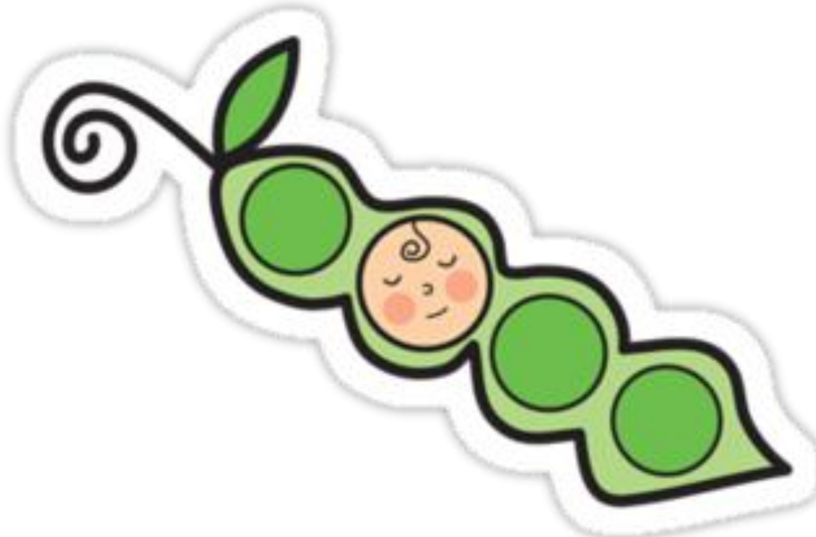
BABY PEAS (Pulse Early Alarm Sensor)

A non-evasive vital monitoring system providing caretakers power to make data-driven decisions for an infant's wellbeing.



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1 Executive Summary

Despite being a successful species at large, humanity starts off life as a weak and wholly dependent creature, with little capacity for communications or self-awareness. An infant requires 24 hours of careful supervision; a daunting task in today's busy world on a good day and a seemingly impossible task on a normal day. The Baby peas unit seeks to take some of the burden from the shoulders of the caretaker, giving him or her ability to multitask and accomplish chores around the house or take a brief moment of watchful relaxation. While not intended as a fully autonomous baby sitter of sorts, incorporating Baby peas in daily life will improve the quality of existence for both the infant and the caretaker.

This document summarizes the thought process behind designing the Baby peas system in terms of medical background, hardware and software solutions. Section 2 details the motivations behind the project and lists out the primary objectives. In addition, this section gives the preliminary parameters for unit operation, including battery life, physical packaging of device, sensor accuracy targets, wireless transmission range, and operating temperatures. Section 3 seeks to flesh out the background of the unit in three categories, existing examples, medical principles, and technological offerings. Starting off with existing projects similar to the Baby peas unit, primarily the owlet care sock and the KnightTime project for University of Central Florida's senior design during Fall 2012 and Spring 2013, the chapter then moves to other market share units, which are conventional baby monitors offered by such major health care companies like Philips. The latter half of section 3 investigates the relevant medical understanding underlining infant health markers and also the technologies involved in monitoring those bio-markers, such as temperature or pulse-ox sensors. Finally, this segment's last half ends with discussions on the choices for communications, mobile applications, the central microprocessor, and power systems. In this section, all of the chosen strategic components are listed. Section 4 delves hardware and software design details, including each sensor chosen, the microcontroller CC2541, the power systems, and mobile application. In addition to those modules, the discussion includes how data transfers between each module, and includes serial protocols such as I^2C and SPI. Unit 5 lists companies for printing the designed circuit board, and in addition lists options for populating the printed board. Once the board is made and populated, section 6 inventories prototype and system level testing. The prototype testing provides a listing of each sensor test, taking care to isolate each system and targeting each system specifically before a general integration test. After ensuring the viability, safety precautions and robustness of the unit, a final test commences on each group member. This document finishes with chapter 7, a section on general milestones for senior design 2, which is the next step in building Baby peas, and also the budget finance discussion and the roles and responsibilities of each member in the group.

2 Project Description

2.1 Project Motivation and Goals

Markets sell a variety of baby monitoring equipment that includes an abundance of features; some common features include infrared cameras and ambient temperature sensor. While many traditional monitors focus on the video as a safety feature, a baby's wellbeing is sometimes hard to decipher on a grainy screen. Our product, instead, focuses on quantifiable bio-markers, such as pulse oximeter, body position, and non-contact temperature sensors, to indicate the baby's health. This project strives to improve upon the current models and involves several factors for specific medical and social considerations. Geared toward infants and young toddlers, Baby Peas is designed to provide an empirical picture of the newborn's physical condition. If the pulse-ox detects sudden drops in pulse or oxygen levels, a triggered alarm alerts the caretaker. Whereas, if relying on video observation, the caretaker could find his attention distracted or misread a picture on the screen and lose critical minutes in a potential serious medical emergency. In addition to basic pulse functions, the body position and the temperature sensors can help monitor against risk factors for sudden infant death syndrome (SIDS). Although no definitive cause is known, the medical community agrees on several factors that can magnify risk of SIDS. The body position and temperature sensor should mitigate the risk factors. The main goal is to attach a small device around the ankle of a baby and secure it in such a way it can read heart rate, oxygen levels, body position, and skin temperature accurately without harm to the child. Once the data is obtained the ankle device will transmit data wirelessly to a host device such as a smart phone. At no time during the project will the ankle device be tried on a child of any age range. The concept can be proven out on members of the team and then scaled down in the future if so desired.

2.2 Objectives

Due to the nature of usage, form and packaging comprises a large portion of design. Because the unit is planned to operate under direct contact with the baby, safety considerations include minimal invasion and heat dissipation. In addition, ergonomic concerns include ease of use, bulk, and portability. Power factors in as well due to the targeted length of function time. Primary objectives are wireless transmissions of the bio marker data to a hand held device which is reliable over a wide range of environmental conditions and for a specific length of time. This objective goal needs to be reached by obtaining the bio marker from the ankle of the user. By reaching these objectives all of the group members will obtain desired knowledge in their respective career interests which will eventually help out with employment options in the future.

2.3 Project Requirements and Specifications

The requirements and specifications of the project can been seen in Table 1. These specifications are baseline goals to be reached which can be measured against for the success of the Baby Peas project.

Device Battery Life	> 12 hours
Weight of the Device	< .5 pounds
Dimensions (Ankle Device)	50 Width x 100 Length x 15 Height mm
Blood Oxygen Level Accuracy	+-20%
Heart Rate Accurcy	+-20%
Skin Temperature Accuracy	+-20%
Position Accuracy	Back , Stomach, right side, Left Side
Wireless Transmission Range	100 Feet

Table 1 Specification for the Baby Peas Project

3 Research Related to Project

3.1 Existing or Similar Project and Products

3.1.1 www.owletcare.com

Owlet Baby Monitor was developed by six students from Brigham Young University and won the first prize of Student Innovator of The Year in 2012. Tanor Hodges, who works at University of Utah Hospital, came up the idea with his friend Kurt Workman who is a chemical engineering student. Student Innovator of the Year (SIOY) is a competition for Brigham Young University for developing and encouraging students with new ideas, products with technology and engineering. It is sponsored jointly by the Ira A. Fulton College of Engineering and Technology and the Rollins Center for Entrepreneurship and Technology at the Marriott School. The sensor is incorporated in the Smart Sock which is worn by babies. It is capable of measuring heart rate, pulse oximetry, temperature and body position. The main motivation for the project was to combat SIDS (Sudden Infant Death Syndrome.) The data collected by the sensors are transmitted to parents' smart phones and the cloud which is accessible via any devices with internet connection. The main transmission method from the portable sensors to the mobile phones is via Bluetooth 4.0. The battery life is unknown but it is rechargeable. Notifications will be sent out when the batteries are running low. The Bluetooth is set at 2.4 GHz so that it would not interference with other cell phones, home alarms, and other electronics. Apple iPhone application has been developed and released; the developers are currently working on android counterpart. Upon the product debut, both platforms will be available to the consumer. The applications can be used with tablets as well. [7]

The notable features on Owlet Baby Monitors:

- Washable when the electronics are pulled out from the Smart Sock.
- Capable of monitoring more than one child at the same time.
- Cloud storage of data.
- Crowd funded.

3.1.2 KnightTime

KnightTime is developed by a group of senior design students from University of Central Florida in 2013. The group members were Anthony Bharrt who was a computer engineering major student as well as Facundo Gauna. The rest of the team members are Ryan Murphy and Bartholomew Straka, both electrical engineering students. The motivation of the project was to improve the quality of the sleep from data collected by biomedical sensors. Individuals could utilize the information gathered from the sleep management system to make decision or adjust personal habits in order to improve the quality of sleep. The key points measured by the KnightTime system are temperature, body movement, and heart rate. The wearable product was designed to be comfortable and non-irritable. Based on the collected data, software algorithms can determine the sleep stage of the individuals and wake them up once the sleep duration is met. Battery was crucial on this project because it had to provide the necessary power to the onboard devices, while maintaining the compact size. The sensors and the peripherals were chosen with low power consumption as top priority. The main focus for the product was user friendliness, modularity, and scalability. The user interface was designed to be very user intuitive. The hardware was simple and easily worn. [11]

The notable features on the KnightTime monitor:

- REM monitoring.
- Typical usage is for adults.
- Privately funded.

3.1.3 Current Majority Market Share Monitors

Various baby monitoring systems are currently available in the market. They can be categorized by functionalities such as visual, audio, and movement monitoring system. Most of the monitoring systems do not have any device implemented or attached to the babies thus they do not require FDA approval. Motorola MBP36 Remote Wireless Video Baby Monitor uses video camera capable up to 590 feet with infrared night vision. [5] It uses AC adapter as the main power source for the video/audio device and sends the video to the parent unit which has rechargeable Ni-MH battery pack. This particular unit also features two-way audio communication system with automatic channel selection. The parent unit is a standalone 3.5 inch LCD display with speakers and microphone. The retail price ranges from $150 to $250 based on additional features availability.

Philips AVENT Baby Monitor has a two-way audio system with guaranteed uninterrupted connection. [6] The packaging state that it provides crystal clear audio signal to the paired unit with automatic channel selection. Both the baby and the parent devices have a rechargeable battery pack with a low-battery warning light. The claimed operation duration is twenty-four hours of usage, and eight hours of battery recharging time. This baby monitor uses DECT (digital enhanced cordless communications) frequency band (1920-1930 MHz in the US and Canada) for encryption and clarity purpose. The streamed audio signals are encrypted with 64-bit encryption. LED lights on the parent unit are the indicators for baby environment sound level even when the units are muted. Similar products with comparable features are ranged between $25 dollars to $120 dollars. Baby movement monitors either utilize sensor enclosed pad or wearable device on the body. Angelcare Movement Monitor has sensor pad which is placed under the mattress to detect the body movements of the baby. If no movement is detected for 20 seconds, the LED light and a sound alarm will go off. Snuza Halo Baby Movement Monitor uses flexible belt with onboard sensor attached to the abdomen of the baby. It sends out alert signals if the baby does not move for 20 seconds or has less than 8 movements per minutes. It is advertised to be small, portable and easy to use. Before sending alert to the parents, Snuza baby monitor will vibrate gently when no movement is detected for 15 seconds.[10] In summation the baby monitors in the existing document focuses similar functionalities, particularly the video monitor portion. The monitoring system is augmented by user input functionality such as two way audio. This is achieved through a wireless component such as WIFI or Bluetooth. The cost varies from $10 USD to upwards of $150 USD. What the current market share lacks is a focusing on empirical data collection. All of the data collected are usually by visual inspection only, and there is no algorithmic manipulation of bio-marker data.

3.2 Relevant Technologies

3.2.1 Medical

Most parents have found infants have totally different sleep cycles then they do; waking up in the middle of the night to take care of screaming babies becomes a daily routine. The newborn spends about 16 hours a day sleeping on average, which is about twice as much compared to adults. As the babies get older, their sleep cycle will start to have a regular pattern. To accommodate the way babies sleep, an understanding of their sleep stages is critical. Just like adults, infants have REM (rapid eye movement) and NREM (non-rapid eye movement). Dreams occur during the REM stage of sleep, which are often referred to as the active stage of sleep. During the first couple months of life, newborns have about 50% of REM stage. As babies get older, the REM stage will become short and by the age of six months, REM state will be about 30% of sleep. NREM is the quiet stage of sleep, where hormones promote growth and tissue generation. Studies have shown the importance of sleep in cellular regeneration and waste product removal. It is important the brain gets rest and energy gets restored.[1] In particular, in babies, due to rapid cellular growth and brain development, REM sleep can have lasting impact on overall health of the baby throughout his/her lifetime.

3.2.1.1 Infant Sleep Cycles

For the first two month of life, the sleep cycles are varied around the clock and may even interfere with mealtime and diaper change. In addition, infants are quite mobile and may appear to be restless during sleep. Parents often learn what the babies want by associating certain gestures to the need. In addition, parents can help the infant adjust to a normal circadian cycle by introducing regularity and patterns. Parents can encourage nighttime sleep by dimming the lights in the evening and reducing the ambient noise level. This signals to the baby that sleep is imminent and will train the baby to form a Pavlovian response. On the other hand, parents may try to stimulate the babies with lights and noise to keep them occupied during the day, forming the opposite Pavlovian response to night time. [2]

From age of three months to one year old, sleep will be more regulated as the infant will tend to sleep through most of the night. The infants will take between one to four naps during the day, each of which can last from thirty minutes to two hours. At this stage of life, the infants may become attached to the caregiver. Separation from the caregiver may cause anxiety to the infants which have negative impact in the quality of sleep. Social and environmental exposure will have an effect to their sleep as well.

Toddlers (one to three years of age) have longer sleep spells, and the nap time is reduced to once a day, which lasts one to three hours. Separation anxiety, social and motor development can affect the toddler. Nighttime fears and nightmares have negative impact on their sleep. They often show symptoms such as drowsiness and lack of energy during the day. Providing a stable environment is the key to ensure quality sleep.[1]

While easy on paper, the act of normalizing a baby's sleep pattern is difficult and can prove trying for any new parents. A baby monitor such as Baby peas can help to quantify the amount of sleep and the pattern of sleep the baby is experiencing. The caretaker can look at the trend in sleep and determine the next steps.

3.2.1.2 SIDS

Sudden infant death syndrome (SIDS) is the sudden and unexplained death of an infant who is younger than a year old. SIDS can affect even seemingly healthy babies. Most instances of SIDS deaths are associated with sleep; where there is an infant is unable to properly react to a life-threatening situation. A SIDS diagnosis usually occurs when all other causes of death have been ruled out. Most SIDS deaths occur between the ages of two and four months. Racial statistics show that African-American and Native-American infants are two and three times as likely, respectively, than Caucasian infants to be struck by SIDS.[21]

Several factors are thought to exacerbate the probability of SIDS; these factors are both environmental and genetic. Stomach sleeping is thought to increase the risk of SIDS. This danger comes from the infant being in a position to restrict airflow as the baby lacks strong stomach and diaphragm muscles to fight against the force of his/her own weight on the lungs. In addition to no completing a full breath and not getting enough oxygen, another possibility is that the infant is rebreathing his or her own exhalation. This could be caused by the infant's weight or by the infant's mouth being surrounded by stuffed toys or blankets. Both factors of the elevated carbon dioxide levels and lack of oxygen could contribute to SIDS. Another possible cause of SIDS is an abnormality in the arcuate nucleus, a part of the brain that helps control breathing and awakening during sleep. Usually a lack of oxygen will cause the infant to wake up and cry, changing the breathing pattern and allowing oxygen levels to return to normal. A dysfunctional arcuate nucleus would not cause this involuntary reaction and increase the chance of SIDS. [22] Sudden unexpected infant deaths may also be explained by poisoning, metabolic disorders, hyper or hypothermia, neglect and homicide.

Other ways to avoid SIDS:

- Avoid bumper pads in cribs
- Studies have shown that immunization can reduce the risk of SIDS by 50%

- Do not expose the baby to second-hand smoke

In summary, due to the varied factors of sudden infant syndrome, it is difficult to pinpoint the exact cause and remove that cause. If all the environmental causes are removed, the baby could still have a defective arcuate nucleus. If the arcuate nucleus is the culprit, there's also hyper or hypothermia. As such, while it is possible to try to remove all factors that can contribute to SIDS, it is difficult to make sure that all factors are completely removed. Instead of preventing by factors, prevention by monitoring and alertness is the best method, due to the dynamic nature of the prevention. Baby peas monitoring system will offer a four pronged approach to help with monitoring factors that affect SIDs. Temperature, pulse, rotation, and oxygen parameters touch on all of the risk factors mentioned above. Having an empirical data stream of these factors could allow the caretaker make a much better decision on the wellbeing of the child.

3.2.1.3 Vital Signs

Vital signs are the initial measurements which represent the general health condition of an individual. The four main measurements in most medical settings include body temperature, heart rate, respiration rate, and blood pressure. Pain level, blood oxygenation may also be included if the appropriate medical devices are available. The Baby Peas project aims to provide parents with reliable, convenient, real time updated vital signs of their babies. Each vital sign related to the Baby Peas project will be discussed in the following sections.

3.2.1.3.1 Skin Temperature

Sudden onset of fever in the newborns, caused by a myriad of factors such as system infection, dehydration and physical surroundings, has caused many parents sleepless nights. The immune system in the infants is not fully developed until around six months of age. In addition, as mentioned above, hyperthermia and hypothermia can be factors leading to SIDS. It is crucial to monitor the temperature in order to make necessary medical evaluation and interventions. A thermometer measuring the babies' temperature continuously can do just that. Many possible causes can make the temperature to rise in the infants, and nearly all of them are signs of a systematic response. The most common cause is infection, whether it is viral or bacterial. When the body encounters foreign microorganisms, the immune system will try to fight them off with antibody responses or produce more leukocytes. Part of the immune response is to raise body temperature since certain bacteria and virus cannot withstand a higher temperature environment. Pyrogens are responsible for raising the body temperature by interacting with the hypothalamus region of the brain. Moreover, dehydration is another cause for fever. Water has a very high specific heat and can absorb very high temperatures or conserve temperature. As such water is critical in maintain homeostasis. When the infant is dehydrated, the body is unable to regulate temperature efficiently and thus body temperature can spike. An adult might be able to deal with dehydration more efficiently due to the larger quantities of water, but an infant has a much more limited amount of storage for water. Identifying the cause of dehydration in a timely manner is crucial. In addition to dehydration and infections, wrapping the babies with too much clothing may raise the body temperature as well. Infants are fragile and any measures are usually amplified by a magnitude, so the caretaker needs to be every vigilant. [3]

A few ways to measure infant's temperature are rectally or orally. While taking the temperature rectally gives the most accurate results, it is inconvenient and may be irritating to some babies. Measuring oral temperature is not recommended since it requires the closure of the mouth and under the tongue for accurate reading. It could also be unsafe to stick object into an infant's mouth. Using ear thermometer may also be irritating and the accuracy could suffer under certain condition such as excessive ear wax. Some hospitals' policy to measure temperature is using temporal artery thermometer. While it's easy to use on adults, it does not necessary apply to infants until they reach three months old. Measuring temperature using regular thermometer under the armpit (axillary temperature) is easy, convenient, and rather safe. On the down side, it is quite inaccurate. [3]

Causes for temperature spikes and ways to measure accurately

- Infections, dehydration and physical surroundings
- Most accurate measurement is rectally
- Most noninvasive is through armpit

Temperature is a vital sign that the caretaker needs to know in order to ensure the safety and health of the baby. Baby Peas can help with monitoring temperature; accuracy may be a trade-off for convenience. As mentioned above, using a rectal thermometer is the most accurate but also the most invasive. Measuring the armpit, while not as accurate, is the least invasive. The danger of temperature is not necessarily in the minute degree differences, but rather in spikes or unusual declines. Using a temperature sensor that can be attached to ankle and wrapped with a sock seems reasonable as long as the normal general temperature in the certain area is taken into consideration. Knowing the long term trend of the baby's temperature tells more about the wellbeing of the baby rather than single point data.

3.2.1.3.2 Blood Oxygen Levels

Blood oxygen is an important part of vital signs. The cells in our bodies consume oxygen and nutrients to maintain their functions. Depending on the environment and activities, saturation of oxygen level may change. There are two ways oxygen is transported in blood vessels. The majority of oxygen is bonded to hemoglobin on the red blood cell. A red blood cell has four heme groups and each of the heme group can bind to one oxygen molecule. Some oxygen can be dissolved in the plasma. While the dissolved oxygen is the minority (3%) compared to the oxygen content of the body; they play a crucial part in deliveries of oxygen to the tissues. Body temperature, pH, abnormal hemoglobin, concentration of carbon dioxide and concentration of carbon monoxide can have physiological effect on the deliveries of oxygen as shown in Figure 1. With portable pulse oximeter sensor such as Baby Peas monitor, the oxygen saturation can be closely monitored at all times.

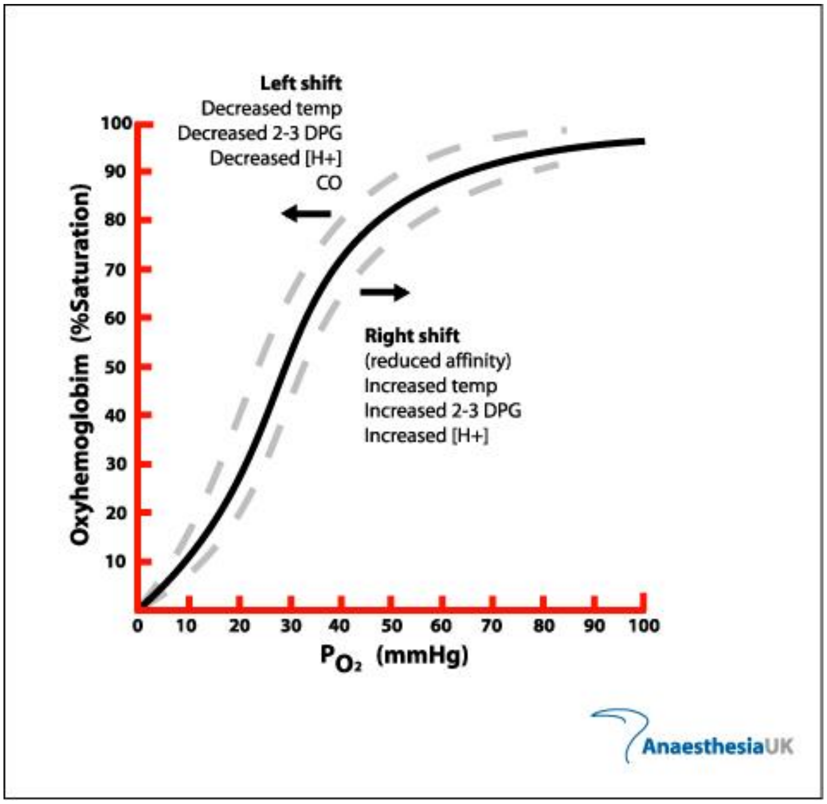

Figure 1 Oxy-Hemoglobin Dissociation Curve. This image has been reprinted from AnaesthesiaUK, with permission (www.AnaesthesiaUK.com)

In general, blood oxygen level measured by the pulse oximeter is accurate in most cases; it is important to consider other factors in certain scenarios.

3.2.1.3.3 Heart Rate

The heart is the vital motor to the body just like the engine is to a car. Blood is the organ being transported by heart to the rest of the body. Nutrients, wastes, oxygen are carried in the blood along with antibodies and foreign material fighting agents. There are four chambers in the heart- right atrium, right ventricle, left atrium and left ventricle. In systemic circulation, blood is pumped out from left ventricle through aortic valve (three leaflets) to the aorta during systole. From the arteries, blood is delivered to the tissues in the capillaries where gases and nutrients exchange occur. The deoxygenated blood moves to the vein and returns to the heart in the right atrium. From the right atrium, it moves to the right ventricle thru tricuspid valves. During heart muscle contraction, the blood is pumped to the lungs via pulmonary artery. Once the blood reaches to the lungs, the oxygen and carbon dioxide exchanges take place and oxygenated blood is carried to the heart thru pulmonary veins. The left atrium receives the blood and transports the blood to the left ventricle through mitral valves during diastole. The heart perfuse itself during diastole phase when the aortic valves close and blood goes through sinus of Valsalva or often called sinus of aorta into the coronary arteries.

Heart rate may change upon exertion; in the cases of babies, the heart rate responds to excitation or stimulation. Compared to adults, babies' heart rates are significantly higher.

As they age, it will drop down slowly. The pattern of the heart beats can be measured by EKG (often referred as ECG, electrocardiogram.) It is done by placing electro-leads in various spot of the body which measures current from one end to the ground lead. Heart rate changes from time to time but should remain in a regular pattern regardless of the frequency. Underlying disease may present if irregular patterns or waveforms are seen on EKG. The maximum heart rate can be calculated by subtracting individual's age from 220. For example, a healthy 35 year old male should have a maximum heart rate about 185 beats per minute. Heart rate may change when illness are present. As discussed in the body temperature section, heart rate rises as body temperature increases for increased metabolism. Medication can affect the heart rate as well. Auscultation is performed by placing stethoscope on the chest and listening to the sound of the heart as it beats. In one heartbeat, a loud thump can be heard during systole and followed by a faint thump which indicates diastole. In patient with congenital defects or dysfunction heart valves, murmur is heard indicating the blood backflows. A specialist should be consulted in these cases.

By employing a Baby peas unit, the caretaker can see the normalized heart beat rate for the baby. In a typical day, a person's heart beat rate can change due to the biological circadian rhythm. For a baby, this is no different. Having a Baby peas unit can help set a base line for the baby and alert the caretaker if a gross deviation happens.

3.2.1.3.4 Breathing Rate

Respiration is measured by a cycle of inspiration and exhalation. The basic function is to exchange oxygen and carbon dioxide to maintain bodily functions. Acid-base balance of the body is regulated via respiration as well. Arterial blood sample is drawn and analyzed if respiration pattern or effort is compromised. Just like heart rate, respiration rate can rise when illness is present. In a healthy baby, the respiration rate is about 35 and up to 70 with excitation. If respiration rate drops below normal and the baby appears to be lethargic, the parents should seek emergency medical attention.

In conclusion, it is important to monitor the babies regularly to prevent tragedy from occurring and provides a peace of mind for the parent. In Table 2, a summarized chart compares newborns, infants, toddlers and adults for their normal vital signs. Please note the vitals are for health individuals without congenital disorders. Certain diseases or health issues may alter the "norm" of each individual. The Baby Peas project aims to provide easy, convenient, and safe ways to monitor babies. Utilizing low power consumption components, heat generation is reduced to minimum. With high quality sensors, we maximize the accuracy to ensure the safety of the babies.

	Heart rate Beat per minute	Oxygen Level Percentage	Respiration Respiration per minute	Blood Pressure mmHG	Sleep Time Hours per day
Newborn (1-2mo)	90-170	>95%	35-70	84/52	16 Hours
Infant (3-11mo)	90-170	>95%	25-70	84/52	9 to 12 with naps
Toddler (1-3y)	80-160	>95%	25-35	84/52	12 to 14 with a nap
Adult	60-100	>95%	12-20	120/80	8 Hours

Table 2 Vital Signs Chart Summary

3.2.2 Pulse Oximetry Sensors

As discussed previously, blood oxygen level is measured by a device called pulse oximeter. Two light emitting diodes are required to differentiate the oxygenated red blood cells from deoxygenated ones. The light travels through the skin and hit the light sensitive detector on the other side. There are two main light waves to be considered. One is at 660 nm (red light) and the other at 940 nm (infrared.) The oxygenated red blood cell absorbs the light source with longer wave length (940 nm) while the deoxygenated red blood cell absorbs 660 nm. As seen in the Figure 2 below, absorbance of wavelength is subjected to the red blood cells with or without oxygen. [12]

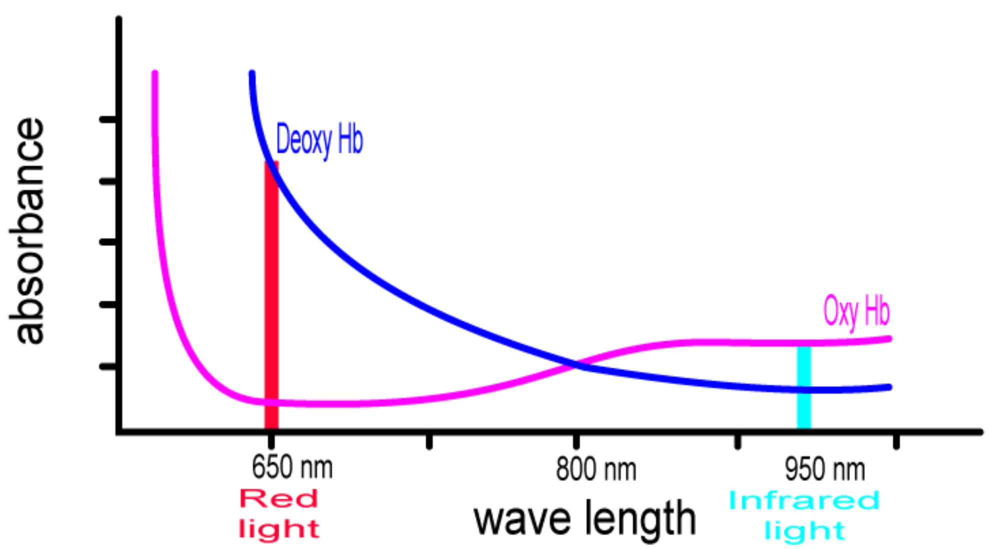

Figure 2 Absorbance vs wavelength diagram. Diagram reprinted via permission from diagram designer Pras at Pras2@onvenus.com

Majority of the light does not reach the light detector due to light absorption by the skin tissue and bones. The amount of the light at the receiver site is actually around 2% of the total emitted. By comparing the amount of light being absorbed at different wavelengths, a ratio can be calculated. The ratio signifies total amount of oxygenated hemoglobin compared to total hemoglobin. In Figure 3, 75% is shown based on absorption of infrared light is 75 percent compared to the amount absorbed in red light.

The mathematical equation for measurement:

$$R = \frac{\log_{Iac} \lambda_1}{\log_{Iac} \lambda_2} \quad \text{SaO2} \propto \text{R}$$

λ_1 = the wavelength of 660nm

λ_2 = the wavelength of 940nm

I_{ac} = the current from analog front sensor

R = ratio used from Figure 4

SaO_2 = oxygen saturation

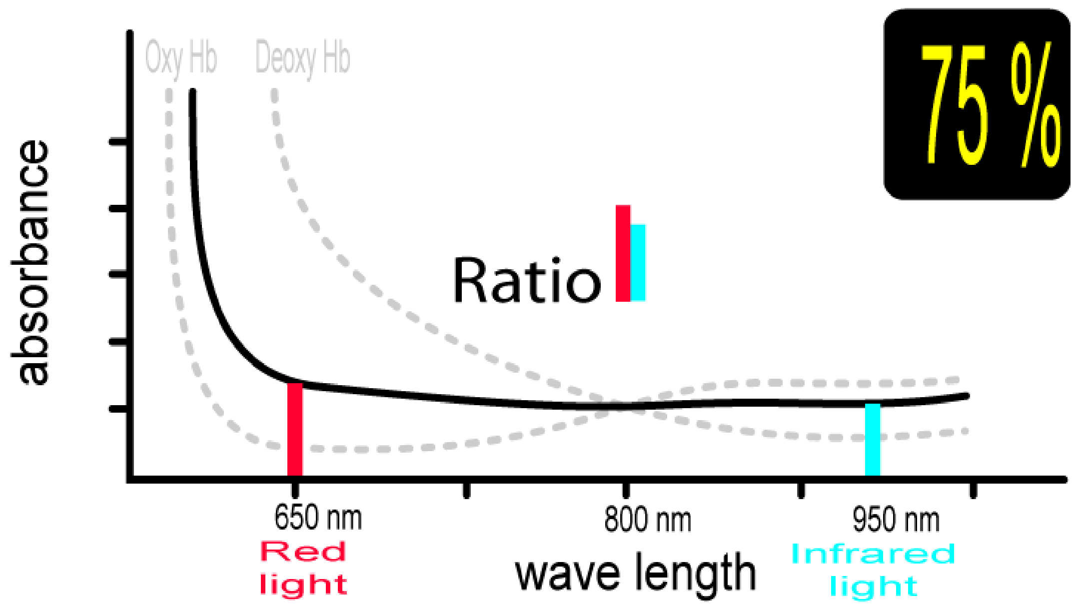

Figure 3 Light Absorption ratio. Diagram reprinted via permission from diagram designer Pras at Pras2@onvenus.com

Note that there are factors which might alter the trustworthiness of final calculations. Methemoglobin and carboxyhemoglobin absorbs light in a different wavelength and is not being calculated in a typical pulse oximeter. CO-oximeter is needed for such circumstance which requires a different design which will not be used in the Baby Peas project. The formula below shows the overall oxygen saturation percentage.

$$SaO_2 = \frac{100 * HbO_2}{Hb + HbO_2 + HbCO + METH + nhemoglobin}$$

Hb = all hemoglobin
HbO2 = hemoglobin binds to oxygen
HbCO = Carboxyhemoglobin
METHb = Methemoglobin
Nhemoglobin = non-functioning hemoglobin

Since only the oxygenated blood is needed for calculation, the change in the signal is used. Filtering out the non-changing signal using complex mathematical manipulation, the remaining data represents the pulsating arterial blood hence the name"pulse oximetry."

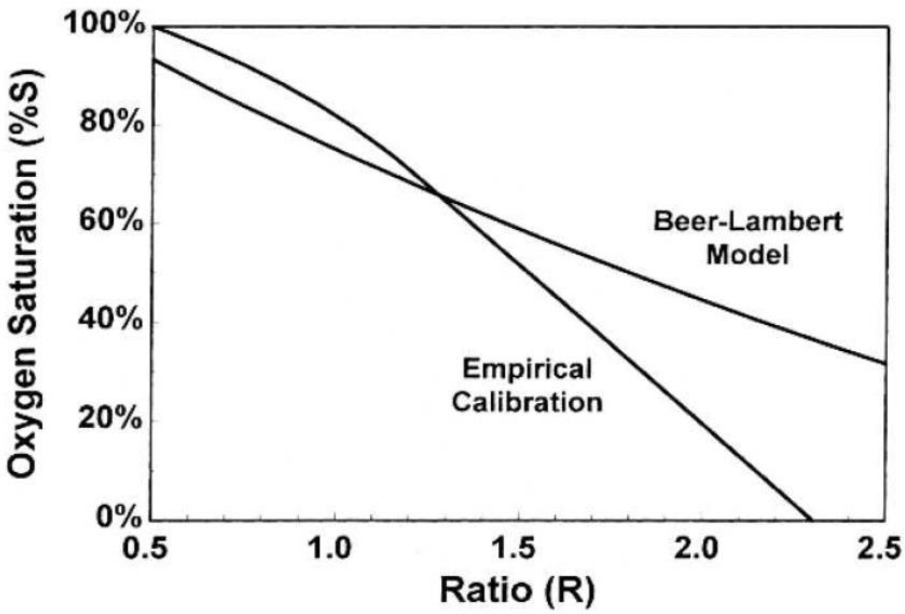

Figure 4 Oxygen Saturation Ratio Plot. Reprinted without alteration with permission by Texas Instruments

The accuracy of the pulse oximeter level can be affected by room ambient light, the position it is attached to be body part, the coverage between light source and receiver. Cool and clammy skin caused by poor peripheral perfusion could prevent reading from the sensor. Care must be taken to package the sensor in a light tight enclosure to shut out possible noise.

3.2.3 Temperature Sensors

General parameters in this application for temperature sensors are low power consumption, easy to integrate, and small form factor. Proper power management is essential for safe operational environment. The sensor will be used to measure skin temperature on the infant. In Baby Peas project, a thermopile sensor will be used due to its capability of measuring temperature without skin contact. With high power consumption, the element may be heated and cause discomfort. Fire hazard is another issue since cloth may be used to conceal the element. With numerous temperature chips available on the market, our goal is to acquire one that can be easily used with our microprocessor. Many microprocessors are under consideration but CC2541 from Texas Instrument meets all the requirements. Sensors that are compatible with CC2541 are the top candidates in this application. Some models of microprocessors are equipped with internal temperature; however, they are read the temperature of the chip, and not necessarily the ambient temperature. A separate chip is needed because the size of the sensor is a major factor to be considered in this project. Many chips met the requirement but not all are necessarily appropriate. Technologies involved with the sensor type include - thermistor, thermocouple, resistance temperature detector (RTD), and semiconductor. As seen in table 3, technology using semiconductor provides excellent accuracy and repeatability as well as low heat generation.

Criteria	Thermocouple	RTD	Thermistor	Semiconductor
Temperature range (typical values)	Very wide –200°C to +2000°C	Wide –200°C to +650°C	Narrow –50°C to +300°C	Narrow –50°C to +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) sensitivity	Excellent	Fair	Good	Good
Lead effect	High	Medium	Low	Low
Self heating	No	Very low to low	High	Very low to low
Overall advantages	Self powered, simple, inexpensive, rugged, variety of physical forms, wide range of temperature	Most stable, most accurate, more linear than thermocouple	High output, fast, two-wire ohms measurement	Most linear, highest output, inexpensive
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

Table 3 Thermo Sensor Technology. Reprinted without alteration with permission by Texas Instruments

The application requires small form factor in order to be applied to the ankle on an infant. Using semiconductor based sensors, we can achieve ultra-low power consumption with a form factor less than 3 mm^2.

3.2.4 Body Position Sensors

Being able to tell what position the baby is in is a critical design specification of the Baby Peas' project. Position of the baby was at the top of a list of 10 steps to help prevent SIDS from a current WebMD article sponsored by Johnson's baby [35]. The CDC

(Center for disease control) states since the 1990's, SIDS related deaths have decreased in the United States by over 50% since the steps to prevent SIDS have been instituted [36]. The Journal of American Academy of Pediatrics suggests babies should be positioned on their back while they sleep. If the baby is placed on their side or in the prone position (sleeping on their stomach) then the risk of SIDS is much higher due to rebreathing of expired gases and also overheating. Stress is also placed on the baby's cardiovascular system during prone sleeping which can increase heart rates to abnormal levels [37]. Since the main goal of this project is to help and aid in the prevention of SIDS, being able to tell whether the baby is in the prone, side, or back position is vital to success. Position of the baby can be monitored through a couple of different methods. The Baby peas' project could keep a camera on the baby being monitored. This idea fits into the goal to achieve non-evasiveness in the project but creates another external peripheral to integrate into the system. Since the main peripheral to be implemented has other sensors attached to it a solution need to be found which can be integrated alongside the other vital signs sensors to keep costs and development time at a minimum. Some technology solutions include the accelerometer or gyroscope.

3.2.4.1 Accelerometers

Accelerometers measure acceleration (time rate of change of velocity) of an object with respect to the Earth's gravitation. While acceleration is not the object of concern for the Baby peas' project, one can derive position from acceleration data because the second derivative of position leads to solving for acceleration. The following equation models acceleration as a function of position:

$$a(t) = \frac{dv(t)}{dt} = \frac{d(x(t))^2}{dt^2}$$

a = acceleration
v = velocity
x = distance/position
t = time
d = derivative notation

Since we are measuring acceleration with the accelerometer, we would need to use the mathematical method of integration to solve for the position. Now how these devices actual measure the acceleration ranges from device to device. Some devices use the piezoelectric effect, which means they contain microscopic crystals which are stressed by the forces of accelerations. These crystals begin to slightly vibrate which will cause a voltage to be generated. Voltage proportions can be used to determine levels of accelerations. Another way is for the device to measure changes in capacitance. This is done by placing two structures close to each other to form a capacitor and if any movement occurs the structures could move, causing a capacitive change which can be monitored as well to determine acceleration. For accuracy purposes, accelerometers can determine 2 dimensional positions or 3 dimensional positions. Since accuracy is critical, a 3 dimensional device which measures the acceleration at 3 axes is better suited to the project. Another aspect to pay attention to with accelerometers is their "g" level of range.

The g level corresponds to reference points. The "g" values also can be referred to as the measurement of the acceleration component of gravity on Earth, which is 9.8m/s^2. So Earth's gravity is 1g.[39] While a higher 'g' may mean the range is greater it does not necessarily mean the precision is better. If the object in which we are trying to measure isn't going to accelerate at more than +/ 2g's, then there is no reason to have a device which can measure up to 24g's. Determining what the max acceleration a human body part can move in terms of 'g' is important and will be a factor in the choice of an accelerometer device. Sensitivity of the device can be determined by the change in output voltage divided by the change in g. The higher the g the more sensitive the device will be; so the project needs to look for a device which has a high g. Having an accelerometer device in the Baby peas' project would be a possible solution for solving position. Accelerometer semiconductor devices range in price, size and accuracy. The most important piece when choosing which device and the trade-offs associated with it will be its power consumption related to accuracy and price. Another aspect is whether we want a device which outputs a digital signal or analog signal. If we choose an analog output then the microcontroller we choose will have to have its own built in analog to digital converter (ADC) circuitry. If analog is chosen, an external ADC may also be used but this drives up the cost and takes up more space on the circuit board. If a digital output accelerometer device is used then the importance comes into play on whether it supports SPI, I^{2}C, or UART. [38]

3.2.4.2 Gyroscopes

Gyroscopes unlike accelerometers measure the angular velocity around a specific axis. Gyros have the unique ability to be unaffected by gravity whereas accelerometers are. Gyroscopes are commonly used to give orientation of an object which is still in motion. Gyroscopes like accelerometers are still references about an X, Y, and Z axis plane system. Sometimes these axes' can be referred to as roll, pitch, and yaw. The Gryo measures the angular velocity in units of degrees per second. The Baby pea's project can use this information to determine the position of the infant. Gyroscope devices, like accelerometers, offer analog and digital outputs. So the design would be similar either for an accelerometer or gyroscope.

3.2.4.3 IMU

Accelerometers and Gyroscopes both offer unique measuring tools on their own, but looking for a device which combines both into one would be the ideal situation for the Baby pea's project. An IMU is such a solution. The IMU combines both the accelerometer and gyroscopes functions to provide the designer with 6 axes' to derive positional data from. Now these calculations can be determined by using both an accelerometer IC and Gyroscope IC on the baby pea's printed circuit board and utilizing the data from both sensors to determine position or a combined one chip solution can be realized which gives a digital output over SPI, I^{2}C, or UART to the microcontroller.

3.2.5 Wireless Technology

One of the striving features for the Baby pea's project was to create something that was non-evasive. Conventional baby vital sign monitors are almost exclusively wired technology and only available by going to the doctor. The commercial industry standard for monitoring anything in the home setting is with video and audio streaming. While these are non-evasive and wireless technologies they do not provide the necessary tools for gathering heart rate, oxygen levels, and skin temperature but do provide baby positioning information if a video option is taken. Although a product offering a video monitor does not provide positional data unless the user is explicitly looking at the video screen of the monitor. Thus the user could be unaware of the position of the infant because the display device will not actively warn when the infant has turned to the side or stomach. So to avoid the clunky and extremely evasive technique used in hospitals and doctor offices (wired), the project has to use a wireless technology to be able to monitor the sensors implemented without much intrusion. In doing this some hurdles must overcome. There are 8 main areas of concern to include battery life, range, data transfer rates, data security, ease of implementation according to project schedule limits, heat dissipation, and network topology constraints. Finding a wireless technology which supports all these features in an advantages way requires consideration of all relevant wireless technology and a final comparison to see which one fits best for the specifications and cost requirements.

3.2.5.1 Bluetooth

Bluetooth is another widely used wireless technology. It, like WI-FI, utilizes a Master/Slave network. Bluetooth can have 1 master and 7 slaves which are formed into a piconet.[30] It has an IEEE 802.15.1 standard protocol certification but the protocol is no longer controlled by IEEE 802 but instead is run by the Bluetooth Special Interest Group. This group is made of over 19,000 members in the consumer electronics industry.[34] Bluetooth works in the ISM band of 2.4 GHz. It uses frequency hopping spread spectrum technology which can help in the avoidance of interference of other ISM devices transmitting in the 2.4GHz spectrum. It uses GSFK (Gaussian Frequency-shift keying) modulation and supports all Network topologies (Mesh does need special application enabling). Bluetooth is especially designed for low power consumption. Its range depends on different protocols and individual setups but can vary between 1 meter to 100 meters. This meets our specification limits for range. Components are very low cost and the design parameters for Bluetooth are geared towards a quick time to market approach. This is good for the baby peas since we have a limited time constraint for development. Bluetooth is also prevalent and almost all cell phones, laptops, and tablets. Bluetooth is also certified and one of the preferred technologies being pushed by the non-profit organization Continua Health Alliance which seeks to set industry standards for health technologies. There are two different protocols to discuss dealing with Bluetooth which are Bluetooth Classic and Bluetooth LE (Low Energy). [34]

3.2.5.1.1 Bluetooth Classic

Most of the specification for Bluetooth classic is already covered in the above paragraph. The max range is approximately 100m. Data rates of 1-3Mbits/s. It’s voice capable but takes around 100ms to transmit data packets. Its peak current consumption is around 30mA

3.2.5.1.2 Bluetooth Low Energy

Bluetooth LE is the newest version of the Bluetooth standard. It can also be called Bluetooth v4.0 and Bluetooth Smart. It has some stark differences between previous versions. One of them is Bluetooth LE is not backwards compatible with previous versions of Bluetooth. Bluetooth LE hardware is different from previous versions. It still uses the same topologies, but Bluetooth LE is geared heavily towards low energy consumption. It has a reduced range of 50 meters, which still meets our range specification. While it still uses GFSK modulation the LE version does not transmit on 79 channels but rather on 40 channels which are 2 MHz wide. It has a maximum transmit power out of 10mW. The data transmit rate is 1Mbit/s but the transmit time is only 6ms which contributes to less power consumption. Most LE devices operate in single mode which means they only operate using the Bluetooth LE protocol stacks, but there are devices which are dual mode which means they can operate either Bluetooth Classic or Bluetooth LE. These devices are called Bluetooth Smart Ready.[30]

Pros:

- Extremely Low Power Consumption
- Battery life using a CR2032 can last up to a year in some applications
- Data Rates needed meet specifications
- Protocol Stacks are already available
- Numerous Vendor supported products
- Compatible will almost all smartphones, tablets, and laptops
- Compatible with all OS platforms
- Very secure (128 bit encryption)
- Minimum interference from household devices using ISM band due to frequency hopping technology.
- Software implementation is made easy with plenty of vendor support

Cons:

- Max range on LE is 50 meters
- Sometimes making a connection between two Bluetooth devices can be difficult.

