LCD.P2	
17	DB1	42	LCD.P1	
18	DB0	41	LCD.P0	

A5 Guide to OpenEmbedded for OMAP5912 OSK

The following is a guide designed to document the steps necessary for getting an OpenEmbedded filesystem and toolchain built in an effort to accelerate the time required to start working with the OMAP5912 OSK development board from Digital Spectrum.

A5.1 System Requirements

The preferred development environment for OpenEmbedded is a dedicated machine running a variant of the Unix operating system—preferably a flavor of Linux. Early on, the team was still deciding which operating system to use on the OMAP5912 OSK development board; the decision was to setup a development machine using a recommended operating system for development between multiple operating systems. MontaVista Linux prefers a development environment on a Red Hat-based system and other development options listed Red Hat as a suitable development environment; that is, Red Hat Package Manager (RPM) files are available to ease into first-time setup. Thus, the decision was to use the latest free distribution from Red Hat as a development operating system—Fedora Core 5 built with the 2.6.17 Linux kernel. It should be noted that the decision to use Fedora Core 5 was made simply out of flexibility and that any Linux distribution (i.e. Ark, Debian, Gentoo, SuSE, Ubuntu, etc.) should be capable of OpenEmbedded development.

A5.1.1 Hardware Requirements

Although OpenEmbedded and BitBake can run on virtually any machine capable of running a Unix-based operating system, it is important to note that the speed of a well-equipped machine is preferred in a development system. It is recommended that future development machines meet-or-beat the project team's primary development machine at this time: a Compaq Presario 2105US notebook computer with the following specifications:

- AMD AthlonXP Mobile Processor @ 1.5-GHz
- 512-MBytes of DDR266 SDRAM
- 15-GByte Linux Partition (from Standard 40-GByte, 5400 RPM, Notebook HDD)
- ATI Radeon IGP Graphics

A5.1.2 Software Requirements

OpenEmbedded requires certain software be present in order to build applications and filesystems directly related to your development board—in our case, the OMAP5912 OSK. As such, it is necessary to ensure that the proper development packages are downloaded and installed before proceeding to acquire OpenEmbedded. Most modern Linux installation utilities will offer an option for a standard *development* build of the operating system—if possible, this option should be selected. In most cases, these options will automatically download, install, and update the most common development packages for use on your machine. Alternatively, a bare bones installation of Linux could be installed and the following required development packages installed and updated manually:

Tools to Download Source Files					
wget	curl	ftp	cvs	monotone	subversion

Tools to Unpack Source Files				
tar	bzip2	gzip	unzip	psyco
ccache	Perl	texinfo	texi2html	diffstat

Tools to Build Various Document Packages			
jade	Docbook	sgmltools	docbook-utils

Other Packages				
sed	Bison	bc	glibc	pcre

It is important to note that this is a partial list that is continuously being updated by the OpenEmbedded project. It is strongly recommended that the official OpenEmbedded Wiki (http://www.openembedded.org/wiki/RequiredSoftware) be consulted to confirm that all required software is gathered. Further information related to the preferred method of setup on a particular Linux distribution is also available at the official OpenEmbedded Wiki (http://www.openembedded.org/wiki/OEandYourDistro).

A5.2 Getting Started with OpenEmbedded

The following sections aim to summarize the official Getting Started guide available at the OpenEmbedded Wiki (http://www.openembedded.org/wiki/GettingStarted). In addition, this guide will tailor its advice and recommendations to that of the OMAP5912 OSK development board.

A5.2.1 Initial Setup

With your development computer now up-and-running with all of the required software (see Section 1.2) installed and updated, it is necessary to begin the process of building the working directory structure that will be used to maintain downloads and unpacked source required for our development environment. Please note that all development should be done from a standard *user account* (i.e. not from a *root* account). This is not only for the security of the development machine or to fulfill standard practices of development in a Unix-based operating system, but also to fulfill certain dependencies that OpenEmbedded requires when creating and for writing to cache files. In addition, it is also useful to have access to a true ${HOME} variable, as only created under a user account.

To create the proper directory structure, please issue the following commands from a user account logged into a valid terminal:

```
$ cd ~
$ mkdir -p /stuff/build/conf
$ cd /stuff
```

The first command ensures that you are in the HOME directory of your user account. The second command creates the directory structure: a folder 'conf' within a folder 'build' within a folder 'stuff'. This directory structure will be expanded upon as we further develop our OpenEmbedded development environment. Finally, the last command changes the current directory to 'stuff', where we will be issue most of our commands to build the toolchain and filesystem for our development board.

A5.2.2 Installing BitBake

BitBake is the build tool of choice for working with OpenEmbedded development environments. Originally created as a spin off of Portage, the preferred package manager for the Gentoo Linux distribution, it is still being updated and maintained by the berliOS (http://developer.berlios.de/projects/bitbake) development team. At the time of this writing, the current version of BitBake is 1.6.0 and is highly recommended over the previous 1.4.2 stable release.

The installation of BitBake requires the 'subversion' tool (see Section 1.2) to download the source tree. Please make sure this application is installed and updated on your machine before proceeding. Then, issue these commands from a valid user account logged into a terminal to download the appropriate source files:

```
$ cd ~/stuff
$ svn co svn://svn.berlios.de/bitbake/branches/`svn ls svn://svn.berlios.de/bitbake/branches/ |grep[0-9] |tail -n 1`
bitbake
```

The first command switches us to the 'stuff' directory, which we created in our initial directory structure setup in Section 2.1, within our user account's HOME directory. The second command is responsible for grabbing the BitBake application from a valid repository. Checking the contents of your 'stuff' directory should reveal the presence of a new 'bitbake' directory.

A5.2.2.1 Updating BitBake

As previously mentioned, BitBake is constantly being updated. Thus, it is important to check periodically that you are running the latest stable release. To update BitBake, simply issue the following command from the terminal of a valid local user account:

```
$ cd ~/stuff/bitbake
$ svn update
```

The first command switches us to the directory in which BitBake has been installed, while the second command uses the 'subversion' tool to check for any updates to the source tree.

If updates are present, it will automatically update your local BitBake repository.

A5.2.3 Getting the OpenEmbedded Development Tree

The OpenEmbedded development tree stores all the build files, packages, and configuration files necessary for working with any of the supported development boards. In order to obtain the database, an updated installation of 'monotone' is required (see Section 1.2). The acquisition of the OpenEmbedded database is a two-part process involving the (1) initial downloading and updating of the database and (2) the decompression of the database into our working directory structure. The following commands are required to complete both steps:

```
$ cd ~/stuff
$ wget http://www.openembedded.org/snapshots/OE.mtn.bz2
$ bunzip2 OE.mtn.bz2
$ mtn --db=OE.mtn pull monotone.openembedded.org org.openembedded.dev
$ mtn --db=OE.mtn checkout --branch=org.openembedded.dev
```

The first command moves us to the root of our development hierarchy, the 'stuff' directory. The second command uses the 'wget' tool to download the latest snapshot (i.e. archived copy) of the OpenEmbedded development tree's database. Because this database is compressed, the third command uses the 'bunzip2' decompression utility to expand the file. Finally, the fourth and fifth commands update the database and download the necessary branches of the development tree for further development. In the end, we are left with an up-to-date 'org.openembedded.dev' development tree that has been copied to our local development computer.

A5.2.3.1 Updating the OpenEmbedded Development Tree

Since the development tree of the OpenEmbedded project is updated quite frequently, it is desirable to synchronize your local copy of the development tree at least once per day. Using a valid local user account, execute the following commands from a terminal to update your local OpenEmbedded repositories:

```
$ cd ~/stuff/org.openembedded.dev
$ mtn pull
$ mtn update
```

The first command bring us to our working 'stuff' directory, while the second and third commands download the latest snapshot of the OpenEmbedded database and synchronize our local expanded repository, respectfully.

A5.2.4 Creating a Local Configuration File

OpenEmbedded uses a local configuration file 'local.conf' as a location for you to store the type of processor you are developing for, along with a host of other specification possibilities. By default, BitBake will look at your PATH for any 'local.conf' file to execute off

of, but it is always safe to simply put your 'local.conf' file in the *~/stuff/org.openembedded.dev/conf* directory providing it is appropriately backed up before performing any updates to your local OpenEmbedded repository.

