# EEL 4914 - Senior Design I – Spring 2015

## **H**ome **H**ealthcare **A**ssistant (**HHA**)

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# 1.0 Executive Summary

In order to alleviate ever-increasing healthcare expenses, the HHA is proposed to assist elderly patients with chronic ailments to perform regular checks of their vital signs and to scout emerging symptoms of patient health deterioration. The amassed data is to be wirelessly transferred to a monitoring station database where the person in charge (ideally, a nurse) is alerted if outlying data is detected. The vital signs' statistical data collected by the HHA aims to allow for quicker diagnoses than an ER visit out of the blue, with the end goal of reducing inpatient overhead experienced by hospitals.

The device is intended to be intuitive to use, compact enough to fit on a nightstand, and an affordable alternative to existing at-home medical monitoring solutions. Its features include the ability to alert the patient via a speaker when it is time for their daily checkup, then it presents a short list of generic questions on a display that a doctor may ask to monitor a patient. The project leaves room to be customized – for a patient with a heart condition, the questions may inquire about current experiences of chest pain, palpitation, light-headedness, swelling of feet, and if the patient had taken their prescribed medication on time. An attached keypad accepts responses to these "Yes/No" questions, and accepts numeric data entry for quantities such as the patient's weight. As part of the examination, the HHA prompts the patient to sequentially use various sensors for data collection of vital signs. The acquired data is sent wirelessly to a remote database which allows medical professionals access to the pertinent patient information upon request. Additionally, if anomalies were to be detected in the questionnaire or in the statistical data collected, the device would alert the receiving party to review the patient's data.

The alert system allows the doctor or nurse to take an active role in providing an informed response to the patient's health condition, and to schedule a doctor's appointment for the patient if needed. This alert system is also a part of the monitoring system software to be written for this project. At the monitoring station, patient data received is chronologically sorted in a database, and the numerical sensor data received throughout the patient's history may be plotted to show outliers.

The HHA aims to assist hospitals in reducing elderly inpatient costs via periodic remote monitoring of patient vital signs, and to inform nurses of patient condition deterioration so that medical intervention may convene before life-threatening issues manifest within the patient.

# 2.0 Project Description

## 2.1 Project motivation

The Home Healthcare Assistant (HHA) takes inspiration from the adage that an ounce of prevention is worth a pound of cure. The HHA device incorporates sensors that allow the accurate monitoring of patient vital signs, which allow medical professionals to know when a patient is ill, before the patient feels so ill that they are obligated to visit the doctor. Although the current implementation of the HHA is meant to be a generic proof-of-concept device, it is highly scalable and customizable to fit the needs for any patient with a chronic illness or ailment. The device may ask focused questions based on the patient's illness, and shall utilize sensors that best monitor the patient's health. In addition, the HHA aims to be an intuitive to use low-cost alternative to existing technologies on the market.

Personal motivation for group members include learning about the programming and use of microprocessors and integrated circuits, implementing wireless data communication, applying digital system design skills learned in the classroom, learning about PCB design, power system design – all things electronics and computer programming. Also, relevant medical standards will be uncovered that will undoubtedly mold our project to conform to standard requirements associated with such devices. Security standards pertaining to the management of personal, sensitive information acquired from a device that reads vital signs are another area to explore.

This project not only serves as a means for group members to hone our skills and prepare us to apply them once we are practicing engineers, but it is also a means to kick-start this journey on a device that has the end goal of improving others' lives. The HHA strives to reward both our hearts and minds, and is the reason that sparked our interest to initially pursue it.

## 2.2 Goals and Objectives

### 2.2.1 Vital Signs Objectives

The Home Healthcare Assistant is a patient-friendly device that comes at a low cost but has access to the commonly measured vital signs. Commonly measured vital signs will be determined by what medical establishments usually measure when the patient arrives for an appointment meeting. The objective is to measure the vital signs with minimal discomfort to the patient. This means the HHA has to measure vital signs without the need of taking blood or any other method that is invasive. Another objective to measuring vital signs that involves comfort issues is the location of where the device is to be attached in the patient's body. The HHA devices have to use easily exposed parts of the body and also use locations on the body that the patient has easy access to. Since the population focus is on the elderly, the available locations on the body is limited compared to a young adult. For the sake of the patients, the HHA has to limit the need for the patient to stretch or bend in any way to be able to have full access to measuring their vital signs.

### 2.2.2 Sensors and Sensor Casing Objectives

Sensors the HHA uses have to be accurate enough to meet the requirements shown in **Table 1** of section **2.3 Project Requirements and Specifications**. Moreover, the patient is expected to have absolutely no direct contact to the electronic devices the HHA uses to measure the vital signs. Instead of having direct contact to the sensors, the sensors will be shielded by either a probe or a casing before reaching contact with the patient's body. Any casing used to measure a vital sign cannot restrict blood flow. Sensors used to measure the vital signs also have to be relatively low-power to avoid any injury in the event of an electrical malfunction. All sensor casing materials that comes in contact with the patient has to be compared to the Restriction of Hazardous Substances (RoHS) to check if it safe. Sensors and their casing have to be relatively small and comfortable for use without creating any rashes, cuts, or scrapes while in use.

### 2.2.3 Powering and Regulating Voltage

Like any home electronic device, the Home Healthcare Assistant needs a power source generated by either a wall outlet or a battery. The HHA will incorporate both types of power sources for safety measures. To make the HHA cost-efficient, a reusable battery will be used as a power source while the device is in use. Much like a cell phone, the battery will be recharged with a safe recharging circuit that will enable power from wall outlets to flow back into the battery. The problem with most batteries is their sustainability, environmental, and health effects. The battery must be relatively safe to use in delicate devices that come in contact with patients. To avoid serious injuries from malfunctions, the HHA device must decide between being recharged and being in use.

Most batteries do not output the voltage or current specified. As a result, it is a goal to add 85% or more efficient voltage regulators in the Home Healthcare Assistant. Voltage regulators will protect voltage-sensitive devices from damage which stops the chain-reaction of device damage causing harm to the patient or surroundings. The 85% efficiency in voltage regulators is more of a goal than a requirement in order to increase the chances of meeting the project requirements and specifications of device battery life. With more efficient the regulators, there are less power losses.

### 2.2.4 Main Controller Subsystem Objectives

At the heart of the HHA device lies a single MSP430 microcontroller unit (MCU) that is connected to the four sensors, the BASYS2 board, and the CC3100 wireless module. As the main controller, the MSP430 orchestrates the routine readings of the HHA device by scheduling all of the tasks needed from a patient in a predictable and predetermined format. **Fig 2.2.4** shows a diagram of how the infrastructure for the HHA is set up. The HHA will manage, at most, three different sensors and will interface with the BASYS2 board as well as the CC3100 BoosterPack.

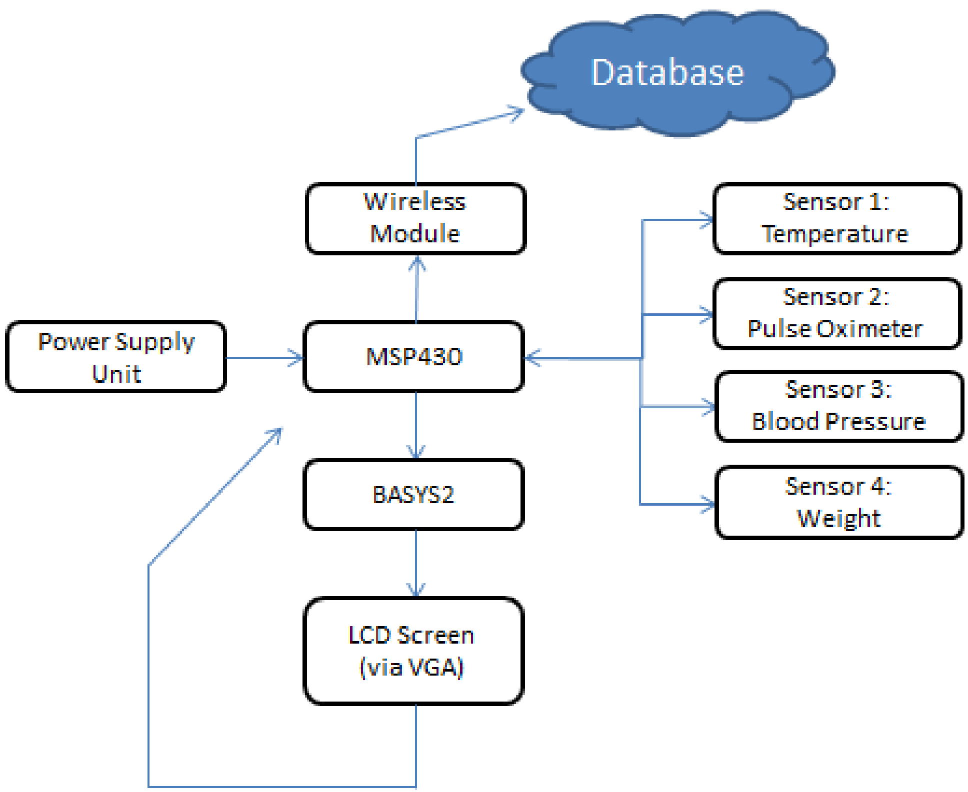


**Fig 2.2.4: Main Controller Subsystem Diagram**

The MSP430, however, needs to rely on the BASYS2 board to display which step of the diagnostic procedure the patient must provide their input or vitals. In order to manage all of tasks at hand, the MSP430 must be able to work in conjunction with the BASYS2 board with proper timing, which has an added layer of difficulty since the two board processors run at different clock speeds. This becomes especially important when the BASYS2 board sends back the responses to the questionnaire. Since the questions have simple "yes" or "no" answers, the responses will be transmitted in a simple bit stream where 1 will indicate a "yes" and 0 will indicate a "no." The MSP430 and BASYS2 boards must be prepared to transmit this information at a synchronized baud rate as the MSP430 prepares to send this information to the database and instruct the BASYS2 board to then display the next set of instructions for a patient to perform their vitals checkup routine.

The connections between the sensors and the MSP430 are the most important connections made in this device, and must therefore work most, if not all, of the time. The MSP430's multiple input pins will mostly all be occupied for the transmission of sensor data; therefore, the wires running between the MSP430 and sensors require a firm connection to ensure stable transmission of data and protection from outside interference to ensure reliable input data.

In addition to coordinating for graphical output, the MSP430 must also coordinate with the wireless module to access and supply data to the database. The wireless CC3100 module must maintain a stable connection since it is dependent on the MSP430 for power and programming instructions. In a working run-through, the CC3100 will be able to connect successfully to the Wi-Fi network and relay the input data from the different sensors to the remote database server and instruct that database to store that data.

It is important to note that even though every component connects to the MSP430, each of those connected components work independently of each other. This master-slave setup allows for the project to have as much, or as little, scalability as is needed. The separation of these connected entities also allows for the routine functions to be inspected more carefully, thus simplifying the process of debugging should a particular module stop responding or responds unexpectedly.

### 2.2.5 Radio Frequency Link (Wi-Fi)

In order to add a layer of uniqueness to this project, we decided that we would implement a wireless protocol to provide both a convenient method of transferring data from the HHA device to a host database, and to provide us with a learning experience in wireless technologies. Our device, being one that is meant to fit on a common nightstand and capable of being relocated when necessary, needs a functionally sound method of transferring data to a host machine no matter where the HHA moves. For a device that is so heavily reliant on data collection and retrieval, there exists a need to have access to a database with a reliable and relatively swift connection. There are many wireless protocols to be considered whose differences can lie in aspects such as their bandwidth, and maximum transfer speed; however, there are other specifications not directly related to the transfer of data that may become unfavorable for our design, including: power requirements, the security of data transfer, and wireless range.

We decided to implement a solution that utilizes Wi-Fi. Because of how affordable it would be to purchase a discrete Wi-Fi chip, it would be much simpler and cost effective for us to implement a technology that is in wide use, heavily documented on, and just overall more convenient for us to access with other Wi-Fi enabled devices. Another leading factor in our decision towards utilizing this protocol lies in the range covered by Wi-Fi. Since our scope lies in the average person’s home or apartment, it is safe for us to assume that even if the device was relocated from one room to another, the HHA would still be connected to the network through the Wi-Fi router’s wide coverage. [1]

### 2.2.6 User Interface Objectives

As part of the HHA patient examination, data is acquired from the user by means of sensors and a questionnaire. The questionnaire aspect is handled entirely by the user interface, and it aids the patient with gathering sensory measurements.

#### 2.2.6.1 Questionnaire

Once the device is turned on, the first of a preset list of questions is presented to the user on a display screen. Almost all questions in this section require Yes or No answers, for which user response is obtained. The response is received via a PS/2 protocol keypad attached to the HHA. Questions may be present which ask the user for a numeric entry, such as their current weight. This data is received as a three-digit input via the keypad. As each question is answered, the next question is sequentially presented to the user, and their response is awaited. Once data has been obtained, all of the acquired responses are stored by the HHA, and the next phase of the user interface initializes to help collect sensor measurements from the patient.

#### 2.2.6.2 Sensor data acquisition

The HHA device instructs the patient via the display screen which sensor to first use. Once the data is acquired, the HHA proceeds to state which sensor to use next, until all sensor data acquisition is completed. This aspect of the user interface can be timing-dependent, as some sensors may require a certain amount of time in order for the HHA to obtain an accurate reading. If unsuccessful, a measurement may have to be repeated and the HHA will instruct the patient to reuse the last sensor again. After all readings have been successfully obtained, the HHA examination is complete and all objectives of the user interface have been met.

### 2.2.7 Desktop Application

The desktop application is comprised of an HTML/PHP webpage running the frontend, and a Microsoft Azure SQL server operating the backend.

#### 2.2.7.1 Web-page

Upon having created and filled in a database with multiple days' worth of vitals and questionnaire answers, some user, be it a physician or even the patient themselves, will want to be able to analyze this data to form conclusions about a patient's health or just to make sure their vitals are stable. The user who wants to view this analytical data will be able to access the contents of the database by logging in with credentials set up by the server's administrator. In a realistic setting, we would expect a medical office to set this up, however the desktop application will be able to set up by even the patient.

Initially, reading in a few days' worth of vitals may seem like a simple task, but as time goes by, trying to make sense of many days' worth of vitals will become overwhelming. To remedy this, we are providing options to whomever is analyzing the data. These options are displayed below in **Fig. 2.2.7.1**.

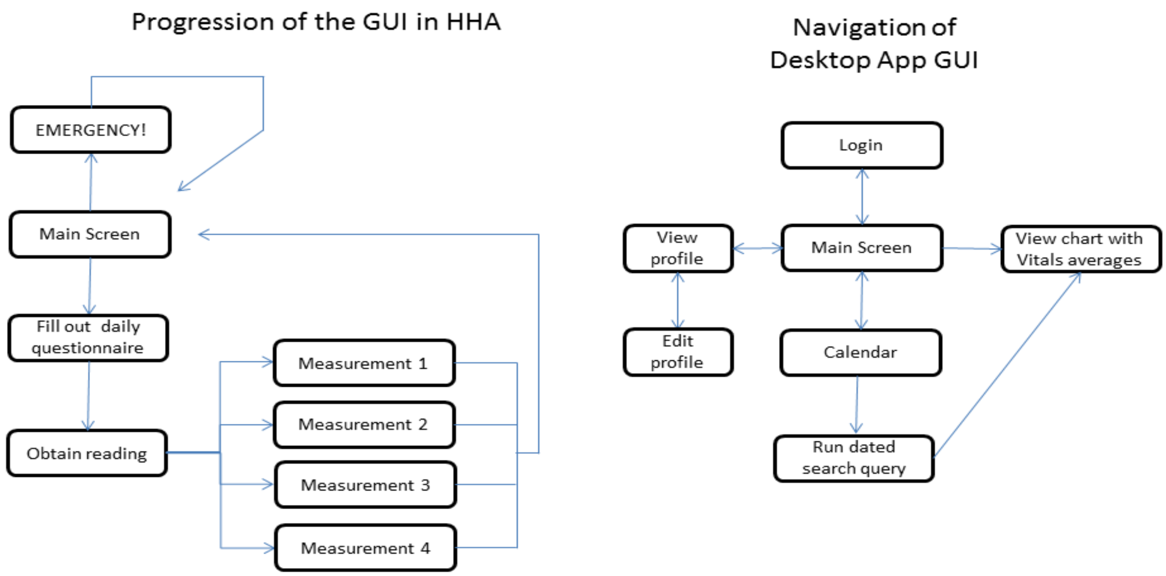


**Fig. 2.2.7.1: Navigation of the desktop app in comparison to HHA**

### 2.2.7.2 Database Server

The database server is remotely located in the cloud with a service provided by Microsoft Azure technologies. Microsoft Azure servers are favorable to use for this type of project because of their compliance with security standards, including HIPAA [2]. The way the database is accessed and manipulated is outlined in **Fig. 2.2.7.2-1**.

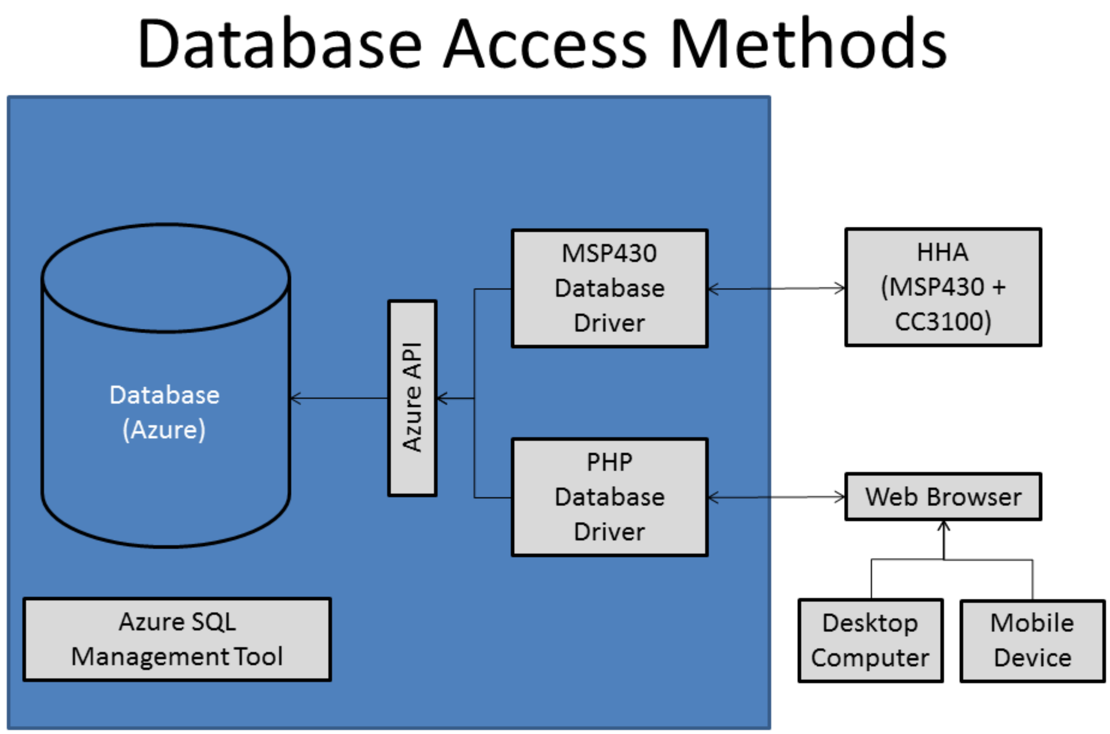


**Fig. 2.2.7.2-1: Accessibility of the database through multiple devices.**

Access to the server is limited to the HHA device and to the patient and certain authorized users on the desktop site. While the HHA is in charge of adding data to the database, any management, such as administratively removing reading entries, has to be done directly on the database. The database's data structure can be seen in **Fig. 2.2.7.2-2**. The database will contain not just the responses from the questionnaire, but also information that will be shown on the website.

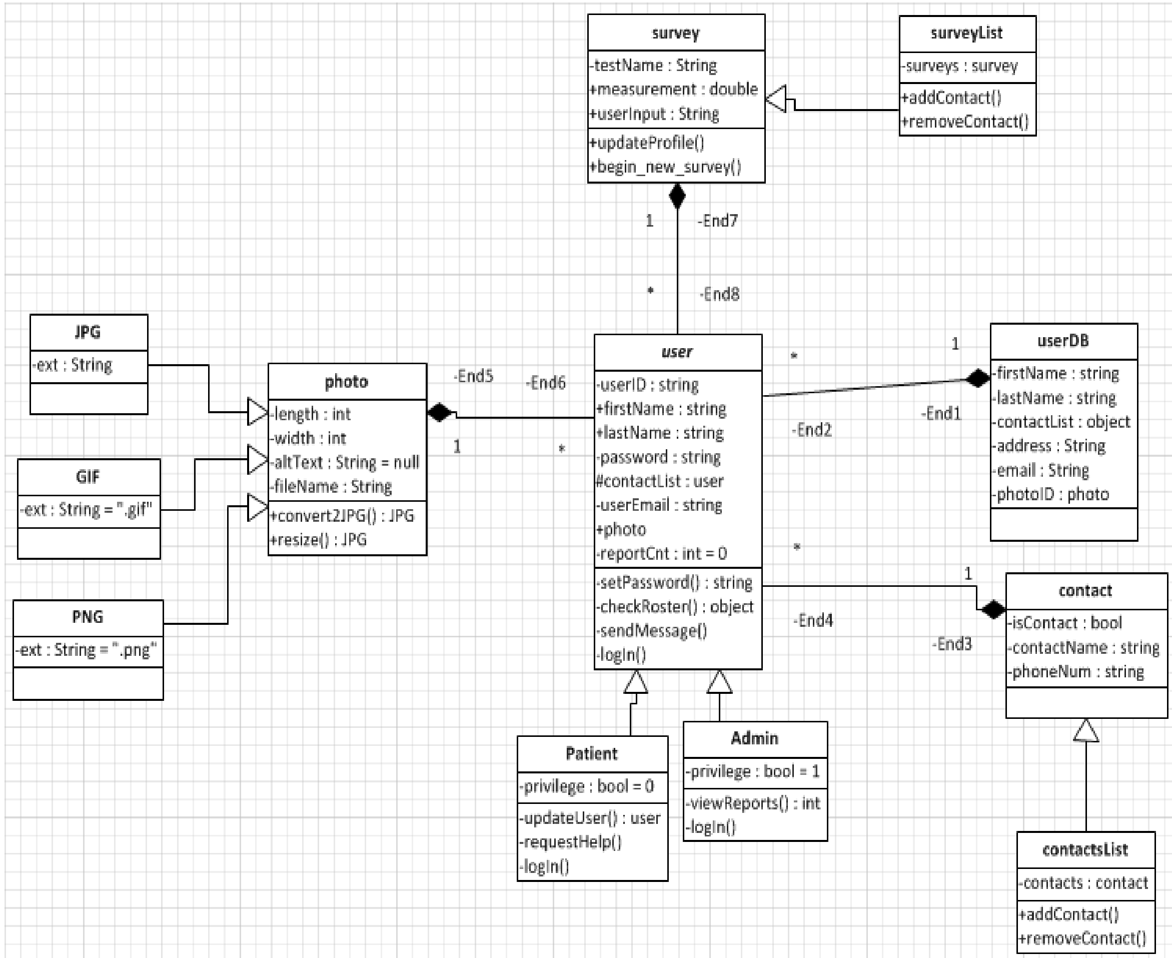


**Fig. 2.2.7.2-2: Database Class Diagram**

The database server will be able to calculate averages based on a particular time period, be it an average for the whole day or, more realistically, for the past two weeks. These averages are then calculated on the host server and sent to the website http://plot.ly. Through the use of plot.ly, the data is graphed, plotted, and has the option of being saved as an image if the person analyzing wishes to do so. That image can be saved and hosted on the website to display on that user's the home profile page for easy access, or it can remain stored in the server.

The goal of having this website's database run on a virtual machine is to be able to reduce expenditures related to server hosting by reducing the amount of hardware that is being used by utilizing virtualization on an existing computer that is already readily accessible on the internet, and to create portability in the event that a migration will be deemed necessary. The portability of this server will aim to facilitate the server admin in cases such as if the admin decides that a hardware upgrade is deemed necessary and must therefore move the virtual machine to a faster virtualization environment on newer, faster hardware. Another example where having to move the virtual machine might be reasonable and pertinent would be if it was done for the security of the system as a whole. Should hardware failure occur or be expected to occur, or in the event that the server is compromised or being attacked by malicious entities (i.e. the server could be under fire from a distributed denial of service (or DDoS) attack). The process of importing a virtual machine into a new server is as simple as copying over the image file of that virtual machine's hard drive and creating a new virtual machine on the host hardware. [3]

## 2.3 Project Requirements and Specifications

The HHA has requirements and specifications it is expected to achieve in its final design are shown in **Table 2.3**. These requirements and specifications will be what determine the success of the Home Healthcare Assistant.

| Table 2.3: Project Requirements and Specifications | |
|---|---|
| **Requirement / Specification** | **Limits** |
| Device battery life while in use | Greater than 1.5 hours |
| Device battery life while in sleep | Greater than 24 hours |
| RoHS Compliant Casing and Probes | Yes |
| Weight of Entire Device | Less than 16 lbs. |
| Dimension of Main Device Casing | 10in. x 10in. x 3in. |
| Blood Oxygen Level Accuracy | ± 20% |
| Body Temperature Accuracy | ±10% |
| Heart Rate Accuracy | ±10% |
| Weight Scale Accuracy | ±10% |
| Screen Readability Range with 20/20 vision | 3 Feet |

# 3.0 Research

## 3.1 Existing Similar Projects and Products

### 3.1.1 Existing Products: E-Health Platform

One of the existing products that is similar to the Home Healthcare Assistant is the E-Health Platform. The E-Health Platform is a sensor platform that acts as a shield for Arduino, Raspberry Pi, and Intel Galileo. E-Health Platform works as a hub that receives data from multiple medical devices which can sense pulse, oxygen in blood (SPO2), airflow (breathing), body temperature, electrocardiogram (ECG), glucometer, galvanic skin response (GSR - sweating), blood pressure (sphygmomanometer), patient position (accelerometer) and muscle/electromyography sensor (EMG) [4]. All 10 sensors are noninvasive with the exception of the glucometer which requires a drop of blood. Most of the sensors of the E-Health Platform already include a display to see the measurements which defeats the purpose of having the hub.

Unlike the E-Health, the HHA will consist of fewer sensors and also the addition of a different one to measure weight. The E-Health also has the capability to output graphs and results from the sensors to a mobile application via Wi-Fi or Bluetooth but requires an extra shield with the wireless module. For the sensors that do not already have a display to communicate with the user, there is also a module with an LCD screen to display the results specifically made for the E-Health Platform. The E-Health also does not take into account the current health problems the user might have nor does it record previous values for comparison in a database. E-Health simply shows the results and no mention of whether the patient is in good health or not. The HHA however, will take a patient's history and apply it to the results. The HHA will detect anomalies, alert the nursing station, and the nursing station will decide on the severity of the symptoms and take an appropriate course of action.

The E-Health also requires the user to be moderately tech savvy since the user has to program either the Arduino, Raspberry Pi, or Intel Galileo to function properly with the E-Health Platform [4]. On top of the user having to program and calibrate the device, the product casing is uncomfortable to have on a desk as it provides virtually no casing; therefore, the casing is lightweight, with a lot of wires that can drag it around with their weight or stick out in an unpleasant way. The biggest obstacle for people who might want the E-health Platform is the price. The HHA is aimed to be low cost and accurate enough to detect patient health problems and alert a medical professional. The E-Health Platform, with only the sensors the HHA will be using, is around $300 USD. This price is excluding the need of buying an LCD screen to read the sensors without display and a wireless module to transmit the data which increases the price.

### 3.1.2 Existing Projects: Baby PEAS

Baby PEAS is a project similar to the Home Healthcare Assistant which was developed by University of Central Florida students in the spring of 2014. The Baby Peas project is similar to the HHA in the sense that it is measuring several vital signs that the HHA will also measure. Baby Peas also compares to the HHA because they are both sending data wirelessly. The wireless data is received by a person monitoring the user who has a better understanding of what is being measured. Unlike the HHA, the population focus of Baby PEAS is literally for babies; therefore their approach in creating a device capable of meeting their requirements and specifications is different.

Baby PEAS uses some existing vital-sign-specific sensors such as the AFE4490 to measure blood oxygen levels as well as simpler devices such as the TMP006 and TMP103 for measuring temperature by digital means. For the wireless communication, their group decided it was appropriate to go with the CC2541 which is a Bluetooth and Wireless MCU. Their expectations were that Bluetooth range was adequate enough for their product since their values did not have to travel large distances or be stored directly into a database. The results from the Baby Peas device would instead need to pair with an Android device and the device could access the results through an application created specifically for Baby Peas.

## 3.2 Relevant Technologies and Possible Architectures

## 3.2.1 Vital Signs

In most, if not all, medical establishments, the first step to detect an abnormality in a person's health is to check their vital signs. These vital signs include: body temperature, blood pressure, heart rate, and breathing rate [5]. There are other, less important and used, vital signs such as weight which the HHA will take into account. With today's current technology, all vitals can be measured through the use of devices such as a device-controlled sphygmomanometer, thermometers, pulse oximeters, and digital weight scales. Although there are multiple brands and prices, there usually is a correlation between the accuracy of the vital readings and the price of the gadget. For this project, accuracy and low cost are a priority; therefore a common middle ground between the two has to be achieved.

### 3.2.1.1 Body Temperature

There are multiple ways medical establishments take a patient's body temperature by the use of thermometers. In the past, glass thermometers with mercury were used to measure a patient's body temperature since it was the only kind of thermometer but with the technological advances made throughout recent years, glass thermometers are no longer used. The reason they are not used is because of the hazards in handling anything with mercury as it acts as a poison once it is somehow released from its glass encasing. **Table 3.2.1.1** shows a list of thermo-sensitive devices that can be considered in the making of a thermometer along with their advantages and pitfalls [6].

**Table 3.2.1.1: Thermo-sensitive Devices**

| Criteria | Thermocouple | RTD | Thermistor | Semiconductor |
|---|---|---|---|---|
| Temperature Range | Very wide<br>−200°C +2000°C | Wide<br>−200°C +650°C | Short to medium<br>−50°C +300°C | Narrow<br>−55°C +200°C |
| Accuracy | Medium | High | Medium | High |
| Repeatability | Fair | Excellent | Fair to good | Good to excellent |
| Long-Term Stability | Poor to fair | Good | Poor | Good |
| Sensitivity (out) | Low | Medium | Very high | High |
| Linearity | Fair | Good | Poor | Good |
| Response | Medium to fast | Medium | Medium to fast | Medium to fast |
| Size/Packaging | Small to large | Medium to small | Small to medium | Small to medium |
| Interchangeability | Good | Excellent | Poor to fair | Good |
| Point (End) Sensitive | Excellent | Fair | Good | Good |
| Lead Effect | High | Medium | Low | Low |
| Self Heating | No | Very low to low | High | Very low to low |
| Overal Advantages | Self powered, simple, rugged, variety of physical forms, wide range of temperature | Most stable, most accurate, more linear than thermocouple | High output, two-wire ohms measurement | Most linear, high output, inexpensive, analog or digital IF |
| Overall Disadvantages | Non-linear, low voltage, reference required, least stable, least sensitive | Expensive, slow, current source required, small resistance change, four-wire measurement | Non-linear, limited temperature range, fragile, current source required | T < +250°C, power supply required |

**Courtesy of Texas Instruments**

From research in famous sites such as WebMD, Mayo Clinic, and written reports, the widely accepted average body temperature of a human being is 98.6°F measured orally [7] [8] [9]. Each person has their own unique characteristics and their body temperature can deviate from the average temperature. The range can be between 97.2°F up to 99.5°F and still be considered healthy [10]. Although all medical institutions agree on the average body temperature, they seem to disagree in what temperature is considered a fever and hypothermia. For this project, the temperature of the mildest possible case of a fever and hypothermia will be used to help the patient detect a possible health complication at an early stage. The temperature for a fever will then be 100.4°F or more and 95.0°F or less for hypothermia. **Figure 3.2.1.1 - 1** shows the range of temperatures and what temperature the HHA will consider as safe.

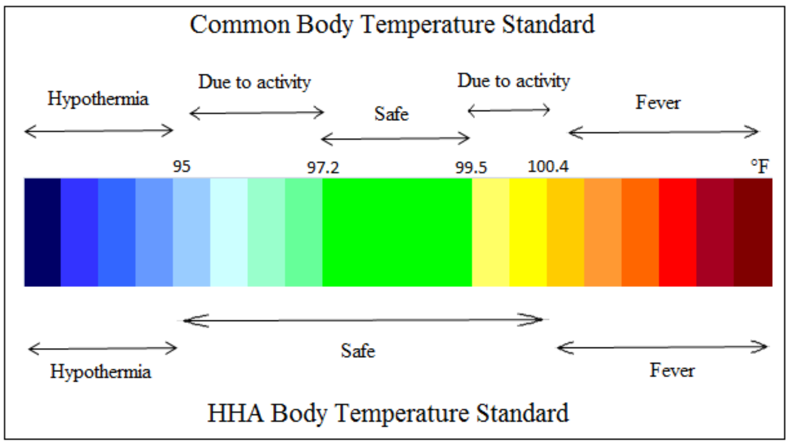


**Figure 3.2.1.1 - 1**

There are four commonly used locations to place a thermometer in order to measure body temperature. These locations are through the mouth, ear, armpit and rectum [9]. These common locations are chosen because of their core temperature being close to the average body temperature as shown in **Figure 3.2.1.1 - 2** [9]. Since the HHA device will be used at least on a daily basis, on the elderly, and will be noninvasive, the idea of the rectum is discarded. Measuring body temperature through the armpit requires a lot of calculations and considerations which also results in being the most inaccurate of the four. Using ear thermometers are a potential risk in causing and spreading ear infections; therefore, the HHA device will be measuring body temperature through the mouth as it is accurate, safe, and relatively comfortable [11].

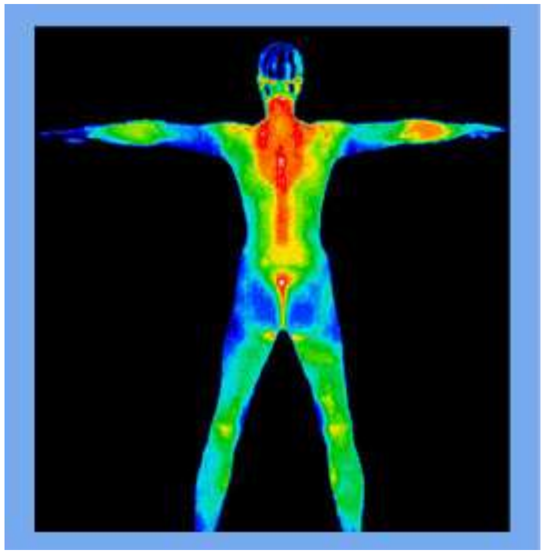

**Figure 3.2.1.1 - 2: Distribution of Heat Throughout a Human Body**
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### 3.2.1.2 Blood Oxygen Levels (SpO2)

SpO2 is an acronym whose definition stands for Saturation of Peripheral Oxygen. For the Home Healthcare Assistant, a device to directly measure breathing rate will not be utilized but SpO2, which has some relationship with the breathing rate, will be measured. Low oxygen levels are signs of health problems. Checking for blood oxygen levels is particularly useful to people with hypoxemia, chronic obstructive pulmonary disease (COPD), asthma, influenza, pneumonia, and any other acute respiratory infections [12]. In recent years, the way to measure blood oxygen level has become with the use of pulse oximeters because it is noninvasive, cost-effective, and quick.

Pulse oximeters usually utilize two light emitting diodes (LEDs) in the visible red and infrared spectrums. Usually the red and infrared LEDs have a wavelength of 660nm and 940nm respectively These two LEDs make it possible to differentiate the oxygenated from the deoxygenated hemoglobin in the blood. The light goes through the finger and reaches a light detector sensor on the other side. The detector then outputs a result that correlates to the light it is sensing which is not absorbed by the finger. The amount of light absorbed by the skin will change every time the heart pumps blood and forces the artery inside the finger to expand and let more blood flow through. The difference of the amount of light absorbed each time the artery expands, with the use of Beer-Lambert's Law and other equations, will be able to calculate the oxygen levels in the blood. These differences in light absorbed can also be used to measure the pulse of the patient. **Figure 3.2.1.2-1** shows the absorbance of light of both oxygenated and deoxygenated hemoglobin versus the wavelength of light [13].

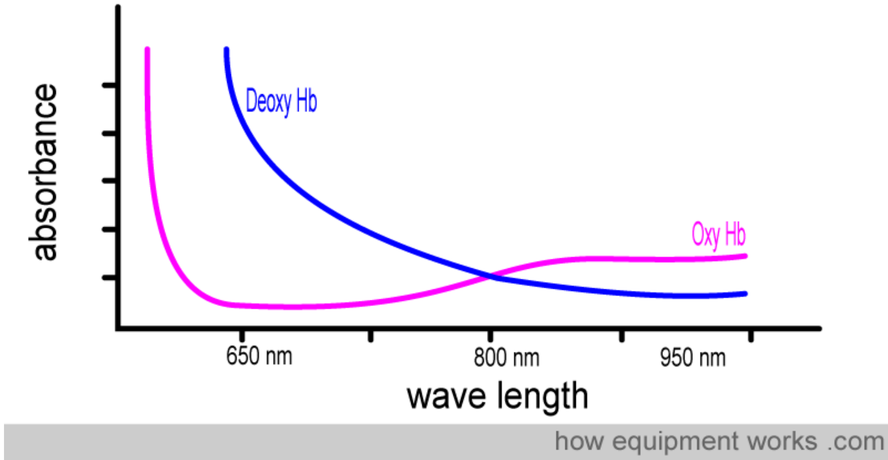



**Figure 3.2.1.2 - 1**
**Made possible with the permission of Prasanna Tilakaratna**

Although Beer-Lambert's Law shows that there is a direct correlation between the absorbance of a molecule to the concentration and the path length of the sample, it is assuming there is no light scattering [14]. It is logical that light scattering will occur as light goes through the patient's finger which is composed of both pulsatile and nonpulsatile arterial blood, venous blood, and tissue [15]. Pulse oximeters sold in the market do not simply work by using Beer-Lambert's law equations. Most, if not all, pulse oximeters use look-up tables with values obtained from real, healthy patients who have undergone invasive blood oxygen testing and have been compared to the results of the pulse oximeter [16]. Due to the nature of the HHA being noninvasive, data will be obtained using Beer-Lambert's Law and any additional calibration will be added when compared to the results of other pulse oximeters. **Figure 3.2.1.2 - 2** shows Beer-Lambert's Law data compared to actual blood oxygen results.

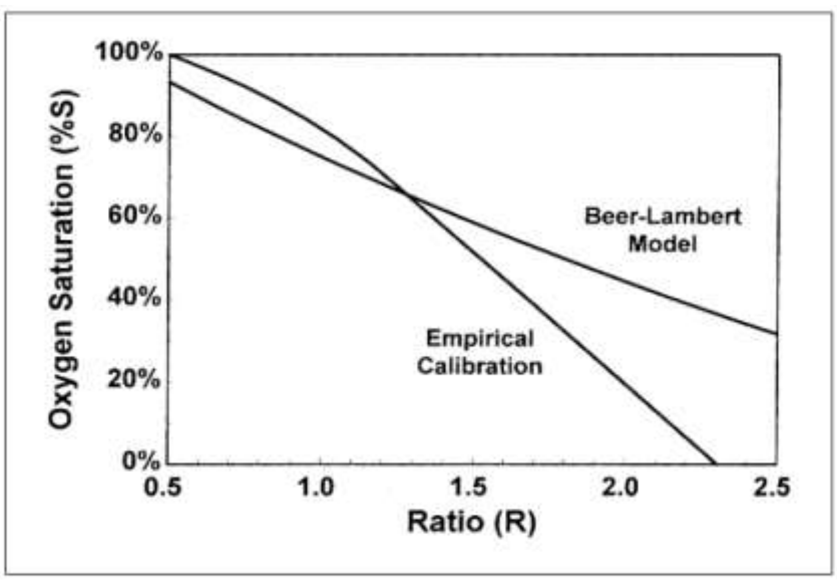
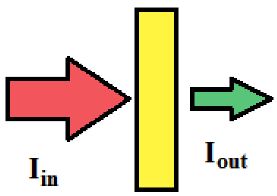



**Figure 3.2.1.2 - 2**
**Reprinted with permission of Lionel Tarassenko**

The equations governing the pulse oximeter of the HHA with the Beer-Lambert Model are shown in **Table 3.2.1.2** [15]. The results obtained from the HHA pulse oximeter will be compared to the results of other pulse oximeters in order to find a mathematical equation to make them have similar answers.

**Table 3.2.1.2**

| Beer-Lambert Law | SpO2 | Alternative SpO2 |
|---|---|---|
| Absorbance<br>$A = \log_{10}(I_{in}/I_{out})$<br> | $R = \frac{log_{10}(I_{ac}) * \lambda_{660}}{log_{10}(I_{ac}) * \lambda_{940}}$<br>I = light intensity<br>λ = wavelength | $R = \frac{(AC_{660})/(DC_{660})}{(AC_{940})/(DC_{940})}$ |

### 3.2.1.3 Heart Rate (Pulse)

A patient's pulse will also be measured in the HHA pulse oximeter because of its crucial importance in a patient's health. An average person's heart rate is usually from 60 to 100 beats per minute (bpm) but it can be as low as 40 bpm if the person is very fit or is using beta-blockers [17]. Because of the large range in a healthy person's bpm, the HHA database will have to compare new and old bpm values in order to determine if the patient is suffering from some sort of health condition. Unfortunately, a patient's heart rate cannot trim the possible number of causes that might be affecting the individual's health. The reason pulse cannot trim down the possible number of causes is because almost all health problems have a change in the patient's pulse. These causes can be categorized as either emotional or physical.

Changes in bpm, mostly in the focused group of the HHA, can be dangerous as it can mean the patient has heart problems. An increase in bpm can also mean the person is currently stressed due to either a current physical symptom that is causing pain or emotionally imbalanced [17]. Therefore, it is safe to assume people suffering from anxiety, depression, and bipolar will exhibit signs of health deterioration when bpm increases above their regular levels. The pulse oximeter could also measure if the patient's pulse is weak, too strong (meaning a hard blood vessel), or a random rhythm (heart murmur) by measuring the highs, lows, and time frame of each pulse in the pulse oximeter [18].