3.2.5.2 WIFI

WI-FI is one of the most widely used wireless technologies available for home use. Around 61% of households within the United States have a WI-FI network according to a research study from Strategy Analytics Connected Home Devices services.[32] WI-FI has a standardized protocol through IEEE 802.11. It uses a star or point to point topology which basically means one WI-FI devices acts as the Master and it can have multiple slave WI-FI devices it connects too. The slaves can only talk with the master and not the other slaves. It has very high bit transfer rate (300 Mbps), great security (WEP, WPA, WPA2), operates in the ISM (Industrial, scientific, and medical) radio band of 2.4 GHz and 5 GHz, range of 35 meters indoors, high power consumption. WI-FI has potential to be used in the baby peas project because of its great range and compatibility with mobile phones, tablet PC’s, laptops, and Smart TV’s, and Gaming consoles which all have WI-FI integrated circuits which support the 802.11 standards. Some of the concerns with WI-FI are the high power consumption and ease of implementation.[30]

Pros:

- High Data Rates
- Less interference if transmitting in the 5GHz range

- Compatibility with most consumer electronics
- Exceeds Range specifications for project
- Protocol support plentiful
- SOC (system on chip) solution

Cons:

- High power consumption
- A lot of interference at the 2.4GHz range

Not so easy to implement

3.2.5.3 ZIGBEE

Zigbee is a wireless technology suited for low power consumption applications. It is maintained under the IEEE 802.15.4 standard. Its main applications are wireless control and monitoring which is exactly what is needed for the baby pea's project. Zigbee uses mesh network topology which basically means there is one Master and many slaves but the slaves can relay messages from one to another. If one of the Zigbee devices breaks down it's still possible to get the data received or transmitted by another Zigbee device handling the data. Zigbee operates in the ISM band of 868 MHz, 915 MHz, 2.4 GHz. Transmission data rates are around 250Kbit/s for the 2.4GHz frequency range and max ranges are around 20m which is a problem for the baby pea's project. Zigbee operates on 16 channels which are 2Mhz wide and 5Mhz apart.[31]

Pros:

- Low power consumption

Cons:

- Does not use frequency hopping which could cause interference with most household devices using the 2.4GHz ISM frequency range
- Low data rates
- Vendors moving away from supporting
- Difficult to implement

3.2.5.4 ANT/ANT+

ANT and ANT+ are proprietary wireless protocol sensor networks. Its main applications are for sport and home health. It also operates in the 2.4 GHz ISM band. ANT products come preloaded with protocol software packages and are controlled through UART, SPI, or USB. It has low power consumption and can operate on a coin cell battery. It can support all network topologies. There are 8 channels and they are bi-directional. It uses adaptive isochronous network technology to avoid interference with other household products transmitting in the ISM RF spectrum. Data rate is 20kbps. Range is 30m.[33][30]

Pros:

- Uses all Network Topologies
- Low power consumption
- No sensor slave limit

- Extremely fast transmit time :

Cons:

- Not all new smart phones support ANT/ANT+
- Lower Range
- Low Data Rate
- Usually transmits on a single channel for each device. If that particular frequency is not free within the band it halts data transfer and could potentially have packet lose.

3.2.5.5 Zwave

Z-wave is another proprietary wireless technology aimed at home automation. It operates in the 900MHz range. Z-wave uses low-latency communications of small data packets. The data rates are around 100kbps. Its range is around 30m. It uses a mesh network topology and its modulation mode is GFSK.[31]

Pros:

- Low power consumption
- Up to 232 devices on one mesh network
- Simple protocol and faster time to market
- Does not interfere with the crowded ISM band of 2.4GHz

Cons:

- Low data rates
- Only 1 source for z-wave components and they only sell to OEMs, and ODMs
- Range might not meet specifications for project.

From an analysis of all the available wireless technologies the Bluetooth Low Energy technology seemed the best suited for the baby pea's project. Due to low power consumption needed and a wealth of vendor support and example projects for both software and hardware implementation the Bluetooth Low Energy solution was thought to have fit best. Unfortunately understanding the BLE software stack for the CC2541 was much more difficult than expected. Problems with IAR embedded workbench design environment and the sample projects complexity level prevented the Baby Peas project with using the BLE design protocol. In the end the BLE portion was dropped and Bluetooth Classic was used.

3.2.6 Data Communications

In computer architecture, data is communicated between components using a bus. Buses are also used to communicate between multiple computers. Buses can be differentiated by the method of transmission, differentiation of bits, and authority to transmit. The method of transmission can be either single-ended or differential signaling. Single-ended signaling is the transmission of an electrical signal through a single wire. The transmitted voltage is compared against a ground voltage to determine if the bit is high or low. Differential signaling sends two signals across two paired wires, called a differential pair. The difference between the two signals is analyzed to determine if the bit is high or low.

The advantage of differential signaling is the ability to deal with electronic noise. When an electric signal is affected by noise in a single-ended transmission, the received signal can be misinterpreted due to the change in voltage. In a differential pair, noise will affect both wire the same. Theoretically, the difference between the wires should stay about the same so the information sent would be unaffected.

A bus can also send the data through serial communication or parallel communication. Serial communication sends data one bit at a time across the bus. Parallel communication sends several bits at a time on parallel channels that are assembled to retrieve the original message. Due to cost and complexity, most buses are serially communicated. Devices may support bus mastering, which enables the device to initiate the transfer of data across the bus. Depending on the nature of the hardware and software, multiple master nodes may be necessary for certain devices.

3.2.6.1 I^2C

I^2C is a multi-master serial single-ended computer bus invented by Philips.

3.2.6.2 SPI

The Serial Peripheral Interface bus (SPI) is a synchronous serial data link developed by Motorola that operates in full duplex mode. Full duplex implies that the link can send data both ways. A data link is synchronous when data is transferred on a clock cycle.

3.2.6.3 UART

A Universal Asynchronous Receiver/Transmitter is a piece of computer hardware that translates data between parallel and serial forms. This type of data transfer is considered "universal" because the data format and transmission speeds can be configured.

3.2.7 Mobile Applications

The project is going to be using a mobile application as the user interface. A mobile application is a piece of software designed to do a useful function beyond the basic functions of making the computer run. Multiple mobile services offer the ability to download and run applications on their mobile operating systems. This includes the Apple App Store, Google Play, Windows Phone Store, and BlackBerry App World.

3.2.7.1 IOS

The iOS is the operating system used for the products developed by Apple Inc., such as the iPhone, iPad, and iPod Touch. The iOS is based off the OS X kernel. Software applications for the iPhone or related products can be downloaded on the Apple App Store. The Integrated Development Environment for Apple products is called Xcode. Xcode supports source code in C, C++, Objective-C, Objective-C++, Java, Applescript, Python, and Ruby programming languages. Xcode is one of the features on the iOS Software Development Kit, which also include the iOS Simulator, iOS Platform-tools, and Interface Builder. The iOS user interface is programmed through a framework called Cocoa Touch. This controls the actions of the touch-screen interface and its interactions with the operating system. Applications for the iOS are usually programmed in a C language (C, C++, C#).

3.2.7.2 Windows Phone

Windows is the operating system developed by Microsoft and is used in most Microsoft products, including many desktop computers, smart phones, and the Xbox. The latest version of Windows is Windows 8. Many programming languages are supported by Windows Store apps. These include Java, HTML5, C#, Microsoft Visual basic, XAML (Extensible Application Markup Language, Visual C++ component extensions, C++, and Microsoft DirectX. The development environment used for Windows is the Microsoft Visual Studio Express 2013. It includes the Windows Software Development Kit, Blend for Visual Studio, and a device simulator to test out the Windows Store apps that are created. There are available templates for beginners to understand the basic structure of an app. Windows has also developed a cloud computing platform called Azure, which provides both platforms as a service (PaS and Infrastructure as a service (IaaS).

3.2.7.3 Android

Android is an operating system based on the Linux kernel. Android is owned and developed by Google. After an update is released, the operating system is open-sourced and allows the Android community and consumers to alter and add on to the operating system, where new features and improvements can be implemented if deemed appropriate. Bugs in the operating system and efficient programming can be more quickly dealt with in this way. Android applications can be downloaded through the Google Play store or the Amazon Appstore. To begin developing an application as a third party, the Android Software Development Kit must be obtained. This can be achieved by purchasing the ADT Bundle from Android. The bundle includes the Eclipse Integrated Development Environment plugin, ADT plugin, Android Platform-tools, the latest Android platform, and the latest Android system image for the emulator. Android apps are usually programmed in Java. [56]

3.2.8 Microcontroller / FPGA

The microcontroller is an essential part of the overall project. The function and data flow of the sensors is determined by the microcontroller. When selecting the appropriate part for the wireless sensor, the performance and power consumption are the primary specifications to consider. This is because the microcontroller will be mounted on a peripheral unit and act as part of a wireless transmitter. The MCU should use a minimal amount of power to maximize battery life while being able to achieve the necessary performance standard needed for its actions. The data processing required will have to do mostly with interpreting analog data coming off of multiple sensors measuring vital signs and position. The microcontroller needs to have at least 4 analog to digital converters, one for each sensor, and a minimum sampling rate of 8 bits of resolution. The microcontroller will also interface with a Bluetooth wireless system and thus must have both SPI and I^2C in order to have the flexibility to integrate sensors into the system.

3.2.9 Power

The power supplied for this project come from two sources, alternating current from the main electrical grid and direct current from battery or power supplies such as those in a PC connected through a USB. In addition to the two types of power source, the unit also uses linear or switching regulator integrated chips to help provide steady power to the modules on the satellite unit.

3.2.9.1 Power Considerations and Safety

There are a number of considerations to be made for the power subsystem. As integrated components shrink and get more efficient, one of the most important decisions that decide the final product and packaging is power. In order to provide the needed functional length and reliability, the power subsystem tends to take up the majority of space and weight in the product.[x] For this project in particular, the sock unit needs to be lightweight. It would be onerous, and maybe even dangerous, for a baby to be wearing anything to heavy. In addition, since this unit is being used to monitor health effects, the power source chosen cannot have weak points in its delivery system or longevity. Providing a seamless experience for the user requires attention to safety measures, efficient usage of power, longevity of operating hours, easy and fast recharge time, and noninterference with the other modules on the unit.

3.2.9.1.1 Safety

Safety is first and foremost due to the sensitive nature of the environmental conditions during operation. The satellite unit not only functions in close proximity to humans, it is primarily designed for users with limited verbal communication, making it hard for the caretaker to gauge feedback on operation and physical status of the unit in the event of a malfunction. In the worst case scenario a runaway heating issue could cause burns on the baby or a shock hazard could happen and cause irreparable damage. The unit has to have safety measures in all aspects, taking in considerations such as shorts and unduly dissipation. Admittedly, there is little chance for arc flash or arc blasts due to the voltage being less than 240, according to the National Fire Protection Association. [42] The baby pea unit itself limits the voltage to a much lower 3.7 volts. However, since the unit is worn against the skin, electric shock and thermal damage does exist. In addition, it is not the voltage that is the primary concern, but the delivered amperage that can harm or kill a person. According to an Ohio State University resource, a shock as low as 10 milliamps can cause a painful shock to an adult. Lethal currents occur starting at 100 mA. Some of the symptoms of electric shock include muscle paralysis, difficulty in breathing, severe burns, ventricular fibrillation, cardiac arrest and death.[42] As table 4 lists, a current as low as 5 mA can cause a painful shock to an average adult individual. At around 6-16 milliamps, the victim will start to lose control of their muscles, and this is known as the let go range due to the fact that any higher amperage can cause spastic contraction of the muscle fibers and prevent the victim from letting go of the live wire. The range of effects is listed in Table 4.

Although fat tissue is a bad conducting material, and the baby might be protected somewhat due to high fatty tissue, the overall threshold for damaging current level is undoubtedly lowered for a baby due to a much lower body mass. A shock that will not cause lasting effects in an average adult can irreparably harm a child. According table 4, a current as low as 100 milliamps can cause ventricular fibrillation in healthy adults. That is enough to kill the said adult. In a child, with a mass order of magnitude smaller than a healthy adult, the100 milliamps potentially becomes lethal by the same order of magnitude. In addition, even if the shock does not cause visible signs, the perception level will cause discomfort to the baby. For a portable circuit, there is no way to bond the circuit to an effective ground-fault path. If the unit inadvertently gets knocked around and expose circuitry, the baby might very well exposed to a lethal current, and the

Current Level in Milliamperes	Probable effect on Human Body
1	Perception level. Slight tingling sensation. Still dangerous under certain conditions.
5	Slight shock felt; no painful but disturbing. Average individual can let go. However, strong involuntary reactions to shocks in this range may lead to injuries.
6-16	Painful shock, begin to lose muscular control. Commonly referred to as the freezing current or let go range.
17-99	Extreme pain, respiratory arrest, severe muscular contractions. Individual cannot let go and death is possible.
100-2000	Ventricular fibrillation and muscular contraction and nerve damage beings to occur. Death is likely.
>2000	Cardiac arrest and internal organ are damaged. In addition, victim will have severe burns. Death is probable.

Table 4 Effects on human body due to different amounts of current [43]

caretaker will have no knowledge of this other than the fact that the baby might cry more or display signs of discomfort that might be attributed to other factors such as hunger or the need for a diaper change. In addition to shocks, burns are another concern when dealing with power supply. If there is not enough adequate heat dissipation the circuit can overload thermally and burn the wearer. The degree of burn is usually a factor of both the thermal level of the object and how long the object is in contact with the skin. Often times, this kind of burn is insidious in nature due to the fact the person being burned does not realized that. The thermal level of the object could be tolerable to the skin, but when taken into account duration, can become deleterious. Just like the harmless feeling of sunbathing, thermal burns sneak up on the user and can have devastating consequences. In fact, there have been cases of serious burns caused by overheating battery packs of laptops. Those incidences involved adults that received the burns unknowingly over a period of hours as they used the devices on their laps and in contact with their legs. Table 5 shows the gradual gradation between the comfortable temperatures to temperatures that can cause irreparable damage.

A baby would be much more susceptible to thermal agitation on its skin. Along with slow heating, the different types of batteries have levels of volatility. The battery type chosen must have long stable life with little to no risks in explosions. In addition, to when the unit is used against the user's skin, the charging portion deals with addition risks as it is going to be connected to a wall socket with the potential of 120 volts. The charging station will need an adequate charging unit with transformer to step down the voltage to the acceptable amount for the circuit. With adequate circuit protection, component selection and circuit board design, these challenges should pose no issue in the final product.

3.2.9.1.2 Operation

After safety, the second design consideration deals with operation. To fully realize the potential of this unit, a priority lies in length of operation and recharge ability of the unit.

Body Temperature (degrees Fahrenheit)	Signs and symptoms
100-110	Brain Damage, fainting, nauseous feeling
98.6	Normal body temperature
90-98.6	Shivering and goosebumps
80-90	Lose power of speech
70-80	Potentially irreversible cooling
60-70	Lowest temperature with recovery
<70	Irreversible recovery

Table 5 Physiological reactions to body temperature. [47]

Designed to last 8 hours a day, Baby Peas will give the caretaker sense of security in its quality performance without the interruption of charging and exchanging out units. Each sock unit should last a day's worth of monitoring. In addition to the battery life of a day, each unit should also be recharged within a reasonable amount of time. This is to ensure quick overturn term if needed and give flexibility to the user, whether at home or on vacation. In addition, each time the sock is exchanged out would mean device wearing, which can prematurely lower life time usage. This is in addition to the issue of weight and scale. All of these need to be considered when searching for the portable DC supply. Some viable options include AA batteries, button batteries, or super capacitors.

Super capacitors are a very attractive option. They have rapid recharge time, have less wear with constant recharging and discharging, and function well under different temperature variations[8]. They are also extremely stable as they use stored static charge rather than energy from chemical reactions. Lithium ion, when exposed to air, is very volatile and can be explosive. The unfortunate thing about super capacitors is size at this time. With current state of technology, a super capacitor is power dense (able to discharge and consequently recharge rapidly), but it is not energy dense (for the comparable size of a batter package, it holds much less charge). In order to have sufficient power for the unit, size would have to be sacrificed. For traditional chemical batteries, the button battery would be the best package for the baby peas unit. It is the lightest in terms of weight, one of the longest continuous usage options, and is often used in medical applications. While danger does exist in the chemical nature of the battery, the packaging is safe enough for usage that these batteries are often used in the hospital setting or with every day consumer goods.[44]

3.2.9.1.3 Interference Considerations

In addition to being a reliable power source for the electronics and peace of mind, the power subsystem also needs to consider causing interference with other subsystems. In general, the different components of a circuit are taught as idealized versions, with no interference among the different components. However in practice, parasitic inductance and capacitance are serious issues that can impact usage hours and quality of usage. According to source [x], "any two conductors will have a capacitance between them, any conductor used for carrying current will have inductance, and parasitic capacitance and inductance create reactive impedance that varies with frequency". For the first point, the capacitance formed between two conductors is given by the equation:

$$C = \frac{q}{V}$$

C = capacitance
q = charge
V = voltage

Inadvertently, capacitance can be formed from "parallel trace runs, or by traces over a ground or power plane".[46] In addition, the wires running the power throughout the circuit also create capacitance.

The general inductance formula is given by [46]:

$$L = \frac{\mu N^2 A}{l}$$

μ = the magnetic permeability of the material
A = the cross-sectional area of coil
l = the length of the solenoid

In addition the normal use intended induction, parasitic inductance effect is given by [45]:

$$Z = j(-\frac{1}{\omega C} + \omega Lparasitic)$$

Z=total impedance
w=omega
C=capacitor value
$L_{parasitic}$=parasitic inductance

Utmost care must be taken in the satellite unit to rid of any preventable noise. As the module is quite small and low powered, any noise can have a catastrophic effect on proper operation.

3.2.9.1.4 Electrostatic Discharge Protection

Finally, a mention of electrostatic discharge is in order to the sensitive nature of the components. Working with open boards is a recipe for disaster without proper ESD protection schemes. Table 6 shows the minimum volts that can start to damage the devices.

Device type	ESD susceptibility threshold(V)
MOSFET	100
JFET	140
CMOS	250
Diodes	300
Transistors	300
SCR	600

Table 6 ESD thresholds for common devices [48]

The values might seem high, but the simple act of walking across a carpet can generate up to 35,000 Volts.[38] Table 7 shows some additional voltages that can happen.

Static generation	Electrostatic voltage (V) at 10% relative humidity
Walking across vinyl floor	12,000
Worker at bench without wrist strap	6,000
Styrofoam packing	120,000
Picking up common plastic bag	60,000

Table 7 ESD generation from various activities [48]

ESD prevention is a mixture of technique, workstations and atmosphere. At the crux of electrostatic protection is keeping the potential between the technician and the board the same. Because the work on this project is being done during the winter, it is crucial to make sure that the surrounding atmosphere of the work area is high in humidity; the lower the humidity, the easier for static to build. A humidifier could help with this, or even leaving out a body of water can help. In addition, all of the workstations where component touching can happen, whether it is soldering or just simple handling, need to be grounded to a common ground. A simple dissipative mat, wrist strap, and finger cots can help prevent potential different buildup on the person's body relative to the board. Each of those components help drain the body voltage and prevent body voltage buildup. In addition, they are often nonintrusive and cheap. Finally any transportation of the boards or sensors outside of the final packaging must be carried with shield bags. Note, ESD protection is for non-energized work. Remember to take adequate precautions when working with live circuits, as discussed in part 3.2.9.1.1

3.2.9.2 AC Power

The AC power component is primarily used for recharging the power supply for the unit. In the alternating current source, in order to be able to use the potential, components like transformers, rectifiers, filters, and regulators needs to be incorporated. After the Transformers help to step down the 120/240 AC down to usable voltage for the power supply, rectifiers in formations such as a full wave rectifier help to covert the sinusoidal supply to a rectified waveform. This, rectified waveform is smoothed out by the filtering capacitor.

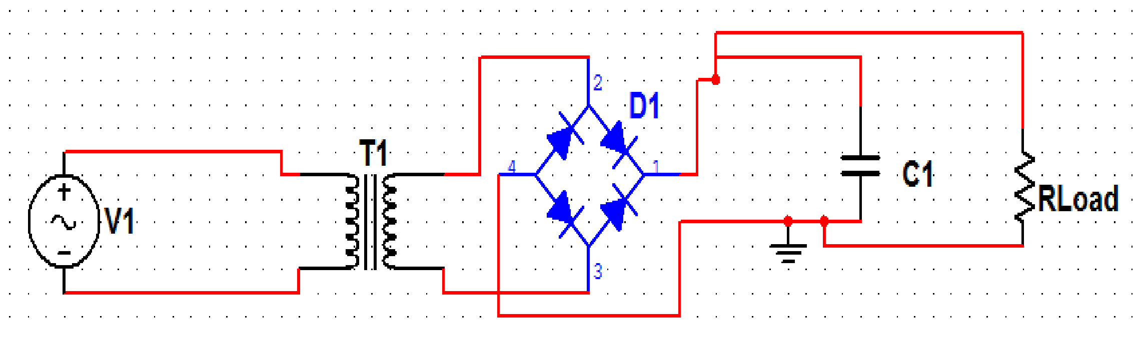

Figure 5 Simple rectifying circuit

An example circuit, Figure 5, shows how an incoming sinusoidal wave is stepped down at the transformer, and then rectified at the bridge rectifier made of four diodes, and finally smoothed out by capacitor, C1. The output of this circuit is a direct current at a usable voltage. In the baby peas unit, this DC voltage is used to charge the rechargeable battery. Figure 5 is an over simplified unit and lack any sort of circuit protection. Fuses will need to be incorporated to protect the circuitry. While it is theoretically possible to build an AC power supply unit for this project, it is recommended to forgo this subsystem due to extreme hazards of working with live mains power. Without Occupational Safety and Health Administration's (OSHA) rated personal protection equipment such as goggles, hard hats, gloves, face shields, and clothing, which all cost a considerable amount, it is foolhardy to build an AC power supply. It is recommended to buy an off the shelf AC power unit for this project.

3.2.9.3 DC Power

DC to DC power supply is used in two aspects—recharging the unit via solar power and supplying power to the different modules in the unit.

3.2.9.3.1 Solar Power

A generic solar power unit consists of the Photovoltaic cells, the combiner, inverter and storage unit. The inverter is used to turn the solar generated DC power into AC as most of the solar units are used to supplement mains power. If the baby peas unit is charged via solar power, this inverter step is not needed. Photovoltaic cells basically work under the principle of the photoelectric effect of some materials. As photons strike the surface, energy is collected and transformed into a current. Figure 6 shows a simple set up of the process.

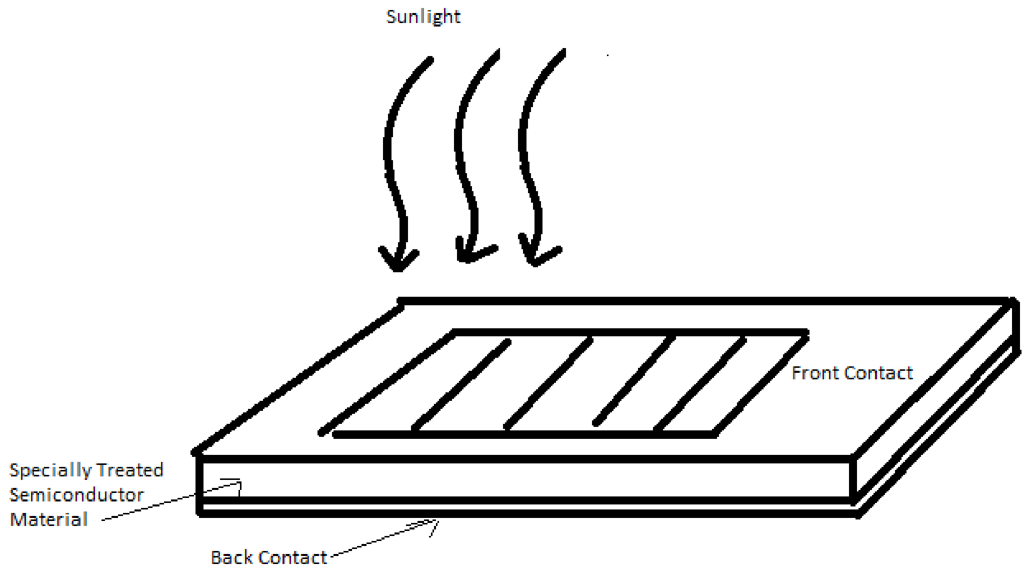

Figure 6 A basic photovoltaic cell operation diagram created by Xin Tong in MSword

Using a number of cells in modules and set in arrays, a multitude of these cells can harvest a considerable amount of power from the Sun. Amorphous photovoltaic cells would be the cheapest options, but is the least efficient and have the least lifespan. Both Monocrystalline and polycrystalline are good choices. If the project basic goals are met and the decision is made to focus on a stretch goal, either monocyrstalline or polycrystalline would be a good choice. It is recommended that the decision be made on the side finance and polycrystalline be the choice due to its lowered costs and comparable characteristics with the monosyrstalline offering. In addition there is a breaking in period for the cells. There are many available schematics for simple solar cell phone charger. The voltage for a phone is around the voltage needed for the module so a solar charger is a very viable option. Several issues to consider in designing the solar unit:

Solar panel collapse: Figure 7 shows the solar cell I-V curve in varying sunlight. At each level, there is an optimal power point. Following the red line, at a certain point any slight increase in current will cause the voltage to drop to 0. The maximum amperage is 0.034 A. At the second line, a lighting condition less optimal than the first line, the maximum amperage is 0.026 A. So imagine if a solar charger is operating at full sunlight and supplying the maximum amperage of 0.034 through the circuit, any changes in lighting condition without changes in the current draw would immediately drop the voltage down to 0. [57]

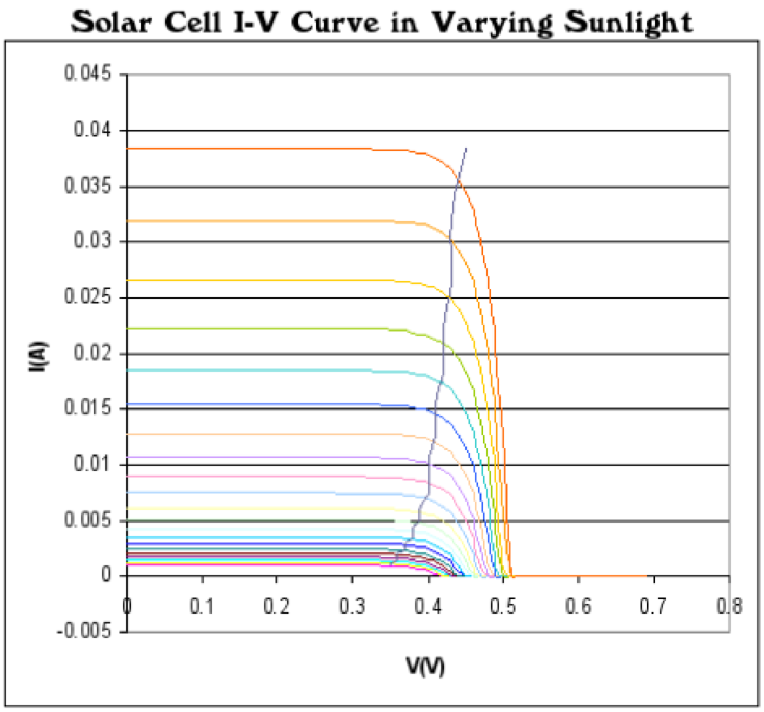

Figure 7 Provided by the openware documentation from Adafruit industries, shows an current-voltage curve of solar cell performance under varying sunlight.

A charging unit has to sense the available current from the solar cells. If the circuitry tries to pull the same amount of current under changing conditions, then the voltage can collapse and the charging action is stopped. This undermines efficiency. Reverse leakage protection: This actually is an issue when there is a storage element in the circuitry. The stored element can leak charge back to the source if the stored element, in the case, the battery, has a higher potential, than the source.

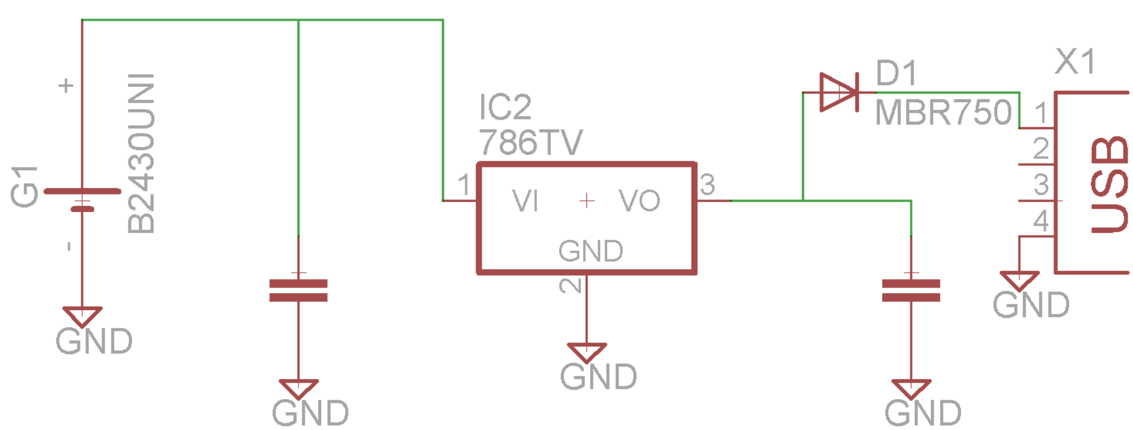

Figure 8 Schematic for phone charger. Created by Xin Tong using Cadsoft Eagle

Figure 8 gives the circuit of a general solar to USB phone charger.[54] The solar cell used here is the 750-00032 manufactured by Parallax and costs $59.99 per unit. The specifications for this cell are 10W power, 18V at Pmpp, and 580 mA at Pmpp. While this unit is very powerful, a better price point could be found with less powerful solar cell that would use a switching regulator. The switching regulator is a good recommendation for the charger due to high efficiency. Noise is not a consideration because the satellite unit would not be transmitting or receiving information when it is docked in the charging station. In addition to the basic phone schematic, an energy storage unit needs to be added, for flexibility in usage and for lower component cost. Due to the two issues discussed above, voltage collapse and reverse leakage, a chip such as TI's BQ24210 unit would be ideal in implementing in a charging circuit. While is nice to have this module to supplement the main AC source, it might prove too ambitious for a single semester project to build this additional module. If time is sufficient, this building this module would very instructional to solar power circuitry and pitfalls.

3.3 Strategic Components

3.3.1 Pulse Oximeter Sensor AFE4490

Choosing a sensor that is compact and high integrate capability along with low power consumption is top priority. Under close evaluation, Texas Instruments AFE4490 is the most suitable for this project. It is compatible to multiple microprocessors and wireless Bluetooth modules with maximum 5.25V required. Its QFN-40 (6mm x 6mm) form factor is ideal for implementing with other sensors in small projects. AFE4490 uses SPI (Serial Peripheral Interface) as the communication bus to send digital data to the MCU. It has configurable LED circuit drive current which low voltage can be achieved. The receiver front end includes photodiode, current to voltage converter done by TIA (transimpedence amplifier.) Ambient cancellation scheme estimates amount of ambient light leakage by sampling ambient light with two LED sending data to SPI and transmitted to the MCU. The MCU has the information of all the data and able to estimate the amount to be subtracted. External 8 MHz crystal generates the frequency responsible for controlling the clock cycles. 4 MHz is used for timer modules, ADC, and the diagnostic.

The detailed pin configuration can be seen in figure 9. To integrate AFE4490 with the microprocessor, a basic understanding of pin function is necessary. The pins can be put into five categories based on functionality. Each category is summarized in table 8. Note the tables do not contain all the pins but the pins which are used or discussed.

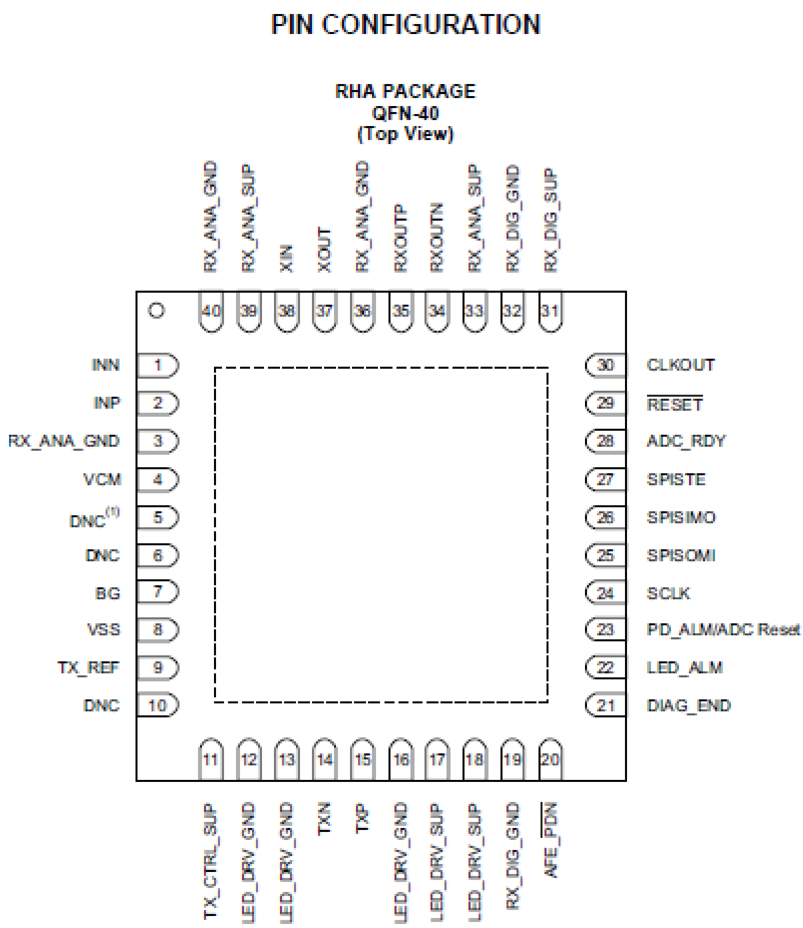

Figure 9 Pin Configuration of AFE4490. Reprinted without alteration with permission from Texas Instruments

3.3.1.1 Analog Pins

Pin 1 and 2 are analog pins connecting the photodiodes with wavelength 660nm and 940nm with analog ground common ground pin 3, 36, and 40. Block diagram and pin connection will be discussed in hardware section 4.1.1

Name	No.	Description
INN	1	Receiver input connected to photodiode anode
INP	2	Receiver input connected to photodiode cathode
RXOUTN	34	External ADC negative input on bypass mode
RXOUTP	35	External ADC positive input on bypass mode
TXN	14	LED driver out B, H-bridge output connected to LED
TXP	15	LED driver out B, H-bridge output connected to LED

Table 8 Analog Pins and Description

3.3.1.2 Digital Pins

Some of the digital pins are made for fault detection or reset. Two of them are for connection to an external 8-MHz crystal. For complete details, please refer to AFE4490 user guide available on Texas Instruments website.

3.3.1.3 Supply Pins

The supply pins are mostly connected to the external power supply or to the common board ground. Decoupling capacitors are required for certain pins. They are not discussed in details.

3.3.1.4 Communication Pins

Name	No.	Description
SCLK	24	SPI clock pin
SPISIMO	25	SPI serial in master out
SPISOMI	26	SPI serial out master in
SPISTE	27	SPI serial interface enable

Table 9 Communication Pins and Description

The communication pins provide data transmission from AFE4490 to CC2541 via SPI protocol. Please refer to hardware section 4.1.1 for details and block diagrams.

3.3.1.5 Reference Pins

The reference pins are connected to decoupling capacitors and the ground. Pin 5, 6, and 10 are open circuit pins and should not be connected to anything.

In conclusion, AFE4490 provides complete solution to analog front end pulse oximeter sensor. Not only it provides many fault detection, but also many advanced features such as ambient light correction and precise timing controller. SPI interface will work well with CC2541 for data transmission. It could take extra time to configure the communication bus since the other sensors use I^2C protocol. Interrupt function will be written for incorporating the sensors communication. AFE4490 is the most qualifying analog front end for Baby Peas Project but in the end the Baby Peas project ended up using a discrete design instead of the AFE4490. While the SPI bus was able to be configured and working there were over 40 register settings which needed to be configured in order to get the timing on the pulse oximeter working properly. With time constraints being taken into consideration the problems associated with using the CC2541 the AFE4490 was dropped in the final design and a more easily implemented discrete design was used. The discrete design did not include the oximeter portion and only provided heart rate data.

The detailed package dimensions are seen in Figure 10. The measurements are important for PCB layout. Cadsoft Eagle is used for creating AFE4490 and the package dimension was taken into consideration.

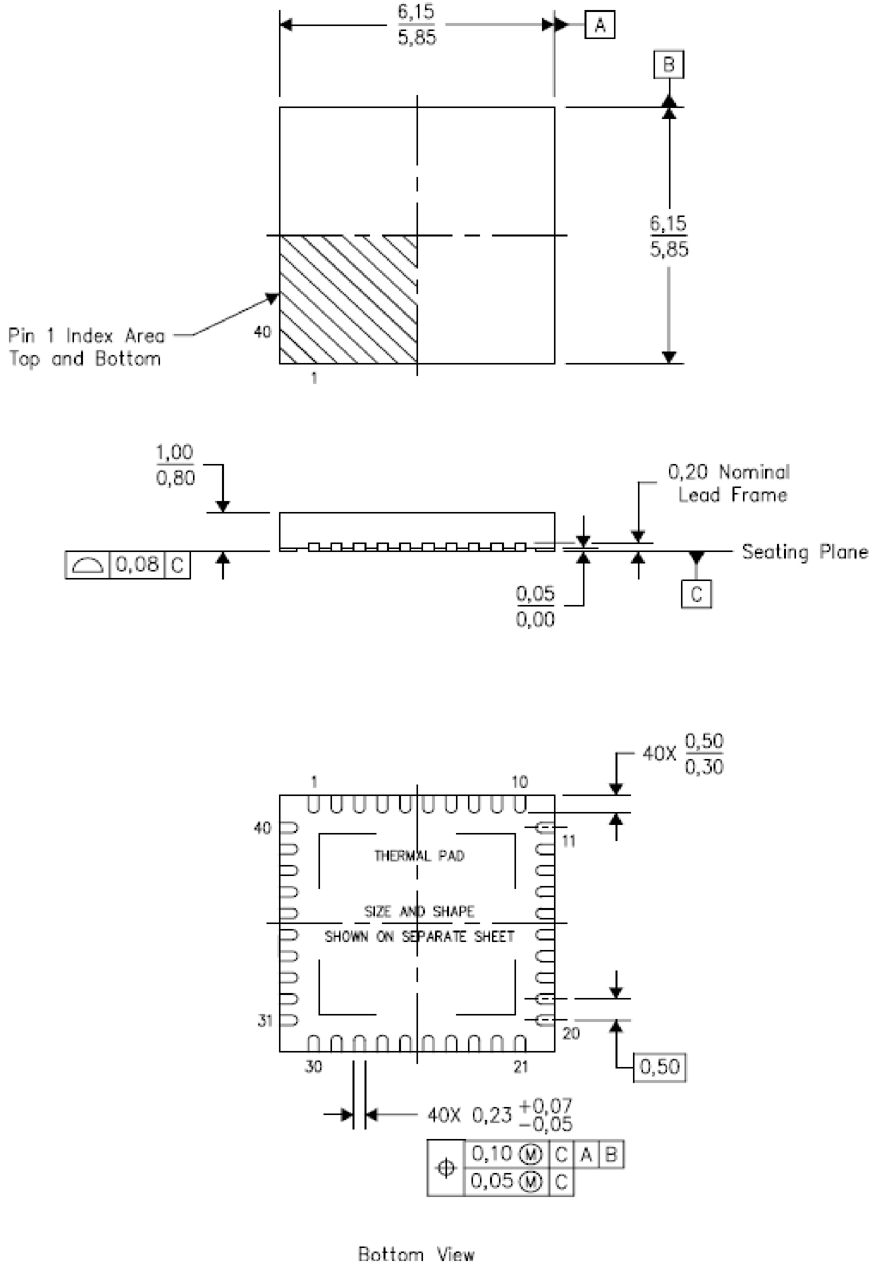

Figure 10 Package Dimension of Texas Instruments AFE4490. All the measurements are in mm. Reprinted without alteration with permission by Texas Instruments.

3.3.2 Alternative Design of Analog Front End Pulse Oximeter

AFE4490 offers many features but not all necessary. A Simplified analog front end can be designed with basic components and may reduce power consumption. A design of an analog front end can be broken down into a few key components. System diagram are shown in Figure 11.

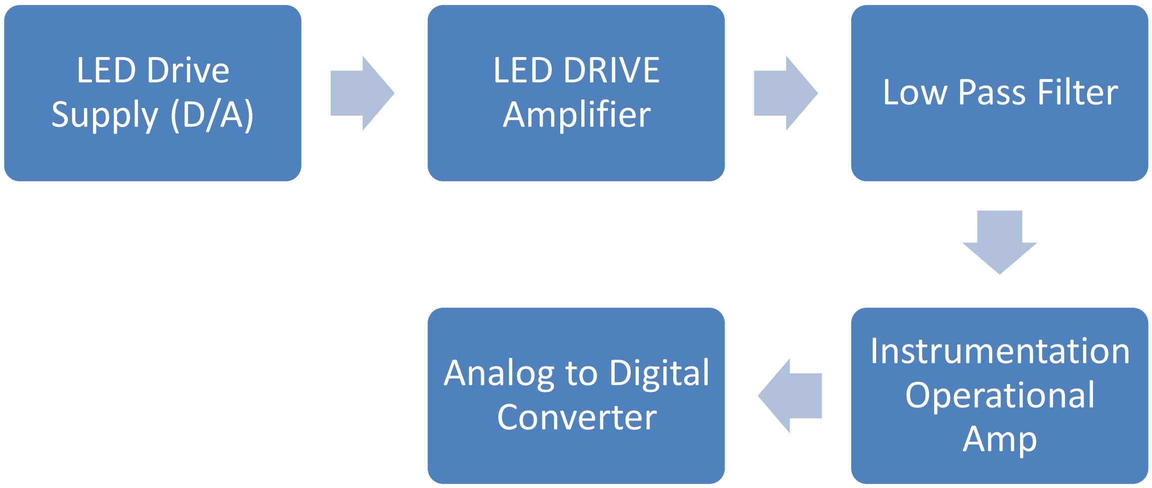

Figure 11 System Block Diagram for Analog Front End Discrete Design

A digital to analog converter sends signal from microprocessor. When it reaches amplifier, the signals are boosted up in order for the driver unit to read the timing sequence for LED. The LED with 660 nm and 940 nm should alternate each other between on and off. When the photodiode sensor gets excited by the light goes through the object, two currents are created based on different wavelength of light input. The signals coming from photodiode sensor are relatively weak and unusable for typical analog to digital converter. Some noise may need to be filtered out for accurate reading. The amplifier portion can break down into three parts- pre-amplifier, low pass filter, and final stage of amplification. Use the pre-amplifier to boost up the currents from the photodiode sensor. Filter can be a simple low pass filter or Butterworth filter for enhanced quality. A final stage of amplifier boosts the currents to match the operational spectrum of analog to digital converter. The currents are converted into voltage and transmitted to corresponding pin on the CC2541 microprocessor or any microprosessor. Many ADC chips are equipped with I2C interface which will be easier to use along side with the temperature and body position sensor.

Compare AFE4490 to a self designed analog front end, AFE4490 offers many additional features such as current fault detection. While AFE4490 may increase interface difficulty because of the SPI interface, it does not require any additional hardware. With AFE4490 single chip solution, it may benefit Baby Peas monitor for increased accuracy and reduced hardware modulation. The price of a single AFE4490 is lower than using multiple chips with different functions. In the end, the discrete design was implemented due to the complexity of using the AFE4490. Using a discrete design cut down on complexity and ease of troubleshooting when problems arose. Discrete designs can also be better simulated with using LTSpice or Multisim.