Since this is intended to be a guide, the 'local.conf' file will be included with a little explanation. More detailed information about each of the fields is available in the *org.openembedded.dev/conf/local.conf.sample* text file. Please copy and paste the following text into your 'local.conf' file as it is pre-configured for use with the OMAP5912 OSK development board:

```
# local.conf for OMAP5912 OSK
# Authored by SRS on 28-Aug-2006

DL_DIR = "${HOME}/stuff/sources"
BBFILES = "${HOME}/stuff/org.openembedded.dev/packages/*/*.bb"
TMPDIR = /${HOME}/stuff/build/tmp

PREFERRED_PROVIDERS = "virtual/qte:qte virtual/libqpe:libqpe-opie"
PREFERRED_PROVIDERS += " virtual/libsdl:libsdl-qpe"
PREFERRED_PROVIDERS += " virtual/${TARGET_PREFIX}gcc-initial:gcc-cross-initial"
PREFERRED_PROVIDERS += " virtual/${TARGET_PREFIX}gcc:gcc-cross"
PREFERRED_PROVIDERS += " virtual/${TARGET_PREFIX}g++:gcc-cross"



MACHINE = "omap5912osk"
TARGET_ARCH = "arm"
TARGET_OS = "linux"
DISTRO = "openomap"
IMAGE_FSTYPES = "jffs2 tar ext2"
BBINCLUDELOGS = "yes"
CVS_TARBALL_STASH = "http://www.oesources.org/source/current/"
```

A5.2.5 Setting Up the Local Environment

BitBake is primarily a command line utility and, as is common in Unix-based environments, it is necessary to specify the location at which your BitBake source is accessible as well as the location of the repository from which BitBake will be building things. Both of these variables need to be applied at the start of each session; therefore, it is in our best interest to include these environment variables in the shell profile of our user account. Since our development machine is a Fedora Core 5 machine, the default shell is the Bourne Again Shell (i.e. bash), which uses the text file *~/.bash_profile* to store its settings. Depending on your Linux distribution and chosen shell, you may need to edit a text file like *~/.profile* or something similar. Likewise, the syntax for the implementation of the environment variables may vary from shell-to-shell (i.e. 'bash' uses *export* whereas 'tcsh' uses *setenv*).

Once you have your profile's configuration file opened in a standard text editor, simply append the following lines into the file:

```
export PATH=~/stuff/bitbake/bin:$PATH
export BBPATH=~/stuff/build:~/stuff/org.openembedded.dev
```

A5.2.6 Building with BitBake and OpenEmbedded

Now that BitBake and OpenEmbedded have both been setup, you are ready to begin the process of building a toolchain and filesystem for use with the OMAP5912 OSK development board. It is important to note that BitBake should always be run from within the *~/stuff/build* directory. This will help keep things organized and speed up future build operations, since your sources will remain intact.

Since we are dealing with the OMAP5912 OSK development board, we will want to build a filesystem for the board using the OpenOMAP distribution of Linux with the stable release of the v2.6 Linux kernel. At the time of this writing, that is the 2.6.12 version of the kernel—despite 2.6.17 being the current stable release for x86-based machines. The following commands can be executed to begin the build process:

```
$ cd ~/stuff/build
$ bitbake linux-omap1
```

You should now be successfully downloading and installing the necessary packages to build the toolchain and filesystem for the OMAP5912 OSK development board. It should be noted that this process will take quite a bit of time to complete—nearly three hours on our team's build machine when starting from a clean *~/stuff/tmp* directory. The speed of your Internet connection will greatly impact the speed at which you can download and patch files from various online repositories and, as such, will effect your overall build time significantly.

Upon successful completion of the build, it will be necessary to build the actual image file that will be copied to the development board. To build the file, issue the following command:

```
$ cd ~/stuff/build
$ bitbake bootstrap-image
```

The first command ensures that we are still in our build directory, while the second executes the BitBake command necessary to build the image file. At this point, you are now able to move on to flashing the development board with your newly made image file.

A5.2.7 Cleaning Files to Achieve Successful Build

It is not uncommon to need to re-build the toolchain, filesystem, or even the image file throughout the development phase of an engineering project. Rather than completely removing the *~/stuff/tmp* directory each time a change is made to a build file to ensure a successful re-build, simply execute the BitBake clean instruction for that particular BitBake build command. For example:

```
$ cd ~/stuff/build
$ bitbake -c clean linux-omap1
```

The first command will ensure that we are still in our build directory, while the second will execute a cleaning loop specificed in the BitBake file. It will automatically remove the necessary directories from your *~/stuff/tmp* directory. When it has successfully completed, simple re-execute the BitBake command you wished to execute.

Please note that although this method is successful a majority of the time, it may be necessary to completely remove the *~/stuff/tmp* directory from time-to-time to solve a build problem. In some cases, it may even be necessary to remove the *~/stuff/sources* directory, too.

A5.3 Solutions to Problems Encountered Building OE

The following section will serve to document problems encountered and the solutions used to successfully build a toolchain and filesystem for the OMAP5912 OSK development board using BitBake and the OpenEmbedded repository. It is important to read the full error messages encountered during any build, as it inevitably points to a text file (or two) that contains more information that may be useful to resolving your issue.

A5.3.1 Preferred Version of Binutils

If you have used the 'local.conf' file presented in Section 2.4, you should not be encountering this problem. If, however, you notice that as BitBake attempts to compile various pieces of the toolchain (i.e. the GNU C Library) it may fail. Thus, it becomes necessary to include the following lines of code your 'local.conf' file before proceeding:

```
PREFERRED_VERSION_binutils-cross = "2.15.94.0.1"
PREFERRED_VERSION_binutils = "2.15.94.0.1"
```

With this change made, you will now need to clear the temporary directory that was holding the current filesystem and toolchain build. This task can be completed by the following command:

```
$ rm -rf ~/stuff/build/tmp
```

When the forced, recursive removal of the 'tmp' directory has been completed, the BitBake build can be attempted once more.

A5.3.2 Modifying the ARM9 Configuration File

The OMAP5912 OSK uses an ARM9 microprocessor and, as such, BitBake relies upon the 'TUNE-ARM926EJS.CONF' file for compilation instructions. The tune file, located in *~/stuff/org.openembedded.dev/conf/machine/include*, has a suggestion to add a hyphen to the

tuned architecture name if it fails a build. In our case, this resolved the issue. Please make sure that your ARM9 tune file contains the following two, uncommented lines of code:

```
TARGET_CC_ARCH = "-march=armv5te -mtune=arm926ej-s"
PACKAGE_ARCH = "armv5te"
```

A5.3.3 Modifying the OMAP BitBake File

Finally, it may be necessary to alter the BitBake configuration file called by the 'bitbake linux-omap1' command. The file *linux-omap1_2.6.12-rc2.bb* is located in *~/stuff/org.openembedded.dev/packages/linux* and can be opened with any standard text editor.

A5.3.3.1 Trouble with Das U-Boot

The first error encountered was in relation to the 'mkimage' application, which is depended on 'uboot'--the application responsible for putting the filesystem on our development board. To resolve this error, simply make sure the following line is uncommented:

```
DEPENDS = “uboot”
```

A5.3.3.2 Configuring for OMAP5912 OSK

It is possible that another error will appear that is directly related to your 'local.conf' file. Although we have specified the 'omap5912osk' in the 'local.conf' file of Section 2.4, it may still be possible that it does not execute the proper deployment loop in this BitBake file. Thus, if another error is encountered, please try modifying the *do_deploy_omap5912osk()* loop to look like:

```
do_deploy_omap5912osk() {
	install -d ${DEPLOY_DIR_IMAGE}
	arm-linux-objcopy -O binary -R .note -R .comment -S arch/arm/boot/compressed/vmlinux
${DEPLOY_DIR}/linux.bin
	gzip -f -9 ${DEPLOY_DIR}/linux.bin
	mkimage -A arm -O linux -T kernel -C gzip -a 0x10c08000 -e 0x10c08000 -n "OE" -d
${DEPLOY_DIR}/linux.bin.gz ${DEPLOY_DIR}/uImage_bb.cc
	cp ${DEPLOY_DIR}/uImage_bb.cc /tftpboot
#	 install -m 0644 arch/${ARCH}/boot/${KERNEL_IMAGETYPE}
${DEPLOY_DIR_IMAGE}/${KERNEL_IMAGETYPE}-${MACHINE}-${DATETIME}.bin
}
```

A5.3.4 Resources for Additional Help

It is possible that, since this is only a compilation of errors encountered by the project team on a specific development machine, that you may encounter other errors during your build.

Thus, it is important to know where to turn for help outside of this basic guide.

OpenEmbedded's documentation is currently divided between a wiki (i.e. an online resource that allows users to add and edit content collectively) and a developing user manual. There is also an online video that shows how to setup a generic OpenEmbedded development machine; however, the details within this guide are far more precise and tuned to the OMAP5912 OSK development board. These resources should be consulted first, in an effort to solve any new problems encountered.

- OpenEmbedded Wiki: http://www.openembedded.org/wiki
- OpenEmbedded User Manual: http://www.openembedded.org/user-manual
- Video Tutorial: http://www.openembedded.org/screencasts/org.openembedded.htm

A5.3.4.1 Live Help

If none of the resources listed in this guide prove helpful, you may always find it useful to turn to a live representative for further assistance with OpenEmbedded and BitBake. Internet Relay Chat (IRC) is still the preferred mode of communication in the open source community and, as such, the OpenEmbedded developers and other enthusiasts can be found on:

- *#oe* on *irc.freenode.net*

A5.4 Updating Das U-Boot

At this point, you should now have successfully completed a 'bitbake linux-omap1' build. During that process, an updated version of Das U-boot, the bootloader for the OMAP5912 OSK development board, should have been downloaded, patched, and had its binary generated. This binary can be transferred to the development board and copied to flash memory.