### 3.2.1.4 Blood Pressure

When the heart pumps, the body receives the energy and oxygen it requires to function properly. To make sure there is no added stress in any vital organ, the pressure of the blood being pumped is measured. Blood pressure monitors the strength of the blood flowing through the arteries. The higher ones blood pressure is the more strain it puts on a person's veins. Because high blood pressure does not always have obvious symptoms, it is very difficult for someone to feel or notice it. [19]

Readings of a blood pressure consists of two numbers. The first number is called the systolic blood pressure which represents the highest a blood pressure value when the heart is beating. The second number is called the diastolic blood pressure which is the lowest blood pressure value when the heart is relaxed between beats. Blood pressure is measured in millimeters of mercury or mmHg. The mean arterial blood pressure, or MAP for short, measures an average blood pressure over the time of an entire cardiac cycle. The MAP is determined by **Equation 3.2.1.4**. The diastolic measurement is counted twice, as it takes twice as long to fill the chambers with blood. [20]

$$MAP = [(2 \times \text{diastolic})+\text{systolic}] / 3 \qquad \textbf{(Equation 3.2.1.4)}$$

For the average adult over 20, a blood pressure of 120/80 mmHg or under is considered normal, as shown in **Table 3.2.1.4.** Although blood pressure can change depending on many factors such as posture, sleep, stress, or exercise, it should normally be below 120/20mmHg. Not always does a single reading of high blood pressure make it true. Sometimes several readings are needed. However, if the results stay persistent over time, you may be diagnosed with high blood pressure. For MAP the value should read somewhere between 70 and 110. Anything lower than 60 and vital organs will not receive enough oxygen from the blood to function. [20]

**Table 3.2.1.4**

| **Blood Pressure Level** | **Systolic mm Hg (Top #)** | | **Diastolic mm Hg (Bottom #)** |
|---|---|---|---|
| **Normal** | less than **120** | and | less than **80** |
| **Prehypertension** | **120 – 139** | or | **80 – 89** |
| **High Blood Pressure Stage 1 of hypertension** | **140 – 159** | or | **90 – 99** |
| **High Blood Pressure Stage 2 of hypertension** | **160** or higher | or | **100** or higher |
| **Hypertensive Crisis (Emergency care needed)** | Higher than **180** | or | Higher than **110** |

**(Pending permission)**

Children's blood pressure varies by age. Because their body is in a continuous state of growth, the blood pressure for any given age is shown in **Figure 3.2.1.4.** In the chart the red category is hypertension, yellow is prehypertension, and green is in the normal range.

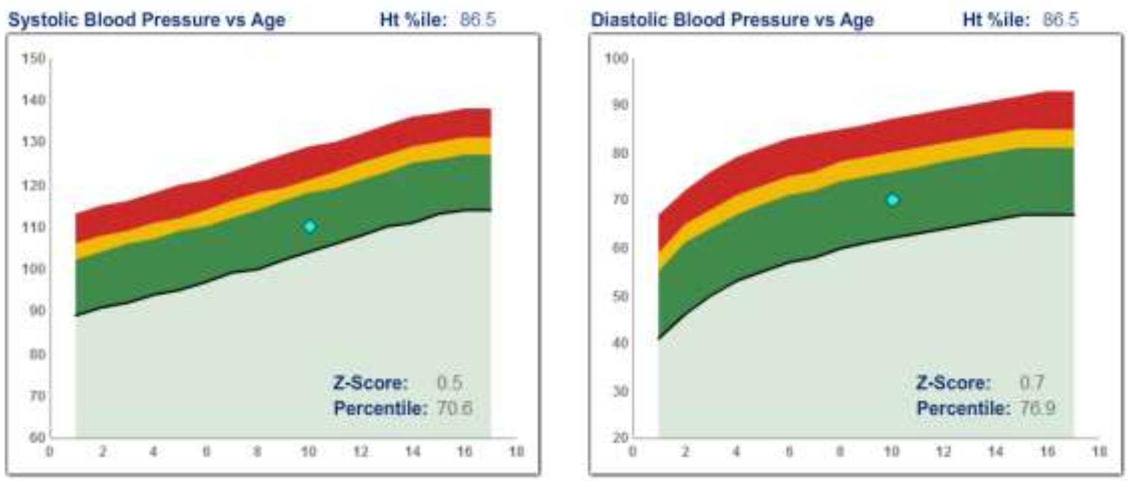



**Figure 3.2.1.4**
**(Pending permission)**

Knowing a person's blood pressure can help prevent fatal incidents due to health problems. If the Home Healthcare Assistant measures blood pressure accurately, it can alert a medical professional who then takes action. According to research, reducing salt intake and other forms of sodium has helped a number of people reduce their high blood pressures. Another possible way to reduce high blood pressure is to reduce the amount of alcohol a person consumes. It is recommended that a person does not drink more than once a day. This recommendation assumes that a drink is 1.5 ounces of 80-proof or 1 ounce of 100-proof whiskey, 5 ounces of wine, or 12 ounces of either regular or light beer. [21]

There are other causes to high blood pressure such as caffeine and stress which increases the blood pressure temporarily. Caffeine and stress are not as dangerous as alcohol or salt but in a person already suffering from high blood pressure, it can be just enough to break the threshold of pressure the organs in the body are willing to take. One of the greatest problems with high blood pressure is related to weight. More than 60% of adults in the United States are overweight. This means more than 60% of adults in the U.S. might have a high blood pressure problem. Reducing weight, even if it is small amounts, greatly helps the body. Unchecked high blood pressure can lead to stroke, damaging the arteries, heart, brain, kidneys, eyes, and cause sexual dysfunction, bone loss, and trouble sleeping. [22]

### 3.2.1.5 Weight

Measuring the weight of the patient gives important insight to the lifestyle or underlying causes for a drastic weight gain or loss. People who lose weight rapidly are prone to problems just like people who gain weight can suffer from high blood pressure. A possible and economic way to measuring weight is using a digital bathroom scale. A digital bathroom scale is an electronic weighing machine that is used to measure a variation of readings such as body fat, BMI, lean mass, or muscle mass. Weight is particular to one's Body Mass Index (BMI) and waist size. Measurements vary immensely from person to person due to the person's uniqueness. A healthy BMI is between 18.5 and 24.9; anything under that and one is considered underweight while anything over 24.9 can be considered overweight or even obese. The average weights for certain heights are shown on **Table 3.2.1.5.** If weight is not controlled, the patient can suffer from coronary heart disease, high blood pressure, stroke, type 2 diabetes, abnormal blood fats, metabolic syndrome, cancer, osteoarthritis, and many other health problems. [23]

**Table 3.2.1.5**

| Height | Weight | | |
|---|---|---|---|
| | **Normal** | **Overweight** | **Obese** |
| **5' 7"** | 121 to 158 lbs. | 159 to 190 lbs. | 191 to 249 lbs. |
| **5' 8"** | 125 to 163 lbs. | 164 to 196 lbs. | 197 to 256 lbs. |
| **5' 9"** | 128 to 168 lbs. | 169 to 202 lbs. | 203 to 263 lbs. |
| **5' 10"** | 132 to 173 lbs. | 174 to 208 lbs. | 209 to 271 lbs. |
| **5' 11"** | 136 to 178 lbs. | 179 to 214 lbs. | 215 to 279 lbs. |
| **6'** | 140 to 183 lbs. | 184 to 220 lbs. | 221 to 287 lbs. |
| **6' 1"** | 144 to 188 lbs. | 189 to 226 lbs. | 227 to 295 lbs. |
| **BMI** | 19 to 24 | 25 to 29 | 30 to 39 |

**(Permission Pending)**

## 3.2.2 Sensors

### 3.2.2.1 Temperature Sensors

#### 3.2.2.1.1 Resistance Temperature Sensors (RTDs)

RTDs are very common among thermometers and come as film thermometers or wire-wound thermometers [6]. Film thermometers come with a thin film of metal on a substrate with relative low cost and fast response time [24]. Usually, the thin film of metal is platinum because of its linearity and long-term stability making it a great metal for repeatability. The drawback of thin-film thermometers is their susceptibility to contamination due high surface-to-volume ratio. However, good packaging techniques are being developed by several companies which are reducing the drift and contamination of film thermometers which is making them the preferred to the wire-wound thermometers and thermistors [6]. RTDs are also known to have positive temperature coefficient (PTC) meaning that it increases resistance as temperature increases.

Although film thermometers is the faster version of RTDs, it is slow compared to other thermo-sensitive devices which means the HHA patient will need to spend more time with a thermometer in their mouth every day. RTDs can be a little expensive compared to other thermal sensors plus the amount of calibration and circuit design needed also raises the price as it needs a 3 or 4-wire configuration as shown in **Figure 3.2.2.1.1** to minimize the effects of line resistances [25]. A constant current source is also needed in RTDs to measure the voltage across the resistance temperature sensor and relate it to a temperature using the equation given in the datasheet for that particular RTD. Multiple wires mean multiple readings that have to be taken. The current flowing the RTD located at R(b) in **Figure 3.2.2.1.1** also cannot exceed 1mA because of the self-heating of the resistor creating erroneous data. Since the current is low, and the resistance of RTDs are low and have little resistance change, an amplifier circuit might also be needed.

**Figure 3.2.2.1.1(a)** shows a 2-wire RTD configuration with line impedances are added to the RTD value R(b). **Figure 3.2.2.1.1(b)** is a 3-wire configuration where the average line impedance is neglected from the sensor measurement. **Figure 3.2.2.1.1(c)** is the 4-wire configuration which is the most accurate of the configuration and can give accuracy up to hundredths of a degree. The 4-wire configuration is the most expensive and is commonly used in scientific apparatus [26]. RTDs cover a wide range of temperatures far exceeding the narrow range of a patient's body temperature.

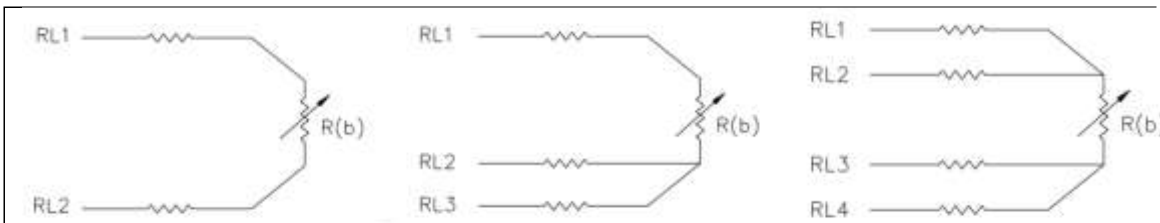



**Figure 3.2.2.1.1(a) Figure 3.2.2.1.1(b) Figure 3.2.2.1.1(c)**
**Figure 3.2.2.1.1 was reprinted with permission of Pyromation**

### 3.2.2.1.2 Thermocouples

A thermocouple is a type of temperature sensor that measures the temperature difference between two probes and converts it directly to an electrical energy equivalent [24]. The way a thermocouple works is by creating two dissimilar junctions composed of different metallic conductors that are joined at one point [6]. One junction of the thermocouple is held at a constant temperature as reference and the other will be the probe to measure the temperature relative to the first one. The temperature difference will create a small voltage which is proportional to the temperature difference between junctions. **Figure 3.2.2.1.2** shows an example of a thermocouple. A thermocouple is a very useful temperature sensor but it does not apply to medical thermometers or the type of thermometers needed in the HHA.

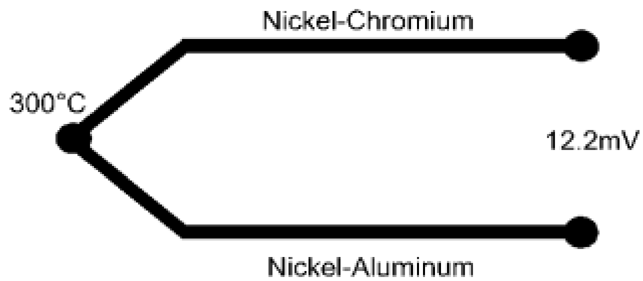



**Figure 3.2.2.1.2**



Thermocouples are very low-cost, self-powered, and cover a huge range of temperatures; however, the accuracy of thermocouples are nowhere near what medical thermometers require. The most efficiently designed and calibrated thermocouples have an accuracy around 1.5°F [24]. Thermocouple's need of a known voltage reference that does not change due to external temperature interference can also be problematic in a small apparatus such as a thermometer. Other disadvantages of thermocouples include their lack of repeatability, sensitivity, stability, and high noise susceptibility. Thermocouples are mainly used in furnaces, jet engines, and laboratory experiments because of their wide temperature sensing range [27].

### 3.2.2.1.3 Thermistors

Thermistors are literally resistors that are affected thermally and work very similar to RTDs except they usually come with negative temperature coefficients. Their low-cost, fast response, and good accuracy comes at a cost of temperature sensing range that is still good enough for a thermometer which is why they are currently one of the leaders in the market for household medical thermometers. The HHA could use this method in creating a body temperature sensor but it lacks several characteristics that a semiconductor integrated circuit (IC) can provide.

Thermistors need a very stable current source that flows across its resistance in order to obtain a voltage that is proportional to the temperature sensed by the thermistor. This means some sort of circuitry would need to be implemented to accurately control it unlike an IC which needs a voltage source easily stabilized with simple electronics such as a zener diode or voltage regulators. Thermistors are also nonlinear and generate more heat than a semiconductor which can cause discrepancies in calculations if not dissipated correctly. Thermistors also provide a larger output impedance which, if connected to an analog to digital converter, would require a buffer. All thermistor architectures require the use of multiple resistors which means more space and bigger design. The last temperature sensing device the HHA could use to measure the patient's body temperature orally is temperature sensing ICs.

#### 3.2.2.1.4 Semiconductor (ICs)

Temperature sensitive semiconductors are a good, low-cost alternative to thermistors. These ICs usually only require a stable voltage source and outputs either an analog or digital result. Out of the four possible ways to measure temperature, semiconductors provide the most linear output, making it easier to calculate the temperature given a certain output. Similar to thermistors, temperature sensor ICs work for a narrow band of temperatures that is more than sufficient for body temperatures. They also provide easier interchangeability which gives the HHA a great comfort zone if something went wrong with the sensor, the implementation, or testing of the device.

Using semiconductors are also an appropriate choice for the HHA to measure temperature because of low self-heating effects and good long-term stability. The patient would not have to worry about the thermometer losing its accuracy. Temperature sensing ICs also use less power than RTDs and thermistors. Current technology is moving at a rapid pace and temperature sensitive ICs are greatly improving. A newly developed IC temperature sensor that will rival all others in the medical field has been introduced. Although the IC is not currently for sale, it shows the IC approach is an appropriate choice for the HHA as it leaves an opening for a major improvement in the thermometer design. The newly developed IC is mentioned in the **Project Hardware and Software Design Details** section.

### 3.2.2.2 Pulse Oximeter

As mentioned in section **3.2.1.2 Blood Oxygen Levels**, a pulse oximeter consists of 2 LEDs and a light detector. The LEDs for the HHA pulse oximeter needs to have a viewing angle of at least 30 degrees because of their location relative to the light detector. Same form factor and similar light radiance is also needed to avoid installation and calculation issues. The key component of pulse oximeters is the type of light sensor integrated within them.

#### 3.2.2.2.1 Photomultiplier Tubes

Photomultiplier tubes are vacuum tubes with a light sensing surface that absorbs incoming light photons and emits secondary electrons. These electrons are accelerated and multiplied within the tube by dynode plates. Each time the electron strikes one of the plates, it has gained enough momentum to create an even larger number of electrons. Eventually, there are enough electrons to create a current to develop hundreds of millivolts across a 50 ohm resistor [28]. Photomultiplier tubes are the ultimate way of light sensitivity detection but it cannot be applied to the HHA. Like most accurate devices, the photomultiplier tubes are very expensive.

The wavelength range of photomultiplier tubes is very limited but with appropriate calculations, it might be possible to use a 900nm near-infrared LED and calculate the oxygenated hemoglobin in the HHA. Another downfall of photomultiplier tubes is the sheer size of the device. Photomultiplier tubes are large and cannot be used to create a comfortable, compact design for the pulse oximeter where the patient needs inserts their finger. Although they can be great devices, the pitfalls of photomultiplier tubes disqualify it as a candidate for the light detector sensor.

### 3.2.2.2.2 Photodiodes

Photodiodes are currently the leading light detectors in pulse oximeters for multiple reasons. One of these reasons is the standard packaging which can be easily integrated in a PCB. Another reason is that the manufacturing process of photodiodes is relatively easy since they are manufactured similarly to semiconductor diodes. Photodiodes are also lightweight, small, have fast response time, relatively cheap, highly linear [28]. For the HHA, photodiodes are a viable option as the light sensor.

Some of the few disadvantages of photodiodes are its low gain, moderate susceptibility to noise, and low output current. Because of these disadvantages, extra components need to be added along with the photodiode if it is going to be implemented in the HHA such as a current to voltage converter, filters, and amplifiers. The photodiodes also have greater dark currents than some integrated circuits that work as light sensors which means the device is always on and works as a bias which offsets the correct values. This bias also increases with temperature. When designing pulse oximeter circuitry that involves photodiodes, the junction capacitance, dark currents, sensitivity, spectral response, and packaging play an important role [29]. Photodiodes are widely used in applications ranging from sensors for door openings, assembly line controls, load levelers in luxury cars, to personal blood sugar meters for diabetics, sun-tan exposure meters, smoke detectors, x-ray baggage inspection systems and even cranial pressure sensors for head injury patients [28]. Since photodiodes are widely used, finding reference schematics should be relatively easy if it is the decided choice for the HHA. A possible block diagram for the pulse oximeter using photodiodes is shown in **Figure 3.2.2.2.2**.

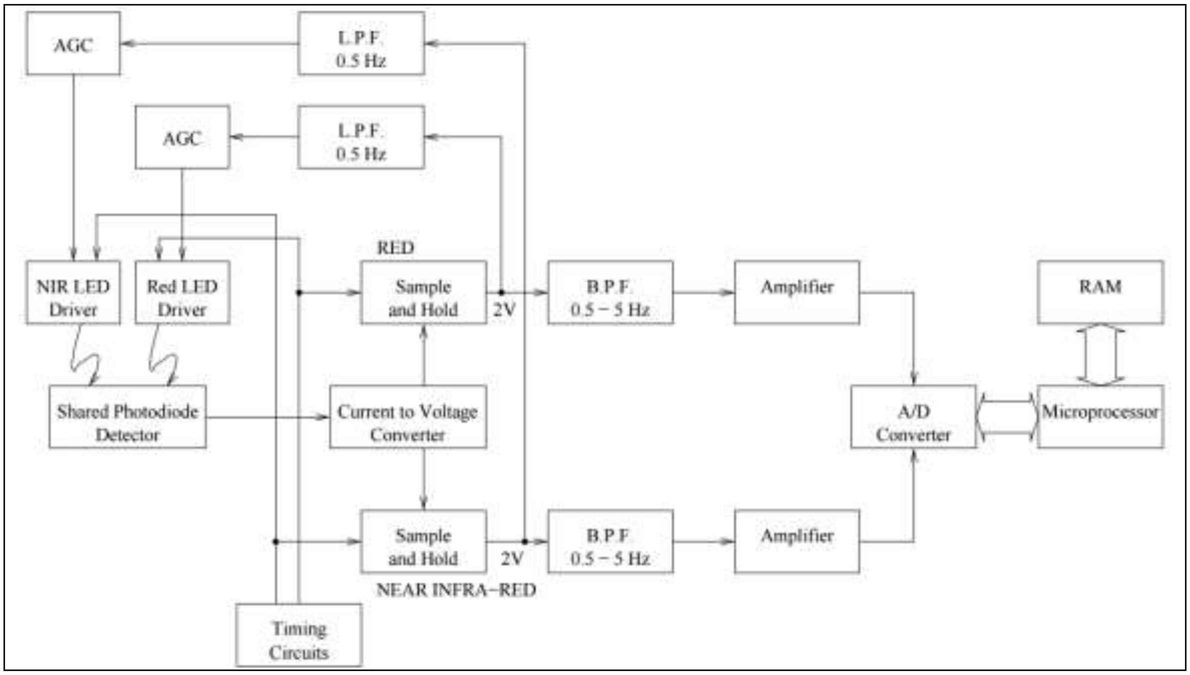



**Figure 3.2.2.2.2**
**Reprinted with permission of Lionel Tarassenko**

### 3.2.2.2.3 Phototransistors / Photodarlingtons

Phototransistors are transistors that work similarly to photodiodes except they have the ability to amplify the current. Photodarlingtons are phototransistors in cascade to multiply the effect of the amplification from about a 1,000 from a single phototransistor to greater than 100,000 [28]. The side effect of phototransistors is that their linearity suffers and has limited bandwidth. Phototransistors are mostly used where very limited optical power is available [28]. Dark currents that flows through the phototransistor are also amplified which makes the accuracy of the final values drop. The dark current amplification in phototransistors can possibly cause damage to other equipment which means extra circuit design for equipment safety a necessary task. Phototransistors could be used for the HHA design but not recommended since the accuracy will decrease and a lot of testing, time, and calibration can become an issue. The HHA does not suffer from optical power so phototransistors are not a convenient choice of light sensing detection.

### 3.2.2.2.4 Optical Integrated Circuits (ICs)

Optical integrated circuits are light sensors that incorporate additional electronics directly onto a semiconductor sensor chip which makes possible to add additional functions [28]. Some of the benefits of using optical ICs for the HHA are that they can already incorporate a current-to-voltage converter, current-to-frequency converter, or reference-level sensing. Since the optical ICs incorporate these benefits in a single monolithic IC, they are highly immune to both ambient and electronic noise. Circuit design with optical ICs then becomes much easier to handle and datasheets also contain adequate references on how to apply them in a design. The only issues with optical ICs are their cost, lack of customization, high linearity, and response time. With research, it was possible to find a limited variety of optical ICs that do not suffer from cost, or linearity. This means that the HHA requirement of low cost and high accuracy is met. Response times are similar to those of phototransistors which are in the range of microseconds instead of nanoseconds in photodiodes. **Table 3.2.2.2.4** shows a summary of specifications for the different pulse oximeter light detector sensors that could be used [28].

**Table 3.2.2.2.4: Light Sensor Technologies**

| | Photo-Multiplier Tubes | Photodiodes | Phototransistors | Integrated Circuits |
|---|---|---|---|---|
| **Wavelength Range (nm)** | 200 - 900 | 200 - 2000 | 400 - 1100 | 200- 1100 |
| **Linearity** | Good | Excellent | Good | Good |
| **Susceptibility to Noise** | Fair | Fair | Fair | Low |
| **Stability** | Very Good | Very Good | Good | Very Good |
| **Cost** | High | Low | Very Low | Very Low |
| **Customize Level** | Poor | High | Fair | Poor |
| **Physical Size** | Large | Small | Small | Small |

### 3.2.2.3 Blood Pressure Monitors

Blood pressure monitors are usually applied in either the upper arm, wrist, or finger for adults. For babies, monitoring is done using a special cuff which is placed over the baby's foot. Blood pressure monitors also come in different forms. One of the types of blood pressure monitors is the manual blood pressure monitors, called aneroid monitors, in which a medical practitioner places the cuff on the patient and manually inflates the cuff. The cuff is connected to a gauge that measures the blood pressure. A stethoscope is placed on the skin over the patient's artery to hear when blood stops circulating through the veins. The medical practitioner then slowly releases pressure from the cuff until blood starts circulating again. [30]

The second, and least efficient, way of measuring blood pressure is through the finger. The last alternative is using a digital blood pressure monitor which works in a similar fashion to that of an aneroid monitor except everything is calculated and monitored by the device [31]. These digital blood pressure monitors can be used in either the wrist of the upper arm cuff. Since there are budget constraints, a wrist blood pressure monitor will most likely be used in the HHA. **Table 3.2.2.3** shows a list of viable wrist blood pressure monitors that could be used for the Home Healthcare Assistant. The list is generated using local stores such as Walmart and Walgreens. The list is also created by taking into account the simplicity of the blood pressure monitor. Simpler screen means it is easier to hack and send the data to the MCU.

| Table 3.2.2.3: Viable Wrist Blood Pressure Monitors for the HHA | | | | |
|---|---|---|---|---|
| **Manufacturer** | **Citizen** | **Jobar International** | **Lifesource** | **Microlife** |
| **Model** | CH-657 | JIT1020 | LSZ1020 | BP3MY1-1P |
| **Price** | $44.93 | $22.98 | $57.99 | $26.99 |
| **Customer Rating** | 4/5 | 4/5 | 5/5 | N/A |
| **Free Shipping** | No | Yes | Yes | Yes |

### 3.2.2.4 Weight Scale

Weight scales come in a large variety of forms including analog, digital, and mechanical. Another category of classification for weight scales are the scale types. These types are equal-arm beams, steelyard scales, Bismar scales, pendulum scales, Roberval scales, spring balances, rocker balances, and platform scales [32]. For simplification, the Home Healthcare Assistant will use any scale available in the market as long as it is inexpensive and accurate. Due to budget constraints, the commonly used mechanical beams will not be used but it is good to note that these beams provide the greatest accuracy in measuring weight. Mechanical beams are the main type of scale in measuring weight in medical institutions; however, mechanical beams are not meant to be mobile or portable. The common "bathroom" digital weight scales will be utilized in measuring the patient's weight. **Table 3.2.2.4** shows a list of possible candidates for the weight scale. The list is composed of scales with simple LCD screen design to simplify the hacking that must be done to communicate the values of the weight scale screen to the MCU.

| Table 3.2.2.4: Viable Weight Scales for the HHA | | | | |
|---|---|---|---|---|
| **Manufacturer** | **Taylor** | **Taylor** | **ADG** | **Escali** |
| **Model** | 7519 | 7405 | "330 lb" | "Extra Large" |
| **Price** | $32.18 | $22.79 | $29.99 | $39.99 |
| **Customer Rating** | 4.5/5 | 4.5/5 | 4.0/5 | 4.7/5 |
| **Free Shipping** | No | No | Yes | Yes |

## 3.2.3 Microcontroller vs. FPGA to Drive VGA Display

Using a microcontroller-based approach to display a large amount of data on a monitor can be difficult, especially when more than just plain text characters are involved. A glance through the VGA Protocol section outlined in section 4.1.4 reveals that an intensive timing-dependent and cycle-accurate assembly program will need to be executed. Another consideration is that a large amount of memory is involved in the storage of image pixel data, which many low-end microcontrollers do not possess. Two approaches for driving a VGA monitor using a microcontroller will be discussed in this section. The first method utilizes SRAM chips to hold pixel data to overcome the limited memory on-board most low-budget microcontrollers. The second technique involves using a driver board to do the heavy lifting of generating the required VGA signals. This leaves the microcontroller free to draw shapes or specify characters of text to display over an SPI (Serial Peripheral Interface) connection, pixel data of which is already present on the driver board.

### 3.2.3.1 Microcontroller with SRAM chips

The Atmel ATMega644 is a microcontroller that meets the memory requirement to store the pixel data for a single image at 128x240 resolution, and with the aid of intricate assembly programming involved in syncing VGA output signals according to the timing constraints of section 4.1.4, the digital signal generation aspect can be handled by this chip [33]. Once this is accomplished, the next step is to convert the digital signals from the microcontroller into the required analog and digital signals that the VGA monitor expects. Conveniently, both the Horizontal and Vertical Synchronization signals are compatible with any 5V or 3.3V microcontroller, so they can be directly connected from the output pins to the VGA connector for the monitor. The three analog color lines that generate red, green and blue intensities are not digital, and the protocol dictates the transmission of voltage levels between 0 and 0.7 V to signify color intensity [34]. Technically, since the color signals are analog, effectively an infinite amount of different colors can be created depending on how many steps exist in the analog voltages [34]. For a system powered by the 8-bit microcontroller in this section, there will only be a single 8-bit port used to generate all three analog color lines, and thus the maximum amount of possible colors displayable are 256 using the RGB-332 format outlined in Section 4.1.4. This is the same number of colors used by early VGA systems, and is sufficient to showcase clear text, graphics and photographic images. As shown in the following schematic, each color has two resistors feeding it, creating a simple 2-bit Digital to Analog converter (DAC) that gives four levels of that color. Since each color has its own 2-bit DAC, there are a total of 64 possible colors (6 bits). The last two bits are connected to three more 2-bit DACs, which then feed the three colors, giving another 2 bits of intensity to each color. As every group of 64 colors has its own four levels of intensity, a color space of RRGGBBII is obtained. The diodes are necessary so that the individual 2 bit DACs do not feed back into each other, as this would mix the colors undesirably. The schematic of **Figure 3.2.3.1-1** shows how the microcontroller will be able to send the RRGGBBII color data to the RGB lines on the VGA connecter by first feeding it to the resistor DAC. The horizontal and vertical sync signals are fed to the monitor directly from the I/O pins. The clock utilized in this approach is a 20MHz oscillator module, though any clock frequency could work that can be subdivided to meet the timing constraints for VGA signal generation. It is imperative that every cycle has to be accounted for during the video rendering interrupt [33].

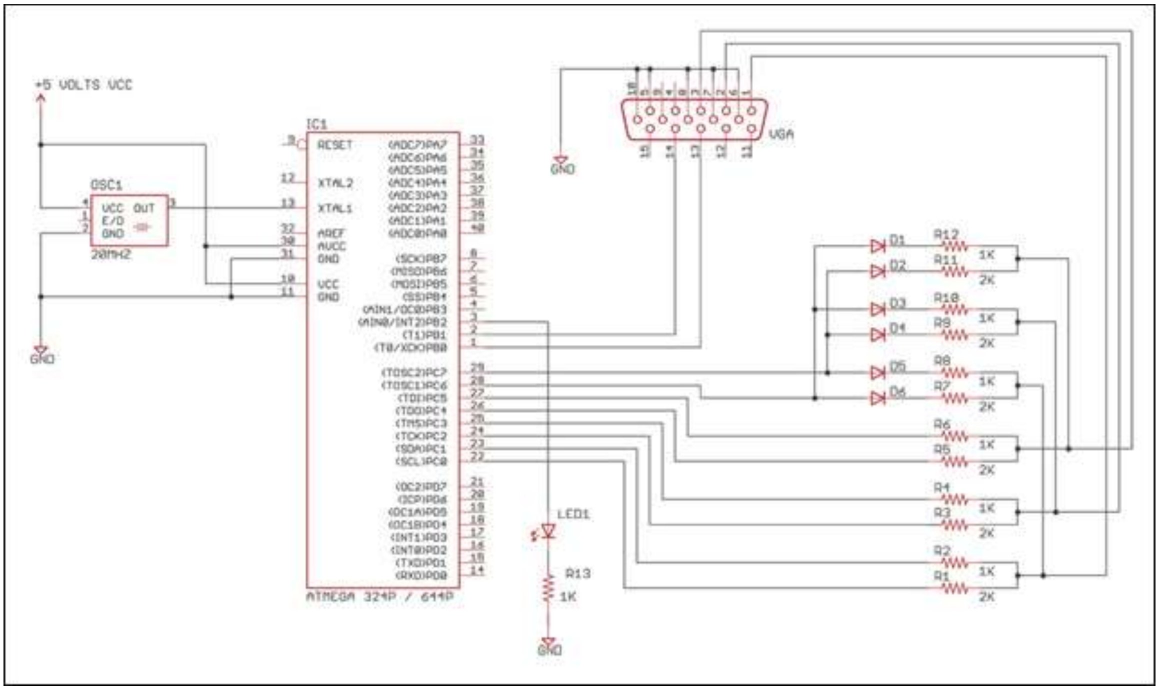



**Figure 3.2.3.1-1: The basic real-time VGA generator schematic using Atmel ATMega644 microcontroller. Image permission pending from LucidScience.**

With the limited memory on board the microcontroller, even the contents of a single frame at 640x480 pixel resolution cannot be stored. This setup attains a maximum resolution of 256x240 over the standard 640x480 screen. With the addition of external SRAM chips as shown in **Figure 3.2.3.1-2**, the image content for two full screens can be stored. The chips are utilized in such a way that one buffer is on the screen while the microcontroller works on generating the next screen. This technique is called “double buffering”, and is the way video games are realized, allowing for frames to be swapped once all graphics are drawn. Using no frame buffer limits the amount of data that can be sent to the screen [33].

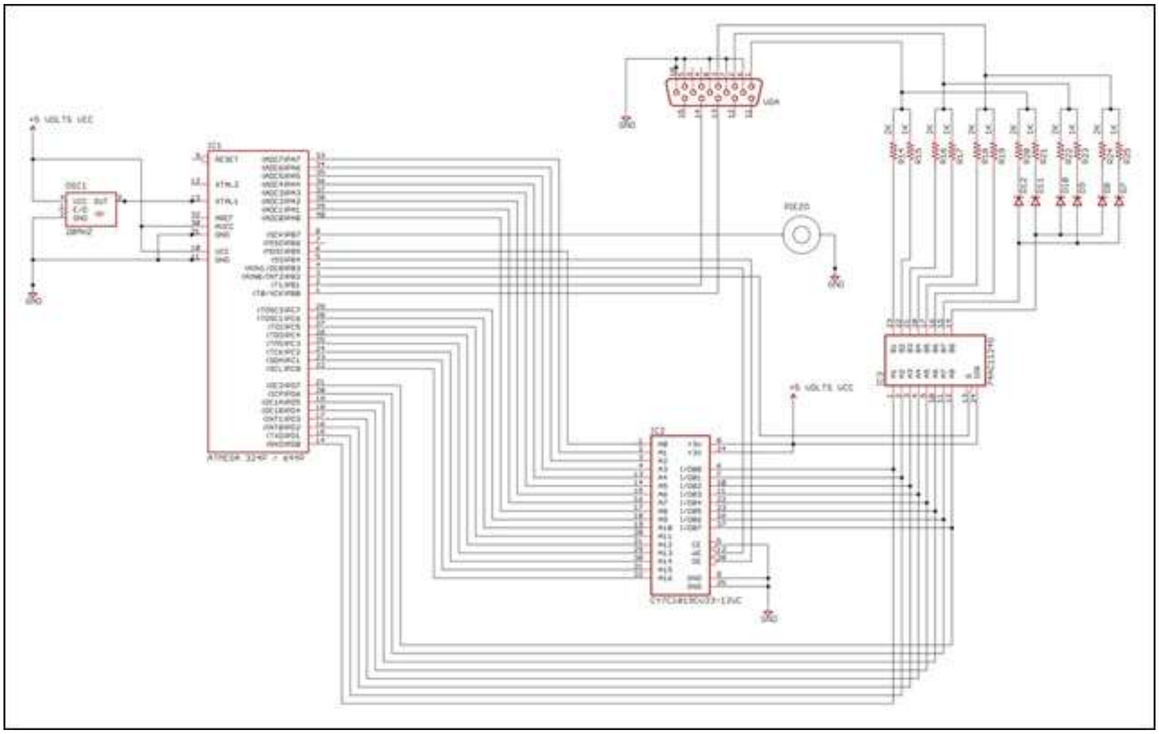


**Figure 3.2.3.1-2: The dual buffer VGA generator schematic using Atmel ATMega644 microcontroller. Image permission pending from LucidScience.**

The schematic of **Figure 3.2.3.2-2** illustrates how the SRAM feeds the video DAC controlled by the addresses and control lines sent from the microcontroller. With the addition of the SRAM chips the schematic complexity has increased, yet the system functionality remains the same as before except that during the horizontal active pixel time, only addresses are sent, not pixels. The addresses tell the SRAM which pixels are to be sent during the active pixel time, and the "page select" pin on the microcontroller allows the switching of video buffers so that the main loop can draw on a one buffer as the video driver sends out the other to the VGA monitor. When the main loop has completed drawing to the hidden buffer, a simple routine swaps the two banks on the next vertical banking period and the new frame is displayed on the monitor. This way, flicker free animations and drawing can be done, making better use of the microcontroller’s processing power and overcoming its memory limitations [33].

### 3.2.3.2 Microcontroller with driver board

This method lets a preconfigured driver board to realize the analog VGA signals that are sent to a VGA monitor. An example board considered in this technique is the RA8875 Driver Board for 40-pin TFT Touch Displays, which can output even for resolutions up to 800x480 pixels. This particular board works in conjunction with an Arduino microcontroller to drive a display over an SPI (Serial Peripheral Interface) connection. The board is already pre-programmed to generate basic shapes such as rectangles and ellipses. In addition, the bitmaps used for a generic English font are included. **Table 3.2.3.2** illustrates how the data transmitted to the driver board by the microcontroller allows for the drawing of ellipse or square shapes. Each bit in the 8-bit Control Register of **Table 3.2.3.2** represents a specific command sent by the Arduino microcontroller. Bits 0-1 instruct the driver board to draw a portion of the ellipse. Binary quantity 2’b00 stored in these bits draws the bottom left quarter segment of an ellipse. By incrementing these bits, the ellipse segment select function proceeds counter-clockwise to draw the bottom-right curve segment at quantity 2’b11. Bit 4 specifies whether a portion of the square/ ellipse or a complete square/ ellipse is to be drawn. Bit 5 allows for the selection between ellipsoids and circle/ squares. Bit 6 then controls whether the shape perimeter is drawn or the shape with a solid color fill. Bit 7 is then used to start and stop the drawing function in write mode. In read mode, bit 7 specifies if the draw function is in process or if the last draw command has completed [35].

**Table 3.2.3.2: Communication between microcontroller and driver board to draw an ellipse, circle or square shape on the monitor. In addition to the aforementioned register, numerous other parameters can be adjusted on the VGA driver board to customize the shape drawn, including but not limited to line thickness and color. Image permission pending from Adafruit.**

**REG[A0h] Draw Ellipse/Ellipse Curve/Circle Square Control Register**

| Bit | Description | Default | Access |
|---|---|---|---|
| 7 | **Draw Ellipse/Circle Square Start Signal**<br>**Write Function**<br>0 : Stop the drawing function.<br>1 : Start the drawing function.<br>**Read Function**<br>0 : Drawing function complete.<br>1 : Drawing function is processing. | 0 | RW |
| 6 | **Fill the Ellipse/Circle Square Signal**<br>0 : Non fill.<br>1 : fill. | 0 | RW |
| 5 | **Draw Ellipse/ Ellipse Curve or Circle Square Select Signal**<br>0 : Draw Ellipse/ Ellipse Curve.(Depend on bit4)<br>1 : Draw Circle Square. | 0 | RW |
| 4 | **Draw Ellipse or Ellipse Curve Select Signal**<br>0 : Draw Ellipse<br>1 : Draw Ellipse Curve | 0 | RW |
| 3-2 | NA | 0 | RO |
| 1-0 | **Draw Ellipse Curve Part Select(DECP)** | 0 | RW |

The possible end results on a monitor due to modification of the draw function’s control register data by the microcontroller is depicted in **Figure 3.2.3.2**. If an ellipse curve is specified in the control register, the respective quarter perimeter of an ellipse is drawn. Filling the curve draws a quarter of an ellipse [35]. The circle square and complete ellipse figures can similarly be drawn by the appropriate register content as described in the discussion for **Table 3.2.3.2**.

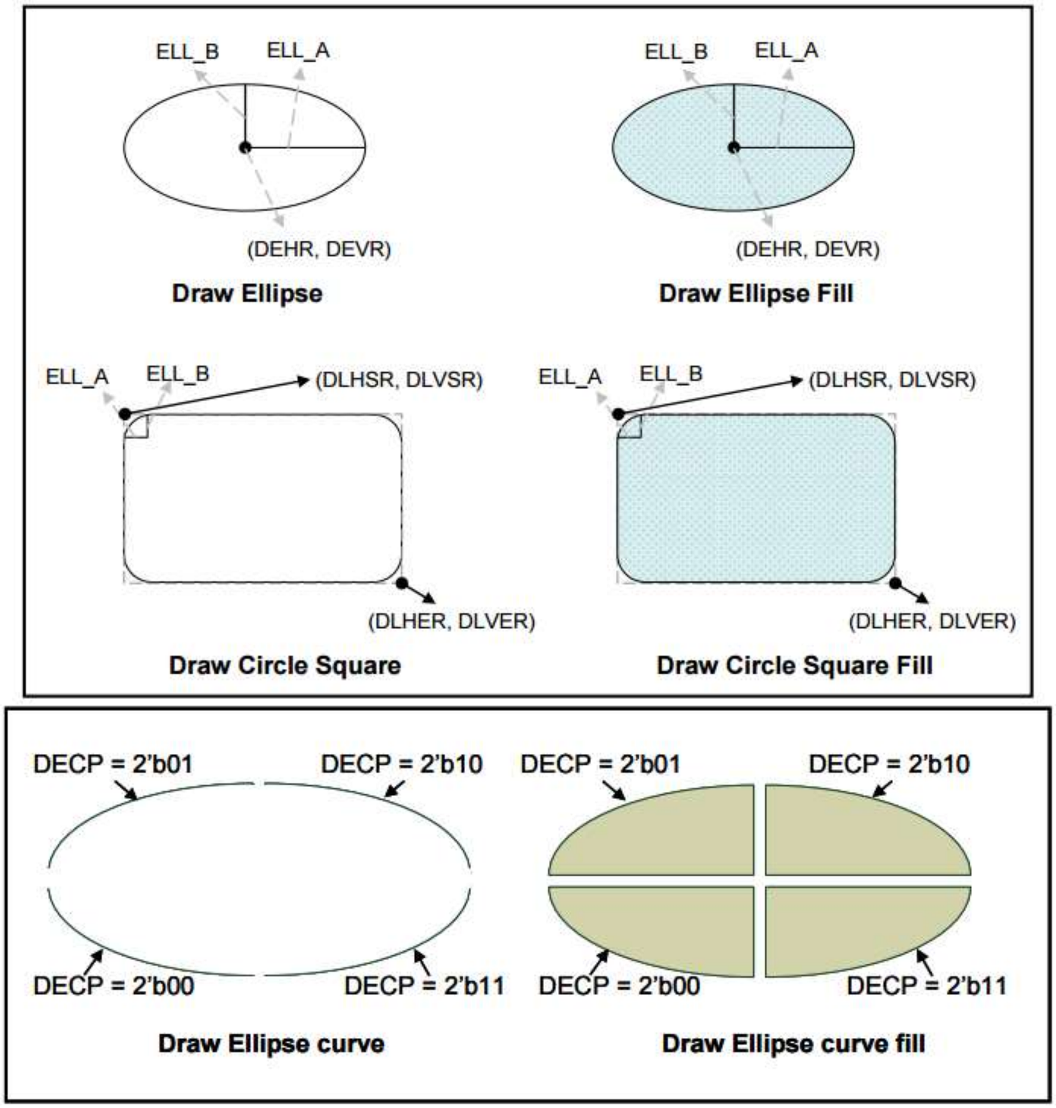



**Figure 3.2.3.2: Monitor output of the drawing function. Image permission pending from Adafruit.**

### 3.2.3.3 Suitable FPGA chip for design

The FPGA design methodology for driving a VGA display is covered completely in Section 6.3. Here a comparison will be made between different options for FPGA boards suitable for the application of driving a VGA monitor and communicating with a microcontroller. To meet the project constraints, the device chosen must be low in cost and should provide enough I/O to create and supply a VGA signal as well as enough to communicate with a central microcontroller. Also, there should be enough logic gates on the device to create and configure memory modules that can store the pixel data for output to a monitor screen. Besides the FPGA board, the microcontroller involved in the HHA project is responsible for acquiring sensor data and receiving user input from the FPGA board and then sending all consolidated information wirelessly to a remote database for analysis. Therefore, on the FPGA board, I/O pins are required to support a connection between the FPGA and the microcontroller. Now that the core requirements have been listed, a few of the common features of FPGA boards available will be analyzed.