3.3.3 Photo Diodes/Photo Diode Sensor

Analog front end incorporated with LED driver is paired with photo diodes. The light wave goes through blood cells and received by photodiode sensor. As discussed in section 3.2.2, specific wavelength must be used in order to obtain accurate measurement. Low power consumption, easy integration, small form factor are the key requirement for Baby Peas monitor.

Advance Photonix Inc DPI-E839 is a four drive emitter with three emitter diodes with wavelength 660nm, 880nm, and 940nm. It has very small form factor of 6.73 mm x 6.73 mm x 1.90 mm. It has maximum power consumption of 250 mW and peak forward current of 200 mA. With a metalized ceramic package, it can be soldered onto PCB along with other components fairly easy. DPI-E839 is ideal to be used with AFE4490 for Baby Peas monitor. The only downside is the unit price. It carries a hefty unit price of $5.95 available on Octopart.

QEB363 is an infrared emitting diode manufactured by Fairchild. It can be paired with QSB34CGR photodiode sensor. It emits wavelength of 940 nm. With a small T-3/4 (2 mm) package and extended lead; it can be mounted in three different configurations. The overall size without counting the lead is 2.2 mm x 2.5 mm x 3.0 mm. it has a power dissipation of 100 mW and continuous forward current of 50 mA. Additional 640 nm LED must be paired with QEB363 for using as pulse oximeter. Marktech optoelectronics manufactures wide selections of 640 nm light emitters. The particular model best suits Baby Peas monitor is MTE5066C- UR. It has a similar form factor of 3.1 mm x 3.1 mm x 4.3 mm. Although slighter bigger, the difference can be neglected because their small size in nature. The power dissipation is 110 mW with forward current of 50 mA according to datasheet. Combining QEB636 with MTE5066C-UR should have similar performance of a single DPI-E839.

In Conclusion the Baby Peas monitor used a discrete reference design offered by www.pulsesensor.com. This design allowed only the heart rate portion of the project to be implemented and the sensitivity only allowed us to gather heart rate information from the fingertip or earlobe. In a future design the AFE4490 would be re-introduced or a better filtered and amplified design would have to be used to gather heart rate from the ankle.

3.3.4 Body Position Sensor

From an overview of relevant technologies consisting of accelerometers, gyroscopes, and IMU's it looks like choosing a component with IMU functionality will be the best choice for the ability to tell in which position the infant is in during the sleep cycle for the baby peas project. IMU's can be extremely costly. Through research it was found that accelerometer IC's were more available and low cost with only a few IMU devices in the price range compatible for this project. A comparison of the IMU's and Accelerometers for this project will be considered. Key factors which weigh on the decision will be accuracy, cost, size, reliability, ease of configuration, ease of solder ability, and of course power consumption. Since the baby peas vital signs monitor is going to be wireless and battery powered the two most important factors will be power consumption and accuracy. With a wide variety of sensor to choose from, a lot of IMU's and accelerometers offer a special function feature which allows the IC to be put into a sleep mode to conserve power. Components which offer this feature will be given special consideration.

3.3.4.1 Invensense MPU-60x0 series

The MPU-6000 and 6050 are IMU's which are integrated onto one chip providing 3-axis accelerometer measurements along with 3 axis gyroscope measurements. The chip is also scalable in it provides a dedicated I^2C bus to accept an external 3-axis magnometer which would give 9 axis data measurements. Range of the accelerometer portion consists of +/- 2g, +/- 4g, +/- 8g, +/- 16g, which are user programmable which means if only +/- 4g range is needed it can be selected and reduce the amount of current the IC would draw. They gyroscope range is selectable as well consisting of +/-250 degrees per second (dps), +/- 500, +/- 1000, +/- 2000 dps. The chip also consists of 6 16bit analog to digital converters (ADCs) to sample all axis points of both the accelerometer and gyroscope. It boasts an onboard 1024 byte FIFO which allows for the microcontroller interfaced with it to read data output from the MPU-60x0 series in bursts. This allows the microcontroller to go into a sleep mode while the MPU collects more samples. The output of the MPU is digital and compatible with both SPI and I^2C (MPU-6050 only uses I^2C). I^2C data rates are up to 400kHz and SPI data rates are up to 1MHz. The input voltage to the chip is between 2.375v -3.46v which is in the boundaries of usable input voltage for this project. Price is around 10 dollars if purchased through Digikey with a lead time of around 2-3 weeks. The MPU also has an additional temperature sensor on the device but this most likely will not be used since another sensor being used in this project will take care of skin temperature.

The MPU also has a unique proprietary Digital Motion Processor™. The DMP offloads the motion processing computations from the system microcontroller and performs them on its own chip. This minimizes the amount of processing power consumed by the system processor. There are different current consumption applications because each feature of the MPU can be configurable to be either off or on. Since the baby peas peripheral device wants the desired accuracy it will run all three characteristics (accelerometer, gyroscope, and DMP) during operation. Running all three options will result in 3.9mA operating current. This should be well in the desired operating current to allow for the baby peas peripheral sensor to run through the night. The idle mode operating current is 5uA with a 100ms ramp rate for the device to return to full operation. Figure 12 below is a diagram of a standard QFN 24 pin 4x4mm PCB layout example.

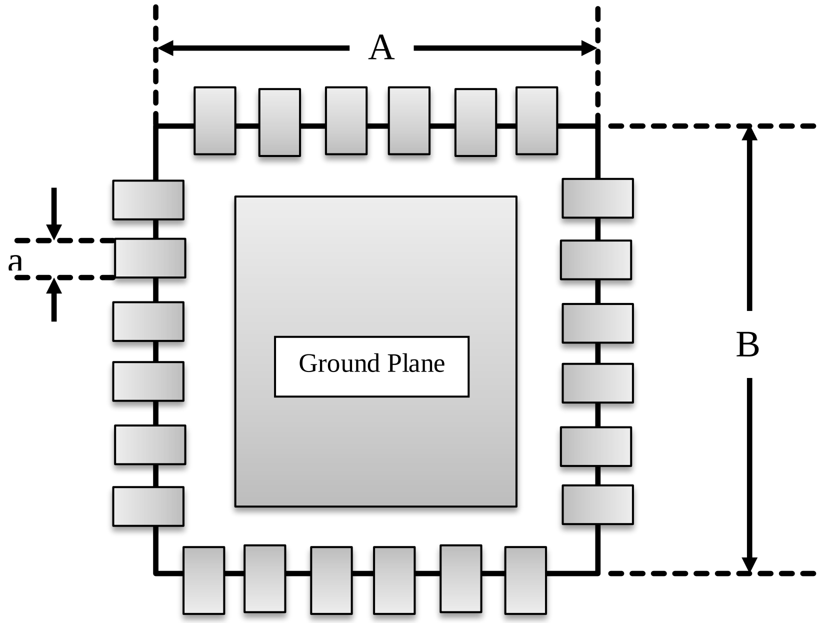

Figure 12 PCB Layout Diagram for a QFN 24 pin 4x4mm package.

The MPU-60x0 series is a QFN package (Quad Flat Pack no leads). From the Figure 12 above we see there is a substantial ground plane and 24 pins to be soldered. Solder ability of a QFN can be difficult especially when the total dimensions of the part are 4x4mm (shown by dimension A x B in Figure 12) and each lead is .25mm (shown by dimension 'a'). While QFN's may be considerably harder to solder down it is possible by using a reflow machine or hot air pencil. The great part about this device is the leads can be seen from the outside of the component and solder can wick up the sides of the leads thus letting the user know a proper solder connection has been made. The baby peas project group has an experienced J-STD-001 certified specialist in soldering of surface mount components so QFN packages should not be a problem.

3.3.4.2 Analog Device ADXL362

The ADXL362 accelerometer made by Analog Devices is an ultralow power digital output MEMS system on chip. During a 400Hz data rate output the device is only drawing 3.0uA with a supply voltage of 2.0v. This is extremely beneficial for the baby peas project due to the desired lower power consumption on the peripheral device. It has 12 bit ADC output resolution and communicates using a SPI interface to the microcontroller. Another feature is the device can be programmable to only output 8 bit resolution if lower resolution is possible. This may prove to be handy if the project notices accurate readings can be taken utilizing less bit resolution giving it less power consumption and easier byte transfers. It is a 3 axis accelerometer and has selectable range measurements of +/- 2g, +/- 4g, +/- 8g with a resolution of 1mg/LSB on the +/-2g range. Like the MPU-60x0 series the ADXL362 has an onboard FIFO which enables burst data transfers which allows the system processor to go into a sleep mode while the ADXL362 is sampling the signal. The device also has a neat feature which allows the chip to go into a sleep mode when no motion is detected and has an adjustable threshold for when the chip should be woken up. This way if the infant is motionless there is no need to run the accelerometer during motionless states. The User Interface can recall the previous data until the baby moves again and causes the chip to "wake-up" and begin another sample to re-adjust the position and update the user if the baby has turned to a harmful state position. This could boost battery life.

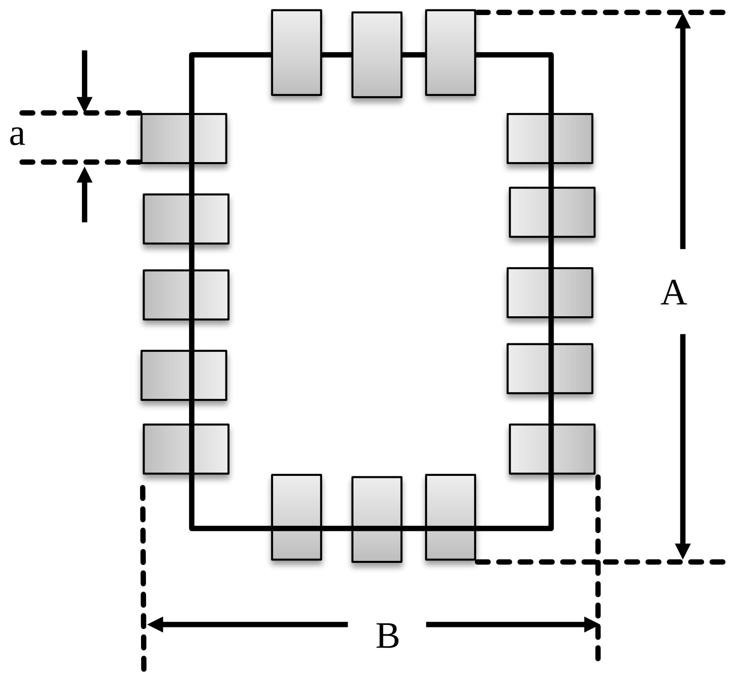

Figure 13 Possible PCB Layout for the ADXL362.

Figure 13 of the possible PCB layout for the ADXL362 are the outer dimensions and recommended PCB layout design from Analog devices. The package is small at 3.5 x 3.5mm (denoted by A X B) 16 pin LGA package with recommended trace widths of .3mm (denoted by a). The device could prove to be difficult to solder because of its LGA (Land Grid Array package). Soldering down the component with a soldering iron is not possible so it would have to be down with a solder reflow machine or hot air pencil. Another negative to the LGA package is there is no way to tell if the part is soldered down correctly. This could prove difficult during debugging of the system and rework if the part needs to be replaced. The part costs roughly 10 dollars from Digikey and is stocked and ready for delivery.

3.3.4.3 Freescale Semiconductor MMA8451Q

The MMA8451Q accelerometer is low power and boasts 3 axis measurements. It contains 14 bit and 8 bit resolution onboard ADC's and user selectable ranges of +/- 2g, +/- 4g, +/- 8g. It too like the ADXL362 can be put into a sleep mode during motionless states of the infant being monitored. The MMA8451Q has output data rates of 800Hz. Output data is transmitted over I^2C to the microcontroller. It also has a 32 sample FIFO which acts similar to the other two devices in question. The supply voltage is from 1.95v to 3.6v which is in the project operational input voltage. At data rates of 800Hz the device is drawing 165uA and a mere 1.8uA during standby. Figure 14 below shows the dimensions of the device.

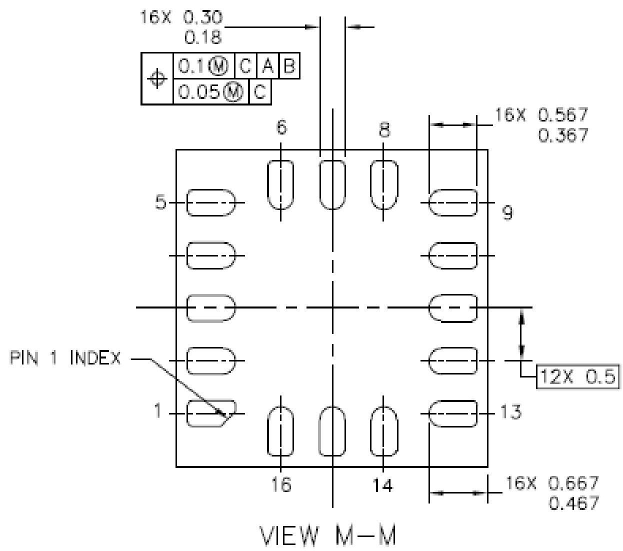

Figure 14 Bottom dimensions of pads for the MMA8541Q. Reprinted without alteration with permission by Freescale Semiconductors

It's a 3x3mm QFN. The leads are .3mm in width and .567mm in length. This QFN is a little different than the MPU-60x0 series in that the leads are not visible from the side edges of the device. It's more similar to the ADXL362 LGA package. This again surfaces the problem of being able to see if the device is properly soldered down. A hot air pencil or solder reflow machine would have to be used in the mounting of this component. One of the best features of this device is cost. Digikey shows this device at as little as $1.82 and the lead time is 0 weeks as this device is stocked and ready for immediate shipment.

Table 10 below is a breakdown of the three devices along with their respective parameters side by side for comparison.

	MPU-60x0 Series	ADXL362	MM8451Q
Input Voltage (volts)	2.375-3.46	1.6 - 3.5	1.95 - 3.6
Gyro / Accelerometer	Both	Accelerometer	Accelerometer
Range	+/- 2g, 4g, 8g, 16g	+/- 2g, 4g, 8g	+/- 2g, 4g, 8g
Degrees Per Second	+- 250, 500 , 1000, 2000	n/a	n/a
Operating Current	3.9mA	3uA	165uA
Standby Current	5uA	.01uA	1.8uA
Data Outputs	SPI and I^2C	SPI	I^2C
Data Output Rates	I^2C (400KHz), SPI (1MHz)	400 Hz	800Hz
ADC Resolution	16 bit	12 or 8 bit	14 bit
FIFO	1024 Byte	512 Byte	32 byte
Packag Type	QFN (leads visible up sides)	LGA	QFN (leads not visible)
Cost	$10.72	$9.22	$1.82
Lead Time	2-3 weeks (Digikey)	Ready to ship (Digikey)	Ready to ship (Digikey)

Table 10 Comparison table of explored devices for body position sensor

From table 10 above it looks like the MPU-60x0 is the best bang for the buck. It fits all categories except for power consumption. The 3.9mA operating current still shouldn't affect the battery life of the entire sensor enough to cause concern. Some of the deciding factors were the QFN package looks to be the easiest to solder down making installation of the device a bit easier and troubleshooting a little less of a worry. The accuracy is much higher and this boosts the reliability of being able to provide the most accurate measurements of position for the consumer. Careful scheduling must be adhered to since the device has a 2-3 weeks lead time.

In the end the MPU-6000 was very easy to implement and derived extremely accurate information. The only problem with the device is it is very sensitive and provide 16 bit resolution so some of the slight changed in data can really show and cause the mapping for position to be difficult. To better stabilize this feature on the microcontroller only the upper byte information was used in order to look for drastic changes in position rather than slight changes which was better suited for the Baby Peas Project.

3.3.5 Skin Temperature Sensor

The application requires small form factor in order to be applied to the ankle on an infant. Using semiconductor based sensor, we can achieve ultra-low power consumption with a form factor less than 3 millimeter squire.

3.3.5.1 TMP006

The first candidate under consideration is TMP006 from Taxes Instruments. TMP006 is meant for non-contact remote temperature monitoring. TMP006 is an infrared thermopile sensor with a size of 1.6mm by 1.6mm. The temperature of the object is measured by the thermopile on the sensor. The thermopile converts thermo energy (infrared energy emitted by the object in this case) into electrical energy. An output voltage is created based on the difference to the local temperature. TMP006 operates between minus 40 degree Celsius to 125 degree Celsius. The way TMP006 communicates is thru SMBus (System Management Bus, or SMB). SMBus is a derivative of I²C which is compatible with our desired microprocessor CC2541 from Texes Instruments. Two variants of TMP006 are available, TMP006 and TMP006B. The main difference is SMBus interface voltage. TMP006 is at 3.3 V while TMP006B is at 1.8 V. The two main constrain of using TMP006 are surface emissivity and target size to sensor placement. Surface emissivity- It is a measurement of a surface that emits energy (thermo energy). If an object has a potential to release an energy value of 200 Jules but only emit 150 Jules by measurement. It has an emissivity value of 0.75 from 150/200. A perfect material with a surface emissivity is called a blackbody with a value of 1. For example, concrete has surface emissivity of 0.85. In our application, the human skin has emissivity of 0.98 to 0.99. TMP006 is capable of calculating temperature from subjects with surface emissivity greater than 0.7 and preferable greater than 0.9. Target size to sensor placement- TMP006 is capable to receive signals 180s directly in front of the surface. The angle of incidence is related to percentage of infrared signal absorbed as shown in figure 15 at 0 degree angle of incidence, 100% of the signal is absorbed. The sensor should be placed parallel to the surface of the object to achieve the maximum IR signal absorption.

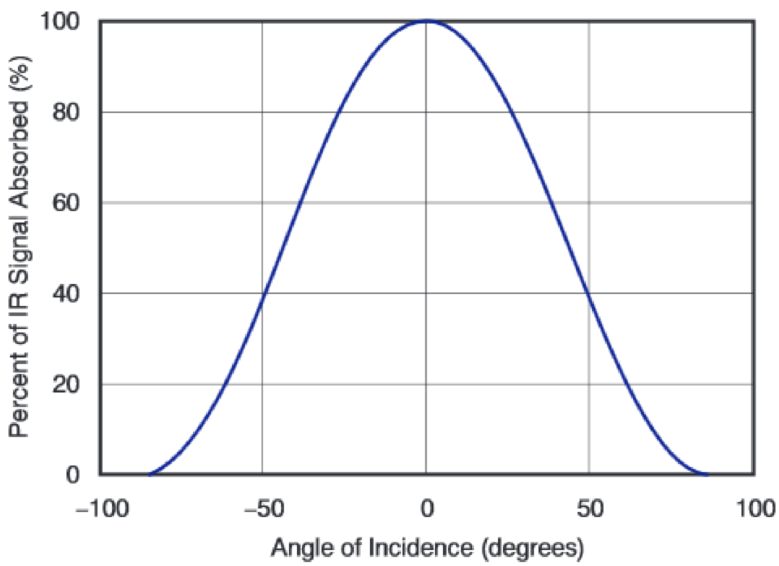

Figure 15 Angle of incidence with respect to IR signal Absorption. Reprinted without alteration with permission by Texas Instruments

A paper cone method was developed by Texas Instruments as a design guideline for TMP006. The field of view must be determined in order to proceed further measurement. In our application, the subject is the skin of a baby's heel. A radius of a one centimeter would be sufficient. The area is about 3.14 centimeter square.
The paper cone method:

$r = d * \tan(75°)$
d = distance to surface.
r = radius of field of view.

The formula is shown above, if we want to find the distance, we plug in r = 1 centimeter, we find the distance is 0.27centimeter or 2.7mm. To eliminate the infrared source signals from ambient sources, a metal shield could be used or place the sensor within the calculated distance. Creating a metal shield for such size would be somewhat unrealistic in this project; using appropriate distance can be easily achieved. As shown in Figure 16, over 90% of the IR signals are from the target object if the distance is less than half of the desired radius.

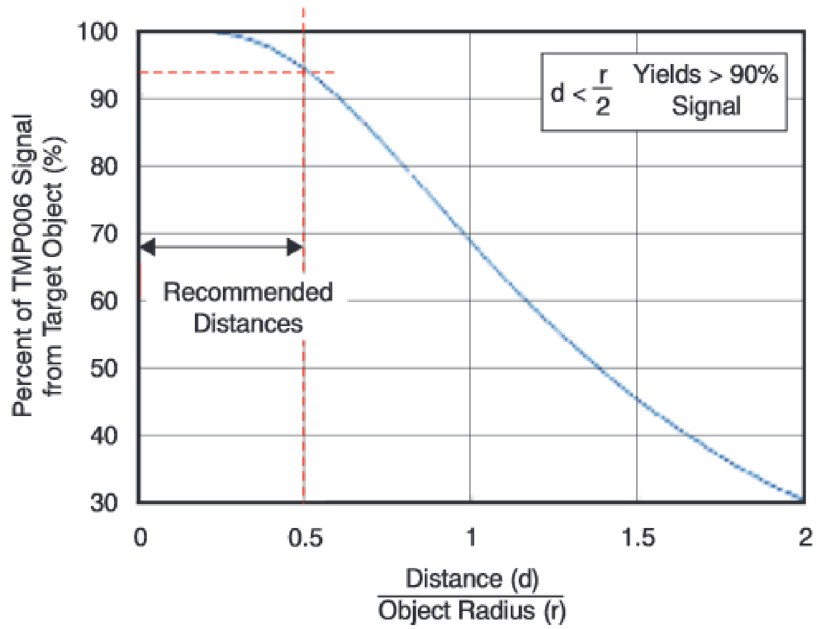

Figure 16 TMP006 Temperature sensor operational distance diagram. Reprinted without alteration with permission by Texas Instruments

To correctly calculate the temperature of an object, it is best to keep TMP006 from the rest components on the system. Heat from the PCB that TMP006 lays on may interfere with temperature calculation as well. A series of mathematical formulas are used for calculation and are discussed shortly. The TMP006 suggested PCB layout can be seen in figure 17. It is a guideline created and tested by Texas Instruments for optimal performance. The design is a two-layer PCB. For Baby Peas project, it will be more than two layers.

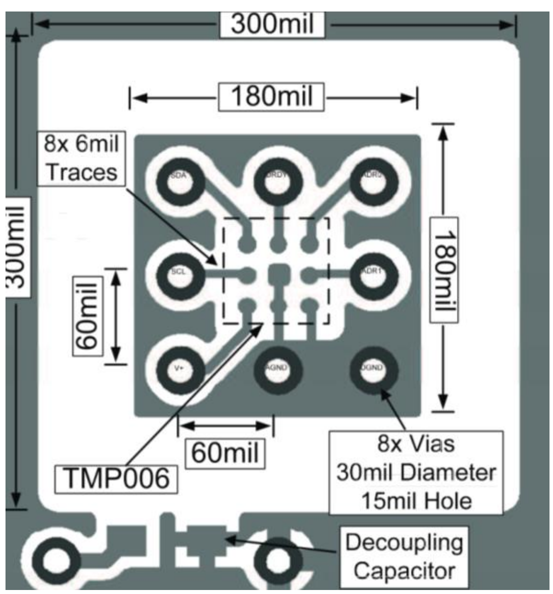

Figure 17 PCB suggested layout of TMP006 on a two-layer PCB. Reprinted without alteration with permission from Texas Instruments

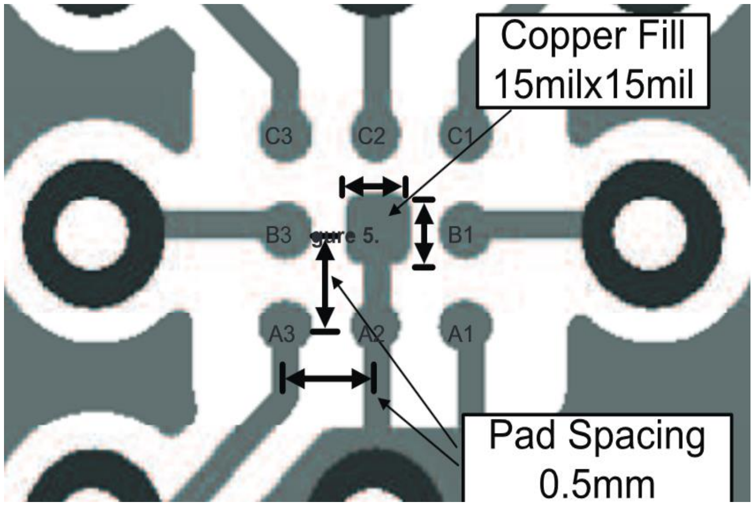

Figure 18 Enhanced view on TMP006, each component will be described in further details. Reprinted without alteration with permission from Texas Instruments

PIN	NAME	DESCRIPTION
A1	DGND	Digital ground
A2	AGND	Analog ground
A3	V+	Positive supply (2.2v to 5.5v)
B1	ADR1	Address pin selection
B3	SCL	Serial clock line for SMBus, open drain, requires pull up resistor to V+
C1	ADR0	Address select pin
C2	DRDY	Data ready, active low, open drain, requires pull up resistor to V+
C3	SDA	Serial data line for SMBus, open drain, requires pull up resistor to V+

Table 11 Pin descriptions of TMP006.

A1 and A2 are the ground which will be connected to the common ground with pulse oximeter ground along with CC2541 microprocessor. SDA, SCL are SMBus compatible interface under I²C protocol and 10kΩ (typical value) is as suggested pull-up resister per Texas Instruments. DRDY pin is output voltage with 0.15 V typical and 0.4 V maximum. A3 is the main supply voltage pin for TMP006 with maximum of 7 V. ADR1 is input pin with voltage of -0.5 V to V_S +0.5 V. Maximum input current is 10mA combined. To calculate the temperature, we have given values from Texas Instruments for each component. Please refer to Table 12. Please note that the final value will be in Kelvins.

Variable	Description/Value
VOBJ	voltage measured by TMP006 stored in register 0
TDIE	temperature measured in TMP006 stored in register 1
S0	calibration factor
a1	1.75 x 10-3
a2	-1.678 x 10-5
TREF	298.15K
b0	-2.94 x 10-5
b1	-5.7 x 10-7
b2	4.63 x 10-9
c2	13.4

Table 12 Variable Description and Value

There are four main equations for object temperature calculation. The thermopile itself must be calibrated over PCB and the energy from ambient environment.

$$S = S_0[1 + a1(T_{DIE} - T_{RED}) + a2(T_{DIE} - T_{REF})2]$$

The offset voltage from TMP006 itself is calculated by:

$$V_{OS} = b_O + b1\ (T_{DIE} - T_{RED}) + b2(T_{DIE} - T_{REF})2$$

Seeback coefficient of the thermopile changed based on temperature:

$$F(V_{OBJ}) = (V_{OBJ} - V_{OS}) + C2(V_{OBJ} - V_{OS})2$$

Once the calibration, offset voltage and coefficient has been calculated, the object surface temperature can be found as in T_{OBJ}.

$$T_{OBJ} = (T_{DIE}{}^{4} + (\frac{F(V_{OBJ})}{S}))^{4}$$

The calibration is discussed in detail in TMP006 user guide which can be found on Texas Instruments website. The equations above will be coded on microprocessor for measurement.

3.3.5.2 TMP103

TMP103 is a four-ball wafer chip-scale package from Texas Instrument. The main communication is a two wire I2C and SMBus interfaces. It is capable of measuring temperature from –40 ºC to +125 ºC within 1 ºC resolution. With an operating voltage of 1.4V to 3.6V, it fits into Baby Peas' low power consumption model. Its simple design makes easy integration to CC2541 microprocessor. TMP103 is the sensor itself thus the ambient temperature must be isolated from the object needs to be measured. TMP103 reads the temperature immediately upon powered on.

TMP103 has internal register for data processing. The most recent converted data is stored in pointer registers which are configured eight-bit read-only. Read and write command is controlled by two LSB on the register. Pointer registers 2 to 7 must be 0 while in write mode. The calculation for TMP103 is relative simple compare to TMO006. All the measurements are present in binary number which can be converted to Hex number. Each degree Celsius is represented as a single bit. For example, normal body temperature is 37 ºC; it will be stored as 0010 0101 in binary and 25 in Hex. Twos compliment is used to represent negative number only. Registers started out in 0s until first conversion is completed.

Built in watchdog function keeps on track of device temperature compared to stored temperature and make sure device temperature is within set limits. Shutdown mode is available for power saving; the only portion powered on is the communication interface. Shutdown mode is enabled when both M0 and M1 bits are set to 0. One-shot mode enables a single conversion read out; once the conversion is done, the device goes back to shutdown mode. It is used for power conservation. The communication interface is under I2C protocol and is discussed in details under section 3.2.6.1.

TMP103 provides an easy integration with standard communication interface with CC2541. The drawback of TMP103 is temperature resolution of 1 ºC. While 1 ºC is not a big difference in many applications but that is not the case for monitoring body temperature. Baby Peas strives to provide safe and accurate measurement. Further testing will be done to ensure TMP103 qualifies the specification required by Baby Peas Monitor.

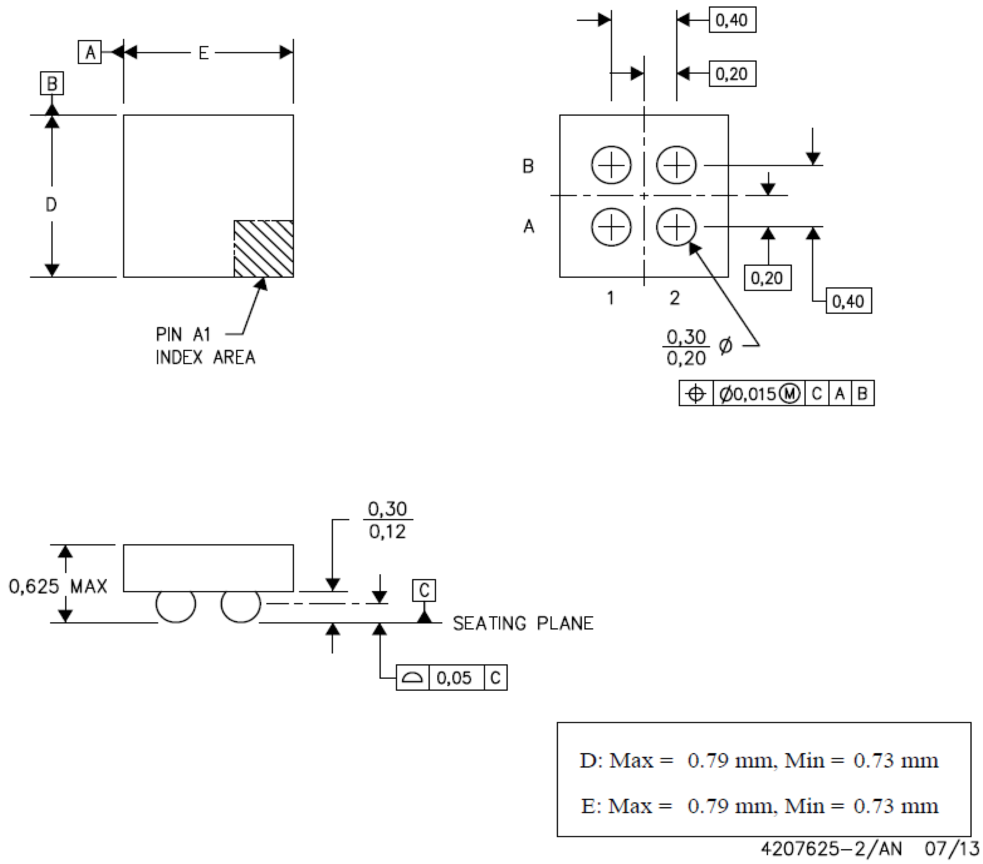

Figure 19 Package Dimension of Texas Instruments TMP103. Reprinted without alteration as allowed by Texas Instruments

Knowing the dimension of wafer chip is essential for successful PCB layout. The maximum and minimum length is given in Figure 19. Cadsoft Eagle was used to create schematic diagram and the package dimension was taken into account.

3.3.6 Communications Sensor

The Baby Peas communications design will be built around using Bluetooth technology. Wireless communications is key to the success of this project. The wireless module will be implemented on the Baby Peas sensor. The wireless module will except data from the microcontroller and convert the data to RF which will be sent to a device with the ability to receive a signal via the Bluetooth standard. Considerations while choosing a particular component to implement will be low power consumption, output transmit power, receiver sensitivity, BIT error rate, ease of implementation, ease of soldering, and low cost.

While there are numerous components which offer Bluetooth technology, priority will be given to components which consume the least amount of battery power while in standby and transmit modes.

3.3.6.1 CC2541 BLE SOC

The CC2541 is a system of chip (SoC) which conforms to the Bluetooth Low Energy standards, but also has a built in microcontroller embedded within the chip itself. It is designed by Texas instruments. It contains 5 different power modes which are available in table 12.

Power Mode	Current Consumption
Active-Mode RX Down	17.9mA
Active-Mode TX 0 dBm	18.2mA
Power Mode 1 (4us Wake-up)	270uA
Power Mode 2 (Sleeper timer on)	1uA
Power Mode 3 (External Interrupts)	.5uA

Table 13 Power Modes CC2541 BLE RF module

The CC2541 is suited for ultralow power consumption systems. Its transmit frequency ranges from 2379-2496 MHz and boasts four different data rates; 2 Mbps, 1Mbps, 500Mpbs, and 250 Mbps. The receiver sensitivity is 1Mbps, high gain mode is -94dBm, and a BER of less than 1% at 5dBm. The CC2451 also feature a unique in band blocking technology which aids in keeping unwanted signals in the 2.4 GHz range from interfering with the transceiver. There is also no need for an output gain stage to boost the range of the transceiver. A development kit (CC2541EMK) made by Texas Instruments can be purchased to quickly bring the project up to speed on the design and implementation of this device into the baby peas project. The CC2541 has a high performance industry stand 8051 microcontroller imbedded onto the chip itself. This portion of the CC2541 is covered in the microcontroller section. The chip comes in a 6mm x 6mm QFN-40 package which can be soldered using a hot air pencil or standard solder reflow machine. Below are the dimensions of the CC2541.

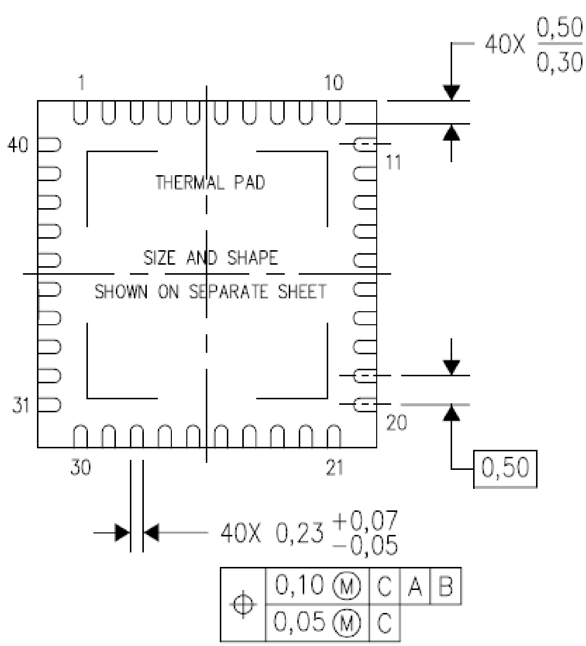

Figure 20 Dimensions of the CC2541, Reprinted without alteration with permission from Texas Instruments

Figure 20 shows the individual pins being .23mm. While this is a QFN device the leads are exposed around the outer part of the device which enables the person soldering the device to be able to tell whether the device is properly soldered. One thing the solder technician will not be able to tell is whether the devices thermal pad is soldered correctly. TI data sheet on the CC2541 gives specific PCB layout recommendations. Careful consideration of PCB layout will have to be utilized to make sure the device can be properly soldered in place. Texas Instruments recommends working with a PCB fabrication facility before the final design is implemented and sent to fabrication.

3.3.6.2 HC-06 Bluetooth Module

The HC-06 is an all in one Bluetooth solution made for quick implementation and ease of use. It is a PCB board which 34 pins but only 5 pins are needed for the design. The Supply, ground, UART TX , and UART RX. It's a basic Bluetooth solution but is limited in interface abilities. The unit can be bought mounted to a breadboard which makes bread boarding this device very simple and easy to get up and running.

Input Voltage (volts)	3.3v
RX current	10 mA
TX current	40mA
Power Output	+6dB
Receiver Sensitivity	-87dBm
Frequency	2.4 GHz
Data Rates	250 kbps , 500 kbps, 1Mbps, 2Mbps
BER	< 1%
Bluetooth Protocol	BLE v4.0 and Bluetooth classic
Solder Package	34 pin
Cost	$12.95 (Amazon)
Lead Time	Ready to Ship

Table 14 HC-06 device specifications

3.3.6.3 nRF51822 BLE Module

The nRF51822 Bluetooth Low Energy Module is made by Nordic Semiconductor. It too is a true system on chip as it incorporates a Bluetooth radio along with a microcontroller. The Bluetooth Radio specifications are listed in Table 15.

Bluetooth mode	Bluetooth Low Engergy (BLE)
Transmit Power	-20 to +4 dBm in 4dBm steps
Receiver Sensitivity	-93dBm at 1 Mbps BLE mode
On air data rates	250Kbps , 1 Mbps, 2 Mbps
Supply voltage normal mode	1.8-3.6v
Operating Tempature	-25 - 75c
Current Consumption during Max transmit	16mA
Current Consumption During Receive	13mA at 1Mbps

Table 15 nRF51822 Bluetooth low energy module specifications.

The nRF51822 uses a 2.4 GHz RF transceiver along with an ARM Cortex M0 32 bit processor. The 2.4GHz Radio can be configurable to not only Bluetooth but ANT and other worldwide ISM band standards. Qualified Bluetooth low energy stacks are available in the s100 series of SoftDevices and the protocol stacks can be downloaded from their site for free. Unlike the other two devices is boast a -30dBm TX power Whisper mode. It has 31 general purpose IO's which 8 can be configured to be ADC's. The ADC's have resolution of 10 bits. It has either 128 or 256kb of flash program memory and 16kB of RAM. The nRF51822 comes in both a 48 pin QFN package and a BGA package. The Baby Peas project would be looking for something a little easier to solder so we would go with the 48 pin QFN package. One careful consideration for using this part is an external antenna must be integrated for proper operation to occur. Nordic Semiconductor examples for designing an external 50 ohm antenna and the schematics and gerber files are available for download from their website. The part dimensions are 6mm by 6mm. Figure 22 is the dimensions of the device

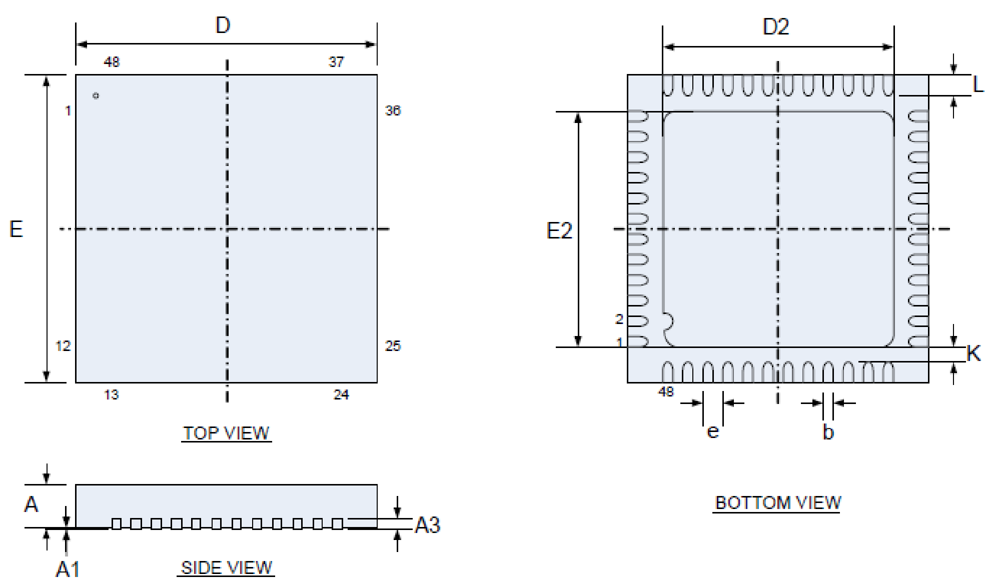

Figure 12 *QFN48 6x6 mm package*

Package	A	A1	A3	b	D, E	D2, E2	e	K	L	
	0.80	0.00		0.15		4.50		0.20	0.35	**Min.**
QFN48 (6 x 6)	0.85	0.02	0.2	0.20	6.0	4.60	0.4		0.40	**Nom.**
	0.90	0.05		0.25		4.70			0.45	**Max.**

Figure 21 QFN48 Device Dimensions for nRF51822. Reprinted without alteration with permission from Nordic Semiconductors

From Figure 22 all dimensions are in mm. The b and E2, D2 values are our main concerns when creating the PCB design. The b measurement is very small at .20mm nominal so a hot air pencil or solder reflow machine will be needed. The individual pins are visible on the outside of the component which will make realization of good solder connections easier to decipher. E2 and D2 are the dimensions of the ground plane which needs a solid solder connection for the device to work properly. Nordic Semiconductor states the PCB must have a minimum of two layers and a ground plane for optimal performance. PCB specifications can be downloaded at www.nordicsemi.com to aid in the RF layout and the surrounding components.

The following Table 16 below is a comparison of the three devices and their respective parameters of importance pertaining to the baby pea's project.

	CC2541	HC-06	nRF51822
Input Voltage (volts)	2 - 3.6	3.3	1.8 - 3.6
RX current	17.9mA	1mA	13mA
TX current	18.2mA @ 0 dB	40mA	16mA
Power Output	0 dB	+6dB	+4dB
Receiver Sensitivity	-94dBm at 1Mbps	-87dBm	-93dBm
Frequency	2.4 GHz	2.4 GHz	2.4 GHz
Data Rates	250 kbps , 500 kbps, 1Mbps, 2Mbps	250 kbps , 500 kbps, 1Mbps, 2Mbps	250 kbps , 1Mbps, 2Mbps
BER	< 1%	< 1%	< 1%
Bluetooth Protocol	BLE v4.0	Bluetooth v2.0 +EDR	BLE v4.0
Special Features	Microcontroller and RF module combined.	n/a	Microcontroller and RF module combined.
Solder Package	40 pin QFN (visible)	32 pin	48 pin QFN (visable)
Cost	$6.62 (Digikey)	12.95 (Amason)	$4.95 (Mouser)
Lead Time	Ready to Ship	Ready to Ship	Ready to Ship

Table 16 Bluetooth Device Comparison

From Table 16 we derive HC-06 to give us the greatest output power but at the cost of a much higher transmit current consumption. One of the downsides of the HC-06 is it doesn't have a build in microcontroller. Also the documentation from the data sheet is extremely confusing because there are several different revisions with all different configurations. The differences between the nRF51822 and CC2541 are very small. The nRF51822 has a slight advantage over the CC2541 in cost current draw but has a slightly larger package size. Since the two devices are very similar in design the Baby Peas project decided to go with the CC2541 for a different reason. Texas Instruments has a wealth of information and application notes to help users starting new projects to come up to speed on Bluetooth Low Energy rather quickly. They offer many example projects in both the hardware and software aspect. Texas Instrument also has an evaluation kit which incorporates six different sensors integrated with a CC2541 package with all relevant information included for $20.00 (Sensor Tag). The evaluation kits for the nRF51822 start at $100 dollars with less examples and documentation. So the CC2541 from Texas Instruments seems the most logical to incorporate as both the RF module and Microcontroller for the baby peas project. Towards the end of the project, the CC2541 proved to be much harder to implement than was thought. To program the CC2541 and develop on it the IAR embedded workbench design environment must be used. IAR embedded workbench costs around $1500 dollars for a student license. They do provide a 30 day full trial period with unlimited code size and free version which is code limited to 4kb. The problem arose when all of the sample projects were over 4kb and our free 30 day trial was about to expire. Also problems arose with the version of IAR that was to be used. The current version does not compile the TI provided current BLE stack but IAR does not mention this. We found out after a week of troubleshooting that an older version of IAR embedded workbench must be used to use the BLE v4 stack from TI. With time running down to providing a working project the Baby Peas design bailed on the CC2541 and implemented the HC-06 with an Atmega328p utilizing the Ardiuno Development environment. This was much simpler and allowed us to redesign our project very quickly.

3.3.7 Microcontroller

The microcontroller is an essential part of the overall project. The function and data flow of the sensors is determined by the microcontroller. The data originates from the sensors and is passed on to the microcontroller through its input/output system. When selecting the appropriate part for the wireless sensor, the performance and power consumption are the primary specifications to consider. This is because the microcontroller with be mounted on a peripheral unit and act as part of a wireless transmitter. The MCU should use a minimal amount of power to maximize battery life while being able to achieve the necessary performance standard needed for its actions. The data processing required will have to do mostly with interpreting analog data coming off of multiple sensors measuring vital signs and position. The microcontroller will communicate with the four sensors through a data bus. The microcontroller will also interface with a *Bluetooth* wireless system and thus must have some form of serial or parallel data communication on it.