A5.4.1 RS-232 Communication with Development Board

The development board is capable of communication with your development computer in several different ways—including RS-232 (serial), 802.3 (Ethernet), and USB. For ease of initial setup (i.e. updating U-Boot), a serial connection has been selected. For proper communication, your development computer requires a valid communications monitoring tool. Since your development machine should be running Linux, the C-Kermit application (http://www.columbia.edu/kermit) is ideal. At the time of this writing, v8.0.211 is the latest release and is the version used throughout this document.

With C-Kermit (not G-Kermit) installed on your development computer, we can proceed to setup the necessary parameters for interaction with the OMAP5912 OSK development board. Because we will be accessing the RS-232 port (i.e. /dev/ttyS0), we will require 'root' access on our development machine. Alternatively, the user account (or a group the user account is in) can be granted privileges over the /dev/ttyS0 device. With the appropriate privileges in place, simply execute 'kermit' from a valid Linux terminal window to launch a C-Kermit terminal. The following parameters should be set manually, one at a time, from the 'kermit' terminal window:

```
C-Kermit> set line /dev/ttyS0
C-Kermit> set speed 115200
C-Kermit> set carrier-watch off
C-Kermit> set handshake none
C-Kermit> set flow-control none
C-Kermit> robust
C-Kermit> set file type bin
C-Kermit> set file name lit
C-Kermit> set rec pack 1000
C-Kermit> set send pack 1000
C-Kermit> set window 5
```

These parameters establish communication over the serial port at a baud rate of 115,200 with no flow control. Alternatively, these parameters can be set permanently by modifying your *~/.kermit* file accordingly. At this point, you can proceed to attach the OMAP5912 OSK to your development computer via a standard null serial cable (female-to-female). Before powering on the development board, type the following at your C-Kermit console:

```
C-Kermit> connect
Connecting to /dev/ttyS0, speed 115200
 Escape character: Ctrl-\ (ASCII 28, FS): enabled
Type the escape character followed by C to get back,
or followed by ? to see other options.
----------------------------------------------------
```

If a successful connection has taken place, you should see text similar to that above. All incoming communication across the serial port will be displayed below the dotted line. Go ahead and power on the OMAP5912 OSK at this time by connecting the 5-V line from the power supply. If successful, you should see U-Boot load and begin counting down to load the kernel or simply be brought to a U-Boot terminal. Press any key to cancel the countdown and be brought to a U-Boot terminal.

A5.4.2 Flashing with New U-Boot Version

We now want to enter a state in which we can receive new files and store them in memory on the development board. At the U-Boot terminal, enter the following command:

```
OMAP5912 OSK # loadb
## Ready for binary (kermit) download to 0x10000000 at 115200 bps...
```

The 'loadb' command sets the development board in receiving mode, using the kermit protocol. It is now necessary to return focus to C-Kermit to setup the U-Boot binary to be sent across the serial connection. To return focus to C-Kermit, type the escape sequence: Ctrl-\ then 'c'. At the C-Kermit terminal, enter the following to prepare the U-Boot binary file for transfer:

```
C-Kermit> add send-list ~/stuff/build/tmp/deploy/images/u-boot-omap5912osk-LABEL.2006.06.30.2020-r0.bin
C-Kermit> send
```

Please note that the specific file name for your U-Boot binary file may vary as the application and its deployment package are updated over time. After executing the 'send' command, C-Kermit should begin sending the package to the OMAP5912 OSK, where the data will be stored in RAM at memory location 0x10000000. If the send fails, please follow any on-screen suggestions for dealing with the send errors. When the send is completed, you will be returned to a C-Kermit command prompt. Issue the 'connect' command again to transfer focus to the development board and the U-Boot terminal. At the U-Boot terminal, you should test the downloaded U-Boot image with the following comand:

```
OMAP5912 OSK # go 0x10000000
```

The 'go' command will move the process counter to that memory location and begin executing. If the binary transfer was successful, you should see similar loading text and an updated U-Boot version number displayed. It will be necessary to reset the development board (type 'reset' at the terminal or use the reset button) and be using the on-board U-Boot before proceeding with the update. The following commands can be issued at the U-Boot terminal to flash the newly downloaded U-Boot binary onto the board:

```
OMAP5912 OSK # protect off 1:0
OMAP5912 OSK # erase 1:0
OMAP5912 OSK # cp.b 0x10000000 0x0 $(filesize)
```

The first command disables protection on the master boot record (MBR) of the development board, while the second command erases the previous U-Boot installation. The third command copies the binary file we previously transferred to memory location 0x10000000 to the first sector of flash. Upon a successful flash, the board can be reset and you should see the new U-Boot working much like when we issued the 'go' command earlier.

A5.5 Loading a Linux Kernel

The second component of setting up the OMAP5912 OSK development board is loading a working Linux kernel onto the device. Your successful execution of the BitBake builds should have produced a kernel binary file in your *~/stuff/build/tmp/deploy/sources* directory (if not, just execute 'bitbake virtual/kernel' from within your build directory). Just as we did with the U-Boot binary file, we will want to transfer the Linux kernel binary file to memory on the development

board, verify the file, and then write it to its appropriate location in flash. With the development board set to receive files and focus returned to C-Kermit, issue the following commands:

```
C-Kermit> clear send-list
C-Kermit> add send-list ~/stuff/build/tmp/deploy/images/zImage-omap5912osk-20060906100754.bin
C-Kermit> send
```

Again, the specific file name for your Linux kernel binary file may be slightly different. Upon completion of the transfer, we will want to again switch focus to U-Boot on the development board by issuing the 'connect' command. The contents now stored in RAM at memory location 0x10000000 can now be written to the flash with the following commands:

```
OMAP5912 OSK # erase 1:8-16
OMAP5912 OSK # cp.b 0x10000000 0x100000 $(filesize)
```

The first command erases the appropriate locations in the first memory bank for where the compressed Linux kernel will reside, while the second command copies the binary file in memory to the kernel's appropriate location in flash (0x100000). Upon successful completion of the copy, you can test the kernel by trying to boot with the following command:

```
OMAP5912 OSK # bootm 0x10000
```

The kernel should successfully uncompress itself, load itself into memory, and then begin to boot. The next step is to setup the root filesystem for the Linux kernel to boot to and then establish any necessary environment boot variables.

A5.6 Loading a Root Filesystem

The successful execution of our original BitBake builds should have also generated a root filesystem compressed into a binary file. With the development board set to receive files and focus returned to C-Kermit, we can issue the following commands to transfer the root filesystem to the OMAP5912 OSK development board:

```
C-Kermit> clear send-list
C-Kermit> add send-list ~/stuff/build/tmp/deploy/images/bootstrap-image-omap5912osk-
20060906093446.rootfs.jffs2
C-Kermit> send
```

The first command will clear the send list, while the second and third commands queue the root filesystem and complete the send, respectively. Please note that your root filesystem name may vary, just like the binary file name may have varied for U-Boot and the Linux kernel before. Returning focus to the development board and the U-Boot terminal, we can execute the

following commands to install the root filesystem to flash:

```
OMAP5912 OSK # erase 1:128-255
OMAP5912 OSK # cp.b 0x10000000 0x1000000 $(filesize)
```

The first command erases the necessary space in the filesystem block while the second command copies the binary image from memory to its appropriate location in flash (0x1000000).

A5.7 Setting-up Environment Variables

At this point, you should have successfully updated U-Boot, installed the Linux kernel to flash, and mounted the filesystem to flash on your OMAP5912 OSK development board. You have noticed at this point that when using C-Kermit to monitor the board, the initial boot still only brings you to the U-Boot terminal rather than booting the Linux kernel immediately. This can be easily remedied with the setup of a few environment variables. From the U-Boot terminal, enter the following commands to set our recommended list of environment variables:

```
OMAP5912 OSK # setenv ethaddr xx-xx-xx-xx-xx-xx
OMAP5912 OSK # setenv bootcmd bootm 0x100000
OMAP5912 OSK # seenv bootdelay 10
OMAP5912 OSK # setenv bootfile uImage
OMAP5912 OSK # bootargs console=ttyS0,115200 noinitrd rw ip=on rootfstype=jffs2 root=/dev/mtdblock3
OMAP5912 OSK # saveenv
```

These environment variables will establish the MAC address of the development (usually found printed on the board and set it to boot after a 10-second delay to the pre-installed kernel and root filesystem. The bootdelay can be adjusted to reach the desired performance of the development board; however, during development, it is usually helpful to have a 10-second window available to allow sufficient time for an interrupt to be passed to gain control of the board from the U-Boot terminal level.

A6 Simulation Results & Logs

Below are the outputted logs and results of the simulations preformed. These simulations are the basis for the circuitry. Also included are comments explaining the results. Those can be seen in italics.