Several boards in the market support features such as VGA, HDMI, serial, Ethernet ports and I/O devices including push-buttons, 7-segment LED displays and serial ports. One primary feature desired on the board for the HHA project is that of VGA support, which takes away the requirement for creating VGA analog signals from the digital output signals at the I/O pins. An additional requirement is enough memory on-board to be able to display different screens of text on the monitor. If the pixel data for each screen of text was independently stored, a tremendous amount of memory would be required for several screens. Alternatively, a much more efficient approach to accomplish this is to create different memory modules for displaying individual characters on the screen, thereby allowing a lot more FPGA development boards to be suitable for the HHA design process without the need for any external memory. Major manufacturers of FPGA boards that meet the HHA's VGA driver design constraints include Xilinx and Altera. The team member responsible for creating the VGA driver has the most prior experience using Xilinx products. Coursework in Digital systems and FPGA Design utilized FPGA boards with Xilinx chips, in addition to the Xilinx ISE software suite for programming them in Verilog HDL (Hardware Descriptive Language). The ISE Design suite is an all-inclusive package that allows users to write and debug HDL code, simulate the designs and generate a bit stream to program the user's respective device. It also includes a large selection of libraries that accommodate all versions of their chips. The ISE also includes capabilities such as the generation of memory modules for quick instantiation of RAM and ROM that can be easily interfaced with other modules in the design that were created either using schematic capture or HDL code. These features are all extremely valuable tools for the design and prototyping aspect of the VGA driver.

Since the Xilinx ISE Design Suite was the only one that the team member received repeated exposure to throughout his education, our FPGA provider was chosen to be Xilinx. Some research into different types of FPGA devices offered by Xilinx yielded that the lowest-cost solutions that met the design requirements included development boards that utilized the SPARTAN 3 FPGA chips. This family of FPGA chips is optimized for the lowest-cost logic, processing and memory. However, the performance features of higher end FPGA chips are not sacrificed. The SPARTAN 3 variety of chips contain 50,000 to 2 million logic gates. Additional features include 6-input Look-Up Tables (LUTs), 18KB of Block RAM, Digital Clock Managers (DCMs), and differential I/O pins. Several of the FPGA boards that were researched either have a Spartan 3E or 3A chip. These boards have prices range of between 50 to 150 U.S. dollars, a range that satisfies the self-funded project budget for our group. The scale of the HHA project and its VGA driver implementation is also small, hence the number of logic gates found on a SPARTAN 3 FPGA chip were deemed to be sufficient. Also, the quantity of Block RAM present on the Spartan 3 devices was satisfactory for the optimized approach to displaying different screens of text, as discussed earlier in this section. The given specifications for the SPARTAN 3 all meet the project requirements, hence any of the devices within the Xilinx SPARTAN 3 family suit our needs. Based on the blocks of memory needed, a device with roughly 100,000 logic gates was chosen to be looked at.

### 3.2.3.4 DIGILENT BASYS 2

DIGILENT is an FPGA board manufacturer that distributes affordable and useful boards, primarily containing Xilinx FPGA chips. They offer numerous boards with the SPARTAN 3 chipset, one of which includes the BASYS 2. This product has two different versions – one with 100,000 logic gates and another with 250,000 logic gates. The first option meets the needs for our project. It can be powered via a USB port or via a battery pack that hooks up to given terminals for connecting 5V DC and ground. The on-board FPGA chip is the Xilinx Spartan 3E that is interfaced with an Atmel AT90USB2 controller. It also contains flash memory that can be configured by the user's bit stream, alloying the board to function once programmed, as long as it is powered. A connection to a PC is no longer required once the flash memory has been programmed by the user using the Xilinx ISE software suite. The on-board clock is a 50 MHz silicon oscillator that can be set to 25 MHz or 100 MHz by shorting given terminals. This is a limitation.

For VGA signal generation, highly strict timing requirements must be reliably satisfied, whereas a silicon oscillator is known to possess a certain degree of jitter that may output an unstable VGA image [34]. However, an additional feature on the BASYS 2 board is the inclusion of a secondary port that allows a DIP-8 package crystal oscillator to be installed. Such oscillators are highly accurate and are completely suitable for VGA signal generation. With a crystal oscillator installed and set to function as the master clock, all the timing requirements for VGA signal generation and clock frequency division can easily be met. This board is priced at approximately 50 U.S. dollars with a student discount. Other features include push buttons, four 7-segment displays, mechanical switches and LEDs. These are all useful features for debugging and testing HDL programs, as the device input can be controlled by the switches and buttons, while the output can be displayed on the built-in 7-segment displays and LEDs, thereby bypassing the need for any attached I/O peripherals.

Other important features present are the PS/2 connector, VGA connector and DIGILENT PMOD connectors [34]. The PS/2 connector is perfectly suitable for receiving user input for the HHA via a keyboard, and the VGA connector is required for interfacing with a VGA monitor. The PMOD connectors can be used to establish communication with the microprocessor in order to relay the user's responses to each question as part of the HHA's examination. For communication between devices, an SPI (Serial Peripheral Interface) connection can be configured that makes use of 4 I/O lines: A master-to-slave data line, a slave-to-master data line, a clock signal and a chip select. The master device can select one of many slaves and send data with respect to the clock signal, or receive data over the slave-to-master data line. Each PMOD connector includes VCC and ground terminals, alongside 4 data lines (for a total of 6 pins). The BASYS 2 board has four of these PMOD connectors. Therefore, just one PMOD connection can be successfully configured to allow communication between the FPGA board and the microcontroller.

A major plus point of this board is that it is already owned by one of the group members, hence its purchase price did not need to be factored into the total budget for the project. It also proved to be very valuable in the testing and debugging of code during Senior Design 1, in order to devote time to other aspects of the project such as PCB design, establishing communication between subsystems and troubleshooting them in Senior Design 2.

### 3.2.3.5 DIGILENT NEXYS 2

One step above the BASYS 2 in DIGILENT's product lineup is the NEXYS 2 FPGA board. This also includes a Xilinx Spartan 3E chip in conjunction with an Atmel AT90USB2 controller to manage the bit stream data transmission. Two versions for this product offer 500,000 logic gates and 1.2 million logic gates respectively. This advantage can lead to a lot more RAM and ROM modules to be internally generated, or for the pixel data storage to be handled less efficiently than as stated within the BASYS 2 discussion. This is an advantage because it speeds up the coding process, allowing us to work with easier but less efficient code, but also because the pixel data for a lot more screens or even background graphics can be stored on the device's memory modules. Instead of a static background color that we can display using the BASYS 2 due to its memory limitation, the NEXYS 2 can allow for prettier graphics to be generated by storing the entire pixel bitmap for a 640x480 VGA resolution screen in memory. To further strengthen this advantage, not only a single background image but a large array of them could be stored in memory since the NEXYS 2 also includes 16 MB of flash ROM and 16 MB of SDRAM [36]. This huge amount of on-board memory provides enough resources to generate a vast variety of images and to allow us to create a sophisticated user interface using just the FPGA board's VGA driver, by displaying different screens of information, graphs against time depicting the patient's health statistics as measured by the sensors, status of data transfer from the MSP430 to the wireless system, and more visual features for which imagination is really the only limit. All of these are bonus features that can make the HHA user experience a lot more pleasant than simply displaying text on a static background color as is possible with the BASYS 2. However, for the HHA proof-of-concept device, all of those pixel bitmaps would need to be generated and would entail a lot more redundant work for the team. For the purpose of this project, the enormous amount of additional memory available on the NEXYS 2 was deemed unnecessary as it does not impact the usefulness of the design in the slightest.

Besides memory, most of the features that we could use for the HHA project are very similar to the BASYS 2 board. A USB port is present for power, or a 5 V DC battery can be used in lieu of it. Like the BASYS 2, the flash memory can be configured via bit stream. The NEXYS 2 also has a 50 MHz oscillator built-in with the option to attach a secondary DIP-8 package oscillator. Since DIGILENT created both the BASYS 2 and the NEXYS 2 primarily for student consumption, neither's primary clock oscillator is well-suited for VGA signal generation, which is a high timing-intensive task. All of the same I/O features are also packed on this board, which are LEDs, mechanical switches, push buttons and four 7-segment LED displays. The four PMOD connectors on this board are larger than the BASYS 2 – each connector can support 8 data signals and provides two

VCC and two ground lines. They are stacked versions of the PMOD connectors on the BASYS 2, thus doubling the PMOD I/O connectivity options. These features are not really required unless some sensor data was also acquired by the FPGA board instead of the microcontroller, for which the group currently does not have a reason to do so. If the need arises, both the BASYS 2 and the NEXYS 2 should be able to support communication with at least two sensors (such as body temperature and the pulse oximeter sensors).

Other FPGA boards are certainly viable for this discussion, which could proceed for a lot longer and features could be compared between boards from different manufacturers. However, a bias towards the BASYS 2 board exists within the project group, and the choice of the hardware is made simpler because of it, as noted in the next subsection.

#### 3.2.3.6 Choice of VGA driver hardware

The two microcontroller approaches mentioned are certainly viable and could have likely simplified this project to a certain degree. The first approach involved the use of extra SRAM chips to hold pixel data in a double frame buffer technique, whereby one frame's data is processed by the microcontroller and respective VGA signals are generated while the next frame's pixel data is being analyzed. The second microcontroller technique involved using a driver board that did all the hard work and left the microcontroller free to input simple commands to generate certain shapes or to display certain font characters, functions for all of which are already present on the driver board.

The first microcontroller approach in particular would have likely been the minimalist approach to driving a VGA display, as a microcontroller is intended to be used for sensor data acquisition already and for wirelessly transmitting acquired data to a remote database. The SRAM chips could hold pixel data to be displayed and, with the use of a few more pins on the microcontroller, a VGA driver could be implemented. However, FPGA experience was highly desired by the member of the group responsible for the VGA driver implementation. Out of the different options for FPGA boards available, it was determined that the Xilinx SPARTAN 3 chipset was ideal, both because it possessed the require feature set for the HHA project as well as because of prior classroom experience with it. Additionally, the Xilinx ISE software suite was utilized in two classes by the responsible group member for this aspect of the project. Out of the boards looked at that utilize this chip, the BASYS 2 FPGA board was found to be perfectly capable and it was already owned by the group member. It was also the same board that was used in the Digital Systems class, using Xilinx ISE software, so the familiarity aspect would undeniably help speed up the design process. It was therefore concluded that the BASYS 2 would be used for VGA driver implementation and for displaying information to the end user as part of the HHA project.

### 3.2.3.7 LCD Display selection

This aspect of the project ties in with a few others – not only do we want to output data to the user on a screen but also acquire data from them. Options such as touchscreen displays are thus open for consideration. There are also non-VGA standard displays on the market that refresh at a faster rate than 60 Hz, or support non-standard resolutions. VGA standard displays are highly convenient for the very reason that they follow a standard – there are standard connectors to the monitor, standard outputs from the driver to the monitor, and all the information required to generate a VGA signal is readily available from numerous resources, including but not limited to the signal timing, bus width and their nature – whether they are analog or digital. The methodology used to implement a VGA driver on an FPGA can also be easily understood. For non-standard displays, acquiring this information was proven to be much more difficult, and will be looked at in this section. To reiterate, the choice of display in this section greatly impacts the design of the display driver itself. The simpler choice is undeniably ideal, which is to go with a display that supports the VGA standard. To meet the HHA requirement of allowing a person with 20/20 vision to see the screen comfortably from a distance of 3 feet from the device,

### 3.2.3.8 Seven-inch 40-pin TFT Display - 800x480

This is an example of a generic display made by numerous off-shore manufacturers and sold for relatively low prices. It is described as a raw pixel-dot-clock display that does not contain any SPI or parallel controller, neither does it offer on-board RAM for video frame buffering. The display has to be constantly refreshed at 60 Hz with a pixel clock, HSYNC, VSYNC signals, and data lines are required to be driven in order to display the color intensity of each pixel. A small microcontroller cannot support this type of display directly, as dedicated hardware or a highly capable processor such as an FPGA chip is required. In addition, the display backlight circuit requires a constant-current mode boost converter supplying 125-150 mA at voltages varying up to 9V. This is the type of display that could be realized with the *microcontroller with driver board* method of Section 3.2.3.2, however that approach was not further discussed since the choice of using the BASYS 2 FPGA development board was made. In addition, this screen comes with touchscreen or non-touchscreen options. The touchscreen aspect was fairly straightforward to understand. It works using two potentiometers in tandem – one for each axis of the screen. When the user touches a point on the display, two analog voltages are sent from the screen. These voltages can be discretized and analyzed by the microcontroller or FPGA to indicate the X and Y coordinates that the user touched on the screen. Thus far, both the touch and non-touch versions of the product seemed to be useful and ideal for implementation.

The product's description shows that it seems to follow the VGA protocol for driving this display. However, there are special power-on and power-off sequences as shown in **Figure 3.2.3.8** that involve various power supply voltages that need to be executed precisely before the standard VGA signals can start sending data to the display. The display datasheet also showcases additional non-VGA standard signals required in these steps. As mentioned, most of these type of displays are from off-shore manufacturers and are sold in the U.S. in bulk. The downside encountered was that the datasheets for these products often contain information translated from foreign languages, which did not present a clear picture of how exactly these signals are generated and why they play a role in the device power on sequence [35]. The datasheet for the TFT LCD module attached to this report failed to elaborate on the nature of those signals. Therefore, the information contained within the product description and datasheet was found to be incomplete and inadequate for us to learn how to drive such a display using an FPGA board. The VGA standard aspect to driving such a display was evident, but the power sequences and additional signals were left unexplained in the datasheet. We were unable to find a suitable resource to shed light on what exactly those signals are and how exactly to execute the power sequence timing constraints. Therefore, even though such a display would have been an interesting addition to the HHA project, the lack of specifics for getting certain aspects of it to work with an FPGA board correctly caused us to disregard this option.

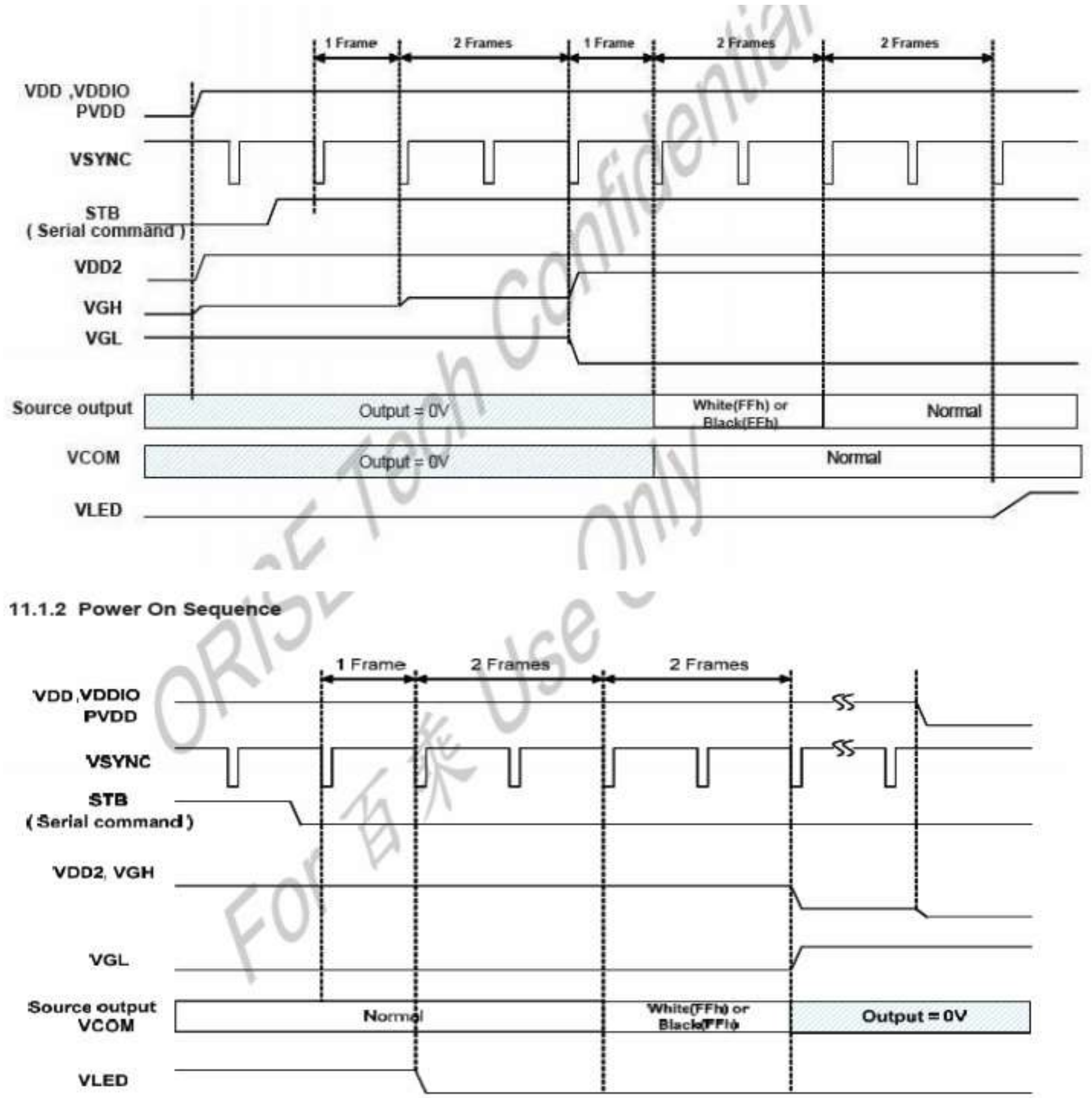



**Figure 3.2.3.8: 40-pin TFT display Power on Sequence. Image acquired from product datasheet made available to the public by U.S. reseller Adafruit. The document contains content generated for the device's confidential Product Specification for Approval, images from which were reused in the non-confidential datasheet. Permission to reprint pending from Adafruit.**

### 3.2.3.9 Seven-inch VGA monitor

This is another class of generic displays that have flooded the market and are readily available. They all acquire frame data via standard 15-pin DB15 VGA connectors, for which all signals are known and information on how to generate them is readily available [33]. The full details of driving a VGA display using a Verilog implementation of the display driver on the BASYS 2 are covered in Section 6.3. Powering up this display entails supplying 7W of power, where the power supply voltage can vary anywhere from 9 to 35V. This can be run off a standard 12V 1A power adapter, which is good for prototyping with the display. The final HHA project will supply its own power to all peripherals and components using an internal battery with a wall-outlet based charging circuit. Also, internal circuitry exists within this class of display devices to accommodate the power-on and power-off sequences that were troublesome with the display type discussed in Section 3.2.3.8.

Since only VGA signals and main power signals need to be provided with this type of display, it is deemed simple and sufficient for our application. A generic 7-inch VGA monitor that retails from 45 to 100 U.S. dollars, depending on whether it's ordered online from the offshore wholesale markets or from a local reseller that imported the product, is the display device chosen for use in the HHA. The selected VGA monitor is not a touchscreen device, therefore the user input acquisition shall be handled via a keypad connected to the HHA device.

## 3.2.4 Powering and Regulating Voltage

### 3.2.4.1 Rechargeable Battery Types

The Home Healthcare Assistant will require a rechargeable battery type because it will operate solely with battery to protect the patient. Rechargeable batteries are convenient because the patient or medical practitioner will not have to go through the trouble or risk of changing the battery. It is a cost-efficient method as long as the rechargeable battery lasts for long a time. To determine if the rechargeable battery is useful in useful enough to be applied to the HHA, research of different battery types are conducted.

#### 3.2.4.1.1 Lead-Acid

Lead-acid batteries are easy to manufacture and inexpensive for the power reliability they provide. These batteries are mainly used in large equipment such as emergency lighting, hospital equipment, and cars. Lead-acid batteries also do not suffer from memory loss which means that it always knows when it is charged and when it is not charged. Without memory loss, no early interruptions in the recharging process are possible. Unfortunately, the downsides of these batteries are greater than its advantages. Some of the disadvantages are high recharge time, low cycle of life, high cycle of life sensitivity to temperature, low-energy density output, heavy design, and it is environmentally unfriendly. Lead-acid batteries also suffer from sulfation if they are not constantly charged which is why cars have alternators constantly powering these batteries. [37]

#### 3.2.4.1.2 Nickel-Metal Hydride (NiMh)

Nickel-Metal Hydride, also known as NiMh, batteries are commonly used in mobile phones and laptop computers. A great advantage of these batteries is that they are non-toxic which means they are environmentally safe to use. Another advantage is that they have a higher energy density compared to the rechargeable Nickel-Cadmium batteries. NiMh are a possible candidate for the Home Healthcare Assistant because it has been used in small applications but its disadvantages also have to be considered. Some of the disadvantages of NiMh batteries are its high self-discharge rate and relatively poor durability when reused frequently or under high temperatures. [37]

### 3.2.4.1.3 Nickel-Cadmium (NiCd)

Nickel-Cadmium, also known as NiCd, batteries are commonly used in two-way radios, power tools, video cameras, and biomedical devices. NiCd batteries are used in these applications because of their long life cycle and high discharge rate. Like any other type of battery, it contains its pitfalls. The disadvantages of nickel-cadmium batteries include high self-discharge rate and memory loss. Memory loss causes the battery to "forget" what the max charge rate because crystals start forming on the cell plates and the battery is never fully charged. [37]

### 3.2.4.1.4 Lithium-ion (Li-ion)

Lithium-ion batteries are low maintenance batteries that contain no memory and no scheduled cycling to prolong battery life. Li-ion battery is also the fastest growing battery type of the 21$^{st}$ century because it contains an energy density 2 to 3 times that of standard nickel-cadmium batteries. Most mobile phones today use Li-ion batteries that contain only 1 cell which simplifies battery design and contains less cell resistance. Despite its advantages, Lithium-ion batteries has its drawbacks which, if implemented in the HHA, will require extra components to take care of the problems. One of the disadvantages is that it requires a protection circuit which limits the voltages and the current of the battery. Other disadvantages include aging, moderate discharge current, subject to transportation regulations, and high cost to manufacture. [37]

### 3.2.4.1.5 Lithium-ion Polymer (Li-polymer)

Lithium-ion polymer, also known as Li-ion polymer and Li-poly, batteries work very similar to Li-ion batteries. Unlike other battery types, lithium polymer batteries use a special type of dry solid polymer electrolyte. The dry polymer design allows for a simplification in battery design in terms of safety, fabrication, and form factor. Because the electrolyte is in a dry state, there is no danger of flammability. Awkward battery form factors is possible with Li-polymer batteries because each cell can be as small 1millimeter. Unfortunately, Li-polymer suffers from poor conductivity which is the reason the latest batteries include a mix of dry and gelled electrolytes to improve conductivity. Unlike Lithium-ion batteries, Li-polymer replaces the porous separator with its dry polymer electrolyte. Li-polymer is a relatively new type of battery and no significant improvements in capacity have been made to surpass and replace Li-ion batteries. **Table 3.2.4.1.5 - 1** shows a list of six commonly used rechargeable batteries compared in terms of energy density, cycle life, exercise requirements and cost [37]. **Table 3.2.4.1.5 - 2** shows a list of possible candidates to power up the HHA.

**Table 3.2.4.1.5 - 1: Types of Rechargeable Batteries**

| | NiCd | NiMH | Lead Acid | Li-ion | Li-ion polymer | Reusable Alkaline |
|---|---|---|---|---|---|---|
| **Gravimetric Energy Density** (Wh/kg) | 45-80 | 60-120 | 30-50 | 110-160 | 100-130 | 80 (initial) |
| **Internal Resistance** (includes peripheral circuits) in mΩ | 100 to 200[1] 6V pack | 200 to 300[1] 6V pack | <100[1] 12V pack | 150 to 250[1] 7.2V pack | 200 to 300[1] 7.2V pack | 200 to 2000[1] 6V pack |
| **Cycle Life** (to 80% of initial capacity) | 1500[2] | 300 to 500[2,3] | 200 to 300[2] | 500 to 1000[3] | 300 to 500 | 50[3] (to 50%) |
| **Fast Charge Time** | 1h typical | 2-4h | 8-16h | 2-4h | 2-4h | 2-3h |
| **Overcharge Tolerance** | moderate | low | high | very low | low | moderate |
| **Self-discharge / Month** (room temperature) | 20%[4] | 30%[4] | 5% | 10%[5] | ~10%[5] | 0.3% |
| **Cell Voltage** (nominal) | 1.25V[6] | 1.25V[6] | 2V | 3.6V | 3.6V | 1.5V |
| **Load Current**<br>- peak<br>- best result | 20C<br>1C | 5C<br>0.5C or lower | 5C[7]<br>0.2C | >2C<br>1C or lower | >2C<br>1C or lower | 0.5C<br>0.2C or lower |
| **Operating Temperature** (discharge only) | -40 to 60°C | -20 to 60°C | -20 to 60°C | -20 to 60°C | 0 to 60°C | 0 to 65°C |
| **Maintenance Requirement** | 30 to 60 days | 60 to 90 days | 3 to 6 months[9] | not req. | not req. | not req. |
| **Typical Battery Cost** (US$, reference only) | $50 (7.2V) | $60 (7.2V) | $25 (6V) | $100 (7.2V) | $100 (7.2V) | $5 (9V) |
| **Cost per Cycle** (US$)[11] | $0.04 | $0.12 | $0.10 | $0.14 | $0.29 | $0.10-0.50 |
| **Commercial use since** | 1950 | 1990 | 1970 | 1991 | 1999 | 1992 |

**Reprinted with permission from Battery University / Cadex Electronics Inc.**

| Table 3.2.4.1.5 - 2: Possible Candidates for Batteries | | | | |
|---|---|---|---|---|
| **Manufacturer** | **Tenergy** | **Tenergy** | **Tenergy** | **Tenergy** |
| **Model** | **N/A** | **18650** | **N/A** | **18650 w/ PCB** |
| **Output Voltage** | 12 V | 11.1 V | 11.1 V | 11.1 |
| **Output Current** | 10 A | 15 A | 125 A | 5 A |
| **Capacity (mAh)** | 10,000 | 5,200 | 5,000 | 4,400 |
| **Battery Type** | NiMh | Li-ion | Li-poly | Li-ion |
| **Cost** | $99 | $58 | $55 | $50 |

### 3.2.4.2 Voltage Regulators

The Home Healthcare Assistant project boasts several subsystems that possess individual requirements for voltage. The power source, determined to be a battery, ideally delivers only one voltage value. Considering the case where the battery can output 12V, and the requirements for three subsystems are 3.3V, 5V and 9V respectively, the question of how all of these different subsystems can be powered needs to be addressed. Voltage regulators provide a solution to this problem. They output a constant DC signal independent of the load current as well as of the input voltage, as long as the operating range is met and the regulators are allowed to function within their specifications [38]. The three main types of regulators qualified for this discussion are linear regulators, switching regulators and Zener diode regulators.

#### 3.2.4.2.1 Linear voltage regulator

These devices present a simple solution to step down a given high voltage to a lower voltage, thereby allowing a subsystem to receive the designated amount that it requires. They are generally inexpensive and easy to use, and are ideal for low power applications. Most linear regulators incorporate an operational amplifier that compares the regulator output to a reference voltage. The amplifier utilizes a feedback loop to vary the output voltage to match the reference voltage. A typical linear regulator circuit is depicted in **Figure 3.2.4.2.1** below. The regulator output $V_{out}$ is sampled using a resistor divider. The error amplifier then compares the output voltage to the reference voltage $V_{ref}$. For the case where the sampled voltage is higher than the reference voltage, the amplifier output is decreased. In case the sampled voltage is lower than the reference voltage, the amplifier output is increased. The error amplifier then passes the corrected voltage through the control element, which is the pass device shown in **Figure 3.2.4.2.1**. The pass device in the diagram consists of an NPN Darlington with a PNP transistor is attached to its base [38].

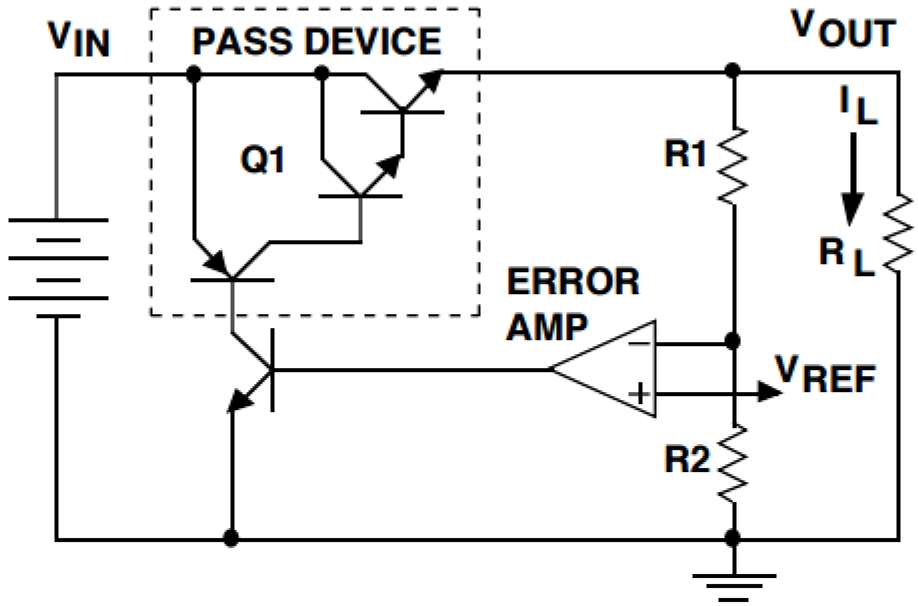



**Figure 3.2.4.2.1: Diagram of a typical linear regulator. Courtesy of Texas Instruments.**

Linear regulators are easy to use and cheap. Given their upsides, they also possess the drawback of being quite inefficient. The power supplied to the regulator is greater than the power delivered by the regulator. The difference of excess power has to be dissipated in the regulator. This dissipation causes the device temperature to increase. To alleviate the effects of high temperature on this electronic device, a heat sink may be used to help keep the temperature relatively low [38].

An important quantity associated with linear regulators is the maximum power dissipation parameter found within their datasheets. This quantity represents the maximum amount of power dissipated as heat by a regulator. The power dissipated in a regulator is calculated using the equation: $P_{reg} = P_{in} – P_{out}$, where $P_{in} = V_{in}*I_{in}$ and $P_{out} = V_{out}*I_{out}$. The efficiency is provided by the equation: Efficiency = $(P_{out}/P_{in})*100\%$. Considering a 12V battery used with a 5V regulator supplying a load with 11A of current, the dissipated power is calculated to be 7W at an efficiency of 42%. A technique to increase the efficiency is to decrease the input voltage to a value closer to its regulated voltage. Considering a case where a 6V battery is used for the same system with the same regulator and load current, the efficiency can be calculated to be 83%.

Also associated with linear regulators is a parameter that specifies a minimum input voltage with which a regulator may function as desired. This is known as the regulator dropout voltage. This quantity is the amount of input voltage required above the output voltage with which the output can be regulated. This minimum input voltage can be calculated as follows: $V_{in}$ (minimum) = $V_{out} + V_{dropout}$. Considering an example with a 5V linear regulator that has a dropout voltage of 2V, the minimum input voltage can be found to be 5+2 = 7V to properly regulate the output. A class of linear regulators called low dropout regulators also exists, which possess a low dropout voltage, as advertised.

These allow a user to apply an input voltage closer to the desired output regulated voltage. A downside to this class of devices is that they tend to be unstable. To combat this issue, capacitors may be utilized in the circuit to manage output stability [38].

### 3.2.4.2.2 Switching voltage regulator

This device functions similar to a linear voltage regulator in that it can step down a higher input voltage to a lower output voltage – an implementation known as a buck regulator. Energy storage elements are utilized in their construction, causing them to be more complex in design and more expensive to purchase as IC (Integrated Circuit) chips. The added complexity provides a serious advantage over linear regulators – switching regulators can provide over 90% power efficiency. This allows less power to be wasted within the regulator, causing less heat loss. A smaller heat sink may thus be utilized with a switching regulator as compared to a linear regulator, or one may not be required at all. Switching regulators can also step up the output voltage from a lower input voltage – a variant known as a boost regulator [38].

These devices utilize a PWM (Pulse Width Modulator) switch. The switch opens and closes at a certain frequency, allowing energy from the input to be transferred to the output. The switch operation frequency is controlled by sampling the output voltage and comparing it to a reference voltage. If the output voltage is below the reference voltage, the pulse width is decreased, allowing more energy to flow through to the output per unit time. If the output voltage is higher than the reference voltage, the pulse width is increased and less energy is transferred to the output terminal [38]. A typical buck switching regulator circuit is depicted below in **Figure 3.2.4.2.2**.

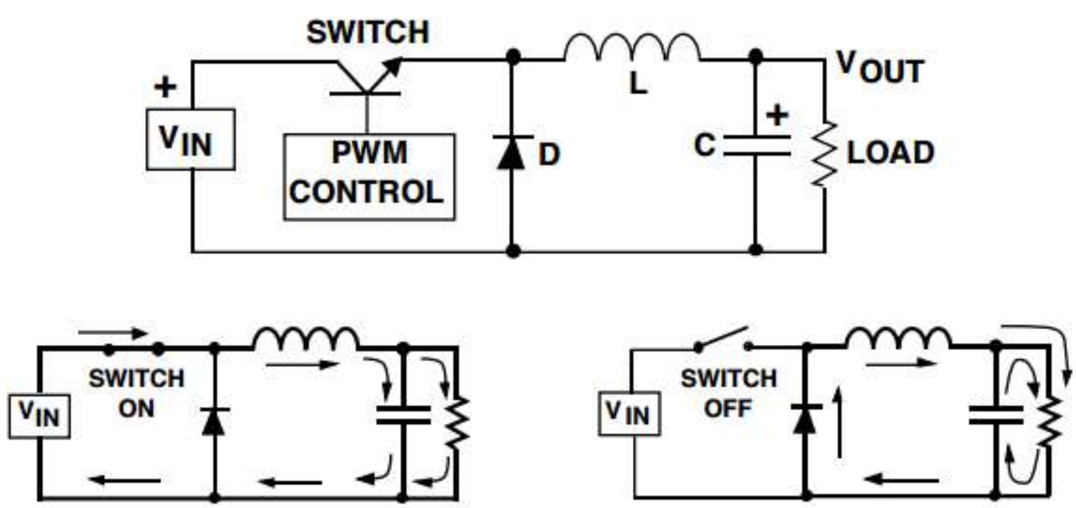



**Figure 3.2.4.2.2: Circuit diagram and functional diagrams for a buck switching regulator. Courtesy of Texas Instruments.**

When the switch is in the on position, the diode is reverse biased and current flows through the inductor and energy is stored in its magnetic field. When the switch is turned off, the diode is then forward biased and energy stored in the inductor is transmitted to the output – current cannot instantaneously go to zero in an inductor, but decreases in an exponential decay fashion. The input and output currents are thus not the same in a switching regulator. The output yields more current at certain points in time than the supplied current. This fact helps switching regulators achieve higher efficiency than linear regulators [38].

The switching frequency produces a ripple at the output voltage. A possible technique to alleviate the ripple voltage, if it is highly undesirable, but to maintain a relatively high efficiency, is to use a low dropout voltage linear regulator in series with a switching regulator. The switching regulator can then input a value close to the desired output from the linear regulator, and the power dissipated in the linear regulator would be low since the power being fed to the linear regulator is almost equal to the power leaving it. The effect of combining a switching and a linear regulator in series is that a constant DC voltage is obtained as the output signal [38].

#### 3.2.4.2.3 Zener diode regulator

A third class of regulators is the Zener diode regulator. This regulator uses a Zener diode in reverse bias to keep a constant voltage at the output. The regulated output voltage is the same quantity as the Zener diode's breakdown voltage [39]. A basic Zener diode circuit is depicted in **Figure 3.2.4.2.3** below.

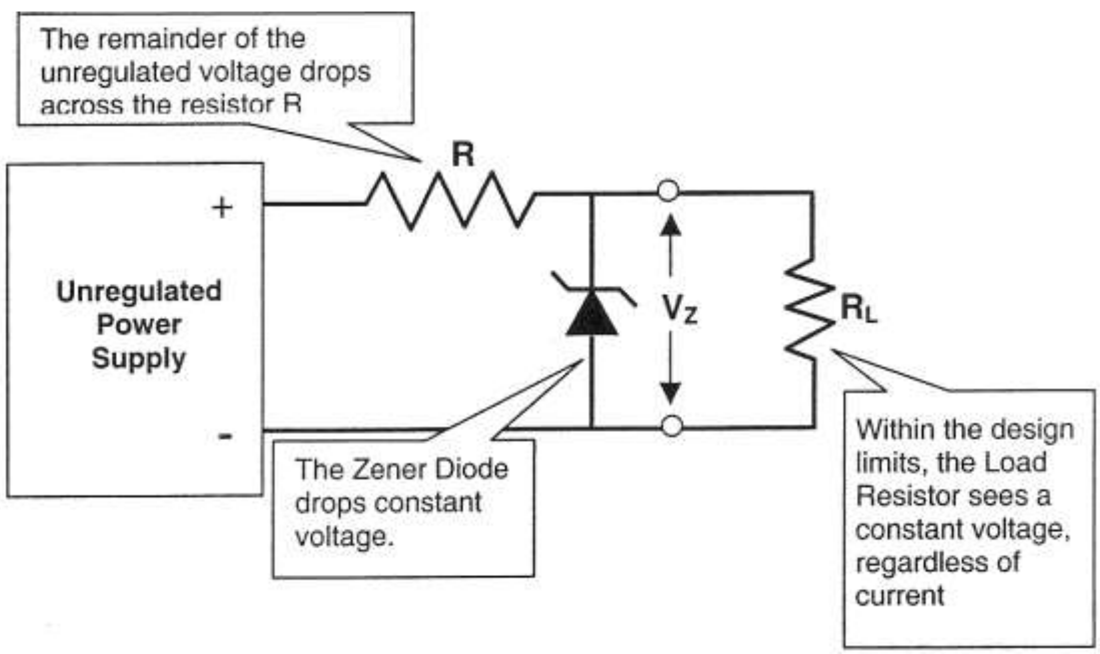



**Figure 3.2.4.2.3: Zener diode rectifier circuit with component explanations. Image permission pending from http://rsandas.com/**

A Zener diode regulator incorporate a resistor near the source voltage that sets the current flowing through the diode. The voltage across the Zener diode is set to a constant value provided that the input voltage is slightly higher than the output voltage. The output voltage of the diode does not depend on the current through it. By changing the resistor to a lower value, more current will be allowed to flow through the Zener diode but the voltage output will not change. This regulator poses the advantages that it is a simple circuit which requires only two components. In addition, these components can be found for cheap. A disadvantage of a Zener regulator is that signal noise can manifest while the output voltage is regulated [39].

#### 3.2.4.3 Recharging

Due to time and safety constraints, recharging the battery will be bought as a module. The charger will recharge the battery when the Home Healthcare assistant is turned off. While the Home Healthcare assistant is being used, the charging process is abruptly shut off to prevent any malfunctions from harming the patient. A mechanical switch will be utilized to turn on the HHA and turn off the charger at the same time. To select the right charger, it has to be compatible with the battery type, have a constant current, and a constant voltage that is not significantly higher than the battery nominal voltage rating. The switch also has to match the voltage rating used for the charger and battery. **Table 3.2.4.3** shows a possible list of battery chargers to be implemented in the HHA. The list is chosen following the safety information given for how to charge the battery when the information was available.

**Table 3.2.4.3: Possible Candidates for Battery Chargers**

| Manufacturer | Tenergy | Tenergy | Tenergy | AA Portable Power Corp |
|---|---|---|---|---|
| **Model** | **Smart for NiMh** | **TB6AC** | **TLP-4000** | **CH-L1118** |
| **Voltage Range** | 7.2V - 12V | 11V - 18V | 11.1V | 11.1V |
| **Output Current** | 0.9A or 1.8A | 0.1A - 5A | 2A | 1.8A |
| **Status Light** | Yes | Display | Yes | Yes |
| **Battery Type Charger** | NiMh | All Types | Li-ion/Li-poly | Li-ion/Li-poly |
| **Cost** | $22 | $60 | $17 | $30 |

### 3.2.5 Microcontrollers

#### 3.2.6.1 TI CC3200

This board is a true Wi-Fi on chip solution as it contains everything that an Internet of Things (IoT) project would need. The single CC3200 chip contains both the processor and Wi-Fi Certified chip needed to get the board connected to the internet. If we did not have the MSP430F5529 and CC3100 readily available, we would have invested in this board, but the CC3100 and MSP430 combo work just as well as this board.

#### 3.2.6.2 TI MSP430EXP430G2

This version of the MSP430 is much like the F5529, however it has a slower clock and less input pins. Most of our group members own this MCU, however, because we wanted to use the CC3100, we were unable to use this microcontroller because it only supports 20 total pins when the CC3100 requires 40.

### 3.2.6 Wireless Technology

#### 3.2.6.1 ZigBee

ZigBee is a wireless standard developed with lower power consumption in mind. ZigBee functions under the IEEE 802.15.4 specification, and operates in common unlicensed bands such as 2.4 GHz and the 868 to 900 MHz range [40]. This could lead to a longer battery life and overall lower power consumption. However, the data transfer rates are considerably slower compared to other wireless standards like Wi-Fi. Because it operates in these bands, the assumption is that ZigBee signals will rarely have to manage packet collision, although in the 2.4GHz range, it is still possible for there to be interference if another device, such as a Wi-Fi router, is operating near the ZigBee device. The ZigBee protocol has little support in commercial products and personal projects, and our group has no experience or existing devices that can interface with a ZigBee antenna. Conversely, we have a multitude of devices that utilize the IEEE 802.11 Wi-Fi protocol. Because of the cost effectiveness, performance, and existing body of knowledge on the subject, we chose to utilize Wi-Fi as our wireless protocol over ZigBee.