3.3.7.1 TI MSP430 FRAM Series

The MSP 430 FR59xx model has a 16-Bit RISC architecture. It offers a low power option with a high speed. It has a max speed of 24 MHz. The FRAM series contains up to 64 KB of Non-volatile memory and 2 KB of static RAM. There are 17-40 general input/output pins. It is compatible with UART, I2C, and SPI data communication. The controller features enhanced serial communication options. This supports eUSCI_A0 and eUSCI_A1, having a UART with automatic baud-rate detection, IrDA Encode and Decode, and SPI with rates up to 10 Mbps. The eUSCI_B0 supports I^2C with multiple slaving addresses and SPI rates up to 8 Mbps. This series also contains a 14 channel Analog to Digital converter, which is acceptable for the project design. The resolution of the ADC converters is 12 bits. The biggest advantage to the FRAM series is the low power consumption to data throughput ratio. Data writes occur at 125 nanoseconds per word. In active mode, the typical power consumption is 103 μA/MHz. In Standby mode, the consumption is 0.4 μA. Shutdown mode typically uses 0.02 μA.[26]

Advantages of the MSP430 FRAM

- Very low power consumption
- 14 channel Analog to Digital converters
- High data throughput ratio
- Fast memory write time

3.3.7.2 ATMEL

The Atmel model ATmega328P is a high performance, low power 8-Bit microcontroller. It features a RISC architecture with 32x8 general purpose registers and 23 programmable Input/Output pins. Data throughput is listed at 20MIPS at 20 MHz. It contains 32KB of programmable flash memory, 1KB EEPROM, and 2KB SRAM. The ATmega328P supports Serial USART, Master/Slave SPI Serial Interface, and is compatible with I2C data transmission. Operating voltage ranges from 1.8 - 5.5V and has a speed of 0-20 MHz. Active Mode consumes 0.2 mA, Power-down Mode at 0.1 μA, and Power-save Mode consumes 0.75 μA. [28]

Advatanges of the ATmega328P

- Multiple data communication options
- Low power usage and Power-save Mode
- Good amount of input/output pins
- RISC architecture

3.3.7.3 PIC(MICRO)

The Microchip Pic model PIC16F720 is a high-performance microcontroller with RISC CPU architecture. Operating speed occurs at 16 MHz with a 250 ns instruction cycle. There is up to 4K x 14 Words of Flash Program Memory and up to 256 bytes of RAM. Operating voltage range is 1.8V to 5.5V. The PIC microcontroller also has multiple low-power settings. Standby mode typically runs at 50 nA at 1.8V. Operating current is 100 μA. The watchdog timer current is another low-power feature that operates at 500 nA at 1.8V. This microcontroller features 17 input/output pins and 1 input-only pin. The analog to digital converter has an 8-bit resolution with 12 separate channels. It supports Asynchronous Receiver Transmitter (AUSART), SPI (Master/Slave), and I2C (Slave) data communication options. [29]

The advantages of the PIC16F720:

- Low power usage
- Cheap, powerful microprocessor
- Sufficient memory space
- Sufficient amount of I/O pins
- RISC architecture
    - Reduced instruction set
    - Faster computations

3.3.7.4 CC2541

The CC2541 is a true system-on-chip (SoC) solution for *Bluetooth* low energy applications. Another feature of the CC2541 is the *Bluetooth* system located on the chip, which supports 250-kbps, 500-kbps, 1-Mbps, and 2-Mbps data rates. The microcontroller core is an enhanced 8051 MCU. The 8051 microcontroller has a computer speed of 33MHz and MIPS at 8MHz. It uses 8-bit architecture. The memory contained within the 8051 is up to 32KB flash memory and up to 1.2KB RAM. There are up to 8 analog to digital converters at a resolution of 24 bits. It supports SPI, I^2C, and

USART serial interfaces for data transmission. One of the advantages of the CC2541 is its compatibility with the TPS62730. The TPS62730 is a 2 MHz Step-Down converter with a bypass mode. The step-down converter takes the input voltage and reduces it to a lower voltage for low-power uses. The TPS62730 extends battery life by up to 20 percent and reduces current in all active modes. The Bypass mode provides a 30-nA current to support low-power modes. The Bypass modes do not affect the RF performance of the Bluetooth module. The CC2541 has multiple low power settings that operate on a voltage range of 2V to 3.6V. The low power Active Mode RX operates at 17.9 mA and the Active Mode TX (0 dBm) operates at 18.2 mA. Power Mode 1 operates at 270 µA with a 4 µs wake up time. Power Mode 2 operates at 1 µA with the Sleep Timer on and Power Mode 3 uses 0.5 µA with external interrupts. The TPS62730 Step Down Converter is on in both active modes. The CC2541 is available in a developmental kit called the Sensortag. The Sensortag comes with a CC2541 interfaced with a number of sensors. The developmental kit will provide a great source of reference material when designing the project. [24]

Advantages of the CC2541

- *Bluetooth* System on Chip solution
- Sensortag development kit allows valuable reference design
- TPS62730 capability affords ultralow power
- 8051 MCU architecture
- High processor speed
- Sufficient memory space

3.3.7.5 MSC1210

The MSC1210 is a precision analog-to-digital converter that comes with an 8051 microcontroller core and flash memory. The analog-to-digital resolution is 24 bits with 22 bits effective resolution at 10Hz and a low noise level at 75nV. The MSC1210 has 8 different ADC differential/single-ended channels. Other features include an on-chip temperature sensor and burnout sensor detection. The memory capability is up to 32KB flash memory and 1.28KB SRAM. There are 34 total Input/Output pins and a 32-bit accumulator. Serial and parallel communications are supported in the form of full-duplex dual USARTs and Master/Slave SPI. This model operates on a range of 2.7V to 5.25V with a low power output at 4mW. Idle mode current is less than 1mA and Stop mode current is less than 1 µA.[27]

Advantages of the MSC1210

- Serial and parallel communication
- On-chip temperature sensor and burnout sensor
- 8051 microcontroller core
- High analog-to-digital converter precision

The general characteristics of the preceding microcontrollers have been presented and were considered as viable implementation options for the project. The chosen microcontroller is the CC2541 for its convenient Bluetooth SoC solution and acceptable CPU parameters.

After Senior Design 1 our implementation utilized the CC2541 but with the difficulties of implementation the Atmel Atmega328p was implemented due to the ease of use and the Arduino Development environment compatibility.

3.3.8 Power Supply

3.3.8.1 Battery

As discussed above in section 3.2.9.1.2 the best packaging for the portable power source is the button package. After determining the needs of the sensor modules and central processing unit, the best battery for the job would be a LIR2477. It is a 3.7 volt, 160mAh battery with 500 cycle life times. Ideally, during a day of normal usage, the user charges the battery once every two days time. At this rate, the battery should have an average lifetime of over 3 years. The cut off voltage of the battery is 3 volts and the max discharge current is 300 mA.

3.3.8.2 AC power supply

As discussed in section 3.2.9.2, it would be too dangerous to make an AC to DC power supply, due to lack of expertise and proper personal protective equipment. A possible choice for the Baby Peas unit would be a consumer grade wall mount charger. PowerStream sells such a unit, called the wall mount lithium ion coin cell and lithium polymer battery charger, at a very reasonable price and for the battery that was chosen for the portable unit. According to the PowerStream website, it is a dual charging unit with indicators showing charge status and polarity. Having a well tested unit will be invaluable to the well-being of group members and any test conditions.

3.3.8.3 DC power supply

3.3.8.3.1 USB

In addition to the AC power supply, a DC power supply can also be implemented. In fact, in some cases, it might be even more desirable due to the widespread usage of USB ports and flexibility. In addition, a USB charger from a PC or a USB wall converter would both work. The three choices are to make a USB charger, integrate a USB charging port on the baby peas unit, or buy a USB charger. In the interest of the time constraints, due to the fact that manufacturing a baby peas unit with a female micro-USB charging point would require some modifications to the schematic already designed, it is recommended to have this as a stretch goal. If the main features on the unit are functioning within required constraints, i.e. the sensors and communications protocol, then it is possible to consider integrating a recharging circuit to the existing circuit using a linear charge controller unit such as MCP73832. This is a decision to be made early on during prototyping section of the project. If it is not possible to integrate a power recharge circuit, many stores also offer PCB breakout boards. A private vendor sells a board, built around the MCP79832, for around 5 dollars.[53] It would be simple to populate and have a viable working unit. Finally, a pre-built USB charger is surprisingly absent from the market. During a cursory search of the available resources, there are no suitable units for sell.

3.3.8.3.2 Solar

For solar supply, the same applies as the USB charger. This feature is considered a stretch goal. As discussed in section 3.2.9.3, a simple schematic is drawn for a solar USB charger kit sold by Digikey. It outputs to a USB, so it is required to have the USB breakout board built before attempting the solar kit. [54]

3.3.8.4 Board supply Regulator

The critical unit for the power supply directly to the board units is the regulator. Earlier in section 3.2.9.3, linear and switching regulators were discussed as the two options for the board. For linear regulators, the low dropout rate regulators were recommended due to efficiency ratio of input and output ratio.

3.3.8.4.1 Linear Regulators Linear Tech LT1761

Linear regulator is a well-known and well-used method to supply the correct voltage throughout the circuit. Fundamentally, the circuitry uses the voltage divider principle to generate the correct voltage at the output of the regulator and input to the circuit. The simplest circuitry would consist of just some resistors and diodes, while more complex circuitry might have error corrections measures, power protection, and voltage references. One of the simplest designs is called a zener regulator, figure 22.

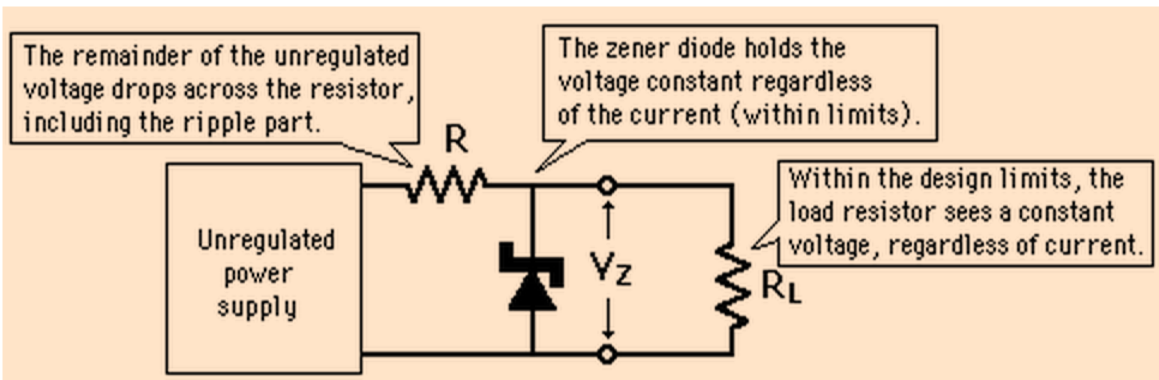

Figure 22 Zener Regulator, reprinted with permission from hyperphysics

The voltage output is constant due to the constant reverse voltage aspect of the zener diode. The extra voltage that is not passed through is dissipated through the resistor that is part of the power regulation circuit. Linear regulators are commonly used in hobby electronics and simple consumer electronic goods due to stability and cheap price point. A familiar family include the LM78xx. The primary disadvantage of the traditional linear regulators is the low efficiency. Regulators such as the LM78xx needs a high buffer zone between input voltage and output voltage. For the LM78xx family, the typically differential voltage is 2 volts. That is an enormous cost, considering that the entire circuit package needs to run around 3.6 volts and every volt added could mean bulkiness and weight in package. In addition, any extra voltage is dissipated as heat, creating a thermal threat to the operation of the package and to the baby's skin. The thermal and voltage differential can be solved by using a low dropout linear regulators.
Nowadays, IC makers offer linear regulators with low differential with input/output, low noise, and a fast transient response. Some of options include such devices such as Linear Technology's LT1761, an option with a low dropout voltage of 300 mV at 100mA of

output current. In a typical application, the input/output differential is a mere 0.4V. This is a 500% improvement over the LM78xx family. What is more, the quiescent current for this unit is also very low at 20 µA. The shutdown Quiescent current is less than 1 µA. The Figure is configured to 5 volts output. This voltage regulator comes in a host of different voltage levels, including 1.2V, 1.5V, 1.8V, 2V, 2.5V, 2.8V, 3V, 3.3V, and 5V.

While the TPS62740 is the ideal regulator for the project, a backup regulator has been chosen in the event TPS62740 does not work as promising as it looks on paper. As discussed earlier in the section on regulator background, switching regulator, due to the frequency at which it opens and closes a switch, can interfere with radio frequency signals. In the case that the signal is noisy and the problem is determined to originate from the switching regulator, a possible replacement linear regulator will be used. The recommended linear regulator is the LT1761-3.3. According to the datasheet on Linear Technology's website, this is a low drop out voltage regulator with low noise design. Figure 23 shows the curve of typical drop out voltage in regards to the differing output currents. For Baby Peas, output current can range from 50mA to over 100mA. At the lower end of that spectrum, 250mW differential will be required from the input to the output. While not ideal, this is very low for a linear regulator. At the higher end of the spectrum, the cost differential is higher. This is why the linear regulator is the backup choice. Despite the cost, the LT1761 is still lower than most of the competitors.

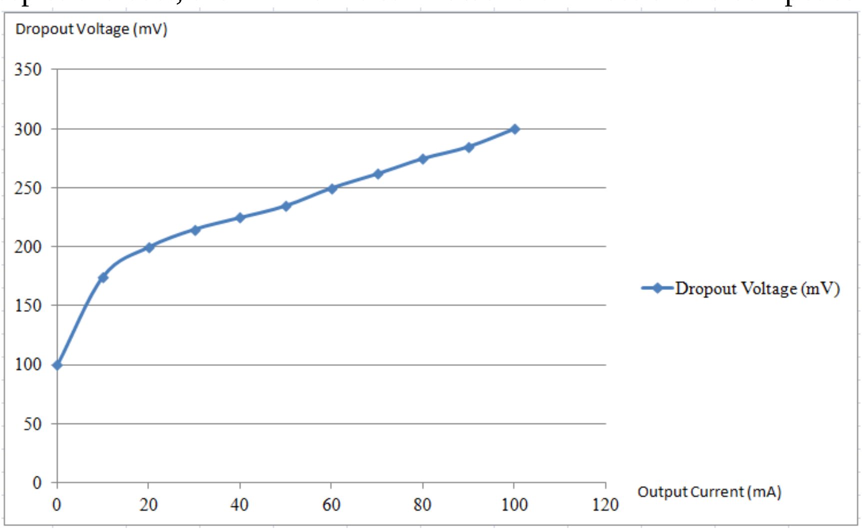

Figure 23 Typical Dropout Voltage approximation diagram for LT1761. Created by Xin Tong in MS Excel

The quiescent current is at 20uA and comes in a static voltage select package. In addition, throughout the course of usage, the quiescent is controlled to near 20uA.

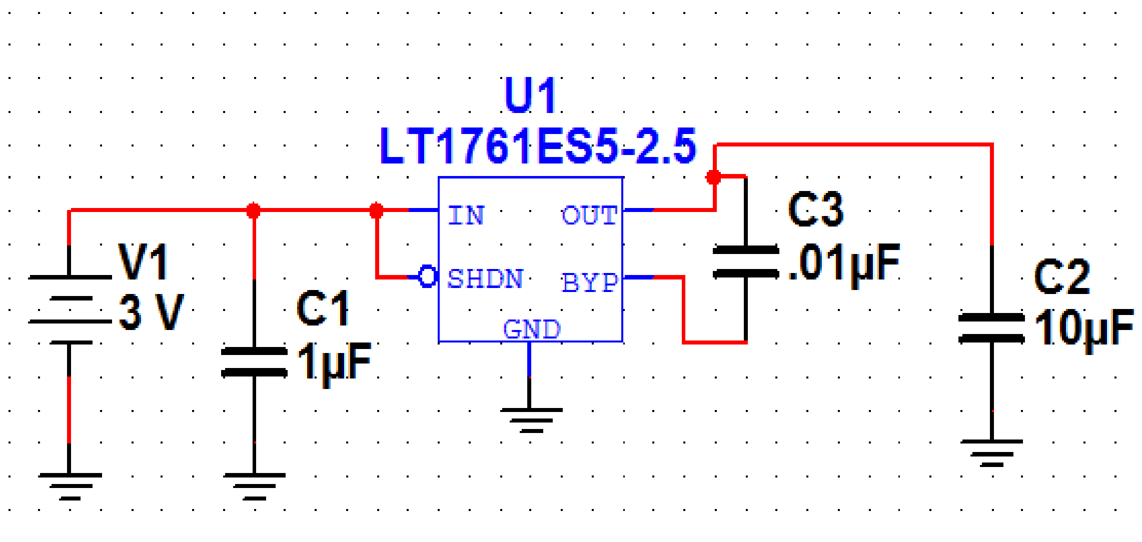

Figure 24 Typical Application for LT1761. Created by Xin Tong in NImultisim

3.3.8.4.2 Switching Regulators Texas Instruments TPS62740

The second option for power regulation is switching, or switched-mode power supply. In this case, the power supply is switched on and off in a swift pace, outputting an average supply voltage. The switching regulator, such as the one shown in Figure 24, control the gate using a certain frequency. The amount of power going through is determined by the amount of time the switch is closed. The output voltage depends on how much voltage is at Vin, and the switch duty cycle.

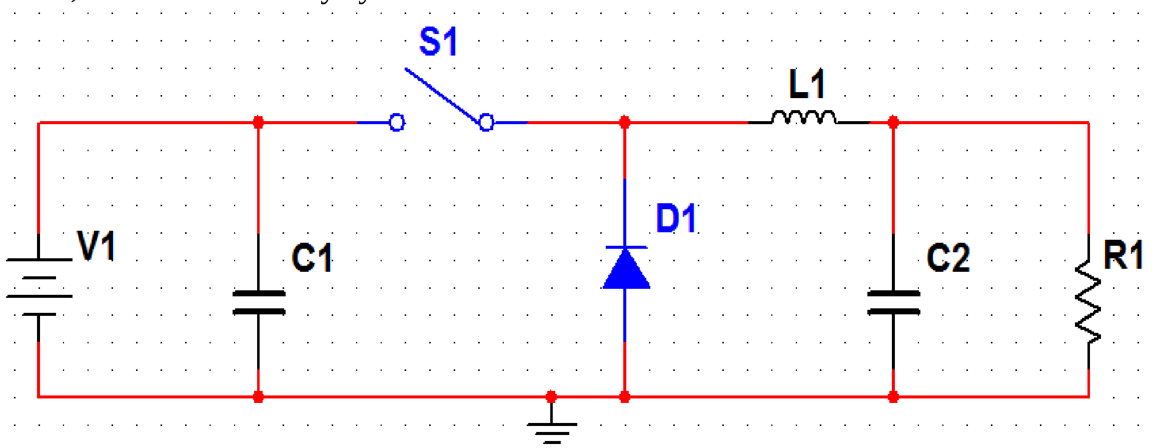

Figure 25 Simplified Switching Regulator. Created by Xin Tong in NImultisim

The controlling gate of the switching regulator is usually a transistor or a thyristor. In addition, extra components are needed to make a circuit function as a useful power supply. Rectifying diodes and inductors help the output capacitor with providing a steady ripple free output. Figure 25 shows one such configuration.

Because there is no constant supply of power, this helps to prevent the waste of power. The advantages of switching regulators are efficiency (longer battery life and less heat dissipation) and size. While switching regulators often require more components than linear regulators, the fact that switching can forgo the heat sinks that are a staple of linear regulators. Some of the disadvantages of switching are a higher cost compared to linear and the introduction of more noise. In addition, switching regulators often require a little more complexity in circuitry, and will need inductors to act as an energy storage element and external diodes. The disadvantages of noise can be ameliorated by using families of ultralow noise regulators. For example, Linear Technology offers packages such as the LT1533. Designed specifically for sensitive instrumentation measurements and medical devices, this regulator is designed so that the noise generated by the frequency of the switch duty cycle will not interfere with other modules on the board. TI's Bluetooth sensor tag uses a switch regulator, the TPS62730.

Key Features

- Input Voltage Range from 1.9V to 3.9V
- Typical 30 nA Ultra Low Power Bypass Mode
- Supports sleep and low power modes on CC2541
- Typical 25 µA DC/DC Quiescent Current
- DC/DC converter connected via typical 2.1Ω Bypass switch to battery

The TPS62730 is a step-down DC/DC buck converter. Figure 26 below shows the typical battery current of the CC2540 model versus the voltage of the battery. The TPS62730 minimizes the current drawn from the battery during both transmission and reception modes. The graph shows a clear reduction of battery current used as the voltage increases. This decrease in current allows the prolonged use of the powered device in transmission mode. A long battery life is essential to the use of the project. The longer the battery can be powered without recharge, the more useful and convenient the device will actually be. This ensures the child will be monitored through a longer uninterrupted period of time, where parents do not have to constantly worry about how much battery life is left. This device supports Lithium powered battery chemistries such as $LiSOCl_2$, $LiSO_2$, LiMnO2, and other two cell alkaline batteries.

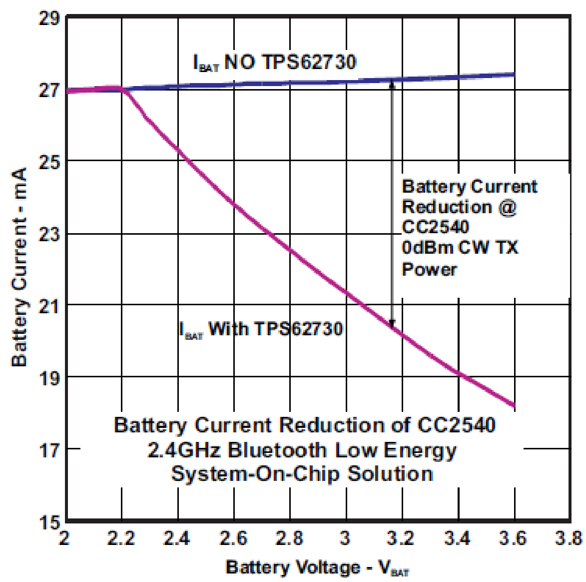

Figure 26 Current vs Voltage with TPS62730, Reprinted without alteration with permission from Texas Instruments

The Figure 27 below show the relative current consumption during data transmission. The bottom axis is labeled as supply voltage increasing from left to right. The left vertical axis is labeled as current in mA increasing upward. The blue bar shows the current consumption at its corresponding voltage without using the TPS62730 DC/DC converter. The red bar shows the current consumption with the CC2541 connected to the TPS62730 DC/DC converter in ON mode. For increasing voltage, the current consumption with the DC/DC converter on steadily declines. The vertical axis on the right side is labeled for percentage of current savings. This is the percentage of current decrease depicted in the red bar with respect to the blue bars. The current savings steadily increases with increasing voltage. This indicates that there is up to 37 percent decrease in current in transmission mode, and up to 35 percent decrease in current in receiving mode. This overall decrease in current in both modes will lead to a much longer battery life as compared to the blue bars, which show an increase in current with its associated increase in input voltage. It stands to reason that without using the TPS62730, the battery life will be approximately one third shorter than the alternative. While the TPS62730 is used in TI's sensor tag, the regulator recommended for this project is the TPS62740.

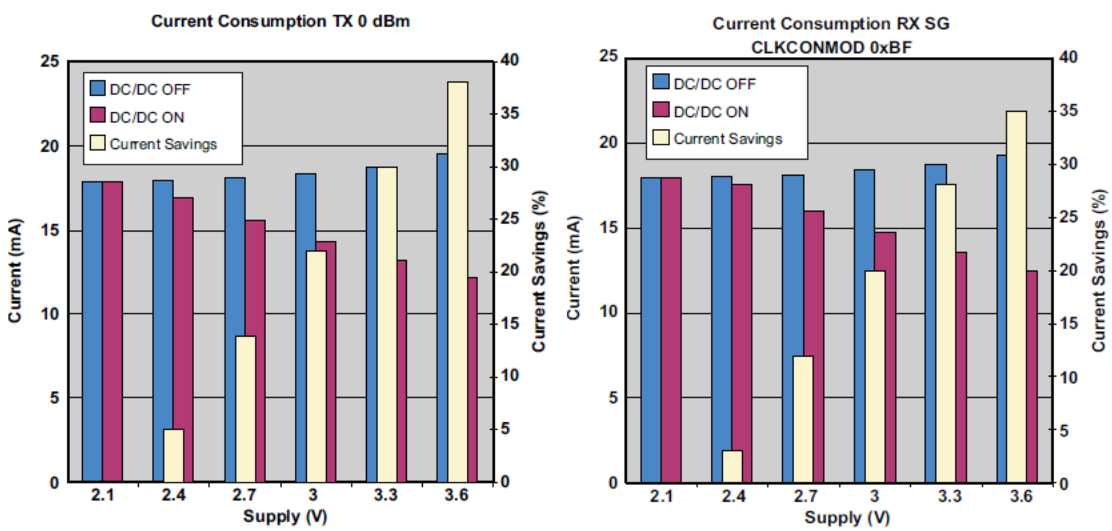

Figure 27 Current Consumption in TX and RX, used with permission from Texas Instruments

Figure 28 below shows an example application of the TPS6270 connected to a CC2540 (similar to the CC2541). The figure shows how the two devices are probably connected in the CC2541 layout. The power-down signal is passed from the P1.2 MUX to the TPS62730 ON/BYP input pin. In this way, the mode selection of the TPS62730 is dictated by the microcontroller programming. If the ON/BYP pin is low, the TPS62730 is in its ultra-low power bypass mode. In this mode, VIN is directly connected to VOUT through an internal Bypass switch and consumes only 30 nA typical input current. The output of the buck converter is connected to the battery VIN. When the pin is high the transition from Bypass mode to DC/DC converter operation is enabled. This transition state is to reduce the amount of ripple voltage to zero or near zero and is regulated by output capacitors (shown in figure) and internal decoupling capacitors. Once the capacitors are discharged sufficiently and internal comparators recognize the increase in input voltage, the bypass switch is deactivated, allowing normal operation of the DC/DC step down converter.

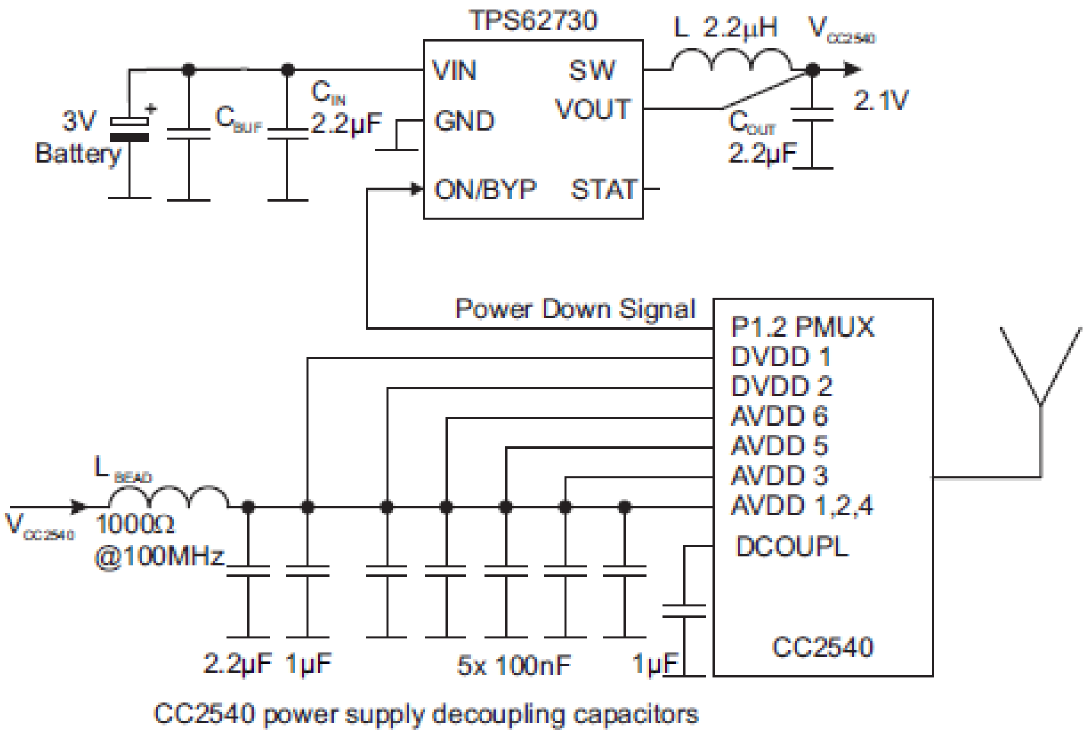

Figure 28 TPS - CC2540 Reference Design. Reprinted without alteration with permission from Texas Instruments

3.3.8.4.2.1 Pin Functions

The pin descriptions, contained in Table 17, for the TPS62730 are helpful references to understanding exactly how the chip will be connected to the CC2541. The functional block diagram is also more easily understood knowing the pin functions.

Figure 29 below depict on the next page shows the efficiency versus Input Voltage (left) and Output Current (right) of the TPS62730 in ON mode (ON/BYP = high). The trends for the efficiency of the chip versus output current shows positive correlation between output current and total efficiency for various input voltages. Although there is an expected dip in efficiency for larger input voltages, all voltages in the operating range are above 85 percent, even towards larger output current values. The orange graph line shows the chip operating in bypass mode. In bypass mode, the efficiency peaks at almost 100 percent from 1-10 mA. This makes sense because in bypass mode the voltage is going straight from VIN to VOUT through the bypass switch. The right figure shows the efficiency with respect to input voltage. The efficiency once again increases for larger values of output current. However, there is a slight negative correlation as the input voltage increases. The efficiency still manages to stay about 80 percent from 1mA to 100mA. At high input voltages, the 100mA ends up being the most efficient.

Pin		I/O	Description
Name	NO		
VIN	3	PWR	Power supply pin
GND	4	PWR	Ground supply pin
ON/BYP	5	IN	Mode Selection pin. Pulling pin low forces device into ultralow power bypass mode. The output of the DC/DC converter is connected to VIN via an internal bypass switch. Pulling this pin to high enables the DC/DC converter operation. This pin must be terminated and is controlled by the system.
SW	2	OUT	This is the switch pin is connected to the internal MOSFET switches.
VOUT	6	IN	Feedback Pin for the internal feedback divider network and regulation loop. The internal bypass switch is connected between this pin and VIN
STAT	1	OUT	This is the open drain status output with active low level. An internal comparator drives this output. The pin is high impedance with ON/BYP = low. With ON/BYP set to high the device and the internal VOUT comparator becomes active. The active low STAT pin indicates if the DC/DC regulator is settled and the output voltage above the V_{TSTAT} threshold. If not used, this pin can be left open.

Table 17 TPS62730 Pin Description [23]

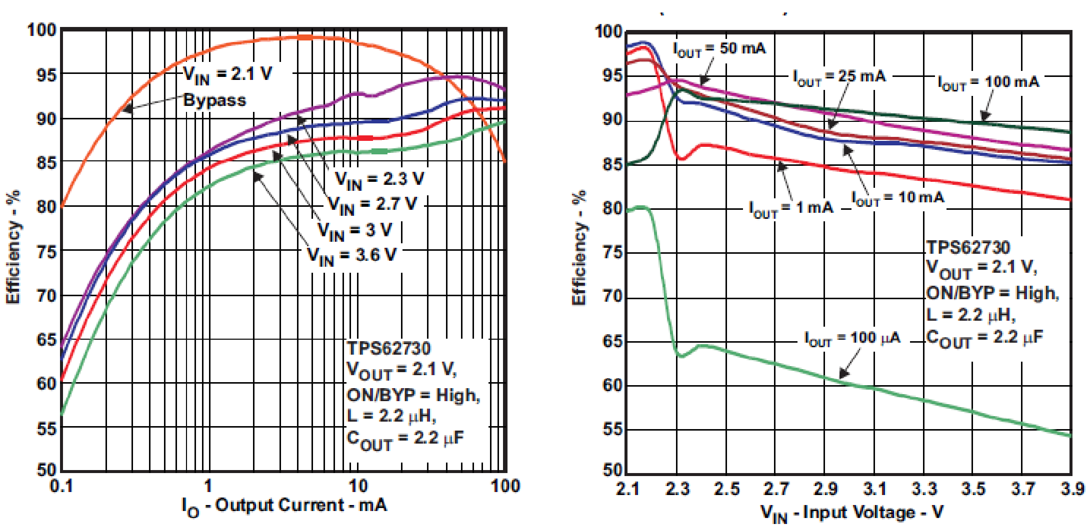

Figure 29 TPS62730 Efficiency Charts, Reprinted without alteration with permission from Texas Instruments

Figure 30 below illustrates the internal components of the TPS62730 with a functional block diagram. The ON/BYP input on the left side determines the running mode. When the pin is low, it shows a low voltage to the AND gate, which in turn gives a low signal. That bypass signal shows up on the switch in the upper right corner labeled “/BYPASS”.

In this mode, the signal from VIN goes directly to VOUT. The signal from VOUT is fed back to the error comparator through the error feedback network. When the ON/BYP pin is high, the buck converter is active. The STAT pin is the status pin used for monitoring the working mode of the TPS62730. When bypass mode is active, the ON/BYP pin is set to low. The STAT pin should then also read as high impedance. When the DC/DC regulator is on, the ON/BYP pin is set high. The STAT pin should read high as well in this setting. This pin is modulated by the internal VIN comparator as seen in the functional block diagram. Because STAT is simply an observation pin, it is optional to connect this pin. However, most of its use can come in the development and testing process. The status pin can be connected and monitored to ensure the components are working properly.

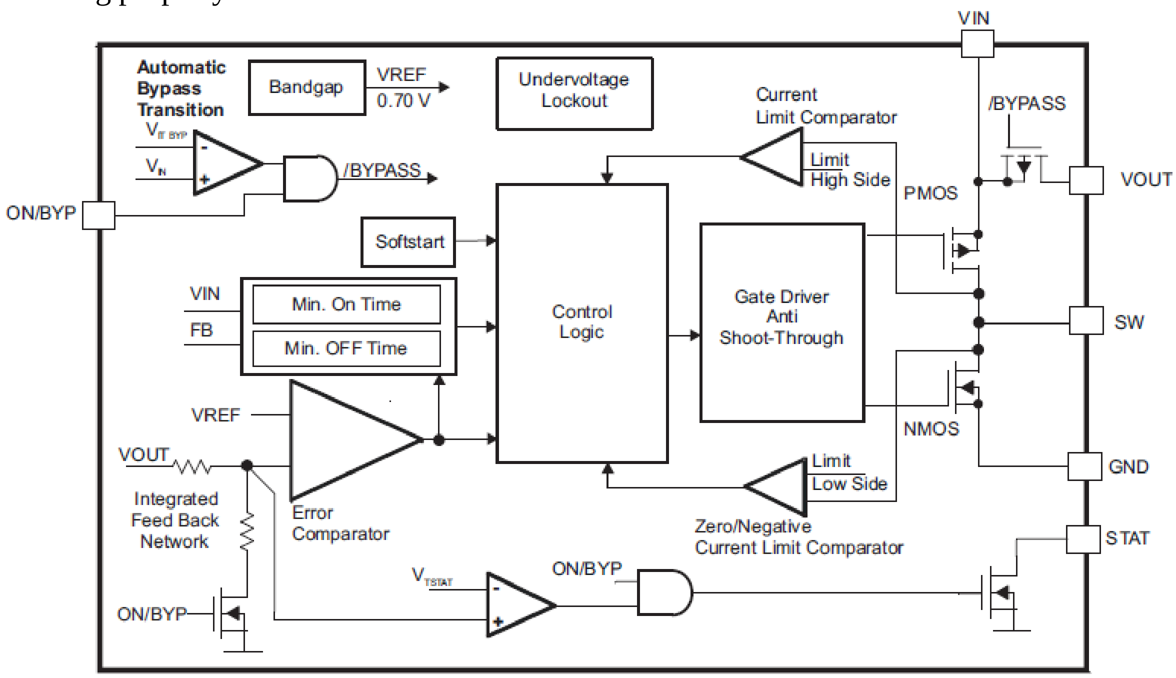

Figure 30 TPS62730 Functional Block Diagram, Reprinted without alteration with permission from Texas Instruments

TPS62740 is the recommended voltage regulator for this project due to its compact size and power parameters. In addition, the family of TPS627XX has proven suitability in a design with the CC2541; this is the regulator that the TI sensor tag developmental kit uses. That kit is using a TPS62730, a lower voltage regulator than the TPS62740. TPS62740 has a new DCS-Control feature that incorporates a tiny inductor and output capacitor to improve efficiency during times of low power usage. DCS-Control, or Direct Control with Seamless Transition into Power Save Mode) is a topology trademarked by Texas Instruments and this topology was developed to aid power density and efficiency. This Direct Control with Seamless Transition into Power Save Mode incorporates AC control loop, Voltage feedback loop, and internally compensated regulation network. The AC control loop "takes information about output voltage changes and feeds it directly to a fast comparator stage for immediate response to dynamic load changes". This feature, in addition to the voltage feedback look feature, which helps to sharpen DC load regulation, allows for a clean and stable output. In addition the internal compensated regulation network is a great buffer package that is able to dynamically stabilize with external components. The DCS-control topology switches between pulse width modulation and power save mode for efficiency for both medium to heavy loads (Pulse Width Modulation) and light loads (Power Save Mode). Figure 31 shows the efficiency gains the new TPS62740 offers at low output current.

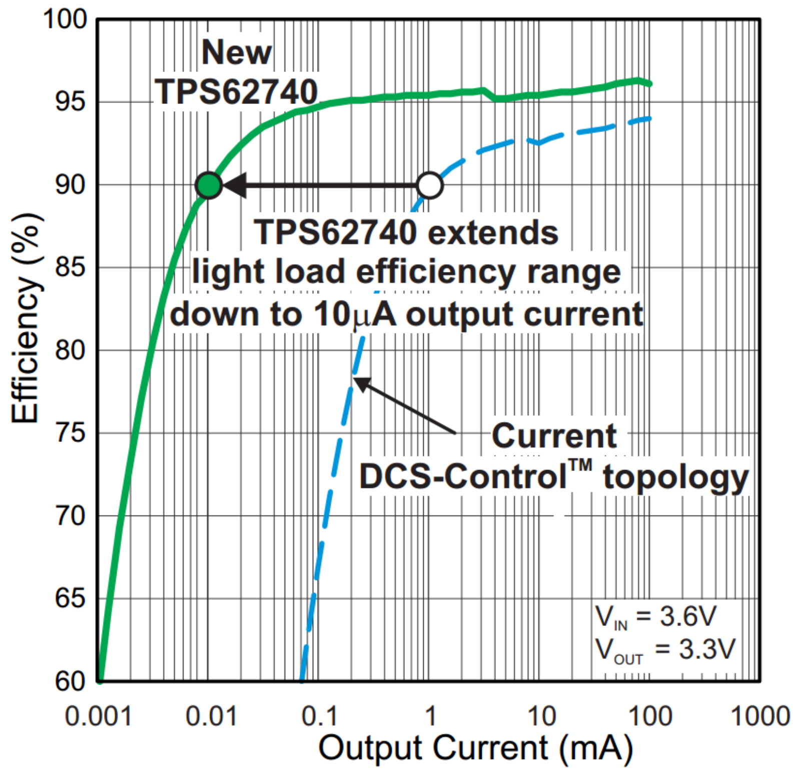

Figure 31 Extension Range of TPS62740 Efficiency Down to 0.01mA. Reprinted with the courtesy of TI documentation on TPS62740

The TPS62740 has improved on the transition between the two modes and decreased voltage ripple and random jitter.[55] The older direct current to direct current regulators, which switched between the two modes by using physically separated blocks for the two different modes, usually set the pulse width modulation mode as default due to the voltage ripple and random jitter. However, this move cost the regulator in efficiency. In the new TPS627XX family, the pulse width modulation and power save mode blocks are integrated into a “single building block”, which provides a “seamless transition between PWM and Power Save Modes”. [55] Due to the architecture of the blocks and internal regulation network, the quiescent current is 360nA during typical operations. Quiescent current is an important consideration in the project due to the way the Baby peas unit operates. Total battery life comes from both the load current and quiescent current, or standby current. The portability of Baby peas faces a huge compromise if the quiescent current is large. Figure 32 shows the different quiescent current with differing voltage in.

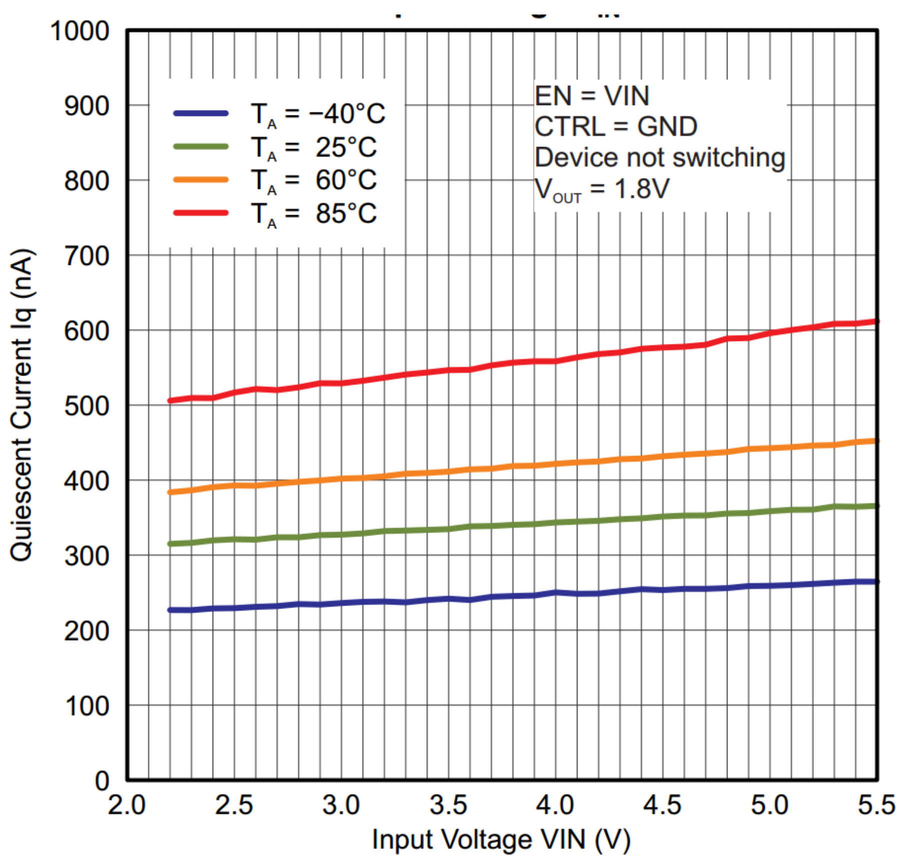

Figure 32 Quiescent Current During Differing VIN. Reprinted without alteration with permission from Texas Instruments.

The maximum operating current goes to 300 mA. At 10uA, the efficiency touches 90%. In order to prevent ripple noise from propagating through the circuit, TPS62740 also "features low output ripple voltage and low noise with small output capacitor".[55] The scheme behind this features is the dynamic operation of the no ripple mode operation. In the past, as the battery source start to get close to the output voltage on the regulator, certain characteristics such as ripple voltage start to increase. To stop this, the TPS62740 uses a 100% mode operation at this point to lessen the impact of the ripple voltage; basically the regulator changes to a linear like device, and "stops switching and the output is connected to the input voltage directly from the battery".[55] Figure 33 demonstrates this principle. The input and output form a y = kx relationship at the lower voltages, while at higher voltages, the out is a constant. The x value is the input value, and the output voltage is the output value, while the k value represents a constant multiplier. At the lower voltages, this just means that what comes into the regulator is output on the other side at an almost 100% mode. At higher voltages, the regulator starts to function like a traditional switching regulator, and regulate the incoming voltage down to the correct output voltage.