A6.1 Driver Sensitivity Results

---- Page: "Sensitivity"
---- Chart: Sensitivity Analysis
Sensitivity Analysis
These results show the DC operating-point sensitivity for each component.
---

rr7	2.76002 p
rr3	-3.03235 u
rr2	9.28264 u
rr1	9.28443 u
rr9	-0.27280 p
rr8	0.00000
rr6	0.00000
rr5	9.27762 u
rr4	-3.03184 u

---- End Chart: Sensitivity Analysis
---- End Page: "Sensitivity"

A6.2 Worst Case Scenarios

The below results are the worst case scenarios. It gives a nominal value for the running of the system, and then right below it gives the value for the worst case run. Then, it gives the nominal value for the component during that run, and then for the worst case run what that component value would be. This continues for each of the particular components. The components are referenced by their reference number in the schematics.

---- Page: "Worst Case"
---- Chart: Worst Case Analysis

$12, Nominal Run 272.79724 m

$12, Worst Case Run 297.45151 m

0.00000

0.00000

---- End Chart: Worst Case Analysis

---- Chart: Run Log Descriptions

Descriptions of the runs

Worst Case Run

DC operating point for all devices: 0.0246543 (9.03758% of nominal)

Tolerance changes needed to achieve worst case:

rr5 resistance increased to 24200

rr9 resistance decreased to 4230

$11, Nominal Run 543.64130 m

$11, Worst Case Run 582.64954 m

0.00000

0.00000

---- End Chart: Worst Case Analysis

---- Chart: Run Log Descriptions
Descriptions of the runs

Worst Case Run

DC operating point for all devices: 0.0390082 (7.17536% of nominal)

Tolerance changes needed to achieve worst case:

rr8 resistance decreased to 4230

rr3 resistance decreased to 162000

---- Page: "Worst Case"
---- Chart: Worst Case Analysis

$10, Nominal Run 3.03097

$10, Worst Case Run 3.05605

0.00000

0.00000

---- End Chart: Worst Case Analysis

---- Chart: Run Log Descriptions
Descriptions of the runs
Worst Case Run

DC operating point for all devices: 0.0250809 (0.827487% of nominal)

Tolerance changes needed to achieve worst case:

rr1 resistance decreased to 19800

rr6 resistance decreased to 4230

---- End Chart: Run Log Descriptions
---- End Page: "Worst Case"

---- Page: "Worst Case"
---- Chart: Worst Case Analysis

$7, Nominal Run 2.76003

$7, Worst Case Run 2.78286

0.00000

0.00000

---- End Chart: Worst Case Analysis

---- Chart: Run Log Descriptions
Descriptions of the runs
Worst Case Run

DC operating point for all devices: 0.0228378 (0.82745% of nominal)

Tolerance changes needed to achieve worst case:

rr1 resistance decreased to 19800

rr6 resistance increased to 5170

---- End Chart: Run Log Descriptions
---- End Page: "Worst Case"

A6.3 DC Analysis Results

DC Analysis determines the dc operating point of the circuit with inductors shorted and capacitors opened. Doing a DC analysis prior to the transient analysis determines the transient initial conditions. If requested, the dc small-signal value of a transfer function (ratio of output variable to input source), input resistance, and output resistance is also computed as a part of the dc solution. The dc analysis can also be used to generate dc transfer curves: a specified

independent voltage or current source is stepped over a user-specified range and the dc output variables are stored for each sequential source value.

Instrument operation performed (2006, September 11, Monday, 13:44:40)

```
|  Instrument Analysis: DC Analysis
|  |  Plot title:
|  |  Analysis settings
|  |  |  Initial Conditions: Automatically generate initial conditions
|  |  |  Starting time (TSTART): 0
|  |  |  Stop time (TSTOP): 1e+030
|  |  |  Plotting increment (TSTEP): automatically calculated (less than: 1e+030)
|  |  |  Maximum time step (TMAX): automatically calculated (less than: 1e+030)
|  |  Perform consistency check
|  |  Variables from analysis
|  |  |  Show device values at the end of the simulation
|  |  Representation as SPICE commands
|  |  |  begin-scope page
|  |  |  checknodes 3
|  |  |  save all
|  |  |  iplot all
|  |  |  set trtol = 7
|  |  |  set itl4 = 100
|  |  |  set convlimit
|  |  |  set rshunt = 1e+012
|  |  |  -param hrange 0 1e+030
|  |  |  save
|  |  |  tran  -env-options 1e-005 1e+030 0 1e-005 auto_ic auto_tstep auto_tmax
|  |  |  if-error end-scope audit-log-show
|  |  |  show all
|  |  |  showmod all
|  |  |  end-scope
|  |  Multisim Default Analysis Options
|  |  |  Truncation error overestimation factor: 7
|  |  |  Upper transient iteration limit: 100
|  |  |  Enable convergence assistance for code models
|  |  |  Shunt resistance from analog nodes to ground: 1e+012
|  Output from instrument analysis
|  |   BJT: Bipolar Junction Transistor
|  |   device          q2:xu2     qsc:xu2      q3:xu2      q1:xu2
|  |   model           qn:xu2      qn:xu2      qp:xu2      qp:xu2
|  |           ic   -0.000118  -3.01e-015  -1.35e-005  -5.56e-005
|  |           ib    0.000135  -3.01e-018   6.77e-006   2.78e-005
|  |           ie  -1.61e-005   3.01e-015   6.77e-006   2.78e-005
|  |          vbe       0.666     -0.0029      -0.666      0.0366
|  |          vbc       0.663           0       0.585       0.622
|  |           gm    0.000617   -4.1e-015   -0.000262    -0.00108
|  |          gpi   5.82e-006   1.03e-015      1e-015   1.16e-015
```

```
| |          gmu      0.0052   1.04e-012    0.000262     0.00108
| |           gx           0          0           0           0
| |           go      0.0052   1.04e-012    0.000262     0.00108
| |          cpi           0          0           0           0
| |          cmu           0          0           0           0
| |          cbx           0          0           0           0
| |          ccs           0          0           0           0
| |
| |  Capacitor: Fixed capacitor
| |  device          c2:xu2      c1:xu2      cn:xu2
| |  model                C          C           C
| |  capacitance   1.59e-013   3.18e-010      5e-011
| |           i   4.62e-021  -2.55e-016  -9.45e-022
| |           p   -9.3e-021   5.14e-016   7.85e-029
| |
| |  CCCS: Current controlled current source
| |  device          fsc:xu2     fsy:xu2
| |           i    3.3e-012     0.00247
| |           v      -0.622       -1.25
| |           p  -2.05e-012    -0.00309
| |
| |  Diode: Junction Diode model
| |  device          d1:xu2     dn2:xu2     dn1:xu2
| |  model           dx:xu2     den:xu2     den:xu2
| |          vd       0.738        0.39        0.39
| |          id     0.00247   3.53e-006   3.53e-006
| |          gd      0.0953    0.000136    0.000136
| |          cd           0           0           0
| |
| |  Inductor: Inductors
| |  device          lo:xu2
| |  model                L
| |   inductance      1e-007
| |         flux   2.29e-012
| |           v   1.25e-016
| |           i   2.29e-005
| |           p   2.86e-021
| |
| |  Isource: Independent current source
| |  device          i2:xu2     isy:xu2      i1:xu2
| |           dc      0.0001     0.00035     0.00121
| |        acmag           0           0           0
| |           v       0.666        1.25        1.21
| |           p  -6.66e-005   -0.000438    -0.00148
| |
| |  Resistor: Simple linear resistor
```

```
| |  device          r8:xu2      r7:xu2      r6:xu2      r5:xu2     rsc:xu2      r4:xu2
| |  model              R           R           R           R          R           R
| |   resistance   4.05e+003   4.28e+003   8.33e+003   1.67e+004       24.5      5e+004
| |          i   -0.000309           0           0           0   -0.000118  -1.24e-005
| |          p    0.000386           0           0           0   3.44e-007   7.74e-006
| |
| |  Resistor: Simple linear resistor
| |  device          r3:xu2      r2:xu2      r1:xu2
| |  model              R           R           R
| |   resistance       1e+006      1e+008      1e+003
| |          i  -2.01e-006  -2.01e-008     0.00121
| |          p   4.05e-006   4.05e-008     0.00148
| |
| |  VCCS: Voltage controlled current source
| |  device          g4:xu2      g3:xu2      g2:xu2      g1:xu2
| |          i  -4.03e-005  -2.01e-006     0.00247  -3.04e-008
| |          v       0.622        2.01        2.01       -1.21
| |          p   -2.5e-005  -4.05e-006     0.00496   3.69e-008
| |
| |  VCVS: Voltage controlled voltage source
| |  device          en:xu2
| |          i   3.06e-008
| |          v  -8.31e-008
| |          p  -2.55e-015
| |
| |  Vsource: Independent voltage source
| |  device         vs2:xu2     vs1:xu2     vsc:xu2      v1:xu2     vn2:xu2     vn1:xu2
| |         dc           0           0           0         1.5           2           2
| |      acmag           0           0           0           0           0           0
| |          i   6.77e-006  -1.61e-005    3.3e-012    -0.00247  -3.53e-006  -3.53e-006
| |          p           0           0           0      0.0037   7.05e-006   7.05e-006
| |
| |  Vsource: Independent voltage source
| |  device          vssvss
| |         dc         3.3
| |      acmag           0
| |          i  -5.07e-011
| |          p   1.67e-010
| |
| |  poly: 2g6 compatible polynomial controlled source
| |  device      a_poly_f1:x
| |  model       a_poly_f1:x
| |     acgains p5 6 {ù>p5
| |
| |  BJT models (Bipolar Junction Transistor)
| |  model           qn:xu2      qp:xu2
```

type	npn pnp
is	1e-015 1e-015
bf	1e+003 1e+003
nf	1 1
vaf	0 0
ikf	0 0
ise	0 0
ne	1.5 1.5
br	1 1
nr	1 1
var	0 0
ikr	0 0
isc	0 0
nc	2 2
rb	0 0
irb	0 0
rbm	0 0
re	0 0
rc	0 0
cje	0 0
vje	0.75 0.75
mje	0.33 0.33
tf	0 0
xtf	0 0
vtf	0 0
itf	0 0
ptf	0 0
cjc	0 0
vjc	0.75 0.75
mjc	0.33 0.33
xcjc	1 1
tr	0 0
cjs	0 0
ccs	0 0
vjs	0.75 0.75
mjs	0 0
xtb	0 0
eg	1.11 1.11
xti	3 3
fc	0.5 0.5
tnom	27 27
kf	0 0
af	0 0