# 4.0 Related Standards

## 4.1 Standards

### 4.1.1 Medical

There is a vast list of medical standards that apply to the Home Healthcare Assistant project but the results have be narrowed down with assumptions. To measure the blood oxygen levels, it is assumed that the HHA will use a noninvasive pulse oximeter and to measure body temperature, the thermometer will be inserted orally. The weight scale and blood pressure device are assumed to have met the requirements of certain standards in order to provide standardized results. Since the weight scale and blood pressure device modules to be used for the HHA project have certain unknown standards met, it is excluded from this section. Only standards that can be applied to the building of vital sign sensors are shown in the following subsections. The HHA is an open-ended project and a project that wishes to increase the variety of sensing devices might want to include extra standards that relate to them.

#### 4.1.1.1 Medical Thermometers

Medical thermometers look relatively simple to make but there are actually a decent amount of things to consider. One of the things to consider is where the thermometer will be placed to measure the patient's body temperature and from there, a specific set of standards are applied to improve the success of the thermometer. The ISO 80601-2-56 standard covers the requirements of basic safety and performance of medical thermometers [41]. ISO 80601-2-56 mainly focuses in the electrical aspect of the design opposed to the materials it is made from. The ASTM E1104-98 standard can be used as guidelines in possible materials to use in building the probe of the HHA thermometer [42]. The standard also covers possible sheaths and sanitary covers that go on top of the probe. Communication between the medical thermometer and other health measuring devices also have a standard dedicated to them. The standard used for personal telehealth thermometer devices and computer engines is the ISO/IEEE 11073-10408 standard.

#### 4.1.1.2 Pulse Oximeters

Standard DANSK-DS-DS/EN ISO 9919 focused in the requirements for basic safety and performance of pulse oximeter equipment for medical use. This international standard covers the safety measures to be taken in the creation of the pulse oximeter monitor, probe, and cable extenders. Moreover, the standard also covers how to estimate the amount of arterial oxygen hemoglobin saturation and pulse rate in patients under the care of healthcare institutions as well as patients under home care [43]. This standard costs around $70 which is not excessively expensive when compared to other similar ones in the $200-$250 range. Using this standard would simplify the work involved in the blood oxygen levels calculation of the HHA pulse oximeter. Other standards that can help in the development of the HHA pulse oximeter is the DANSK-DS-DS/EN ISO 80601-2-61 and the CSA-CSA-CAN/CSA-Z9919-07 standards.

### 4.1.1.3 Health Insurance Portability and Accountability Act of 1996 (HIPAA)

#### 4.1.1.3.1 Overview

In order to fulfill the need for standardizing the security and privacy of medical records and healthcare information of Americans, the Department of Health and Human Services (HHS) developed a set of standards known as the Health Insurance Portability and Accountability Act of 1996 (HIPAA). This law protects sensitive information such as the names, addresses, medical history, social security numbers, and other personal, identifying pieces of information that needs to be protected in any medium. HIPAA created a solid foundation for maintaining the privacy and security of these pieces identifiable information and as a law, must be complied with by health care providers and health plans. [44] As a prospectively major healthcare device, the HHA will aim to comply to these standards by taking as many steps deemed necessary to make sure that all data, both stored temporarily locally and permanently remotely, cannot be accessed by unauthorized parties. Additionally, the information stored on the database can be accessed by provided to authorized parties within the legal waiting period.

#### 4.1.1.3.2 Administration of HIPAA in the HHA Infrastructure

- Privacy
  - All data recorded by the HHA will be stored securely on a cloud-based database.
  - No other user in the HHA system can see another user's information unless the owner of that information approves it.
- Data management
  - As data becomes accumulated throughout time, the associated parties a patient will want to authorize for access may change. As such, the HHA database is prepared to make those changes by excluding or including those parties from the patient's access table.
  - Though the patient will not have direct access to the database, a direct change can be requested.
- Accessibility
  - When a patient exerts their right to see their personal information or to receive a copy of the information stored on the database, the HHA can provide all of the information belonging to the patient listing their readings and personal biographical information they may have added to their profile,
    - HHA also provides the plotted graph to allow for easier interpretation of the collected data
    - Should a physical copy of the data be requested, a printout of the requested data can be provided, albeit at a later date, within the constraint of sixty days with no more than a thirty day extension.
- Management of requests and complaints
  - Because a patient has a right to know about how their personal information is being handled,
  - At any time, data can be removed at the request of the patient.
  - At any time, data can be fixed to update or amend an erroneous entry.

### 4.1.2 IEEE 801.11 (Wi-Fi)

A wireless technology and standard developed by the Institute of Electrical and Electronics Engineers (IEEE) in their 802 family of standards for local and metropolitan area networks. IEEE 802.11 specifically standardizes wireless area networks (WANs) whose frequency bands most commonly range between 2.4 and 5GHz through the 802.11b and 802.11n protocols, respectively. This protocol also has a number of encryption methods for privatizing networks, including schemes as simple as the 64-bit Wired Equivalent Privacy (WEP) security algorithm and the 64 to 128 bit Wi-Fi Protected Access scheme.

Pros:

- Very common, implemented in most wireless devices
  - Affordable ICs
- Efficiently handles data transfers and collisions

- Relatively high data transfer rates
- Standard range covers the area necessary for a home environment

Cons:

- Difficult to implement into a project if wireless chip created from the ground up
- Relatively higher power requirements for stable implementation
- More susceptible to interference, as with any wireless technology

### 4.1.3 Simple Mail Transfer Protocol (SMTP)

SMTP is a well-established protocol used for sending e-mails with many different mail servers that still support and use it for sending e-mail. For the scope of this project, the HHA will only need to send e-mails through SMTP, but not receive mail. Therefore, this is the only e-mail protocol that will be needed. By default, the SMTP protocol uses the TCP port 25. Knowing this, we could potentially send e-mails from any location so long as the HHA has a working internet connection. It is important to note that this protocol is only capable of sending plaintext. For the purposes of HHA, which only involve sending text alerts to users and patients, this protocol provides enough functionality. [45]

### 4.1.4 VGA Standard Protocol

The BASYS 2 FPGA development board contains a VGA (Video Graphics Array) connector to transmit generated video signals suitable for output to a VGA monitor screen. This standard protocol for video signal transmission directly applies to our project since it was decided that our group shall utilize the inherent features of the BASYS 2 as much as possible – thereby minimizing the need for external parts – to create a user GUI (Graphical User Interface) for the HHA user. The VGA standard for outputting a video signal is elaborated upon below.

A VGA signal consists of 5 unique data signals: three primary color video signals in Red intensity, Green intensity, and Blue intensity (R, G, B) as well as two synchronization signals called HSYNC (Horizontal Synchronization) and VSYNC (Vertical Synchronization) [46]. The R, G, B signals are analog signals that carry pixel color data using the additive color model – these three primary colors are added together to produce a wide range of possible colors, as shown in **Figure 4.1.4-1**. It is noteworthy that on the BASYS 2 FPGA development board uses three bits to represent the intensity of each of the Red and Green signals, but only two bits to represent Blue intensity [34]. This format is known as RGB-332. Less variation in the blue color is thus allowed using the BASYS 2, but for the purpose of this project, this constraint is not a hindrance as no sophisticated images are intended to be displayed on the monitor.

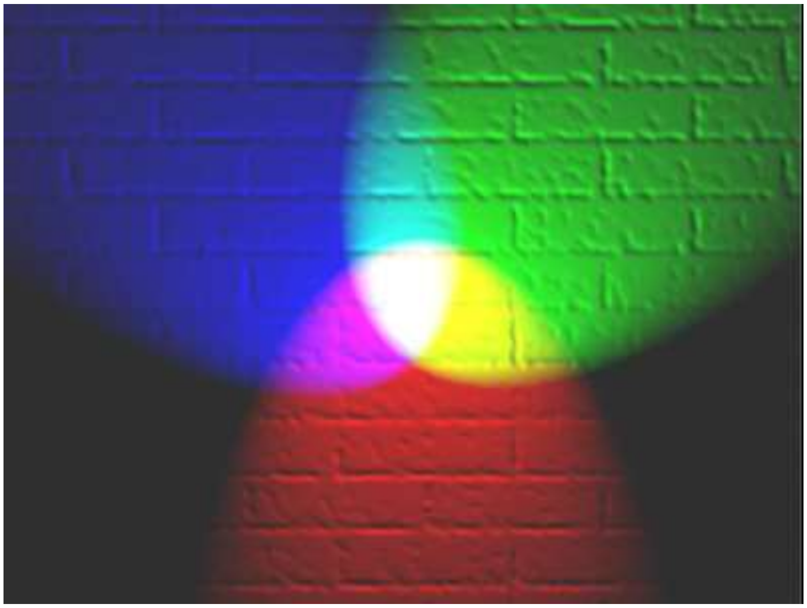


**Figure 4.1.4-1: A model of additive color mixing is utilized in the BASYS 2 RGB signal generation for VGA. Public domain image obtained under the GNU Free Documentation License**

To display an image on a monitor, multiple horizontal lines of pixels are stacked to compose a vertical frame. A single frame of VGA video typically contains 480 lines, while each line consists of 640 pixels. To generate a frame of video, deflection circuits are present within the monitor that move electrons emitted from guns that paint the pixels left to right as well as from top to bottom across the screen. The deflection circuits require two synchronization signals to start and stop the electron guns at the right instants so that a line of pixels is generated across the monitor and such lines are stacked on top of each other, thereby displaying an image [47].

The HSYNC and VSYNC signals define the screen resolution and provide the necessary timing information for a monitor to correctly display the associated pixel color data. By nature, they are a train of square pulses (digital signals) of either +5 V or +3.3 V. The pulses on the HSYNC signal pinpoint the start and end of a pixel line and ensure that all the pixels between the left and right edges of the visible screen area are displayed on a monitor. The VSYNC pulses mark the start and end of a vertical frame which consists of a set of horizontal video lines to ensure that all lines between the top and bottom edge of the monitor receive pixel data. [46]

By contrast, the R, G, B signals take on continuous (analog) voltage values from 0 V, which indicates complete darkness, to 0.7 V for maximum brightness. Any color displayed on a monitor is the result of a mixture of different levels of brightness of the 3 primary colors. The total number of possible colors that can be distinguished using the 8-bit VGA output on the BASYS 2 is $2^8 = 256$ colors. [34]

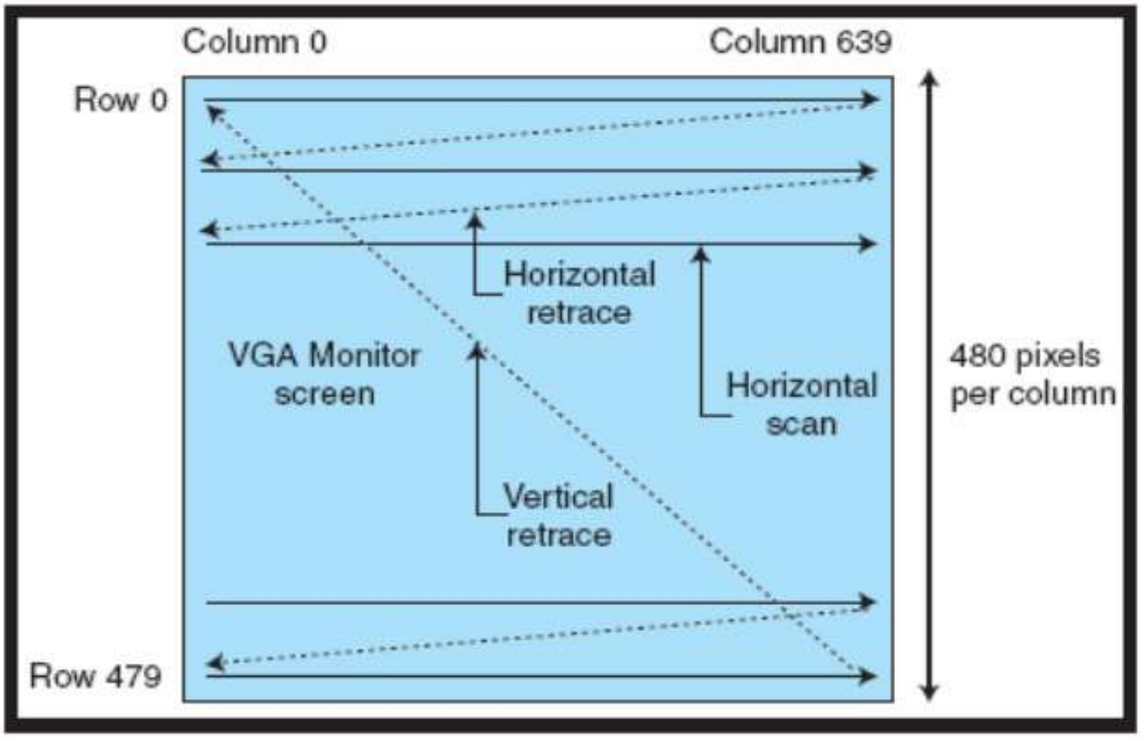



**Figure 4.1.4-2: Pixels are drawn left-to-right to display a line of pixels, then lines are drawn from top to bottom to create a single frame of VGA video. Image permission pending from Dr. Mingjie Lin, UCF**

For a 640x480 pixel resolution screen, 640 pixels are contained in each line, as shown in **Figure 4.1.4-2**. The horizontal synchronization timing information in relation to each line of a single frame of video transmitted to a monitor is shown in the first half of **Figure 4.1.4-3**. The 25.17 µs interval indicates the active region of pixel transmission to the monitor within a single horizontal video line. Between the 26.11 µs and the 25.17 µs periods is the region known as the *horizontal back porch*, where the horizontal pixel counter has been maxed yet the horizontal synchronization signal remains active. The HSYNC signal is then set to zero after the horizontal front porch, and is reset at 29.88 µs. Until 31.77 µs, no pixel data is again transmitted. This region between 29.88 µs and 31.77 µs is known as the *horizontal front porch* [34].

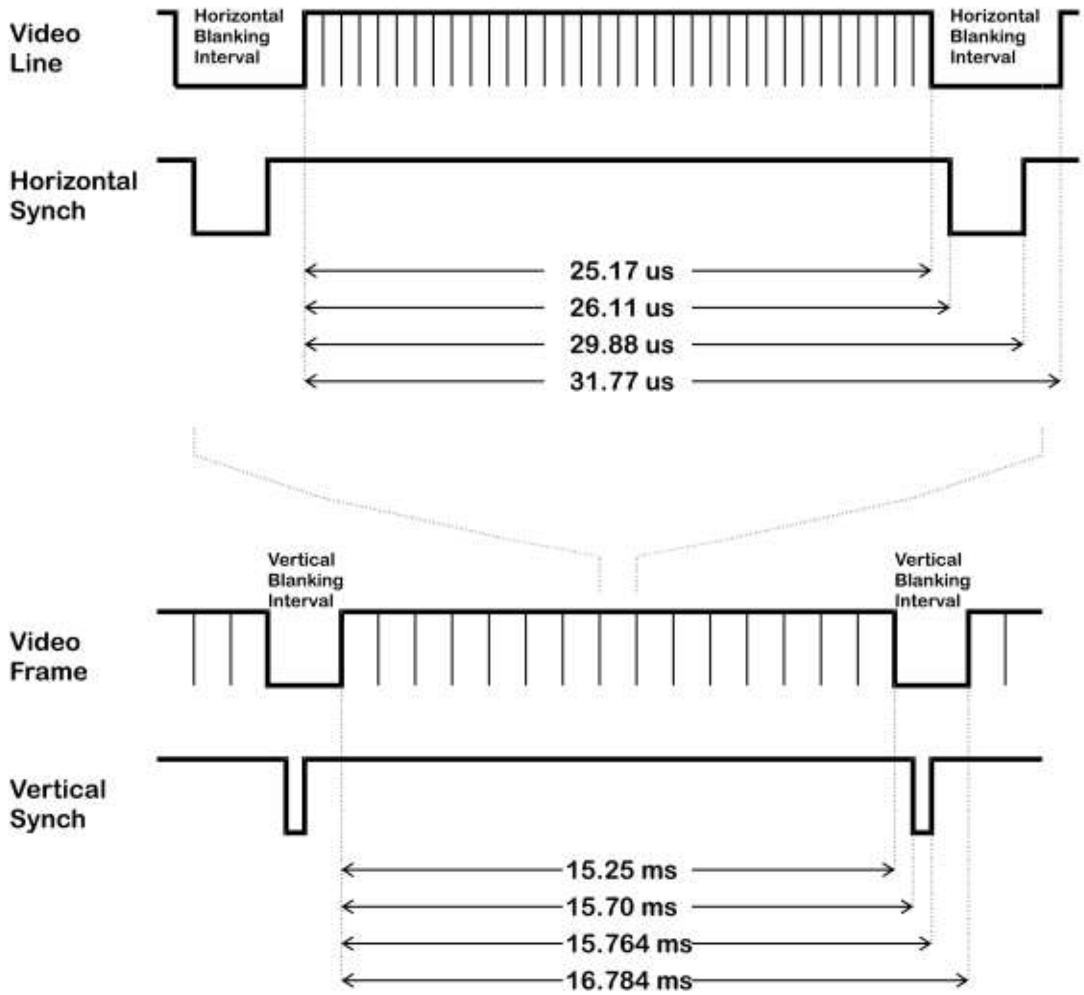



**Figure 4.1.4-3: Horizontal and vertical synchronization timings to display a single frame of video. Reprinted with permission from Mr. Javier Valcarce García.**

In the second half of **Figure 4.1.4-3**, the vertical synchronization timings are illustrated. Each discretized portion of the video frame diagram represents a single horizontal line, which is generated using the horizontal synchronization timings as described. The vertical column of lines – consisting of 480 lines for the given resolution – is sent to the monitor within a 15.25 ms window. The VSYNC signal then drops low for 0.65 ms in a region known as the *vertical back porch*. The VSYNC signal remains low for another 64 µs and is then reset into the region called the *vertical front porch*. Between the start of the vertical back porch and the end of the vertical front porch, no line data is transmitted to the monitor, and the screen remains dark. These synchronization timing requirements are an integral part of the VGA protocol [47].

The BASYS 2 board utilizes the HD DB-15 connector to transmit VGA data to a monitor [34]. The synchronization and pixel data signals described in this section are transmitted to a monitor using this connector. The pinouts for the required connections are depicted in **Table 4.1.4**.

**Table 4.1.4: HD DB-15 connector pin out. NC indicates no connection**

| Pin | Signal |
|---|---|
| 1 | Red |
| 2 | Green |
| 3 | Blue |
| 4 | NC |
| 5 | Ground |
| 6 | Red Ground |
| 7 | Green Ground |
| 8 | Blue Ground |
| 9 | NC |
| 10 | Sync Ground |
| 11 | NC |
| 12 | NC |
| 13 | HSYNC |
| 14 | VSYNC |
| 15 | NC |

**Source: Digilent BASYS 2 Reference Manual**

## 4.1.5 PS/2 Keyboard Standard Protocol

Another feature incorporated within the BASYS 2 FPGA board is the inclusion of a PS/2 port which allows for the interfacing of a keyboard or mouse with the FPGA board. For the HHA project, user data was decided to be acquired using a keyboard input. In order to program the FPGA to communicate with a PS/2 keyboard, the communication protocol is first understood.

The PS/2 keyboard uses a two-wire serial bus for clock and data to establish communication with the BASYS 2 host device. 11-bit words are serially transmitted that contain a start bit, stop bit and an odd parity bit. The same components of these words exist for mouse and keyboard communication to a host device, however the data packets are organized differently. Also, the keyboard interface makes use of bi-directional data transfers allowing the host device to illuminate status LEDs on the keyboard, such as the *Num Lock* key. Both the clock and data signals are active low and are driven only when data transfer initiates, i.e. when a key is pressed on the keyboard. Otherwise, the signals are held at logic high [34].

Scan codes, shown in **Figure 4.1.5-1**, are utilized by PS/2 keyboards during communication to a host device. Each key is represented by a unique code that is sent whenever it is pressed, thereby allowing the host device to determine which key was pressed on the keyboard. If a key is held down, the scan code is sent periodically every 100 ms. Upon release of a key, an “F0” code is sent, followed again by the scan code of the released key. For characters that utilize the shift key, for example to transmit the character “A”, the scan code that is sent is still the same as the character “a”. The difference is that the shift character is sent after the scan code. This allows the host device to interpret which ASCII character has been sent by the keyboard. Extended keys also exist which send an “E0” before the scan code, and may also send more than one scan code. When such a key is released on the keyboard, an “E0 F0” code is sent, followed again by the scan code(s) [34].

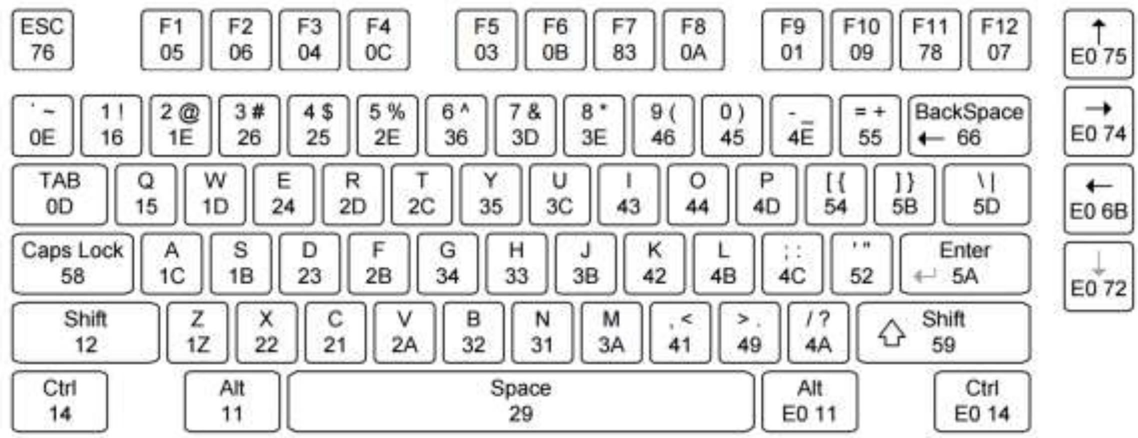



**Figure 4.1.5-1: PS/2 standard keyboard scan codes. The directional keys illustrated on the right of the figure are examples of extended keys. Image printed with permission from DIGILENT Inc.**

Data transfer occurs only when both the data and clock lines are logic high, or in the idle state. As the host device is the bus master and the keyboard is the slave, the keyboard checks for incoming data before it drives the bus. The clock line is thus used as a “clear to send” signal. If the host sets the clock line low, the keyboard may not send data until the clock is released [34].

Once data transfer from the keyboard to the host can occur, keyboard data is sent in 11-bit words consisting of the following sequence of bits: a ‘0’ start bit, 8-bit scan code transmitted LSB first, an odd parity bit, and finally terminating with a ‘1’ stop bit. 11 clock cycles total are used for the data transfer of a single key press. The keyboard clock runs between 20-30 KHz, and the data is valid on the negative edge of the clock cycles [34]. The bus timing diagram shown in **Figure 4.1.5-2** defines the signal requirements for bi-directional keyboard communication. The timings are explicitly provided in **Table 4.1.5-1**, and the pin out of the 6-pin mini DIN connector used with the PS/2 interface is depicted in **Table 4.1.5-2**.

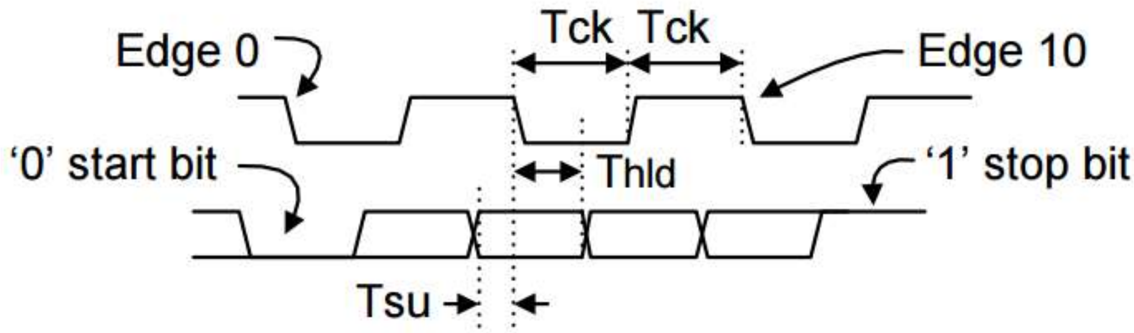


**Figure 4.1.5-2: PS/2 standard signal timing diagram. Image printed with permission from DIGILENT Inc.**

**Table 4.1.5-1: PS/2 signal timings enumerated**

| Symbol | Parameter | Minimum Value | Maximum Value |
|---|---|---|---|
| $T_{CK}$ | Clock time | 30 µs | 50 µs |
| $T_{SU}$ | Data-to-clock setup time | 5 µs | 25 µs |
| $T_{HLD}$ | Clock-to-data hold time | 5 µs | 25 µs |

Source: Digilent BASYS 2 Reference Manual

**Table 4.1.5-2: 6-pin mini DIN connector pin out. NC indicates no connection**

| Pin | Signal |
|---|---|
| 1 | Data |
| 2 | Data |
| 3 | Ground |
| 4 | NC |
| 5 | Vdd (5 V) |
| 6 | Clock |
| 7 | NC |
| 8 | Clock |

Source: DIGILENT BASYS 2 Reference Manual

## 4.1.6 Electrical Component Packaging

### 4.1.6.1 Through-Hole Technology (THT)

Through-hole technology is based on semiconductor packaging form factors that use several long pins that go through the PCB and are soldered on the opposite side of where it is mounted. Although through-hole technology is slowly fading away from the industry due to its relatively large form factor, power inefficiency, and lower accuracy, it is still a convenient way to prototype circuits. THT chips will be utilized by the HHA to easily prototype circuits on a breadboard and many of those chips have a surface mount device (SMD) chip. Since this technology is still being utilized and will be seen in the Home Healthcare Assistant PCB, the SEMI-G54 standard has an influence in the design.

The SEMI-G54 standard provides accurate information about the dimensions and tolerances used to manufacture both THT and SMD molded plastic packages. These packages include information about PDIP, PLCC, PQFP, SOIC (both Gull-Wing and "J" Lead), and PTAB packages. Header-pins also follow the THT in-between lead spacing, also called centers, convention of 2.54mm [48]. If the HHA was designing specific semiconducting chips for the purpose of this project, it would have to follow the SEMI-G54 standard.

#### 4.1.6.2 Surface Mount Devices (SMD)

Surface mount devices are the industry's most commonly used type of packaging. SMD packaging provides a form factor usually about half the size of THT chips, better power efficiency, accuracy, but harder to prototype since it has to be soldered to a PCB. The center spacing is half of that of THT which makes it 1.27mm. The IPC - SMC-WP-003 standard provides important information about the dimensions, advantages, and disadvantages of all sorts of chip mounting technology (CMT). The standard also provides useful information in the historical transition from one technology to the next and other information such as the size of silicon die [49]. If access is granted to this standard, the HHA could implement the effective packaging in terms of power, prototyping, heat dissipation, implementation, size, and cost.

### 4.1.7 Printed Circuit Board (PCB)

#### 4.1.7.1 Design

In PCB design, land pattern geometries are different based on the type of electronic device being mounted but many times they are also different depending on the type of soldering used to attach the device. Standard IPC - 7351B shows generic requirements for surface mount design and land patterns. The standard takes into account the location, size, device type, conditions, and requirements to meet different levels of reliability. If using this standard was economically feasible to buy, read, and apply to the HHA, reliability of the PCB would greatly improve. IPC - 7351B is part of a bigger family of standards that focus on specific types of surface mount components [50]. Since it is not currently possible, the HHA will have to be soldered with the knowledge of other colleagues and consultants who have more knowledge in the subject. The reliability of the PCB design will be partially reliant in the software used.

#### 4.1.7.2 Component Mounting

The IPC-CM-770E standard focuses on methods to mount components on the PCB. Unlike the IPC - 7351B standard, IPC-CM-770E is a guideline for designers in how to mount devices such as LCDs onto different types of PCBs. The standard also talks about how to mount a chip onto a flexible printed board, which is called Chip-On-Flex (COF), and on glass substrate, also known as Chip-on-Glass (COG) [51]. Another good feature of this standard is the in-depth categorization of levels, classes, and types of finished PCB product a designer wishes to accomplish. For the HHA, access to this standard would provide extra information in mounting THT and SMD components and also LCDs in case it is decided to add LCDs showing the user their vital results. The IEC-61191 standard also focuses in soldering through-hole and surface mount as well as terminal-mount components.

## 4.2 Impact on Design

The standards found through research are good guidelines on where to start. Medical standards, although not bought, provided a good summary in parts of the medical devices that could cause problems. Some of these parts are cable extenders, probes, and monitors. Other standards such as those for VGA protocol and PS/2 keyboard protocol provided a guideline in how to communicate between devices. With the VGA protocol, it is possible for the Home Healthcare Assistant to communicate with the patient using a VGA screen. The HHA then can wait for the patient's answer which is to be chosen through the PS/2 keyboard. Without the PS/2 keyboard protocol, patient feedback would not be possible. The IEEE 802.11 and Simple Mail Transfer Protocol (SMTP) standards work in a similar manner in terms of communications. The IEEE 802.11 is a standard for implementing wireless local area network (WLAN) communication. Following the guidelines of this standard makes it possible for the patient to indirectly communicate with a medical practitioner. Results can be sent through WLAN communication into a database which then takes action based on the results. The database results could alert a medical professional that the patient's health is deteriorating which is where feedback from the doctor is recommended. The SMTP standard is another possible way the Home Healthcare Assistant could receive feedback from the database. Feedback from the database would be in the form of an electronic mail to confirm that the results have been successfully stored and give an update on the health of the patient.

# 5.0 Design Constraints

## 5.1 Economic

The HHA is a project being funded by its own creators which creates economic constraints. Due to the economic constraints, most of the parts and methods taken to build the Home Healthcare Assistant are as low-cost as possible without significant harm to the integrity of the project. With a company or organization to sponsor the HHA, better technology such as wavelength-specific photodiodes can be used to create the pulse oximeter. The display size of the screen could also have been bigger in order to reduce the amount of strain needed to use the HHA in vision-impaired patients. The accuracy of all sensors could also be improved with more accurate and expensive electronic devices such as high precision op-amps. The requirements and specifications could also be more accurate in terms of sensor accuracy, wireless transmission range, and even device weight.

## 5.2 Time

### 5.2.1 Calibration

Due to calibration, the HHA will have a short span of time to obtain accurate results from some of the results. An accurate pulse oximeter uses look-up tables from data obtained invasively from patients. The HHA device itself is non-invasive but the calibration could be invasive if the appropriate time is given to sign and process legal paperwork. Most pulse oximeters use data obtained from a few hundred patients. For the HHA to obtain that many patients, it is probably best to use the help of a local clinic who is willing to share anonymous data from patients and use our device for testing. Since there is no time available to undertake such endeavor, the values obtained from the HHA pulse oximeter will follow general laws of physics. The values obtained will be somewhat close to the actual value and a values will be compared to results from already existing pulse oximeters products. Differences between HHA pulse oximeter and actual pulse oximeter results will be studied to make the HHA values more accurate. The HHA will also have a limited amount of testers compared to pulse oximeters already in the market.

### 5.2.2 Other Vital Signs

The Home Healthcare Assistant is a project that encompasses only a small portion of what is needed in nursing homes, clinics, and other medical establishments. The HHA is proof that a device that obtains multiple medical data can be built at a relatively low price. Given extra time to continue developing and improving the HHA design, other vital signs and medical measurements could be implemented. Other vital signs include airflow, galvanic skin response, electrocardiogram, patient position, and muscle/electromyography. Another vital sign that could be considered is a glucose meter but it would change the HHA from noninvasive to an invasive device. A port for the glucose meter could give the option for the patient to not include it in the device. If the HHA could use all these sensors, it would give the medical practitioner a better understanding of the patient's health.

## 5.3 Environmental

### 5.3.1 Batteries

According to research analyst, C.R. Malavika, an average person living in the United States throws away about 8 batteries per year. There are about 300 million people living in the U.S. which puts the number of thrown away batteries in the billions. These waste is then permeated in the soil and ground water which causes a variety of serious illnesses if exposed long enough [52]. As a result, one of the design constraints for the Home Healthcare Assistant is that it has to be environmentally safe. This is a self-inflected design constraint in order to help the environment and reduce the damage to the surrounding if anything were to go wrong. Since the HHA is aiming to be environmentally friendly, the variety of rechargeable battery types is greatly reduced. Lead-acid batteries are in no way a viable option for powering the HHA.

## 5.4 Health

There are some health constraints in the HHA design that are to protect the patient. One of the constraints of the design is the use of nontoxic, waterproof, and water-resistant materials in the HHA thermometer probe. If the probe will only be the tip of the thermometer, it has to be tightly bound to the rest of the casing. The probe has to be smooth all around, with no possibilities of cutting or damaging the skin in order to avoid infections. Thermometer probes should always use disposable, protective sheaths to prevent the spread of contagious diseases. Any parts in any device which the patient has access to touching are to be RoHS compliant.

## 5.5 Safety

The HHA safety constraints revolve around the soldering of equipment and charging of the device. While soldering, if leaded solder is used, the room must be well ventilated in order to protect the person soldering from the fumes. When soldering, all nearby equipment must not be flammable. While using the hot-air soldering gun, nearby equipment must be held tightly in its position. Never should a hot-air soldering gun be pointed anywhere but downwards. The HHA device must not work while it is charging to prevent any power failures from reaching the patient. If the HHA is plugged into an outlet for charging while it is on, it will automatically shut off.

# 6.0 Project Hardware and Software Design

## 6.1 Sensor Subsystems

### 6.1.1 Body Temperature System

With the comparison of possible thermal sensitive device options, the decision is to use a semiconductor integrated circuit to measure the patient's body temperature in the HHA. Since the HHA is not aiming to replace a doctor but to alert nurses and doctors of a possible health problem in the patient, the actual value of the body temperature value is not displayed to the patient. Instead of body temperature value, the thermometer will send a signal to tell a microcontroller unit (MCU) whether the patient has reached the temperature point that is classified as hypothermia or a fever. Small status LEDs will be inserted in the thermometer so the patient knows it is working and if they seem to have any health problems. **Figure 6.1.1 - 1** shows the block diagram of the body temperature sensor to be designed for the HHA.

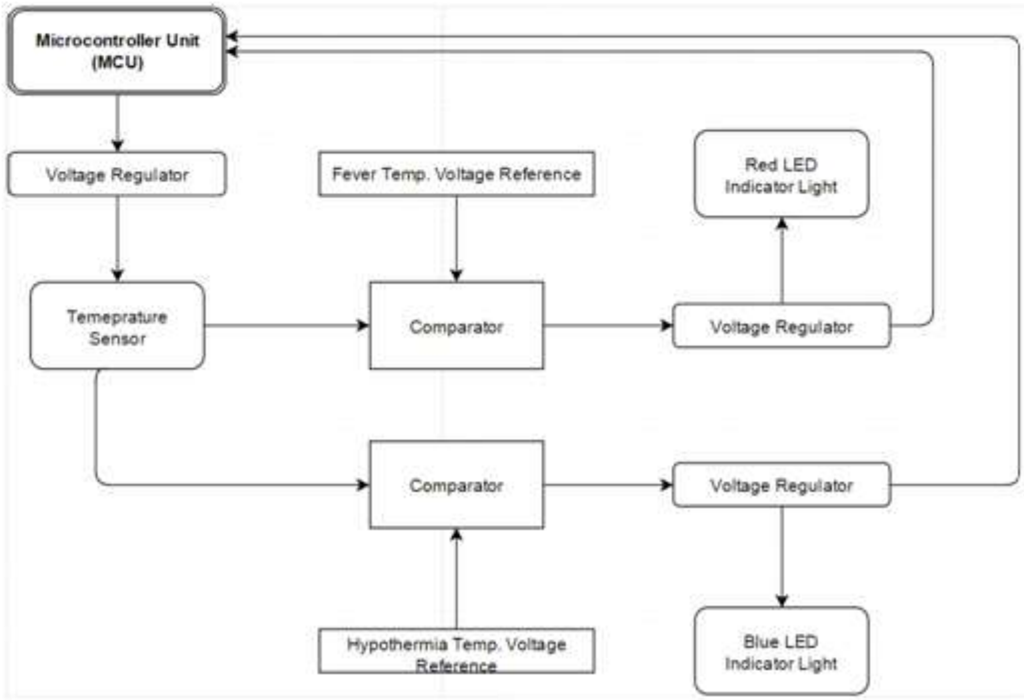



**Figure 6.1.1 - 1: Body Temperature System Block Diagram**

For the temperature sensor, an integrated circuit chip of small size is needed in order to fit inside a closed-end probe tube. The probe will work as a shield for the sensor and go inside the patient's mouth. To get the circuit block diagram to work, the IC sensor has to output a voltage that correlates to the temperature. The results are then fed to comparators that determine if the patient has either a fever or hypothermia. Since accuracy is another important factor in selecting the appropriate temperature IC, many choices in temperature IC sensors have to be discarded as viable options for the HHA.

The most accurate and low-cost temperature sensors are Texas Instruments (TI) LM and LMT series. From research of multiple datasheets it is noticeable that the LM series IC temperature sensors provide a smaller temperature accuracy error range than the LMT series. However, the LMT is lower cost, currently advertised, and has much lower typical accuracy error than the LM series. A test conducted by TI also showed that the LMT series holds true to the typical accuracy by taking 96 randomly chosen LMT84 temperature ICs and graphing their accuracy results as shown in **Figure 6.1.1 - 2** [53]. The results are very similar to the LMT84 datasheet's typical accuracy results shown in **Table 6.1.1 - 1.** [54]

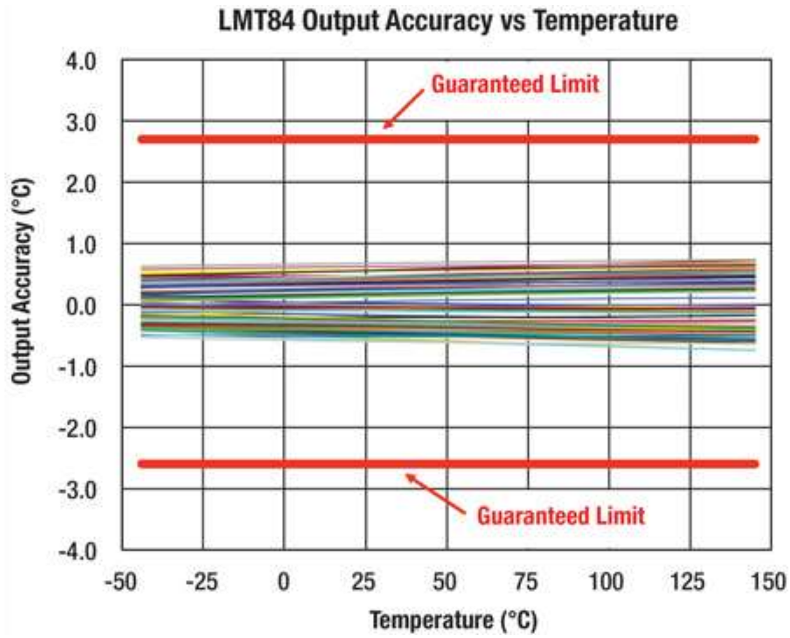



**Figure 6.1.1 - 1: LMT84 Output Accuracy**
**Courtesy of Texas Instruments**

**Table 6.1.1 - 1: Temperature Accuracy of LMT84**

| PARAMETER | TEST CONDITIONS | MIN(1) | TYP(2) | MAX(1) | UNIT |
|---|---|---|---|---|---|
| Temperature Accuracy (3) | 70°C to 150°C; $V_{DD}$ = 1.5 V to 5.5 V | -2.7 | ±0.6 | 2.7 | °C |
| | 0°C to 70°C; $V_{DD}$ = 1.5 V to 5.5 V | -2.7 | ±0.9 | 2.7 | °C |
| | –50°C to 0°C; $V_{DD}$ = 1.6 V to 5.5 V | -2.7 | ±0.9 | 2.7 | °C |
| | –50°C to 150°C; $V_{DD}$ = 2.3 V to 5.5 V | | ±0.4 | | °C |

**Courtesy of Texas Instruments**

With the results of this test, the LMT series typical accuracy is good enough for the thermometer. Any problems with accuracy, either with LMT or LM series, due to bad manufacturing of the IC, would completely throw off the values; therefore, temperature centigrade range is of little use compared to the typical temperature range for the HHA thermometer. Research into the LMT series results in using the LMT87 as it provides the lowest temperature error compared to other LMT sensors as shown in **Table 6.1.1 - 2**. The temperature range of interest in the datasheet is between 20°C to 40°C. However, TI recently developed the LMT70 which is high accurate, extra small, temperature IC which only has 0.1°C of inaccuracy. Unfortunately, the LMT70 is not for sale yet but will be considered in the making of the HHA thermometer if it is released before reaching the building of the final product.

**Table 6.1.1 - 2: Temperature Accuracy of LMT87**

| PARAMETER | CONDITIONS | MIN[(1)] | TYP | MAX[(1)] | UNIT |
|---|---|---|---|---|---|
| Temperature accuracy[(2)] | 70°C to 150°C; $V_{DD}$ = 3.0 V to 5.5 V | -2.7 | ±0.4 | 2.7 | °C |
| | 20°C to 40°C; $V_{DD}$ = 2.7 V to 5.5 V | | ±0.6 | | °C |
| | 20°C to 40°C; $V_{DD}$ = 3.4 V to 5.5 V | | ±0.3 | | °C |
| | 0°C; $V_{DD}$ = 3.0 V to 5.5 V | -2.7 | ±0.6 | 2.7 | °C |
| | 0°C; $V_{DD}$ = 3.6 V to 5.5 V | | ±0.3 | | °C |
| | –50°C; $V_{DD}$ = 3.6 V to 5.5 V | -2.7 | ±0.6 | 2.7 | °C |
| | –50°C; $V_{DD}$ = 4.2 V to 5.5 V | | ±0.3 | | °C |

**Courtesy of Texas Instruments**

The safe temperatures for the HHA body temperature sensing system has to be between 35°C to 38°C as stated previously. To achieve this, comparators will use a voltage references that directly correlate to the predicted output voltage of the LMT87 temperature IC. The voltages for both 35°C and 38°C can be obtained from **Equation 6.1.1 - 2** [55]. The voltages that correspond to 35°C and 38°C are 2.122V and 2.163V respectively. Any voltage below 2.122V is to be considered a fever and any voltage higher than 2.163V is to be considered hypothermia. Since the output voltage of the sensor is very delicate and voltage precision is a must, preset voltages will be applied using resistors and small-value potentiometers to manually calibrate the supply voltage using voltage divider. **Equation 6.1.1 - 2** makes it possible to find the limits of each of the comparator input depending on the potentiometer limits [55]. Both fever and hypothermia detection temperatures have to possibility to be the same because potentiometers and resistor tolerance values have been considered and a wider range of resistivity has been taken into account. Calibrating the potentiometers will allocate the fever and hypothermia temperatures to their corresponding values according to HHA standards.

$$V_{TEMP}(mV)=2230.8mV-\left[13.582\frac{mV}{°C}(T-30°C)\right]-\left[0.00433\frac{mV}{°C^2}\left(T-30°C^2\right)\right]$$

**(Equation 6.1.1 - 1)**

$$T\ (°C)=\frac{13.582-\sqrt{(-13.582)^2+4\times 0.00433\times(2230.8-V_{temp}(mV))}}{2*(-0.00433)}+30$$

**(Equation 6.1.1 - 2)**

To ensure the accuracy of the results, a constant, stable, relatively high voltage needs to be supplied to the temperature sensor. The comparators that receive the voltage of the temperature sensor only output a voltage which is read as either a high or a low by the MCU. Since the comparators will be doing an easy job, the low-cost and general-purpose LM393 will be used. The MCU pins cannot receive more voltage than the comparator outputs. To prevent damage to the MCU, the supply voltage of the LM393 comparator cannot be the same as the output voltage of the MCU pin. Although the LM393 comparator has to output a lower voltage, it has to be noticeably higher than half of the voltage supplied to the microcontroller unit.