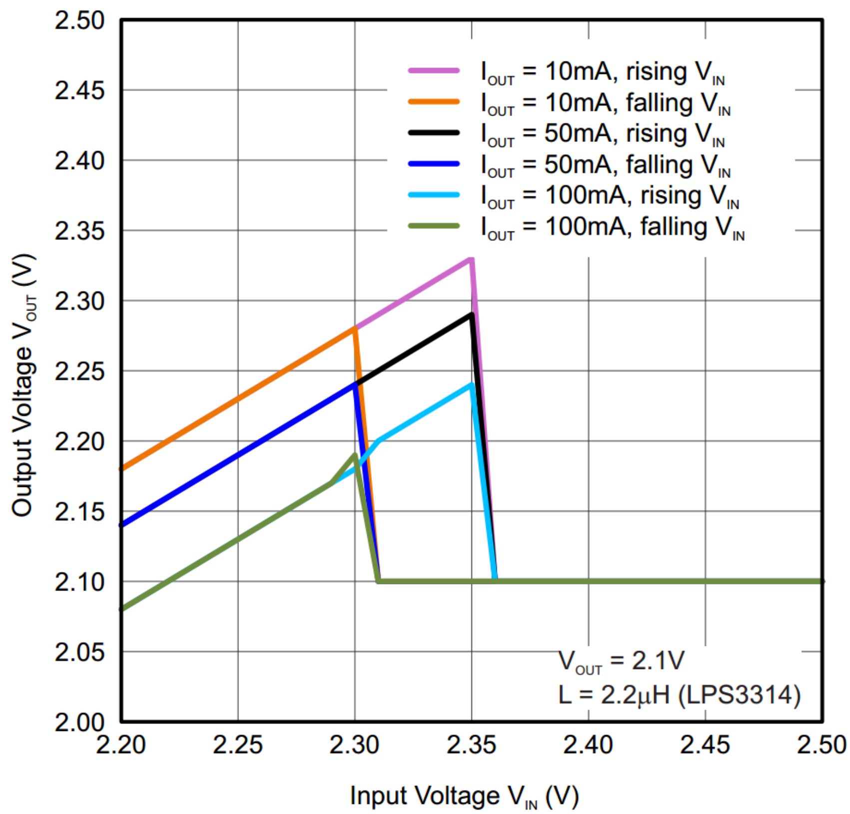

Figure 33 100% Mode Transition for Vout of 2.1V. Reprinted without alteration with permission from Texas Instruments.

Intended to run from rechargeable Li-Ion batteries, this unit can have an input range of Vin from 2.2 V to 5.5 V. The additional nicety about this unit is the different levels of voltage output. Ranging from 1.8V to 3.3V, four voltage select pins can be pulled high in different configurations in order to output differing voltages in 100mA steps. Table 18 shows the different voltage selections levels and pin configuration logic for the Baby Peas project

This feature is great due to the scalability for future boards. While current modules on the Baby Peas require voltages around 3V, the future iterations or different models could require less or more voltage. For example, the pulse-ox unit raises the voltage requirement for the entire unit. The accelerometer and temperature sensors hover around 2.75 for voltage requirement, but the pulse-ox require a 3-3.3V input. If a baby peas unit was built only around the accelerometer and temperature, the regulator could be configured to select only pins VSEL 4 and VSEL2. That could length the battery life by a magnitude. The ability of the pin select allows the designers to choose the best output voltage for the system. Currently for the Baby Peas unit, all the VSEL pins, VSEL1 through VSEL 4, are going to be pulled high, so the output voltage of the TPS62740 is going to be at 3.3. The overall efficiency of the regulator TPS62740 when all the VSEL pins are pulled up for an output of 3.3V is given in figure 34. As you can, with the button batter LIR2477, the efficiency curve lies somewhere between the green and orange curve. The LIR2477 outputs 3.7 potential. This is close to a 95% percent efficiency, meaning

Device	VOUT	VSEL4	VSEL3	VSEL2	VSEL1
TPS62740	1.8	0	0	0	0
	1.9	0	0	0	1
	2.0	0	0	1	0
	2.1	0	0	1	1
	2.2	0	1	0	0
	2.3	0	1	0	1
	2.4	0	1	1	0
	2.5	0	1	1	1
	2.6	1	0	0	0
	2.7	1	0	0	1
	2.8	1	0	1	0
	2.9	1	0	1	1
	3.0	1	1	0	0
	3.1	1	1	0	1
	3.2	1	1	1	0
	3.3	1	1	1	1

Table 18 Different Voltages Based on the Selection of the Pins, with the Highlighted Numbers as the Chosen for Baby Peas

longer battery life and less thermal dissipation.

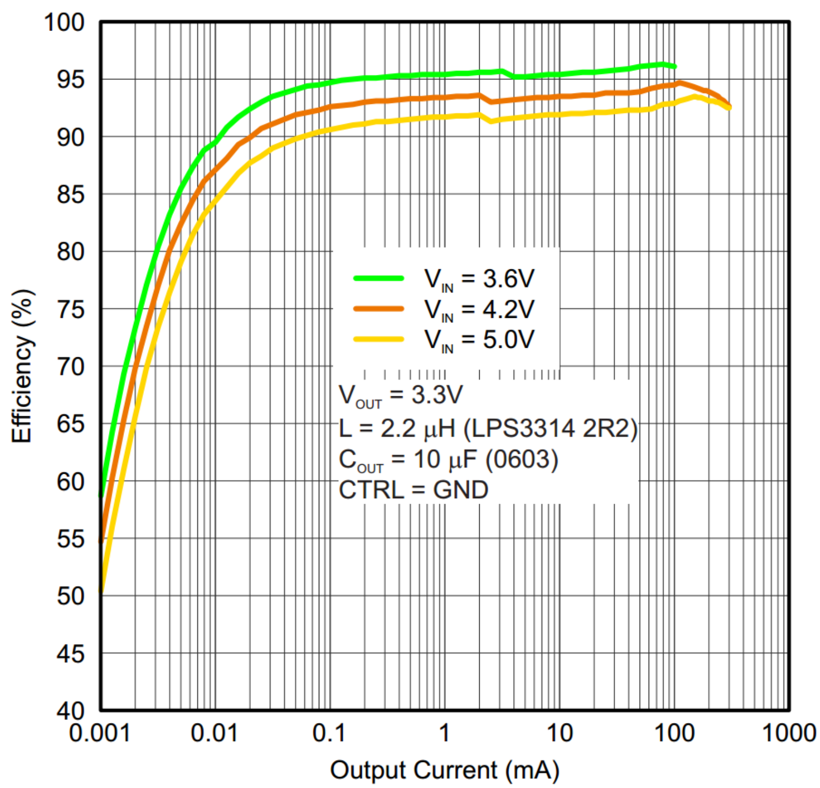

Figure 34 Efficiency of Regulator with Different Output Current. Reprinted without alteration courtesy of Texas Instruments

3.3.8.5 Requirements

As discussed above, the either a linear or a switching regulator can be used to augment the power coming in from a battery. Also discussed prior, the battery unit can be either coin packaging or a super capacitor; either option could theoretically work. It is best to test to see which option does best in the field.

Requirements for the subsystems:

MPU - 6050			
	Operating Current	Voltage Min	Voltage Max
Gyroscope + Accelerometer + DMP	3.9 mA	2.375 V	3.46 V
Gyroscope + Accelerometer	3.8 mA	2.375 V	3.46 V
Gyroscope + DMP	3.7 mA	2.375 V	3.46 V
Gyroscope only	3.6 mA	2.375 V	3.46 V
Accelerometer only	500 µA	2.375 V	3.46 V

Table 19 Normal Operating Current for MPU-6050

Other modules			
Current Max	Voltage Min	Voltage Max	Recommended Voltage
CC2451			
	-0.3	3.9	2 to 3.6
AFE4490			
50mA	5.25V	7V	3-3.2
Tmp006			
10mA	2.2	7V	

Table 20 Normal Operating Requirements for Modules

3.3.8.6 Schematics for TPS62740

Figures 35 through 38 shows the schematic and package views of TPS62740 regulator. It is important to know the size of the package, including height, due to the unforgiving size of the entire unit. In addition, figure 40 shows the thermal pad of TPS62740. Special care should be made when soldering the thermal pad as it acts as the heat sink for the regulator and any defectiveness in contact could mean catastrophic consequences for the entire unit. A figures not created in Eaglesoft are courtesy of Texas Instrument's datasheet for the TPS62740

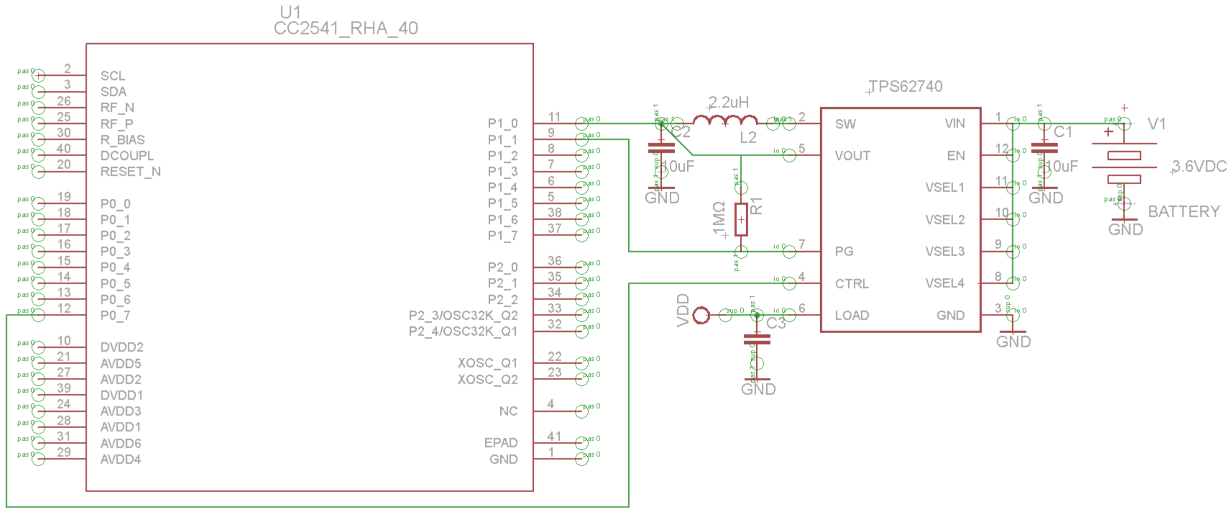

Figure 35 Configuration for integration of TPS62730 with the CC2541. Created using Cadsoft Eagle

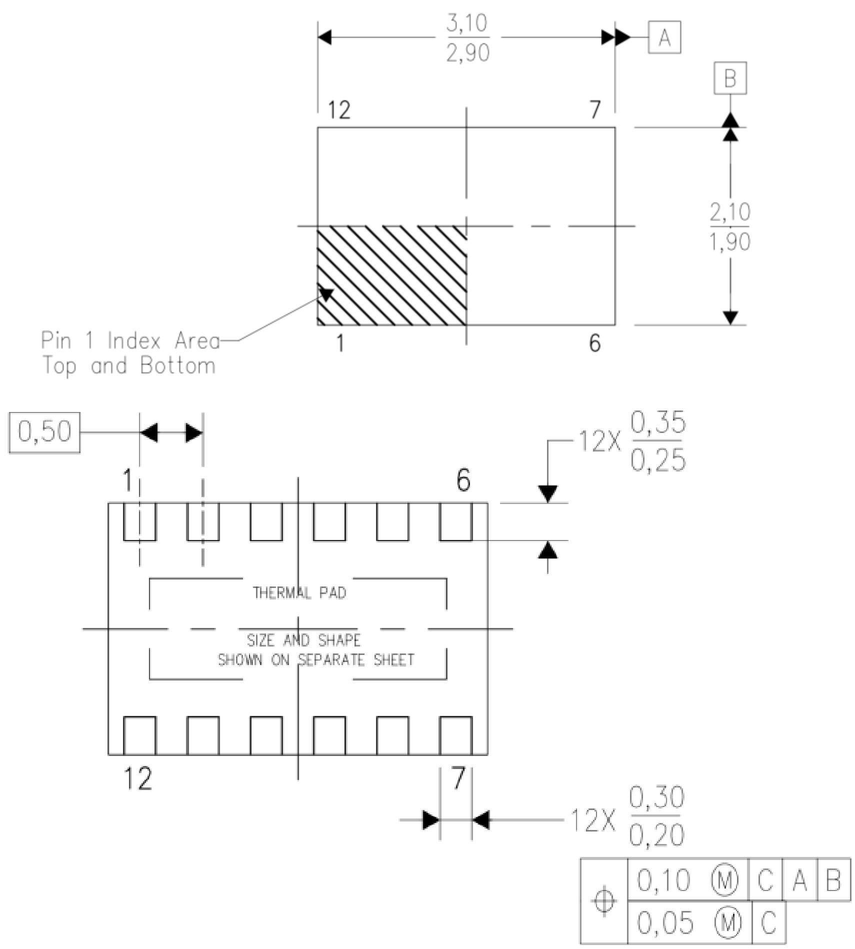

Figure 36 Shows the Package Size and Pin Size of TPS62730

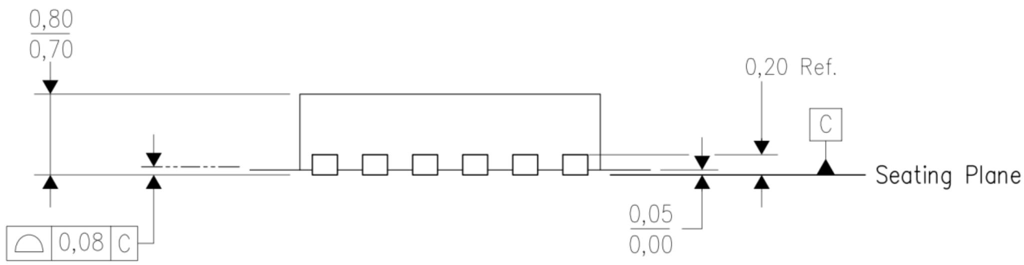

Figure 37 Shows the Seating Plane and Height of TPS62730

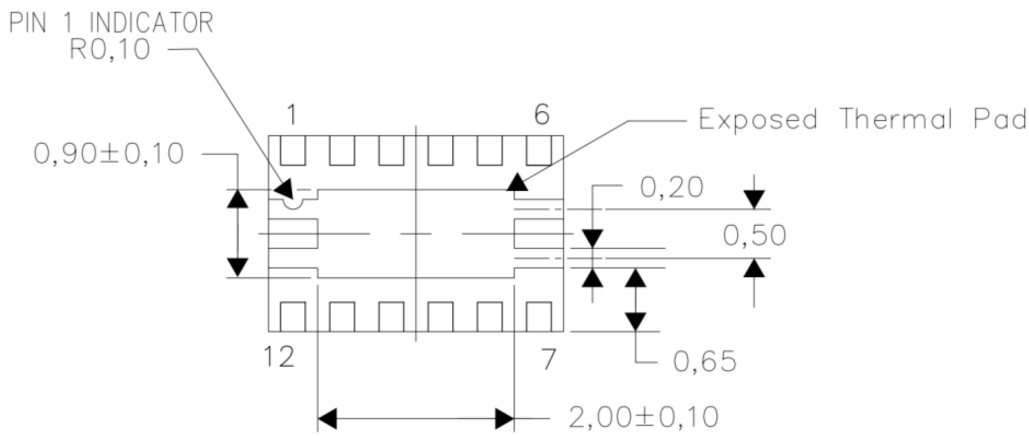

Figure 38 Shows the Thermal Pad for TPS62730

4 Project Hardware and Software Design Details

4.1 Hardware

The Hardware high level System block diagram shown in Figure 39 gives a nice overview of each subsystem and on how each individual sub-system will interact with each other. The Battery Re-charge section will serve as both as a re-charge circuit for the battery and also a protection circuit for the system not allowing the system to be in operation during re-charge mode. The Re-chargeable battery will be a simple Coin Cell re-chargeable battery feeding into the DC-DC voltage Regulator circuit. The Voltage regulator circuit will provide isolation to the rest of the circuit along with power to each sensor and the RF/Microcontroller module. Each sensor will interact with the infant in some way and transmit data over either SPI or I^2C to the CC2541. The CC2541 will process the data received and transmit data packets to the user display device. The following sections will dive deeper into the hardware design of each subsystem providing schematics for each section with a final schematic of the overall system.

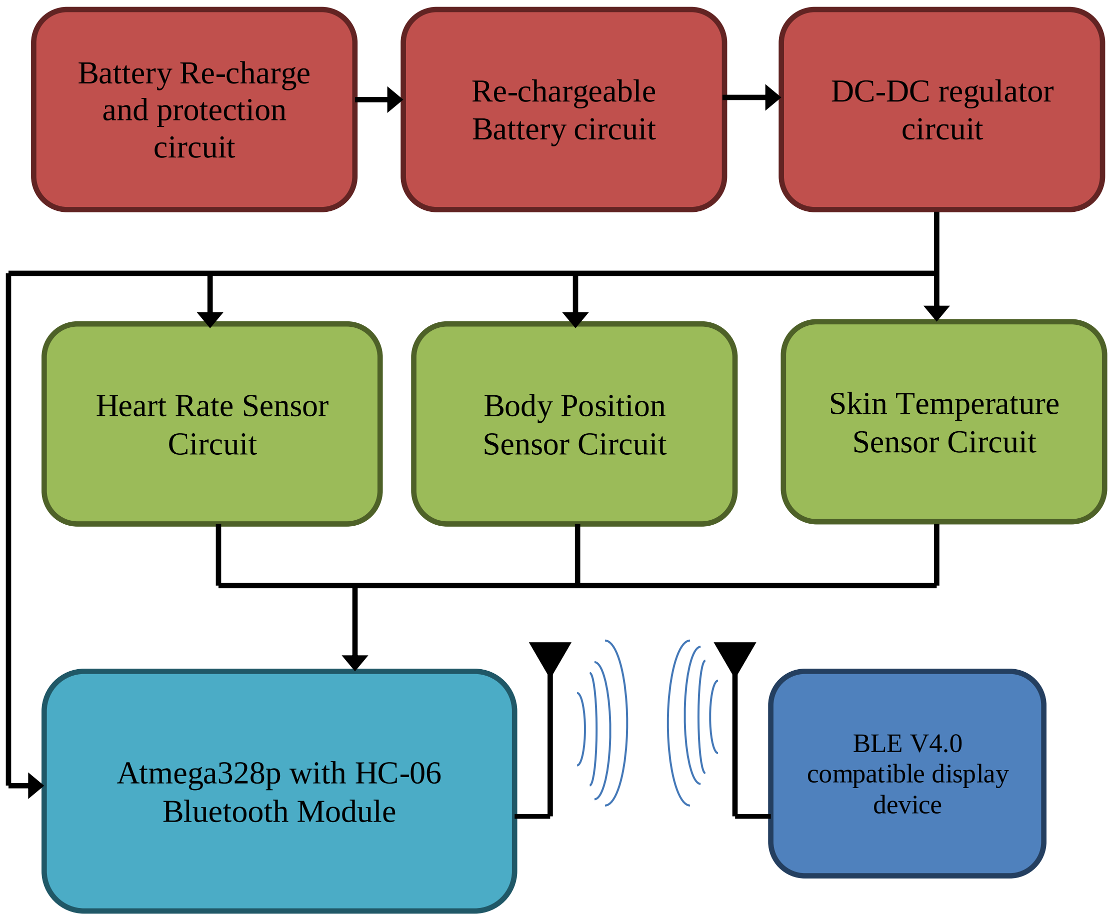

Figure 39 Baby Peas System Hardware Block Diagram

4.1.1 Pulse Oximeter Sensor Design

AFE4490 was the analog front end chip that was used in Baby Peas as the first choice. The detailed description can be found in 3.2.2 In the schematics, all the decoupling capacitors were added. The SPI interface is pin 24 to pin 27 in the following order; SCLK, SPISOMI, SPISIMO, and SPISTE. The corresponding digital I/O for SPI interface on CC2541 is P0_5, P0_2, P0_3 and P0_4.

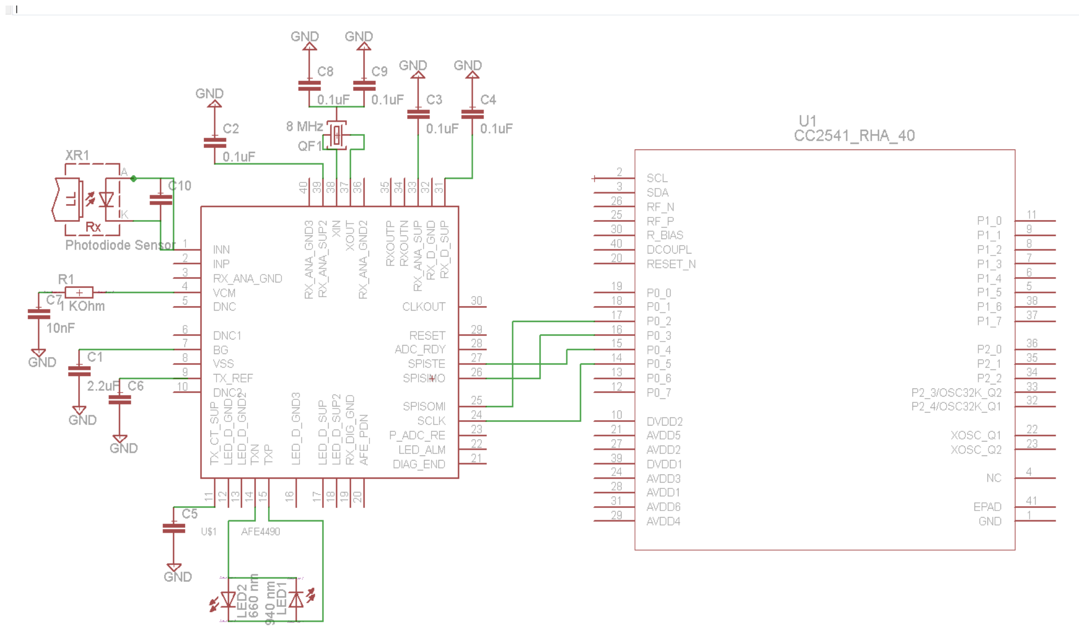

Figure 40 Schematic Diagram Shows Texas Instruments AFE4490 connected to Texas Instruments CC2541 System on Chip. Schematic Created in Cadsoft Eagle by Yowwu Lin

The SPI interface pin connection can be found on CC253X/4X User guide. The circuit was created using Cadsoft Eagle. All the capacitor and resistor values were specified in AFE4490 datasheet.

In the end, a discrete design was implemented an can be shown in Figure 41 below. The design was implemented using Cadsoft Eagle and derived from the reference design provided by www.pulsesensor.com

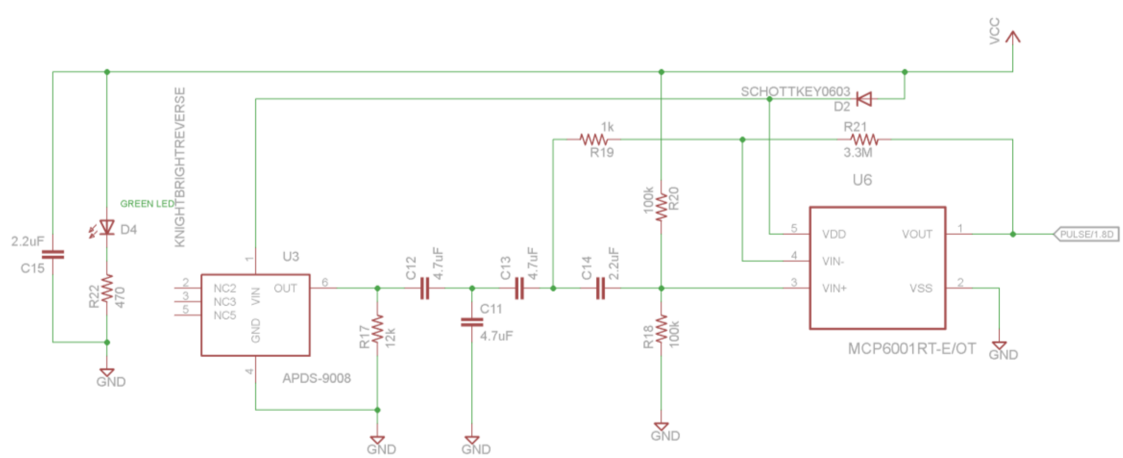

Figure 41 Pulse Sensor Circuitry. Schematic Created in Cadsoft Eagle by Christopher Ramirez

4.1.2 Body Position Sensor Design

For the body position sensor the IMU-6000 was chosen from Invensense. Figure 42 below block diagram of the connections between the MPU-6000 and the Atmega328p Microcontroller

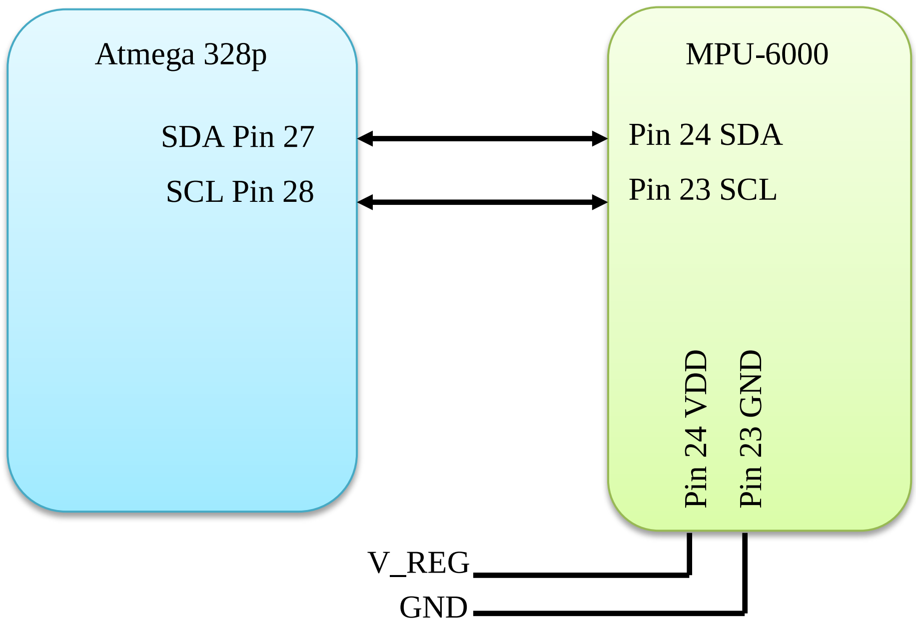

Figure 42 Block Diagram for Body Position Sensor

From Figure 42 we see the data transfer and communications for the device will be using I^2C. The SDA line is where the data will move through serially. The SCL line is the clock and SDA line is used for data transfer. The Atmega328p I^2C lines for SCL and SDA are hard line wired to Pins 27 and 28 respectively. V_REG will be the input voltage line from the regulator circuit and GND is connected to system ground. Figure 43 is the schematic diagram layout for the MPU-6000.

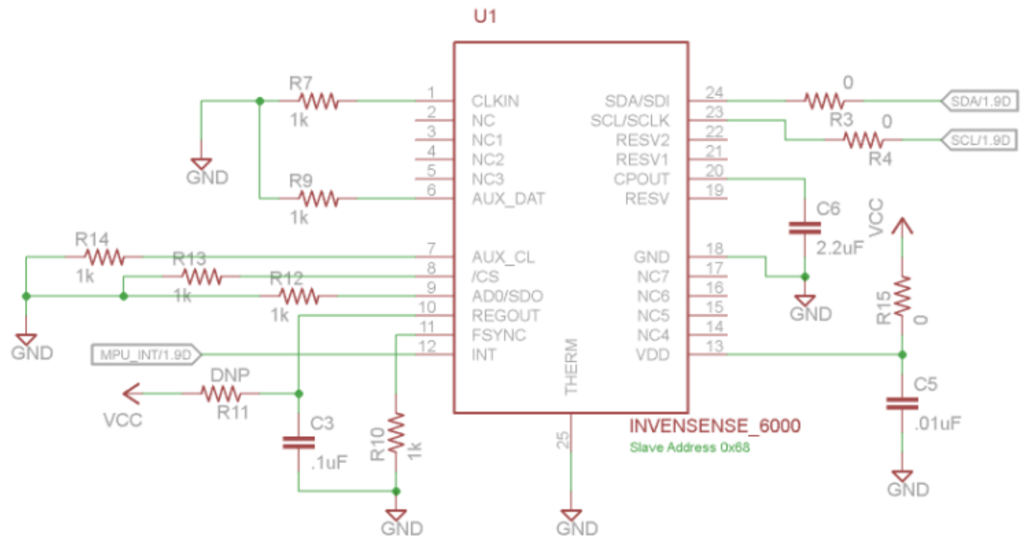

Figure 43 Schematic Diagram for Position Sensor Utilizing Cadsoft Eagle. Circuit created by Christopher Ramirez

4.1.3 Skin Temperature Sensor Design

For the Skin Temperature Section the TMP006 was chosen because of its ability to read temperature without having to make contact with the infant. Figure 44 below is the block diagram of the connections of the TMP006 with the Atmega328p.

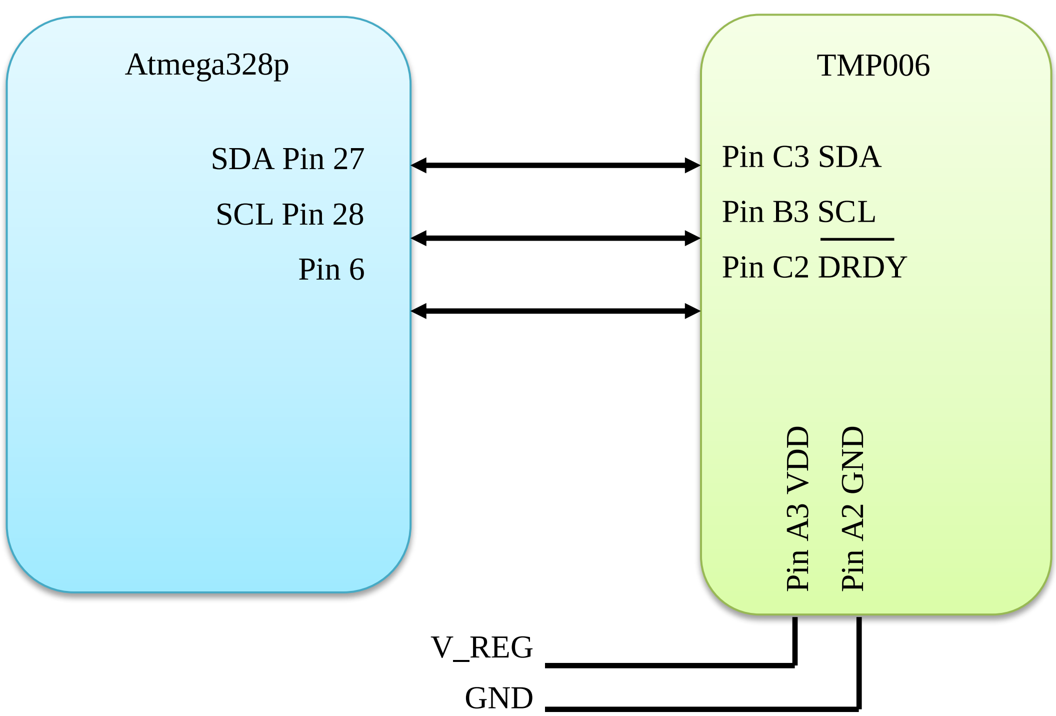

Figure 44 Block Diagram for Skin Temperature Sensor

From Figure 44 the data transfer lines are utilizing I^2C as well communications between the TMP006 and Atmega328p. The only difference is the designation name for chip select on the TMP006 which is labeled as $\overline{\text{DRDY}}$ instead of CS. The over line means the line is active low. Pin 6 on the Atmega328p is another digital I/O line. It is port P1.3 and is used for toggling the chip select line. Figure 45 below is the schematic diagram for the TMP006 created in CADsoft EAGLE.

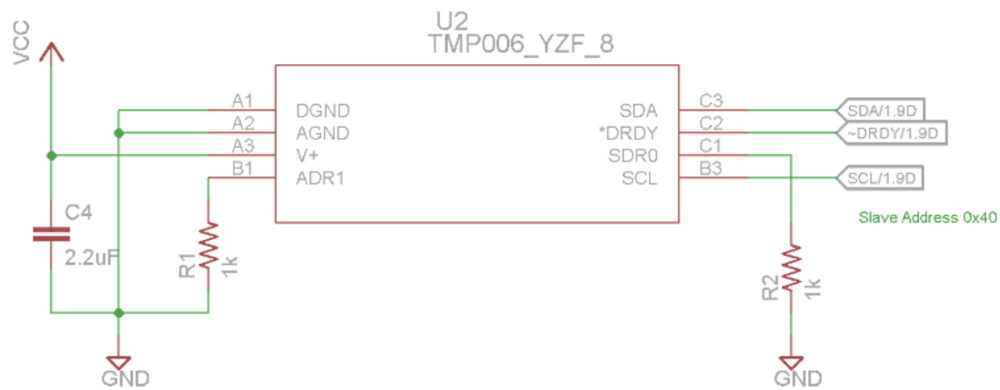

Figure 45 Schematic Diagram for Temp Sensor Utilizing Cadsoft Eagle. Circuit created by Christopher Ramirez

If the TMP006 proves to be difficult to work with will will have enough space on the PCB to also utilize the TMP103 by Texas Instruments. Texas Instruments TMP103 is a four ball wafer chip-scale package features two-wire interface digital output temperature sensor that may be used for Baby Peas monitor. The simple and straight forward design is easy to integrate with Atmega328p. The interface is I2C and SMBus protocol. In the schematic diagram shown in Figure 45, the supply voltage 3.6 V is connected to V+ port and ground has been connected. The resistor is recommended to have value equal or less than 5 K Ohm and capacitor in parallel value of greater or equal to 10 nanofarad. Because of the simplicity nature of TMP103, it has low noise level. An additional RC filter may further reduce the noise level.

4.1.4 Communications / Microcontroller Design

Due to the nature of the Bluetooth Module and Microcontroller being on the same integrated circuit the communications design and microcontroller design specifications and characteristics will be discussed and explained in the same section.

4.1.4.1 Communications

The CC2541 was decided at first to be the Bluetooth Low Energy RF module used by Baby Peas project team. As in all RF designs careful consideration was adhered to during the layout process to ensure proper impedance matching is upheld on the output RF pins of the CC2541. Figure 47 shows the block diagram for the configuration of the communications section of the Baby Peas project.

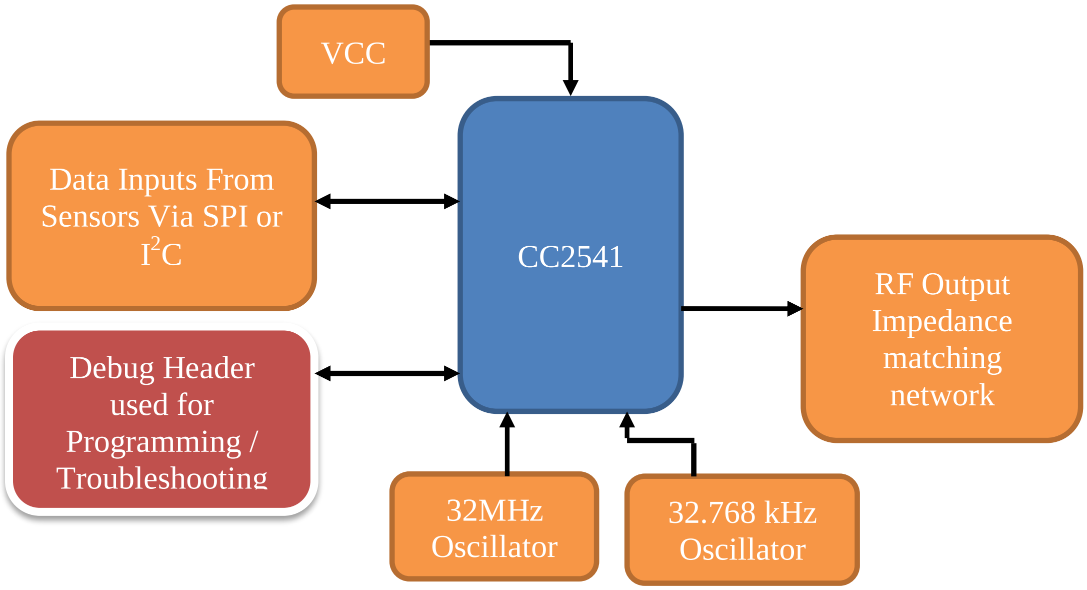

Figure 46 Block Diagram for CC2541

From Figure 48 one can observe the CC2541 is the heart of the system because it handles both the RF and Microcontroller aspects of the baby peas design. Figure 48 is the schematic design for the CC2541 and will be discussed in the following sections for both the RF and Microcontroller aspects of the project.

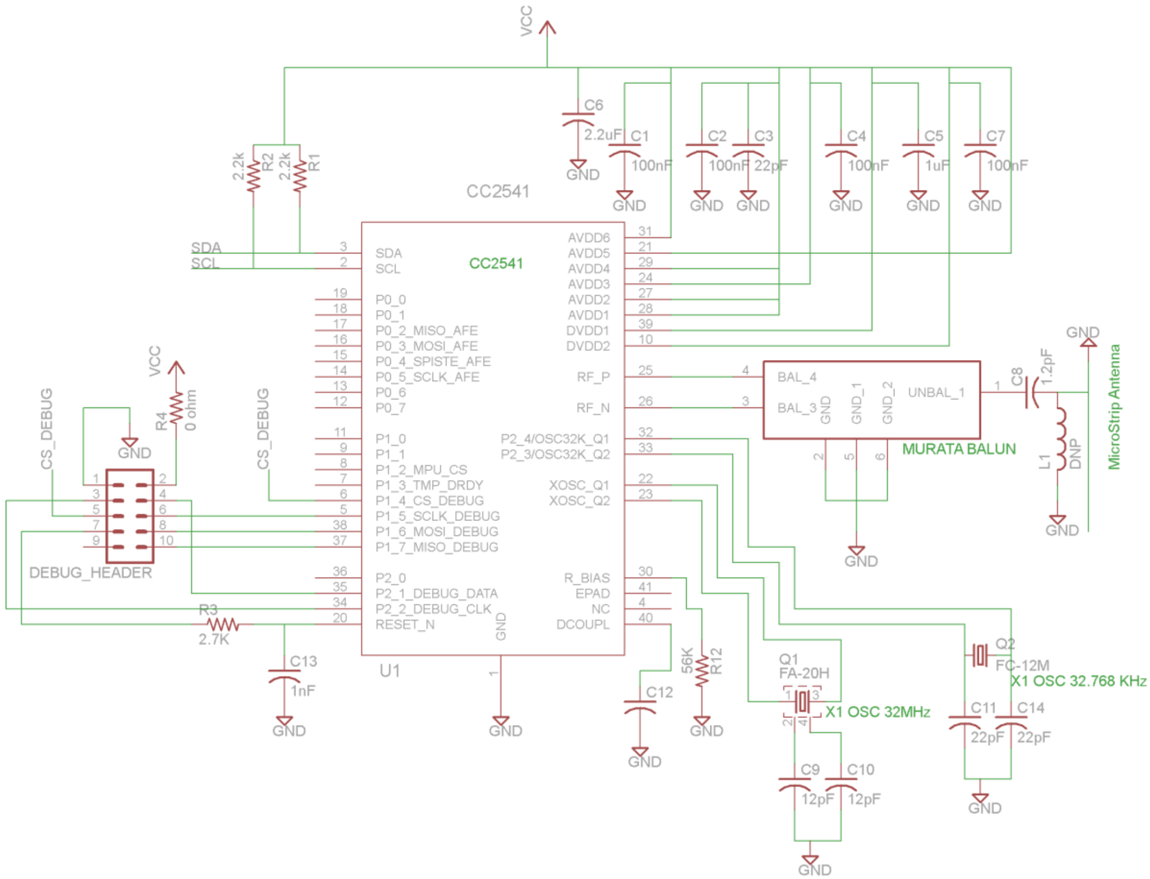

Figure 47 Schematic design for the CC2541 Communications / Microcontroller. Created in Cadsoft Eagle by Christopher Ramirez

From Figure 48 we see that most of the capacitors connected in parallel have to do with low and high frequency noise filtering. This is a critical portion of the project since a switching regulator is used. RF devices need clean power to be able to transmit data bits efficiently. Noise on the device can effect receiver sensitivity and cause degradation of the system. The impedance matching network was chosen to be a murata balun which was suggested for ease of implementation to guarantee proper impedance matching to 50 ohm so the transmit and receive power levels are accurate with the ones provided on the data sheet. Discrete inductors and capacitors can be used also if the murata balun proves to be difficult to install. The antenna used will be constructed within the microstrip line itself. Design details for the microstrip line are provided by Texas Instruments. The remaining items on the schematic are talked about extensively in the following sections

4.1.4.2 Microcontroller CC2541 Design characteristics

The CC2541 was determined to be the microcontroller with the specifications which is best suited for the Baby Peas peripheral sensor system. The advantages to using this particular model include the *Bluetooth* module on the same chip, large amount of memory, and high efficiency through the flexible power modes. The microcontroller itself supports enough flash memory and is fast enough to successfully handle the processes that are required of it. The number of input/output ports is also a sufficient number and resolution to support the sensors to be used. The development kit comes with examples of how to program biomedical devices, which will be a valuable resource during the building phase.

4.1.4.2.1 Electrical Characteristics

The typical current consumption of the cc2541 in different settings are as follows. In standard and RX mode with no peripherals active and low MCU activity, the current consumption is typically 17.9 mA. If the standard mode is switched to high-gain mode, keeping everything else the same, the core consumes 20.2 mA. In TX mode and -20 dBm output power the core current is 16.8 mA. At 0 dBm, it is 18.2 mA. For general low MCU activity, the 32 MHz XOSC is running with limited flash access. No radio or peripherals are active and RAM cannot be accessed. The current consumed is 6.7 mA.
Power mode 1 implies the following: the digital regulator is on, the 16-MHz RCOSC and 32-MHz crystal oscillator is off, the 32.768-kHz XOSC, POR, BOD and sleep timer is active, RAM and register data is retained. The current consumed is 270 µA. Power mode 2 implies the following: the digital regulator is off, the 16-MHz RCOSC and 32-MHz crystal oscillator is off, the 32.768 kHz XOSC, POR, and sleep time are active, RAM and register data is retained. The current consumed is 1 µA. Power mode 3 implies the following: the digital regulator is off, there are no active clocks, the POR is active, RAM and register data is retained. The current consumed is 0.5 µA. Peripheral current usage of the cc2041 adds to the core current when the peripheral unit is activated. The analog-to-digital converter uses 1.2 mA when converting. Timer 1-4 runs with the 32-MHz XOSC. Timer 1 uses 90 µA, Timer 2 90 µA, Timer 3 60 µA, and Timer 4 70 µA. The Sleep timer includes the 32.753-kHz RCOSC and uses 0.6 µA. The output power of the device is associated with a typical current consumption. When the output power is 0 dBm, the current consumption is typically 18.2 mA. At -20 dBm, the current consumption is typically 16.8 mA.

4.1.4.2.2 Current Consumption with TPS62730

In RX mode, standard mode, with no peripherals added and low MCU activity at 1 MHz, the current consumption is 14.7 mA. In RX mode and high-gain mode, keeping everything else the same, the current consumption is 16.7 mA. In TX mode at -20 dBm output power, with no peripherals active and low MCU activity at 1MHz, the current consumption is 13.1 mA. In TX mode at 0 dBm, keeping everything else constant, the current consumption is 14.3 mA. The current used in both transmit and receive modes are relatively small. It follows that the larger the signal, the more power is required to power the device

4.1.4.2.3 General Characteristics

The wake-up and timing characteristics are as follows. Power 1 means the digital regulator is on and the 16-MHz RCOSC and 32-MHz crystal oscillator is off. The start-up of the 16-MHz RCOSC to active mode takes 4 µs. In Power mode 2 or 3, the digital regulator, 16-MHz RCOSC and 32-MHz crystal oscillator are off. The start-up of the regulator and 16-MHz RCOSC to active mode takes 120 µs. The timing of active mode to TX or RX are as follows: with the 16-MHz RCOSC on and 32-MHz XOSC off, 500 µs; with the 32-MHz XOSC initially on, 180 µs.