Capacitor models (Fixed capacitor)

| | model C
| |
| | cj 0
| | cjsw 0
| | defw 1e-005
| | narrow 0
| | tc1 0
| | tc2 0
| | vc1 0
| | vc2 0
| | cmult 1
| | t_measured 27
| | t_abs -273
| | t_rel_global -273
| | t_rel_local -273
| |
| | Diode models (Junction Diode model)
| | model dx:xu2 den:xu2
| |
| | is 1e-015 1e-012
| | rs 0 4.56e+005
| | n 1 1
| | tt 0 0
| | cjo 0 0
| | vj 1 1
| | m 0.5 0.5
| | eg 1.11 1.11
| | xti 3 3
| | kf 0 2.81e-017
| | af 1 1
| | fc 0.5 0.5
| | bv 0 0
| | ibv 0.001 0.001
| | ibvl 0 0
| | ikf 1e+030 1e+030
| | isr 0 0
| | nbv 1 1
| | nbvl 1 1
| | nr 2 2
| | tbv1 0 0
| | tbv2 0 0
| | tikf 0 0
| | trs1 0 0
| | trs2 0 0
| |
| | Inductor models (Inductors)

```
| |   model              L
| |
| |         tc1          0
| |         tc2          0
| |         il1          0
| |         il2          0
| |       lmult          1
| |   t_measured         27
| |       t_abs       -273
| | t_rel_global      -273
| |  t_rel_local      -273
| |
| |   Resistor models (Simple linear resistor)
| |   model              R
| |
| |         rsh          0
| |      narrow          0
| |         tc1          0
| |         tc2          0
| |        defw      1e-005
| |        tnom         27
| |         tce          0
| |       rmult          1
| |       t_abs       -273
| | t_rel_global      -273
| |  t_rel_local      -273
| |
| |   poly models (2g6 compatible polynomial controlled source)
| |   model      a_poly_f1:x
| |
| |        coef          0
| |              2.43e-005
| |              2.43e-005
```

A6.4 Transient Analysis Results

Below are the transient analysis results. In these simulations, MultiSim takes a collection of resistive and energy-storage components, then finds its time response to an arbitrary input waveform. Below is the log and results of this analysis.

Instrument operation performed (2006, September 14, Thursday, 13:44:04)
| Instrument Analysis: Transient Analysis
| | Plot title:
| | Analysis settings
| | | Initial Conditions: Automatically generate initial conditions
| | | Starting time (TSTART): 0
| | | Stop time (TSTOP): 1e+030
| | | Plotting increment (TSTEP): automatically calculated (less than: 1e+030)
| | | Maximum time step (TMAX): automatically calculated (less than: 1e+030)
| | Perform consistency check
| | Variables from analysis
| | | Show device values at the end of the simulation
| | Representation as SPICE commands
| | | begin-scope page
| | | checknodes 3
| | | save all
| | | iplot all
| | | set trtol = 7
| | | set itl4 = 100
| | | set convlimit
| | | set rshunt = 1e+012
| | | -param hrange 0 1e+030
| | | save
| | | tran -env-options 1e-005 1e+030 0 1e-005 auto_ic auto_tstep auto_tmax
| | | if-error end-scope audit-log-show
| | | show all
| | | showmod all
| | | end-scope
| | Multisim Default Analysis Options
| | | Truncation error overestimation factor: 7
| | | Upper transient iteration limit: 100
| | | Enable convergence assistance for code models
| | | Shunt resistance from analog nodes to ground: 1e+012
| Output from instrument analysis
| | BJT: Bipolar Junction Transistor
| | device q2:xu2 qsc:xu2 q3:xu2 q1:xu2
| | model qn:xu2 qn:xu2 qp:xu2 qp:xu2
| | ic -0.000118 -3.01e-015 -1.35e-005 -5.56e-005
| | ib 0.000135 -3.01e-018 6.77e-006 2.78e-005
| | ie -1.61e-005 3.01e-015 6.77e-006 2.78e-005

		vbe	0.666	-0.0029	-0.666	0.0366
		vbc	0.663	0	0.585	0.622
		gm	0.000617	-4.1e-015	-0.000262	-0.00108
		gpi	5.82e-006	1.03e-015	1e-015	1.16e-015
		gmu	0.0052	1.04e-012	0.000262	0.00108
		gx	0	0	0	0
		go	0.0052	1.04e-012	0.000262	0.00108
		cpi	0	0	0	0
		cmu	0	0	0	0
		cbx	0	0	0	0
		ccs	0	0	0	0

Capacitor: Fixed capacitor

	device	c2:xu2	c1:xu2	cn:xu2	
	model	C	C	C	
	capacitance	1.59e-013	3.18e-010	5e-011	
		i	-3.21e-022	1.99e-016	-9.45e-022
		p	6.47e-022	-4e-016	7.85e-029

CCCS: Current controlled current source

	device	fsc:xu2	fsy:xu2	
		i	-3.01e-015	0.00247
		v	-0.622	-1.25
		p	1.87e-015	-0.00309

Diode: Junction Diode model

	device	d1:xu2	dn2:xu2	dn1:xu2	
	model	dx:xu2	den:xu2	den:xu2	
		vd	0.738	0.39	0.39
		id	0.00247	3.53e-006	3.53e-006
		gd	0.0953	0.000136	0.000136
		cd	0	0	0

Inductor: Inductors

	device	lo:xu2	
	model	L	
	inductance	1e-007	
		flux	2.29e-012
		v	-1.01e-016
		i	2.29e-005
		p	-2.3e-021

Isource: Independent current source

	device	i2:xu2	isy:xu2	i1:xu2	
		dc	0.0001	0.00035	0.00121
		acmag	0	0	0

```
| |          v      0.666       1.25       1.21
| |          p  -6.66e-005   -0.000438    -0.00148
| |
| |  Resistor: Simple linear resistor
| |  device          r8:xu2     r7:xu2     r6:xu2     r5:xu2     rsc:xu2     r4:xu2
| |  model              R          R          R          R          R
| |   resistance   4.05e+003  4.28e+003  8.33e+003  1.67e+004       24.5      5e+004
| |          i   -0.000309          0          0  -6.04e-021   -0.000118  -1.24e-005
| |          p    0.000386          0          0   6.08e-037   3.44e-007   7.74e-006
| |
| |  Resistor: Simple linear resistor
| |  device          r3:xu2     r2:xu2     r1:xu2
| |  model              R          R          R
| |   resistance      1e+006     1e+008     1e+003
| |          i  -2.01e-006  -2.01e-008     0.00121
| |          p   4.05e-006   4.05e-008     0.00148
| |
| |  VCCS: Voltage controlled current source
| |  device          g4:xu2     g3:xu2     g2:xu2     g1:xu2
| |          i  -4.03e-005  -2.01e-006     0.00247  -3.04e-008
| |          v      0.622       2.01       2.01       -1.21
| |          p   -2.5e-005  -4.05e-006     0.00496   3.69e-008
| |
| |  VCVS: Voltage controlled voltage source
| |  device          en:xu2
| |          i   3.06e-008
| |          v  -8.31e-008
| |          p  -2.55e-015
| |
| |  Vsource: Independent voltage source
| |  device         vs2:xu2    vs1:xu2    vsc:xu2     v1:xu2     vn2:xu2     vn1:xu2
| |         dc           0          0          0        1.5           2           2
| |      acmag           0          0          0          0           0           0
| |          i   6.77e-006  -1.61e-005  -3.01e-015   -0.00247  -3.53e-006  -3.53e-006
| |          p           0          0          0     0.0037   7.05e-006   7.05e-006
| |
| |  Vsource: Independent voltage source
| |  device          vssvss
| |         dc           0
| |      acmag           0
| |          i  -4.46e-012
| |          p           0
| |
| |  poly: 2g6 compatible polynomial controlled source
| |  device      a_poly_f1:x
| |  model       a_poly_f1:x
```

```
| |     acgains p5 6 {ù>p5
| |
| | BJT models (Bipolar Junction Transistor)
| | model          qn:xu2     qp:xu2
| |
| |        type        npn        pnp
| |          is     1e-015     1e-015
| |          bf     1e+003     1e+003
| |          nf          1          1
| |         vaf          0          0
| |         ikf          0          0
| |         ise          0          0
| |          ne        1.5        1.5
| |          br          1          1
| |          nr          1          1
| |         var          0          0
| |         ikr          0          0
| |         isc          0          0
| |          nc          2          2
| |          rb          0          0
| |         irb          0          0
| |         rbm          0          0
| |          re          0          0
| |          rc          0          0
| |         cje          0          0
| |         vje       0.75       0.75
| |         mje       0.33       0.33
| |          tf          0          0
| |         xtf          0          0
| |         vtf          0          0
| |         itf          0          0
| |         ptf          0          0
| |         cjc          0          0
| |         vjc       0.75       0.75
| |         mjc       0.33       0.33
| |        xcjc          1          1
| |          tr          0          0
| |         cjs          0          0
| |         ccs          0          0
| |         vjs       0.75       0.75
| |         mjs          0          0
| |         xtb          0          0
| |          eg       1.11       1.11
| |         xti          3          3
| |          fc        0.5        0.5
| |        tnom         27         27
```