For both the makers and the user's convenience, status LEDs are available in the HHA. A green LED will demonstrate the device has been turned on, a yellow LED will show if the person has hypothermia, and a red LED will tell the patient if he/she has a fever. A dual Op-Amp following the comparators is needed to remove the loading effect of the status LEDs on the comparators and also to work as LED drivers and avoid damage. The Op-Amp of choice is Microchip's MC3307APG because it has unity gain capability, high common-mode rejection ratio (CMRR), and is low-cost. **Figure 6.1.1 - 2** shows a schematic of the body temperature sensor with the comparators, op-amps, potentiometers, and status LEDs. While making the schematic, all power, currents, voltages, as well as precaution from failures have been measured. **Figure 6.1.1 - 2** assumes preset values of the temperature sensor for testing and a constant 5V supply voltage on all devices at all times. The actual HHA body temperature circuitry will not have supplies connected as shown, instead, an analog switch IC will determine whether the supply voltage is being supplied to the devices including the temperature sensor. All the devices in **Figure 6.1.1 - 2** are through-hole in order to get early preliminary testing underway and easily replace chips if something goes wrong.

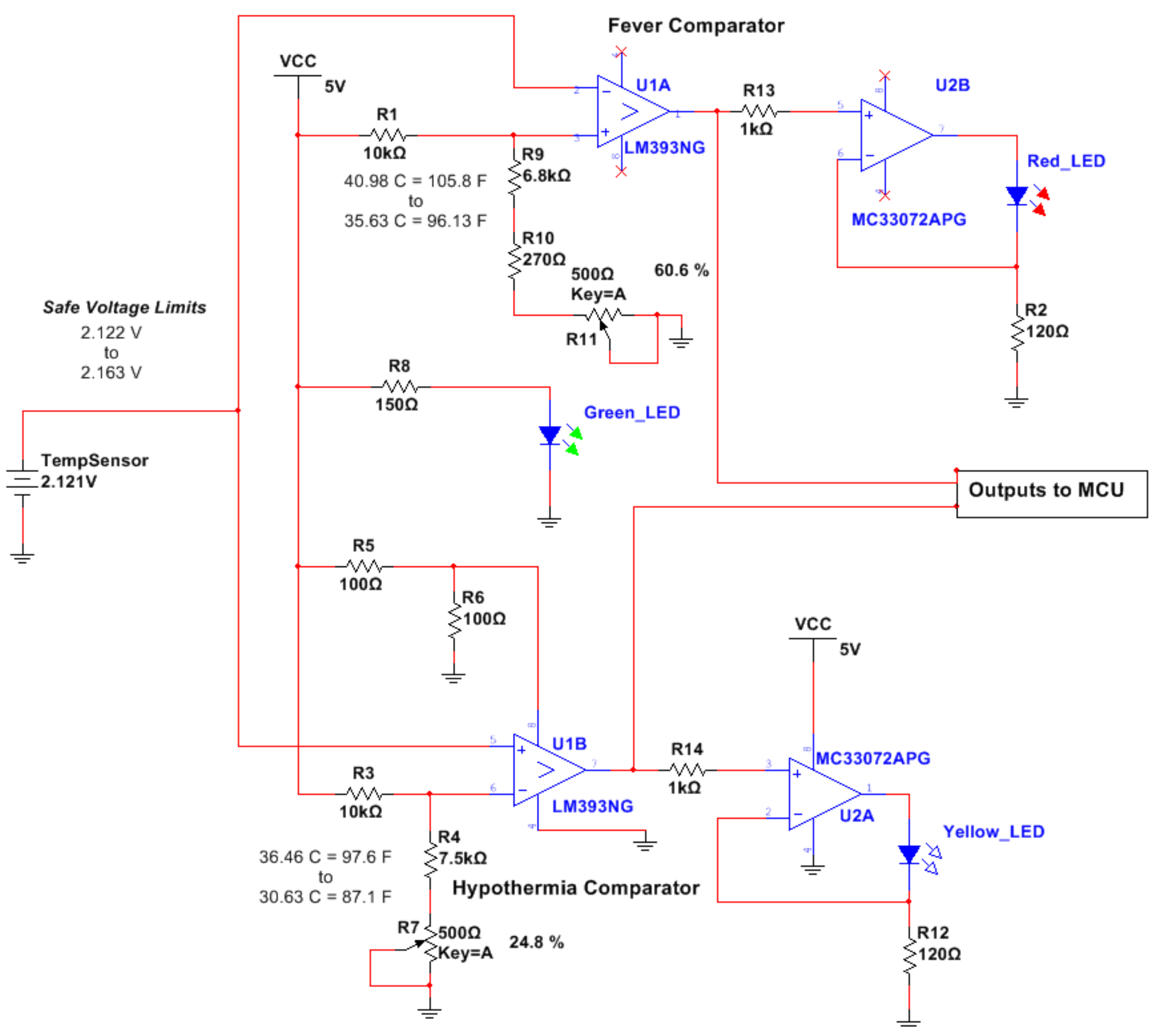



**Figure 6.1.1 - 2: Body Temperature Schematic**

To determine which analog switch integrated circuit to use, low-cost and efficiency are a priority. In this case, efficiency of the device means the device applies a very small resistance when it is supposed to make voltage flow through; therefore, it will not reduce the amount of supply voltage reaching the devices. The switching IC also has to be able to supply enough current to all devices. Adding the currents of all the devices in the body temperature schematic reaches close to 100mA. Out of the many possible options, the ADG884BRMZ analog switch IC is chosen over other possible options mostly due to its low 370 mOhms resistance and low-cost. Since it is a dual switch IC, it can also be used to power HHA's pulse oximeter. **Figure 6.1.1 - 3** shows the schematic of the ADG884BRMZ analog switch IC connected to the supply voltage and the MCU which decides the sensor to turn on. The schematic also shows the voltage output if pin 1 is high, pin 2 is low, and the pins could output 3.3V.

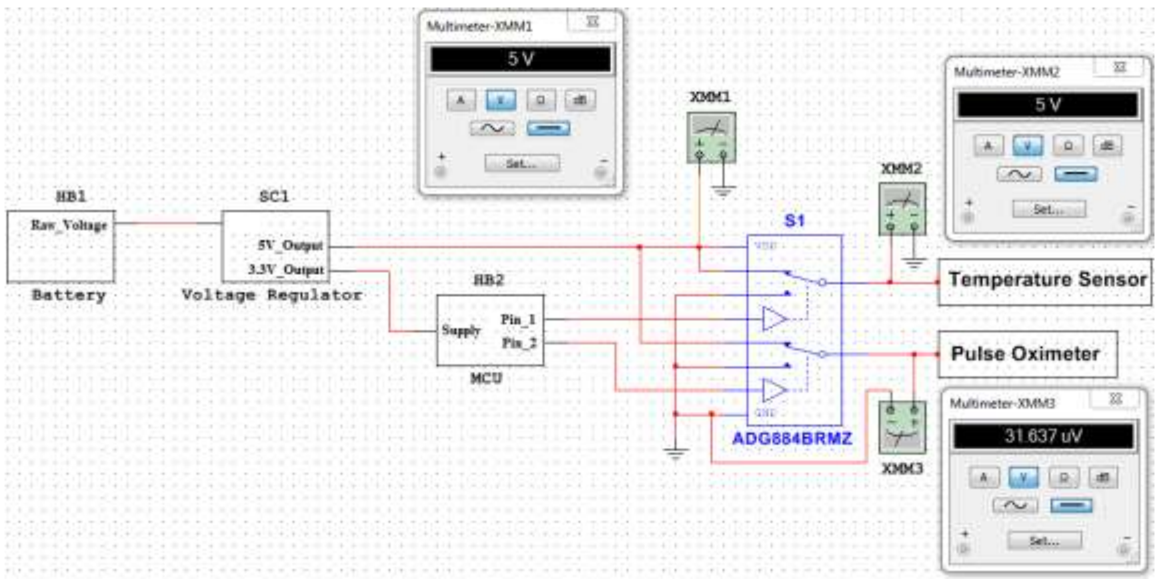



**Figure 6.1.1 - 3: Sensors connected to switching IC**

## 6.1.2 Pulse Oximeter System

### 6.1.2.1 Switching and Timing

The pulse oximeter requires LEDs whose illumination goes through the patient's finger and has an adequate amount of the illumination absorbed; therefore it cannot be too strong or too weak in order for the sensor to detect appropriately. Another important feature to consider in the implementation of the LEDs is that a very constant current source is needed. With a stable constant current source, the illumination of the LEDs will be the same every time it pulses which reduces the amount of discrepancies in the results. The LEDs chosen for this task come from LEDSupply since they are the same form factor and have a viewing degree angle of 30° degrees or more. From the different light sensing technologies, the more appropriate choice for the HHA pulse oximeter is the optical integrated circuits. The best low-cost optical IC of choice due to limited variety, low cost, and linearity is the TSL14S. **Figure 6.1.2.1 - 1** shows the HHA pulse oximeter block diagram.

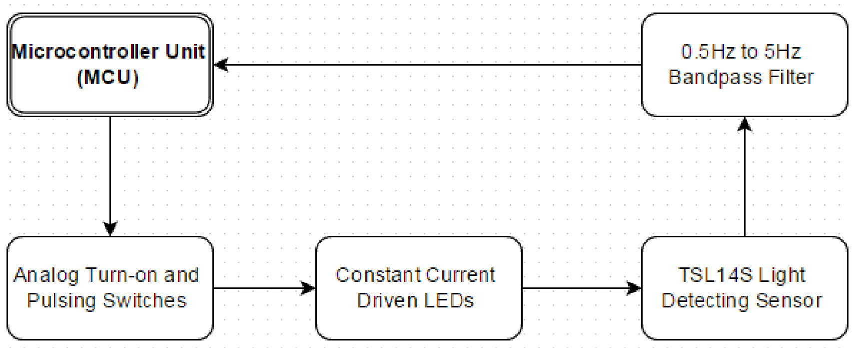


**Figure 6.1.2.1 - 1**

In order to save battery power, the MCU will give the signal to turn on the pulse oximeter and turn off all other sensors at the appropriate time. In order to achieve this, the same switching IC the HHA thermometer uses is shared with the pulse oximeter. The analog switching IC will turn on the next cascaded analog switching IC which will decide when the LEDs will be turned on and off. **Figure 6.1.2.1 - 2** shows the schematic of the cascaded analog switching ICs and the MCU deciding which switch to be turned on. For example, using **Figure 6.1.2.1 - 2**, will require pin 1 and 4 to be low and pin 2 and 3 to be high in order to enable the pulse oximeter's red LED. Based on research, a cycle where both the near-infrared (NIR) and red LEDs are pulsated and registered can be done at a frequency of 1kHz [16]. The timings are done through the microcontroller unit. **Figure 6.1.2.1 - 3** shows the timing diagram of the LEDs.

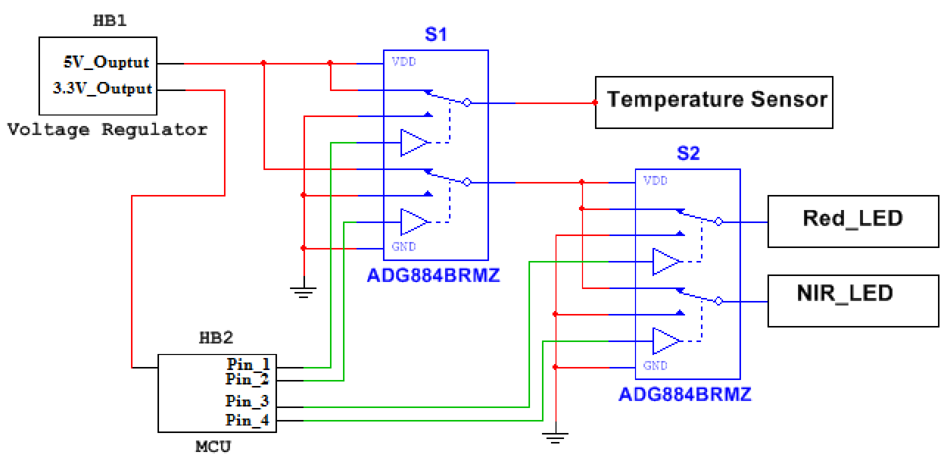


**Figure 6.1.2.1 - 2: Pulse Oximeter Switching ICs**

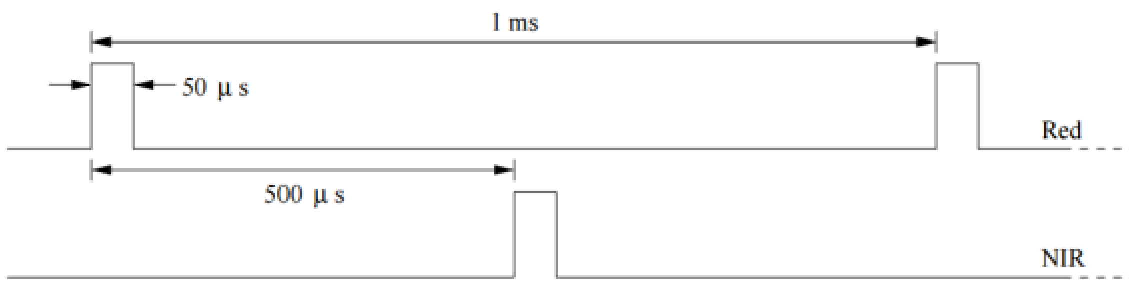



**Figure 6.1.2.1 - 3: Timing signals for LED drivers**
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### 6.1.2.2 Constant Current Driver for LEDs

In order to drive the LEDs at a constant current with minimal circuitry problems and to protect the LED, the HHA uses Bipolar Junction Transistors (BJTs). The BJTs chosen are the 2N2222 because it is low-cost, can be run at high frequencies, and can handle the voltages. When the pulse oximeter is running, a BJT turns on when current is flowing through the switch. The excess voltage that is not used by either the bipolar transistor's turn on voltage or the LED, will be used to turn on the second BJT. The second bipolar transistor then filters any excess current straight to ground. The current is then governed by the second BJT's turn on voltage and the resistor connected to ground. Simple ohm's law will give the appropriate 20mA current for the LEDs. The HHA does not produce a perfect 20mA current due to real-life factors in the BJTs and the resistors but it can easily be constraint to the safe current values which are between 20-30 mA. Moreover, the current will be relatively constant. **Figure 6.1.2.2** is a schematic of the switch ICs connecting the MCU to the constant-current driven LEDs.

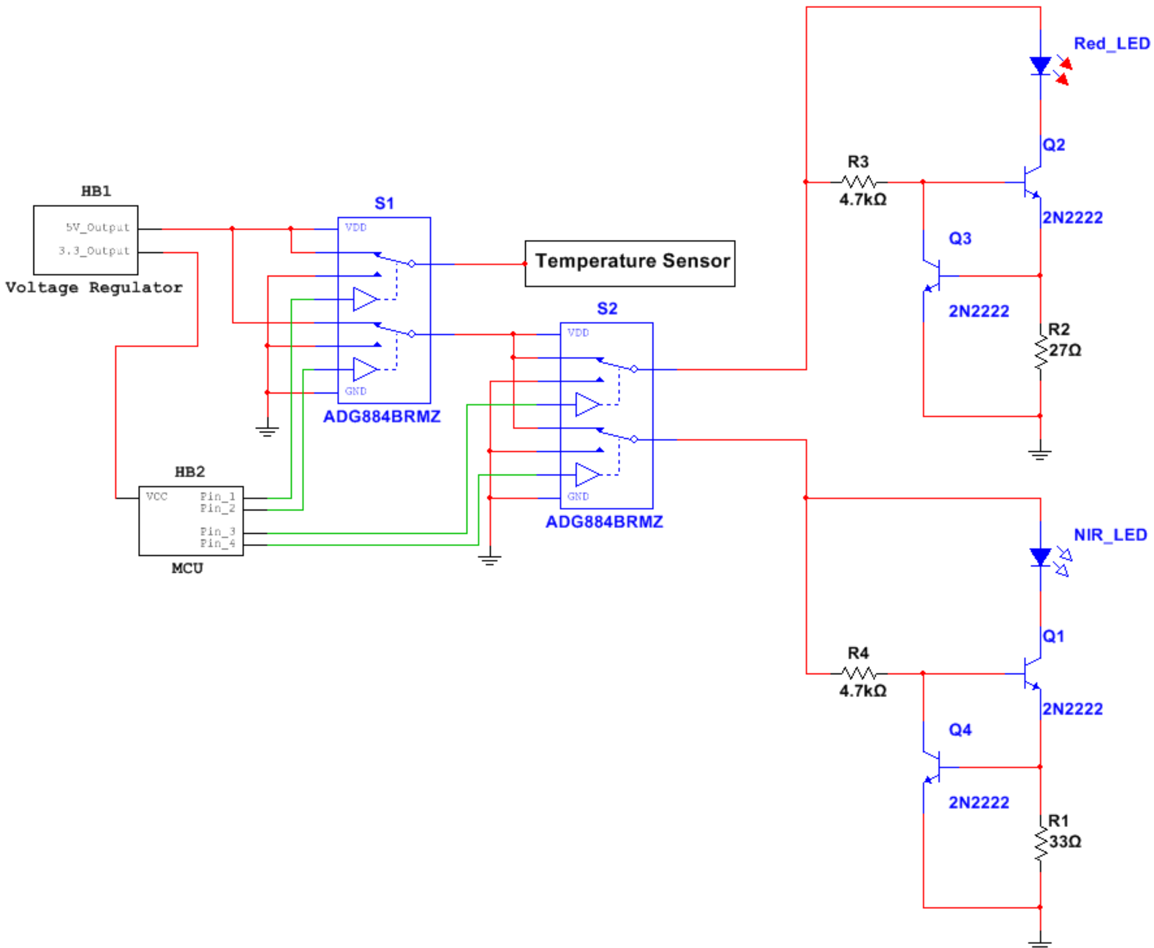


**Figure 6.1.2.2: Schematic of switching ICs and constant-current LED drivers**

### 6.1.2.3 Light Sensor Bandpass Filter

Each time the red and NIR LEDs pulsate, the TSL14S light sensor across the finger captures a fraction of the light emitted to the finger. The TSL14S is a low-noise IC, but to reduce the noise even more and limit the frequency further, two first-order filters are connected in cascade to make a band-pass filter. The band-pass filter is between 0.5Hz to 5Hz because the maximum cardiac frequency is never more than a few hertz [16]. **Equation 6.1.2.3 - 1** and **Equation 6.1.2.3 - 2** shows the formulas that govern the low-pass and high-pass filters needed for obtain the band-pass filter. The gain, K, is set to 1 on one of the filters which means that the op-amp has to be unity-gain stable. The second filter has a gain slightly higher than 1 to make up for the loss of gain due to op-amp imperfections and the small bandwidth. Because of the small bandwidth, the high-pass filter does not have enough time to stabilize at unity before it has to start decaying to match the low-pass filter's cut-off frequency. To calculate correct values for the resistor and capacitor, a preset value of 10µF for the capacitor is chosen and then the resistor is matched to obtain the correct cut-off frequency. Simulations through NI Multisim's AC analysis then outputs a graph whose values are slightly off and have to be tweaked in order to precisely set the cut-off frequencies of the band-pass filter.

$$\omega_o = \frac{1}{RC}$$ **(Equation 6.1.2.3 - 1)**

$$K = \frac{R_B}{R_A} + 1$$ **(Equation 6.1.2.3 - 2)**

Since the HHA operates with a single supply, all the electronic parts run with a positive voltage. Because all devices run with a positive voltage, the op-amps used for filters have to be able to work with a single supply. Single supply op-amps require a slightly different design for filters than dual supply op-amps. Vcc/2 is required and it also needs to be isolated from loading effects; therefore, a voltage divider at the input of a unity gain op-amp is used. The HHA uses the MC33078P Op-Amp because of its high-speed, low-noise, and low-cost. **Figure 6.1.2.3 - 1** shows the band-pass filter schematic for the light sensor output. All op-amps for the pulse oximeter are supplied power after the switch for the pulse oximeter turns on. The output voltage of op-amp U2A shown in **Figure 6.1.2.3 - 1** is then connected to the MCU which will do the necessary calculations with the aid of its internal analog-to-digital converter (ADC) and finally arrive at the correct blood oxygen levels. **Figure 6.1.2.3 - 2** shows the schematic of the both the HHA pulse oximeter and thermometer connected together along with how power will flow to devices. The red wires shows normal connections and the green wires are power traces that turn on the devices.

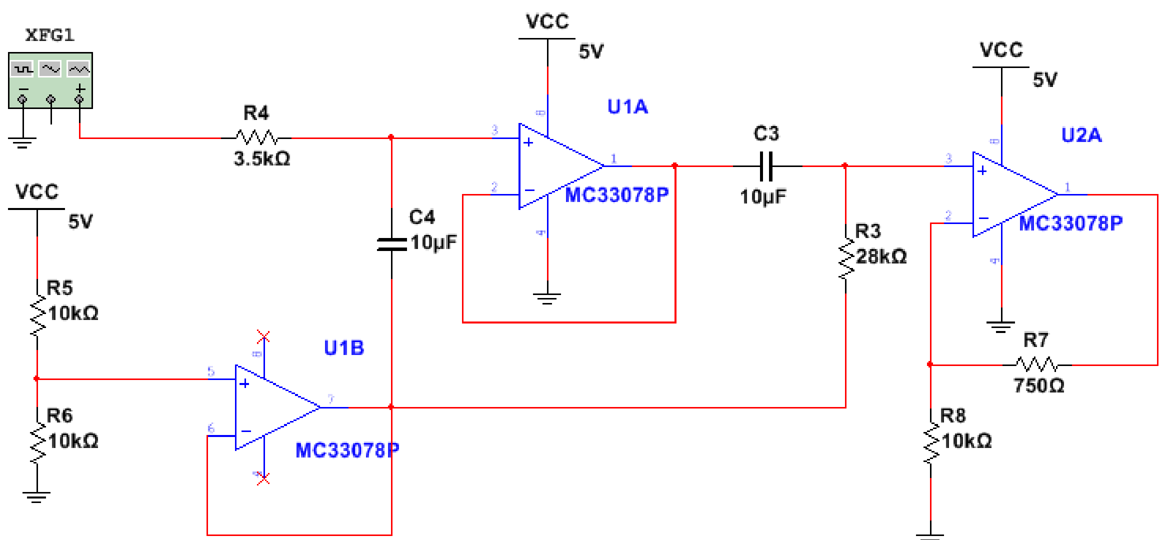


**Figure 6.1.2.3 - 1: 0.5 - 5 Hz Bandpass Filter**

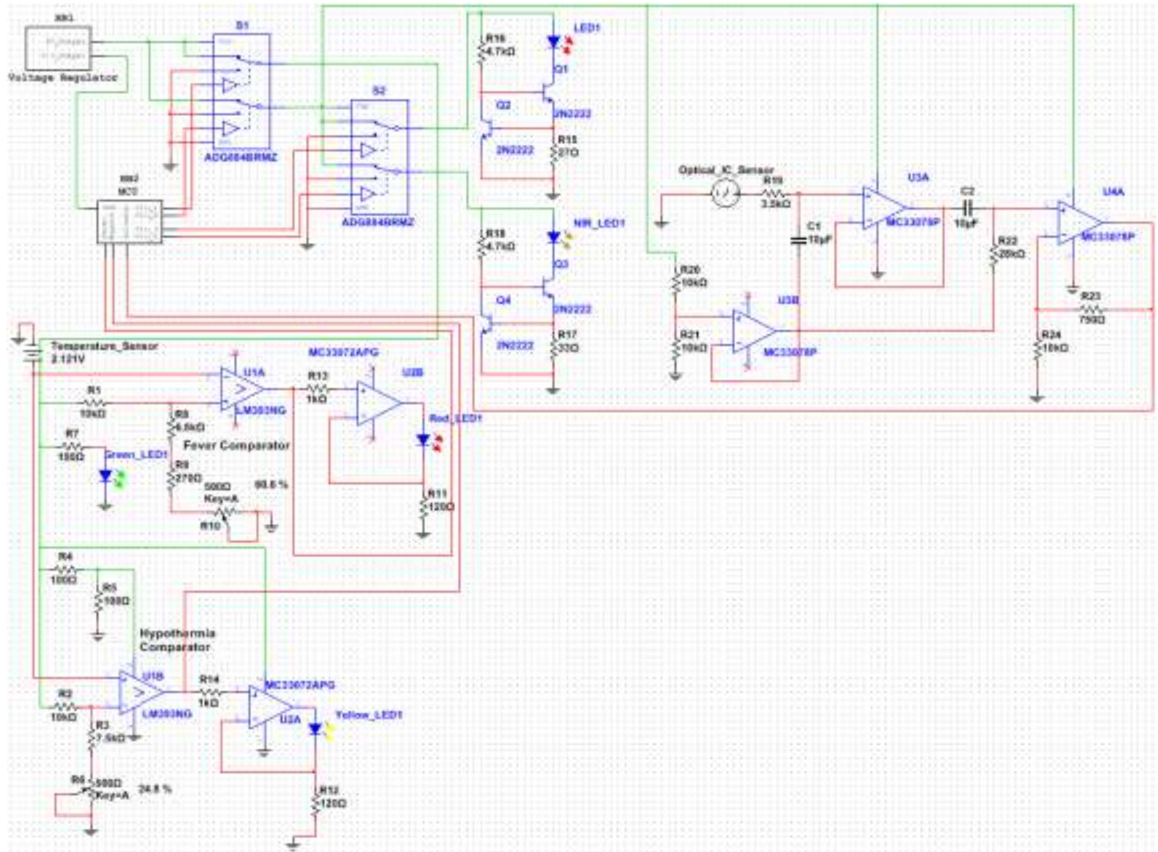


**Figure 6.1.2.3 - 2**

### 6.1.2.4 Pulse Oximeter Casing

The casing of the pulse oximeter weighs heavily in the accuracy of the results. Pulse oximeters have to be systems completely closed to external light sources or the photo sensing devices will measure values of the alternating LEDs plus external light. As a result, the sensor will output extra voltage depending in the intensity of external light. To avoid inaccurate results, the pulse oximeter has to be tightly closed around the patient's finger without obstructing the blood flow. Extra space revealing the sides of the finger when inserted into the pulse oximeter have to be blocked by the casing as well. The outside casing material can be 3D printed using almost any type of plastic but the material touching the patient's finger has to be made out of rubber. Rubber is a non-reflective material that will not intensify the amount of light emitted from the LEDs. Rubber will also comfortably wrap around the patient's finger and reduce the finger's movement when inside the device, increasing the accuracy of the results.

### 6.1.2.5 Calculating Blood Oxygen Levels ($SpO_2$)

The greatest challenge in designing a pulse oximeter that meets the requirements and specifications of the HHA is combining the right method to calculate SpO2 with the circuitry used. **Figure 6.1.2.5 - 1** shows the transmission of light through the finger and the expected waveform assuming the circuit designed for the Home Healthcare Assistant works. **Figure 6.1.2.5 - 1(a)** shows an AC signal stacked on top of the DC signal when light is transmitted through the finger. The AC signal is equivalent to the artery expanding each time the heart beats and the DC signal is equivalent to the constant light absorbed by the rest of the finger. **Figure 6.1.2.5 - 1(b)** and **Figure 6.1.2.5 - 1(c)** are the red and near-infrared LED AC signal with the DC offset removed.

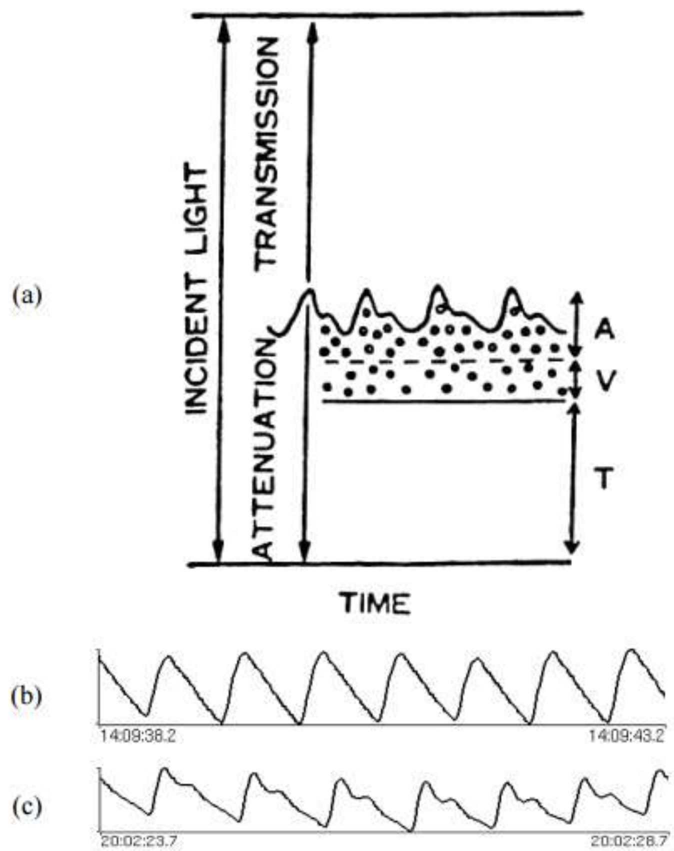


**Figure 6.1.2.5 - 1: Attenuation of light and optical sensor outputs**
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To calculate the $SpO_2$, the exact voltage values have to be stored in the MSP430's memory for at least one cardiac period using the MSP430's internal analog-to-digital converter. Since the cardiac frequency varies from person to person, the coding in the MSP430 must be able to determine when the voltage is increasing or decreasing. When the device is on and when it detects a peak or a trough in the signal, it begins storing the TSL14S output voltage in memory at a 1kHz frequency; therefore, every cardiac period is being sampled at a 1kHz frequency. From the values stored in memory, the first peak and trough become useful values in determining the AC signal. **Equation 6.1.2.5 - 1** and **Equation 6.1.2.5 - 2** show two possible methods of measuring the blood oxygen levels [15]. Since **Equation 6.1.2.5 - 2** is easier to implement in the code for the MSP430, it is the preferred method of calculating $SpO_2$. Also, since $SpO_2$ is a ratio between values obtained from the two different wavelength LEDs, the AC signal can be determined as either $V_{rms}$, $V_{pp}$, or $V_p$ as long as it is consistent. For simplification, the AC signal is calculated with peak-to-peak voltage as shown in **Equation 6.1.2.5 - 3**. The trough voltage then becomes the DC value of the signal. **Figure 6.1.2.5 - 2** shows a visual representation of how the HHA pulse oximeter calculations are being done assuming a perfect sinusoidal wave for the AC part of the signal.

$$R = \frac{log_{10}(I_{ac}) * \lambda_{660}}{log_{10}(I_{ac}) * \lambda_{940}} * 100 = SpO_2$$ **(Equation 6.1.2.5 - 1)**

$$R = \frac{(AC_{660}) / (DC_{660})}{(AC_{940}) / (DC_{940})} = SpO_2$$ **(Equation 6.1.2.5 - 2)**

$$AC_x = V_{ACx\_peak} - V_{ACx\_trough}$$ **(Equation 6.1.2.5 - 3)**

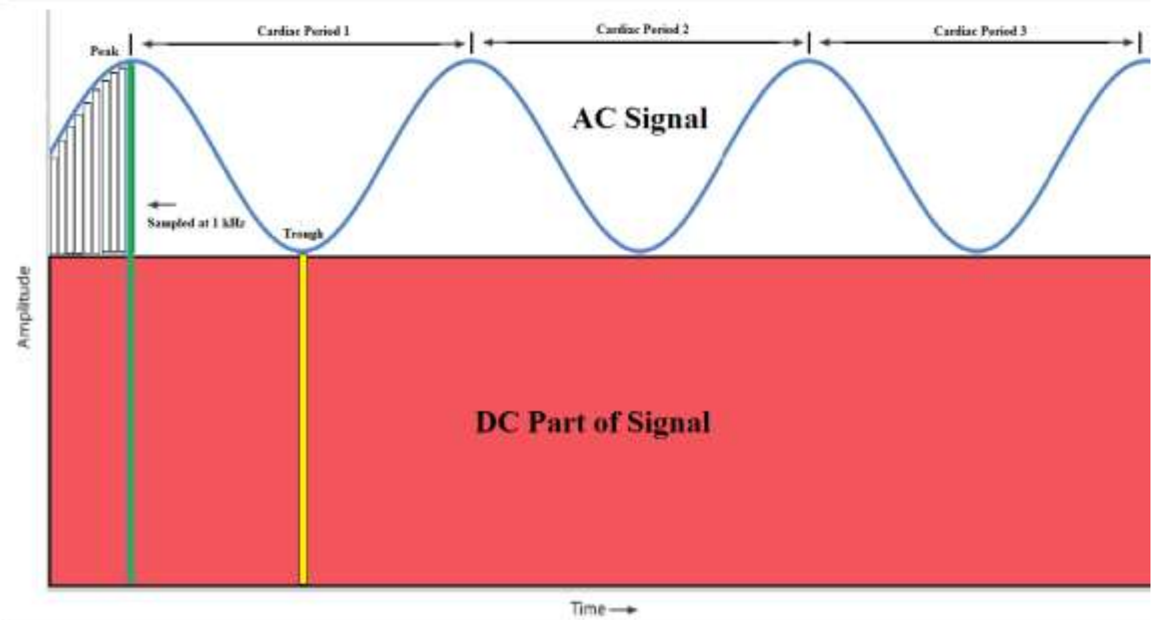


**Figure 6.1.2.5 - 2**

The result of each cardiac period can be stored in memory until the HHA pulse oximeter test ends. Other values stored in memory such as each voltage value while sampling at 1 kHz can be reused once the cardiac period ends. At the end of pulse oximeter calculations, the values obtained can be averaged and extreme outliers can be discarded. The sampling and storing process has to be done for both LEDs simultaneously. At the end of each cardiac period, the blood oxygen levels are calculated. When the test ends, the BPM will be calculated. Assuming the test lasts 20 seconds, the number of peaks or troughs in the signal multiplied by 3 will result in the patient's average heartbeats per minute.

## 6.1.3 Blood Pressure System

From the possible blood pressure monitors, the Microlife BP3MY1-1P is the most appropriate device for the Home Healthcare Assistant. Some wrist blood pressure monitors do not provide accurate results which would make the HHA results just as inaccurate [31]. Unlike the other viable options for the HHA blood pressure monitor, Microlife BP3MY1-1P guarantees medical grade accuracy. The Microlife device is also one of the cheaper options and has a simple screen. By having a simple screen, hacking is more doable by searching the screen serial number which is most likely labeled in its PCB. Schematics for the device and/or the screen can also be found surfing through the net. To power the device, a ADG884BRMZ analog IC chip will power the devices only when it receives the signal from the MCU to turn on. The battery connections inside the device will be connected in series and then connected to one of the outputs of the analog IC chip.

### 6.1.4 Weight Scale System

Choosing a scale that is sold on local stores is difficult because local stores do not have all the specifications of the device; however, it must be done this way to reduce the price of the weight scale. From the list of viable options, the Taylor 7519 weight scale is the best choice for measuring the patient's weight. Taylor 7519 focuses on only measuring weight which means communication with its LCD display is simple when compared to the ADG Digital Scale. Taylor 7519 also uses more advanced technology which includes invisible electrode attachments giving more accurate results than the Taylor 7405. The Taylor 7405 also increments and decrements by 0.2. which means there's a possible 0.2lb error. The Taylor 7519 weight scale provides all the specifications desired to be included in the HHA design at a cheaper price than the Escali weight scale. To power the Taylor 7519, the battery connections will be studied with trial and error until there is a good idea of how it is wired (most likely 2 batteries are connected in parallel and then in series with the other 2 AA batteries it requires). The weight scale will share the same ADG884BRMZ switching IC as the blood pressure sensor and occupy the rest of the pins. The MCU will decide which of the devices to power and when.

## 6.2 User Interface

The user interface is the patient’s primary means of interaction with the HHA. The purpose of the interface is divided into three distinct categories, as follows:

- To sequentially display simple questions to the patient on a VGA monitor as part of the HHA examination.
- To acquire user responses to these questions in the form of Yes or No answers. These responses are recorded via two buttons on a keyboard.
- To inform the patient which sensor to use at a particular moment. Once data is acquired from all sensors, the examination is complete.

The HHA is a proof-of-concept device which can be customized to suit the needs of patients with particular chronic disorders or ailments. Considering a heart patient, for example, the examination questions may ask about the presence of symptoms such as sweaty palms, swelling of feet, palpitation, chest pain or dizziness. In addition, a special set of sensors would be attached to the HHA that acquire readings best suited to a heart patient. However, in its current form, the HHA poses a short list of generic questions and asks the user to attach various sensors that our team deemed practical to install on the HHA for the purpose of this senior design project. It is noteworthy that these readings and Q&A results will still be helpful to a medical doctor, but for patients with specific disorders, a customized or fine-tuned version of the HHA would likely prove to be more insightful for a doctor.

Medical doctors were consulted to help obtain a short list of generic questions that the HHA could ask a patient during examination. These questions are:

- Have you recently visited the hospital?
- Have you recently experienced vomiting, nausea, diarrhea or fever?
- Do you experience any change in shortness of breath or cough?
- Has there been any major change in life that adversely affects your well-being?

The questions are of the variety that a doctor would ask a patient during a clinical examination. To pinpoint a root cause for the ailment and to make a diagnosis, questions that receive a simple Yes or No response are favorable to ask. Open-ended questions may receive responses that hinder a doctor’s ability to make a quick diagnosis. As such, this short list of questions is deemed sufficient for the purpose of this project. In sequence, the patient’s response to each question is stored and the next question is displayed. Once all the answers have been recorded, the sensor data acquisition phase begins.

For our senior design project, the HHA aims to be interfaced with the following four sensors: blood pressure, pulse oximeter, body weight and body temperature. The FPGA board driving the monitor display tells the user which sensor to attach to their body after the Q&A portion of the examination has been completed. As sensor data acquisition is handled by the MSP430 microcontroller in the project, the FPGA board will communicate with the microcontroller using an SPI interface. As the reading for the first sensor is obtained, the microcontroller tells the FPGA that data is acquired. The FPGA then sequentially moves on to the next sensor, and displays to the user which sensor to attach next. Once all sensor readings have been obtained, the examination is complete.

This approach allows for an easier implementation than one that our team brainstormed proposed, which was to allow the user to choose which sensors they want to use during an examination. Allowing the user to choose desired sensors would require the creation of a menu system for the patient to navigate through and select particular sensors to use. However, the simplicity of a simple sequential graphical user interface has its own merits. Since this device is meant to assist the elderly with their healthcare, an easy-to-use device is more likely to see regular use than a complex one that may save time for some patients but may be unpleasant to use for others. In addition, regular acquisition of data from all the sensors as opposed to sporadic readings obtained from some of the sensors may only prove to be beneficial. With the acquisition of sensor data over several examination periods, a core component of the HHA project involves analysis of sensor data to showcase outliers and plots of readings over time. Intermittent readings from a particular sensor may not provide enough data to justify plot generation, or may lead to inaccurate statistical analyses over time.

## 6.3 BASYS 2 UI Implementation

The core requirements of the UI as outlined in section 6.1.2 include displaying text on a monitor, obtaining user input from a keyboard, and communication with a microcontroller to know which sensor data has been acquired and what text to display next. In the following subsections, the programming techniques used to achieve these goals will be elucidated.

### 6.3.1 VGA LCD display driver design

With the VGA standard at hand, it became possible to implement a 640x480 resolution VGA driver on the BASYS 2 FPGA development board. **Table 4.1.4** in Section 4.1.4 lists the required signals that are sent via an HD DB-15 connector to a monitor. Additionally, the timing constraints on the HSYNC and VSYNC signals are enumerated in **Figure 4.1.4-3**, in accordance with the VGA standard protocol. In order to implement digital circuits to generate these signals under the given timing constraints, Verilog Hardware Descriptive Language (HDL) was used in the Xilinx ISE 14.7 WebPack FPGA Design Suite.

The first signal that is the backbone for this aspect of the project is the master clock. The BASYS 2 board includes an adjustable silicon oscillator that could be set at either 25 MHz, 50 MHz or 100 MHz by shorting out respective pins on the MCLK terminal on the development board itself [34]. A VGA signal was attempted to be generated using the internal oscillator, but the resulting image displayed on a monitor was found to be very unstable. With research, it was determined that the internal oscillator is not suitable for projects dependent on crucial timing requirements. The internal clock possesses a degree of jitter that manifests as image instability when a VGA signal is attempted to be generated. For projects with more relaxed timing requirements, the internal silicon oscillator functions sufficiently. The inclusion of this silicon oscillator seems to be a manufacturing decision by DIGILENT Inc. to keep the price of the BASYS 2 board down for students, who are the target audience for this development board. However, a DIP-8 socket was provided on the board for use with an external crystal oscillator that generates clock frequencies via a piezoelectric effect. Oscillators of this variety are known to be extremely accurate. With the purchase and installation of a 100 MHz external crystal oscillator on the DIP-8 socket, the generated VGA signal was found to be very stable.

The next signal considered is the pixel clock, which generates pixels consecutively along a horizontal line. Once a single line of pixels has received RGB data, the next line is illuminated and thus forth until the entire frame has received data. The frame is then refreshed at a rate of 60 Hz in order to display VGA video. The pixel clock functions at a rate of 25.175 MHz, but an approximate frequency of 25 MHz was found to be sufficient to drive the display in a stable manner. In order to implement this signal, a register $q$ was created that incremented at the occurrence of every positive edge of the master clock. The pixel clock was then assigned the second bit of the register $q$, which was incremented every 4 cycles of the master clock. Since the master clock was based on a crystal oscillator running at 100 MHz, a pixel clock of 25 MHz was able to be generated.