4.1.4.3 CC2541 Block Diagram

Modules can be divided into three categories: CPU-related modules; Power, test, and clock distribution; radio-related modules. The CPU related modules refer to the 8051 core architecture and the memory associated with the 2541. This includes RAM, ROM, flash memory, and the memory arbitrator. Data buses are also grouped together in this category. Power, test, and clock distribution modules are lumped together. This refers to the VDD pins, debug pins, crystal oscillator pins, and timers. The radio-related modules are the RF pins that receive and transmit wireless data to other peripherals. The Block Diagram of the CC2541 can be referenced in Figure 49 for the RF portion of the project and Figure 50 for microcontroller aspects of the project

4.1.4.4 CPU and Memory

The CPU is the source of all essential mathematical data manipulation that occurs throughout the microcontroller. The data is then sent out to its appropriate destination as designated by the coding. The Direct Memory Access (DMA) is the component used to actually move the data around, thus enabling the CPU to concentrate on other processes. The CPU and DMA are connected by the Memory Arbiter. Data that must be reserved for later is stored in memory, where it can be later accessed if needed for other miscellaneous tasks. Ultimately, the success of the project depends on efficient use of the CPU and memory modules. (Referenced to Figure 50)

- 8051 CPU core
    - Single-cycle 8051-compatible core
    - Three different memory access busses (SFR, DATA, and CODE/XDATA)
    - Debug interface
    - 18-input extended interrupt unit
- Memory arbiter
    - Connects CPU and DMA controller with physical memories and all peripherals through SFR bus
    - Four memory-access points
        - SRAM
        - Flash memory
        - XREG/SFR registers
    - Responsible for performing arbitration and sequencing between simultaneous memory accesses to the same physical memory
- SFR bus
    - Connects hardware peripherals to memory arbiter
    - Provides access to radio registers
- 8-KB SRAM
    - Maps to DATA memory space and parts of the XDATA memory spaces
    - Ultralow-power non-volatile SRAM (power mode 2 and mode 3)
- 128/256 KB flash block
    - In-circuit programmable non-volatile program memory
    - Maps into CODE and XDATA memory spaces

4.1.4.5 Peripherals

The peripheral modules support the core CPU and memory modules in running the microprocessor by controlling the flow of data to or from the central components. The DMA, Interrupt, and Input/Output controllers all administrate the accurate transfer of data within memory and with external sources. The timers specifically control the timing of the system, providing an ordered sequential structure to the various processes that take place. The rest of the peripheral modules, including the UART, I^2C, SPI, and AES components, enable the communication of data between devices. The project will be exchanging data between components, so these peripheral modules will be used extensively. (Referenced to Figure 49)

- DMA controller
  - Five channel
    - Trigger, Priority, Transfer mode, Addressing mode, source and destination pointers, and transfer count
    - Each channel is configured with DMA descriptors
    - Can be located anywhere in memory
  - Accesses data using XDATA memory space, allowing access to all physical memories
  - Many hardware peripherals are used with the DMA controller
- Interrupt controller
  - Controls 18 interrupt sources
  - Further divided into 6 interrupt groups
  - 4 interrupt priorities
  - I/O and sleep timer interrupt requests work when the CC2541 is in power mode 1 or 2 (sleep mode) to bring it into active mode
- Debug interface
  - Two-wire serial interface
  - In-circuit debugging
  - Capable of erasing or programming the entire flash memory
  - Stop/start execution of user program
  - Execute 8051 core instructions
  - Set code breakpoints
  - Single-step through code instructions
- I/O controller
  - Controls all general purpose I/O pins
  - CPU assigns control of pins to peripheral modules or software
  - Assigns input or output configuration of pins
  - Connects pullup/pulldown resistors
  - Peripherals can choose between two I/O pin locations
- Sleep Timer
  - Ultralow-power timer
  - Uses either external 32.768 kHz crystal oscillator or internal 32.753-kHz RC oscillator
  - Runs continuously in all modes except power mode 3
- Watchdog Timer

- Allows the CC2541 to reset itself
- Timer 1
  - 16-bit timer
  - Timer/counter/PWM functionality
  - 16-bit period value
  - 5 individually programmable counter/capture channels
- Timer 2
  - 40-bit timer
  - 16-bit counter and 24-bit overflow counter
  - 40-bit capture register to record start and end of transmission
  - Two 16-bit output compare registers and two 24-bit overflow compare registers to record start of RX/TX or general interrupts
- Timer 3 and Timer 4
  - 8-bit timers
  - Timer/counter/PWM functionality
- USART 0 and USART 1
  - Can be used as either SPI master/slave or UART
  - Provides double buffering
- AES encryption/decryption
  - Uses AES algorithm with 128-bit keys
  - Supports ECB, CBC, CFB, OFB, CTR, and CBC-MAC
- ADC
  - 7-12 bit resolution from 30-kHz to 4-kHz, respectively
  - Single-ended or differential
  - Reference voltage can be internal, AVDD, or single-ended/differential external signal
- I^2C
  - Digital peripheral connection with two pins
  - Supports both master and slave operation
- Analog Comparator
  - Enables applications to wake up from Power Mode 2 or Power Mode 3 based on an analog signal

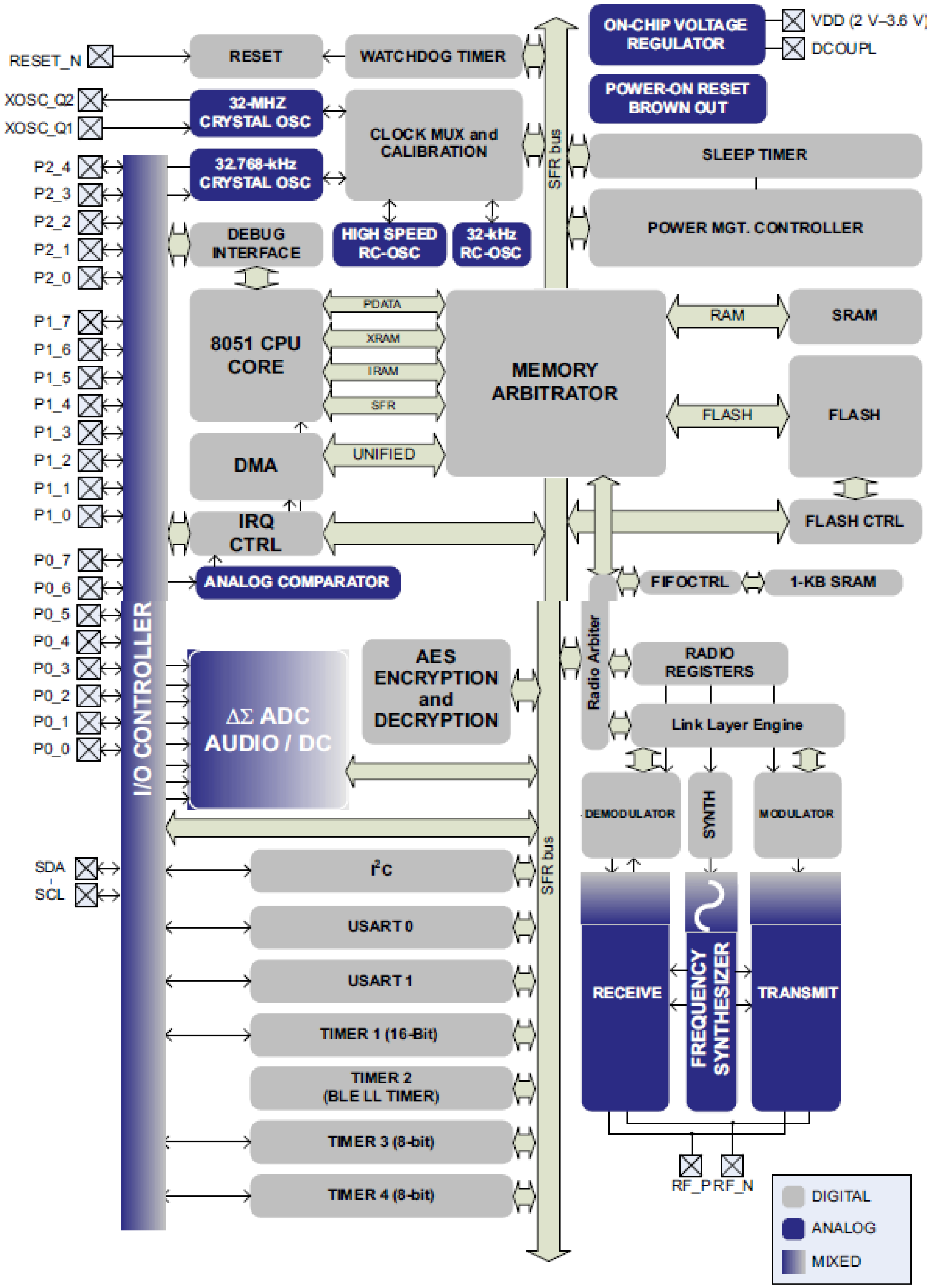

Figure 48 CC2541 Block Diagram, used with permission from Texas Instruments

4.1.4.6 Application information CC2541

The schematic configuration of the CC2541 is shown again in Figure 50. The remaining sections walkthrough the different uses of the pins which have not be covered yet.

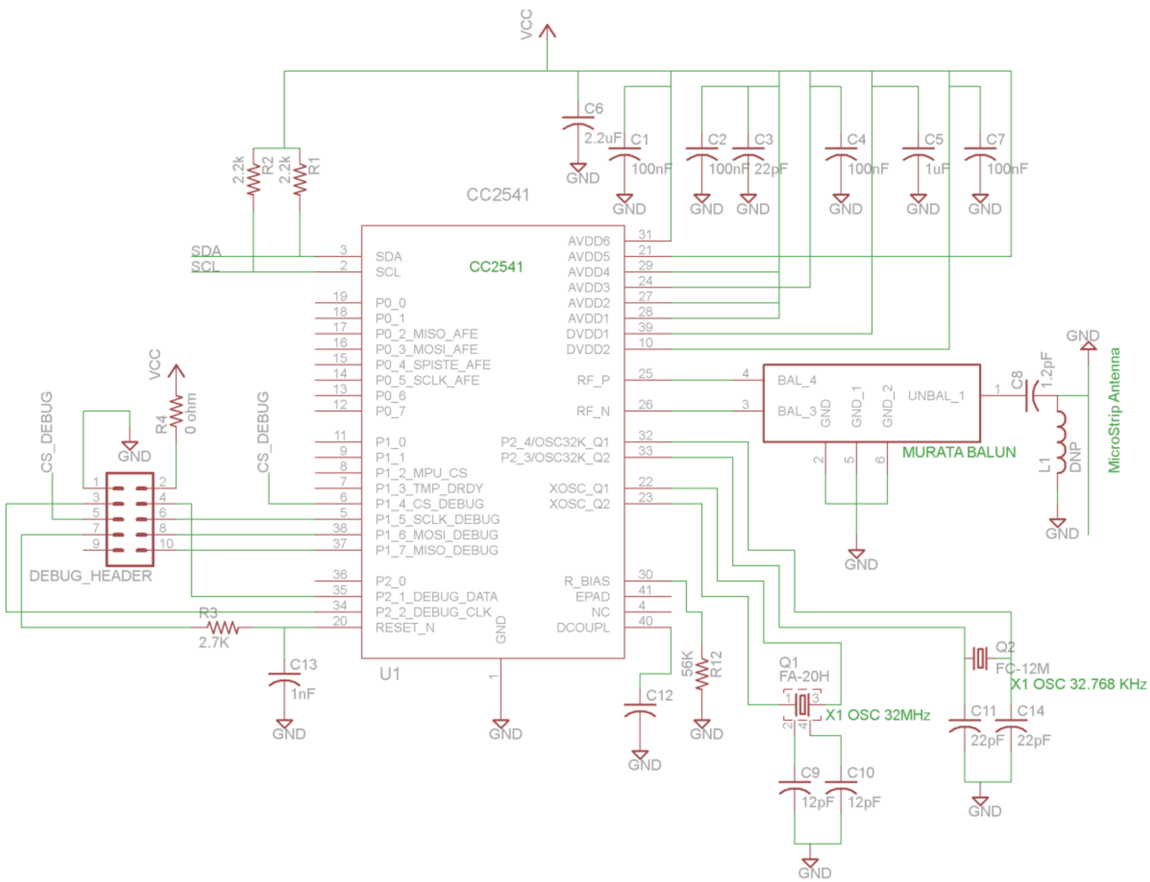

Figure 49 Schematic design for the CC2541 Communications / Microcontroller. Created in Cadsoft Eagle by Christopher Ramirez

4.1.4.6.1 Power configuration

A 2 to 3.6-Volt power supply is connected to pin 10, 21, 24, 27, 28, 29, 31, and 39. Each of these pins are a DVDD or AVDD pins which are the Digital voltage inputs and Analog voltage inputs. These can be tied together because a separate digital voltage line is not being used in the Baby Peas project. XOSC_Q1 Pin 22, XOSC_Q2 Pin 23 - These two pins are attached to an external 32 MHz oscillator. This oscillator is used to clock the central operations of the CC2541 hardware. RBIAS Pin 30 – The resistor R301 is attached from pin 30 to ground. This resistor is used for internal biasing. The biasing resistor will add voltage offset where needed and stabilize transistor current to avoid saturation or cut-off of electrical signals. If a biasing resistor was not connected to this position, the voltage applied to the internal components may not be constant, resulting in unintended outputs. The R301 resistor is a precision resistor ±1% at 56 kΩ. Pins RF_P Pin 25 and RF_N Pin 26 connect the CC2541 internal components to the electrical signals provided by the RF network and the *Bluetooth* modules. RF_P deals with the positive component of the radio signal either being received or broadcasted. RF_N deals with the negative component of the radio signal being received or broadcasted. These two pins are extremely important to layout correctly to adhere to impedance matching characteristics which arise in mircrowave circuits. P2_3/XOSC32K_Q2 (Pin 33) and P2_4/XOSC32K_Q1 (Pin 34) pins are attached to an external 32.768 kHz oscillator. This oscillator is used as a clock for the input/output pins and receives information from the high level clock MUX and calibration circuits. DCOUPL Pin 40 – A capacitor is attached from this pin to ground. It acts as a decoupling capacitor for the CC2541. A decoupling capacitor is used to filter low frequency noise out of the circuitry. Without a capacitor at this pin, the internal components of the microcontroller would see more noise, potentially causing a slowdown of processing speed or incorrect information being passed through the system.[25]

4.1.4.6.2 SPI bus AC Characteristics of CC2541

A SPI bus will be needed for the implementation of the AFE4490 pulse oximetry circuitry and Debug capabilities. It is important to understand how the SPI bus operates in order to successfully program the hardware. The SPI bus also allows for scalability if more sensors are desired to be added to the Baby peas' peripheral device. The AC characteristics of the SPI bus are the timing cycles of the bus during data transmission.

The Serial Peripheral Interface bus specifies four logic signals:

- SCK – Serial clock (output from master)
- MOSI – Master output, slave input (output from master)
- MISO – Master input, slave output (output from slave)
- SSN – slave select (active low, output from master)

Figure 51 below shows the direction of signals in the SPI connection from one master device to multiple independent slave devices. The SPI Master sets the clock frequency to one that is at most the maximum frequency supported by the slave device. During each cycle, the master device sends a bit to the slave device, which is read. The slave device sends a bit to the master device and the master device reads the bit. If these four actions occur, the transmission is said to be full duplex because information is sent both ways.

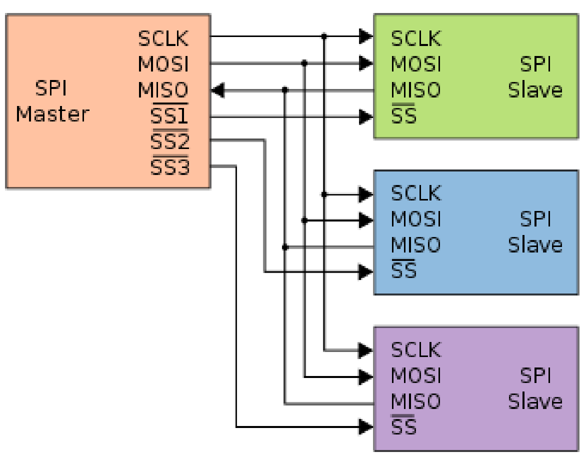

Figure 50 Example of SPI interface. Reprinted without alteration with permission from Texas Instruments

Once a SPI bus connection is confirmed on the hardware, the master device and slave device can transmit data bits. The master and slave usually consist of two shift registers set up in a circular buffer. The SPI bus is programmed to send a predetermined amount of data per transmission. At the end of the entire cycle, the slave device register will have the data from the master device, and vice versa. This setup is full duplex since data is being passed between the master and slave device. Figure 52 is an example of Master/Slave interactions and shift registers.

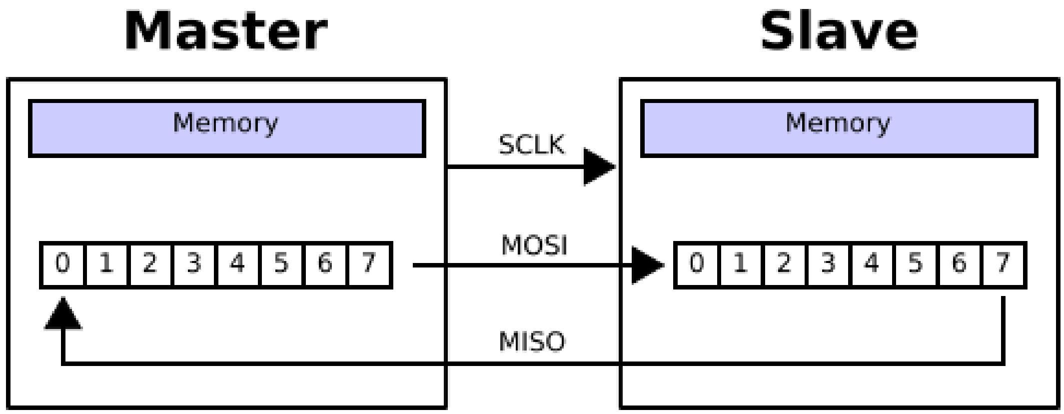

Figure 51 Master/Slave Interactions. Reprinted without alteration with permission from Texas Instruments.

Table 21 below lists the AC characteristics of the CC2541 for the SPI data bus. The parameters for each of the variables t_x are shown in table 21 and in figures 54 and 55.

Parameter	Test Conditions	Min	Typ	Max	Unit
t_1 SCK period	Master, RX and TX	250			ns
	Slave, RX and TX	250			
SCK duty cycle	Master		50%		
t_2 SSN low to SCK	Master	63			ns
	Slave	63			
t_3 SCK to SSN high	Master	63			ns
	Slave	63			
t_4 MOSI early out	Master, load = 10 pF			7	ns
t_5 MOSI late out	Master, load = 10 pF			10	ns
t_6 MISO setup	Master	90			ns
t_7 MISO hold	Master	10			ns
SCK duty cycle	Slave		50%		ns
t_{10} MOSI setup	Slave	35			ns
t_{11} MOSI hold	Slave	10			ns
t_9 MISO late out	Slave, load = 10 pF			95	ns
Operating Frequency	Master, TX only			8	MHz
	Master, RX and TX			4	
	Slave, RX only			8	
	Slave, RX and TX			4	

Table 21 AC characteristics

The SCK period is the set period coming from the master device, namely the CC2541. Parameters t_2 and t_3 are the time it takes the master device to respond to the slave select signal notification. Parameters t_4, t_5, and t_9 describe the time necessary to send out the data bit through the bus. The parameters t_6 and t_{10} are the time it takes either the master or slave device to set up the response signal to send the bit. The corresponding t_7 and t_{11} describe the time needed to hold the signal high to confirm the state of the signal. If the signal flips quicker than the hold time, the sent bit may be untrustworthy data. The duty cycle of both the master and slave serial clock is 50 percent.

figures 53 and 54 below show the SPI master and SPI slave AC characteristics. The top waveform is the serial clock signal. Shown in this diagram is one rising edge and one falling edge. The second waveform is the select slave signal. The selection signal is low to indicate the bus is clear to transmit. The master output device has the data bit D0 ready to transmit. The master device inputs the bit as shown in the bottom MISO waveform. The master device also presents its own data bit for output to the slave device. This is shown in the third MOSI waveform.

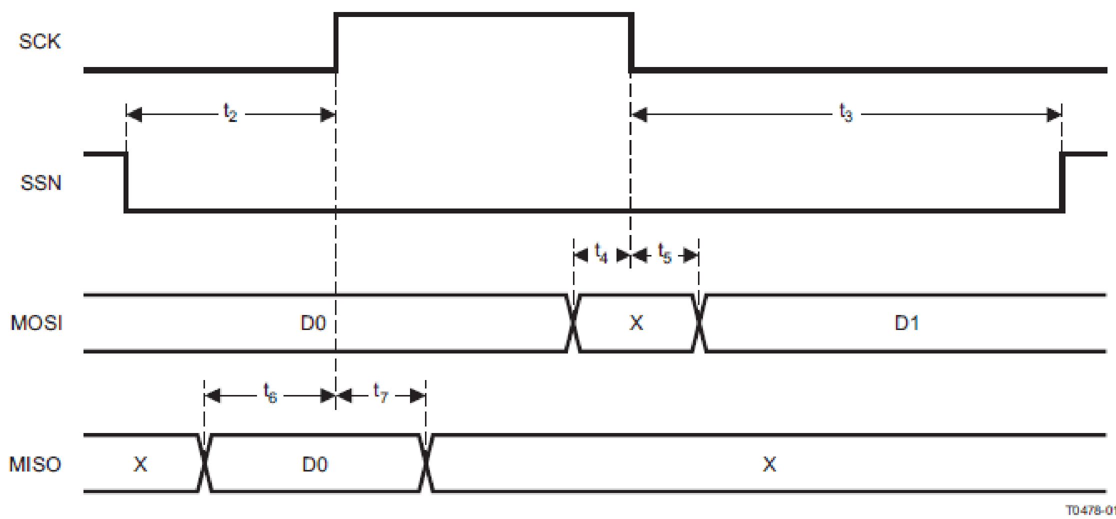

Figure 52 First SPI Waveform. Reprinted without alteration with permission by Texas Instruments

The second figure shows the same configuration and data transfer concepts except from the perspective of the slave device. It makes sense that both the master and slave devices will have the configurations. A difference in timing can result in a data transfer error, where the active edges or timing parameters become convoluted. Understanding the timing of the SPI bus will be crucial for correctly programming the hardware such that communication runs smoothly.

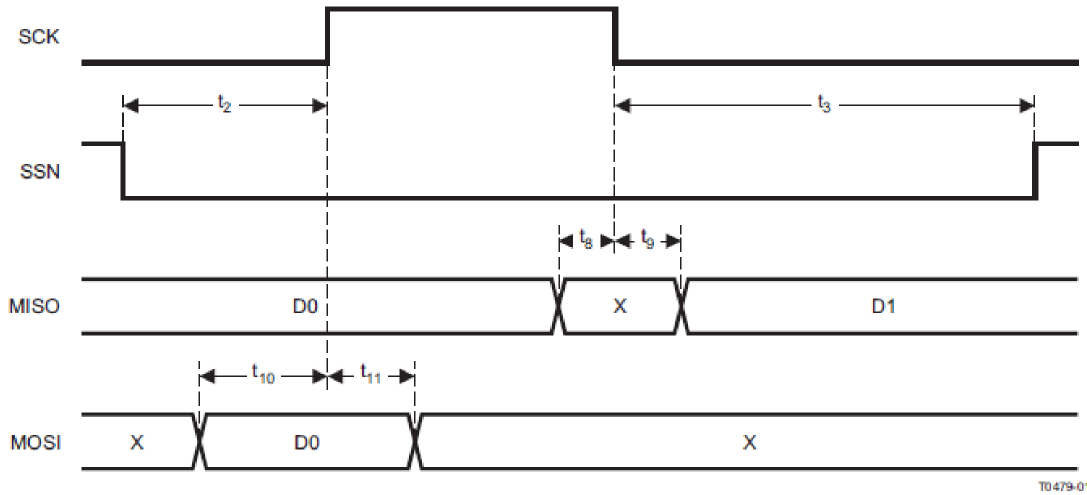

Figure 53 AC characteristics of the CC2541. Reprinted without alteration with permission by Texas Instruments

4.1.4.6.3 I^{2}C of CC2541

The CC2541 supports I^{2}C data communication with the TMP006 and MPU-6000 sensors contained within the Baby peas project. The I^{2}C module is attached to compatible external device through a two-wire I^{2}C serial bus. The CC2541 will also use digital I/O ports as chip select lines to activate each device. The I^{2}C module features include:

- Compliance with the I^{2}C specification v2.1 (published by Philips Semiconductor)
- 7-bit device addressing modes
- General call
- START/RESTART/STOP
- Multi-master transmitter/receiver mode
- Slave receiver/transmitter mode
- Standard mode up to 100kbps and fast mode up to 400-kbps support

The I^{2}C module is accessed through pins 2 and 3 on the CC2541. Pins 2 and 3 can be reconfigured as general purpose I/O pins if the module is not needed. The I^{2}C data communication sets up a master device and slave device. The master initiates the data transfer and also generates the clock signal. Data is transferred through the serial data (SDA) pin and the serial clock (SCL) pin. Both of these pins are bidirectional. The I^{2}C module is enabled by setting the I2CCFG.ENS1 bit. This puts it into the not-addressed slave state. When the CC2541 is put into sleep mode (Power mode 2 or Power mode 3), it resets the I^{2}C module. The module must then be reconfigured when coming out of sleep mode. The master device initiates data transfer when the start condition is present. This occurs when the SDA falls from high to low and the SCL is high. The stop condition occurs when the SDA rises from low to high and the SCL is high. The stop condition is necessary to cut off the transmission of data. The SDA bit must be stable during the high period of the SCL. The SDA can only change during data transmission while the SCL is low to avoid a mistaken start or stop condition. Another start condition during data transfer is referred to as a "restart." The slave address is once again sent with the R/W bit. This is used to switch data directions. Data is transferred MSB first. The first byte of data transferred is the 7-bit slave address and the R/W bit. The R/W bit determined if the master is outputting data or inputting data. The R/W bit is low when transmitting data to the slave device. The R/W bit is high when receiving data from the slave. The acknowledgment bit (ACK) is sent from the receiver after each byte on the ninth SCL clock. Figure 55 illustrates the I^2C data transfer procedure.

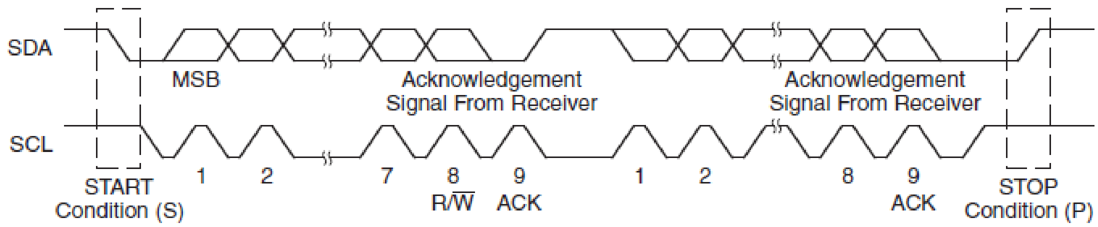

Figure 54 I2C Module Data Transfer. Reprinted without alteration with permission by Texas Instruments

4.1.4.6.4 8051 CPU

The 8051 contains internal ROM and RAM with a Harvard architecture. This means the CPU can use the same address in different memories for code and data. The memory where the address is accessed by the circuitry determines the nature by which the address is used. This is in contrast to Von Neumann architectures, which use a single memory address for either code or data, but not for both. The decision to use the address as data or code is based on the way the address is accessed. Programming the CC2541 to correctly handle the allocation of memory is an essential component of this project. The 128-byte internal RAM is divided into three areas:

- 00h – 1Fh: 32 working registers, organized as four banks of eight registers each
- 20h – 2Fh: Bit-addressable memory; a total of 128 addressable bits. Bit addresses can be specified from 00h to 7Fh. Byte addresses can be addressed from 20h to 2Fh. For example, in this organization scheme, bit address 4Fh can also be referred to as byte address 29h. This memory layout allows the memory to be conserved. For instance, a single bit needing to be changed will only use that one bit. An entire byte does not have to be used for every action.
- 30h – 7Fh: General purpose RAM, addressable as bytes

Internal ROM is contained from address space 0000h to 0FFFh. Attempting to access addresses higher than 0FFFh automatically seeks external program memory. When programming the CC2541, the working registers located in the register bank will most likely be used to store data incoming from the peripheral systems through the *Bluetooth* wireless connections. The general purpose RAM space will most likely be used to dynamically allocate memory through miscellaneous programming tasks. The bit addressable memory will have an advantage of toggling and storing input or output bits that are necessary to track throughout the computing process.

4.1.4.6.4.1 Serial Data Input/Output

The 8051 serial data communication circuit uses a number of special function registers (SFR) to oversee the transfer of data. The rate of data transmission is known as the baud rate, measured in bits per second. The baud rate varies depending on the mode selected by the SFR register. Serial data bits are first sent to the register SBUF to hold the data. Register SCON controls data communication, register PCON controls data rates, and pins RXD (P3.0) and TXD (P3.1) connect to the serial data network. SBUF is physical two registers, both using address 99h. One transmits data through TXD and the other reads data through the RXD pin. Data transmission begins whenever data is written to the SBUF register. Figure 56 is a representation of how the SCON Register looks

7	6	5	4	3	2	1	0
SM0	SM1	SM2	REN	TB8	RB8	TI	RI

Figure 55 SCON Register

There are four possible modes depicted in Table 22 for the SCON:

SM0	SM1	Mode	Description
0	0	0	Shift register; baud = f/12
0	1	1	8-bit UART; baud = variable
1	0	2	9-bit UART; baud = f/32 or f/64
1	1	3	9-bit UART; baud = variable

Table 22 Possible modes of the SCON Register

The TI bit is set high whenever data is transmitted and the SBUF register is clear to be written to. The receive enable bit (REN) must be set to 1 for data to be received. Once data is received, receiver interrupt flag (RI) must be set to 0 to obtain new data after the previous data has been interpreted and dealt with. Reception of data can start in modes 1, 2, and 3 if RI is 0. RI must be reset by the program before the last bit of data is received or the incoming data will not be transferred to the SBUF register.
Serial Data Mode 0 – Shift Register Mode

Pin RXD is used to receive or transmit eight data bits. The TXD is connected to the internal shift frequency pulse source. The shift frequency in this mode is 1/12 the oscillator frequency. The 8051 is the CPU core of the CC2541 and will thus act as the master device. This gives it the authority to set the serial clock and baud rate.

4.1.4.6.4.1.1 Serial Data Mode 1 – Standard UART

SBUF is a 10-bit full duplex receiver/transmitter that can receive and transmit data simultaneously. Pin RXD receives data and pin TXD transmits. The transmitted data begins with a start bit followed by eight data bits and finally a stop bit. After the stop bit, the interrupt transmission flag is set to indicate the end of that section of data. Received data occurs in the same manner. RI is set to 0 to indicate the previous data has been read and it is clear to receive the next byte. The eight data bits are sent to SBUF, the stop bit is put into RB8 of SCON, and the start bit is discarded. RI is set to 1 to indicate new data is received to be read. Timer 1 is used to generate communication frequencies. The figure 57 below illustrates the process. The first start bit initiates the transfer, the 8 data bits are sent; then there is a stop bit, which triggers the idle time until the next byte is ready to be sent. The receiver samples the data at the center of the bit time to make it as accurate as possible. The baud rate is determined by the timer 1 overflow flag. If timer 1 is not in timer mode 2, the baud frequency is generated using the following equation:

$$F_{baud} = 2^{SMOD} / 32d * (timer\ 1\ overflow\ frequency)$$

The term SMOD is the control bit for the special function register PCON and can be either 0 or 1. The 2 in the equation is raised to either a 1 or 2, respectively.

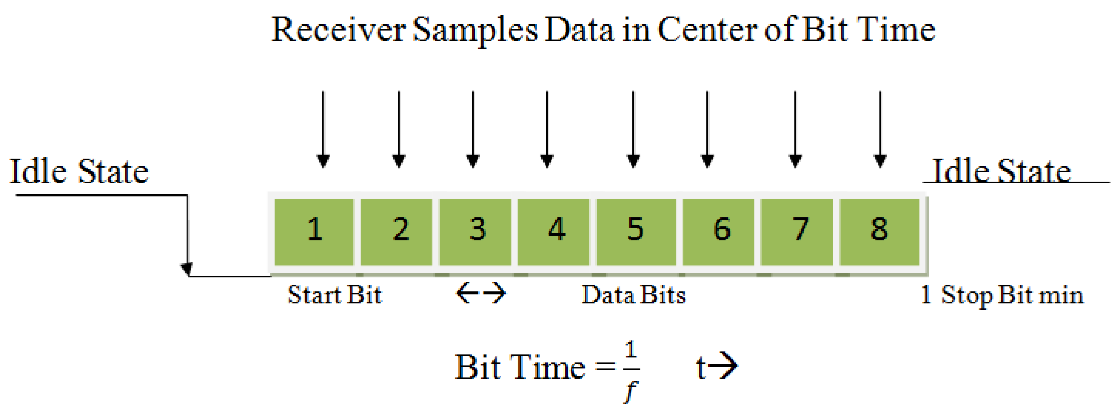

Figure 56 Standard UART DATA WORD. Created by Xin Tong in MS Word

4.1.4.6.4.1.2 Serial Data Mode 2 – Multiprocessor Mode

This mode is basically the same as the Standard UART mode, but nine data bits are sent instead of only eight. The ninth data bit is taken from TB8 in SCON during transmit and stored in RB8 of SCON when received. Timer settings are similar to mode 0. Figure 58 below illustrates the data transfer occurring in serial data mode 2. Note the extra bit. The baud rate is determined by the equation:

$$F_{baud} = 2^{SMOD} / 64d * (Oscillator\ Frequency)$$

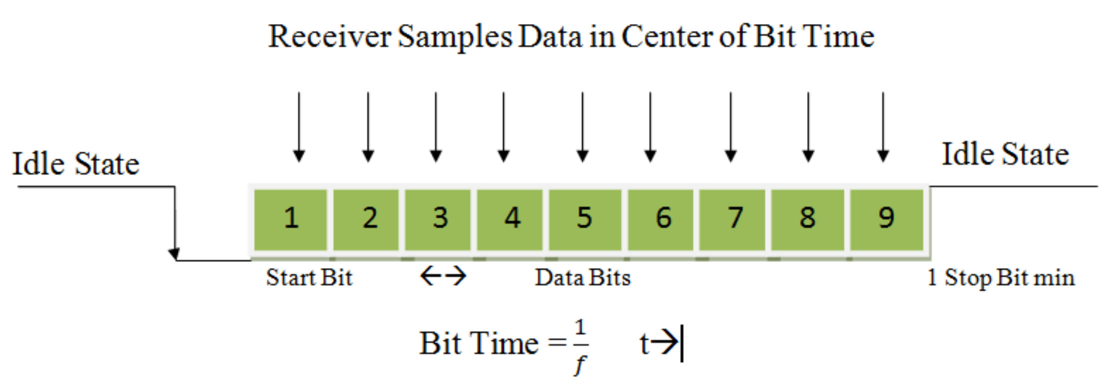

Figure 57 Serial Data Mode 2. Created by Xin Tong in MS Word

4.1.4.6.4.1.3 Serial Data Mode 3

Mode 3 is the same as mode 2 except the baud rate is determined the same way as mode 1 by using Timer 1 to generate communication frequencies.

4.1.4.7 Microcontroller Coding Software

The actions of the microcontroller hardware is controlled and regulated by its installed software. For this project, the CC2541 will be programmed in an integrated development environment capable of compiling high level languages. The program code will be written in C/C++ as opposed to assembly language. This is due to the inherent complexity and relatively large amount of code needed to program the microcontroller directly with assembly code. The data coming from each of the peripheral component will have to be organized, manipulated, and then sent out to the display. In this case, the display and user interface will be the smart phone application developed for the Android mobile operating system. The peripheral systems will be the different sensors attached to the central system. This includes the pulse oximeter sensor, body position sensor, and temperature sensor. Each of these components will obtain and consolidate their own data which will be sent to the central microcontroller. The CC2541 will then have to organize that data from multiple sources within its memory. The data will then be sent out to the user interface through the *Bluetooth* SoC module. The CC2541 will continuously communicate with the user interface. This way, the data from the peripheral units will be constantly updating the display on the smart phone. Input from the user will also be sent from the smart phone to the microcontroller via the *Bluetooth* wireless connection.

Considering the data transfers that are necessary for the project to work, an outline of the software functions and header files can be created. A huge emphasis will be put on data communication between peripheral components, the central microcontroller, and the user interface. Therefore, a number of functions must be defined that transfer data from the input pins connected to the peripheral components to a predetermined area in the internal RAM. Each of the external components will need to have their own area in memory to write to. Another group of functions will regulate the transfer of data from internal memory to output of the MCU. This will ensure consistency in the output of data to the correct output pins so as not to confuse the data that shows up on the output display. For example, if the data from the temperature sensor accidentally ended up be sent to the output for the pulse oximeter, the user might interpret the data as their child being in danger. The coding that dictates the techniques for accessing the memory can be grouped together as memory management functions. Any change or access of memory will be tracked and monitored by these functions. Another set of functions will handle interrupts in processing priority. Interrupts will come from either the central computing unit or from the user. The interrupt functions must be created to deal with a range of interrupt scenarios. A couple scenarios might be that an alarm is triggered or the user requests specific historical data at a time. A final group of functions will deal with instructions coming from the user. Input requests originated from the GUI must be interpreted on the mobile phone application and sent to the microprocessor to be executed by these functions. Each group of functions can be described as a class. Each class will also include multiple functions to check for legitimate function execution to ensure there isn't a mistake in the coding. These will act as debugging functions that will seek out any flaws in the programming and correct them.

Header Files

The header files are the pre-coded portions of C-code that are used to define basic functions and type definitions. Without header files, every function would have to be programmed from scratch, taking up a large amount of time and resources to understand exactly how the memory is accessed and displayed. Header files also ensure a common base language that can be easily read by the programming population. For example, the standard input/output header file includes a print function called "printf". This function prints a string to the screen. By using standard header files, two different programmers can look at the printf function and know immediately what it is doing. The alternative would be to have two programmers defining their own print functions and using it in their code. The two unique print functions would not only be redundant in the code, but might cause confusion between programmers. A compiler comes with a number of header files that can be used to begin coding general projects. These include the stdio.h file and math.h file. To begin coding for a specific part such as the CC2541, the manufacturer provides a number of header files to use.

ioCC254x_bitdef.h

This header file contains the coding that defines the bit definitions of registers in the CC2540/CC2541. Each register in the RAM is located at a specific address in the internal memory. This header file defines each location in memory that corresponds to its certain register. Comments are provided that explain each definition and that specific register's function in the overall circuitry. In addition, each bit of the special function registers toggle some setting in the microcontroller. For instance, the difference between receive data and transmit data is only a few bits being changed. This header file also gives an invaluable reference as to the inner workings of the microprocessor. The definition of each of the registers and their role will enable the programmer to create a more efficient run-time code.

Hal_types.h

The HAL types header file defines the different variable types and ensures that the basic value types are defined. Include guards are set up as to ensure each type is only declared once. Certain function prototypes are also included in the Hardware Abstraction Layer header file. This header file is essential to the program because it enables the overall code to be properly defined and all necessary variables are declared. Without this header file, it would be up to the user to define all variables each time new code is created. This would be the source of a number of errors and ultimately cause time to be wasted.

Dma.h

The DMA header file declares the variables and functions necessary for the user to code for direct memory access. Direct memory access is a feature that allows certain subsystems on the hardware mainframe to access memory independently of the central processing unit. The DMA header file includes variable and macro definitions. Without the ability of other components to directly access memory, the CPU would be occupied totally for the entire read or write operation of data transfer. The CPU would then be unable to perform other tasks while data is being transferred. In this project, data will constantly be updated and transferred from multiple sources. The CPU would be unable to do basically anything but reading and writing data. Other tasks would be put on low priority, resulting in a tremendous slowdown of reaction time or other basic tasks. If other tasks are put on high priority the overall time to execute is still much longer. The CPU will need to allocate all its resources toward either data transfer or other computations. Because the DMA header will be included, the CPU will be able to delegate memory accesses to other components. This will greatly increase the overall speed of the microprocessor and result in a better user experience.

Data Input/Output

A large amount of processing time will be spent managing data input and output. The peripheral sensors will be constantly sending in new data to be manipulated. The CPU will take care of many of the miscellaneous computing tasks that need attention while other components will be allowed to directly access the memory at any point. A group of functions are needed to moderate the stream of input data into the internal memory. Input data will be processed by the CPU and sent to the appropriate address in memory. The software must be able to keep track of the locations of all the different memory within the RAM and flash memory. Another set of functions will then access the memory when needed to output data to the UART. The memory must also have a number of safeguards to ensure memory does not get unintentionally erased due to lack of space or bad allocation determination. A series of program tests will elucidate the effectiveness of the programming. Figure 59 below is a representation of the data flow inside the CC2541

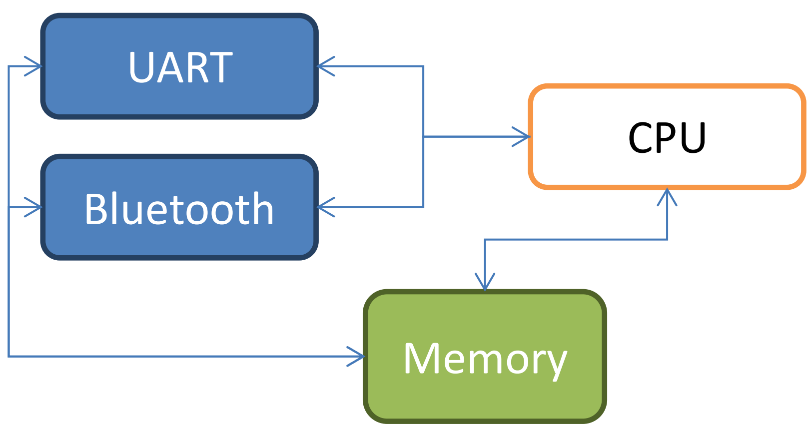

Figure 58 Data flow inside CC2541

Interrupts

The processor needs to have a hierarchy of tasks to execute throughout the run time of the system. The software will have a section of code that checks the state of the system and assigns priority when needed. When a high priority task reveals itself, the software should recognize the urgency of the task and put it at the top of the tasks to be executed. All other tasks will be momentarily suspended and the previous state will be saved in memory. Once the high priority task is complete, the previous state will be obtained from memory and regular processes will resume. Based on this description, the flow of command will come from an interrupt source to halt operation. An interrupt can originate from the hardware, the software, or the processor itself. An example of a hardware interrupt would be some sort of user input on a traditional computer. For instance, if a key on the keyboard is struck, the priority task is to execute the task indicated by the keystroke. If a letter is typed, the letter will show up on the screen. In this project, the user interface is the Android GUI. Input from the user via the smart phone will be sent to the processor as a priority task. An interrupt may also come from the software. An example of a software interrupt would be something like a new external input being detected that requires attention. This could be a disc or USB drive. In terms of this project, a software interrupt could come from one of the sensors that are programmed to send an interrupt request if something out of the ordinary occurs. If the child has a spike in temperature, the software will trigger some form of alarm that will be executed before other activities. Finally, the processor can interrupt itself. For instance, if something goes wrong with the memory, there should be a failsafe that recognizes the error and deals with it. All three types of interrupts may occur during run-time. The coding should include functions that recognize all types of possible interrupt conditions and lists those tasks as priority execution. The interrupt process also includes a number of memory access processes that must be handled during the interrupt process. All software should handle interrupt requests and memory access in the order illustrated in Figure 60 Interrupt Process.

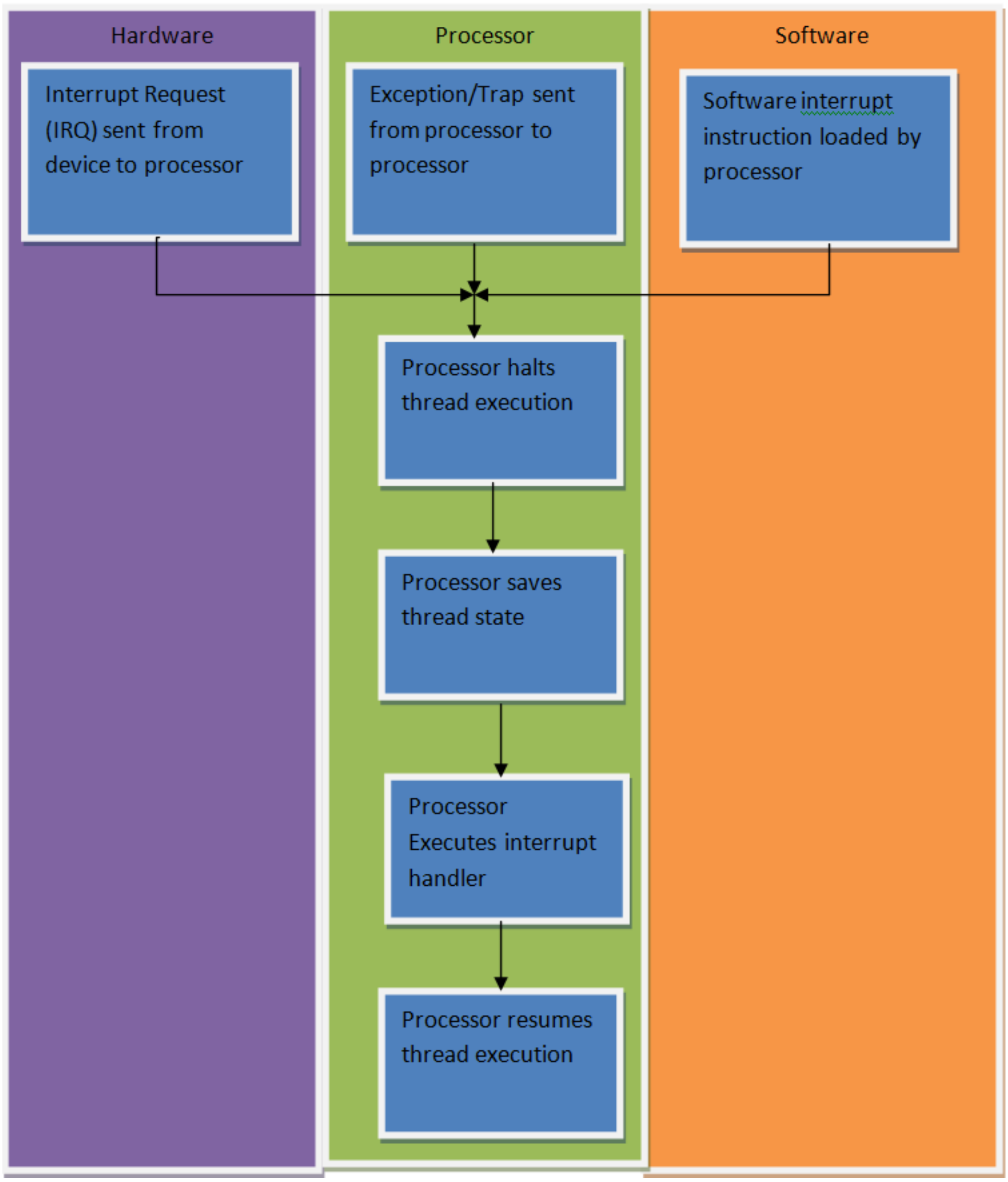

Figure 59 Interrupt Process Flow

UART/SPI/I^2C

Data transmission is essential to the success of this project. Data will flow from the peripheral units to the central processing unit through the SPI and I^2C channels. A number of functions must be programmed to first initialize the SPI and I^2C, and then set the destination for all data coming in from each component. This section includes the memory access and input/output function previously described.