		kf	0	0
		af	0	0
		Capacitor models (Fixed capacitor)		
		model	C	
		cj	0	
		cjsw	0	
		defw	1e-005	
		narrow	0	
		tc1	0	
		tc2	0	
		vc1	0	
		vc2	0	
		cmult	1	
		t_measured	27	
		t_abs	-273	
		t_rel_global	-273	
		t_rel_local	-273	
		Diode models (Junction Diode model)		
		model	dx:xu2	den:xu2
		is	1e-015	1e-012
		rs	0	4.56e+005
		n	1	1
		tt	0	0
		cjo	0	0
		vj	1	1
		m	0.5	0.5
		eg	1.11	1.11
		xti	3	3
		kf	0	2.81e-017
		af	1	1
		fc	0.5	0.5
		bv	0	0
		ibv	0.001	0.001
		ibvl	0	0
		ikf	1e+030	1e+030
		isr	0	0
		nbv	1	1
		nbvl	1	1
		nr	2	2
		tbv1	0	0
		tbv2	0	0
		tikf	0	0

```
| |         trs1          0          0
| |         trs2          0          0
| |
| |   Inductor models (Inductors)
| |   model                 L
| |
| |          tc1          0
| |          tc2          0
| |          il1          0
| |          il2          0
| |        lmult          1
| |    t_measured         27
| |        t_abs        -273
| |  t_rel_global       -273
| |   t_rel_local       -273
| |
| |   Resistor models (Simple linear resistor)
| |   model                 R
| |
| |          rsh          0
| |       narrow          0
| |          tc1          0
| |          tc2          0
| |         defw      1e-005
| |         tnom         27
| |          tce          0
| |        rmult          1
| |        t_abs        -273
| |  t_rel_global       -273
| |   t_rel_local       -273
| |
| |   poly models (2g6 compatible polynomial controlled source)
| |   model       a_poly_f1:x
| |
| |         coef          0
| |               2.43e-005
| |               2.43e-005
| |
```

A6.5 User Defined Simulation Results

In this simulation, we ran all given initial conditions and examined the circuitry at different locations. Below is the log of the results.

```
Instrument operation performed   (2006, September 15, Friday, 13:48:47)
|   Instrument Analysis: User Defined
```

| | Plot title:
| | Analysis settings
| | | Initial Conditions: Automatically generate initial conditions
| | | Starting time (TSTART): 0
| | | Stop time (TSTOP): 1e+030
| | | Plotting increment (TSTEP): automatically calculated (less than: 1e+030)
| | | Maximum time step (TMAX): automatically calculated (less than: 1e+030)
| | Perform consistency check
| | Variables from analysis
| | | Show device values at the end of the simulation
| | Representation as SPICE commands
| | | begin-scope page
| | | checknodes 3
| | | save all
| | | iplot all
| | | set trtol = 7
| | | set itl4 = 100
| | | set convlimit
| | | set rshunt = 1e+012
| | | -param hrange 0 1e+030
| | | save
| | | tran -env-options 1e-005 1e+030 0 1e-005 auto_ic auto_tstep auto_tmax
| | | if-error end-scope audit-log-show
| | | show all
| | | showmod all
| | | end-scope
| | Multisim Default Analysis Options
| | | Truncation error overestimation factor: 7
| | | Upper transient iteration limit: 100
| | | Enable convergence assistance for code models
| | | Shunt resistance from analog nodes to ground: 1e+012
| Output from instrument analysis
| | BJT: Bipolar Junction Transistor

	device	q2:xu2	qsc:xu2	q3:xu2	q1:xu2
	model	qn:xu2	qn:xu2	qp:xu2	qp:xu2
	ic	-0.000118	-3.01e-015	-1.35e-005	-5.56e-005
	ib	0.000135	-3.01e-018	6.77e-006	2.78e-005
	ie	-1.61e-005	3.01e-015	6.77e-006	2.78e-005
	vbe	0.666	-0.0029	-0.666	0.0366
	vbc	0.663	0	0.585	0.622
	gm	0.000617	-4.1e-015	-0.000262	-0.00108
	gpi	5.82e-006	1.03e-015	1e-015	1.16e-015
	gmu	0.0052	1.04e-012	0.000262	0.00108
	gx	0	0	0	0
	go	0.0052	1.04e-012	0.000262	0.00108
	cpi	0	0	0	0

		cmu	0	0	0	0
		cbx	0	0	0	0
		ccs	0	0	0	0

Capacitor: Fixed capacitor

device		c2:xu2	c1:xu2	cn:xu2	cc1	cc2
model		C	C	C	C	C
capacitance		1.59e-013	3.18e-010	5e-011	1e-006	1e-006
	i	-4.48e-021	-7.66e-017	2.03e-021	0	0
	p	9.01e-021	1.54e-016	-1.69e-028	0	0

CCCS: Current controlled current source

device		fsc:xu2	fsy:xu2
	i	3.3e-012	0.00247
	v	-0.622	-1.25
	p	-2.05e-012	-0.00309

Diode: Junction Diode model

device		d1:xu2	dn2:xu2	dn1:xu2
model		dx:xu2	den:xu2	den:xu2
	vd	0.738	0.39	0.39
	id	0.00247	3.53e-006	3.53e-006
	gd	0.0953	0.000136	0.000136
	cd	0	0	0

Inductor: Inductors

device		lo:xu2
model		L
inductance		1e-007
	flux	2.29e-012
	v	1.22e-016
	i	2.29e-005
	p	2.79e-021

Isource: Independent current source

device		i2:xu2	isy:xu2	i1:xu2
	dc	0.0001	0.00035	0.00121
	acmag	0	0	0
	v	0.666	1.25	1.21
	p	-6.66e-005	-0.000438	-0.00148

Resistor: Simple linear resistor

device		r8:xu2	r7:xu2	r6:xu2	r5:xu2	rsc:xu2	r4:xu2
model		R	R	R	R	R	R
resistance		4.05e+003	4.28e+003	8.33e+003	1.67e+004	24.5	5e+004
	i	-0.000309	0	0	0	-0.000118	-1.24e-005

```
| |          p    0.000386          0          0          0   3.44e-007   7.74e-006
| |
| |  Resistor: Simple linear resistor
| |  device          r3:xu2      r2:xu2      r1:xu2
| |  model              R           R           R
| |   resistance      1e+006      1e+008      1e+003
| |          i  -2.01e-006  -2.01e-008     0.00121
| |          p   4.05e-006   4.05e-008     0.00148
| |
| |  VCCS: Voltage controlled current source
| |  device          g4:xu2      g3:xu2      g2:xu2      g1:xu2
| |          i  -4.03e-005  -2.01e-006     0.00247  -3.04e-008
| |          v       0.622        2.01        2.01       -1.21
| |          p   -2.5e-005  -4.05e-006     0.00496   3.69e-008
| |
| |  VCVS: Voltage controlled voltage source
| |  device          en:xu2
| |          i   3.06e-008
| |          v  -8.31e-008
| |          p  -2.55e-015
| |
| |  Vsource: Independent voltage source
| |  device          vs2:xu2     vs1:xu2     vsc:xu2      v1:xu2     vn2:xu2     vn1:xu2
| |          dc            0           0           0         1.5           2           2
| |       acmag            0           0           0           0           0           0
| |          i   6.77e-006  -1.61e-005    3.3e-012    -0.00247  -3.53e-006  -3.53e-006
| |          p           0           0           0      0.0037   7.05e-006   7.05e-006
| |
| |  Vsource: Independent voltage source
| |  device          vssvss vvss_0v_126 vvss_0v_126 vvss_0v_126
| |          dc         3.3           0           0           0
| |       acmag           0           0           0           0
| |          i  -6.06e-011   2.29e-005   -3.3e-012    3.3e-012
| |          p      2e-010           0           0           0
| |
| |  poly: 2g6 compatible polynomial controlled source
| |  device      a_poly_f1:x
| |  model       a_poly_f1:x
| |     acgains p5 6 {ù>p5
| |
| |  BJT models (Bipolar Junction Transistor)
| |  model           qn:xu2      qp:xu2
| |
| |         type         npn         pnp
| |           is      1e-015      1e-015
| |           bf      1e+003      1e+003
```