In order to assist with the timing aspect of the HSYNC and VSYNC signals, parameters were assigned values based on the criteria shown in **Figure 4.1.4-3**. These parameters included measures of the number of pixels per line, number of lines per frame, HSYNC and VSYNC pulse lengths, and HSYNC and VSYNC back porch and front porch locations. Additionally, two counter were used – a horizontal pixel counter and a vertical line counter. Upon every positive edge of the pixel clock, the horizontal counter was incremented until the maximum pixels per line was reached. This counter was then reset and the vertical counter was incremented to pinpoint to the first pixel on the next line. Once all of the pixels in the entire frame had been covered, both the horizontal and vertical counters were reset to start back at the top-left pixel in order to generate pixel data for the next frame. As the HSYNC and VSYNC signals are digital in nature, they were assigned logic high when their respective counters had surpassed the respective pulse lengths. Outside of this range, the HSYNC and VSYNC signals remain at logic zero. This zero region occurs after the back porch and before the front porch of the respective synchronization signals [47].

The next step in VGA driver implementation is to know when to send RGB signal data to the monitor. The Red, Green and Blue signals are assigned pixel values when the following two criteria are met: The vertical counter is between the vertical back porch and vertical front porch, for a total line count of 480, and the horizontal counter is between the horizontal back porch and horizontal front porch, for a pixel count of 640. These two constraints define the entire active video region where all pixels are present and are required to be illuminated on the monitor screen. Outside of these vertical and horizontal ranges, the RGB signals receive values of 0 [47]. Within these ranges, the RGB signals receive pixel data as defined below.

A primary background color can be displayed on the monitor by assigning static values to the RGB signals within the active video range. For instance, to display a background color of blue, the Red signal can be assigned a value of 000, Green signal a value of 000, and Blue signal a value of 11. The BASYS 2 FPGA board uses the RGB-332 standard format, where three bits are used to represent color intensity for the Red and Green signals, but only two bits are used for the Blue signal [34]. The outlined process in this subsection achieves the preliminary requirement of sending a VGA signal of a static color to the monitor. The complete Verilog module designed for use on the BASYS 2 FPGA board is shown in **Figure 6.3.1**.

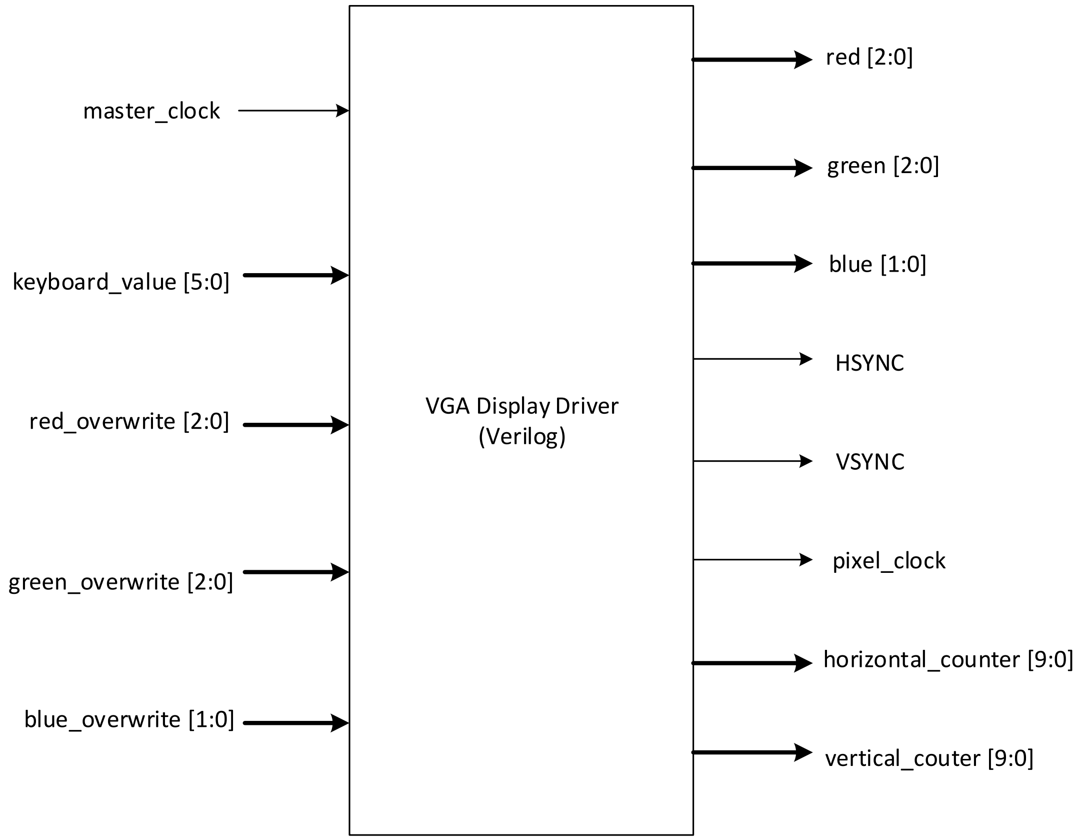


**Figure 6.3.1: VGA driver block diagram for the BASYS 2 implemented in Xilinx ISE 14.7**

### 6.3.2 Displaying text on the LCD

Once a background color has been established, the next step is to display text. This involves the use of a font memory which is implemented as an 8x8 pixel bitmap for each character of the alphabet. Other font sizes such as 6x8 are also possible (which save memory), but 8x8 was chosen for its symmetry and larger size, thereby allowing displayed text characters to be easier to read on the monitor. The workings of the memory module is explained in Section 6.3.3. In order to display a single character of the alphabet, for example in the top-left 8x8 pixels, the respective character's pixel bitmap is pulled from memory and the relevant pixels' RGB signals are assigned values based on this bitmap. To display white text, all RGB signals for active pixels according to the bitmap will be set to a logical 1. To display a second character after this, the next 8x8 region of pixels receives values based on the desired character to be displayed. This technique can be utilized in order to generate a sentence of text. It is noteworthy that the entire screen may first set to a static background color, and then specific pixel values may be overwritten in order to overlay text content where desired.

To streamline the sentence generation procedure involved in showing different questions to the HHA user, separate modules are utilized to assign pixel values for each sentence separately. The purpose here is to display a single question to the end user and receive the user's response. Then, the next question will be displayed on a fresh screen and its response will be recorded. After the Q&A section of the examination, the user is requested – one screen at a time – which particular sensor to use for data acquisition by the HHA. Separate *screen* modules thus allow for the implementation of the GUI to be as straightforward as possible.

Each screen module contains pre-established RGB pixel data according to pixel bitmaps stored in memory. To display a particular sentence, specific pixel data is pulled and displayed on the respective active pixel regions. The list of questions shown in section 6.2 presents the exact sentences that will be shown to the user in unique screens on the monitor. The screens relevant to the sensors will then be presented. All of the RGB pixel values assigned by the screen modules overwrite the pixel values of the appropriate regions in the VGA display driver of section 6.3.1, which is set to display a static background color over the entire active video region of 640x480 pixels unless forcibly overwritten. A block diagram of the Verilog module used to accomplish the tasks of this subsection is shown in **Figure 6.3.2**.

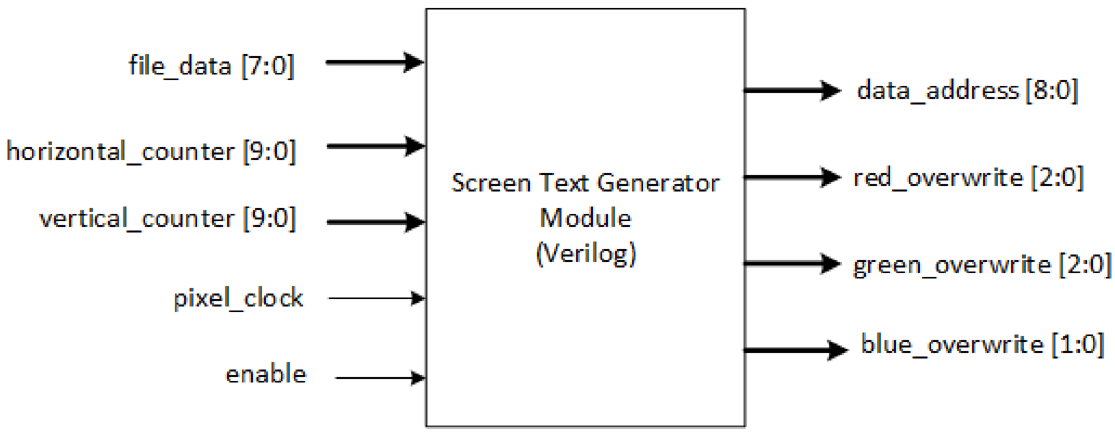


**Figure 6.3.2: Screen text generator module that overwrites RGB pixel values based on predetermined text to be shown on screen. Each unique screen of text possesses its own module with the same I/O as shown in this figure.**

### 6.3.3 Font memory

The font memory contains the vocabulary of the sentence generation procedure. As outlined earlier, 8x8 font sizes were chosen for all characters due to the symmetry and larger size for better readability. For each character stored in memory using the binary pixel bitmap method: zeros represent off pixels, and Ones indicate that RGB values for that pixel are all set to their maximum values: 111 for Red, 111 for Green and 11 for Blue. These values are in accordance with the RGB-332 format in order to display white text [47]. Each character was self-designed by a group member to maximize readability.

The font memory for this project contained all alphanumeric characters from 0 to 9, followed by A through Z. Only uppercase alphabet representations were stored to save space in memory and to allow for smaller data address bus widths in design implementation. The character bitmaps were stored as a column 8 pixels wide. This allowed for the starting pixel for each character stored in memory to be addressable by pointing to its respective starting line. Using this approach, any character could be displayed anywhere on screen. A desired 8x8 pixel active region is selected on the LCD screen, and then the desired 8x8 bitmap content is assigned to it from the font memory.

Although it was experimentally found that there are enough LUT (Look Up Table) resources available on the Xilinx Spartan 3E FPGA chip present on the BASYS 2 board to store bitmaps of lowercase alphabet characters as well, the bitmaps for all characters thus far was manually created in Microsoft Word. A more efficient approach to generate a bitmap file was diligently searched for, yielding only a MATLAB script that generated hexadecimal bitmaps instead. As opposed to understanding the complex code and functions utilized in that script in order to create a binary bitmap, it was determined that the more painstaking approach to create the bitmap manually may help save time overall. The bitmap file used for this project hence terminates with the capital letters of the alphabet. A block diagram depicting the font memory module is shown in **Figure 6.3.3**.

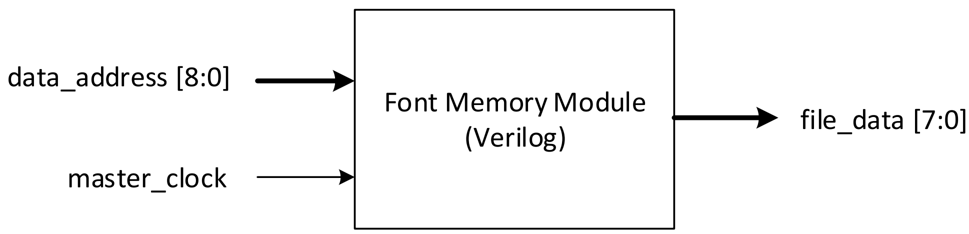


**Figure 6.3.3: Font memory block diagram for the BASYS 2 implemented in Xilinx ISE 14.7**

### 6.3.4 PS/2 keyboard interface design

In order to establish communication The PS/2 keyboard protocol standard and involved signals are as detailed in section 4.1.5. The keyboard clock input signal is active low, and data transfer can only occur when the data and clock lines are both set to logic 1. In the Serial Peripheral Interface (SPI) connection between the host device (the BASYS 2) and the keyboard, the host device is configured to be the master and the keyboard is the slave. This is to allow for bidirectional data transfer, such as to allow the host to activate illumination of keyboard LEDs when certain keys are pressed on the keyboard. For this project, bidirectional data is not required as the keyboard is used to obtain user responses to the HHA's questions only. As such, the Verilog keyboard interface module can solely checks for the occurrence of a negative edge of the keyboard clock signal. The keyboard clock negative edge is triggered when a key is pressed on the keyboard – otherwise the clock signal remains at logic high.

Once the first negative edge of the keyboard clock occurs, the 11-bit data transfer outlined in section 4.1.5 begins. A clock counter keeps track of the incoming data and stops receiving data when it has counted 11 bits. However, only the 8-bit scan code data is stored in a register, which is the means to know what key on the keyboard was pressed. **Figure 4.1.5-1** showcases the relevant scan codes of all keys on a standard QWERTY keyboard. The scan code data is sent by the keyboard LSB first and is stored into an input array. To reorder the data from MSB to LSB left-to-right, a loop is utilized to invert the input array's contents and store it into a data array. As long as the key is held down, the data array content is next sent to an output array as-is. However, when a pressed key is released, the keyboard sends the scan code of 0F in hexadecimal. This simply indicates a key release and does not represent the scan code of a particular key press, so this data is not required to be sent to the output array. The output array now contains the scan code of the last key on the keyboard that was pressed (and released). The acquired scan code from the keyboard is then compared with an existing list of scan codes for all characters, as obtained from **Figure 4.1.5-1**. This determines the ASCII character that was pressed by the user, which is then stored into a keyboard value register.

By knowing which key press occurred, programming of the FPGA to handle user responses is now straightforward. A press of the 'Y' key can indicate that the user responded 'Yes' to a question asked by the HHA, while the 'N' key can indicate 'No'. Alternatively, the user input could be received via one or two directional arrows which select one of the Yes or No options displayed on the monitor (visibly underlining the current choice on the screen), and with a single button the user may 'Enter' the response. The I/O block diagram for this keyboard interface is shown in **Figure 6.3.4**.

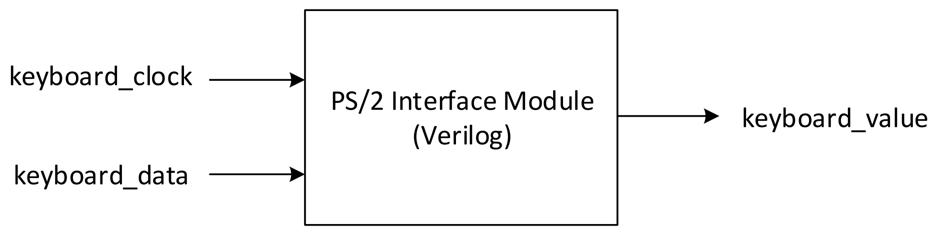


**Figure 6.3.4: PS/2 interface module block diagram for the BASYS 2 implemented in Xilinx ISE 14.7**

### 6.3.5 Establishing communication with the microcontroller

The SPI (Serial Peripheral Interface) is a functionally simple interface that allows one master chip to communicate with one or more slave chips. Considering a sequence where only two chips have to communicate, a 4-wire SPI connection may be established between the two. **Figure 6.3.5-1** demonstrates the interaction between two chips when set up with an SPI connection. The signals involved entail the clock signal sent out by the master device (SCLK), master-to-slave data transfer (MOSI), slave-to-master data transfer (MISO), and a chip select line that activates communication by the master to a given slave (SSEL). [56]

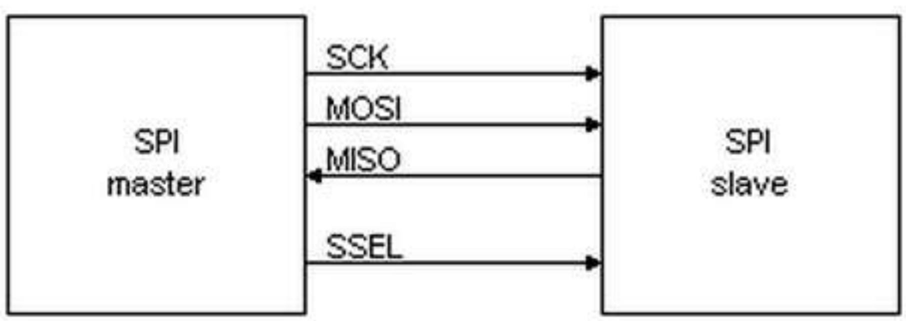

**Figure 6.3.5-1: SPI connection between a master and a slave device. Image permission pending from fpga4fun.com**

Fundamentally, SPI is a serial and synchronous connection that is full-duplex (allows two-way communication). In order for communication to take place, the master device generates a clock signal and one bit of data is sent on a data line at each pulse of the clock. The data is sent serially, bit-by-bit, allowing it to be fit on a single wire without the use of a data bus. To achieve full-duplex operation, each direction of data transfer (from master to slave or from slave to master) requires its own wire. Both the master and the slave device are aware of the communication protocol, which includes bit order and length of data words to be exchanged, to allow for valid communication. In addition, the master device is the one that always initiates communication [56]. Given that the SPI protocol is synchronous and full-duplex, with each clock pulse, two bits of information are actually transmitted – one bit is sent in each direction. A depiction of SPI data transfer is shown in **Figure 6.3.5-2**, and is explained below.

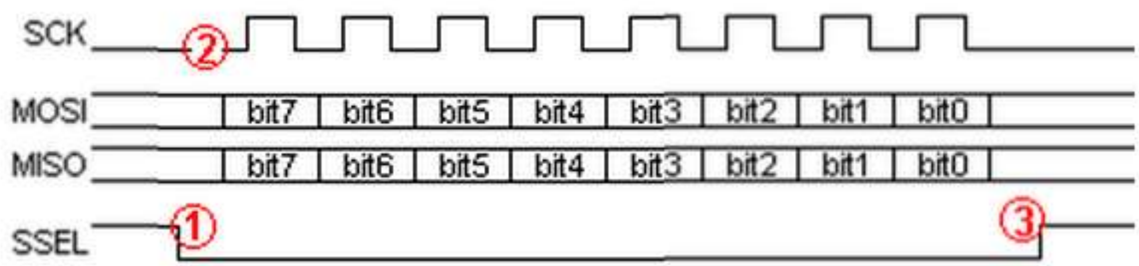


**Figure 6.3.5-2: SPI data transfer. Image permission pending from fpga4fun.com**

At point 1 in **Figure 6.3.5-2**, the master device pulls the active-low SSEL (Slave Select) line down to indicate that the communication is initiating. At point 2, the master toggles the clock signal eight times and sends eight respective bits on the data line to the slave device, MOSI (Master Out, Slave In). Concurrently, eight bits of data are received from the slave on the slave-to-master line, MISO (Master In, Slave Out). Once data transfer has commenced, the SSEL line is set back to 1. For a larger data transfer, the SSEL line could simply be held down for longer, and bits in either direction could be sent at every occurrence of the clock positive edge. The biggest advantages of this communication protocol lie in its simplicity of implementation as well as the speeds of a few megabits per second that it can achieve. The high speed capability allows this protocol to be used for uncompressed audio or compressed video data [56].

In order to implement this protocol between a microcontroller and an FPGA board, the microcontroller may be set as the master device and the FPGA the slave. At the microcontroller end, the protocol may be implemented by simply initializing the required data registers and then reading or writing data to send and receive it synchronously without intervention. At the FPGA side, since the SPI bus is much slower than typical FPGA clock speeds (a 100 MHz crystal oscillator is used on the BASYS 2 for this project), the SPI bus can be over-sampled using the FPGA clock. This has the advantage of allowing the SPI logic to run in the FPGA clock domain, which allows for easier HDL programming. This method is perfectly suited for an easy, fast and reliable implementation of a communication protocol between the microcontroller and FPGA [56].

### 6.3.6 Interfacing all UI components

A top module governs the interaction between all modules described in this section. Its block diagram, as shown in **Figure 6.3.6 - 1**, demonstrates the overall interactions between input and output pins of the BASYS 2 FPGA development board. **Figure 6.3.6 - 2** shows all the components that interface with the BASYS 2 board.

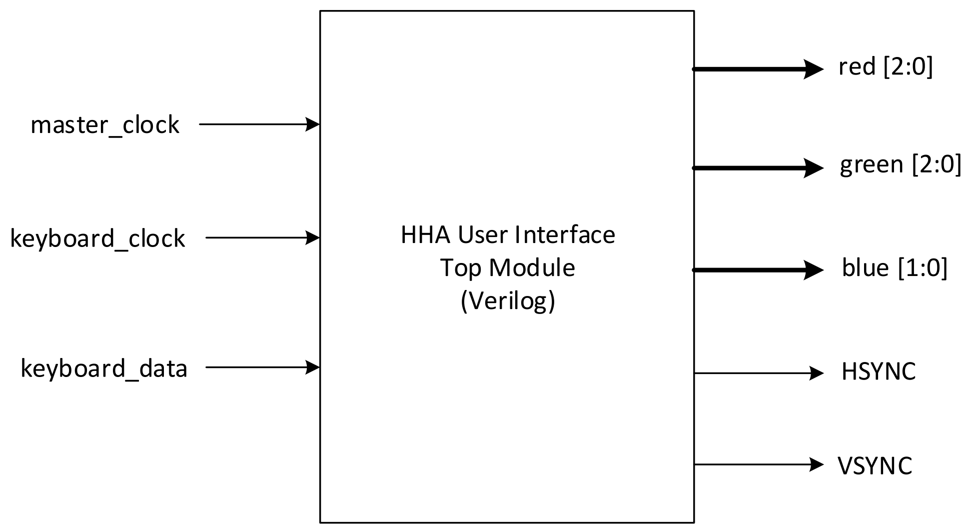


**Figure 6.3.6 - 1: Top module block diagram for the BASYS 2 implemented in Xilinx ISE 14.7**

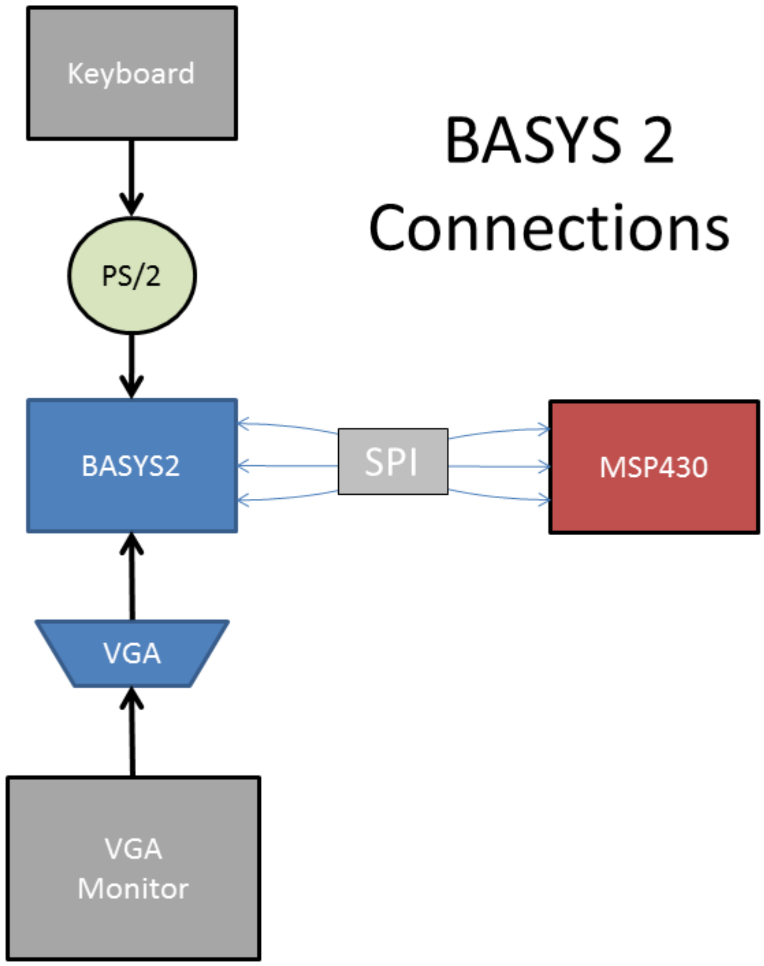


**Figure 6.3.6 - 2: Image shows all devices that interface with the BASYS 2 development board**

# 6.4 MSP430F5529

## 6.4.1 Overview

For this project, all of our group members were already experienced with programming with an MSP430 MCU. Along with this familiarity, our group members also have these devices accessible to them already. Overall though, the MSP430F5529 processor and Launchpad were chosen due to the vast amount of documentation, knowledge bases, and example code of the Launchpad used in conjunction with the CC3100 for creating Internet of Things (IoT) projects like ours. The decision to use this particular MCU came naturally and because of the fact that these devices were at our disposal, our overall bill of materials is reduced and our experience with a previously learned piece of technology grows as our knowledge expands about the capabilities of these devices.

### 6.4.2 Specifications and Features

The MSP430F5529 processor features the following specs:

- Low Supply-Voltage Range (1.8-3.6V)
- 25MHz 16-bit RISC processor
- 128KB Flash/8kB RAM
- 4 16-bit Timers
- 2 I2C, 4 SPI, and 2 UART pins available for I/O

as well as containing a 40-pin BoosterPack connector and usb port on the Launchpad for easy flashing. [57] The 40 connections on this processor appeals to our project which requires many input lines from the sensors and Basys2 board.

## 6.5 CC3100 SimpleLink Wi-Fi Booster Pack

The CC3100 is a network processor with a certified IEEE 802.11 Wi-Fi protocol pre-implemented. It provides the MSP430 Launchpad with Wi-Fi connectivity, expanding the functionality and output possibilities of the MSP430 by turning it into an Internet of Things (IoT) device.

Since both the CC3100 and MSP430F5529 are both TI products, they naturally work in conjunction with relative ease. The booster pack easily attaches to the MSP430 Launchpad through the 40 pin header connections onboard which allows for a smoother development and debugging experience. Programming for the two components together works within the same platform, whether Code Composer Studio or Energia is used.
The CC3100 features the following specs:

- Wi-Fi CERTIFIED™ Chip
- IEEE 802.11 b/g/n Radio
- 256-Bit AES Encryption Engine
- WPA2 personal and enterprise support
- Dedicated ARM MCU for the Wi-Fi network processor subsystem

and the Launchpad itself consists of a 40-pin BoosterPack connector parallel to the MSP430's connector and a micro-USB port on the Launchpad for providing power. [58] Unlike the MSP430, flashing the CC3100 requires a separate Launchpad, the CC3100 Advanced Emulation BoosterPack, which will allow updates to be flashed to the board. This will be required for the CC3100 to connect and authenticate itself with the Azure SQL server.

## 6.6 Battery Recharging System

To recharge the battery, the battery connection to the voltage regulators has to be cut off. This will ensure any charging malfunctions does not reach the patient while in use. **Figure 6.6 - 1** shows the block diagram of the battery recharging system and the flow of power. To enable and disable the charging process or to completely turn off the device, a double-pole-double-throw switch will control the flow of power. A double-pole-double-throw (DPDT) switch literally contains 2 poles for the positive and negative terminals. The switch also has 2 "throws" meaning it can power devices connected on one pair of poles or power devices connected on another pair of poles.

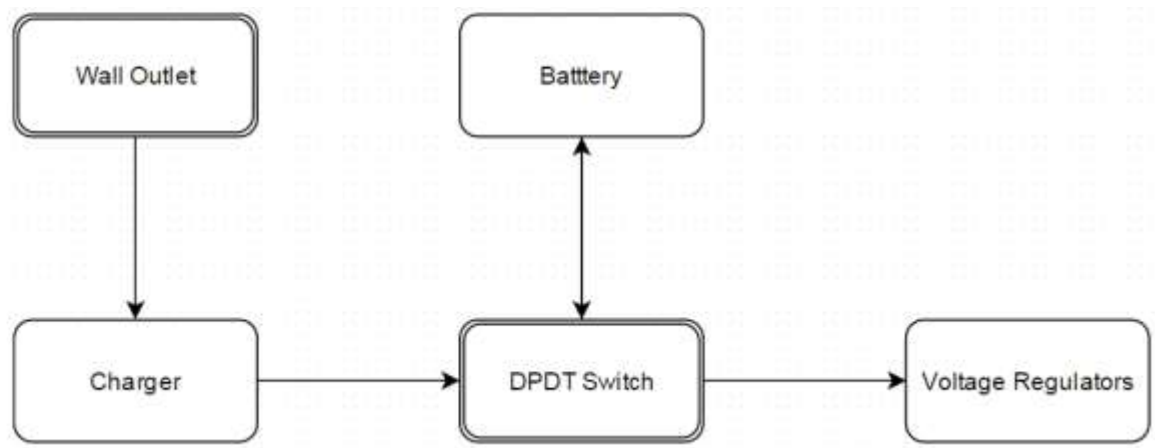


**Figure 6.6 - 1**

**Figure 6.6 - 2** shows how a DPDT switch works [59]. For the Home Healthcare Assistant, the positive and negative terminals of the battery will be connected to pins 3 and 4. The switch will then decide if those terminals are to be connected to the charger in pins 1 and 2 or if the charger should be disconnected. If disconnected, the switch can be set to neutral in which the switches are left open. Another option is to keep the charger disconnected, and connect the battery pins to pins 5 and 6 which would connect the voltage regulators to the battery. The voltage regulators will then power all the components in the HHA.

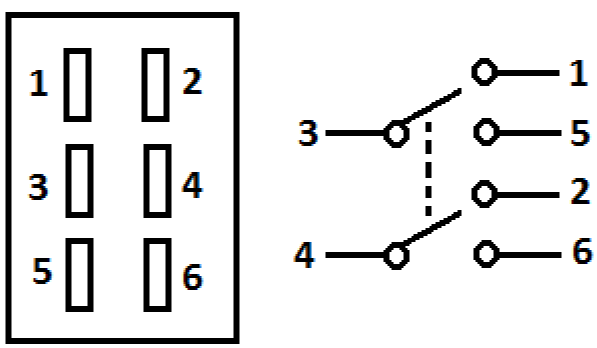


**Figure 6.6 - 2**
Permission pending from "Learning about Electronics"

From the possible battery candidates to power the device, the Tenergy Li-ion 18650 11.1V 5200mAh Rechargeable Battery Module w/ PCB protection is the most appropriate. The battery chosen is convenient for the HHA because it is focused for PCB designs and offers some protection. Compared to the other candidates, this battery is also inexpensive compared to other alternatives by containing a $57.58 price tag. The highest voltage device the HHA will have is an 7" LCD screen which requires a minimum of 9V and at least 1A to be powered. Using this battery, the voltage requirements to power the screen are met. An average amount of current must be calculated to meet the power demands of all devices in the HHA. **Table 6.6** shows an estimated max power consumption expected from the Home Healthcare Assistant. Since only one sensor will be powered at a time, the power consumption will be significantly less than if everything was powered at the same time. **Table 6.6** also assumes that the weight scale or blood pressure sensor will need 1A to work. From the combination of estimated and known power specifications of the devices, the battery should be able to power the entire device with plenty of current to spare. Using **Equation 6.6**, the battery is expected to last 2 hours before it is completely depleted and recharging is required.

**Table 6.6: Average Power Consumption of Devices**

| | Max Voltage (V) | Max Current (A) |
|---|---|---|
| **LCD Screen** | 9 - 17 | 1.0 |
| **MSP430 + Basys + Extra Components** | 5 | 1.5 |
| **Highest Power Consuming Sensor** | 5 | 1.0 |
| **Total Required** | 9 | 3.5 |
| **Battery Limits** | 11.1 | 15.0 |
| **Leftover Margin for Error** | 2.1 | 11.5 |

$$\text{Battery Life} = \frac{\text{Capacity}}{\text{Operating Current}} = \frac{5200\text{ mAh}}{3.5\text{ A}} = 1.486\text{ hours} \qquad \textbf{(Equation 6.6)}$$

The battery to be used contains Lithium-ion cells which have to be carefully recharged. Any mishandling of the battery can result in an explosion. Due to the complexity of creating a charger for high-voltage battery, time constraints, and safety precautions, a pre-built charger is bought. From the possible charger candidates, the Tenergy Smart Charger for 11.1V (3S) Li-ion/LIPO Battery Pack is the fastest and well within the safe margin for charging the battery. The charger has worldwide power support which means a person who moves from the United States to Europe, will still be able to charge their HHA device. The charger outputs 2A which is well-within the 4.4A max charge rate of the Lithium-ion battery chosen. Another perk the charger has is the status LED lights embedded in the case. Choosing a DPDT switch only requires filtering results based on voltages and currents in websites such as Mouser or Digikey. Prices between most of the results are in the $3 range; therefore the most inexpensive DPDT switch is selected. The DPDT switch chosen is TE Connectivity Alcoswitch's 2-1825138-8 switch.

## 6.7 Power Regulating System Design

The battery chosen outputs a voltage range from 7.2V to 13.05V, a range which depends on the remaining charge on the battery. Initially design, at full charge, the battery outputs at the peak value of 13.05V and then decreases over time. The battery can also supply a maximum load current of 15A. These specifications leave more than enough current overhead for the HHA subsystems to be powered comfortably with room for current spiking. The monitor used with the HHA functions with an input voltage range from 9V to 24V, and according to its specifications, it consumes 8W of power. This predicts a current draw of slightly under 1A for the screen. The BASYS 2 FPGA board functions at 5V input voltage with a current draw of about 500 mA for a dense implemented on the device and all peripherals connectors in use. In addition, the sensor circuits will work with a 5V input signal and are predicted to consume a maximum of 0.5A. The MSP430, which is the sole component powered by 3.3V, is predicted to not consume more than 0.3A. A booster pack mounted on our PCB for wireless data transmission will be connected to the 5V power supply and is 0.5A. The total consumption adds up to be 2.8A, and upon tripling this quantity to account for any possible transient current spikes, a maximum current consumption value of 8.4A. Given that the battery can offer 15A peak current, the battery choice shall lead to a robust design unaffected by large values of transient current drawn.

To provide the different levels of voltage required, the power system design shall be initiated with selection of the 5V regulator. The Webench Designer Power Architect application by Texas Instruments is an important tool that can be used for designing a power system with a given DC voltage input range that regulates the signal to produce different DC output values. Accounting for the operating conditions earlier stated, the battery was chosen to be DC source that varies between 6V and 14V input. This accounts for any unexpected dips in current and allows the design to be more robust. In order to allow our system to attain high power efficiency, the decision to incorporate switching regulators into our design was made. Although a ripple voltage is present at the output, it is restricted within the TI Webench software to 2% and provide a near-DC voltage to the regulated outputs. Compared with the inefficiency and instability of linear voltage regulators, and the signal noise that is generated at the output using Zener diode regulators, the high power efficiency and stability of switching regulators were decided to be important factors for our design that outweighed the switching regulator drawbacks of larger footprint and increased design complexity. Three regulators are chosen as shown in **Figure 6.7.1-1** that provide the required voltage and current outputs to the load. The circuit topologies and their characteristics are depicted in the figures that follow.

### 6.7.1 Implementation #1:

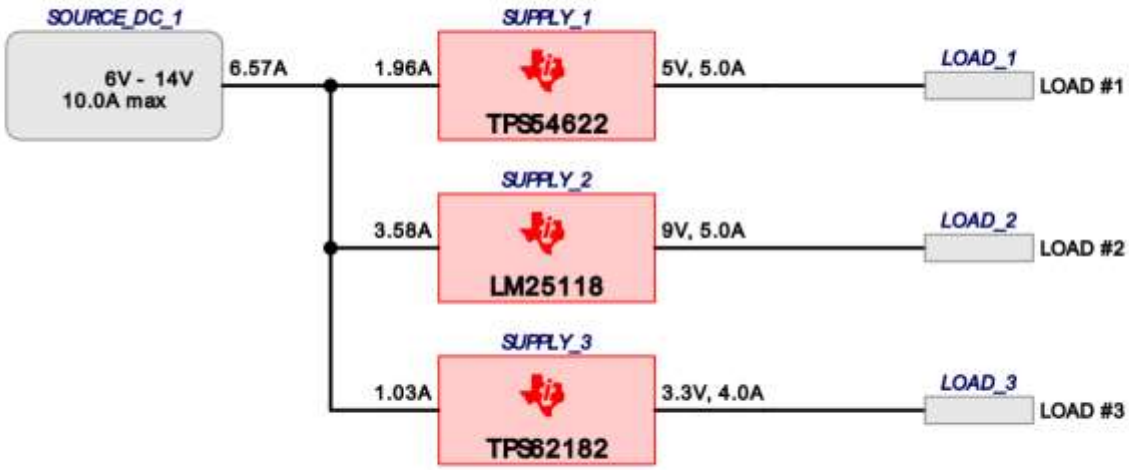


**Figure 6.7.1-1: Power supply system block diagram of Implementation #1 to regulate battery voltage to 5V, 9V and 3.3V output. System designed using TI Webench application.**

Individual power supply characteristics are listed in **Table 6.7.1**. The efficiency, footprint size and costs for all circuit components in this implementation will be used for comparison after another implementation of all regulators is generated.

**Table 6.7.1: Efficiency, footprint and cost comparison of individual regulator topologies for first power regulation system implementation**

Power Supplies

| # | Name | NSID | Description | Vout | Iout | Efficiency | Foot-print | Cost | Design | Page |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | SUPPLY_1 | TPS54622 | Switcher : 6A Synchronous Step Down SWIFT Converter with Hiccup Current Limit | 5 V | 5.0 A | 91% | 184 | $3.40 | 1 | 4 |
| 2. | SUPPLY_2 | LM25118 | Switcher : Wide Range BuckBoost controller | 9 V | 5.0 A | 89.9% | 1608 | $9.26 | 2 | 10 |
| 3. | SUPPLY_3 | TPS62182 | Switcher : 6A, Ultra-Small Solution Size, 2-Phase Step-Down Converter | 3.3 V | 4.0 A | 91.6% | 196 | $2.97 | 3 | 21 |

The 5V switching regulator circuit topology is shown in **Figure 6.7.1-2**. This is a relatively easy to implement design which requires only a buck converter to attain the desired 5V output from the variable battery voltage input. For circuit implementation, a 2% output ripple voltage was selected. This allowed for switching regulator implementations to be applicable to the project. This is a quality feature of the power supply system of the HHA project since switching regulators can output the desired voltage at very high efficiencies. As shown in **Table 6.7.1**, this particular circuit demonstrates an efficiency of 91%.

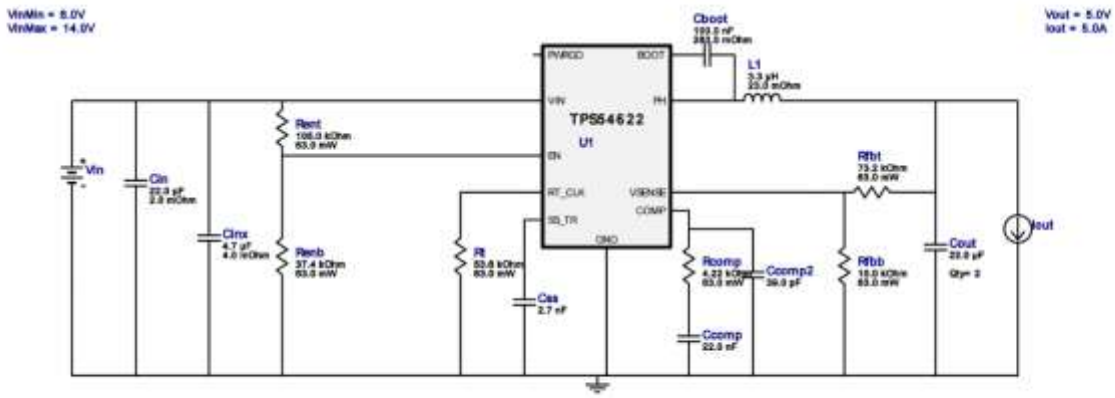


**Figure 6.7.1-2: 5V switching regulator circuit used to convert wide range of possible input battery voltage to 5V output. Maximum current supported is 5A. Circuit designed using TI Webench**

Next, the 9V regulator circuit of **Figure 6.7.1-3** is considered. Since the battery input can vary from below 9V to above 9V, the switching regulator required is a buck-boost converter. This steps down the input voltage to obtain 9V when the input is higher than the regulated output, or steps up the input voltage when it is lower than 9V. This circuit has the largest footprint in this design, at 1608 kmm2.

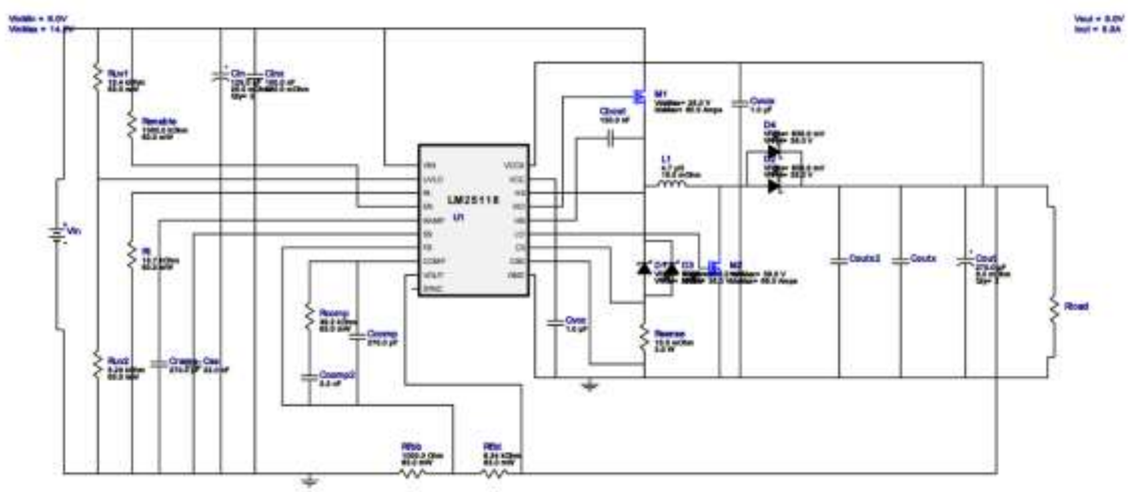


**Figure 6.7.1-3: 9V buck-boost switching regulator with 2% output ripple and 89% efficiency. Circuit designed using TI Webench**

The 3.3V switching regulator topology is shown below in **Figure 6.7.1-4**. Like the 5V switching regulator, this is a simple buck regulator with a small footprint, high efficiency and relatively simple design.

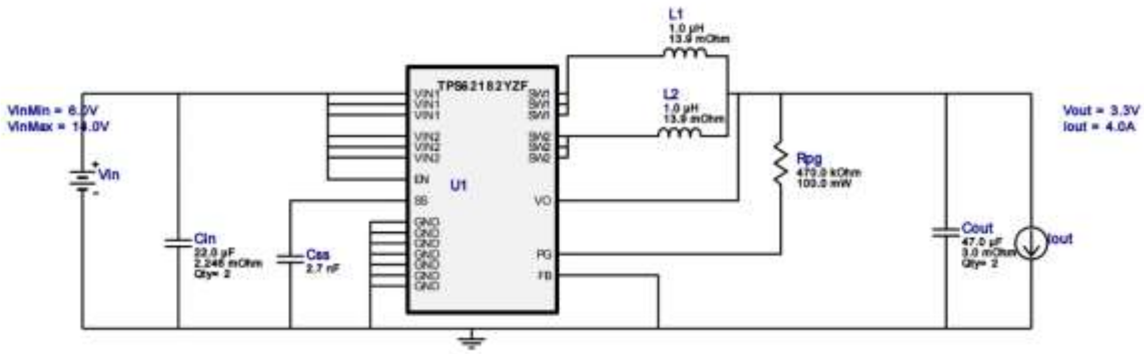


**Figure 6.7.1-4: 3.3V switching regulator topology. Circuit designed using the TI Webench application. Circuit presents the characteristics of 91% efficiency with 2% output voltage ripple.**

Given the initial design, a secondary design is generated for comparison with the first. The best of both designs – for each regulator – will be picked, where the grading criteria includes overall circuit efficiency, simplicity, and footprint size. The same parameters will be specified for both design implementations – each circuit must work with the same battery input voltage range, and produce the required output voltages with a 2% ripple at the output. Switching regulator topologies are again considered due to their efficiency compared to other regulator types discussed in Section 3.2.4.2.

## 6.7.2 Implementation #2

The system block diagram of **Figure 6.7.2-1** depicts an alternative approach to the power regulating system design. Each regulator component was chosen based on certain characteristics that set it apart from its counterpart in Implementation #1 – at least one of the following parameters was enhanced: device footprint, efficiency, BOM (Bill of Materials) cost, or visual design complexity. Implementation #2 is shown below.

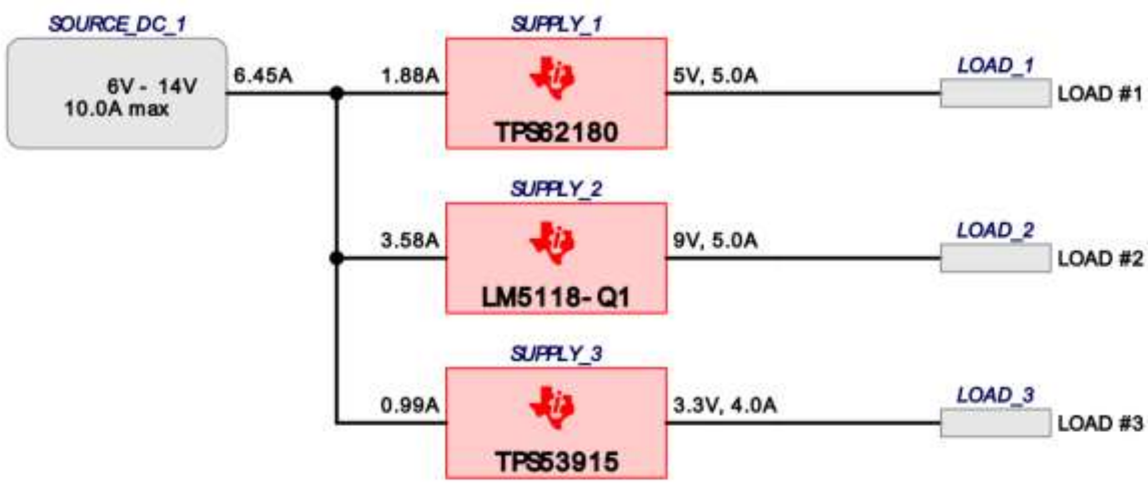


**Figure 6.7.2-1: Power supply system block diagram of Implementation #2 to regulate battery voltage to 5V, 9V and 3.3V output. System designed using TI Webench application.**

The characteristics of this implementation are shown in **Table 6.7.2**. Comparisons are made for circuit efficiency, footprint size and circuit part costs, as provided by TI Webench.

**Table 6.7.2: Efficiency, footprint and cost comparison of individual regulator topologies for second power regulation system implementation**

Power Supplies

| # | Name | NSID | Description | Vout | Iout | Efficiency | Foot-print | Cost | Design |
|---|---|---|---|---|---|---|---|---|---|
| 1. | SUPPLY_1 | TPS62180 | Switcher : 6A, Ultra-Small Solution Size, 2-Phase Step-Down Converter | 5 V | 5.0 A | 94.9% | 129 | $3.21 | 4 |
| 2. | SUPPLY_2 | LM5118-Q1 | Switcher : Wide Range BuckBoost controller | 9 V | 5.0 A | 89.9% | 1608 | $10.16 | 5 |
| 3. | SUPPLY_3 | TPS53915 | Switcher : PMBus High-Performance 12-A Single Synchronous Buck Converter | 3.3 V | 4.0 A | 94.9% | 223 | $4.82 | 6 |

In comparison with Implementation #1, the 5V output switching regulator shown is 3.9% more efficient, has a smaller footprint and costs less. The 9V supply circuit has the same PCB footprint and efficiency as the design chosen in Implementation #1, yet it costs $0.90 more. The 3.3V regulator of Implementation #2 is 3.3% more efficient, has a larger footprint, and costs $1.85 more. The topologies of the switching regulator circuits used in Implementation #2 are presented in the following figures.

The 5V switching regulator design topology is shown in **Figure 6.7.2-2**. This design bodes a similar level of design complexity to its counterpart circuit used in Implementation #1. However, due to its lower cost and higher efficiency, this circuit of Implementation #2 is chosen to be in the final implementation for the power system regulation design.

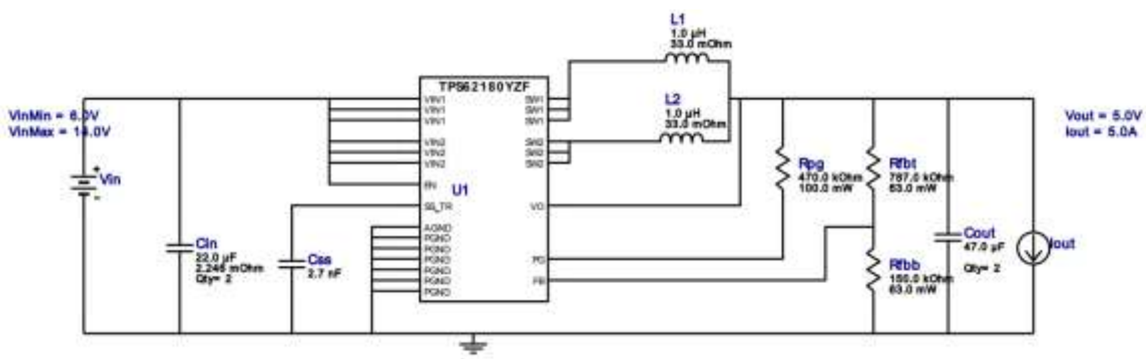


**Figure 6.7.2-2: 5V switching regulator circuit chosen in Implementation #2. Design generated using the TI Webench application**

The 9V switching regulator topology of Implementation #2 is shown in **Figure 6.7.2-3**. Performance characteristics for this design were identical to the circuit of Implementation #1, yet this one costs more without an observable advantage of any reduced design complexity. For these reasons, the 9V switching regulator circuit of Implementation #1 was chosen to be a component of the final power regulating system design implementation.

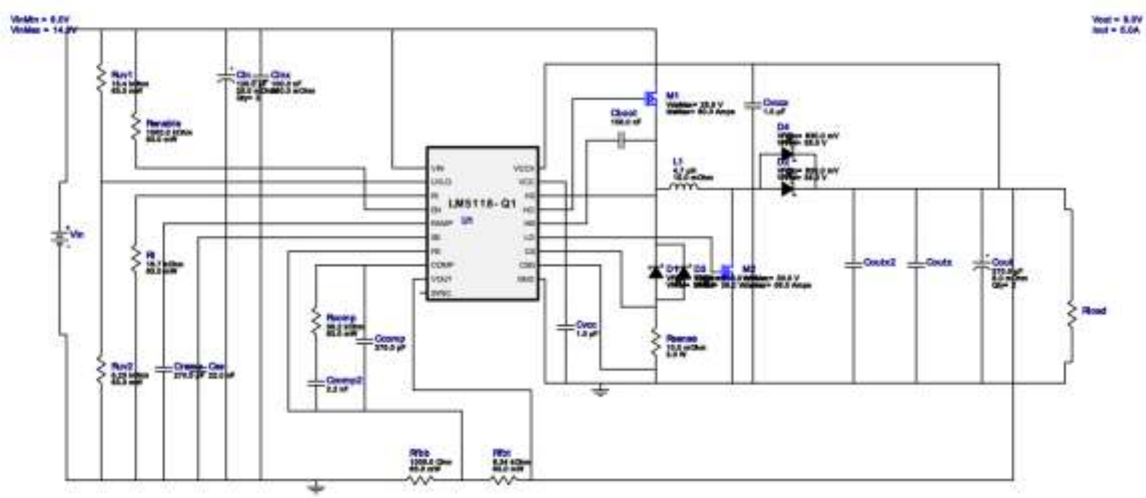


**Figure 6.7.2-3: 9V switching regulator circuit topology for device chosen in Implementation #2. Design generated using the TI Webench application**

Lastly, an alternative design of the 3.3V switching regulator circuit is generated for Implementation #2 and is shown below in **Figure 6.7.2-4**. This particular circuit costs more, yields higher power efficiency, but also has a larger footprint. On the downside, it also demonstrates a higher degree of complexity than its counterpart design in Implementation #1. Due to its increased complexity, footprint and added cost, the circuit of Implementation #1 is chosen to be incorporated into our final design despite its slightly lower power efficiency. The HHA power regulation system requirement of 85% is met by the design shown in Implementation #1.

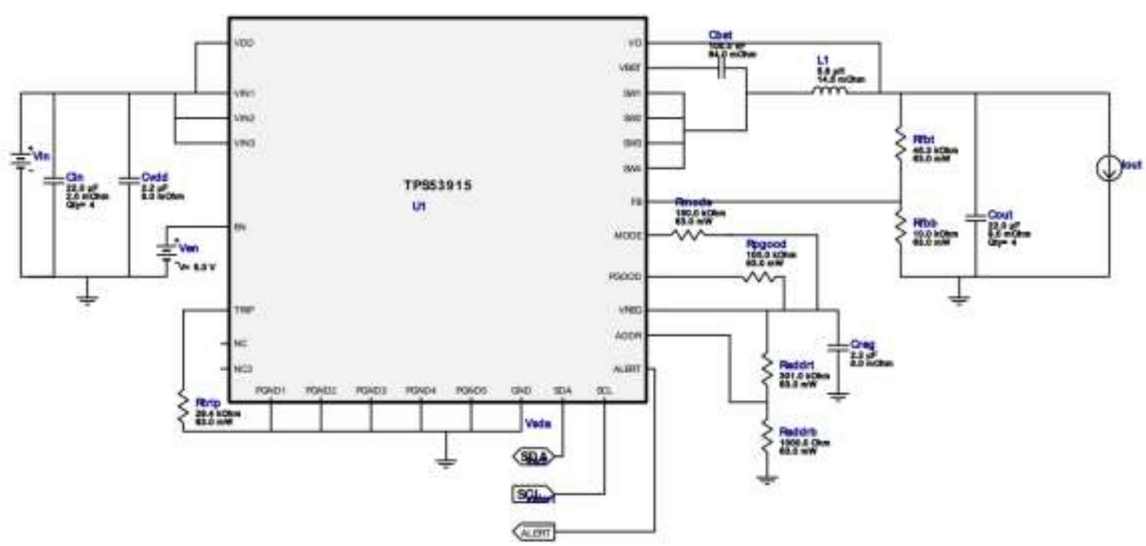


**Figure 6.7.2-4: 3.3V switching regulator schematic for design chosen in Implementation #2. Design generated using the TI Webench application**

### 6.7.3 Final power regulation system design

The final design incorporates the switching regulators chosen from Implementations #1 and #2, as discussed in the preceding section. The list of regulators using in this design are reiterated in **Table 6.7.3-1**. This stage attains the power regulation system design requirements.

**Table 6.7.3-1: Efficiency, footprint and cost comparison of individual regulator topologies for final power regulation system implementation**

Power Supplies

| # | Name | NSID | Description | Vout | Iout | Efficiency | Foot-print | Cost | Design |
|---|---|---|---|---|---|---|---|---|---|
| 1. | SUPPLY_1 | TPS62180 | Switcher : 6A, Ultra-Small Solution Size, 2-Phase Step-Down Converter | 5 V | 5.0 A | 94.9% | 129 | $3.21 | 7 |
| 2. | SUPPLY_2 | LM25118 | Switcher : Wide Range BuckBoost controller | 9 V | 5.0 A | 89.9% | 1608 | $9.26 | 8 |
| 3. | SUPPLY_3 | TPS62182 | Switcher : 6A, Ultra-Small Solution Size, 2-Phase Step-Down Converter | 3.3 V | 4.0 A | 91.6% | 196 | $2.97 | 9 |

The overall design block diagram is shown in **Figure 6.7.3** below.

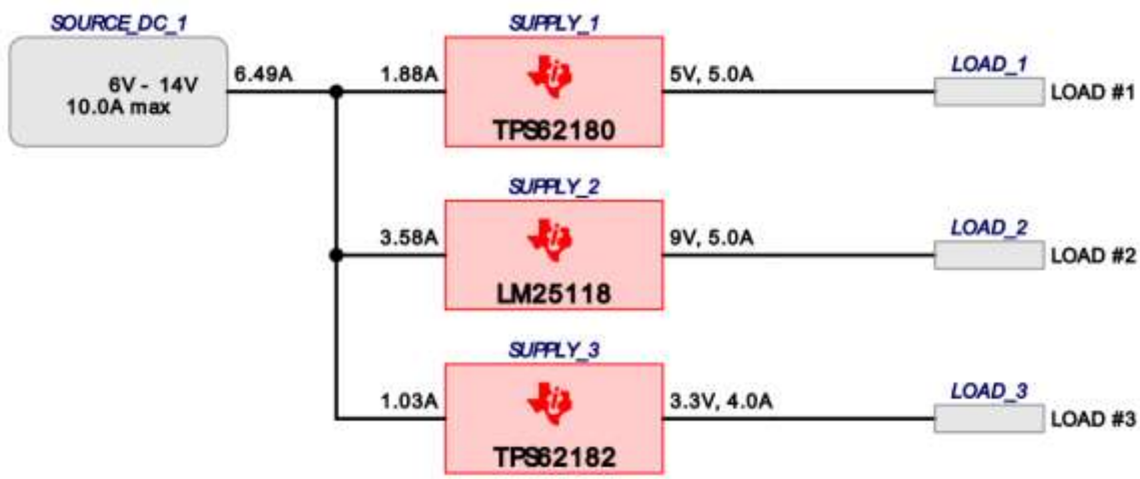


**Figure 6.7.3: System block diagram of final power regulation system. Diagram generated using TI Webench application**

This system meets the design specifications of achieving at least 85% efficiency, has a cost without our allocated budget for the design of this system, and meets the current load requirements for the HHA subsystems. Additionally, due to its high efficiency, heat dissipation is minimized and the device should not be unpleasantly warm in close proximity to the HHA user.

The complete list of parts involved in realizing the system of **Figure 6.7.3** is shown in **Table 6.3.2-2**. The total Bill of Materials (BOM) cost amounts to $15.44.

**Table 6.7.3-2: Parts and Bill of Materials (BOM) document for final power regulation system design. Table generated using TI Webench**

**Electrical Procurement BOM**

| Manufacturer | Part Number | Description | Quantity | Budgetary Price | Footprint ($mm^2$) |
|---|---|---|---|---|---|
| AVX | 08053C104KAT2A | 0805 | 1 | $0.01 | 7 |
| Panasonic | 16SVPG270M | CAPSMT_62_C10 | 2 | $0.70 | 74 |
| Panasonic | 20SVPF120M | CAPSMT_62_F61 | 2 | $0.43 | 74 |
| TDK | C2012C0G1H271J | 0805 | 2 | $0.01 | 14 |
| TDK | C3216JB1E226M | 1206 | 4 | $0.32 | 22 |
| Yageo America | CC0805KRX7R9BB222 | 0805 | 1 | $0.01 | 7 |
| Yageo America | CC0805KRX7R9BB223 | 0805 | 1 | $0.01 | 7 |
| Bourns | CRA2512-FZ-R010ELF | 2512 | 1 | $0.17 | 43 |
| Vishay-Dale | CRCW0402150KFKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW040215K4FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW040218K7FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW04021K00FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW04021M00FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW040239K2FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW04025K23FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW04026K34FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW0402787KFKED | 0402 | 1 | $0.01 | 3 |
| Texas Instruments | CSD16327Q3 | TRANS_NexFET_Q3 | 1 | $0.44 | 19 |
| Texas Instruments | CSD17304Q3 | TRANS_NexFET_Q3 | 1 | $0.36 | 19 |
| MuRata | GRM155R61A105KE15D | 0402 | 2 | $0.01 | 6 |
| MuRata | GRM188R71E272KA01D | 0603 | 2 | $0.01 | 9 |
| MuRata | GRM21BR71E104KA01L | 0805 | 1 | $0.01 | 7 |
| MuRata | GRM31CR60J476ME19L | 1206 | 2 | $0.12 | 11 |
| MuRata | GRM31CR61A476KE15L | 1206 | 2 | $0.21 | 11 |
| Texas Instruments | LM25118MH/NOPB | MXA20A | 1 | $2.40 | 71 |
| Vishay-Semiconductor | MBRB1635PBF | DDPAK | 4 | $0.71 | 839 |
| Susumu Co Ltd | RR1220P-474-D | 0805 | 2 | $0.01 | 14 |
| Bourns | SDR0403-1R0ML | SDR0403 | 2 | $0.18 | 55 |
| Bourns | SRN6045-1R0Y | SRN6045 | 2 | $0.16 | 128 |
| Bourns | SRP1250-4R7M | SRP1250 | 1 | $0.64 | 253 |
| Texas Instruments | TPS62180YZFR | YZF0024AMAM | 1 | $1.75 | 13 |
| Texas Instruments | TPS62182YZFR | YZF0024AMAM | 1 | $1.75 | 13 |
| **Total** | | | **48** | **$15.44** | **1,742** |

# 7.0 Project Prototype Construction and Coding

## 7.1 Parts Acquisition and BOM

### 7.1.1 Parts Acquisition

Before any prototyping or coding can be done in the HHA, the parts need to be acquired. Most common electrical components such as SMD resistors, operational amplifiers, LEDs, and bipolar junction transistors are acquired through main distributors such as DigiKey and Mouser. Even more common components such as through-hole resistors are found using sources such as eBay. Difficult and/or expensive devices needed in the HHA such as the LCD screen, batteries, and charger, are found through other sources. LCD screen is found navigating through eBay and Amazon while the batteries and its chargers are found surfing through All-Battery.com. Some parts have a predetermined supplier because of special requirements such as the NIR and red LED lights.

### 7.1.2 Bill of Materials (BOM)

Before buying any components, a list of prices for all components is created to avoid spending large amounts of money for equipment that are not needed at the beginning of the prototyping phase. Another useful advantage of having a list of components from different suppliers, is that some components can be found at a cheaper price than their competitors. Supplies can also be divided into separate lists to reduce cost. **Table 7.1.2** shows the prices of the components needed for the HHA along with the suppliers shipping costs. The number of capacitors and resistors are estimated based on circuit design and possible soldering mistakes while mastering how to solder. Parts that are already owned is from previous experiments or personal use. These parts reduce the total overall cost in creating the Home Healthcare Assistant.

**Table 7.1.2: Bill of Materials List (BOM)**

| Component / Part Number | Supplier / Distributor Price | | | Quantity | Already Owned? |
|---|---|---|---|---|---|
| | Digikey | Mouser | Other | | |
| CC3100 Booster | $20.39 | $20.39 | $19.99 | 1 | Yes |
| MSP430F5529 | $8.05 | $8.05 | $8.06 (Free Sample avail.) | 1 | Launchpad |
| Basys 2 Board | $89.00 | $89.00 | $69.00 | 1 | Yes |
| ADG884BRMZ | $2.86 | $2.70 | N/A | 3 | No |
| LM393NG | $0.45 | $0.46 | N/A | 1 | No |
| MC33072APG | $1.12 | $1.12 | N/A | 1 | No |
| MC33078P | $0.88 | $0.88 | $0.77 | 2 | No |
| 2N2222 | $0.85 | $1.79 | N/A | 4 | No |
| 7" LCD Screen | N/A | N/A | $46.00 | 1 | No |
| DPDT Switch | $2.83 | $2.83 | N/A | 1 | No |
| Battery | N/A | N/A | $50.39 | 1 | No |
| Battery Charger | N/A | N/A | $16.68 | 1 | No |
| Buzzer | N/A | N/A | $3.99 | 1 | Yes |
| Red LED | N/A | N/A | $0.49 | 2 | Yes |
| Yellow LED | $0.10 | $0.10 | $0.49 | 1 | No |
| Green LED | $0.19 | $0.19 | $0.49 | 4 | No |
| NIR LED | N/A | N/A | $0.60 | 1 | Yes |
| TSL14S-LF | $1.48 | $1.54 | N/A | 1 | Yes |
| LMT87LP | $1.00 | $1.00 | $0.98 | 1 | Yes |
| All Regulators Combined | N/A | N/A | $15.44 | 1 | No |
| PCB | N/A | N/A | $66.00 | 3 | No |
| Weight Scale | N/A | N/A | $32.18 | 1 | No |
| Wrist Blood Pressure Monitor | N/A | N/A | $26.99 | 1 | No |
| Total Price of Parts Not Owned | $403.59 | | | | |

## 7.2 Proof of Concept

### 7.2.1 Database Management

To begin with, access the database is limited to the administrator(s). The contents of the database must be obscured from everyone, even the administrators. In order to achieve this, the database must apply a cryptographic solution to the sensitive data. Upon successfully transmitting in the questionnaire and sensor data to the host server's database, the information received will be added in a systematic manner. The data itself will come in the form of a bit stream from the MSP430 through the CC3100 chip. The first few bits will consist of Boolean answers to the questionnaire. Afterwards, segments of bits will be read in as values taken in during the vitals reading. The length of the bits used will vary per vital reading, as some vitals' values are more complex than others.

## 7.3 Programming Workload Agreement

### 7.3.1 Alex's Responsibilities

While Zishan works on the frontend, Alex will be in charge programming the backend and managing the database and off-site functions. Alex's total responsibilities can be outlined as such:

- Instruct BASYS2 board when to begin prompting patient with the questionnaire
    - Set up MSP430 for communication with BASYS2 board
- Program MSP430 to instruct sensors to begin taking vitals
    - Additionally, prepare the data that is read into a packed format that the database can manipulate.
- Communicate MSP430 with the database through the CC3100 booster
- Design a database for the questionnaire answers and vitals per patient
- Design a desktop application that can perform analytical queries on the database

### 7.3.2 Zishan's responsibilities

Group 8 team member Syed Zishan Zaidi's responsibilities included programming the BASYS 2 FPGA board using Verilog HDL to generate a UI to display pertinent data to a patient on a VGA monitor as part of the HHA examination. In order to accomplish this, various modules were written including one to generate a basic VGA signal that displayed a static background color, a memory module to store alphanumeric characters for display on the monitor and screen modules to showcase different sequences of text. A PS/2 communication module was also written to receive user input for responses to the examination questions. An SPI communication module was written to send the user-acquired data to a microcontroller.

Research and comparisons between different approaches to UI implementation were also made, based on microcontroller techniques, VGA driver boards and using other FPGA boards. The VGA standard protocol was thoroughly understood and dissected in order to implement the critical timing requirements for VGA signal generation using the BASYS 2. The PS/2 standard protocol was also analyzed to set up user communication to the HHA device. In addition, the schematic foundation was laid out for the final implementation of the complete UI using Xilinx ISE Design Suite 14.7.

Zishan also discussed what different types of regulators bring to power regulation system design, and designed a power regulation system for the HHA using the Texas Instruments Webench application. This system is set to be powered by a battery with a variable input voltage between 7.2V to 13.05V, while the output is different levels of constant DC voltage with a small ripple of 2% and a high efficiency of above 85%.

## 7.4 Electrical Workload Agreement

### 7.4.1 Nicholas's Responsibilities

Nick's, short for Nicholas, responsibilities were to create a power system that meets the demands of the Home Healthcare Assistant. Creating the power system entails researching the most convenient way to obtain a battery, a charger compatible with the battery, voltage regulators to power all other components, and some type of switch to enable or disable different parts of the power system. Nicholas was also responsible for keeping track of power consumption while creating the power system. Another task that fell under Nick's domain is finding cost-effective weight scale and blood pressure sensor modules to be hacked. These hacked components are to transfer data to the MSP430 which is eventually transmitted to the database. The last responsibilities Nicholas had is keeping track of the budget, and researching the effects of blood pressure.

Due to lack of research and dedication, a great amount of Nicholas's work was distributed to other members of the group. Zishan took on the task of designing and comparing voltage regulator designs which will safely control power distribution across the HHA. Jonathan took on the role of finding viable candidates for the HHA weight scale and blood pressure sensor. Moreover, Jonathan took the task of finding ways to hack or insert the values shown in the weight scale and blood pressure sensor into the MCU. Other tasks given to Jonathan were to design the power supply system, excluding the voltage regulators, keeping track of power consumption, and keeping track of the budget.

### 7.4.2 Jonathan's Responsibilities

Jonathan's main responsibilities lays in creating the electrical circuits and diagrams for the body temperature sensing system and pulse oximeter system to meet the HHA requirements and specifications. He will also have to find the correct RoHS compliant materials to protect the user from the sensors. Jonathan will also be involved with the other group members in the communication between the sensors and the MCU by providing accurate information that will be implemented in the coding. Supervising current, voltage, and power flow across the circuit to prevent future problems will be part of Jonathan's responsibilities. Another responsibility includes helping in regulating the battery supply voltage for efficient use in the entire device, if needed. Jonathan will help choose a battery and create a battery charging system for the HHA. Moreover, Jonathan will help in soldering electrical devices to the PCB and work in the PCB design. Jonathan's responsibilities revolves around his intellectual strength of electrical hardware design and implementation across the Home Healthcare Assistant project.

# 8.0 Project Prototype Testing

## 8.1 BASYS 2 FPGA Development Board

### 8.1.1 Initializing the VGA display

In order to verify the efficacy of the basic VGA driver written in Verilog for the BASYS 2, this primary test checks whether the required signal timings have been satisfied and the correct data is successfully being sent to the monitor. This is achieved when a constant color is able to be displayed on the monitor using the BASYS 2 board as the display driver. To accomplish this goal, a Verilog program was written that output the same pixel data to all pixels in a 640x480 resolution screen. For display of a static blue background color as the test condition, the RGB signals of the BASYS 2 VGA output port received values of 3’b000, 3’b000 and 2’b00 respectively. The signals are according to the RGB-332 format outlined in Section 4.1.4, which is the standard used by the HD-DB15 connector of the BASYS 2. The test is performed on a 21” computer monitor present at a team member’s residence. A necessary step entails adjusting the monitor settings to fit the data sent to its full screen capacity – which occasionally does not occur on its own – and which leaves dark vertical bands on the sides of the widescreen monitor. The test is concluded when a constant blue background is visible throughout the display region of the monitor.

### 8.1.2 Displaying a single character

A memory module is added to the core program that generates a VGA signal. This memory module contains the 8x8 pixel font bitmap for a single character of the alphabet, the letter ‘A’. The objective here is to display this character in the top-left 8x8 pixel region of the 640x480 resolution screen. In order to accomplish this, the VGA driver functions normally to display the static blue background of Section 8.1.1. Another clause is then written in the Verilog code which seeks out the top-left 8x8 pixels of the active video region. Once it is determined that the pixel data for that region is being written, the respective bitmap pixel values are pulled from the memory using their addressable locations. The 8x8 bitmap values are either 0 or 1, which indicates whether that pixel is off or on. For an on pixel in the 8x8 active region, the VGA driver’s already set RGB pixel values for displaying a blue color are overwritten with the values of 3’b111 for Red, 3’b111 for Green, and 2’b11 for Blue respectively, in accordance with the RGB-332 format. This generates a white pixel as the additive color model for displaying images on a monitor screen indicates that RGB signals of equal intensity produce a white color when they are added together. All respective on pixels in the active 8x8 region are thus set to display white pixels by overwriting the blue pixel values initially assigned by the VGA driver. When successful, the character ‘A’ is displayed in the top-left 8x8 pixel region while the remainder of the screen remains blue. The test concludes when this result is obtained and visually verified.

### 8.1.3 Displaying a sentence

The memory module is now heavily modified to include all alphanumeric characters – namely, the 8x8 font bitmaps for digits 0-9, all uppercase characters of the alphabet, and the space bar were all arranged in ascending order. A bit file for the program is generated to ensure that the memory module does not require the use of too many LUTs (Look-Up Tables) on the BASYS 2 FPGA chip, which would either severely limit the upcoming steps or be impossible on this board. **Figure 8.1.3** shows the result for the test run in Xilinx ISE 14.7: it was found that only 2% of the total LUTs and 4% of the total slices were occupied after creating the final memory module. To see if a more sophisticated approach to display images was possible using the BASYS 2, an attempt was also made to store the pixel data for only a 256x256 resolution image in the memory. That image utilized 800% of the total LUTs available, so that design was found to be impossible to implement on the BASYS 2 board.

| Device Utilization Summary | | | |
|---|---|---|---|
| Logic Utilization | Used | Available | Utilization |
| Number of Slice Flip Flops | 35 | 1,920 | 1% |
| Number of 4 input LUTs | 50 | 1,920 | 2% |
| Number of occupied Slices | 42 | 960 | 4% |
| Number of Slices containing only related logic | 42 | 42 | 100% |
| Number of Slices containing unrelated logic | 0 | 42 | 0% |
| Total Number of 4 input LUTs | 74 | 1,920 | 3% |
| Number used as logic | 50 | | |
| Number used as a route-thru | 24 | | |
| Number of bonded IOBs | 13 | 83 | 15% |
| Number of RAMB16s | 1 | 4 | 25% |
| Number of BUFGMUXs | 2 | 24 | 8% |
| Average Fanout of Non-Clock Nets | 2.61 | | |

**Figure 8.1.3: On-board logic utilization on the BASYS 2 FPGA chip after the final memory module used with the HHA was instantiated**

Once the complete memory module is written, additional code is added to display a certain sentence on the monitor. This works much like the code for displaying a single character, except that the location for each active 8x8 pixel region is incremented by 8 pixels horizontally. This allows for the next character to be displayed on the same line. Following this progression, an entire sentence can be displayed on the active region for the first row of 8x8 pixels. The test concludes when a successful programming file is generated that allowed the BASYS 2 to display a predetermined sequence of characters in the top row of 8x8 pixels, thereby outputting a sentence on the VGA monitor.

### 8.1.4 Displaying a screen of sentences

The concept for displaying a sentence is slightly modified to show more than one sentence in the 640x480 pixel active video region of the VGA monitor. Now, not only are the 8x8 pixel regions horizontally incremented to display characters next to each other, they are also vertically incremented to show more than one sentence as well as the Yes and No options that the user is allowed to pick from. Cursors are also added that will highlight either of the Yes or No options. The test concludes when an entire screen of desired sentences is displayed on the monitor on top of a static blue background color with one of the Yes or No options highlighted, a preset for which is assigned within the Verilog code.

### 8.1.5 Displaying several screens

In order to display more than one screen, an additional module is written that overwrites the VGA driver's static background color pixel data. The new module functions identically to the module described in Section 8.1.4, except it is used to show new sentences and user options, thus it is a new screen. A select input is added to the program and assigned to a push button available on the BASYS 2 FPGA board. Pressing the button each time toggles between the two screens now programmed on the FPGA board. The test concludes when a single screen of text is displayed on the monitor on top of a static background color, and a press of the push button moves on to the next screen of data. This test procedure can be taken further to verify that several screens of data can be stored and displayed, as required by the HHA.

### 8.1.6 Receiving input

A PS/2 keyboard communication module is written in Xilinx ISE 14.7. This receives user input from a keypad and displays the entered numeric character at a predetermined location on the monitor. The steps taken to achieve this result are elaborated upon in Section 6.3.4. The test concludes when any sequence of digits from 0-9 are displayed as entered by the user, in the top row of 8x8 pixels.

### 8.1.7 Using the input

Now the PS/2 module works in conjunction with the predetermined sequence of screen modules. For the first screen shown, user input is obtained. This input is stored in a register and is ready to be transmitted to the microcontroller. For the purpose of testing the validity of the data received, a keyboard register value is assigned a value of 1 for a user-entered Yes response and 0 for a No response and the output is set to an LED on the BASYS 2 FPGA board. The test concludes when, for a certain displayed screen, the user enters any response and the output LED reflects the result.

The secondary test case is for questions that require a numeric response from the user, such as entry of their weight. This test case is identical to 8.1.6, where the user entered data is echoed back to the user via the monitor. The test concludes when a three-digit sequence representing the user's current weight is entered on the keypad and is shown back to the user on the monitor.

### 8.1.8 Communication with the microcontroller

The protocol used for communication between the BASYS 2 board and the microcontroller was the master-slave SPI (Serial Peripheral Interface) connection. This requires that a host device toggles the clock and sends data to a selected slave chip, synchronously. The slave can also send data back to the master, but only when the master is not toggling the clock. This method of communication works very much like the PS/2 interface for communication with a keyboard. To test the implementation of an SPI connection, the BASYS 2 is set as the master device and the microcontroller is set as the slave. Once a particular screen is displayed, the BASYS 2 sends an associated binary value of that screen to the microcontroller followed by the user entry for the answer to that screen's Yes/ No question, all in one bit stream. For an implementation with four possible screens, only three bits of data need to be transmitted to the microcontroller to signify the question as well as its response – the two MSBs (Most Significant Bits) can represent the screen number while the LSB (Least Significant Bit) holds the user's answer to the question. The microcontroller assigns three LEDs values based on the data transmitted. The test concludes when the LED values reflect the data sent by the BASYS 2 board to the microcontroller.

### 8.1.9 UI end screen

After the complete sequence of screens has been exhausted and user data for all responses has been sent to the microcontroller, the final step is to complete the HHA examination. This shows an end screen where the user can press one button on the keypad to initiate a new examination. The other option for the user is to turn off the HHA with a mechanical switch. To test that this step is working, a complete examination is ran through by the user. Once all data has been acquired, the end screen is displayed. This step concludes the test procedures for the BASYS 2 implementation of the UI and communication between user and the BASYS 2 and between the BASYS 2 and the microcontroller.

## 8.2 CC3100 Booster for MSP430

### 8.2.1 - Description of the Test Environment

The CC3100 BoosterPack is entirely reliant on the MSP430 infrastructure for both being powered on and receiving instructions to execute on its unique chip. For this reason, the CC3100 must always be attached via the pins connected via the I/O pins on the MSP430 processor, to be able to run any sort of task. The CC3100 will be preconfigured to be connected to a local Wi-Fi network and have the proper authentication steps implemented to connecting to that network. A test program will be pre-flashed onto the MSP430 that will prioritize that the CC3100 connect to the network.
For the sake of simplicity and to save time, only one sensor will be connected to the main microcontroller. Once the MSP430 receives power, the CC3100 can begin logging into both the Wi-Fi and the databases —the Microsoft Azure and Plot.ly databases— to prepare them for the incoming live readings. Eventually, the MSP430 will power on the

sensor chosen for this testing environment and sensor data should begin to stream on Plot.ly and be written into the Azure database.

### 8.2.2 - Stopping Criteria

The HHA as a whole system is expected to function at all times. Therefore, it would be insufficient to stop observing the testing done on the CC3100 after it successfully connects to the Wi-Fi network and performs a successful write to the database. In order to fully confide in the reliability that the CC3100 provides, or is supposed to provide, a long term test case must be performed. The CC3100 should be powered on and transmitting data for hours, if not days, on end to verify that it can perform its given task once the entire project is complete and contains a set schedule for obtaining readings and sending them to the remote database.

## 8.3 MSP430 Main Controller

### 8.3.1 - Description of the Test Environment

The MSP430 will be pre-programmed to run a diagnostic test for the different components attached to it.

### 8.3.2 - FPGA Interfacing Test Procedure

The MSP430 instructs the FPGA when to advance the screen it is currently displaying. The FPGA, in turn, sends a series of bits to the MPS430 representing the answers to the questionnaire questions. In order to test the interfacing of the FPGA and MSP430, the BASYS2 FPGA board will need to have the VGA monitor and keyboard interfaced into its board first. It is necessary that the BASYS2 board have all the final equipment attached to it during the test because we need to be ensured that the BASYS2 board has enough power to interface with everything, along with the MSP430 and to also ensure that there are enough working connections on the BASYS2 or MSP430 board. Additionally, the MSP430 must also have the CC3100 BoosterPack attached for the same preventative reasons.

Once these prerequisites have been met, testing can begin. In a successful test, the BASYS2 board will display the questionnaire and progress forward with the next question once it it given the go signal from the MSP430. If the the VGA monitor displays questions immediately or does not progress at all, then it is not properly communicating with the MSP430. After failing a test case, debugging to find where the problem lies would involve paying attention to which board responded. Possible solutions could involve using different pins for interfacing or providing more power to the MSP430.

### 8.3.3 - Host Computer Wi-Fi Interfacing Test Procedure

Wi-Fi interfacing will begin with the setup of the CC3100 by obtaining the connection credentials for the Wi-Fi network. Next, a CC3100 Emulator booster pack will be needed to flash the CC3100 chip with a Microsoft Azure driver for MSP430. This will allow it to connect to an Azure SQL server.
Once the CC3100 has the driver installed, the server's IP address and login credentials are entered the azure login settings where, hopefully, the MCU will connect with the database. Since this interface is one-way, the only testing to be done is on the MSP430 and CC3100 combo. The pair can send either a real vital reading or hard code a few values to fill in the database in a fashion that the server is prepared to expect. A failed test will be indicated by a lack of updated values in the database.

### 8.3.4 - Sensor Input Test Procedure

For every sensor, there are different types of data that the microcontroller can be expected to receive. Therefore, each sensor's test procedure will be the same, however the expected output must be observed before judging whether or not the test case is successful or not. A successful test will result in that sensor's reading being added to the database. If the sensor does not power on, tests would have to be made to see if the MSP430 is delivering a voltage to the sensor to power it on or if there is a problem unrelated to the sensor being tested.

## 8.4 Sensors

### 8.4.1 Thermometer Test

In the testing of the HHA thermometer, the most important step is confirming the temperature probe is accurate. To ensure the LMT87 sensor inside the probe is accurate, a multimeter will be connected to the output of the sensor and the sensor will go through a set of trials in which the LMT87 voltage-to-temperature equations will be used. These trials will use two randomly chosen thermometers bought online in addition to the HHA thermometer. The thermometers will be placed right above boiling water because of its known boiling temperature of 100°C. Recordings will be taken to verify the accuracy of the LMT87. Another test will be using an ice bath where the expected temperature is 0°C on all thermometers. After concluding that the probe is within the requirements and specifications in terms of accuracy, a set of phases will be used in building the body temperature sensing schematic.

The HHA thermometer schematic uses through-hole devices to conveniently build the circuit on a breadboard. Testing the thermometer will be done in several phases which will also give ample time for other group members to work in their part of the project and have the required parts ready when a certain phase arrives. The first stage is the building of the thermometer schematic with the exclusion of status LEDs and the op-amps that drive them. At room temperature, the comparator that determines hypothermia should output a voltage greater than 2V. The bare sensor can be positioned hovering a hot plate or boiling water to verify that the other comparator also outputs a voltage greater than 2V signifying the patient has a fever.

For the second phase of the thermometer test, the LED driving op-amps and the status LEDs will be added to the circuit design. The same procedure of using room temperature and a hotplate will be applied to ensure precise results are being received. Moreover, phase two will still have a multimeter checking the outputs of the comparators to ensure there is no changes in the output voltage which will eventually be fed to the MCU. The third phase will need the switching IC to be soldered onto a PCB and tested using a microcontroller to enable and disable the thermometer circuitry. The next phase is connecting the battery, voltage regulator, switching IC, and thermometer circuit before soldering into the printed board. Phase 5 will consider sing surface mount equivalent of several of the chips will also be discussed before ordering and soldering the parts into the PCB. **Table 8.4.1** shows a summarized version of all the phases in circuit prototype testing.

| Table 8.4.1: Steps in Testing Thermometer | |
|---|---|
| **Phase 1** | Build HHA thermometer schematic excluding status LEDs and the Op-Amps that drive them. |
| **Phase 2** | Include status LEDs, Op-Amps and verify there is still more than 2V output from comparators. |
| **Phase 3** | Add switching IC and MCU to control the on/off status of the thermometer. Verify the results are stored in the MSP430 Launchpad. |
| **Phase 4** | Connect battery, voltage regulator, switch IC, thermometer circuit, and MCU for testing. |
| **Phase 5** | Consider replacing through-hole for surface mount equivalent ICs. Solder entire circuit onto PCB. |

### 8.4.2 Pulse Oximeter Test

Phase 1 in testing the HHA pulse oximeter will require the 3D printed case to avoid errors in the results received by the optical IC. After having built the case for the pulse oximeter, the LEDs and LMT87 optical sensor are installed within the case. A small strip of PCB will have the wires of the LEDs and sensors connected to it. Five small wires will exit through the rear of the pulse oximeter casing from the PCB and connect to the main device. The five wires will be one for sensor the supply voltage, 1 for the red LED supply, 1 for the NIR LED supply, 1 for the sensor output, and the last one is reserved for ground. The last part of this phase is to test to verify all the components are working.

When the pulse oximeter is built, the second phase is building the entire pulse oximeter schematic onto a breadboard and have the pulse oximeter casing connected to it. The entire schematic consists of the constant current LED driver, the LEDs, and bandpass filter. The switching ICs will not be included since it is not necessary for testing until there is prove that the pulse oximeter works as intended. To check the results of the pulse oximeter, phase 3 will be coding a program into the MSP430 which will time when the LEDs will alternate between on and off. The sensor will output a voltage value each time an LED pulses which will go through the MSP430's internal analog-to-digital converter. The value is then stored in memory until the following LED is pulsed, stored, and used for the calculations of $SpO_2$. This process repeats every millisecond. Calculations of $SpO_2$ will be compared to other pulse oximeter products. The HHA pulse oximeter will then be calibrated according to the results.

The program also has to be able to determine the pulse rate of the patient. Values obtained from the NIR LED will create a graph similar to a sinusoid where changes in concavity are equivalent to the pulses. After confirming the pulse oximeter works, phase 4 includes the switching ICs and testing that it does not influence the timings of the pulse oximeter. Phase 5 is soldering everything to the main PCB. **Table 8.4.2** contains a summary of the steps in building and testing the HHA pulse oximeter.

| Table 8.4.2: Steps in Testing Pulse Oximeter | |
|---|---|
| **Phase 1** | 3D print the HHA case. Install all components, wiring, and PCB within the pulse oximeter. Have all appropriate wires coming out of the pulse oximeter and test all components are working |
| **Phase 2** | Build the constant-current LED driver and bandpass filter onto a breadboard. Connect the casing's wires to the circuit. |
| **Phase 3** | Make a program used to test the pulse oximeter system on several volunteers. Compare values to other pulse oximeter products. Calibrate pulse Oximeter. |
| **Phase 4** | Add switching ICs to the circuit design. Confirm timings and results are not affected. |
| **Phase 5** | Solder all the parts to the PCB and test everything is working properly. |

## 8.4.3 Weight Scale and Blood Pressure Test

Since the weight scale and blood pressure will be bought as modules and then hacked to work with the Home Healthcare Assistant, calibration of the devices will be almost nonexistent. However, the accuracy of the devices can be tested. For comparing weight scales, a mechanical beam weight scale can be used because it provides highly accurate weight readings and is the preferred method of measuring weight in medical institutions. The mechanical beam weight scales are in the $200-$400 price range which make them difficult to obtain for a self-funded project. Since it is expensive, help will be needed in providing access to mechanical beam weights. University of Central Florida's Health and Public Affairs (HPA) can guide us to the correct place to get access to mechanical beam weights. Testing the HHA blood pressure device can also be done in a similar fashion. If the HPA is unable to help with the project, local hospitals and clinics could be willing to help the HHA project.

After determining the blood pressure and weight scale are within the requirements and specifications of the HHA, the devices can be connected to the MSP430F5529. The MSP430 will store the values the devices output at the end of their tests. The data stored will be compared to the value displayed in the devices to check if they are equal. Once the values are stored successfully, the data is sent wirelessly to the database. Database, stored values, and displayed values all have to be equal. This will require a decent amount of programming and understanding of the device schematics. Finding schematics of the LCD display used in the devices will most likely be where the data will hacked and connected to the MSP430 for testing.

# 8.5 Desktop Application

## 8.5.1 - Description of the Test Environment

For the desktop application, a web-based solution will be used in the form of a Microsoft Azure cloud-based website and SQL relational database. This website will be created with a design that takes into account access from mobile devices as well as desktop environments. The website will be hosted on a virtual machine running Windows Server 2010 with the aforementioned Windows Azure services. The website should also be able to handle multiple users at once. For the scope of this project, this website should be able to handle at minimum two users logged in at once —one being the patient, the other being a physician or other medical authorized user— without rendering data inaccessible at any time during either user's session.

## 8.5.2 – Test Cases

## Test Case #1: User logs in

When a user intends to log in, they should expect to see a login page asking for a unique username and password. If the person trying to log in is a new user, they will also have the option to register for an account and then immediately be given the option to log in. For this test, we will assume that the user already has a an account in place. The intended outcome is for the user, upon successfully logging in, to see a welcome message with their name at the top of the page and the most recent graph saved from plot.ly showing up on the main screen. If a graph has never been saved, then that space will remain empty.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/04/15 | Fail | The system doesn't seem to let the user log in at all. |
| 2 | 04/12/15 | Pass | Log in successful for a single user |
| 3 | 04/13/15 | Pass | Log in successful for alternative user |
| 4 | 04/16/15 | Pass | Log in successful for user with viewable readings. |
| 5 | 04/15/15 | Pass | Log in successful for authorized users with access to every reading on database, include those of unauthorized patients. |
| 6 | 04/15/15 | Pass | Log in successful. Users and authorized users are assigned specific access to certain accounts. |

## Test Case #2: User searches for a certain date's readings

The user should be able to run a search query to find vital readings from a certain day and/or time. Only authorized users can see more than one specific patient's readings. If any other records are found for another patient, then the website is not complying to HIPAA standards.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/04/15 | Fail | Record system not fully implemented yet |
| 2 | 04/18/15 | Fail | All readings for a particular user can be accessed if the user's ID is known. No authentication or restrictions added to search yet. |
| 3 | 04/25/07 | Pass | Users can search a certain date's readings with new query. No authentication or restrictions added to search yet. |

## Test Case #3: Authorized User searches for a reading(current or previous)

In the event that an authorized user, such as a physician or other healthcare practitioner, wants to see their patient's vital records, they should have access to querying a result from the database to analyze their patient's readings. A successful test case results in the authorized user being able to pull vitals data from the server from an authorizing patient and perform a plot.ly graphing if desired. A failed test case results from the authorized user unable to access the data that they have the permission to view.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/05/15 | Fail | No readings. |
| 2 | 04/18/15 | Pass | Authorized user can search for a set list of readings. |
| 3 | 04/25/15 | Fail | Authorized user can search for a set list of readings. Other authorized accounts can search for other patients' readings. |

## Test Case #4: Patient adds a sensor's vitals reading to readings list

This is a temporary test case that will allow patients to send their readings to the database while the microcontroller automated solution is still being worked on. A successful attempt entails that the patient was able to access the submission page (located through a navigational button on their profile page), entered in valid values for the readings, and the web page successfully sent the values to the update the database.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/09/15 | Fail | Function not implemented. |
| 2 | 04/12/15 | Fail | Manual addition page added. No fields added yet. |
| 3 | 04/14/15 | Fail | Temporary fields added. No functionality to submit values added yet. |
| 4 | 04/19/15 | Fail | The code to submit data to the database is nonfunctional. A different server infrastructure is being considered. |

## Test Case #5: User enters in profile information (for the first time)

Upon entering the main screen, the user should be able to enter their profile. There, they will find an option to edit their profile, which will take them to a new page. “Edit Profile” page to make modifications or add in new data. The page itself contains text fields that directly link to the database server. A successful test case consists of a user entering the “Edit Profile” page, filling in the preliminary information where needed, applying the filled in information, and ensuring that the data is transferred to the database server, and finally, having the updated data reflected on the profile page. Users should only be able to edit their own profile information, as well as only being able to access only their own profile or their patient’s profile if they are an authorized user.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/04/15 | Fail | Users’ information added manually and directly to database server. |
| 2 | 04/05/15 | Fail | Alternative (Authorized) users (i.e. physicians) implemented. |
| 3 | 04/18/15 | Fail | Registration process works when done manually, server-side. |
| 4 | 04/26/15 | Pass | User able to enter profile information. |

## Test Case #6: User wants to submit a reading to be plotted

The user will first enter a search query for the desired time range to be plotted. The query will return numerical results to the webpage and will present an option to plot the data using plot.ly’s graphing service. A successful test case will result in the user receiving a plotted graph representing the selected data either as a graph object embedded from plot.ly itself, or as an image saved in the database and/or embedded on the home page.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/11/15 | Fail | No readings to send, therefore no graphs to chart. |
| 2 | 04/12/15 | Fail | Sample data sent to plot.ly manually. Plot added as object to database manually. |
| 3 | 04/25/15 | Fail | Synchronized database with plot.ly. Plots can be generated with query. |

## Test Case #7: User modifies profile information

Upon entering the main screen, the user should be able to enter their profile. There, they will find an option to edit their profile, which will take them to a new page. "Edit Profile" page to make modifications or add in new data. The page itself contains text fields that directly link to the database server. A successful test case consists of a user entering the "Edit Profile" page, entering in information where needed, applying the changes by having the data transferred to the database server, and finally, having the updated data reflected on the profile page. Users should only be able to edit their own profile information, as well as only being able to access only their own profile or their patient's profile if they are an authorized user.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/04/15 | Fail | Can't enter info for the first time so there's no modification yet. |
| 2 | 04/15/15 | Pass | Profile information can be properly modified. However, only first and last name can be modified. |
| 3 | 04/18/15 | Pass | Profile information can be properly modified. Added ID number field. |
| 4 | 04/24/15 | Pass | A user's profile information can be properly modified. Additionally, profile information cannot be modified by other users. |

## Test Case #8: Navigation through the web-page

The user needs to be able to navigate the webpage and use all of functions available to them. When the user enters their profile, they should also be able to edit their details, such as their address, phone number, and password.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/03/15 | Fail | None of the objects on screen are responsive. Web page just stays stuck on the initial screen. |
| 2 | 04/10/15 | Fail | Navigation of pages implemented, however the pages themselves need functionality. |
| 3 | 04/14/15 | Pass | User able to interact with the web page |

| | | | |
|---|---|---|---|
| | | | components, however their functionality doesn't work in conjunction with the rest of the subsystems. |
| 4 | 04/15/15 | Pass | User still able to interact with GUI although the underlying program still doesn't work. |
| 5 | 04/16/15 | Fail | Website inexplicably failed to function when navigating to the records view. Database connectivity must be disabled. |
| 6 | 04/19/15 | Pass | Problem fixed; GUI back to normal. |

### Test Case #9: User logs out

When the user clicks on the logout button, the expected behavior is for the user to be taken into the login screen and have their session end. Going back into the system via a direct link or the back button in the browser should not load a functional page of the previously logged in user.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/16/15 | Pass | Log out successful. |
| 2 | 04/26/15 | Pass | Log out successful. |

### Test Case #10: Database protection

This test case will test for whether or not a user can directly access the database to modify or destroy existing data, to create new data, or to access the database with user or server side scripting from the website. A failed test case would become the result if the user becomes able to perform any of the previously mentioned tasks to access the database and its functions.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/10/15 | Pass | Regular users cannot directly access the database. |
| 2 | 04/12/15 | Pass | Upon adding a working login, regular users still cannot directly access the database. |
| 3 | 04/25/15 | Pass | Neither patients nor authorized users cannot directly access the database. |

## Test Case #11: Testing Data Abstraction

There exists the possibility that a user could exploit a vulnerability in either the web development language, PHP, or in SQL that would allow them to access commands and data that extends beyond their authorization. Because the information to be safeguarded involves the personal information of patients, it is of the highest importance that any exploits and vulnerabilities be prevented from being executed to save this information.

The intended result of having either a patient or authorized user log into the system is to have these users access only what they are approved to access. If the user is able to change or spoof their status as an administrator, then the test case has failed.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/11/15 | Fail | Flag works that doesn't let users have administrative access. However, administrative access is not needed to view all of the records online. |
| 2 | 04/25/15 | Pass | Flag works that doesn't let users have administrative access. |

## Test Case #12: Testing both extremes (high and low) of input

The database has fields of which certain input types can be expected. If somehow, an unexpected input occurs for a field, the input shall be rejected in its entirety and treated as corrupt data. Regular expressions will automatically decide if an input is valid or not.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/02/15 | Fail | Strings that are too short and too long are still accepted. |
| 2 | 04/03/15 | Pass | System no longer allows strings that are too long or short. |
| 3 | 04/16/15 | Pass | System has expected number of info to be received from microcontroller. No automation or connectivity between the two has been implemented thus far. |

## Test Case #13: General security of the site

The website that is accessible to end users provides the only a convenient transport to view the vitals readings. Such information is considered sensitive and private, and must therefore be obscured and protected from access by the general public. Information that is both private and related to the medical field falls under the data protection standards standardized by HIPAA. Aside from the physical protection requirement, which is handled by the remote server host(s), the information on the database itself must be obscured in such a way so that (1) only HHA customers and authorized users can access information on the database, and (2) of those customers and authorized users, only the information pertaining to those specific patients can be accessed.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 03/26/15 | Fail | Access to database is open only to database host manager. |
| 2 | 04/03/15 | Fail | Access to database open to registration for anyone who can access it. |

## Test Case #14: Website stability (10 - 12 people using at the same time)

The website application should be able to support many users at once, all of which request actions that require database access. Databases are naturally slow when it comes to data retrieval, so in high volume cases, a slowly generated result should be expected and accepted as a passing test case.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 04/14/15 | Fail | Website works fine with 1 users in the system. |
| 2 | 04/18/15 | Fail | Website works fine with 12 users in the system. Database still not implemented with the website. |

### Test Case #15: SMTP alerts

One of the goals of the HHA is to have email alerts be sent to patients and/or physicians and other authorized users in the event that a vitals reading has not been performed. These email alerts are sent from the CC3100 through the server with the SMTP protocol to the intended recipients [60]. Using SMTP, the CC3100 can also send text messages if the carrier and phone number of the cellphone company is known.

| Attempt # | Date | Result | Description |
|---|---|---|---|
| 1 | 03/01/15 | Pass | Simple email with subject and test message lines sent to personal G-Mail account via PuTTY terminal commands. |
| 2 | 03/30/15 | Pass | Text message sent to personal phone number using the previous method of sending emails. |
| 3 | 4/20/15 | Pass | Website server can obtain phone number and carrier information for patients. Automated emails from microcontroller is still a work in progress. |

# 9.0 Administrative Content

## 9.1 Timeline and Milestones

### 9.1.1 Modification of Sensor Parts

Within 4 weeks of the submission of this report, the HHA thermometer's probe manufacturer must have replied with positive feedback and/or produced the required probe. If no manufacturer has replied or created the probe for the body temperature sensor, alternative measures might have to be taken. These measures include research in possible thermally conductive and electrically nonconductive materials that can be 3D printed to house the sensor. The material also has to be waterproof, stable and relatively nontoxic to be inserted orally. With the addition of the disposable oral thermometer probe covers, taking body temperature measurements should be safe. These methods should not take more than an extra 2 week. If no convenient materials for the probe are found, a pre-existing probe will have to bought which will be a lot more expensive and a lot more accurate. This option will be the last resort when all other measures fail.

In the event the body temperature sensor is inaccurate and cannot be calibrated correctly due to the sensor's lack of customization, the temperature sensor might have to be replaced with the next possible alternative. The next alternative is to choose a temperature sensor from Texas Instrument's LM series because of their small max inaccuracy temperatures. If the LM series temperature sensor fails to give accurate results, a different type of temperature sensing technology will be utilized. LM series testing should not take longer than an extra week. The next temperature sensing technology would be using thermistors which requires reworking the circuitry and calculations within 2 weeks following the deadline of the probe manufacturing.

For the HHA pulse oximeter, a CAD drawing of the casing must be done within 4 weeks of the submission of this report in order to use the 3D printer and be able to test it. The following 2 weeks will be for calibration and testing of the pulse oximeter. If the pulse oximeter does not produce useful results, the fault has to be found immediately and fixed. Such problems might be the intensity of the LEDs is too high or too low in which different LEDs can be chosen with ease. If the problem is generated from the choice of sensor, photodiodes might be used instead of optical sensing ICs because of the lack of optical sensing IC variety. Since there will be significant changes in electrical schematics and calculations, an extra 3 weeks after the changes will be used in the fixing of the pulse oximeter design. Another 2 weeks will be used for the calibration.

The weight scale and blood pressure sensor will be hacked and the displayed measurements will be sent to the MCU which will also show those values. Getting the correct communication going between the device and the MCU will be the greatest problem. Another problem to overcome is connecting both of them for testing. There will be 6 weeks after the submission of this report to work in that area. If the weight scale or the blood pressure sensor is not accurate enough when compared to more precise medical equipment, they will have to be replaced since they are pre-built devices. These changes have to be done and tested within 4 weeks. **Table 9.1.1** shows a summarization of the timeline of modification of sensor parts. "Within" a certain amount of weeks means starting at the report due date and extra weeks means weeks added to the "Within" weeks.

| Table 9.1.1: Modification of Sensor Parts Average Timeline<br>Report Due Date: 04/30/2015 | | |
|---|---|---|
| **Thermometer** | Probe manufacturing | Within 4 weeks |
| | No probe manufactured? | Extra 2 weeks |
| | Inaccurate? LM series testing | Extra week |
| | Still inaccurate? Thermistor design | Extra 2 weeks |
| | Still inaccurate? Pre-built probe | Extra week |
| **Pulse Oximeter** | Casing CAD drawing | Within 4 weeks |
| | Calibration and testing | Extra 2 weeks |
| | Needed changes in design | Extra 3 weeks |
| | Calibration of new design | Extra 2 weeks |
| **Weight Scale** | Hacking and testing | Within 6 weeks |
| | Exchanging parts needed + testing | Extra 4 weeks |
| **Blood Pressure Sensor** | Hacking and testing | Within 6 weeks |
| | Exchanging parts needed + testing | Extra 4 weeks |

## 9.1.2 - Interface Microcontroller and FPGA

Our goals and milestones for interfacing the MSP430 and BASYS2 boards are outlined in **Fig. 9.1.2.** Development of both boards and the database are taken into account since the boards will be working together to have that data sent and stored remotely.

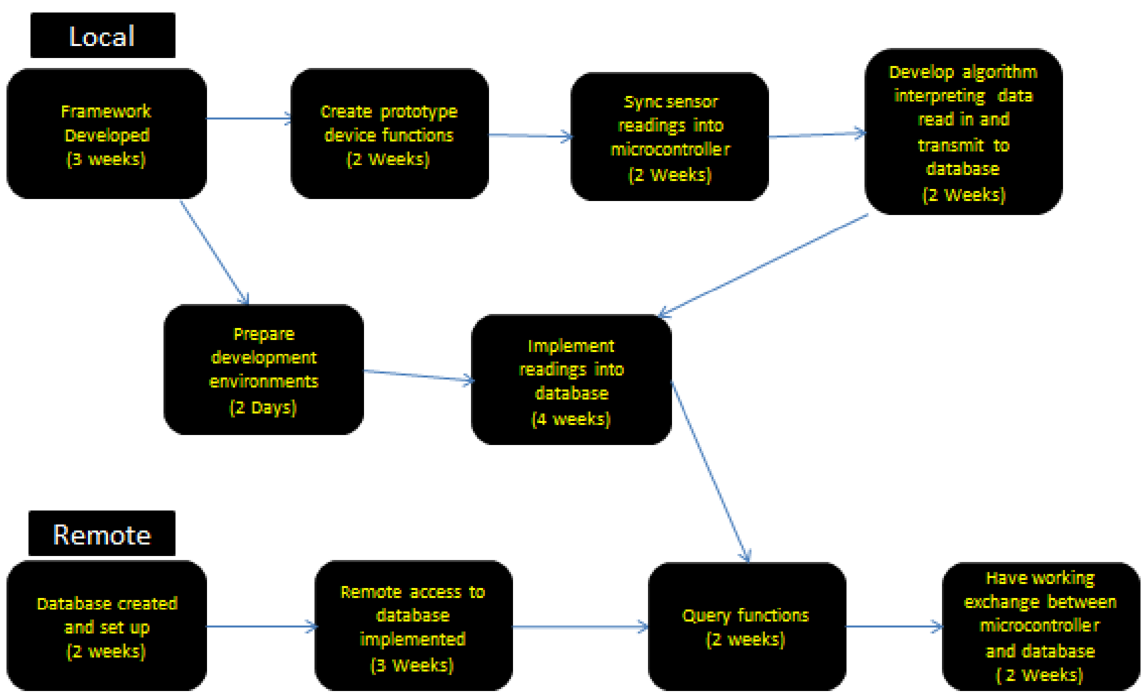


**Fig. 9.1.2 PRT chart outlining the timeline and milestones for interfacing the microcontroller and FPGA.**

### 9.1.3 Troubleshoot Sensor-to-MCU Power Requirements

In case there is an issue with the values the MCU receives from the sensors, power requirements for each of the electronic devices used for the sensor in question have to be checked. If there is a power problem, datasheets for the components will be searched and compared to the amount measured. Anomalies in power reaching the electronic devices are most likely due to insufficient current flowing to all the devices. There might be a problem with the voltage regulated output current or the battery simply cannot output enough current to power the devices. The voltage regulator components will have to be redesigned or the battery might have to be replaced with a more powerful one. The power system of the HHA projects needs to be ready for use within 10 weeks of submission of this report and troubleshooting plus testing should not take more than an extra 2 weeks. Other troubleshooting events that might arise in the communication between sensor and the MCU is insufficient voltage reaching the pins. For example, the HHA thermometer's comparators could output a voltage that is too low to be registered by the microcontroller's pin. Researching, changing parts, and changes in schematic should not take longer than a week.

### 9.1.4 - Derive Analytical Graph of Inputs

The derivation of analytical graphs will require that many readings be in the database for the graphing service to create a worthwhile graph. In order for the data to be analyzed, it must first be obtained and transmitted from the MSP430's CC3100 booster directly to the database. This milestone will take no more than eight weeks to accomplish. Once the data has been collected, we expect to have the database and the online graphing service to be working together in no more than two weeks. The most challenging aspect of this task is to have the graph or the image generated from the graph become accessible to the end user. This will be handled by the database and web servers after the graphs have been created.

For this project, we will be using the service from the website plot.ly to chart out the different readings HHA will collect throughout time. Plot.ly's API allows for the streaming of external, real-time data into its own database where it will automatically generate a graph based on preconfigured options on how the data should be expected to be interpreted. The graphs generated from this site can be saved as an image file for easy interpretation remotely [61]. Such a feature for image generation can be utilized by the HHA website to show information from a user-defined range of time.

An important caveat to note from the plot.ly service is that while the HHA is connected, the host plot.ly server must be receiving some sort of input every minute or else it closes its transmission stream. In order to avoid having to re-authenticate and login every time that the HHA is idle or cannot transmit data in this time period, a newline ("\n") can be sent before that time out limit can be reached. This is known as a "heartbeat," and when it is sent, it will not affect the final plot generation [62].

### 9.1.5 Integrate All Devices

Before integrating all devices, each part has to be tested individually to see that they function properly. The very last step of the project is to integrate all devices module by module and checking everything is running smoothly. **Table 9.1.5** shows the timeline of when the pieces are supposed to be combined.

| **Table 9.1.5: Integration**<br>Report Due Date: 04/30/2015 | | |
|---|---|---|
| **Battery, Charger, DPDT Switch, Voltage Regulators** | Testing / Soldering | Within 8 weeks |
| | Troubleshooting | Extra 2 weeks |
| **Body Temperature Circuit** | Testing / Soldering | Extra half week |
| | Troubleshooting | Extra half week |
| **Pulse Oximeter, Weight Scale, Blood Pressure, MSP430** | Testing / Soldering | Extra week |
| | Troubleshooting | Extra week |
| **Any other component** | Testing/Soldering | Extra 1/2 week |
| | Troubleshooting | Extra 1/2 week |

## 9.2 Budget and Finances

### 9.2.1 Budget Management

The overall price of the project will be divided as evenly as possible between each member of the HHA group. If a member is in charge of the more expensive part of the project, the member is required to ask for financial help unless it is not a burden or the person wishes to buy a quantity larger than needed for personal reasons. The member can then keep the extras to themselves but record the cost for record keeping. Since it is a self-funded project, the group can reach a consensus as to whether or not to disassemble the HHA after all project presentations and project displays are finished. If a consensus is achieved, each member of the group is entitled to keep the parts they paid for.

### 9.2.2 Finances

Due to lack of sponsorship and having a low budget, the HHA project is recycling several expensive devices. Because of the complexity of designing and soldering the Spartan-3E FPGA to the Home Healthcare Assistant PCB, the Basys 2 board is utilized. This is convenient because some of the HHA developer already own the board saving the group at least $68.00. Other components that are owned and drop the amount the group has to pay are the MSP430, buzzer, potentiometers, resistors, capacitors, LEDs, and sensors which average about $26. All savings mentioned are excluding shipping costs.

### 9.2.3 PCB Vendors

Printed circuit board costs will be a large portion of the overall cost needed to make the Home Healthcare Assistant device work. As a result, research in possible PCB vendors is required to lower the overall cost of the HHA without compromising the effectiveness of the device. Some requirements in the PCB are needed in order to increase the success of the design such as a 4-layer because of the CC3100 SimpleLink Wi-Fi. Another requirement is that an approximate 30 square inches of PCB will be needed to design the entire device. Using the large list of PCB manufacturers located in the North America from CadSoft Eagle, a handful of manufacturers are selected based on price and relevant information about prices located in their websites. Other manufacturers are not selected because they require creating an account, having a Gerber file, no information on prices, sending emails with specific details not yet designed, or simply only have a mail contact information.

#### 9.2.3.1 Advanced Circuits (4pcb.com)

If it is decided that the CC3100 will be soldered instead of using the booster shield, a 4-layer PCB will be needed. Advanced Circuits has an offer of $66 each for a 4-layer, 30 square inch, 5-day shipping, a legend, 35 drilled holes per square inch, 1 free part number per order and lead free finish PCB. Although the price is great per PCB, the customer is forced to buy a minimum of 4 board which increases the price to $264. If the CC3100 booster shield is used in the final design of the project, only a 2-layer PCB is needed for the Home Healthcare Assistant. For a 2-layer PCB, Advanced Circuits also has a good offer of $33 per printed board with similar specifications to the 4-layer PCB offer. The overall price of the 2-layer offer would be $132 and would include a PCB twice as big in square inches compared to the 4-layer PCB. The high number of printed boards also gives a large amount of room for possible errors.

#### 9.2.3.2 Pentalogix (pentalogix.com)

Pentalogix is another PCB vendor that could be used to manufacture the Home Healthcare Assistant printed circuit board. Using Advanced Circuits specifications on their 4-layer PCB deal, Pentalogix PCBs require a higher price. Pentalogix charges $110 for each printed board of 30 square inches and a minimum of 4 PCBs. The total cost would be $440. Their 2-layer PCB costs $75 each giving a total of $300. Pentalogix only real advantage when compared to other manufacturers relies on their 2-layer PCB lead time of 3 days as opposed to the common 5 days. They also provide an option for expedited service which costs a percentage of the total cost added to the overall cost.

#### 9.2.3.3 PCB-Pool (pcb-pool.com)

PCB-Pool is a printed circuit board manufacturer that is very flexible in requests but also charges considerably high for those extra requests. For a 4-layer PCB of similar specifications to the Advanced Circuits deal, the total price is close to $350. For a 2-layer printed circuit board of the same specifications, the price is about $220. PCB-

Pool's forte is that they can also assemble and solder all the parts instead of having to solder them by hand. They charge a fixed rate for each type of technology such as through-hole or surface mount. The amount of devices does influence the price. Having enabled the option to have PCB assembled does greatly increases the price to higher than $500. Their 2-layer PCB costs a little over $250 and over $400 if assembling is required. PCB-Pool might be an appropriate choice if it is certain only 1 PCB is needed for the HHA or if lead time was an issue.

#### 9.2.3.4 PCBunlimited (pcbunlimited.com)

For a 30 square inch printed board that is 4-layers, the price in PCBunlimited is $301.50. This price also includes a total of 3 PCBs which means each one costs a little more than $100. For a 2-layer printed circuit board of the same dimensions and specifications, the price is $148.50 which is less than $50 for each individual PCB. PCBunlimited provide several specifications for free along with their deal. Some of these specifications are FR4 material, tin-lead HASL finish plating, green solder mask for both sides, white silkscreen for both sides, internal cutouts, irregular board shapes, and they provide an electrical test.

#### 9.2.3.5 Gold Phoenix PCB (goldphoenixpcb.com)

Gold Phoenix Printed Circuit Board Co., Ltd is a company who greatly reduces its price depending on the quantity of PCBs a person wishes to order. For a 4-layer, 30 square inch PCB, the price is $60 per printed circuit board assuming 5 boards are bought. This overall price of $300 is relatively low and can also include one extra PCB for only $13. For a 2-layer PCB, each PCB board is $22 giving a total of $110 for all 5 printed circuit boards. An extra PCB can be bought for half-price. The specifications of the board include FR4 material, 0.062inch thickness, HAL finish, green solder mask, one side silk screen, no electrical testing, white silk screen, and it must be a regular shape. These specifications can be changed with free registration to their website. Some cosmetic changes in the specifications of the printed board do not increase the price. The Home Healthcare Assistant might utilize this vendor depending on how many boards might be needed and also because of their low price even with fewer PCB quantities.

# 10.0 Tentative HHA Owner's Manual

The Home Healthcare Assistant (HHA) is a device meant to measure essential vital signs in patients who are susceptible to health complications. The HHA is by no means a substitute for a medical professional's diagnosis. Instead of being a substitute, it is a tool a medical practitioner uses to quickly focus on the problem and/or a device to efficiently set-up appointments with your physician. This user manual is meant to guide the patient step-by-step in installing, using, and troubleshooting the device. Safety steps are also covered in this manual.

## 10.1 Safety Before Powering Device

In order to protect against possible harm, follow the safety indications listed:

1. Make sure no sensors are attached to the patient and connect the device to the power outlet to charge it.
2. If the red LED status light turns on in the charger, do not use the device until it turns green.
3. If the green LED status light is lit, use the switch to turn off the charger to avoid over-charging the battery.
4. Double-check all cables to and from the probes for any loose or torn connections. If there are any cables or connections that are not connected properly, do not turn on the device.
5. Make sure the HHA device is placed on an elevated, flat surface. If all safety indications have been met, the HHA is ready for use.

## 10.2 Capabilities

The Home Healthcare Assistant is a useful tool in measuring vital signs but it has its limits. The following is a list of the HHA capabilities:

1. Measure the patient's body temperature.
2. Measure the patient's blood oxygen levels.
3. Measure the patient's heart rate.
4. Measure the patient's blood pressure.
5. Measure the patient's weight.
6. Daily alarm as a reminder to take the test.
7. Transmit patient's measured vitals wirelessly to a database.
8. Alerts a medical practitioner through a smart decision-making database using the data of the patient's medical history.
9. Allows for an appointment with a medical professional by submitting a complaint.
10. Survey of questions related to the health of the patient.

## 10.3 Using the HHA Device

The HHA device follows a systematic, sensor-by-sensor approach. Do not wear any medical device without being prompted to do so. To use the HHA, follow the next set of instructions:

1. Do not use this device if the patient has eaten, drank, exercised, taken a bath, or recently woke up in the past 30 minutes.
2. To be able to turn on the HHA, use the switch to turn off the charger and turn on the device.
3. Wait until the screen instructions are displayed.

4. Answer the question displayed in the screen: "Do you wish to take the exam?" Using the keypad, press "1" for "Yes" or "0" for "No".
5. If you pressed "1", follow the instructions displayed in the screen: "Add a protective sheath to the HHA thermometer and insert it below the patient's tongue"
6. Press "Enter" on the keypad to begin measuring. The green LED status light in the temperature section of the device will be lit if the device is working.
7. The red and yellow LED status lights tells if the patient has a fever or hypothermia respectively.
8. If no status light except the green is on by the end of the test, then the patient has a safe body temperature. When the temperature's green LED light turns off, it is safe to remove the thermometer.
9. Wait until the next screen displays a set of new instructions.
10. When instructed, insert the patient's finger inside the pulse oximeter until it touches the end of the device. Make sure the finger is centered in the pulse oximeter.
11. Close the pulse oximeter and check that movement is restricted but confirm it is not too tight as to block the blood flow through the finger. Have your arm slightly stretched and relaxed before testing.
12. Do not wear nail polish, band-aids in the finger or anything that will block the transmission of light.
13. Press "Enter" on the keypad to begin measuring the patient's pulse and blood oxygen levels. The green LED status light in the pulse oximeter section of the case will light up if the device is working.
14. When the green LED turns off, the test has finished and it is safe to remove the patient's finger from the pulse oximeter.
15. Press "Enter" to move to the next step.
16. Follow the instructions in the screen. "Step on the weight scale and press "Enter" when ready". The green LED in the weight scale section of the HHA case will turn on.
17. Once the green LED is off, it is safe to step off the weight scale. Press "Enter" to continue.
18. Follow the instructions in the screen. "Put on the blood pressure upper-arm cuff and press "Enter" when ready". Have your arm slightly stretched and relaxed before testing.
19. The green LED in the blood pressure section will light up. Once the green LED is off, it is safe to remove the blood pressure sensor.
20. Press "Enter" to continue and answer the survey of questions.
21. Press "1" to answer "Yes" or Press "0" to answer "No" to the questions.
22. If the question asks for a specific numerical value, use the keypad's numbers to answer it. Press "Enter" to submit the answer.
23. When the patient has reached the end of the test, a confirmation screen is displayed.
24. To retake a test, wait until the confirmation screen returns to the first screen and prompts the user to take the test.
25. To set the device in sleep mode, press "0" to say "No" to taking the test.

26. To return from sleep mode, press "1".
27. To reset the time, switch the device off. To set the daily alarm, turn on the battery at the time the alarm is supposed to go off. Every 24 hours the alarm will go off.
28. Never switch off the HHA device if you wish to keep the alarm time.

## 10.4 Troubleshooting

If the HHA is not working properly, the following can be checked with relatively little electronics skills.

1. If the body temperature sensor is not measuring properly, the potentiometers located under the temperature sensor have not been calibrated. Use a multimeter to measure the voltage across the series of resistors to read 2.122V for fever and 2.163V for hypothermia. The printed board will contain labels for the fever and hypothermia sections.
2. If the HHA is not turning on, plug the device to the power outlet. A red LED light should turn on in the charger. This means that the battery needs to be recharged.
3. If the HHA is still not turning on, make sure the device is charged and that it is disconnected from the power outlet.
4. If the HHA suddenly turns off, connect the device to the power outlet and check if the red LED is lit on the charger. If it is lit, then the device has run out of battery and needs to recharge.
5. Check with a technician if any other problems occur.

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# Emails of Image Permissions

Pico Technical Support <servers@picotech.com>

Mon 3/30/2015 8:55 AM

Senior Project

To: shaka <shaka@knights.ucf.edu>;

This is in reference with your Request Ticket Number: TS00068534.
Subject: Technical Support Enquiry

Hi Jonathan,

Thanks for your enquiry. You are welcome to use images from https://www.picotech.com/library/application-note/thermocouple-application-note in your report subject to our usual two conditions:

1. You print the text "Image copyright (C) 2015 Pico Technology Ltd. Reproduced with permission." under each image.

2. You send us a copy of your report before publication.

We do not allow copying of complete articles, but short quotations and copies of numerical data are OK.

Best regards,

Jeff Bronks
Technical Author

Please reply back to this email without changing the subject line if you have further clarifications.

Pico Technical Support Team

Visit our forums
- Test and Measurement
- Automotive

Skype: pico_tech_support
Tel: +44 (0) 1480 396 395

outlook_6201ca3d19b8ff38@outlook.com on behalf of
pras tila <web21@freshgasflow.com>

Sat 3/14/2015 6:01 AM

Senior Project

To: shaka <shaka@knights.ucf.edu>;

Hi Jonathan.
You are most welcome. When completed, if possible, do email me a copy. I am not an engineer, but would love to read it.
Thank you for contacting me.
Pras

Sorry for short email. I have sent it via my phone.

---

**From:** shaka
**Sent:** 14/03/2015 02:18
**To:** web21@freshgasflow.com
**Subject:** Hi, I am asking for permission to use information

Hey, my name is Jonathan Stagnaro. i am an electrical engineering student at the University of Central Florida and I was wondering if you would grant me permission to use the diagrams, pictures, and information in your website at:

http://www.howequipmentworks.com/pulse_oximeter/#oxygen_saturation

How pulse oximeters work explained simply.

Principles of how pulse oximetry works explained without using complicated physics.

Read more...

I am going to use this information for my senior design project and I will make certain you are referenced in any information that belongs to you.

Jonathan Stagnaro
UCF Undergraduate Student
407-668-3060
shaka@knights.ucf.edu

# RE: Requesting information / permission

Lionel Tarassenko <lionel.tarassenko@eng.ox.ac.uk>

Sat 3/21/2015 9:32 AM

Senior Project

To:shaka <shaka@knights.ucf.edu>;

I wrote the notes with Neil (who is now working as a Pastor in a local church). Please feel free to use any of the graphs.

Best wishes,

Lionel Tarassenko

*Professor Lionel Tarassenko* CBE FREng FMedSci
Professor of Electrical Engineering
*Head, Department of Engineering Science*
University of Oxford, OXFORD, OX1 3PJ
T: +44 (0)1865 273002 M: +44 (0)7896 101508

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**From:** shaka [mailto:shaka@knights.ucf.edu]
**Sent:** 21 March 2015 10:04
**To:** Lionel Tarassenko
**Subject:** Requesting information / permission

Hello. My name is Jonathan Stagnaro and i am currently a student at the University of Central Florida working on my senior design project. I was wondering if you are still in contact with Neil Townsend. Although the report is old, there are some graphs in one of his reports that i am interesting in using but I think I would need his permission to use it. I visited his website and he makes reference to you and as I searched through the Oxford website I knew for sure your were the one (Nice video on the IdeasLab2014).

If you could figure out if I am allowed to use some of the graphs in the report, please contact me.
The website link is shown below:

http://www.robots.ox.ac.uk/~neil/teaching/lectures/med_elec/notes6.pdf

Jonathan Stagnaro
UCF Undergraduate Student
407-668-3060
shaka@knights.ucf.edu

# Permission from Pyromation

Greg Craghead <gcraghead@pyromation.com>

Tue 3/24/2015 9:25 AM

Senior Project

To: shaka <shaka@knights.ucf.edu>;

Cc: Scott Farnham <scott@pyromation.com>; Mike Thaxton <mike@pyromation.com>;

Jonathan,

We received your request for use of content from "Training RTD Theory", located on the www.pyromation.com Web site, in your project. Pyromation grants you permission to use the material, with notation of the source, for this project.

Thanks for contacting Pyromation, and we're glad the information is of value to you. We would be interested in seeing your final report when it is completed.

Greg

**Greg Craghead**
Marketing Manager
Tel: (260) 484-2580 Ext. 1535
Fax: (800) 837-6805
[www.pyromation.com]www.pyromation.com
E-mail: gcraghead@pyromation.com

Description: Description:
Description:

5211 Industrial Road, Fort Wayne, IN 46825 USA

# RE: Request to use information from a PDF file for a senior project

Bassuk, Larry <l-bassuk@ti.com>

Mon 4/27/2015 5:03 PM

Inbox

To: shaka <shaka@knights.ucf.edu>;

Cc: Sheets, Cindy <c-sheets@ti.com>;

Thank you for your interest in Texas Instruments. We grant the permission you request in your email below.

On each copy, please provide the following credit:

Courtesy Texas Instruments

Regards,

Larry Bassuk
Deputy General Patent Counsel &
Copyright Counsel
Texas Instruments Incorporated
214-479-1152

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**From:** shaka [mailto:shaka@knights.ucf.edu]
**Sent:** Friday, March 13, 2015 4:35 PM
**To:** copyrightcounsel@list.ti.com - Copyright and trademark web requests (May contain non-TIers)
**Subject:** [Requests & questions from ti.com] Request to use information from a PDF file for a senior project

Hi, my name is Jonathan and I am currently a student at the University of Central Florida. I am working with a group of students for our senior design project that will be able to measure all sorts of vitals in a patient and then take an educated conclusion based on the results. For the research of our project, we ran into a very useful pdf file with tables that we wish to include in our report and I was wondering if we can use this information. The link of the pdf file is shown below:

http://www.ti.com/lit/ml/slyb211/slyb211.pdf

Thank you for your time.

Jonathan Stagnaro
UCF Undergraduate Student
407-668-3060
shaka@knights.ucf.edu

# Re: Battery University Contact Form

John Bradshaw <John.Bradshaw@cadex.com>

Tue 4/28/2015 4:18 PM

Inbox

To:shaka <shaka@knights.ucf.edu>;

Hi Jonathan,

Yes, you may use the material as requested. Please cite sources where appropriate.

Regards,

John Bradshaw - Marketing Communications Manager
Cadex Electronics Inc. | www.cadex.com
Vancouver | Minneapolis | Frankfurt
Tel: +1 604 231-7777 x319 | Toll Free: 1-800 565-5228

Follow us on Twitter: twitter.com/cadexelectronic
Join us on Facebook: facebook.com/cadexelectronics
Add us on Google+: plus.google.com/+Cadex

>>> "Battery University" <web@batteryuniversity.com> 4/28/2015 12:52 PM >>>
Someone has submitted a Battery University contact form.

Here are the details:

Entry Date: 2015-04-28 12:52 PM

Attachments: 0
Collection Name: Contact Form
First Name: Jonathan
Last Name: Stagnaro
Email: shaka@knights.ucf.edu
Company: University of Central Florida
Comments: Hey, my name is Jonathan Stagnaro. I am a student at the University of Central Florida currently working in my Senior Design project. I was wondering if permission might be granted to copy some of the figures shown in your site and present it in my design. The figures would be referenced in any way you like... The website I wish to copy figures from is shown below:

http://batteryuniversity.com/learn/article/whats_the_best_battery

Thank you for your time and consideration

**Subject:** Re: Website image permission request
**From:** Javier Valcarce García <javier.valcarce@gmail.com>
**Date:** 4/7/2015 5:21 PM
**To:** Syed Zishan Zaidi <zishan@knights.ucf.edu>

Hi Zishan.
Sure, feel free to use those images in your report.
Thanks for asking.

2015-04-07 22:21 GMT+02:00 Syed Zishan Zaidi <zishan@knights.ucf.edu>:

> Dear Mr. Valcarce,
>
> I am an electrical engineering student in Senior Design at the University of Central Florida. I would like to request permission to use images in your VGA Video Signal Format and Timing Specifications webpage found at
>
> http://javiervalcarce.eu/html/vga-signal-format-timming-specs-en.html
>
> in my Senior Design Report, with the source cited.
>
> I am writing about how the VGA protocol works and some of those images will be quite helpful. Thank you very much for your kind response.
>
> Sincerely,
> Zishan Zaidi

**Subject:** Re: BASYS 2 reference manual permission request
**From:** Digilent Sales <sales@digilentinc.com>
**Date:** 4/14/2015 12:48 PM
**To:** Syed Zishan Zaidi <zishan@knights.ucf.edu>

Sorry I didn't get back to you sooner. I had to ask around to get an answer for you. Our Marketing manager informed me that "All images and info is Creative Commons attribution!" Hopefully this makes sense to you, but if not let me know and I will ask her to explain her answer in other words. As well, we'd love to see a copy of your report once you are finished. Good luck and let me know if you have other questions. --Sheri

---

**Digilent Sales Team |**

sales@digilentinc.com |

From: Syed Zishan Zaidi <zishan@knights.ucf.edu>
To: <sales@digilentinc.com>,
Date: 04/07/2015 01:12 PM
Subject: BASYS 2 reference manual permission request

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Dear Sir or Madam,

I am an electrical engineering student in Senior Design at the University of Central Florida. I would like to request permission to use images from the Digilent BASYS 2 reference manual in my Senior Design Report, with the source cited. Specifically, I would like to use images from the PS/2 Port and the VGA Port sections of the manual (pages 5 - 8). Thank you!

Sincerely,
Syed Zaidi