4.1.4.8 Debugging Feature CC2541

The debug interface is used during the development phase to manipulate the processor if any problems arise. It is almost guaranteed that there will be some part of the initial versions of the microprocessor programming that does not work the way it is intended to. The debugging system can be used to step through the run time task executions on the microprocessor to identify the problems. This is invaluable if a part of the program does not work in the way it is supposed to. The debug interface uses a SPI-like two-wire interface using the pin P2.1 for debug data and P2.2 for the debug clock. Table 23 shows the basic AC characteristics of the debug interface.

Parameter	Test Conditions	Min	Typ	Max	Unit
f_{clk_dbg} Debug clock frequency				12	MHz
t_1 Allowed high pulse on clock		35			ns
t_2 Allowed low pulse on clock		35			ns
t_3 EXT_RESET_N low to first falling edge on debug clock		167			ns
t_4 Debug data setup		83			ns
t_5 EXT_RESET_N high to first debug command		83			ns
t_6 Debug data setup		2			ns
t_7 Debug data hold		4			ns
t_8 Clock-to-data delay	Load = 10 pF			30	ns

Table 23 AC Characteristics of the debug interface

Figure 61 below illustrates the timing characteristics of the debug clock when the RESET_N pin is pulled low. Initially, there is a short delay between the reset and the first falling edge of the debug clock. When the reset pin is pulled high again, there is another pause before the first rising edge of the clock.

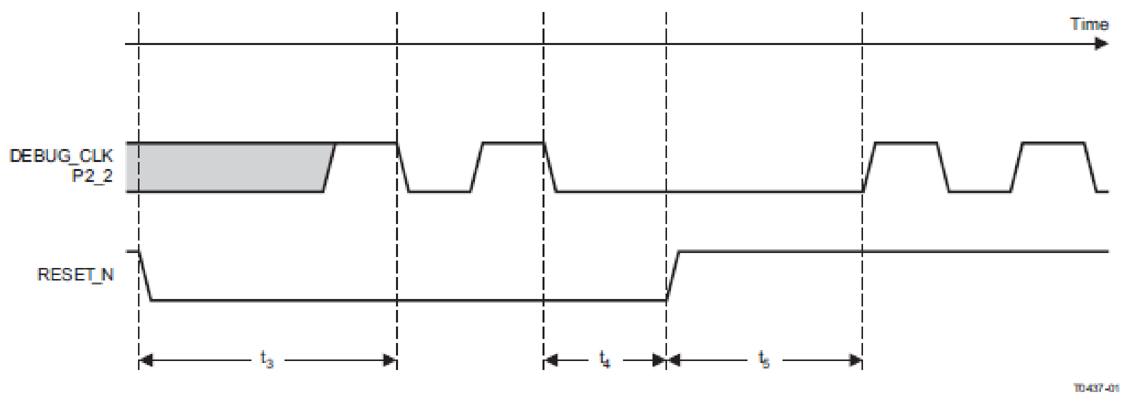

Figure 60 Timing Characteristics of the Debug Clock. Reproduced without alteration with permission from Texas Instruments

Figure 62 below shows the data signal characteristics of the debugging system. The debug data is setup on the rising edge of the debug clock. The setup time of the debug data originating from the CC2541 is shown by the term t_6. The next term, t_7, shows the hold time that the data must remain at a constant level in order to be successfully read by the system. The data is read on the falling edge of the debug clock. The last term, t_8, shows the delay time from the rising edge of the clock to the end of the data bit.

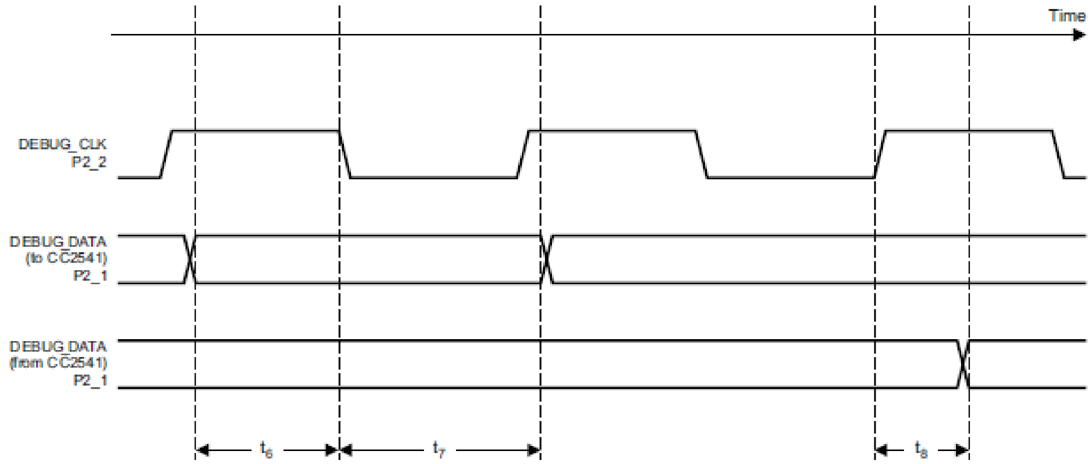

Figure 61 Timing Characteristics of the Data Signal of the debugging system. Reproduced without alteration with permission by Texas Instruments

Figure 63 below illustrates a typical debug command sequence. The command byte is read by the debug interface to configure the debugger. Data bytes are then read to the system until the data pad direction is changed from input to output. Then data can be transferred out from the system.

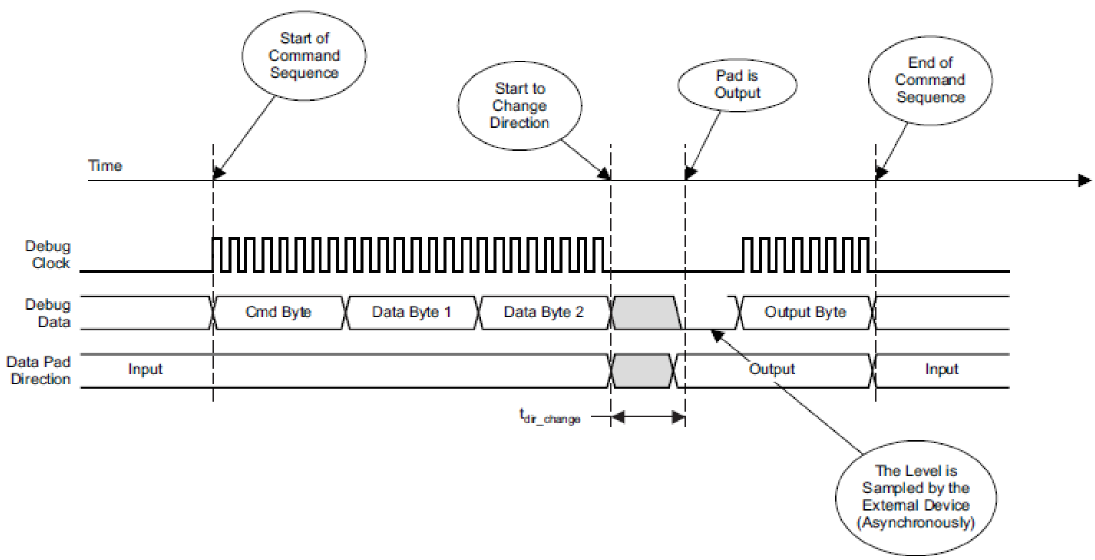

Figure 62 Typical Debug commence sequence. Reprinted without alteration with permission from Texas Instruments

4.1.4.9 CC2541 debug device

The CC2541 requires a programming application to implement the software designed to run the microprocessor. The CC debugger is a device that is used to run debugging software and for flash programming. There are two PC tools that couple with the CC debugger to run the software on the microprocessor: the SmartRF Flash Programmer from Texas Instruments and the IAR Embedded Workbench for 8051 from IAR Systems.

The SmartRF Studio is the preferred PC tool in this project due to the cost of the IAR Embedded Workbench. In the beginning the understanding was extremely thin on the use of SmartRF Studio. This only allows for projects to be loaded onto the CC2541 rather than a development environment so IAR embedded workbench was used because the code needed to be changed to work with our design.

The minimum connection for the connecting the CC Debugger to the System on Chip device requires the Debug Clock signal and Debug Data signal connected from P2.1 and P2.2, respectively, on the SoC to pin 3 and 4 on the Target Connector. Resetn must also be connected between devices. The pin-out diagram is shown in Figure 64. To use the full packet sniffer capabilities of the debugger, the SPI bus must also be connected to the SoC device. The SPI bus is used to read RF packets from the SoC device. The CC2541 can also configure its RF SoC to operate as SPI slaves through one of the USART terminals. The TI SoC devices only support two pin configurations to act in this manner: USART0, alt1; USART1, alt2. The CC2541 supports the USART1, alt2 configuration. Table 24 shows the pin out details of this configuration. The CC debugger will be connected to the CC2541 in this manner and can be referenced back to the schematic diagram in Figure 48 and 50

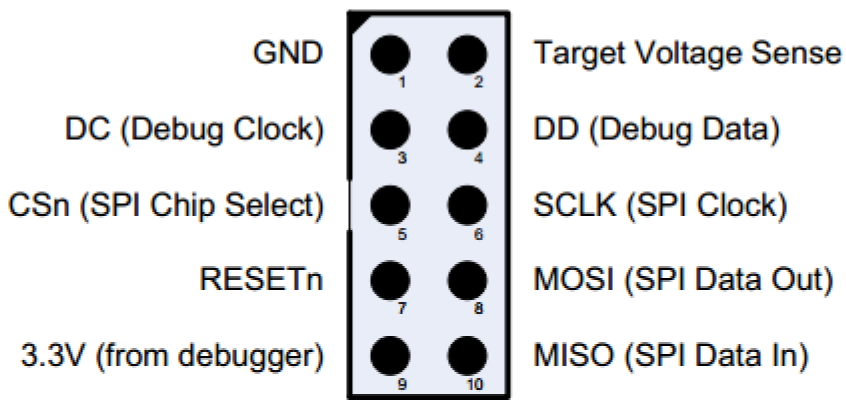

Figure 63 CC Debugger Target Connector Pin-Out. Reprinted without alteration with permission from Texas Instruments

	USART0, alt 1	USART1, alt 2
SCLK	P0.5	P1.5
CS	P0.4	P1.4
MOSI	P0.3	P1.6
MISO	P0.2	P1.7

Table 24 USART Pin Out Details. Reprinted without alteration with permission from Texas Instruments

4.1.5 User Interface Design

As the most visible aspect of the product, having an instinctive experience for the user interface is a huge advantage. A clunky user experience can kill an application in its infancy. In particular, in the case of a baby monitor, experience flow is paramount to the entire operation. With important aspects such as safety, security and responsiveness, a baby monitor requires the highest standards for human computer interaction (HCI). For Baby Peas' ground station unit, a number of choices exist; the three most common ones are simple embedded LCD screens, desktops, and smart phones. While the first option, embedded LCD screens, would be the cheapest selection, it also tends to be the least attractive and least consumer friendly. Intended for a more industrial settings or niche markets, these screens would not function well for the needs of a baby monitor. The chance of missing critical information undermines the safety and security goals. In addition, having a separate ground station, to the peripheral ankle mounted sensor, generates more clutter in the unit. Parents of newborns would surely appreciate any effort in removing clutter. Option two, desktops, has much potential and offers a greater power in applications and calculations. In addition, most households that would purchase the Baby Peas unit would have some version of a home pc. However, it does not matter how powerful the unit is if the unit lacks ergonomics. Having mobility in baby monitors trumps the desktop option, leaving smart phones as the best option, having both clarity and mobility. Despite the obvious suitability of cell phones or tablets, LCD with resistive touch and personal computer options are still considered for the developmental portions of the peripheral sensors and microprocessor prototyping, and can be included in the final product if the mobile phone or tablet does not provide the best user experience. There are several options for touch screens.

4.1.5.1 Touchscreen

In today's world, a common user interface for everyday consumer smart phone applications is a touch screen due to its innately intuitive nature. The tangibility of a touch screen creates a closer experience for the user and allows the developer to create applications that may be complex in the backend, but have clear and concise availability on the front end facing the consumer. This suits Baby Peas particularly well due to the strong date driven character of the unit. All information gathered is quantifiable to both general statistics and to the individual's historical statistics. To have a user shift through all that can create confusion. Having a touch screen simplifies the process, leaving the caretaker free to make higher level decisions. As mentioned above, one route for design is the mobile phone, the second route is an LCD touch screen attached to a base station, and the third route is a personal computer screen. The next section goes over the finer points of the two types of touch screens and why resistive was selected.

4.1.5.1.1 Resistive Touch

Resistive touch screens comprise of electrically conductive and resistive layers on a glass panel. Sometimes acrylic panels are also used. Figure 65 shows a generalized picture of the glass material and two layers that are typically manufactured with indium tin oxide.[52]

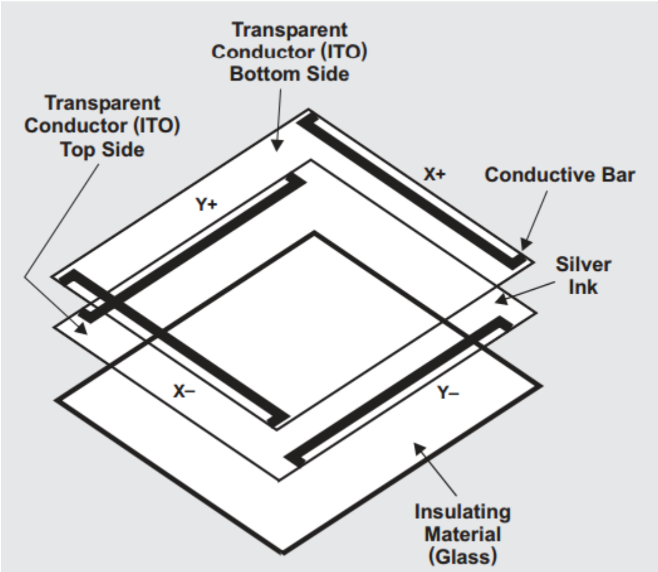

Figure 64 Resistive Touch Screen, Reprinted without alteration with permission from Texas Instruments

The base layer is called the matrix, a layer with stripped electrodes in a pattern, while the second layer is called the analogue, a layer with transparent electrodes. As the user draws their finger across the screen, the layers touch at the figure junction and complete the circuit at the point, causing a differential in the system. The primarily mode of sensing is pressure, so a resistive touch screen can be used by any object such as human finger, pen, or pointer. The coordinates of activity is sensed using two industry standard, the 4-wire and the 5-wire configuration. Figure 66 shows the two typical layouts.[52]

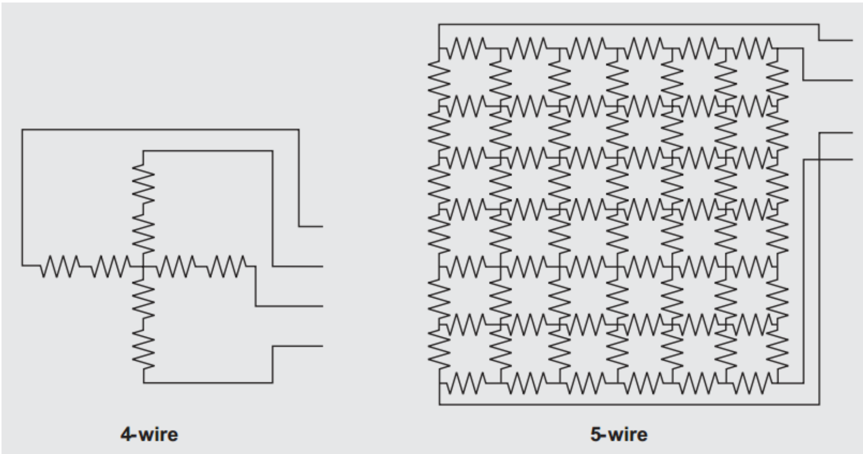

Figure 65 Resistive Touchscreen Layouts, Reprinted without alteration with permission from Texas Instruments

Resistive screens are the cheaper of the two touch screen options and have higher resolution, often being used in handwriting recognition capacity. In addition, as discussed earlier, any object can be used as the pen. However, it does have some disadvantages, including less responsive to the pressure of touch. Because the top layer is being pressed down into the bottom layer, a certain pressure threshold must be met before the circuit registers the touch. In addition the screen might not have as great of a contrast due to internal reflections. In addition, because the top layer is flexible enough so that it can deform to a closer position with the bottom layer, it damages more readily than capacitive screens. Finally a resistive screen captures one touch a time and will not support multi-touch.[49]

4.1.5.1.2 Capacitive Touch

The capacitive touch has two layers of glass, spaced out slightly, and coated with a conductor. This basically forms parallel plate capacitor. As the user touches the screen, the capacitance changes and the microprocessor can sense the change in the electrostatic field. While the screens look very sharp due to the rigid nature of the two glass layers and lack of deformation from the stylus or finger, capacitive touch screens are rather expensive and require the user to employ finger or other conductive material to register touches. The other upside of capacitive touch is the ability to multi-touch. However, due to the nature of the project, developing a capacitive touch screen would be prohibitively expensive. [50]

4.1.5.1.3 Touch Screen kits

It is recommended to buy a kit rather than develop a prototype touch screen due to cost, time and expertise. There are several kits available in the market for purchase. For example, 4D systems makes a resistive LCD that interfaces with a Raspberry Pi, a cheap and light portable microcontroller. It is recommended to develop touch screens as plan b, for it introduces more unknowns into the project and raises development costs by quite a bit. A 3.2” screen from 4D sells for $84.95 on the well-known hobby site, Sparkfun.[51]

4.1.5.2 Software Development

Writing and optimizing code forms a significant portion of this project. An earlier section went over the three major market share platforms for development: Android, Windows, and iOS. The choice between the three involved several levels of calculations; availability of open source, entry to market cost, east of development, and market share. As a student project, gleaning information from other sources constitute a significant portion of the journey. An open source platform usually contains a larger and more active developer user base. In this case, of the three platforms, Android is known for being open source and having large samples of code available for learning. While Windows has the backing of Microsoft and large amounts of documentation, its market share is simply too low compared to Android or iOS to seriously consider having the Windows platform as the ground unit. The entry to market is also another serious consideration, due to the novice nature of the group’s experience in mobile development. In addition, the group also has limited funds and the mobile portion is just a part of the whole project. After looking at the different price points of developer sign up fees, Android was deemed the best due to the low onetime cost. One hurdle is the newness of the Bluetooth Low Energy protocol. Android devices being released presently support the Bluetooth LE, however, android devices released before, despite having the necessary hardware, do not support Bluetooth LE.

4.1.5.3 Software diagrams

Software High Level System Block Diagram

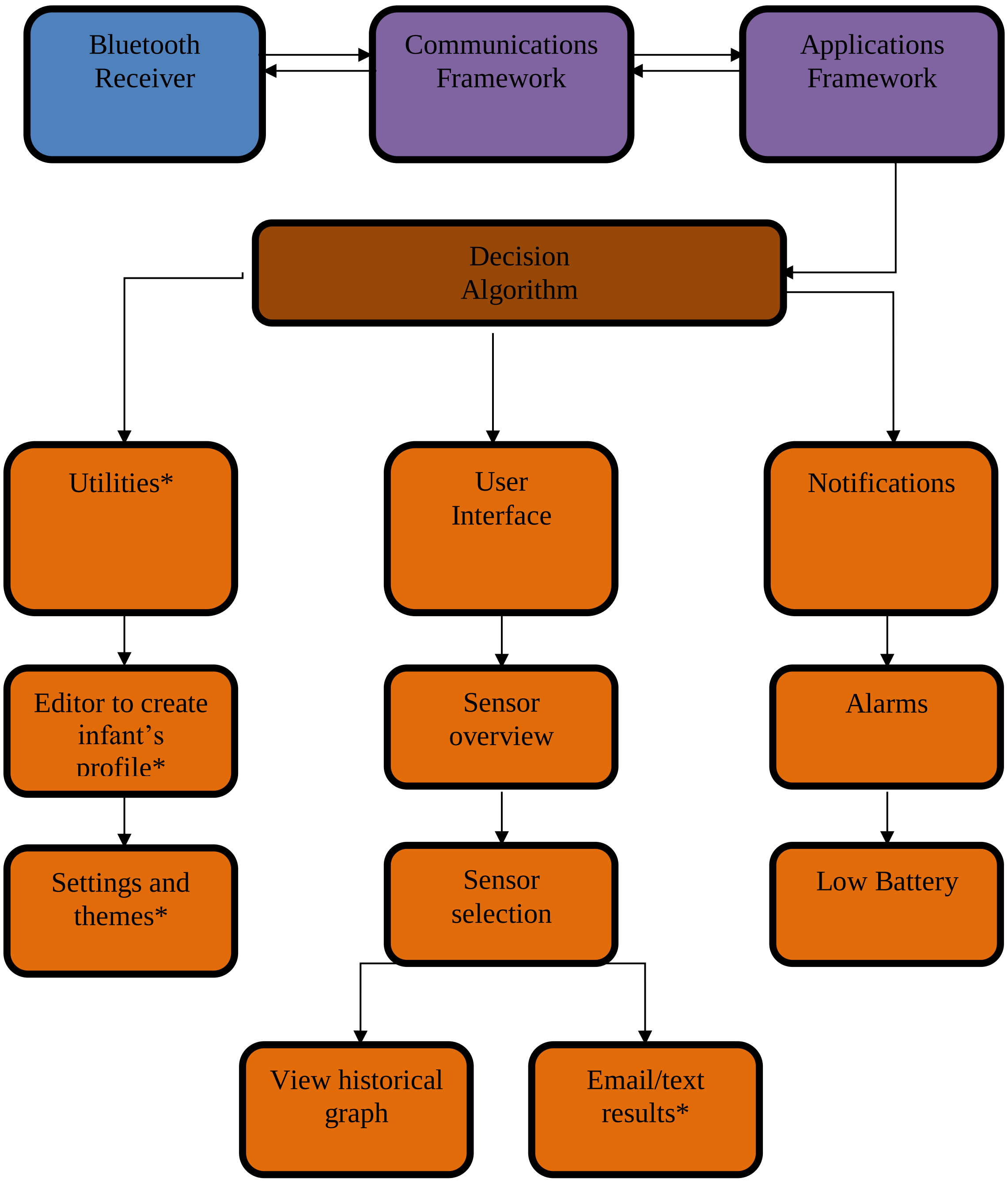

Figure 66 Software Block Diagram

*These are optional modules. If time permits, optional modules will be added to the system.

4.1.5.4 Class diagram

Problem statement: Need to create a program to gather data, sort data and display it to end user. The program will be used by the end user to see the status of infant's biomarkers of pulse, temperature, oxygen level, and orientation. The program will also alert the user if certain conditions are not met for each sensor. Figure 68 below is the class diagrams for the base station monitor (Smart Phone).

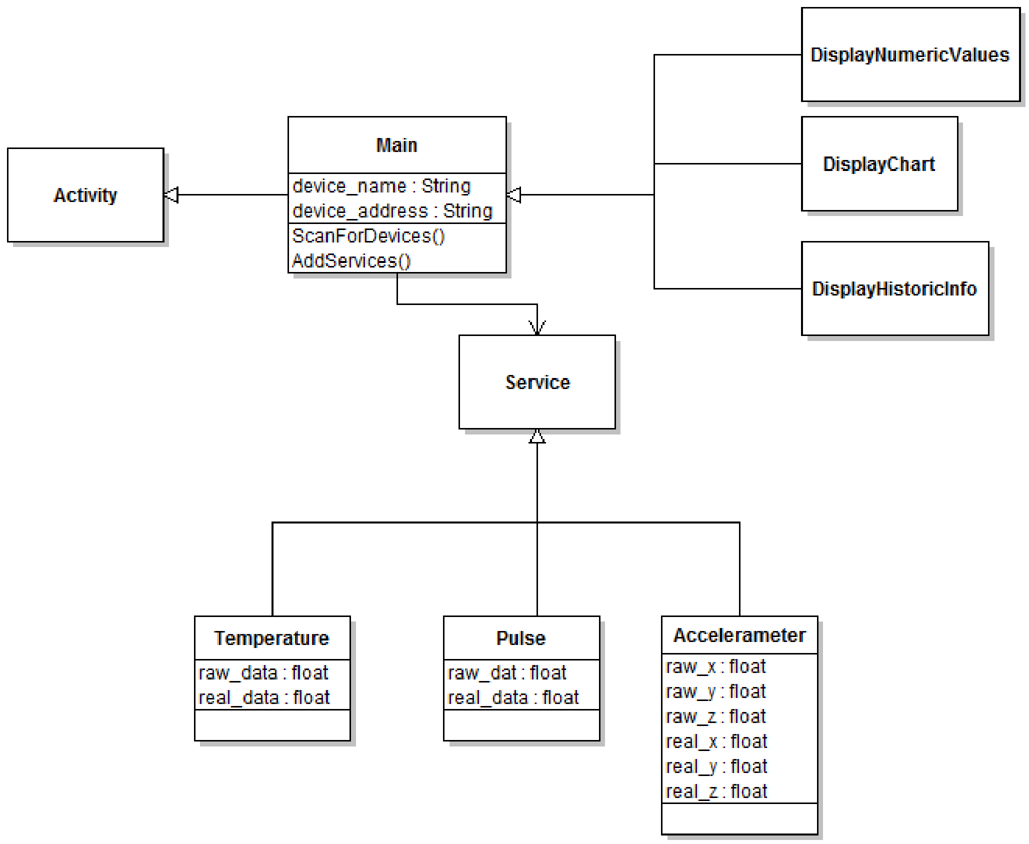

Figure 67 Class Diagram for Smart Phone User interface device - data collection, parsing and humane computer interaction Class Diagram.

4.1.6 Bluetooth Handshake

As discussed in 3.2.4, after looking through the different communication protocols, it is decided that Bluetooth would be the best fit for Baby Peas. Light on power consumption, this protocol is well used and well documented. Additionally, the new Bluetooth Low Power, or Bluetooth Smart, lowers the power even more.

4.1.6.1 Android Platform for Classic Bluetooth

Bluetooth network stack is already supported in the Android platform, and native application programming interface (API) operations include other Bluetooth device scan, query local Bluetooth adapter for paired Bluetooth devices, RFCOMM channels, service discovery, data transference between devices and multiple connections. Basically, API is a set of functions with an unique task. Android Bluetooth API can be broken into four categories of setting up the Bluetooth device itself, searching for other Bluetooth devices in the vicinity, connecting, and data transference. [56]

4.1.6.1.1 Setting up the Bluetooth device:

Step one is to verify Bluetooth capability and switch on the Bluetooth. The user can manually enable Bluetooth option under system menu, but if the option is disabled, the application can ask the user to enable the Bluetooth with the Bluetooth Adapter API (Figure 69).

Figure 68 Bluetooth Adapter API, reprinted without alteration and with permission courtesy of Android

The Bluetooth Adapter is the basic requirement for any Bluetooth activity. In the code, the device is first asked to search for the device's Bluetooth adapter by the getDefaultAdapter() call. If the call returns null, then the adapter does not exist and no Bluetooth connection can be made. If an adapter exists, the code can use isEnabled() to look at the status of the adapter. If the user has manually enabled the Bluetooth module, then the result would indicate false. If the user has not manually enabled the Bluetooth module, then the code can enable the Bluetooth by startActivityForResult() function call and ACTION_REQUEST_ENABLE Intent. This displays Figure 70 screen to the user. When the user clicks yes, then the Bluetooth device is enabled and can start searching for other devices in the vicinity.[56]

4.1.6.1.2 Searching for other devices:

The two options for this portion is device discovery or looking for list of paired devices. Either method should work for Baby Peas. For device discover, a general call is made out to any discoverable devices in range, and once an object is discovered, a connection is made by exchanging identifying information. For list of paired devices, identifying information is already stored on the home Bluetooth device, and the benefit of that is the connection can be made whenever the range is optimal. Due to the time saving nature of paired devices, it is probably the best method for Baby Peas. To have a unique monitor for each baby furthers the cause of individualized units.

The first step to query is to use the getBondedDevices() call. This allows the home device to look for unique media access control address (MAC address) that is stored in the hardware of the network interface controller. In addition to the phone doing the querying, the satellite device, the peripheral ankle sensor unit, can also query for the phone. In that case, the phone will have to enable discoverability. Using the startActivityForResult(Intent, int) and ACTION_REQUEST_DISCOVERABLE, the phone is able to be discovered by the sock unit. This is a decision for the designer, due to power and timing considerations. Figure 70 below is an example of what alert might look like on the smart phone devices once the peripheral ankle sensor unit queries for other devices and the smart phone picks up that query.[56]

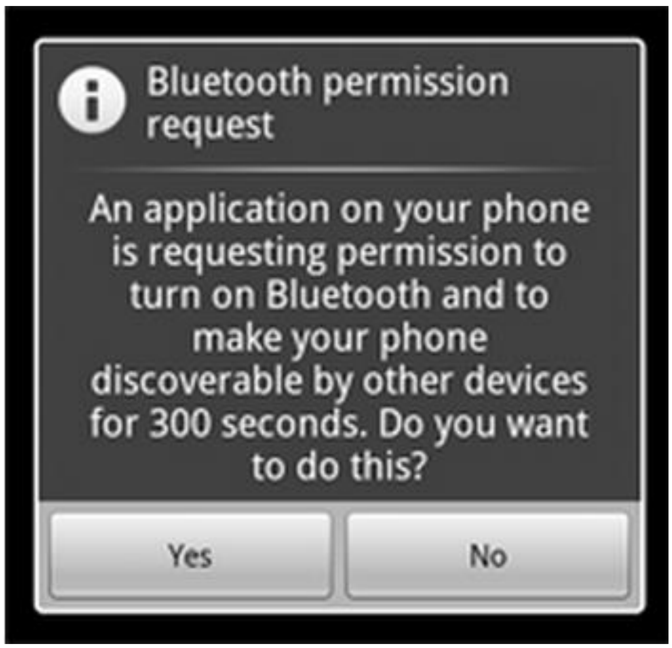

Figure 69 Possible alert form and smart phone device, reprinted without alteration courtesy of Android

4.1.6.1.3 Connecting device as server-side:

This step is critically important to the communications portion of the unit; server-side and client-side operations must take place on the same RFCOMM channel. Server-side portion opens with BluetoothServerSocket API, and listens to requests for connection. Once server-side accepts the connection, the BluetoothSocket is connected and the server-side can stop BluetoothServerSocket (so additional requests will not be honored). Some commands used are listenUsingRFcommWithServiceRecord(String, UUID), accept(), and close(). For the first one, the string is the name of the service. The accept command will initiate connected BluetoothSocket only if the query was accepted. Finally the close() call sets down the query and no additional connections will be made. In the case of multiple satellite units, the close() call can be adjusted so that more connections can be made. To the right is a sample connection code from android developer site.Connecting device as client-side:

The ground station must first get BluetoothDevice that represents the satellite device. Several commands used are creatRfcommSocketToServiceRecord(UUID), listenUsingRfcommWithServiceRecord(String, UUID), and connect(). Figure 71 below is sample code for Android applications on how the Bluetooth connection could be made. The Baby Peas project could use this as a platform in helping the development of the smart phone application.[56]

```
private class AcceptThread extends Thread {
    private final BluetoothServerSocket mmServerSocket;

    public AcceptThread() {
        // Use a temporary object that is later assigned to mmServerSocket,
        // because mmServerSocket is final
        BluetoothServerSocket tmp = null;
        try {
            // MY_UUID is the app's UUID string, also used by the client code
            tmp = mBluetoothAdapter.listenUsingRfcommWithServiceRecord(NAME, MY_UUID);
        } catch (IOException e) { }
        mmServerSocket = tmp;
    }

    public void run() {
        BluetoothSocket socket = null;
        // Keep listening until exception occurs or a socket is returned
        while (true) {
            try {
                socket = mmServerSocket.accept();
            } catch (IOException e) {
                break;
            }
            // If a connection was accepted
            if (socket != null) {
                // Do work to manage the connection (in a separate thread)
                manageConnectedSocket(socket);
                mmServerSocket.close();
                break;
            }
        }
    }

    /** Will cancel the listening socket, and cause the thread to finish */
    public void cancel() {
        try {
            mmServerSocket.close();
        } catch (IOException e) { }
```

Figure 70 Example code for Android Bluetooth Connections, reprinted without alteration and with permission from Android

4.1.6.1.4 Managing a connection:
Once connection is made, the devices exchange data via InputStream, OutputStream, read(byte[]), and write (byte[]) calls.

4.1.6.1.5 Profiles:
Android offers several Bluetooth profiles: Headset, A2DP, and Health Device. Headset is a profile for using wireless headsets via interprocess communication, a method for exchanging data through many threads. A2DP stands for Advanced Audio Distribution Profile and it controls the audio quality coming in from the wireless device. The project is concerned primarily with the Health Device profile. With this profile, the Android device can exchange information with health monitors such as pulse, temperature, weight, and blood monitors. [56]

APIs for the health profile include BluetoothHealth, BluetoothHealthCallback, and BluetoothHealthConfiguration. The arrangement of the two devices is of source and sink; the source is the measuring device and the sink is the home station that is receiving the data. [56]

5 Project Prototype Construction and Coding

5.1 Parts Acquisition and BOM

5.1.1 Part Vendors
To ensure uninterrupted progress in the project, we have to find reliable part and components providers. Newark, Digikey, and Sparkfun are the main distributors along with local hobby stores like Skycraft Part and Supply.

5.1.2 Newark
Newark Corporation (Newark element 14) is an electronic component distributer based in Chicago, Illinois. Founded in 1934, Newark Electric was a small shop mainly selling radio parts. It is one of the major distributors of electronic components and testing hardware today. One of the advantages of using Newark is its affiliation with Cadsoft Eagle schematic capture software. Cadsoft Eagle has an option provided by Newark which allows the designer, once the schematic is complete, to assign specific manufacturing part numbers from its database to easily create a bill of material. This feature alone could save hours in looking up each individual component on the 3 different websites and then comparing costs. Newark provides both the manufacturing part number and the Newark assigned part number. This way if Newark does not stock the item it allows the designer to look elsewhere for a possible part solution.

5.1.2.1 Digikey
Digikey was founded in 1972 providing wide selections of electrical components. It is now serving North America, Europe, and Asia. Its headquarters is based in Thief River Falls, Minnesota, USA. With 99.95% orders shipped on the same day, it could be a very reliable source for Baby Peas project.

5.1.2.2 Sparkfun and local hobby centers

Sparkfun is an online retail store which offers parts for electronic projects. Sparkfun also offers classes and online tutorials through its department of education, a valuable resource for hobbyists and developers.

5.1.2.3 Price list of Hardware "BOM" / Development Tools

Based on our research, most suppliers have plenty of quantity in stock or offer alternatives. Newark offers the lowest prices. Some parts are available as free samples from the manufactures. Parts needed for the fabrication of the PCB are listed Bill of materials Table 25. Not all components are listed which are needed for the PCB but the high level sensor parts which are the most expensive are listed. Table 26 is a list of Development Kits the Baby Peas project will need for product realization.

Part	Quantity	Price	Vendor	Sample
TI AFE4490	1	$18.67	Digikey	Yes, from TI
TI TMP006	1	$3.89	Digikey	Yes, from TI
Invensense MPU-60x0 series	1	$10.72	Digikey	N/A
		$12.95	Sparkfun	
TI TMP103	1	$1.46	Digikey	Yes, from TI
		$1.01	Newark	
MTE5066C-UR	1	$2.73	Digikey	N/A
Fairchild QEB363	1	$0.46	Mouser	N/A
Fairchild QSB34CGR	1	$0.84	Mouser	N/A
Advance Photonix	1	$5.95	Octopart	N/A
PDI-E839				
TI CC2541	1	$6.62	Digikey	Yes, from TI
		$5.75	Newark	
TPS62730*	1	$2.31	Digikey	Yes, from TI
		$1.82	Newark	
PST-LC24*	1	$15.00	Powerstream	N/A
Lir2477*	1	$5.00	Powerstream	N/A
PCB board	1	$33.00	4PCB	N/A
Crystal 32.786 KHz	1	$0.24	Digikey	N/A
Crystal 8MHz	1	$0.20	Digikey	N/A
Crystal 4MHz	1	$0.21	Digikey	N/A
Capacitor 0.01uF	1	$0.10	Digikey	N/A
Capacitor 0.1uF	1	$0.10	Digikey	N/A
Resistor 1M Ohm	1	$0.10	Digikey	N/A
Resistor 0 Ohm	1	$0.10	Digikey	N/A
Inductor 2.2uH	1	$0.14	Digikey	N/A

Table 25 Introductory BOM for the Peripheral sensor PCB

Part	Quantity	Price	Vendor	Sample
SK-24PTU-PI*	1	74.4	Mouser	N/A
CC2541 SensorTag Development Kit	1	33	TI	Yes, from TI
CC2541 SensorTag Development Kit	1	99	TI	Yes, from TI
CC2541 Evaluation Model Kit	1	99	TI	Yes, from TI

Table 26 Software Development Kit BOM

5.2 PCB Vendor and Assembly

Printed Circuit Board Vendors provide services which take something called gerber files which are generated from a type of CAD software tool (like CAD EagleSoft) and are able to generate a fabricated Printed Circuit Board without any components soldered to the board. Printed Circuit Board assembly houses provide services which place each component on the circuit board and then solder them. They use pick and place machines which automatically place each part in the right location and position on the PCB and then run the board through an oven at a specified temperature per part which enables the part to be properly soldered down. They then run the board through a machine which automatically provides visual inspection of the solder connections. They have certified inspectors which provide visual inspection of the boards as well.

5.2.1 PCB Vendors

Printed Circuit Board (PCB) fabrication has a wide selection of possibilities to choose from. Due to time constraints a vendor which offers low pricing and quick turnaround time will be used for the PCB fabrication of the peripheral device PCB.

5.2.1.1 4PCB

4PCB is an online manufacturing provider of Printed Circuit Boards. They provide 2 layer boards (student pricing) covering 60 square inches of circuit board space for $33.00 dollars or a 4 layer board covering 30 square inches of circuit board space for $66.00 dollars. They have a turnaround time of 5 days and also provide free Design for manufacturing tests which means they look at the PCB layout provided and check to make sure tolerances between trace widths and such are within the standards for PCB fabrication.

5.2.1.2 PCB Fabexpress

PCB Fabexpress is another online PCB vendor which provides quick turnaround times of 5 days but have some minimum order requirements which drive up the price. Any 2 layer bare bones PCB (no silk screen or solder mask) has a standard cost of $40.00 with $.60 added for every square inch. While customization for size and cost is a great option the minimum order quantity could get expensive if a redesign effort needs to be done during the project testing and evaluation period.

5.2.1.3 Custom Circuit Boards

Custom Circuit Boards provides PCB fabrication with extremely fast turnaround time of 24 hours if needed. They do not have a standard 2 or 4 layer pricing matrix but quote each PCB separately. When the PCB design is completed for the Baby Peas project the gerber files will be submitted for quote to obtain pricing.

From the evaluation of these three companies it is decided the Baby Peas' PCB fabrication will be done by 4 PCB. The pricing and space could not be matched along with the added feature of the design for manufacturability allows an expert pair of eyes to evaluate the PCB for any mistakes which could hinder the assembly of parts onto the board. Custom Circuit Boards will be approached once the PCB layout design is completed to receive a price quote. Once completed it will be a backup plan in case schedules start to become a problem and a PCB is needed quickly.

5.2.2 PCB Assembly Houses

For the PCB assembly, the Baby pea's project wanted to approach local PCB assembly houses which provide component assembly to PCB services. Two local companies were researched as possible candidates for assembly of the PCB due to the small nature of QFN package devices. Pricing and turnaround times will be the driving factor in choosing an assembly service.

5.2.2.1 QMS (Quality Manufacturing Solutions)

Quality Manufacturing Solutions is a local PCB assembly house located in the Lake Mary, Fl area which not only provides PCB assembly services but a host of engineering, manufacturing, test, configuration control, quality and supply chain management services to their customers. They specialize in rapid prototype to medium volume production. They have the ability to perform BGA rework and X-ray services if needed. Judy Kelch is a project manager at QMS and will be approached for sponsorship options with the Baby Peas' project which could involve financial contributions or design advice for PCB layout and inspection services of the solder connections. Pricing for QMS to perform a pick and place operation and run the boards through their ovens would be beyond the affordability of the project if the group had to pay for it.

5.2.2.2 Conilec

Conilec is a local PCB assembly house located in Deland, FL. They too provide a wealth of services to their customers. They assign specific program managers to all their customers and are the point of contact for any interactions between the two parties. Conilec will be approached for sponsorship options as well. A price quote could not be obtained without a finished PCB layout design.

5.2.2.3 DIY (Do it yourself)

The baby pea's project has a certified J-STD-001 surface mount solder technician which is able to solder down to 0201 size packages along with LGA and QFN packages. The group has obtained a hot air pencil soldering system along with soldering iron equipment for surface mount PCB assembly and a microscope for inspection of solder connections. The group has the ability to solder all components onto the PCB and rework each component of the PCB as needed.

The DIY approach seems to be the best option since the only cost incurred will be solder materials and time, but it allows for flexibility in the schedule because the assembly and rework are not relied upon by people outside of the group. The hot air pencil will be used for difficult components like the QFN and BGA packages. The soldering iron will be used for all other leaded surface mount components. In addition, the do it yourself approach will give invaluable experience to the inexperienced group members.

6 Project Prototype Testing

6.1 Hardware Prototype Testing

Hardware testing needs to be thorough, methodical, and controlled for the Baby peas' project to be successful, unfortunately due to time constraints the following testing was not entirely completed or thoroughly incorporated. Hardware testing can make or break a project. There is a fine line between how much a company should spend on testing hardware and software before releasing products to market. Testing costs companies money and for every day the product is not on the shelves is more money the company is losing. However, projects also realize not enough testing can lead to product failure in the field which can be detrimental in the long run for the survival of the company. The Baby pea's project is opting for an abundance of test scenarios because of the nature of the product. Since safety is of the utmost concern, any failure on the device which could cause even the slightest amount of harm to the individual is unacceptable. The project specifications must be met and back up protection code and hardware must be put in place to allow for as many possible scenarios which could cause harm to the user are explored. In addition, testing parameters must be calibrated with the baseline set for infants and not adults. In the following sections a comprehensive hardware and software test matrix will be provided as to cover each sub system and full system test parameters which have to meet a certain criteria before the product could be labeled as a success. To such an end, the Baby pea's project will take time to layout the PCB in a specific way which allows each sub system to be connected and disconnected from the CC2541 and power supply circuitry through the use of series 0 ohm resistors. This way each sub system can be connected and tested separately from all other interactions with other subsystems. This will allow individual sub systems to be brought up to specifications and debugged easily. Any dysfunction can be located in a timely manner and either switched out or replaced with another component. After all subsystem categories completed testing, one subsystem at a time will be added in and retested for compatibility. The test equipment used for evaluating the hardware will be oscilloscopes, function generators, digital multimeters, power supplies, spectrum analyzers, and logic analyzers. All the testing will be done with electrostatic protection in mind.

6.1.1 Battery, Regulator, and Charging Circuits

The first circuit to be tested is the battery, regulator, and charging circuit. To test this circuit, the TPS62740 will be soldered onto the PCB first with supporting circuitry (CC2541 will also be soldered to the PCB). On the switched output of the regulator there will be a 0 ohm series resistor which will not be placed. This will allow isolation to the rest of the PCB and an external dummy load resistor can be soldering in via a white wire. Another white wire can be connected to the battery terminals, allowing for an external power supply to be connected in. Table 27 walks through the necessary tests which will be performed.