		nf	1	1
		vaf	0	0
		ikf	0	0
		ise	0	0
		ne	1.5	1.5
		br	1	1
		nr	1	1
		var	0	0
		ikr	0	0
		isc	0	0
		nc	2	2
		rb	0	0
		irb	0	0
		rbm	0	0
		re	0	0
		rc	0	0
		cje	0	0
		vje	0.75	0.75
		mje	0.33	0.33
		tf	0	0
		xtf	0	0
		vtf	0	0
		itf	0	0
		ptf	0	0
		cjc	0	0
		vjc	0.75	0.75
		mjc	0.33	0.33
		xcjc	1	1
		tr	0	0
		cjs	0	0
		ccs	0	0
		vjs	0.75	0.75
		mjs	0	0
		xtb	0	0
		eg	1.11	1.11
		xti	3	3
		fc	0.5	0.5
		tnom	27	27
		kf	0	0
		af	0	0
		Capacitor models (Fixed capacitor)		
		model	C	
		cj	0	
		cjsw	0	

	defw	1e-005
	narrow	0
	tc1	0
	tc2	0
	vc1	0
	vc2	0
	cmult	1
	t_measured	27
	t_abs	-273
	t_rel_global	-273
	t_rel_local	-273

Diode models (Junction Diode model)

model	dx:xu2	den:xu2
is	1e-015	1e-012
rs	0	4.56e+005
n	1	1
tt	0	0
cjo	0	0
vj	1	1
m	0.5	0.5
eg	1.11	1.11
xti	3	3
kf	0	2.81e-017
af	1	1
fc	0.5	0.5
bv	0	0
ibv	0.001	0.001
ibvl	0	0
ikf	1e+030	1e+030
isr	0	0
nbv	1	1
nbvl	1	1
nr	2	2
tbv1	0	0
tbv2	0	0
tikf	0	0
trs1	0	0
trs2	0	0

Inductor models (Inductors)

model	L
tc1	0
tc2	0

```
| |          il1          0
| |          il2          0
| |        lmult          1
| |    t_measured         27
| |        t_abs       -273
| |  t_rel_global       -273
| |   t_rel_local       -273
| |
| |   Resistor models (Simple linear resistor)
| |   model               R
| |
| |          rsh          0
| |       narrow          0
| |          tc1          0
| |          tc2          0
| |         defw      1e-005
| |         tnom         27
| |          tce          0
| |        rmult          1
| |        t_abs       -273
| |  t_rel_global       -273
| |   t_rel_local       -273
| |
| |   poly models (2g6 compatible polynomial controlled source)
| |   model      a_poly_f1:x
| |
| |         coef          0
| |              2.43e-005
| |              2.43e-005
| |
```

A7 Guide to PCB Manufacturing

At the University of Limerick, there is a PCB manufacturing centre where we were able to manufacture our PCB in house. If all of the necessary facilities and equipment is available, manufacturing your PCB in house, it will reduce prototyping costs of the project. This guide will lead you through the systematic processes in order to create your own PCB.

A7.1 Materials

To make PCBs in house, you will require the following raw materials, which you will have to buy:

- One (1) double sided UV-sensitive photoresist coated PCB, 1.5mm thick, with 35microns copper cladding
- Overhead projector transparency sheets (one sheet per side of board)

It is necessary to have access to the following materials in order to successfully produce a PCB. These include:

- Printer
- Running water

The following machinery/ chemicals are required to complete a PCB:

- 1kg of NaOH pellets
- 1kg of Iron chloride pellets
- UV PCB exposure box with timer
- Developer trays
- Drill press
- Drill bits (0.6mm and 1mm)

The material available to us at the University of Limerick included the above mentioned. The University had a machine, which included all of the trays in one convenient location, along with control features for each of the baths as shown by Figure A7-1.

Figure A7-1: Etching Machine

A7.2 Preparation

After completing the design and inspection of your printed circuit board, print the design onto transparencies. However, you will have to invert your design onto the transparency if your design is double sided. When printing the design, make sure that your printer is on the highest

resolution possible. Remember that one sheet of transparency is for each side of your board. Once the transparencies are printed, review them once again. You will see that the images are inverted, which is correct since during exposure the ink side of the transparency will be touching the PCB. Allow the transparencies to dry for at least an hour before working with them again. Once dried, align the two sheets of the transparencies together. To do this, one must ensure that the ink sides of the transparencies are facing each other. Ensure that the top and bottom of the board transparency align, as you want them on PCB. Staple each corner of the aligned transparencies to ensure they will not move and alter the board layout.

Take the PCB and cut it to size using an industrial strength cutter, which you can find in many labs. Do not cut the board exactly to size allow some space for mistakes. Illustrated in Figure A7-2.the cutter that we used to cut the side of the boards.

Figure A7-2: Cutting PCB board to size

Now that the transparencies are set up for the insertion of the board, it is time to develop the necessary solutions. Most labs will have the solutions already prepared; however, if it were necessary to prepare the solutions from scratch it is possible to do so. To prepare the developer solution, you must dissolve one tablespoon of NaOH pellets.

WARNING: Dissolving NaOH in water produces a large amount of heat, which may cause the NaOH solution to burn your skin or damage clothing.

Take one litre of water into one of the developer trays and sprinkle the NaOH evenly into the water, ensuring that the entire bottom of the tray is coated evenly. Ensure that all the 'sprinkles' are dissolved into the water, since if there are still chunks of NaOH than that will cause overdevelopment in certain regions of the board.

Now that the developer solution is created, an etching solution needs to be created. Using a litre of warm water, dissolve about 1 kilogram of iron chloride. The warm water should be about 50 degrees centigrade, however, if you prepared the solution ahead of time, than you

will need to heat up the developed solution to 45 degrees centigrade. Do this not by stove, but by running hot water around the tray.

A7.3 Manufacturing

The preparation process allows the manufacturing process to go much easier. First step in the manufacturing process is to expose the PCB. The PCB that you purchased should have come with a blue or black, self-adhesive protective layer as shown in **Figure A7-4**. This layer must be removed before exposure and processing. Remove this layer by peeling it off. Do so carefully ensuring not to scratch the UV-sensitive resist layer, which is beneath.

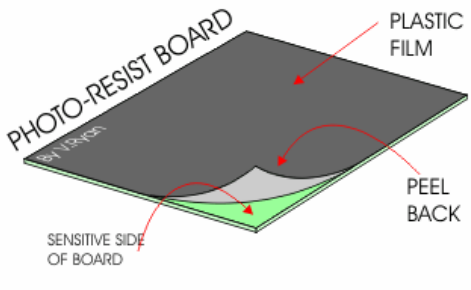

Figure A7-3: Photo-resist board diagram (PCB 2006)

Figure A7-4 shows the careful process of peeling back the protective layer. As you can see, it is important not to touch the UV-sensitive resist layer, since fingerprints will leave smudges on the board and will impair the quality of the PCB. Once you have removed both sides of the protective layer, slip the PCB into the slot of the transparency packet created previously. Ensure that you do not touch the board in the process. Figure A7-5 shows a diagram illustrating the sensitive side of the board being place to the transparency or the PCB mask.

Figure A7-4: Removing Photo-resist Protective Layer

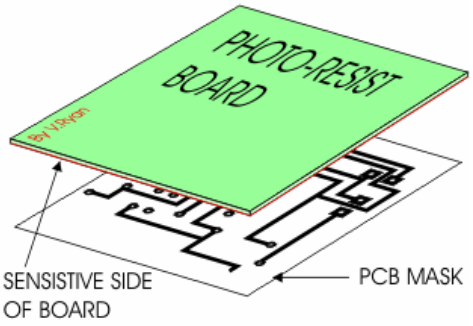

Figure A7-5: Diagram of combining board with mask (PCB 2006)

Figure A7-6 shows the physical implementation of the board to the transparency packet or PCB mask created previously.

Figure A7-6: Board insertion to Transparencies

Now place the packet into the UV-exposure machine. Figure A7-7 shows the UV-exposure box that was available to us at UL.

Figure A7-7: UV Exposure machine at the University of Limerick

The machine shown in **Figure A7-7** has florescent bulbs on the top and bottom. Placing the packet onto the bottom layer and then lowering the top layer down will commence the process. This machine has clips, which fasten for an airtight seal. If the machine that you are using does not have such a mechanism, then placing books on the top of the machine will work just as well. Figure A7-8 shows our boards on the machine

Fasten the clamps on the machine and set the machine for 300 seconds (which is equal to 5 minutes). Once the buzzer alarms that the 5 minutes are up, remove the boards, and examine the PCB. If you look carefully at the exposed PCB, you can see the traces in the resin coat as a slight discoloration. This discoloration can be darker or lighter than the

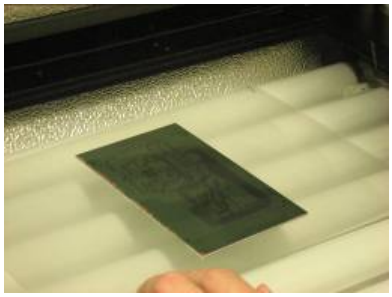

Figure A7-8: PCB board placed in Exposure Machine

surrounding area.

Now that the PCB design is on the board, it is time to develop the design. Place the PCBs in the NaOH solution. Figure A7-9 shows the PCB boards in the tray being placed in the solution. The green outer layer is the photo-resist of the board. You have to stir and move the PCB at regular intervals. If nothing is happening within 2 minutes than the board is underexposed. On the other hand, if within two minutes the photosensitive resin comes off completely, then the board was overexposed. With a correctly exposed PCB, the resin partially comes off, and the traces become much easier to see. With many PCBs, a thin layer of photo resist still covers the PCB, even though the development seemed complete. We recommended that after you think the development is finished, you leave the board in for an extra 2 minutes. We left our boards in the solution for 5 minutes. Figure A7-10 shows an example of some boards, which are ready to be removed from the developer solution. The traces are clear and the photo resist is gone everywhere it was exposed to the UV light.

Figure A7-9: Board with Photo-resist

Figure A7-10: Boards at the end of developer bath

Now, you place the developed boards in the iron chloride solution. This solution should have a temperature of about 45 degrees centigrade. Temperature plays a large part in the development and etching of the boards. If the temperature is too high, it can ruin the PCB in two ways. One, it can cause strong under etching of the tracks or it can deteriorate the photosensitive resist layer. On the other hand, if the temperature is too low than it can cause the traces to be under etched. If you start with fresh enchant of about 45 degrees centigrade, you will be able to etch a PCB in about half an hour without reheating. The end temperature of the solution is about 30 degrees centigrade then, depending amongst others on room temperature, volume, and rate of agitation. If the temperature becomes lower than about 25 degrees centigrade etching will be slow. Another factor in the length of time needed for etching is movement of the solution. If the

solution is stirred or has a bubble, making mechanism the length of the process will be much shorter. The equipment at UL has a bubble etcher, where there is a pump and produces bubbles. However, when production of our PCB occurred the pump was broken, and we did not manually agitate the solution. This process usually takes about 15 minutes; however, since the bubbler was not working and we did not agitate the solution, it took 30 minutes. Boards with thin traces must be watched closely because the traces can be etched away from the sides where the photo resist does not cover the copper. If possible, design a board with thick traces to allow for as much error time as possible. After etching is complete rinse and scrub the PCB in warm running water for at least two minutes to remove all chemicals. It is important to check the PCB for any open connections or broken traces. Our PCB can be seen in Figure A7-11 this is after it was placed through the running water. These can be very small, but if they are present on the board, will cause the board to malfunction.

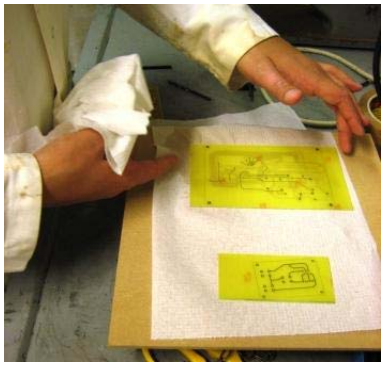

Figure A7-11: Drying PCBs after bubble etching

When drilling the holes wear protective glasses. The machinery we used at UL was a solid table mounted miniature drill press. The small holes were drilled first using a 0.6mm drill bit and the corners were drilled with the larger drill bit. Figure A7-12 shows the small drill that was used to make the holes.

Figure A7-12: Smaller Drill

Precision and accuracy is very important when drilling these holes. Since there is only tenths of millimetres to spare, it is important that we accurately drill our holes. Figure A7-13 and Figure A7-14 illustrate the drilling of the holes into the boards.

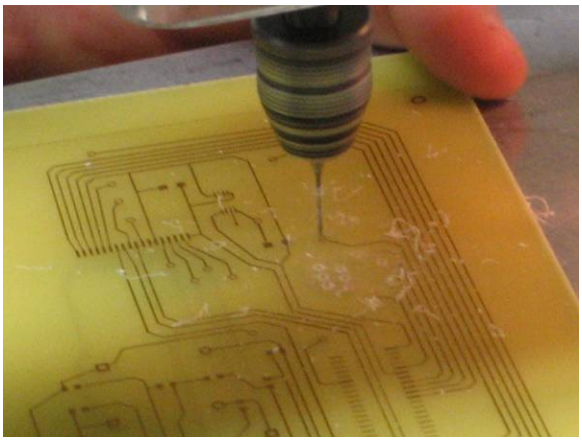

Figure A7-13: Drilling holes on the LCD driver circuit.

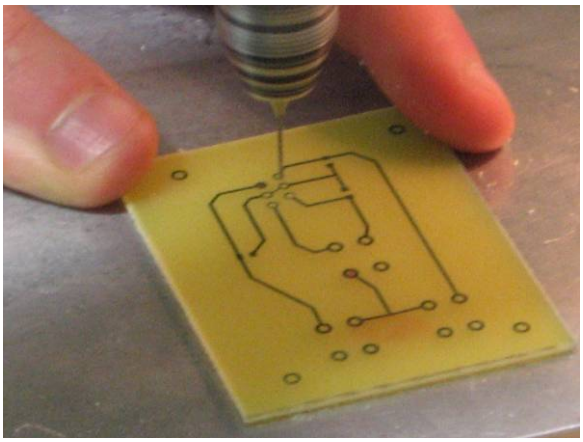

Figure A7-14: Drilling holes the user interface PCB.

We also had to switch drills, in order to drill the 1mm holes. Figure A7-15 shows the drill used.

Figure A7-15: Large Drill.

Creating a PCB in house is a complicated task; however, with the right machinery available, it is possible to create one. Figure A7-16 shows a flow chart of the PCB creation process.

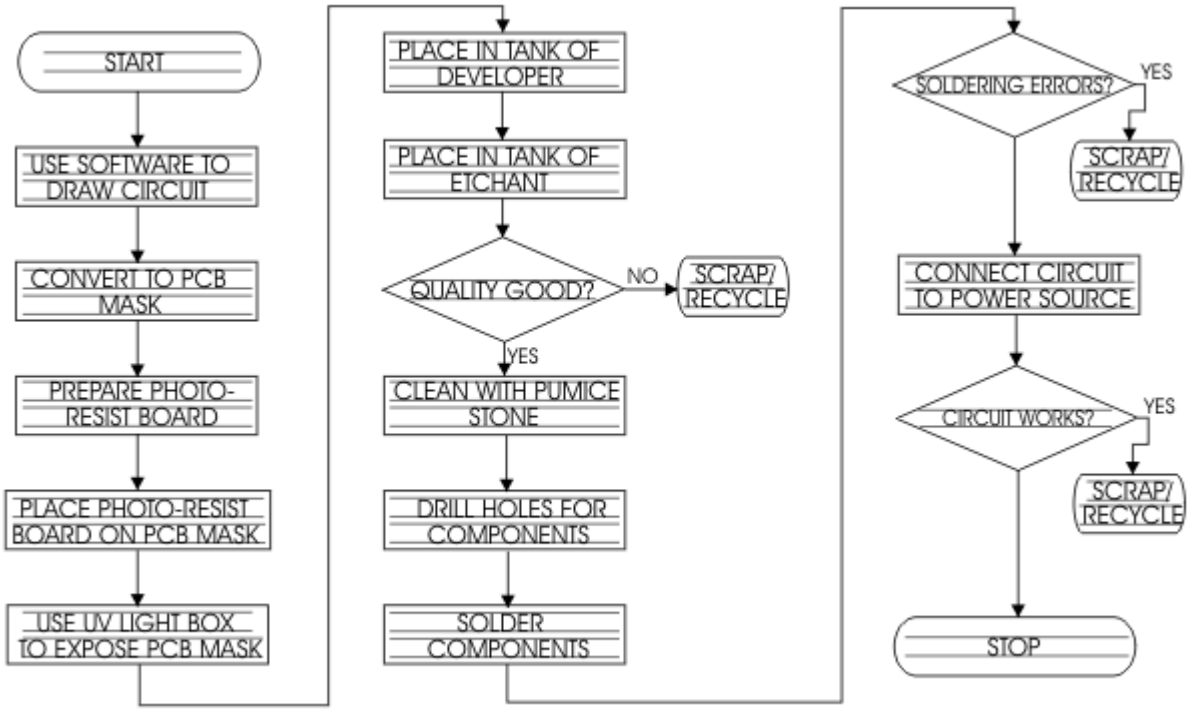

Figure A7-16: PCB Creation Flow Chart
(PCB 2006)

A8 Source Code

Due to the size of the various source code and configuration files, please consult the CD that accompanied this report or contact the project team directly at ulie-a06@wpi.edu for more information.