	TEST	Procedure	Description	Expected Result
1	In/Out Resistance Checks	With DMM Measure Vin and Vout pins on TPS62740	Test validates input and output are not connected to ground and Vin and Vout soldered properly	Vin = High impedance Vout = High Impedance
2	Input Voltage Measurement	Connect external DC power supply to Battery Terminals, V = 3.6v , I limit = 110mA	Validates input battery terminals are properly designed for Input Voltage	Vin = 3.6V
3	Switched Vout measurement	Same Vin setup, High set on pin 12 (EN), O-scope on Switched line Test Point	Checking the 3.3v rail to validate output switched signal	Vout = 3.3v Vripple < 20mVpp
4	Switched Vout response to High and Low impedance loads	external High ohm and low ohm dummy loads switched by external fet controlled by function generator	Validates output stability of the TPS62740 to the varying load resistances experianced during full operation.	Output Voltage remains stable with no ringing on the output after High/Low switch
5	Battery Function Test	Remove External Power Supply and insert Coin Cell Battery into Battery holder clip and Retest parts 1-4.	Validates the Battery can operate the voltage regulator	Same as expected results from parts 1-4
6	Battery Charging Circuit	Plug in external battery charging circuit and verify battery is charging via digital multimeter	This validates the TPS62740 is in shut down mode during charging operations and the battery is charging properly	Vin on the TPS62740 = 0v and proper battery charging operation is observed.

Table 27 Battery, Regulator, and Charging circuit Test Matrix

6.1.1.1 Temperature Sensor Hardware

The temperature sensor will be the next system to be tested on the PCB. For all the peripherals, the Atmega328 software code will have to be completed and debugged at the same time as the peripherals are being added. Once this is completed the data communication (I^2C) can be probed and evaluated using an O-scope to check the SDA, SCL, and Chip select lines are operating properly. For the hardware test the output of the data from the TMP006 is inconsequential. Hardware testing is making sure the device operates under the specifications in the data sheet. Table 28 below transitions

	Test	Procedure	Description	Expected Result
1	Proper Solder connections	Measure the input resistance on Vin pin to ground with a DMM	This verifies the component Voltage input is not shorted and should operate properly when powered	High impedance
2	Chip Select Line	Measure the chip select line with an O-scope to verify proper high low transitions	This verifies the ouput from the CC2541 is controlling the chip select line	High / low transitions from 0v to VDD (square wave)
3	SDA / SCL line test (chip select line active high)	Measure the chip select line, SDA, and SCL lines with an O-scope to verify clock frequency (SCL) and verify SDA (Data)	Verifies accuracy and operation of the clock frequency from the CC2541 on the SCL line and verifies SDA high/low transitions the data is being ouput from the TMP006	SCL should measure the clock frequency output from CC2541 / SDA should be a sqaure wave
4	SDA / SCL line test (chip select line active low)	Measure the chip select line, SDA, and SCL lines with an O-scope.	Verifies when chip select line is active low the TMP006 should be off and SDA output data should be either always high or always low.	chip select line to be low. SDA line to be constant high or constant low.

Table 28 TMP temperature Hardware Test Matrix

6.1.1.2 Body Position Sensor Hardware

Once the TMP006 hardware device is tested the next device to be placed into circuit will be the MPU-6000 body position sensor. First the TMP006 will be disconnected from the circuit. The MPU-6000 will then be installed and tested in the same manner as the TMP006. Since both devices interact with the Atmega328p over I^2C, the device testing characteristics will be the same as shown in Table 28 with the difference being the device name.

6.1.1.3 Pulse Oximetry Sensor Hardware

The pulse oximetry sensor hardware circuit is tested next. The temperature sensor TMP006 and the MPU-6000 can remain in circuit except for their input voltage. Their data lines interact with the Atmega328p over I^2C whereas the Pulse Sensor uses an analog output to connect with the microcontroller. Table 29 displays the test matrix for the Pulse Sensor hardware circuit.

	Test	Procedure	Description	Expected Result
1	Proper Solder Connections	Measure input resistance on Vin to ground with a DMM	Verifies the input voltage line to the ADS-9800 is not shorted to ground	High impedance
2	LED1 on	Visually check to make sure the LED is on	the Green LED should be lit	LED shoul be lit
3	Photo Diode Check	Measure in line current to using a DMM to verify current pulses are present	Measuring the in line current will display the Photo Diode is picking up the light from the LED when they are on	Durring LED's on the Photo Diode Currents should be increasing while when the LED's are off the current should be decreasing.
4	OP Amp Output Measurements	Using an O-scope. Measure the ouput of the operational amplifier circuit	setting the O-scope to time devision of around 1 sec should enable the 1hz signal to be seen	a 1-2hz sign wave pulses should be visible on the O-scope while a finger is placed over the sensor

Table 29 Test Matrix for AFE4490 Pulse Oximetry Sensor

6.1.2 Wireless Communications Hardware Test

Due to the nature of the wireless communications hardware being a System on Chip CC2541 most of the testing on the input circuitry was taken care of during previous testing of the sensors. Things which can be tested are the output RF power from the system to verify proper gain flatness is maintained over the entire transmit frequency band. Software settings within the CC2541 can program the different transmit output power settings. Tests will be conducted which check the Max, Mid, and Min output power settings. Also two external crystal oscillators are being used which need to be verified as operational. Table 30 below displays the test matrix for the CC2541 circuitry portion. While the CC2541 was not used in the end this text matrix was somewhat implemented. For the HC-06 output measurements could not be taken due to the difficulty of being able to solder into the transmit circuitry. The HC-06 was also not configurable on output power so the only test was making sure data was streaming out and this was verified by the phone app being utilized.

	Test	Procedure	Description	Expected Result
1	Output Power Test RF_N pin (Max Power)	Using a Spectrum Analyzer and RF probe check RF_N pin during transmit. (TXPower Mode set to 0xE1)	This test will look at the gain flatness over the operating frequency band to verify the CC2541 is properly transmitting	Gain flatness should be +/- 1dB over frequency band with an output power of 0dB
2	Output Power Test RF_P pin (Max Power)	Using a Spectrum Analyzer and RF probe check RF_N pin during transmit(TXPower Mode set to 0XE1)	This test will look at the gain flatness over the operating frequency band to verify the CC2541 is properly transmitting	Gain flatness should be +/- 1dB over frequency band with an output power of 0dB
3	Output Power Test RF_N pin (Mid Power)	Using a Spectrum Analyzer and RF probe check RF_N pin during transmit. (TXPower Mode set to 0x91)	This test will look at the gain flatness over the operating frequency band to verify the CC2541 is properly transmitting	Gain flatness should be +/- 1dB over frequency band with an output power of -10dB
4	Output Power Test RF_P pin (Mid Power)	Using a Spectrum Analyzer and RF probe check RF_N pin during transmit(TXPower Mode set to 0X91)	This test will look at the gain flatness over the operating frequency band to verify the CC2541 is properly transmitting	Gain flatness should be +/- 1dB over frequency band with an output power of -10dB
5	Output Power Test RF_N pin (Low Power)	Using a Spectrum Analyzer and RF probe check RF_N pin during transmit. (TXPower Mode set to 0x41)	This test will look at the gain flatness over the operating frequency band to verify the CC2541 is properly transmitting	Gain flatness should be +/- 1dB over frequency band with an output power of -20dB
6	Output Power Test RF_P pin (Low Power)	Using a Spectrum Analyzer and RF probe check RF_N pin during transmit(TXPower Mode set to 0X41)	This test will look at the gain flatness over the operating frequency band to verify the CC2541 is properly transmitting	Gain flatness should be +/- 1dB over frequency band with an output power of -20dB
7	32MHz crystal oscillator Test	Use an O-scope to measure 32MHz crystal oscillator	Verifies a proper 32 MHz stable oscillator frequency is present	O-scope will read 32MHz signal with 3.3vpp applitude
8	32.768 kHz crystal oscillator Test	Use an O-scope to measure 32.768 kHz crystal oscillator	Verifies a proper 32.768 kHz stable oscillator frequency is present	O-scope will read 32.768 kHz signal with 3.3vpp applitude

Table 30 Test Matrix for CC2541 Wireless Communications Hardware

Once the completion of the CC2541 device has been tested, all devices will be inserted back into the circuit and will be ready for system level testing.

6.2 Software Prototype Testing

The Software testing consists of the CC2541 embedded coding and the user interface display device for Android compatible Bluetooth smart devices. Software "glitches" and non-intuitive user interface applications can cause the reliability of the product to be called into question from the user. The following table documents the possible route of testing for the software usability. In addition to the table, the unit should be operated by those who are unfamiliar to the project. This ensures that the design of the app is intuitive enough for the lay users.

6.2.1 CC2541 Software Testing

Software loaded onto the CC2541 is imperative for the hardware sensors of the system to work properly. The testing of the code will consist of a parallel path along with the hardware section during hardware prototype testing. Since the embedded code will be split up into separate function operations for talking to and sorting data from each sensor at different times the software code can be commented or uncommented depending on which functions are needed for each specific sensor device. Table 31 is a walkthrough of the individual tests which will be run to verify the software code loaded on the CC2541 is functioning properly.

	Test	Procedure	Description	Expected Result
1	CC2541 hardware init() is compiled and properly loaded onto CC2541	Use IAR embedded workbench to compile code and load onto CC2541	Verifies the ability to compile and load code onto the CC2541	Code compiles with no errors compiled code loads successfully onto CC2541
2	Function for enabling TPS62740	Compile TPS62740 function interactions and verify TPS62740 is operating per Test Matrix Table X	Verifies the enable and soft start of the TPS62740 voltage regulator for proper operation	No errors in compiled code. TPS62740 operating correctly
3	Function for enabling TMP006	Compile TMP006 function interactions and verify TMP006 is operating per Test Matrix Table X	Verifies the enable and soft start of the TMP006 voltage regulator for proper operation	No errors in compiled code. TMP006 operating correctly
4	Function for enabling MPU-6000	Compile MPU-6000 function interactions and verify TPS62740 is operating per Test Matrix Table X	Verifies the enable and soft start of the MPU-6000 voltage regulator for proper operation	No errors in compiled code. MPU-6000 operating correctly
5	Function for enabling AFE4490	Compile AFE4490 function interactions and verify AFE4490 is operating per Test Matrix Table X	Verifies the enable and soft start of the AFE4490 voltage regulator for proper operation	No errors in compiled code. AFE4490 operating correctly
6	Function for enabling wireless communications portion of the CC2541	Compile CC2541 wireless communications settings	Verifies the proper setup of the wireless communications settings	No errors in compiled code. Bluetooth operating correctly

Table 31 Test Matrix for Software functions of the CC2541 microcontroller

6.2.2 User Interface Module Software Test

The user interface hardware to be used for the baby peas' project will be either a Samsung Galaxy S3/4 phone or some other Bluetooth low energy compatible device with a display. The main reason to test an applications user interactive software is this is what the customer sees all of the time. If this portion of the device is not quick, easy, robust, and intuitive then the user will have no desire to use the device regardless of how good the hardware accuracy is. The Software will be tested by loading the designed application on the smart device and walking through each feature and validating features load quickly and display in a way which provides all the necessary data features. For the user interface module testing, the data being displayed does not need to be accurate. This will be covered in the final system testing. Table 32 is a breakdown of the necessary tests which will be accomplished to validate the user interface module software testing.

	Test	Procedure	Description	Expected Result
1	Software (SW) application build	Compile SW code in Software Development Kit for Android program	Verifies properly compiled software code	Compiled code has no erros.
2	Software application load onto smart device	Connect USB cable from laptop to smart device and upload application software build	Verifies proper loading of the SW application onto the smart device	Application load onto smart devices is successful
3	Application Login	Open the Application on the Smart Device and provide a Login	This verifies the application will open on the smart device and start to run	Application opens and asks the user for a login. Login is entered and the application moves to user interface window
4	User Interface Window	Walkthrough all available options and verify each option opens into its respective function when chosen	This verifies all functions within the user window opens and displays the proper information	All options available open quickly and start to display the necessary information requested.
5	Sensor Information Window	In the user interface window choose "Monitor my child".	Main data display window which shows all 4 sensors being monitored and their respective information	Heart Rate, Oxygen level, Body Position, and Temperature are all displayed in the diplay device window.
6	Shutdown	A stop operation is made by the user and "Shutdown" device is chosen	Verifies the application can be disabled and closed out	Application closes

Table 32 User Interface Software Test Matrix

6.3 System Level Testing

System level testing can be completed once all the individual subassemblies are proven to be operating properly. System level testing verifies our project meets all the design parameter specifications and goals required to be a successful product. System level testing also needs to be tested in a variety of scenarios to allow for proper testing of the different situations which may occur during the night if the product were to be placed on a sleeping child. While child testing will not be taken, the peripheral device will be worn by the project members and monitored throughout sleeping to validate some of the tests. Most of the tests can be accomplished in a lab environment. Environmental temperature testing will occur at L-3communication/Cyterra division in South Orlando. They have graciously allowed the baby peas' project to utilize their temperature test chambers for environmental test validation.

6.3.1 Skin Temperature Final Test

Skin temperature final testing will be accomplished by connected the peripheral sensor onto a group member's ankle, turning the device on, opening up the application and choosing the "monitor my child" option. This is the main monitoring display and will display all 4 sensor data. The development kit "Sensor Tag" device will also be mounted to the user very close to the project peripheral device. The Sensor Tag development kit utilizes the same sensor device in the Baby pea's project. The sensor tag will be wirelessly connected to a laptop where a user interface GUI will be running displaying the sensor tag's skin temperature readings. The sensor tag is a known good device and we can use it to compare the data displayed from the sensor tag to the data being displayed from the baby pea's peripheral device. Table 33 is the test matrix to verify the Skin temperature sensor meets project specifications

	Test	Procedure	Description	Expected Result
1	Skin Temperature of User in Ambient Room Temp	Attach peripheral and sensor tag to user ankle and power on both assemblies	Verifies the proper reading of the skin temperature	Baby peas' peripheral and sensor tag sensors are within 5% of each other
2	Skin Temperature of User in Ambient Room compared to thermometer data taken orally	Attach peripheral and oral thermometer to user and compare temperature results	Comparison test between oral temperature and skin temperature	Baby peas's peripheral should read within +/-10% of oral temperature.
3	Increasing temperature	Place peripheral sensor on table top and utilize a heat gun to heat the sensor	Verifies the sensor will be updating the user display with increasing temperature readings	User display should show rising temperatures
4	Decreasing temperature	Place peripheral sensor on table top and spray the sensor with a freeze spray	Verfies the sensor will be updating the user display with increasing temperature readings	User display should show decreasing temperature.
5	User Interface Alarms	Place peripheral sensor in environmental chamber and set chamber to 25 degrees C. Once stable set temperature to 30 degrees C. Repeat at 25 degrees C.	Verifies as a temperature changes by 5 degrees it causes an alarm on the user interface display device (adroid phone)	Alarm sounds if : Temp Δ +/-5 degrees from baselined temperature readings Baseline Temp 25c Alarm sounds @ 30c and 20c

Table 33 Skin Temperature Final Acceptance Test matrix

6.3.2 Body position Final Test

The body position final acceptance testing will be performed in a lab environment with no need to be attached to a user. The peripheral sensor will lay on a flat surface and be orientated in different angles to observe accuracy of position along with alarms on the user interface device when moved into different positions. Also being tested is a settling time check. This test allows the user to receive a notification symbol "MOV" stating the infant is moving and cannot obtain a steady reading for body position. Simulations of this will entail placing the sensor on a table top in a stable position for 1 minute then moving it rapidly for 20 seconds then setting it down again in a different position and verifying the "MOV" icon under the body position data display portion is active during movement and inactive during no movement. Table 34 is a the test matrix for the final acceptance testing of the body position sensor

	Test	Procedure	Description	Expected Result
1	Stable up Postion	Place peripheral device on a flat surface facing up and power sensor on	Verifies with the sensor a flat position the reletavive reading on the display should be up.	User interface display window displays "up" position being read
2	Stable Left/Right Side Position	Place peripheral on one side first and then other side next	Verifies sensor updates position setting and gives alarm	User interface displays new position of "right side" or "left side" and gives audible alarm to the user.
3	Stable down Position	Place peripheral device on a flat surface facing down	Verifies sensor updates position settling and gives alarm	User interface displays new poistion of "down" and alerts the user audibly
4	Settling Time	Place peripheral device on flat suface facing up, obtain stable reading. Shake sensor for 20 seconds then set back down	Verifies sensor can display movement and recover with stable readings	During movement, user display should indicate "MOV" and once sensor settles proper position reading should be displayed within 5 sec

Table 34 Body Position Final Acceptance Test matrix

6.3.3 Pulse Oximetry Final Test

The pulse oximetry test is the heart and soul of the baby peas' project. It provides heart rate and blood oxygen levels which are critical to the data needed to see if the body is starting to dive into a fatal state. Pulse oximetry testing will be conducted at a medical facility which a group member is employed at. The facility has graciously allowed the baby peas project the use of a pulse oximetry sensor to compare our sensor readings. Table 35 is the test matrix for the pulse oximetry sensor. The sensor will be attached to each member of the Baby pea's project for validation over a different range of users.

	Test	Procedure	Description	Expected Result
1	Heart Rate Accuracy Test (stable)	Attach peripheral to ankle of users. Attach medical facility Pulse Oximetry Sensor equipment to index finger of user	Verifies the Pulse Oximetry sensor and obtain accurate heart rate information	User displays heart rate information and accuracy is within 20% of the medical facilities output results
2	Blood Oxygen Accuracy Test (stable)	Attach peripheral to ankle of users. Attach medical facility Pulse Oximetry Sensor equipment to index finger of user	Verifies the Pulse Oximetry sensor can obtain accurate blood oxygen levels from a user	User display shows blood oxygen information and accuracy is within 20% of the medical facilities output results
3	Sensor movement and recovery	Attach peripheral to ankle of users. Attach medical facility Pulse Oximetry Sensor equipment to index finger of user	Verifies sensor can still obtain an accurate reading while sensor is still moving	User displays accurate heart rate and oxygen levels during slight movements

Table 35 Pulse Oximetry Final Test Matrix

6.3.4 Weight, Battery Life, and Wireless Range Final Test

The weight test can be conducted in a lab environment using a calibrated scale. The Battery life will be tested overnight at each group member's house. The wireless range test will be conducted on UCF campus and in group member's houses. Table 36 is the test matrix for the remaining system parameter test specifications.

	Test	Procedure	Description	Expected Result
1	Weight Test	Place baby peas' peripheral sensor on calibrated scale	Verifies weight of device is less than 1lbs	Device weighs < 1lb
2	Battery Life	Power on baby peas' peripheral sensor and let sensor run until battery dies or 12 hours is reached	verifies the sustained operation of the device for 12 hours	Device runs for > 12 hours
3	Wireless Range Outdoors	Turn on the baby peas' peripheral sensor and establish bluetooth connection to user display device (Android Phone). Move display device 100 feet away from the sensor.	Verifies the wireless range specification is met	Device continues to monitor all sensors and transmits the data to the display device at a range of 100 feet in 12 different radial points.

Table 36 Weight, Battery life, and Wireless Range Final Test matrix

7 Administrative Content

The administrative content of the Baby Peas project group consists of project schedules, milestones charts, and group roles and responsibilities. It is of the highest importance the administrative duties to not be let go by the way side but are adhered to strictly.

7.1 Milestones and Schedule Discussion

The baby peas project was under and extremely tight schedule due to the nature of trying to come up to speed on android application development, Bluetooth low energy development, PCB circuit design and component interactions. It was the intent of the group to have weekly and sometimes bi-weekly meetings to discuss actions of the week and to monitor the progress of the schedule milestones. Table 37 and 38 below are the Hardware and Software milestones chart, respectively, and weekly schedules for Senior Design 1 Fall 2013.

		5-Aug	19-Aug	2-Sep	16-Sep	30-Sep	14-Oct	28-Oct	11-Nov	25-Nov	2-Dec
	Hardware Tasks	W1-2	W3-4	W5-6	W7-8	W9-10	W11-12	W13-14	W15-16	W17-18	W19
Hardware Milestone 1	Research similar projects	■	■	■							
	Determine appropriate sensors for development		■	■							
	Determine appropriate microcontroller for development		■	■							
	Look for integration platforms for similar projects			■	■						
Hardware Milestone 2	Start parsing thorugh data sheets for each sensor and start on document				■						
	Research power considerations and have 75% of document done					■	■	■			
	Regroup and see if software and hardware are compatible and have 90% of document done						■	■			
	Have 100% rough draft done and edited						■	■	■		
Stretch Goals	Start requesting sample modules								■		
	breadboard sample modules								■		
	having working sensors								■	■	
	Have working communications								■	■	■

Table 37 Hardware Tasks Milestones Chart Senior Design 1

The hardware portion schedule is primary driven by research on three sections – sensor components, central processing unit, and power unit. The sensor component and the microcontroller that controls them should be researched and procured in conjunction with each other, as both will have to mesh for the entire unit to work. Power source research must wait until the parameters for each sensor, the central processing unit and wireless protocol are determined. In addition to the component selection, the hardware schedule also includes the documentation required at the end of senior design 1. This massive document will require a lion's share of work and work needs to start on that as soon as possible.

		5-Aug	#####	2-Sep	16-Sep	30-Sep	14-Oct	28-Oct	11-Nov	25-Nov	2-Dec
	Software Tasks	W1-2	W3-4	W5-6	W7-8	W9-10	W11-12	W13-14	W15-16	W17-18	W19
Software Milestone 1	Research similar projects										
	Determine appropriate platform for development										
	Determine appropriate language for development										
	Look for code resources for similar projects										
Software Milestone 2	Order sensor tag from TI										
	Understand the loading mechanism for android										
	Run sample code on galaxy nexus										
	Have successful handshake with developmental kit										
Stretch Goals	Start parsing through existing code										
	Start writing code specific to Baby peas										
	Have user interface design started										
	Have working user interface										

Table 38 Software Tasks Milestones Chart Senior Design 1

In addition to the hardware schedule, the software schedule for senior design 1 was a rough guideline for the development life of this product. Like the hardware schedule, the software also starts by researching through similar projects. This was to gain both an understanding of the available resources and also help formulate the framework for this project. In addition to software research, the group needs to learn some sort of object oriented language, as most of the mobile platforms operate on object orient languages such as Java or C#. As the group is composed of electrical engineering students who have a foundation in C and little to no experience in object oriented programming, this is a critical step in the developmental cycle. In addition, while the prototype will not be built until second semester of senior design, it is feasible to look for development kits to test out the software portion. Usually companies such as Texas Instruments or Freescale will have developmental kits for developers and hobbyists to write applications for. Below are tables 39 and 40 for the milestone charts and weekly schedules for Senior Design 2 Spring 2014.

		16-Dec	30-Dec	13-Jan	27-Jan	10-Feb	24-Feb	10-Mar	24-Mar	7-Apr	21-Apr
	Hardware Tasks	W1-2	W3-4	W5-6	W7-8	W9-10	W11-12	W13-14	W15-16	W17-18	W19-20
Hardware Milestone 1	Order Long Lead Parts	■									
	Order Common Parts	■									
	PCB design Layout	■	■								
	PCB Design Review		■	■							
	PCB for DFM 4PCB			■							
	Import Changes			■							
	Order PCB			■							
	HW Milestone 1 comp			■							
Hardware Milestone 2	Solder Batt, Reg, Charge				■						
	Reg Test into D-Load				■						
	Populate PCB Full				■						
	Load Microcontroller Code				■						
	Test Temperature Sensor				■	■	■				
	Test Position Sensor				■	■	■				
	Test Pulse Oximetry Sensor				■	■	■				
	Test RF performance				■	■	■				
	Test Battery life specs				■	■	■				
	Test Recharge CKT				■	■	■				
	Mod Micror Code					■	■				
	Finalize Micro Code					■	■				
	Reload Micro Code					■	■	■	■		
	Repeat Test Matrix							■	■		
	HW Milestone 2 comp								■		
Stretch Goals	Design Review / WW mods						■	■			
	Small PCB design							■			
	New Layout Comp							■			
	DFM to 4PCB							■	■		
	Order Final PCB							■	■		
	Populate PCB Full								■		
	Repeat test matrix								■	■	
	HW Milestone 3 comp										■

Table 39 Hardware Tasks Milestones Chart Senior Design 2

Hardware Tasks are driven with respect to completing the PCB design and performing a PCB design review before the start of Senior Design 2. 4PCB manufacturing house offers free Design for Manufacturing checks on the PCB to be sure all specification of the PCB design layout allow the PCB to be built within standard practice tolerances. Once the DFM is approved by 4PCB the PCB can be placed on order. Upon ordering of the PCB Milestone 1 will be complete. 4PCB has between a 3 to 4 day turnaround. Once the PCB is received the first circuits to be implemented will be the battery, recharge circuit, and regulator circuit. Design measures were taken to allow the output of the regulator to be connected to an external dummy load by removing a series resistor and connected in a high ohm load along with a low ohm load and driving a FET with a function generator to simulate the widest array of loads possible to make sure our regulator stability loop is critically damped and not ringing. Once the stability of the regulator is within specifications the remaining components will be soldered into place. The Micro Controller will then be loaded with the latest software and then testing of each sensor will occur. It's expected this process could take up to 5 weeks or more to complete. Once each device is working properly and wireless communications is established with mobile user interface module then the project hardware is complete. The baby peas project has left room starting in the last week in February to try and complete a polished prototype PCB consisting of no white wires. If time permits it is the goal to redesign the PCB to a smaller package for an infant, repopulate the PCB, retest, and be able to present our polished design project for the final presentation.

		16-Dec	30-Dec	13-Jan	27-Jan	10-Feb	24-Feb	10-Mar	24-Mar	7-Apr	21-Apr
	Software Tasks	W1-2	W3-4	W5-6	W7-8	W9-10	W11-12	W13-14	W15-16	W17-18	W19-20
Software Milestone 1	Review Java										
	TI Sensor tag interface with existing code										
	User Interface design										
	Notification algorithim										
	Graphing libraries										
	Data algorithim										
Software Milestone 2	TI Sensor tag interface with new code										
	Integrate code with hardware										
	Test Temperature Sensor										
	Test Position Sensor										
	Test Pulse Oximetry Sensor										
	Test RF performance										
	Test Battery life specs with code										
	SW Milestone 2 comp										
Stretch Goals	Utilities portion design										
	Editor and Email										
	Integrate into existing code and test										
	Repeat test matrix										
	SW Milestone 3 comp										

Table 40 Software Tasks Milestones Chart Senior Design 1

Software tasks are designed with two main hurdles to cross; a working code with the sensor tag and working code with the designed PCB. The first hurdle can be crossed without the hardware component integration. TI's CC2541 developmental sensor tag is designed specifically for developers to write applications. Using that tag, the project can get a working code in order before the PCB boards are populated, sensors integrated and tested. A sensor tag was ordered on 11/12/2013 and is currently in the project's stock. The only hurdle from current development at the time of writing is an updated android device, but the project stock is expected to be in the recipient of a working android device by 1/1/14. Once the device is in hand, a period of two weeks is given to developing working code for Bluetooth handshake, temperature, and accelerometer. Unfortunately the sensor tag lacks a pulse module, so instead of a working code, the goal is to have a code that will be tested once the module for the pulse is integrated into the hardware board. Starting week 9, the hardware side should have an assembled board, along with a week of preliminary testing. This is to insure that all power parameters are functioning and the board won't be irreparably harmed once the testing phase is moved to a higher level. A month and a half is given to integrate the software and hardware, including all levels of testing and reworking. Once this second hurdle is crossed, all basic features will have been implemented. In addition to the basic features, the software schedule also have several stretch goals, including two additional features of a utilities design and an editor and email functionality. It is unlikely that both would be integrated, but at least one software stretch goal is likely.

7.2 Roles and Responsibilities

The roles and responsibilities were divided up based on each individual in the group's goals and desires for learning different technologies to help in further career options. While all members of the Baby Peas project will help develop and design each aspect of the project, specific roles were assigned and accepted by each member to be the lead designer of their specific subsystem.

Christopher Ramirez

- Hardware PCB design layout and schematic capture.
- PCB assembly (soldering) and test
- Bluetooth RF section design
- Embedded Coding on the CC2541
- Embedded Coding on the Atmega328p
- Power Supply Design
- Temperature / Body Position Design

Xin Tong

- Android Development
- Arduino Development

Yowwu Lin

- Pulse Oximetry Design
- Hardware PCB design layout and schematic capture
- Embedded coding for Atega328p

Benjamin Goolsby

- Embedded coding for CC2541.

- Android Development.

7.3 Budget and Finance Discussion

The budget for the project is maxed out at $1000 dollars. While the components and board construction will not approach the cost of $1000 dollars, the budget allows for purchasing various development kits to help in the building of the baby peas device. The development kits can range from $20 dollars to $300 dollars. In the end the project ended up costing a total of $1240 due to the project having to be re-directed into using some different components and having to lay out another PCB. Also overnight shipping costs caused a lot of undesired cost. If this wouldn't have happened then we would have come under budget.

The group decided to split the cost evenly at 25% of the total cost incurred for a max of $310.00 per individual member.

7.4 User Manual

This portion of the document is to provide one with the necessary information to take our design and get it up and running and ready to demonstrate.

Below in Figure 72 is a picture of the final design in the Power Off State.

Figure 71 Baby Peas Vital Signs Monitor in the Power Off State

The Baby Peas board is turned on by connecting the pins with a shorting connector to allow for the battery voltage to be applied to the circuit. The Green LED on the board should indicate power is on and is shown in Figure 73. To verify the Bluetooth is transmitting one must use an android based phone with Bluetooth capability. Since all phones are different version of Android one must follow their user manual for their phone to configure the Bluetooth pairing. In those menus one will find the HC-06 is broadcasting and must pair with that device. Once paired the Baby Peas application can be opened.

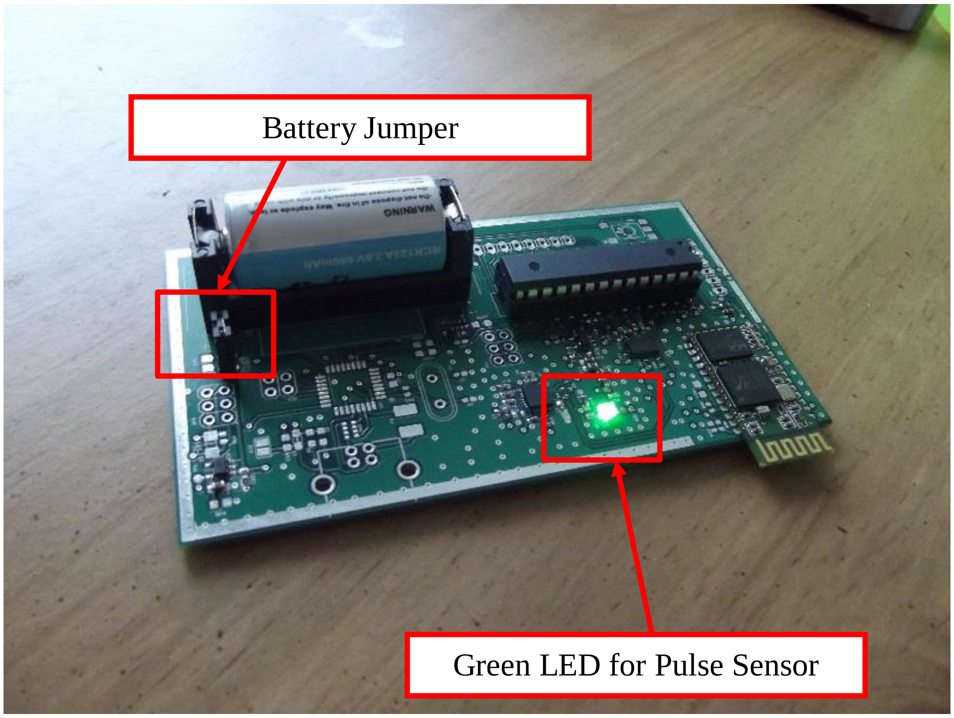

Figure 72 BabyPeas battery Jumper and Pulse LED Locations

On the Baby Peas Application click on the "Monitor" button to open the monitoring section of the application. Once in the Monitoring section is open you must hit the "connect" button and choose the HC-06 available for connecting too. Below in Figure 74 is a display of the Menu Screens.

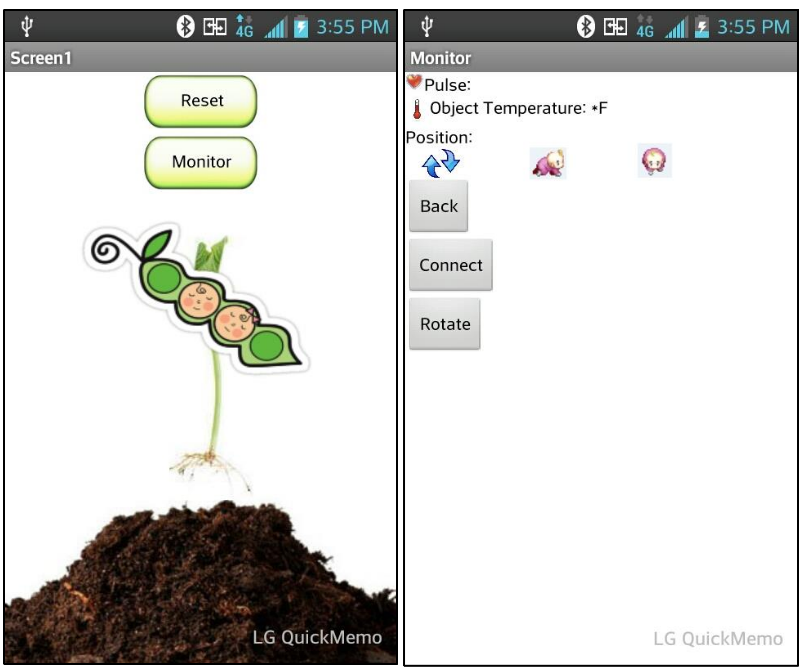

Figure 73 Menu Screens

Once connecting to the BabyPeas device once should start to see data displayed for the pulse, object temperature, and position. The data is updated throughout using the Baby peas product. To obtain the pulse place your finger on the opposite side of the board over the portion of the board where the green LED is showing through. Your finger must be free of moisture and must remain still for the pulse to be detected. Once detected, the pulse portion of the monitor should start updating and show accurate pulse readings. To obtain object temperature, one must hold the baby peas circuit board over a portion of the skin (but not touching) and observe changes in the Skin Temperature under the object temperature portion of the monitor. To check position one can flip the board back and forth from once side to the other and observe the Position will go from safe to danger depending on which way the PCB is orientated.

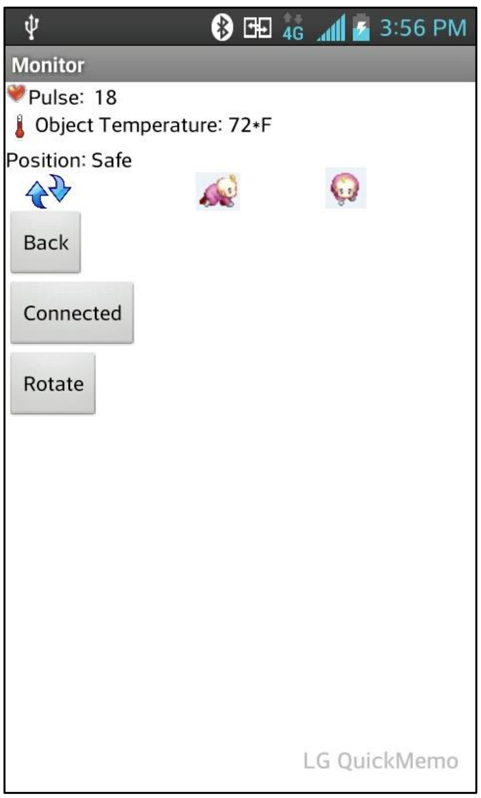

Figure 74 Screen shot of the application showing data

7.5 Conclusion

In the end the Baby Peas project didn't necessarily have a working product able to be strapped onto an infant but a proof of concept was designed in order that with enough funding and a lot of software development help the baby peas project could be developed into a product in the future. The team members learned a lot from this experience not just in designing a product but working as a team to solve the challenges they faced. When the CC2541 design approach wasn't working out a quick solution had to be realized in a very short amount of time. This is why the team decided to go with an Arduino based design because the skills required to embedded code for the CC2541 were not enough to overcome some of the hurdles faced. While the hardware worked great, configuring the CC2541 proved to be extremely difficult and the IAR embedded workbench licensing was a nightmare. In the end the product did was we set out have it do. It provides vital signs information to a person over wireless communications which could provide an early warning capability to another person which could save a life.

8 Appendices

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8.2 Appendix B: Copyright Permissions

1. Nordic Semiconductors

From: Keeping, Steven [mailto:Steven.Keeping@nordicsemi.no]
Sent: Tuesday, November 26, 2013 7:30 PM
To: cramirez36@cfl.rr.com
Subject: Re: nRF51822 permission to use diagrams and figures from data sheet
Hi Christopher,
Thanks for your interest in Nordic Semiconductor.
I checked with Nordic corporate in Oslo and you have permission to go ahead and use the layout diagrams.
Good luck with your project.
Kind Regards,
Steve
From: Christopher Ramirez <cramirez36@cfl.rr.com>
Date: Saturday, 23 November 2013 3:43 PM
To: Steven Keeping <steven.keeping@nordicsemi.no>
Subject: nRF51822 permission to use diagrams and figures from data sheet.
Hello,
My name is Christopher Ramirez and I'm an electrical engineering student at the University of Central Florida. I'm currently working on our senior design project documentation. We are designing a vital signs baby monitor which wirelessly transmits, heart rate, position, and temperature of an infant while sleeping. Of course we won't be testing this on any infants ☺ but we are looking at using the nRF51822 for our wireless communication to a smart phone or other peripheral device. We were hoping we could get permission to use some of the layout diagrams in our senior design document. Our design will not be used for consumer use and none of the diagrams or figures will be altered. We will also properly cite Nordic Semiconductor for any information we use from the data sheet. Thanks for your time !!
Happy Holidays,
Christopher Ramirez

2. Freescale Semiconductors

From: Freescale_Customer_Supply@freescale.com
[mailto:Freescale_Customer_Supply@freescale.com]
Sent: Monday, November 25, 2013 5:27 PM
To: cramirez36@cfl.rr.com
Subject: RE: FSL SR# 1-1214068461 : Permission to use graphs, figures, tables, information

Dear Christopher Ramirez,

Of course you can make reference to our documentation, however we are not lable in any way for th use or missuse of it, attached to this e-mail I'm sending you an executable file including the tables from Apendix B which I assume ar ethe one syu need, all the schematic files are icluded in compressed file AN4327.zip; please read carefully the disclaimer and make sure you fully understand its implications and limitatioms; the disclaimer will pop up once you execute the file.

I had to chage the file's extension from ".exe" to ".doc" in order to avoid rejection from your e-mail filter, just change it back and you will be able to use it. I hope you find this information useful.

Shall any question arise feel completely free to contact me through this service request.

Thank you for your interest in Freescale Semiconductor products and for the opportunity to serve you.

Best Regards,

Augusto Panecatl
Technical Support

Freescale Semiconductor

This message has been sent in reply to the following service request:

SR Number: 1-1214068461
Date Opened: 20-Nov-2013 04:01:33 PM
Subject: Permission to use graphs, figures, tables, information
Description: Hello, My name is Christopher Ramirez and I am currently a student at the University of Central Florida. I'm in Senior Design 1 and we are designing a device which monitors infant heart rate and transmits the data over bluetooth to a smart phone. We have a senior design paper to write and I was hoping we could have permission to use some of the figures, tables, and graphs from the ANA4327.pdf document. I was also wondering if you be able to email me the originals of those figures. We have to print out the document in 300dpi and some of the figures don't look that great when I take a screen shot and paste them into the paper. Thanks so much for you help. Take care Christopher Ramirez Electrical Engineer University of Central Florida cramirez36@cfl.rr.com

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How to best communicate with us regarding this Service Request SR# 1-1214068461:

- You may reply to this message by email. Make sure the SR number is included in the subject line.
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3. Texas Instruments

From: support@ti.com [mailto:support@ti.com]
Sent: Thursday, November 21, 2013 6:46 PM
To: cramirez36@cfl.rr.com
Subject: RE: GEN, Email Technical Support, www.ti.com, n/a 1-1215158584

christopher,

Thank you for contacting TI customer support, and thank you for using TI products. You are free to use materials from our datasheet so long as you properly credit TI when doing so and do so without manipulating, altering, skewing, or otherwise misrepresenting the images and figures.

Have a great evening!

Regards,

Siebel Administrator
TI Customer Support
Americas Customer Support Center
512-434-1560

http://www.ti.com/e2e-support

http://www-k.ext.ti.com/sc/technical_support/pic/americas.htm

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[SR THREAD ID: [Service Request.Id]]

[THREAD ID: 1-K3H2DC]

[THREAD ID:1-K3H2DC]

-----Original Message-----
From: cramirez36@cfl.rr.com
Sent: 11/21/2013 08:17:23 AM
Cc: "cramirez36@cfl.rr.com" <cramirez36@cfl.rr.com>
Subject: GEN, Email Technical Support, www.ti.com, n/a

[This Email Sent From: Email Technical Support
http://www.ti.com/ww/en/csc/support-Americas.html]

[wfsegen]

[DATE / TIME (UTC): Thu, 21 Nov 2013 14:17:21 GMT]
[CUSTOMER'S REGIONAL LOCAL TIME: Thu 21 Nov 2013 09:17:21 AM EST]

[Name: Christopher Ramirez]

[Prefix: Mr.]
[First Name: Christopher]
[Last Name: Ramirez]
[Job Title: student]
[Company: University of Central Florida]
[Email: cramirez36@cfl.rr.com]
[Phone: 407-310-0830]
[FAX:]
[Country: USA]
[Address1: 840 saint johns river dr]
[Address2:]
[City: sanford]
[State: FL]
[Postal Code: 32773]
[Part# or Description: N/A]
[Category: Technical Documentation]
[Application: Other]
[Design Stage: Prototype]
[Estimated Annual Production: n/a units]
[Production Date: n/a]

[Problem:
I'm an electrical engineering student currently at the university of central Florida. We are currently building a vital signs baby monitor for our senior design project and we came across a .pdf file with some explanations on accelerometers. The .pdf was created by TI and we were hoping to have permission to use some of the figures and graphs from the .pdf in our senior design 1 technical paper. We ofcourse will not change the graphs or

figures in anyway and will properly cite TI's work. The link to the .pdf is : http://www2.usfirst.org/2005comp/Manuals/Acceler1.pdf .]

4. www.AnaesthesiaUK.com

From: adrienne@frca.co.uk

To: wasiasd@hotmail.com

Subject: RE: AnaesthesiaUK Web Site Feedback

Date: Tue, 26 Nov 2013 08:45:29 +0000

Dear Yowwu,
It would be fine for you to use this image, free of charge, providing that the website is acknowledged. Please use the wording "This image has been reproduced from AnaesthesiaUK, with permission (www.AnaesthesiaUK.com)"
Good luck with your paper.
With kind regards,
Adrienne
(Dr) Adrienne Penfield
AnaesthesiaUK

From: yow-wu lin [mailto:wasiasd@hotmail.com]
Sent: 25 November 2013 19:14
To: adrienne@frca.co.uk
Subject: RE: AnaesthesiaUK Web Site Feedback
Hello Adrienne,

Thank you for replying. The particular information I need is in this weblink http://www.frca.co.uk/article.aspx?articleid=100345
I'm using it as a reference for my school paper and may I use the oxygen dissociation curve graph for the paper? It will include the mark for AnaesthesiaUK and any citation will be done properly. Thank you so much.

Sincerely
Yowwu Lin
> From: adrienne@frca.co.uk
> To: wasiasd@hotmail.com
> Subject: RE: AnaesthesiaUK Web Site Feedback
> Date: Mon, 25 Nov 2013 08:12:31 +0000
>
> Hi,
>
> Please send a link to the web page you are referring to and we will then be
> able to tell you if we can grant permission.
>
> Kind regards,
>

> Adrienne
>
>
>
> (Dr) Adrienne Penfield
> AnaesthesiaUK
>
> -----Original Message-----
> From: wasiasd@hotmail.com [mailto:wasiasd@hotmail.com]
> Sent: 23 November 2013 04:00
> To: sumit@frca.co.uk; adrienne@frca.co.uk; ray@frca.co.uk; luke@frca.co.uk
> Subject: AnaesthesiaUK Web Site Feedback
>
> We've had feedback from the following person via the enquiry section:
>
> Name: Yowwu Lin
> E-mail: wasiasd@hotmail.com
> Feedback: Hello, I would like to request permission to use the graph on
> pulse oximetry on my research paper for school. Thank you for the
> information. Please respond to wasiasd@hotmail.com.

4. http://www.howequipmentworks.com/physics/respi_measurements/oxygen/oximeter/pulse_oximeter.html

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From: pras2@onvenus.com
To: wasiasd@hotmail.com
Subject: Hello
Date: Sat, 23 Nov 2013 10:04:59 +0000

Many thanks for your kind donation. The pulse oximeter diagrams are rough sketches of the real thing. However, I believe it should be adequate for your school project, and please fell free to use them.
When finished, do email me a copy if you can ...for my curiosity.
Good luck.
Pras

5.

Rod Nave <RodNave@gsu.edu>
Sun 11/24/2013 3:20 PM

To: x.tong <x.tong@knights.ucf.edu>;

Action Items

Hi, Xin,

You are welcome to use anything from HyperPhysics for the purpose of your academic assignments.

Best wishes with the paper.

Regards,

Rod Nave   RodNave@gsu.edu
HyperPhysics Project
Department of Physics and Astronomy
Georgia State University
Atlanta, GA 30302-4106

6.

Google android development content: