Blood Pressure Tester

Initial Project and Group Identification
EEL 4914 Senior Design I
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Table of Contents

1.0 Executive Summary:

The blood pressure tester is an automatic, one-button operated, sphygmomanometer; which utilizes the oscillometric blood pressure method. It has the capability to wirelessly send data to other terminals for data analysis. The human interface is an upper arm cuff that is used to occlude blood flow to the lower arm. A rubber tube transmits air pressure from the occlusion cuff along with underlying air oscillations, which are made by skin movement due to artery movement, to a ratio metric pressure sensor. This mechanical to electrical transducer outputs a mixed voltage signal. A filter and gain topology separates the air oscillations from the mixed air pressure signal for use in an oscillometric algorithm. The calculations utilizing this algorithm are performed within the Texas Instruments Inc., msp430f5438 microprocessor code. The power management topology includes power regulators to provide ample voltage and current to the varying demands of the system while maintaining the device's low power consumption profile.

As world populations grow and lifestyles change, there will be a growing need for health monitoring. Increased ability to consume as well as physical activity changes are all triggers for preventable diseases. Blood pressure is a major sign of overall health and can provide warning signs for specific diseases based on average pressure ranges of specific patient profiles. The intention for designing a low power, battery operated device with wireless data transfer capability is to provide an easy to use device that can help in distance monitoring of patients. Logging of readings can lead to early detection of potentially fatal diseases. Commercially, a manufacturing company offering a device with such characteristics could easily garner contracts from major healthcare institutions as well as government agencies that understand the implications that major lifestyle changes can have on overall public health and national budgets. Such organizations would be able to monitor health trends daily, interact more frequently with individuals, and institute preventative measures in advance of irreversible damage.

As the blood pressure tester is battery powered its power consumption must be as low as possible. To reach this goal, the design of the device went through various prototypes to minimize its power use. Prototypes improved from their last implementation to further improve on the lower power requirement. Each design included the selection of a low power topology while improving in its use of voltage regulation control together with switching sequences in an effort to avoid scenarios in which all parts would be consuming maximum power at the same time. Current and voltage requirements were not the only considerations taken into account during power regulation research. The analog signal chain, starting with the mechanical occlusion cuff, passing through the pressure transducer, and on through the electrical analog filter and gain signal chain; accurately obtains the blood pressure signals to be utilized in calculating the patient blood pressure reading.

With the push of a button a patient can engage the device to perform the blood pressure testing process. Taking safety into account, pushing the same button at any time during the process will exit the testing process, deflate the cuff and turn off the device. Excessive movement by the patient will be detected and an error will be reported prompting the user to start over.

Through the use of efficient coding methods matched with carefully designed circuitry, the blood pressure tester has been able to deliver accurate blood pressure readings. The data can be wirelessly transmitted to a receiving computer which can log and transmit the data to health professionals for analysis.

2.0 Project Description:

The device is an automatic electronic blood pressure tester utilizing the oscillometric blood pressure method. It has the capability to wirelessly send data to other terminals for data analysis.

2.1 Project Motivation:

Our motivation to do this specific blood pressure monitoring device project emerged from the opportunity to be sponsored and mentored professionally by engineers and technicians from Texas Instruments Inc. Representatives from a medical devices group at Texas Instruments Inc., were involved in the design steps as the project progressed. The idea was presented to us by a medical devices team at Texas Instruments Inc. The group suggested that a blood pressure monitoring device with wireless capabilities be designed and built. Having professional assistance, guidance, and experience to learn from and work with throughout a design project such as this one provided immense motivation to see the project through to a complete working state. This project gave four engineering students with many interests the opportunity to learn more about their specific interests and to come together to create a working device. The design and implementation of this device involved: power management to maintain its small scale and low power consumption profile, understanding of motors and electric machinery, analog and digital signal processing to convert raw signals into data that can be processed and calculated by a microcontroller for meaningful information, use of algorithms to derive information from data streams, computer language programming for system processes, microcontroller communication programming, wireless technology transmission, and an understanding of biomedical physiology. Furthermore, learning the engineering design process through experience, particularly for medical devices, was highly beneficial as the need for these devices will grow with a rising world population. After further investigation the far reaching possibilities of this blood pressure monitoring device being able to help many people are evident. Blood pressure has long been used as a health standard from which the early onset of other diseases and health issues can be detected. Raised blood pressure is a common worldwide cause of death and disability. Therefore having regular blood pressure readings will provide early warning signs to prevent disease. Studies in many countries have shown that an increase in blood pressure levels often lead to a higher risk of heart attacks, strokes and kidney disease. With as small as an average increase in the population of 2 mmHg in systolic blood pressure, an increase in the death rate from stroke by 10% and from coronary heart disease by 7% has been observed. Mobile monitoring in comfortable, familiar locations while the patient goes about their daily routine, have been found to give more reliable results than blood pressure measurements in the presence of healthcare professionals.

2.2 Objectives:

Our objective was to design and build a fully functional automated blood pressure tester that gathers raw data from which pressure and pulse information could be extracted. Sub systems objectives were met in that the motors and valves are controllable for desired pressure and timing by a program within the microcontroller. The pressure sensor fed air pressure signals is by way of a plastic tube that is connected to an occlusion cuff. The pressure sensor is a transducer of air pressure and oscillations into a wide frequency band, mixed AC and DC, voltage signal. The signal is separated by analog circuitry into AC and DC signals to determine a patient's blood pressure. The two signals along with a reference voltage signal are sent to three different inputs of an analog to digital converter. The microcontroller contains a program written to compute the blood pressure using an algorithm and the values of the AC and DC signals along with a clock. The blood pressure reading is sent to the wireless transceiver for distance monitoring and analysis. The blood pressure reading is within +/- 3 mmHg or 2% of a manual reading AAMI (Assoc. for the Advancement of Medical Instrumentation) standards. This coincides with AAMI standards for safety. The device has an immediate pressure release function to prevent injury.

The device completes 60 blood pressure readings on 4 AAA batteries. This makes it possible to have at least one blood pressure reading per day with one set of batteries / one full charge of rechargeable batteries for two months. The reason that daily blood pressure readings are an important factor in maintaining health and being aware of health issues is that blood pressure is linked to many other health factors.

2.3 Future Objectives:

Several objectives were devised for subsequent implementations of the blood pressure tester. With excellent power management it could be possible to maintain a low a power profile and still add features such as pulse and oxygen level sensors. Other methods of blood pressure monitoring could be used in mobile device pulse wave technology.

Indicator lights would be another feature that would make the device commercially viable. This could be accomplished with low power LED lights of various colors.

To make the device more accessible to a wider range of patients, an audio reading of the blood pressure could be given for visually impaired patients. With a smart phone and / or pc application, this would be an easy application addition.

Another possible addition is to develop an easy to use smart phone application to directly obtain results from the wireless transceiver of the blood pressure device. As this would require understanding the protocol required to communicate with different smart phones directly, such as API coding, such endeavors were put aside for future attention as it would require us to employ additional members with expertise in the field. A possible solution to this objective would be to collaborate with Allogy, a research and design group that is affiliated with the University of Central Florida. They are involved with many mobile teaching and healthcare related applications. There technical expertise as well as their already established network would help greatly not only in developing a mobile smart phone application but implementing its use and marketing its use to groups who could benefit. Agency specific software could be developed to track healthcare trends of large populations. Disease prevention could be better managed with these applications.

A senior design group at the Georgia Institute of Technology, is testing a blood pressure monitor for use with gorillas. This device takes into account many different environments as well as rugged conditions. Furthermore it is able to monitor patients while asleep or while moving. The extra procedures necessary to obtain accurate readings from this device is a great benefit to pediatric care as children are less patient than adults. As children run, jump, and fall more frequently than adults do, the system for gorillas could easily be adjusted to get better accuracy in young patients. A future objective would be to incorporate this feature into the blood pressure tester.

2.4 Goals:

The goal to make the device efficient in terms of power consumption was met. Another goal was to make the device as simple as possible for the user to operate. As it has only one button to operate, the goal to make the device's operation simple was achieved. Along with a push button that initiates operation, the same button can initiate a safety deflation procedure to avoid injury to the patient.

2.5 Future Goals:

The wireless component and the device's ease of use give it the ability to be used anywhere. As the world population increases and economies become more developed there will be more consumption. This is due to rising salaries as well as higher standards of living. With this disposable income increases and less attention paid to everyday health. The ability for more people to partake in a lifestyle of excess consumption and more stressful lifestyles is introducing the factors for a world health epidemic of modern diseases related to diet, stress, and lack of exercise. With evermore taxed healthcare systems around the world, low cost monitoring can be a part of a healthcare solution. The wireless component opens up the ability to serve communities in rural locations as well as big cities. In many developing countries wireless internet access is far more common than landline high speed access. This device's information can be made available to the same research and health professionals monitoring health trends around the world. Traveling costs associated with professional visits can be reduced.

The wireless component implemented in this blood pressure tester is very important for future development and use of this device. In the near future the device could be used in hospitals and other facilities such as assisted living facilities. Data from the device can be compiled in a computer log to monitor trends in the patient's health. Additionally, the ability to transfer the readings wirelessly and to be used in software applications for analysis will be a welcome addition to a device that could potentially be used in a hospital. As the new healthcare bill demands that electronic records be used nationwide by 2014, medical records in a hospital could instantly update with patient data from this mobile device. To protect patient privacy and maintain HIPAA regulations, the readings could be encrypted from the mobile device and encrypted again with patient's electronic medical records.

Another future goal would be to integrate the device with an analysis software application and offer it as a total package. Not only could the data be logged it could be compiled and analyzed by a program remotely to warn of signs of health problems over time. Since the healthcare professional observing this would not need to be present for each reading, more readings could be completed for a more definitive health picture.

To make the device even less prone to error a cuff that does not require the patient to adjust the strap would utilized. The cuff of the Omron 1500PRO Ultra Premium Blood Pressure Monitor is design that would be implemented in the design of the device. This device is less prone to human error because the patient does not need to adjust the cuff.

Part 2.4.1 - Omron 1500PRO Ultra Premium Blood Pressure Monitor (AppA [16])

2.6 Project Requirements and Specifications:

Power:	Runs on 3-9 Volts
Power Life:	Able to run for 2 months with 1 daily measurement
Pressurization:	Automatic, using micropump.
Deflation:	Active exhaust valve.
Type:	Oscillometric
Accuracy:	Pressure: plus or minus 3mmHg or plus or minus 2%
Pressure Range:	20mmHg to 280 mmHg
Wireless Range:	Greater than or equal to 10m
Display:	Digital 10-mm character height, 4 lines, 30 characters
BP Cuff:	Adjustable for most sizes

Component	Quantity	Price	Total (Tax+Shipping)
Batteries	8	10	20
BP Motor	2	5	10
BP Pump	3	10	30
BP Valve	3	3	9
BP Cuff	2	20	40
Microcontroller	3	1	3
Op-Amp	5	2	10
Resistors	10	0.7	7
Capacitors	10	1	10
Experimental Board/Display	1	200	200
Pressure Sensor	4	65	65
Wireless Component	2	120	240
PCB Board	1	55	55
Sub Total:	54	492.7	699

Table 2.3.1: Requirements

Sponsored by TI (Texas Instruments), the most important parts and equipment financing were courtesy of Texas Instruments and Workforce Central Florida. Everything else was purchased online. All the components selected were from the top of the line in the market and with a reasonable price. Table 2.3.1 is showing the prices found online.

2.7 Milestones:

Present milestones encountered:

- Full project outline - the first milestone encountered was figuring out how the project works and what is necessary to make it work in the best way possible. Also, some researches online looking for related projects was done.
- Pricing and supplier – The second milestone encountered was trying to seek for the best quality components in the market, also seeking for the best price. TI (Texas Instruments) is going to provide most of the components.
- Obtain all parts and device necessary for design implementation before the end of fall 2012 semester.

Future Milestones to be encountered:

There are some milestones that will be encountered; some may appear as problems, which will be avoided if possible. One being wires that could get overly confusing, this will be avoided by having wireless. Even though having no wires will avoid one problem, it may create another because of interference. Interference in wireless devices is common, since various devices such as cordless phones, home networks and baby monitors all share 2.4-gigaherts radio frequency bands. Also to avoid any possible mishaps and have time to fix them if they do occur, a strict schedule will be followed and adjusted only if absolutely necessary. Situations where this might be absolutely needed would be if the parts do not arrive on time or if the part gets damaged while it is being shipped.

Week	Software	Hardware
Jan 9th	Download software and write pseudocode	Order parts
Jan 16th	Code	Test parts
Jan 23th	Code	Test parts
Jan 30th	Code	Put parts together
Feb 6th	Test code	Put parts together
Feb13th	Put parts together with code	Put parts together with code
Feb 20th	Put parts together with code	Put parts together with code
Feb 27th	Put parts together with code	Put parts together with code
Mar 5th	Test and fix	Test and fix
Mar 12th	Test, fix and write paper	Test, fix and write paper
Mar 19th	Test, fix and write paper	Test, fix and write paper
Mar 26th	Test, fix and write paper	Test, fix and write paper
Apr 2th	Test, fix and write paper	Test, fix and write paper
Apr 9th	Last minute testing	Last minute testing
Apr 16th	Finish	Finish

Everything went accordingly to the schedule shown on the table above, this project works properly.

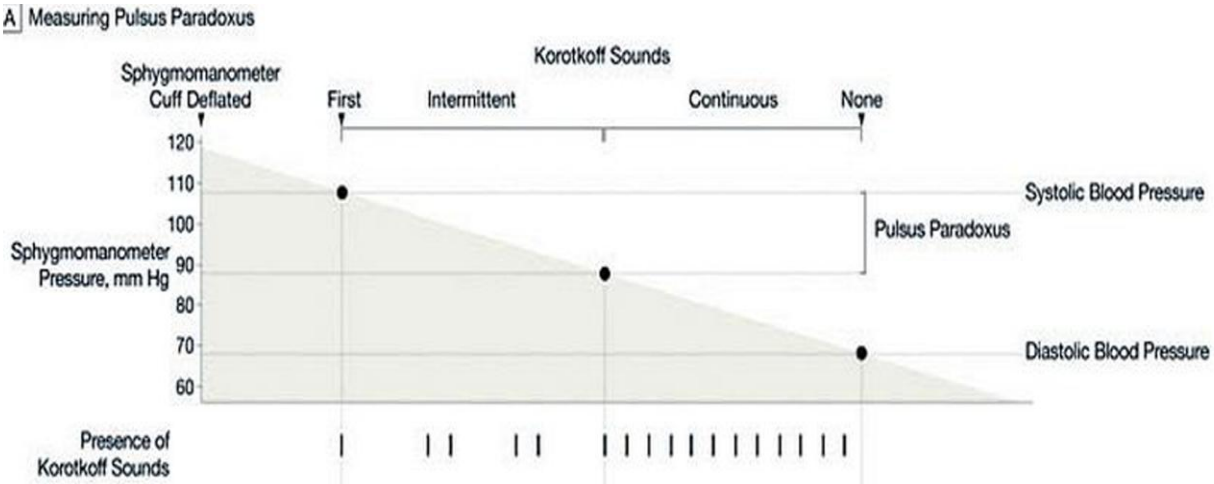
3.0 Research Related to Project definition:

A sphygmomanometer is the term used for the device also known as a blood pressure monitor. Blood pressure readings are given in units of millimeters of mercury (mmHg) because traditionally non-invasive methods of blood pressure reading have been done with a manometer filled with mercury. Mercury as a liquid metal has been used due to its highly reliable and stable performance characteristics. The basic configuration of a manual sphygmomanometer is an inflatable occlusion cuff to restrict blood flow and a mechanical aneroid dial gauge or mercurial liquid filled manometer to visually measure and note pressure at different points in time during the blood pressure process. The cuff is inflated with a manual bulb and released with a manually opened release valve. Observation of the meter is when the flow of blood begins after being cut off by the cuff. The professional listens to the patient’s brachial artery on the arm below the cuff with a stethoscope. As the pressure in the cuff is slowly released by the professional, the blood starts to flow. Because the artery had to be cut off to blood flow, using a pressure higher than normal systolic pressure usually about 30 mmHg higher than normal systolic pressure, the reintroduction of blood flow immediately into the artery is not the point at which the systolic pressure is noted. After the immediate sounds of blood flow are heard then the next sounds are recorded from the reading of the meter to be the systolic pressure. The point at which the sounds can no longer be heard is when the cuff is no longer blocking the flow of blood to any degree; this is recorded as the diastolic pressure. If the environment is not quiet enough to hear the fainter sounds after systolic pressure, only the systolic pressure is recorded. If the environment is still too noisy to hear the systolic point, the systolic point can felt when a pulse is felt at the point on the arm where the stethoscope would have been placed. The occlusion cuff is normally put around the patient’s upper arm at the same elevation of the heart. In some cases it has also been put around the thigh. Setting the size adjustment of the cuff is critical for accurate readings. If the cuff is too small the pressure reading will be in error too high. If the cuff is left too loose and therefore larger than need be, the resulting pressure reading will be in error too low. While the traditional method involves putting the cuff on the left arm which is closest to the heart; to get the most accurate reading, both arms are tested and the arm which gives the highest reading is chosen for accuracy. As the AAMI now requires an accuracy of +/- 3mmHg and previously +/- 5 mmHg, the smallest inaccuracies can lead to false information.

The pressure readings are conventionally separated into systolic and diastolic. Systolic pressure is the maximum blood pressure during the contraction of the ventricles of the heart; diastolic pressure is the minimum pressure recorded just prior to the next contraction. Heart beats occur faster than the time that it takes to deflate an occlusion cuff. So it may seem odd that the diastolic (blood pressure in between beats) would not be noted until the sounds are too faint to hear. This is done because after the blood is reintroduced to the artery the artery takes some time to return to its normal size. It is only at this normal artery size that the diastolic pressure is noted.

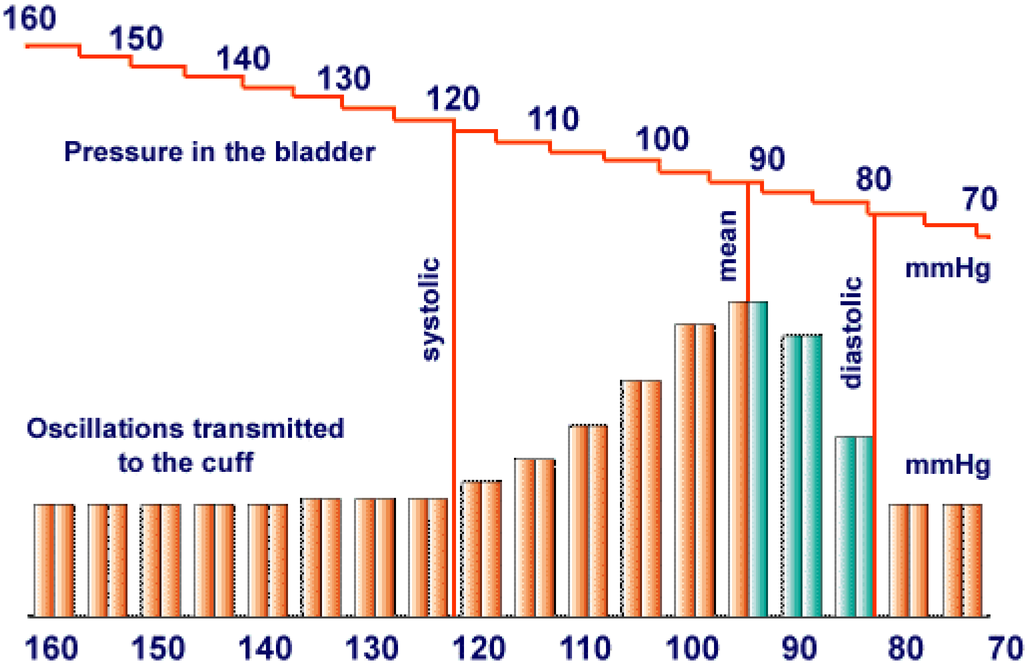
Two common non-invasive blood pressure methods are the auscultatory and oscillometric methods. The non-electronic auscultatory method involves a patient having an occlusion cuff wrapped around his or her left arm (closest to the heart) at the same elevation of the heart. As before, the occlusion of the artery and the reentry of blood into the artery at a higher than systolic pressure creates turbulent blood flow oscillations that can easily be heard. The benefits of the auscultatory method are that instead of only a systolic and diastolic point being observed, five phases are noted of pressure are noted which can provide much more information regarding the patient's blood pressure. This method is also thought to be more accurate because it has more pressure reading points than before. The sounds observed with the stethoscope are called Korotkoff sounds. The first Korotkoff sound is heard when the pressure in the cuff is released and reaches the same pressure as the patient's systolic blood pressure, and is not the sound heard when the blood immediately returns to the artery. The first Korotkoff sound is a tapping sound and is repetitive for at least two heart beats. The second set of Korotkoff sounds are distinct heart murmurs sounds that take place for most of the time between the systolic and diastolic pressure points in time. The third Korotkoff sound is a loud tapping sound that is also distinctive because it louder than the soft murmurs of the second set. The fourth Korotkoff sound is softer and occurs around the 10 mmHg pressure point higher than the diastolic pressure point. The fifth Korotkoff sound is actually silence and is the diastolic pressure point. Sound is heard after the silence therefore the point at which sound is heard again is observed on the pressure meter. The pressure that is 2mmHg higher than this point is recorded at the diastolic pressure. A recent revision to the Korotkoff / Auscultatory method is determining the diastolic pressure to be at a point 2mmHg higher than the fifth sound. Before the revision, the diastolic pressure was considered to be the fourth faint sound. Because silence is more definite it has been determined to be more accurate.

The electronic auscultatory blood pressure is based on the manual method however it does not record readings of pressure directly. The method involves three sensors. One sensor is a air pressure sensor transducer which senses the pressure in the occlusion cuff and converts it into a voltage signal. The other two sensors are electronic microphones which listen for the Korotkoff sounds and convert them to electronic voltage signals. Instead of hearing the sounds the points at which different voltage signals are recorded from the microphone sensors are noted as points in time. These points in time are correlated with the pressure reading from the cuff air pressure sensor. As blood pressure measurements are given in mmHg and pressure sensors usually are calibrated in pressure per square inch, another conversion in an electronic device must be calculated to give an accurate blood pressure reading. As there are more signals to convert there are more calculations and possibilities for error. In addition to errors, more power is needed for three sensors. As one of the objectives of the design of this device is to maintain a low power profile, the auscultatory method of blood pressure monitoring and reading was not utilized.



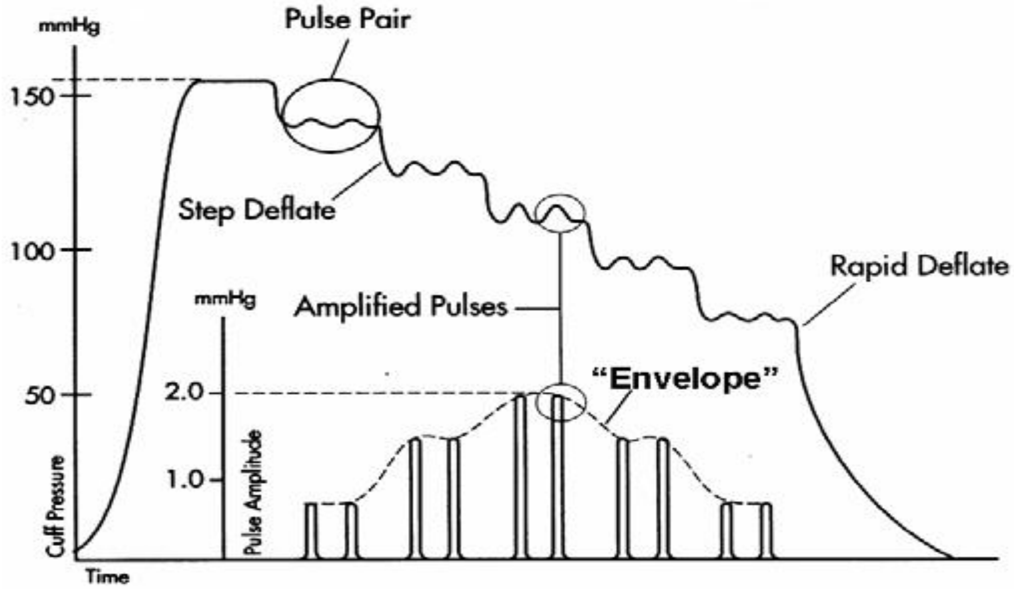
1st, intermittent, and final Korotkoff sounds observed against pressure in mmHg (JAMA AppA [17]) – Graph 3.0.1

The oscillometric method of blood pressure is not a direct method of blood pressure measurement. In this method the systolic and diastolic pressures are derived from an algorithm which uses data from a pressure sensor that converts mechanical air pressure inside the occlusion cuff as well as oscillations of arterial blood flow due to reintroduction to the artery after being cut off. The pressure sensor converts this air pressure into a mixed voltage signal. The mixed signal is comprised of AC and DC signals that must be separated by analog circuitry before being converted digitally for processing and blood pressure calculation. As oscillations in the artery increase in amplitude during reintroduction of blood flow, the converted signal relaying this information is recorded. The peak of these oscillations is noted as the mean arterial pressure or MAP, pressure point. During the pressure decrease in the cuff, the oscillations will become increasingly significant, until maximum amplitude of these oscillations defines the average blood pressure or MAP. The DC voltage signal relays the cuff pressure. The AC signal is the voltage signal relaying the oscillations within the cuff that are caused by the artery flexing upon blood flow reintroduction. The artery actually increases in pressure higher than the cuff pressure and lower than the cuff pressure as it tries to reach its equilibrium pressure. This flexing produces turbulent oscillating blood flow instead of a laminar smooth flow that is normal to the artery. The point in time in which the MAP occurs is recorded. The systolic and diastolic points' occurrences in time are derived through taking a percentage of the MAP before and after. The three points in time are correlated to the cuff pressure recording. The points in time of the AC signal are correlated to the DC signal's pressure values at the same times. The graphs below are 3.0.2 and 3.0.3.



Graph 3.0.2: AC signal correlated to the DC signal

The DC signal is representative of the pressure in the cuff (bladder), the AC signal is representative of the oscillations in the cuff due to the artery flexing. The mean arterial pressure is the only point in time that is directly obtained from the AC signal. From this signal the systolic and diastolic pressures are derived. (Oscillometric Method AppA [18])



(Oscillometric Method Phillips AppA [19]) – Graph 3.0.3

In the oscillometric method the systolic and diastolic pressure values are derived from understanding the relationship of the mean arterial pressure (MAP) to the systolic and diastolic pressures. When the systolic and diastolic pressures are known the MAP can be calculated from which much health information can be gathered.

Mean Arterial Pressure = 1/3 * Systolic pressure + 2/3 * Diastolic pressure

To derive the systolic and diastolic pressures the microcontroller which will process the data sent to it to calculate a blood pressure reading will multiple specific percentages before and after the MAP point in time.

0.54 * MAP = Systolic 0.72 * MAP = Diastolic; points in time on the DC pressure curve.

Because the Oscillometric method uses only one sensor and less circuitry, this method was utilized in the design of the blood pressure tester as it maintains the low power profile of the device.

Just as in the electronic auscultatory method, the pressure readings must be converted from pressure per square inch to mmHg. The picture below is 3.0.4

$$P_{psi} = 0.0193368 \times P_{mmHg}$$
$$P_{mmHg} = 51.7149 \times P_{psi}$$

(NOAA pressure conversions AppA [20]) – Picture 3.0.4

The major difference between the auscultatory and oscillometric methods is that the oscillometric method indirectly measures the mean arterial pressure from which the systolic and diastolic pressures are derived while the auscultatory method assesses the systolic and diastolic pressures.

3.1 Existing Similar Projects

There are many health monitoring device projects existing that contain blood pressure monitoring devices within their design. Learning about other groups' designs can help in error checking as well as maintaining higher standards in testing and verifying data.

A design group from The Mechanical and Materials Science Department of Duke University is designing a Blood Pressure Testing Machine. The group intends to develop a device to test other blood pressure monitoring devices. The group plans to test multiple devices to the point of failure. They define failure as loss of accuracy or physical destruction. They started the process of design by creating a prototype device to simulate pulse pressure and heartbeats. The device's output would then be connected to the inputs of the other devices' inputs. This would provide a constant source of data and negate the need for live human test subjects. The devices were tested one thousand times each. By comparing the cycle time and its change with cuff pressure changes over time, the group was able to measure fatigue especially in the mechanical parts of the monitoring devices. Afterwards they researched and proposed designs for better mechanical implementations in these devices so that they could be used for extended amounts of time and in less ideal environments.

Another group at Vanderbilt University is designing a Portable Automatic Arm Blood Pressure Monitor Recalibration system. The group's objective in designing this device is that it can be part of existing devices. As the previous group from Duke University found that after one thousand tests, these devices start to lose accuracy because the cuff and other mechanical parts change physical characteristics. The group will work on developing a calibration method that gives the device the ability to re-zero blood pressure monitors. While the device would still have fatigued parts over time the readings would be based on the parts' current states on and not on how they came from the factory. Therefore the blood pressure readings would always be accurate to the device in its specific current form. This implementation could save individuals money from having to repurchase devices. If their method is successful it could possibly be implemented in this blood pressure tester device to add to its ability to serve people. As was tested in the University of Central Florida, blood pressure tester, the device began to lose reporting accuracy after 90+ readings due to stretching of the cuff. Upon replacement of the cuff the accuracy returned. Therefore an automatic recalibration system would help to maintain accuracy in readings.

A senior design group from North Carolina State University is designing a blood pressure monitoring system similar to this project in that it also contains a wireless component. The group's objective is to implement the wireless component using a CMOS microcontroller with a UHF transmitter. They also plan to keep the device in the low power operating range. There design includes two sensors one for pressure and another to detect the sounds involved in the auscultatory method.

Another group comprised of The Twin Cities IEEE Phoenix Project along with a senior design group from The University of Minnesota is designing a blood pressure monitor that utilizes a pulse transit time technique. One of the objectives of their project is to design a monitor that is more comfortable than wearing a cuff which they intend to allow for continuous blood pressure readings. The device will include two sensors at two different locations on the arm to measure the time a pulse take from one sensor to the next. This will employ the pulse wave velocity method of blood pressure monitoring. The group has "stretch goals," that include making the device battery operable. While they will certainly need to have power management methods involved in their design. By stating that it is only a stretch goal of theirs to use battery power, it is clear that designing a low power device is not their top priority while it is one of the top priorities of this device.

A senior design group from the Georgia Institute of Technology is creating a blood pressure device which will utilize an inflated cuff to take blood pressure readings from captive gorillas. The design idea and its implementation not only lead to many insights into gorilla health but because the device must be made rugged and to work while the gorillas are sleeping, moving, and in any other position it can lead to breakthroughs in blood pressure monitoring for humans.

A Body-heat powered, wearable health monitoring system from HealthPals, relies on the power generated by human body heat and vibrations. This system monitors temperature, blood pressure, brainwaves and heartbeats. Each piece of the system comes with a vibration energy harvester and thermoelectric generator and capacitor for energy storage. The device will gather all the data from the sensors and send it onto the patient's Smartphone or also computer via Bluetooth. Health professionals will be able to monitor and analyze the results remotely from patients.

3.2 Relevant Technologies

The growing need for healthcare devices for a wide range of health issues has created many devices. The technologies that devices utilize can be helpful in the design and implementation of this device.

WIN Human Recorder Co. Ltd, recently introduced a health monitoring service which monitors many vital health signs. The monitoring service utilizes a sensor network to function. The system measures electrocardiograph signals, heart rate, brain waves, body temperature, respiration, pulse waves for blood pressure readings. The system's output is viewable and configurable with a mobile phone and/or a desktop computer. With all the vitals signs that are measure the system utilizes one sensor module that is attached to the chest of the patient. Implementing a smart phone application to coincide with this device is a future goal.

Some wearable continuous non invasive blood pressure sensors exist on the market. One device that was developed by MIT faculty with outside private collaboration was designed to help diagnose hypertension, heart disease, as well as patients that have anxiety that distorts blood pressure readings. The blood pressure monitor requires no cuff to wrap around the upper arm, instead uses a method called pulse wave velocity, which allows pressure to be calculated by measuring the pulse at two points along an artery. The two points are one on the wrist and one on the pinky finger. With a cuff blood pressure system the pressure is read at the same elevation as the heart. One of the problems about getting a blood pressure reading from another location on the body is knowing whether the location is above or below the heart, readings from below or above the heart are different. Therefore the device has a sensor that measures acceleration in three dimensions and allows the hand position to be calculated at all times to adjust the readings accordingly. This additional sensor could be a possible addition to this design that could help in more accurate readings due to variable cuff placement in relation to the heart. This device also has wireless transmission capabilities.

There is another device that is on the market from Contec, model ABPM-50 is an ambulatory blood pressure monitor. It utilizes a traditional upper arm cuff wrapped around the upper arm. The devices store information in a computer for future use. The information that it stores is systolic blood pressure, diastolic blood pressure, mean blood pressure, pulse rate, error message and logging record number. While it does not have continuous measurement, it does allow for multiple automatic readings.

The Omron 1500Pro blood pressure monitor is a currently available, completely automatic blood pressure monitor. With its unique automatic cuff system, it offers professionally reliable upper arm blood pressure measurement. Many patients have difficulty wrapping a normal cuff, which can lead to inaccurate results. The No-Wrap system ensures a hassle-free fit for both regular and large size arms with correct cuff placement. The patient simply inserts his or her into the automatic cuff, rests it on the convenient arm positioning guide and presses the start button. The No-Wrap cuff automatically inflates, measures blood pressure and displays readings on the large digital display.

The advanced features of the 1500Pro provide memory for two users/ 200 total measurements, that allows you to review an eight week history of morning and evening blood pressure averages. By monitoring weekly morning averages morning hypertension can be detected which is an important predictor of increased risk of stroke and heart attacks, which are more common in the early morning hours. The No-Wrap cuff is pre-formed for a quick and proper fit for both medium and large sized arms (fits arms 9” to 17”). This monitor detects advanced diagnostics including morning hypertension and irregular heartbeat. Monitoring these important factors with Omron's software allows the patient to share valuable information with a physician.

Allogy, a research and development group affiliated with the University of Central Florida is involved in many mobile applications. The group has been involved in many distance education and healthcare related projects. One such project has involved the use of old vending machines that have been remade to vend and track prescriptions in rural locations of Kenya and Haiti. The expansion of their project will allow different healthcare groups such as Centers for Disease Control and other agencies to monitor trends in prescriptions for various medications across continents. This can lead to detection of disease outbreaks as well as prevention of disease based on statistical data finding trends. Additionally the application has been utilized to track and prevent fraudulent prescriptions and false medicines from being sold and used. The possibility of collaborating with this group may create the possibility to tap into the same network as the prescription tracking application for health monitoring.

As blood pressure readings provide so much information regarding a person’s health. Health trends for various diseases and other issues related to heart problems could be studied from large populations. Recommendations, prevention as well as cost savings could be realized.

3.3 Research

3.3.1 Sensors:

In choosing the sensor for the blood pressure monitoring device many sensors were considered. Many factors were taken into account including the voltage input range for operation, current range for operation, as well as what is actually being sensed. Blood pressure through electronic means is often done in an indirect method in which information is derived from a signal and information known about signals and pressure. Therefore what is actually being sensed directly is not blood pressure. The signal received from the sensor starts as a mechanical signal and a transducer changes it into a voltage to be fed into a processor for deducting information.

With the electronic auscultatory method small piezoelectric contact microphone sensors are used to listen for Korotkoff sounds. The Korotkoff sounds are then correlated in the microprocessor with pressure information from a second pressure sensor which converts air pressure into a variable voltage signal. If the auscultatory method were to be utilized, two or more different types of sensors would need to be obtained and utilized in the design of the device. Not only does this increase the power consumption profile of the device, it also increases the physical size of he final product. Wires from the microphone sensors on the patient would need to be connected to the circuit board for amplification. A tube from the cuff to the air pressure sensor would need to be connected to the circuit board as well and its transformed signal would need to be amplified similarly.

The electronic oscillometric method for blood pressure monitoring avoids the necessity of extra hardware and thereby helps to meet the goal of an ambulatory device maintaining a low power usage profile. It avoids extra hardware by utilizing one pressure sensor unlike other methods of blood pressure measurement. The pressure sensor is also known as a pressure transducer as it takes in mechanical air pressure and outputs an electronic voltage carrying the information from pressure wave. With the oscillometric method it is assumed that the cuff membrane in contact with the patient's skin virtually becomes one, they are assumed to share the same surface pressure. Any temporary changes in the skin's pressure due to the arterial walls flexing from blood flow will cause pulses in the skin. As the skin is viewed as being one with the cuff, any pulses in the skin will cause air oscillations in the cuff. This will in turn change the profile of the air pressure wave being sensed by the pressure sensor. While this is an indirect method that uses algorithms and analog circuitry to derive the Systolic, Diastolic and mean blood pressure values, it is a method that has been proven to be reliable as well as one that avoids a second sensor which would require more power. In choosing a pressure sensor for the oscillometric method; analog as well as digital output sensors were considered.

Oscillometric raw data signals is shown in the Figure 3.3.1.1

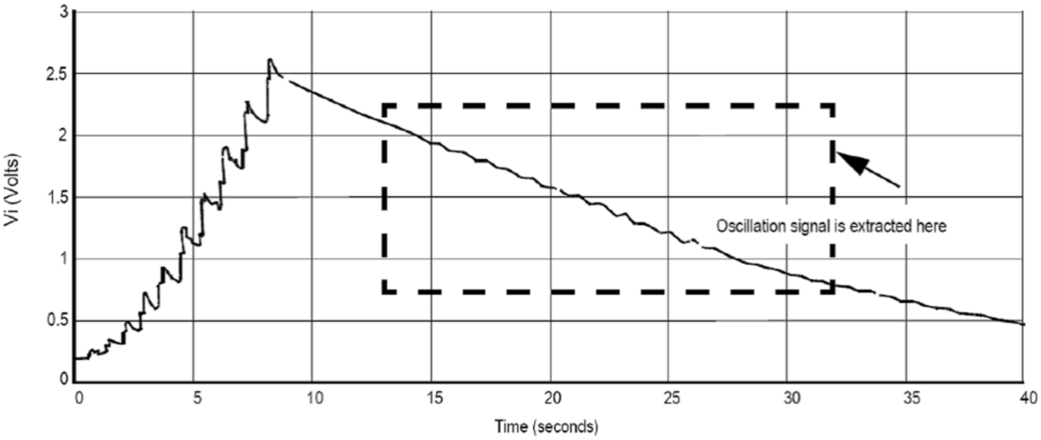


Figure – 3.3.1.1: Raw data signals

The mixed voltage signal from the pressure sensor is shown (Automated Digital Blood Pressure Meter AppA [21]) The DC signal after amplification is input to the analog to digital converter for cuff pressure to time logging.

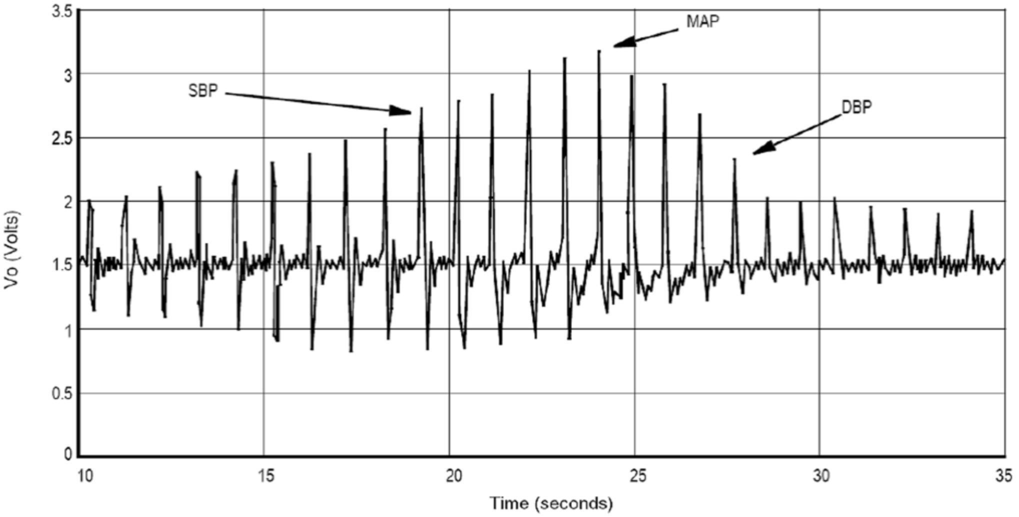
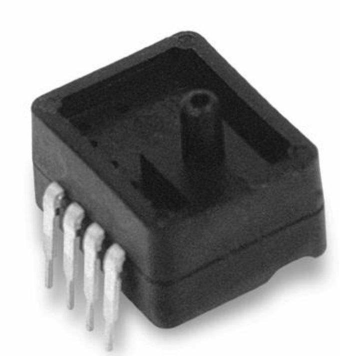


Figure – 3.3.1.2: Mixed voltage

The filtered AC signal representing arterial pulse oscillations in the cuff after being amplified and filtered from the original mixed signal is sent to another input of the analog to digital converter. (Automated Digital Blood Pressure Meter AppA [21])

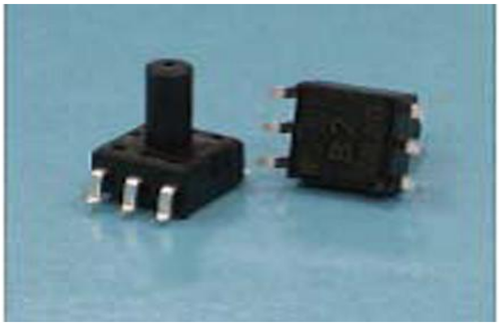
The advantage of a digital output air pressure sensor is that either there is an output or there isn't. A digital output pressure signal would not include filtering circuitry to enable two discrete signals from the original mixed signal. Therefore, the AC and DC signals would have to be derived through digital filtering in the microcontroller unit. Both analog and digital filtering of mixed signals was investigated. The device uses analog filtering to separate the signal before being converted into the digital domain. Once the signal is in the digital domain it is filtered further to reduce noise.

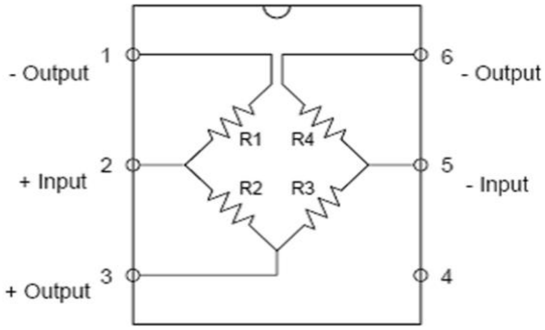
ASDXL DO Digital Output pressure sensor from Honeywell utilizes a Wheatstone bridge circuit in converting mechanical pressure on the resistor to voltage changes. It provides an amplified mixed digital signal. The circuitry within requires a supply voltage of 4.25V- 5.25V and 6mA of current. This sensor could possibly maintain the low power profile of the device negating the need of analog circuitry with its own necessity of constant current and 3mV of supply voltage. However, the signal would need to be filtered digitally to obtain an AC and DC signal for algorithmic processing.



Honeywell ASDXL DO AppA[25]
Figure 3.3.1.3

The MPS-3117 pressure sensor from Taiwan Metrodyne System Corporation, utilizes a special case of the Wheatstone Bridge, the Wien Bridge which is driven by a constant current source of 1mA to 3mA and requires 2-5V of supply voltage. Utilizing the Wien Bridge allows the capacitance of two capacitors to be compared because the resistance values of the circuit are known. The pressure sensor is therefore able to send the double-ended output differential signals depending on profile of the air pressure wave. The signal is an analog mixed signal with an output voltage in the range of 0-40mV that is proportional to the differential input mechanical air pressure.

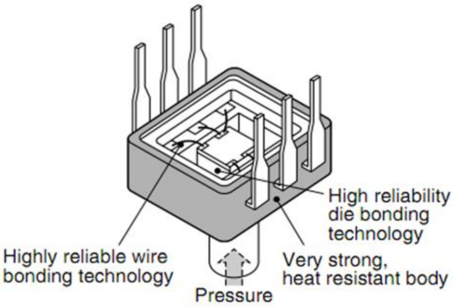




Taiwan Metrodyne System Corporation Wein Bridge circuit pin assignment

MPS-3117 pressure sensor   Figure – 3.3.1.5 AppA[26]
Figure – 3.3.1.4 AppA[26]

The Matsushita Electric Works –NAIS ADP1 pressure sensor was recommended as a possible analog output pressure sensor solution by a member of the medical device group at Texas Instruments. The device maintains the low power profile requiring a 1mA constant current source and 3.0V to 5.5V voltage source. The diameter of the air entry port is 3mm.



NAIS ADP1 pressure sensor
Figure – 3.3.1.6 AppA[27]

The Freescale Semiconductor M3V5050GP pressure sensor was chosen for this device. It maintains the low power profile requiring a 7mA constant current source and a 3.0 voltage source. Its output maximum is 2.82 volts which is reduced by the filter network to avoid reaching the MCU's analog to digital converter's maximum input.

3.3 Research

3.3.2 Microcontroller

A microcontroller is a dedicated computer in electronics that is used to perform specific tasks. For the purpose of this project, a microcontroller was used because, besides being a low-power device, it has a low cost and it is designed to be as compact as possible. The microcontroller will take input from the device that it is controlling and it will be sending signals constantly to different components of the device so it performs the desired tasks.

Among all the microcontrollers available at the market, the project uses the MSP430. This microcontroller was designed by Texas Instruments and it has several attributes that will help us develop this project. The MSP430 is a 16-bit, ultra low-power, can be compiled using C language (which is the language that the group is familiarized with), is a 16-bit CPU partnered with flexible low power modes and intelligent, and finally, it is versatile because it can be applied to different equipments, including medical equipments such as a blood pressure sensor. It also has the capacity of measuring, metering, sensing, and it offers a broad suite of ULP solutions for wireless applications, which are essential characteristics for the success of this project.

MSP430FG439 – This is an ultralow power microcontroller which consists of five low power modes that is optimized to achieve the extended battery life in portable measurement applications. It features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that attribute to maximum code efficiency. It also contains a digitally controlled oscillator (DCO) that allows wake-up form low-power modes to activate mode in less than 6µs. The MSP430G43x series are microcontroller configurations with two 16-bit timers, a high performance 12-bit A/D converter, dual 12-bit D/A converter, three configurable operational amplifiers, one universal synchronous/asynchronous communication interface (USART), DMA, 48 I/O pins, and a liquid crystal display (LCD) driver.

Features:

- Low Supply-Voltage Range, 1.8V to 3.6V
- Ultralow-Power Consumption:
  - Active Mode: 300µA at 1MHz, 2.2V
  - Standby Mode: 1.1µA
  - Off Mode: 0.1µA
- Five Power-Saving Modes
- Wake-up From Standby Mode in less than 6µs
- 16-Bit RISC Architecture, 125-ns Instruction Cycle Time
- Single-Channel Internal DMA
- 12-Bit A/D Converter With Internal References, Sample-and-Hold and Autoscan Feature
- Three Configurable Operational Amplifiers
- Dual 12-Bit D/A Converters With Synchronization
- 16-Bit Timer_A With Three Capture/Compare Registers
- 16-Bit Timer_B With Three Capture/Compare-With-Shadow Registers
- On-Chip Comparator
- Serial Communication Interface (USART), Select Asynchronous UART or Synchronous SPI by Software
- Brownout Detector
- Supply Voltage Supervisor/Monitor WIth Programmable Level Detection
- Bootstrap Loader
- Serial Onboard Programming, No External Programming Voltage Needed Programmable Code Protection by Security Fuse
- 3 OPAMP
- 2KB RAM
- 60KB Flash

MSP430FG4618 – This is an ultralow-power microcontroller which consists of five low-power modes, it is optimized to achieve extended battery life in portable measurement applications. It features a 16-bit RISC CPU, 16-bit registers and a digitally controlled oscillator (DCO) that allows a wake-up from low-power modes to active mode in less than 6µs. The MSP430xG461x series are microcontroller configurations with two 16-bit timers, a high-performance 12-bit A/D converter, dual 12-bit D/A converters, three configurable operational amplifiers, one universal serial communication interface (USCI), one universal synchronous/asynchronous communication interface (USART), DMA, 80 I/O pins, and a liquid crystal display (LCD) driver with regulated charge pump.

Features:

- Low Supply-Voltage Range: 1.8V to 3.6V
- Ultralow-Power Consumption:
    - Active Mode: 400µA at 1MHz, 2.2V
    - Standby Mode: 1.3µA
    - Off Mode: 0.22µA
- Five Power-Saving Modes
- Wake-up from Standby Mode in less than 6µs
- 16-Bit RISC Architecture, Extended Memory, 125-ns Instruction Cycle Time
- Three Channel Internal DMA
- 12-Bit A/D Converter With Internal Reference, Sample-and-Hold, and Autoscan Feature
- Three Configurable Operational Amplifiers
- Dual 12-bit DAC with Synchronization
- 16-Bit Timer_A With Three Capture/Compare Registers
- 16-Bit Timer_B With Three Capture/Compare-With-Shadow Registers
- On-Chip Comparator
- Supply Voltage Supervisor/Monitor With Programmable Level Detection
- Serial Communication Interface (USART1), Select Asynchronous UART or Synchronous SPI by Software
- Universal Serial Communication Interface
    - Enhanced UART Supporting Auto-Baudrate Detection
    - IrDA Encoder and Decoder
- 3 OPAMP
- 8KB RAM
- 116KB Flash

MSP430FG479 – This is an ultralow power microcontroller which consists of five low power modes that is optimized to achieve the extended battery life in portable measurement applications. It features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that attribute to maximum code efficiency. It also contains a digitally controlled oscillator (DCO) that allows wake-up form low-power modes to activate mode in less than 6µs. The MSP430G47x series is a microcontroller configuration with two 16-bit timers, a basic timer with a real-time clock, a high performance 16-bit sigma-delta A/D converter, dual 12-bit D/A converter, two configurable operational amplifiers, two universal serial communication interface, 48 I/O pins, and a liquid crystal display (LCD) driver.

Features:

- Low Supply-Voltage Range: 1.8V to 3.6V
- Ultralow-Power Consumption:
  - Active Mode: 262µA at 1MHz, 2.2V
  - Standby Mode: 1.1µA
  - Off Mode (RAM Retention): 0.1µA
- Five Power-Saving Modes
- Wake-up from Standby Mode in less than 6µs
- 16-Bit RISC Architecture, 125-ns Instruction Cycle Time
- 16-Bit Sigma-Delta Analog-to-Digital (A/D) Converter with Internal Reference and Five Differential Analog Inputs
- Dual 12-bit DAC with Synchronization
- 16-Bit Timer_A With Three Capture/Compare Registers
- 16-Bit Timer_B With Three Capture/Compare-With-Shadow Registers
- Two Universal Serial Communication Interfaces (USCI)
  - USCI_A0
    - Enhanced UART Supporting Auto-Baudrate Detection
    - IrDA Encoder and Decoder
    - Synchronous SPI
  - USCI_B0
    - I^{2}C™
    - Synchronous SPI
- Integrated LCD Driver with Contrast Control for Up to 128 Segments
- Brownout Detector

MSP430FR5739 – This is an ultralow power microcontroller which consists of several devices featuring embedded FRAM nonvolatile memory, ultralow power 16-bit MSP430 CPU, and different sets of peripherals targeted for various applications. The architecture, FRAM, and peripherals, combined with seven low-power modes, is optimized to achieve extended battery life in portable and wireless sensing applications. FRAM is a new nonvolatile memory that combines the speed, flexibility, and endurance of SRAM with the stability and reliability of Flash all at lower total power consumption.

Features:

- Embedded Nonvolatile FRAM
  - Supports Universal Memory
  - Ultra-Fast Ultra-Low-Power Write Cycle
  - Error Correction Coding (ECC)
  - Memory Protection Unit
- Low Supply Voltage Range, 2.0 V to 3.6 V
- 16-Bit RISC Architecture, Up to 24-MHz
- Low Power Consumption
  - Active Mode (AM): All System Clocks Active, 103 µA/MHz at 8 MHz, 3.0 V, FRAM Program Execution (Typical),60 µA/MHz at 8 MHz, 3.0 V, RAM Program Execution (Typical)

  - Standby Mode (LPM3): Real-Time Clock With Crystal , Watchdog, and Supply Supervisor Operational, Full System State Retention: 6.4 µA at 3.0 V (Typical), Low-Power Oscillator (VLO), General-Purpose Counter, Watchdog, and Supply Supervisor Operational, Full System State Retention: 6.3 µA at 3.0 V (Typical)
  - Off Mode (LPM4): Full System State Retention, Supply Supervisor Operational: 5.9 µA at 3.0 V (Typical)
  - Real-Time Clock Mode (LPM3.5): 1.5 µA at 3.0 V (Typical)
  - Shutdown Mode (LPM4.5): 0.32 µA at 3.0 V (Typical)
- Power Management System
  - Fully Integrated LDO
  - Supply Voltage Supervision and Brownout
- Clock System
  - Factory Trimmed DCO With Three Selectable Frequencies
  - Low-Power/Low-Frequency Internal Clock Source (VLO)
  - 32-kHz Watch Crystals and High-Frequency Crystals up to 24 MHz
  -

MSP430F5438A – This is an ultralow-power microcontroller that consists of several devices featuring different sets of peripheral targeted for various applications. The architecture of this device combines five low-power modes, it is optimized to achieve extended battery life in portable measurement applications. It also features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 5 µs.

Features:

- Low Supply Voltage Range: 2.2V to 3.6V
- Ultralow Power Consumption
  - Active Mode (AM): All System Clocks Active
    312 µA/MHz at 8MHz, 3.0V, Flash Program Execution
    140 µA/MHz at 8MHz, 3.0V, RAM Program Execution
  - Standby Mode (LPM3):
    Real-Time Clock with Crystal, Watchdog, and Supply Supervisor Operational, Full RAM Retention, Fast Wake-Up: 2.6 µA at 3.0V
    Low-Power Oscillator (VLO), General Purpose Counter, Watchdog, and Supply Supervisor Operational, Full RAM Retention, Fast Wake-Up: 1.8 µA at 3.0V
  - Off Mode (LPM4):
    Full RAM Retention, Supply Supervisor Operational, Fast Wake-up: 1.69 µA at 3.0V
- Wake-Up from Standby Mode in less than 5 µs.
- 16-Bit RISC Architecture
- Flexible Power Management System
  - Fully Integrated LDO with Programmable Regulated Core Supply Voltage

  - Supply Voltage Supervision, Monitoring, and Brownout
- Unified Clock System
- 16-Bit Timer TA0, Timer_A with five capture/compare registers
- 16-Bit Timer TA1, Timer_A with three capture/compare registers

Table 3.3.2.1 shows a comparison between all the microcontrollers mentioned previously. These comparisons are made using important parameters for the development of this project.

MSP430	**FG439**	**FG4618**	**FG479**	**FR5739**	**F5438A**
Frequency (MHz)	8	8	8	24	25
Flash (KB)	32	116	60	-	256
FRAM (KB)	-	-	-	16	-
SRAM (B)	2048	8192	2048	1024	16384
ADC	12-bit SAR	12-bit SAR	16-bit Sigma Delta	10-bit SAR	12-bit SAR
USCI	USART (1)	USCI_A (1) USCI_B (1)	USCI_A (1) USCI_B (1)	USCI_A (2) USCI_B (1)	USCI_A (4) USCI_A (4)
Approx. Price (US$)	6.60 | 1ku	8.35 | 1ku	6.20 | 1ku	2.45 | 1ku	4.55 | 1ku

Table 3.3.2.1: Comparison of important parameters

After comparing all the MSP430s, the microcontroller that was more appropriate for the design was the MSP430F5438 because it has all the features that led us to accomplish our goals with the blood pressure tester. Those features include a reasonable amount of Flash memory to store temporary data, 12-bit Digital to Analog converter, OpAmp, and 16KB of RAM. This MCU was able to receive information from the Analog to Digital Converter Circuit, process the data, and send it, wirelessly, to the display. Besides all those characteristics, this is a low cost, easy to use MCU.

3.3 Research

3.3.3 Wireless Research:

The wireless display is an ideal situation for this project; it is used so that the person viewing the patients' blood pressure has the freedom to view it from the comfort of wherever they want to be in the building. For example, if a doctor wanted to know the patients' blood pressure in a room on the other side of the building, he/she could just tell the nurse in charge of that patient to take it and he could see the results at a display in his office, such as his/her computer instantly.

There are some specific regulations when it comes to using wireless communications such as Bluetooth, Radio, and Wi-Fi in the United States and in some European countries. They regulate what exactly is allowed to be transmitted through the air, such as radio waves or microwaves. First, The Federal Communications Commission (FCC) regulates the use of the radio spectrum for non-federal use such as state, local government, commercial, private and personal use. Second, the National Telecommunications and Information Administration (NTIA) regulate the use of the radio spectrum for federal use. Therefore, since this project is a non-federal project, it was followed the FCC bands. The bands designated for personal and private applications by the FCC are the Industrial, Scientific and Medical (ISM) bands.

The research that follows looks into all the different types of communication methods available for this type of project. This includes, but not limited to, Bluetooth, Radio, and Wi-Fi. All of these are forms of RF communications. Bluetooth is a form of wireless communication in which it exchanges data over short distances, it connects more than one device in witch synchronization is not a problem. For the use of Bluetooth, the ISM band to use is 2.4GHz short-range radio frequency bandwidth, since there is a lot of applications on this frequency such as microwave ovens, which are the primary user of this bandwidth, it is anticipated that some interference result from all these technologies operating in the same environment and frequency space. There are a few different types of Bluetooth, such as Bluetooth 1.0 which has a data rate of 1Mbps, Bluetooth 2.1 which has a data rate of 1-3Mbps for and Bluetooth 3.0 which has a data rate of 54Mbps. There are also different types of classes of Bluetooth: Class 1 is 100mW of power with a transmit distance of 100m, Class 2 is 2.5mW of power with a transmit distance of 10m, and Class 3 is 1mW of power with a transmit distance of 1m.

<u>Bluetooth</u> could be a great use for this project, in the sense of how it clearly shows that the wireless portion of this project can work. However, in a more concrete view of the purpose of the wireless portion of this project the distance that Bluetooth provides could not be enough in a more real world sense. Also it is known that Bluetooth does not deal well when it comes to wall penetration witch could pose as a big problem when dealing with a more concrete view of this project. *(App A: FCC [1])*

Listed below are some overall pros and cons of using Bluetooth.

Pros
· Low power
· Bluetooth does not need to be in a straight line of sight
· Endless options for short range wireless
· Simplicity to show transferring data for this project

Table 3.3.3.1A--*(App A: FCC [1])*

Cons
· Pairing is required
· Short distance
· Wall penetration not so good
· Interference due to the 2.4 GHz ISM band

Table 3.3.3.1B--*(App A: FCC [1])*

Wi-Fi is used for wirelessly connecting electronic devices, such as a personal computer, video game console, smartphone, etc. Wi-Fi also operates in the 2.4GHz radio band, but also operates in the 5GHz radio band. This can also cause some issues for interference as in the Bluetooth device since many electronic devices operate in the frequency, this could become a bigger problem in high-density areas such as large apartment complexes or office building with many Wi-Fi access points. Since this project is simply transferring very little data to a display, the protocols that are required to use Wi-Fi are a bit of overkill for this project, making it unnecessary. *(App A: FCC [1])*

Pros
· Readily available in most locations
· RF bands
· Reliable error correction

Table 3.3.3.2A--*(App A: FCC [1])*

Cons
· RF common band interference
· Overkill for the scale of this project
· Overhead costs
· External components for connection purposes.

Table 3.3.3.2B--*(App A: FCC [1])*

Radio Frequency can range from frequencies from 300Hz to 300 GHz, for industrial, scientific and medical (ISM) applications such as the common radio the frequencies allowed for this are 915MHz, 2.45GHz, 1GHz, and 5GHz. In order to be allowed to use these frequencies absolutely no licensing or ownership granted by the Federal Communications Commission (FCC). For transferring on two, three digit numbers to a display the 1GHz band is sufficient. There is a possibility for noise issues, however, with the availability of this type of frequency it can be easily utilized and found in many transmitting integrated circuits. *(App A: FCC [1])*

For this project, the standard radio frequency communication is the better choice that made the wireless portion of this project a success. General radio frequency bands follow no protocol witch in this situation could be a great advantage. Witch in turn is the main difference between radio frequency communication and Bluetooth, and Wi-Fi operating on their own specific bands. Being able to create the wireless protocol would mean it was made specifically for this project, taking care of any worry about overkill with Bluetooth, and Wi-Fi.

Pros
· 1GHz frequency available
· Low Power
· Easy to find transceivers
· Custom protocol

Table 3.3.3.3A--*(App A: FCC [1])*

Cons
· Interference
· Not secure
· No help with protocols

Table 3.3.3.3B--*(App A: FCC [1])*

Wireless Summary:

Bluetooth vs. Wi-Fi – based on the specifications listed above for Bluetooth, it really did not do the project justice to utilize Bluetooth in the project. Bluetooth for the most part is used only as a general cable replacement, for things like computers, and phones. Low power is also an important aspect for this project, since Bluetooth uses more power for the distance that it travels it does not makes sense for the project to use it. Wi-Fi can be more complex to use, seeing as it requires a wireless adaptor on all the devices of the network, a wireless router and/or wireless access points. It also requires configuration of hardware and software. It’s also primarily used for laptops, desktops and servers. However it does have a substantial range compared to Bluetooth at 10 meters, Wi-Fi has a range of about 100 meters. When it comes to security Wi-Fi could be considered less secure in some cases since all it takes is for someone to access one part of a secured network in order to get access to everything. Since Bluetooth can cover shorter distances and has a 2 level password protection, it is considered to be more secure. The cost of Bluetooth compared to Wi-Fi is considered to be substantially low for Bluetooth and pretty high for Wi-Fi. They both for the most part operate in the same frequency domain, the 2.4 GHz frequency domain and operate in different bandwidths, for Bluetooth it is low bandwidth at (800 Kbps) and for Wi-Fi it is high bandwidth at (11 Mbps). *(App A: FCC [1])*

RF vs. Wi-Fi – When it comes to using generic RF, the amount of actual functionality drops substantially when compared to Bluetooth and Wi-Fi. However, all this extra functionality is really unnecessary when it comes to this project. Seeing how expensive Wi-Fi is compared to generic RF, it does not make sense to drain the budget just to be able to use Wi-Fi. The project uses the generic RF 1.0 GHz band which may cause some trouble since it's so cluttered, however since it was decided to use the least amount of power possible this is the best route to go. *(App A: FCC [1])*

Conclusions – Although Bluetooth and Wi-Fi have so much to offer when it came to different types of functionality for this project it was decided to just show that the technology works. Obviously there is a bigger picture here when it comes to range and reason behind the wireless portion of this project; however for demonstration purposes it is just shown that the data is displayed wirelessly in a relatively short range. So based on the research from above, it was decided to stick with the RF wireless demonstration.

3.3.4 Transceivers Research:

CC1101 – based on the research for what transceiver to use for this project, the Texas Instruments CC1101 is on the top of the list. Since it was decided to use the laptop as the display and wireless demonstration there are only a few options for the transceiver that will be used on the designed PCB board, when it comes to the CC1101 it's a very low cost transceiver working around the sub-1 GHz. Its main purpose from its design is to generate a very low power wireless application. The operating bands that the CC1101 operates in are based off of its circuit which is mainly intended for the ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency bands at 315, 433, 868, and 915 MHz Another great thing about this transceiver is that it can be easily be programmed for operation at other frequencies in the 300-348 MHz, 387-464 MHz and 779-928 MHz bands. *(App A: CC1101 [2])*

The CC1101 RF transceiver has a baseband modem that has the ability to be highly configurable. The modem itself has can support many different modulation formats, and has a configurable data rate up to 600 kbps.

Since the CC1101 is such a widely used device the product itself provides a lot of hardware support for packet handling, burst transmissions, link quality indication, wake-on-radio, data buffering, and clear channel assessment. Another great thing about the CC1101 is that things such as the main operating parameters and the 64 byte transmit/receive FIFOs can all be controlled with an SPI interface or a Serial Peripheral Interface, which in turn means that data is shifted out and in one bit at a time. Of course the CC1101 in most cases if not all cases will be used together with a microcontroller and a few additional passive components in a typical system. *(App A: CC1101 [2])*

If it was decided that it was wanted to extend the range of the CC1101 it can attach the CC1190 to it witch is an 850-950 MHz range extender. It has the ability to improve range, sensitivity and higher output power. Below you can see what the CC1101 actually looks like and you can also see what the pin layout is. Also, the CC1101 with attached CC1190 can be seen as well. There will also be a list of pros on cons based on this researched in order to use the CC1101 in this project.

Pin Layout- It would be best to get a better understanding of what each pin does in the CC1101 in order to make the decision of whether it would benefit this project the most. The pin layout for the CC1101 is very straight forward as it is. For the wireless circuit design a lot of these pins will be used. Just to have a better understanding of what each pin actually does here is what each pin means and what it is used for:

Starting with *Pin 1* (SCLK) is a digital input pin, the main reason why this pin would be used in the design would be for a serial configuration interface, clock input. *Pin 2* SO (GDO1) is a digital output pin, the main reason for this pin is for the serial configuration interface, data output, it's the optional general output pin when CSn is in the high position. *Pin 3* (GDO2) is similar to pin 2 as in it is also a digital output pin, however it's more of a general output pin for general uses such as testing signals, FIFO status signals, clear channel indicator, clock output, down-divided from XOSC, and serial output RX data. *Pin 4* (DVDD) is power in the digital form and would be used for the power in the digital form which is used at a 1.8-3.6V digital power supply for digital I/O' sand for the digital core voltage regulator. *Pin 5* (DCOUPL) is also power in the digital form that is used at the 1.6-2.0V digital power supply output for decoupling, however this pin is intended for the use of the CC1101 ONLY. It can't be used to provide power to different components surround the CC1101. *(App A: CC1101 [2])*

Pin 6 GDO0 (ATEST) is the digital I/O, it's a digital output pin for general use mainly to test signals, FIFO status signals, clear channel indicator, clock output, down-divided from XOSC, serial output RX data, serial input TX data, also used as an analog test I/O for prototype/production testing. *Pin 7* (CSn) is the digital input pin, it is used for the basic serial configuration interface, chip select. *Pin 8* (XOSC_Q1) is the analog I/O pin, which is used as the crystal oscillator pin1, or also for the external clock input. *Pin 9* (AVDD) which is a power pin in the analog form, which is used for 1.8V – 3.6 V analog power supply connection. *Pin 10* (XOSC_Q2) is the analog I/O pin which is used for the crystal oscillator pin 2.

Pin 11 (AVDD) is also a power pin in the analog form, which is used in the 1.8-3.6V analog power supply connection. *Pin 12* (RF_P) is the RF I/O pin, which is used for the positive RF input signal to LNA in receive mode and also the RF output signal from the PA in transmit mode. *Pin 13* (RF_N) is also an RF I/O pin, which is used for negative RF input signal to LNA in receive mode, also for negative RF output signal from PA in transmit mode. *Pin 14* (AVDD) is a power pin in the analog form, which is a 1.8-3.6V analog power supply connection. *Pin 15* (AVDD) is another power pin the analog form, which is a 1.8-3.6 V analog power supply connection pin. *(App A: CC1101 [2])*

Pin 16 (GND) is the analog ground pin which is used as the analog ground connection. *Pin 17* (RBIAS) is another analog I/O pin, which is the external bias resistor for reference current. *Pin 18* (DGUARD) is another power pin in the digital form, which is the power supply connection for the digital noise isolation. *Pin 19* (GND) is the ground pin in the digital form, which is the ground connection for digital noise isolation. *Pin 20* (SI) is a Digital input pin, which is the serial configuration interface, data input. *(App A: CC1101 [2])*

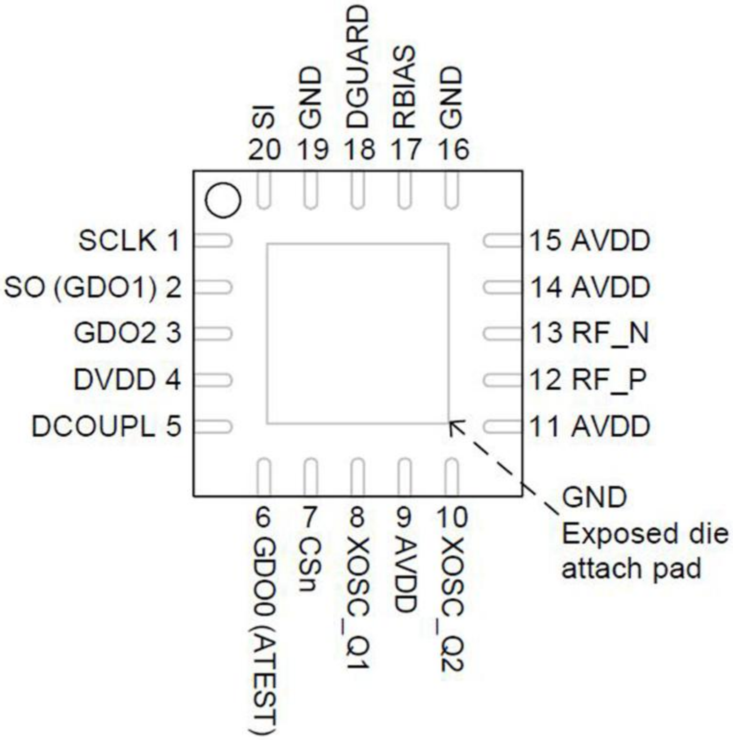


Figure 3.3.4.1: CC1101 Pin Configuration – Courtesy of Texas Instruments

Pros
· Excellent receiver selectivity and blocking performance
· Frequency bands: 300-348 MHz, 387-464 MHz and 779-928 MHz
· Programmable data rate from 0.6 to 600 kbps
· 64-byte Rx and Tx data
· 4mm x 4mm package with 20 pins
· Complete on-chip frequency synthesizer
· No external filters or RF switch needed.
· Low cost
· Low power

·	Range extender available with attached CC1190
·	High sensitivity
·	Flexible support for packet oriented systems.

Table 3.3.4.1A--*(App A: CC1101 [2])*

Cons	
·	Inexperienced programing

Table 3.4.4.1B--*(App A: CC1101 [2])*

The layout with the attached CC1190 witch is a board with a visible antenna attached. Below you will see the actual block diagram of the CC1190 and what it looks like, and simplified CC1101-CC1190 Application Circuit.

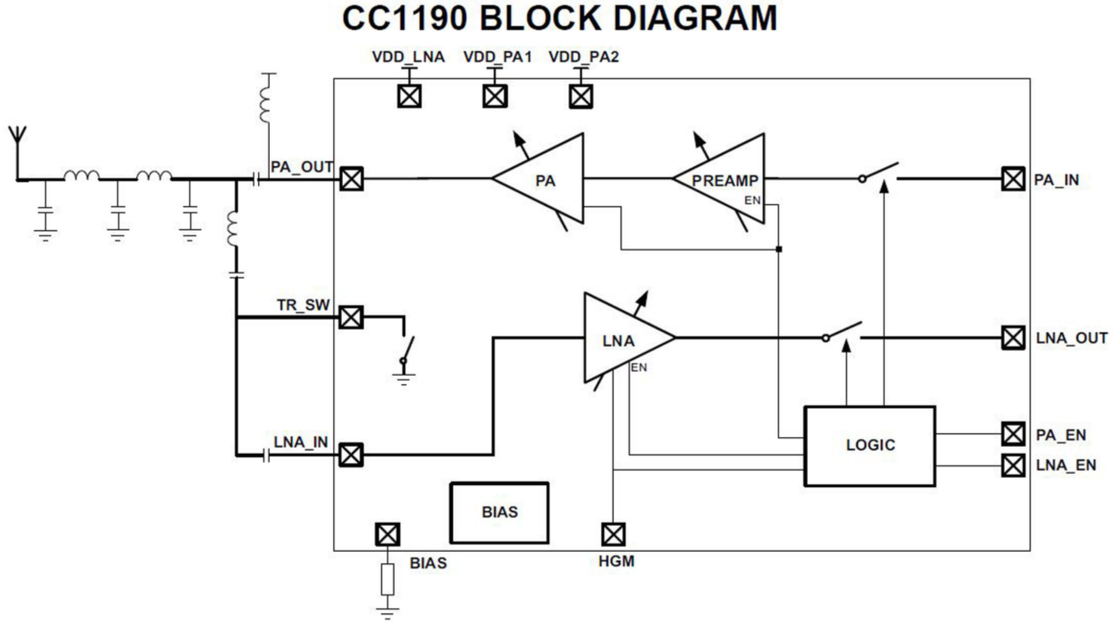


Figure 3.3.4.2A – *(App A: CC1101 [2])*

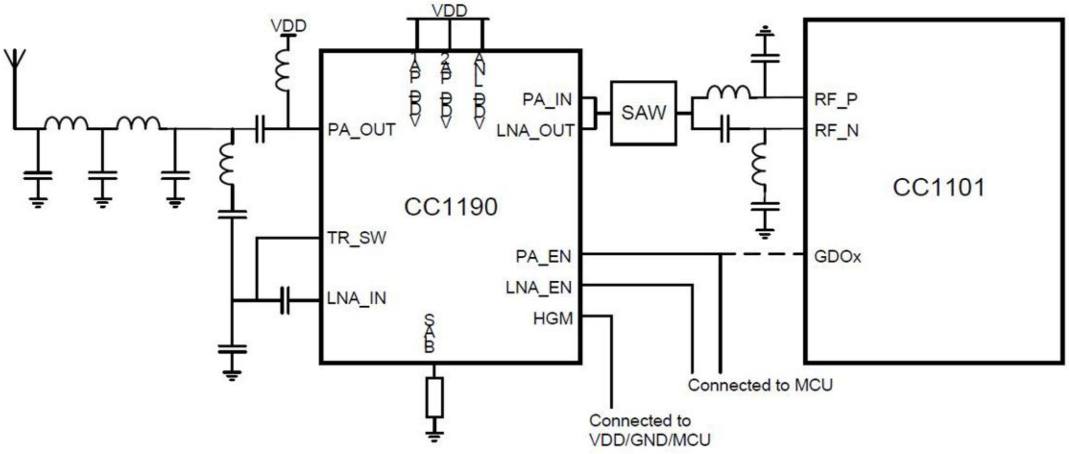


Figure 3.3.4.2B – *(App A: CC1101 [2])*

For this particular project it is uncertain if the CC1190 is really necessary since all this project is going to show is that the technology works. Ideally in its actual form of use, this device will have a much larger range than what will be shown in this projects demonstration. Because of this reason it has yet to be decided if the project will be using the attached CC1190 for an extended range.

CC2500 - Another option for the wireless attachment to the MSP430F5438 experimenter's board is the CC2500. It's pretty similar to the CC1101 with some differences. Along with the CC1101 the product itself is low-cost and low power, one notable difference is that the CC2500 is a 2.4 GHz transceiver when the CC1101 was a 1.0 GHz transceiver. For this project it was decided to stick with the 1GHz transceiver since there could be some more issues arising from the 2.4 GHz range with wavelength congestion. The circuit on this device is intended for the 2400-2483.5 MHz ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency band. Along with the CC1101 the CC2500 is also has a baseband modem that has the ability to be highly configurable. The modem itself has can support many different modulation formats; however the configurable data rate is up to 500 kbps for the CC2500. *(App A: CC2500 [3])*

The CC2500 is also a popular option with the Texas Instruments wireless attachments so there is again extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication, and wake-on-radio. The CC2500 is also a device that also has the main operating parameters and the 64 byte transmit/receive FIFOs can all be controlled with an SPI interface or a Serial Peripheral Interface, which in turn means that data is shifted out and in one bit at a time. Of course the CC2500 in most cases if not all cases will be used together with a microcontroller and a few additional passive components in a typical system. Below you can see the recommended layout for this device on a PCB and also you can see the pin configuration of the device. *(App A: CC2500 [3])*

Pin Layout- It would be best to get a better understanding of what each pin does in the CC2500 in order to make the decision of whether it would benefit this project the most. The pin layout for the CC2500 is very straight forward as it is. For the wireless circuit design a lot of these pins will be used. Just to have a better understanding of what each pin actually does here is what each pin means and what it is used for:

Starting with *Pin 1* (SCLK) is a digital input pin, the main reason why this pin would be used in the design would be for a serial configuration interface, clock input. *Pin 2* SO (GDO1) is a digital output pin, the main reason for this pin is for the serial configuration interface, data output, it's the optional general output pin when CSn is in the high position. *Pin 3* (GDO2) is similar to pin 2 as in it is also a digital output pin, however it's more of a general output pin for general uses such as testing signals, FIFO status signals, clear channel indicator, clock output, down-divided from XOSC, and serial output RX data. *Pin 4* (DVDD) is power in the digital form and would be used for the power in the digital form which is used at a 1.8-3.6V digital power supply for digital I/O' sand for the digital core voltage regulator. *Pin 5* (DCOUPL) is also power in the digital form that is used at the 1.6-2.0V digital power supply output for decoupling, however this pin is intended for the use of the CC2500 ONLY. It can't be used to provide power to different components surround the CC2500. *(App A: CC2500 [3])*

Pin 6 GDO0 (ATEST) is the digital I/O, it's a digital output pin for general use mainly to test signals, FIFO status signals, clear channel indicator, clock output, down-divided from XOSC, serial output RX data, serial input TX data, also used as an analog test I/O for prototype/production testing. *Pin 7* (CSn) is the digital input pin, it is used for the basic serial configuration interface, chip select. *Pin 8* (XOSC_Q1) is the analog I/O pin, which is used as the crystal oscillator pin1, or also for the external clock input. *Pin 9* (AVDD) which is a power pin in the analog form, which is used for 1.8V – 3.6 V analog power supply connection. *Pin 10* (XOSC_Q2) is the analog I/O pin which is used for the crystal oscillator pin 2.

Pin 11 (AVDD) is also a power pin in the analog form, which is used in the 1.8-3.6V analog power supply connection. *Pin 12* (RF_P) is the RF I/O pin, which is used for the positive RF input signal to LNA in receive mode and also the RF output signal from the PA in transmit mode. *Pin 13* (RF_N) is also an RF I/O pin, which is used for negative RF input signal to LNA in receive mode, also for negative RF output signal from PA in transmit mode. *Pin 14* (AVDD) is a power pin in the analog form, which is a 1.8-3.6V analog power supply connection. *Pin 15* (AVDD) is another power pin the analog form, which is a 1.8-3.6 V analog power supply connection pin. *(App A: CC2500 [3])*

Pin 16 (GND) is the analog ground pin which is used as the analog ground connection. *Pin 17* (RBIAS) is another analog I/O pin, which is the external bias resistor for reference current. *Pin 18* (DGUARD) is another power pin in the digital form, which is the power supply connection for the digital noise isolation. *Pin 19* (GND) is the ground pin in the digital form, which is the ground connection for digital noise isolation. *Pin 20* (SI) is a Digital input pin, which is the serial configuration interface, data input. *(App A: CC2500 [3])*

Although the CC2500 is the same pin layout as the CC1101 it is different in many ways, especially when it comes to what wavelength these two components operate in. as described before the range RF extender can only be added to the CC1101 the CC1190 to it witch is an 850-950 MHz range extender. With this sort of pin layout for both of these transceivers there are only a couple things separating which one would be easier to work with. Most people have decided to go with the CC1101 for the simple fact that it could potentially have a larger range than the CC2500. One would still have to construct the two circuits together and make them work as one but the range seems to be worth it. Personally the range is not as important for this project since it will be scaled way down as mentioned before. The project only wants to show that the wireless portion is a "doable" thing. So all in all, when considering these two transceivers soly based on pin layout there is not one better than the other since they are the same exact thing. The thing that came down to the final decision for the choice of transceiver it was simply decided based on the wavelength at which the CC1101 operated in vs. the CC2500. As mentioned above you can see the pin layout for this transceiver below and what it actually looks like.

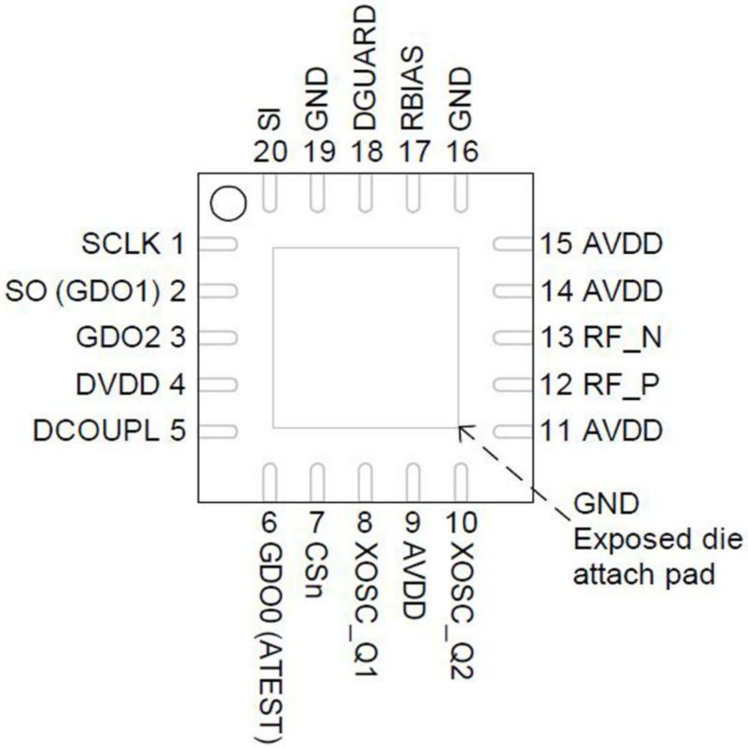


Figure 3.3.4.3A: CC2500 Pin Configuration – Courtesy of Texas Instruments

Pros
· Low power
· Low cost
· Frequency range 2400-2483.5 MHz
· Programmable data rate from 1.2 to 500 kBaud
· Flexible support for packet oriented systems
· Few external components
· Small size 4x4 mm
· 20 pins
· Programmable preamble quality indicator
· Low current consumption

Table 3.3.4.5A--*(App A: CC2500 [3])*

Cons
· 2.4 GHz frequency
· Inexperienced programing

Table 3.3.4.5B--*(App A: CC2500 [3])*

CC2420 – Another option for the wireless attachment to the MSP430F5438 experimenter's board is the CC2420 is a 2.4 GHz IEEE 802.15.4 ZigBee-ready RF Transceiver. Unlike the other two transceivers the CC2420 is ZigBee ready which means' it will work with ZigBee systems. The CC2420 is designed for low power and low voltage wireless applications. It's modem is a digital direct sequence spread spectrum baseband modem, therefore is will be able to provide a spreading gain of 9 dB and a data rate of 250 kbps. A good thing about this device as like the other devices it complies with worldwide regulations with the robust wireless communications in the 2.4 GHz unlicensed ISM (Industrial, Scientific and Medical) band, it also has a lot of hardware support for packet handling, data buffering, burst transmissions, data encryption, data authentication, clear channel assessment, link quality indication and packet timing information. All of this in turn reduces the load on the host controller so in that case the CC2420 can use low-cost microcontrollers. *(App A: CC2420 [4])*

Along with the other transceivers the CC2420 has things such as the main operating parameters and the 64 byte transmit/receive FIFOs can all be controlled with an SPI interface or a Serial Peripheral Interface, which in turn means that data is shifted out and in one bit at a time. Of course the CC1101 in most cases if not all cases will be used together with a microcontroller and a few additional passive components in a typical system. Below you can see what the integrated circuit looks like for the CC2420 and also the pin configuration of the CC2420.

Pin Layout – The CC2420 has more pins than both the CC1101 and the CC2500, in the sense that this particular wireless transceiver has more applications than the other two transceivers. It would be a good idea to go through every pin on this transceiver and see exactly what it does and what it can be used for as it was done for the other transceivers.

To start things off the first pin that will be looked at is the *pin "-"* which is the (AGND) pin, this pin is the ground pin in the analog form, it's basically an exposed die attach pad, which must be connected to solid ground plane. *Pin 1* (VCO_GUARD) is the power pin in the form of analog, which is the connection of guard ring for VCO (to AVDD) shielding. *Pin 2* (AVDD_VCO) is another power pin in the analog form that has a 1.8V power supply for the VCO. *Pin 3* (AVDD_PRE) is another power pin in the analog form with a 1.8V power supply for the Prescaler. *Pin 4* (AVDD_RF1) is another power pin in the analog form that is a 1.8 V power supply for the RF front-end. *Pin 5* (GND) is the ground in the analog form which is a grounded pin for the RF shielding. *(App A: CC2420 [4])*

Pin 6 (RF_P) is the RF I/O pin which is the positive RF input/output signal to LNA/from PA in receive/transmit mode. *Pin 7* (TXRX_SWITCH) is another power pin in the analog form which is a common supply connection for integrated RF front-end. This particular pin must be connected to the RF_P and RF_N externally through a DC path. *Pin 8* (RF_N) is the RF I/O pin which is the negative RF input/output signal to LNA/form PA in receive/transmit mode. *Pin 9* (GND) is another ground pin in the analog form which is the grounded pin for the RF shielding. *Pin 10* (AVDD_SW) is another power pin in the analog form which has a 1.8V power supply for the LNA/PA switch. *(App A: CC2420 [4])*

Pin 11 (NC) is a useless pin that is “not connected”. Similar with Pin 11, *Pin 12-13* are both (NC) which is not connected to anything and is a useless pin. *Pin 14* (AVDD_RF2) is another power pin in the analog form which has a 1.8V power supply for receive and transmit mixers.*Pin 15* (AVDD_IF2) is another power pin in the analog form which has a 1.8 V power supply for transmit/receive IF chain.

Pin 16 (NC) is another useless pin that is not connected to anything. *Pin 17* (AVDD_ADC) is another power pin in the analog form which has a 1.8V power supply for analog parts of ADCs and DACs. *Pin 18* (DVDD_ADC) is a power pin in the digital from which has a 1.8 V power supply for the digital parts of receive ADCs. *Pin 19* (DGND_GUARD) is a ground pin in the digital form which a ground connection for the digital noise isolation. *Pin 20* (DGUARD) is another power pin in the digital for which has a 1.8 V power supply connection for digital noise isolation. *(App A: CC2420 [4])*

Pin 21 (RESETn) is a digital input pin which is asynchronous, active low digital reset. *Pin 22* (DGND) is another ground pin in the digital form which is a ground connection for the digital core and pads. *Pin 23* (DSUB_PADS) is another ground pin in the digital form which is a substrate connection for digital pads. *Pin 24* (DSUB_CORE) is another ground pin in the digital form which is a substrate connection for digital modules. *Pin 25* (DVDD3.3) is another power pin in the digital form which has a 3.3V power supply for digital I/O’s. *(App A: CC2420 [4])*

Pin 26 (DVDD1.8) is another power pin in the digital form which has a 1.8V power supply for digital core. *Pin 27* (SFD) is a digital output pin which is a SFD(start of frame delimiter) and digital mux output. *Pin 28* (CCA) is another output in the digital form which is a CCA(clear channel assessment) and digital mux output.*Pin 29* (FIFOP) is another output pin in the digital form which is active when the number of bytes in FIFO exceeds threshold and is a serial RF clock output in test mode. *Pin 30* (FIFO) is the digital I/O pin which is active when data in FIFO, serial RF data input, and output in test mode. *(App A: CC2420 [4])*

Pin 31 (CSn) is another input pin in the digital form which is the SPI chip select, active low. *Pin 32* (SCLK) is another digital input pin, which is the SPI clock input; up to 10MHz. *Pin 33* (SI) is another input pin in the digital form which is an SPI slave input pin that’s sampled on the positive edge of SCLK. *Pin 34* (SO) another output pin in the digital form (tristate) which is the SPI slave output pin that is updated on the negative edge of SCLK, and tristates when CSn is high. *Pin 35* (DVDD_RAM) is another power pin in the digital form which has a 1.8 V power supply for the digital RAM. *(App A: CC2420 [4])*

Pin 36 (NC) is a pin that will not be used since it’s not connected. *Pin 37* (AVDD_XOSC16) is another power pin in the analog form which is a 1.8 V crystal oscillator power supply. *Pin 38* (XOSC16_Q2) is an analog I/O pin which is a 16MHz crystal oscillator pin 2. *Pin 39* (XOSC16_Q1) is another analog I/O pin which is a 16MHz crystal oscillator pin 1 or external clock input. *Pin 40* (NC) is another pin that is not connected which is no use to the pin layout. *(App A: CC2420 [4])*

Pin 41 (VREG_EN) is another input pin in the digital form which is a voltage regulator enable, active at high, held at VREG_IN voltage level when active. Note: that the VREG_EN is relative VREG_IN, not DVDD3.3. *Pin 42* (VREG_OUT) is a power output pin which is a voltage regulator with 1.8V power supply output. *Pin 43* (VREG_IN) is another power pin in the analog form which is a voltage regulator with 2.1 to 3.6 V power supply input. *Pin 44* (AVDD_IF1) is another power pin in the analog form which is a 1.8 V power supply for a transmit/receive IF chain. *Pin 45* (R_BIAS) is an analog output pin which has an external precision resistor, 43Kohm, +/- 1%. *(App A: CC2420 [4])*

Pin 46 (ATEST2) is an analog I/O pin which is an analog test I/O for prototype and production testing. *Pin 47* (ATEST1) is another analog I/O Pin which is and analog test I/O for prototype and production testing. *Pin 48* (AVDD_CHP) is another power pin in the analog form which has a 1.8 V power supply for phase detector and charge pump. *(App A: CC2420 [4])*

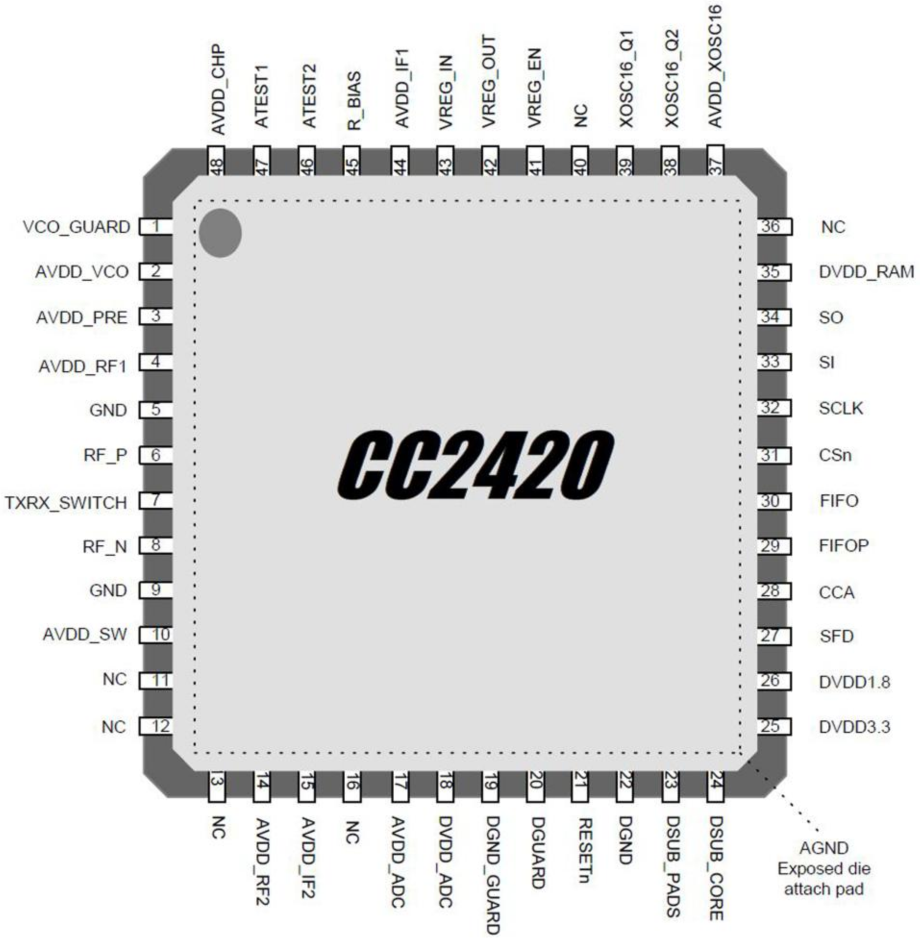


Figure 3.3.4.4: CC2420 Pin Configuration – Courtesy of Texas Instruments

Pros
· Low voltage
· Low power
· Low cost
· Samples available
· Programmable output power
· Powerful and flexible development tools available
· No external RF switch/filter needed
· Battery monitor
· Low supply voltage (2.1-3.6 V)
· Integrated voltage regulator

Table 3.3.4.6A--*(App A: CC2420 [4])*

Cons
· 2.4 GHz ZigBee
· Inexperienced programing

Table 3.3.4.6B--*(App A: CC2420 [4])*

<u>*CC2520*</u> – Another option for the wireless attachment to the MSP430F5438 experimenter's board is the CC2520 which similar to the CC2420, the CC2520 is Texas Instruments second generation Zigbee-ready IEEE 802.15.4 radio frequency transceiver for the 2.4 GHz unlicensed ISM (Industrial, Scientific and Medical) band. This particular integrated circuit offers a state-of-the-art selectivity/co-existence, great link budget, operation up to 125 Degrees Celsius and low voltage operation. *(App A: CC2520 [5])*

Along with the other transceivers the CC2520 provides a lot of hardware support for frame handling, data buffering, burst transmissions, data encryption, data authentication, clear channel assessment, link quality indication and frame timing information. The host controller can therefore be a low cost controller due to these features with the CC2520, and in a typical situation the CC2520 will be used with a microcontroller and a few additional passive components. Below you can see the pin configuration of the CC2520 and what the integrated circuit looks like, along with some pro and cons when it comes to using this device for this particular project. *(App A: CC2520 [5])*

<u>*Pin Layout-*</u>

Signal	**Pin#**	**Type**	**Description**
SPI			
SCLK	28	I	SPI interface: serial Clock. Maximum 8 MHz
SO	1	O	SPI interface: Serial Out

SI	2	I	SPI interface: Serial In
CSn	3	I	SPI interface: Chip Select, active low
General Purpose digital I/O			
GPIO0	10	IO	General purpose digital I/O
GPIO1	9	IO	General purpose digital I/O
GPIO2	7	IO	General purpose digital I/O
GPIO3	6	IO	General purpose digital I/O
GPIO4	5	IO	General purpose digital I/O
GPIO5	4	IO	General purpose digital I/O
Misc			
RESETn	25	I	External reset pin, active low
VREG_EN	26	I	When high, digital voltage regulator is active.
NC	15,18,21		Not connected.
Analog			
RBIAS	23	Analog IO	External precision blas resistor for reference current 56 Kohm, +/- 1%
RF_N	19	RF IO	Negative RF input signal to LNA in receive mode and Negative RF output signal from PA in transmit mode
RF_P	17	RF IO	Positive RF input signal to LNA in receive mode and Positive RF output signal from PA in transmit mode
XOSC32M_Q1	13	Analog IO	Crystal Oscillator Pin1
XOSC32M_Q2	12	Analog IO	Crystal Oscillator Pin2
Power/ground			
AVDD	11,14,16,20,22	Power (Analog)	1.8 V 3.8 V analog power supply connections
AVDD_GUARD	24	Power (Analog)	Power Supply connection for digital noise isolation and digital voltage regulator.
DCOUPL	27	Power (Digital) O	1.6 V to 2.0 V digital power supply output for decoupling. Note: this pin cannot be used to supply any external devices.

DVDD	8	Power (Digital)	1.8 V to 3.6 V digital power supply for digital pads.
AGND	Die Pad	Ground (Analog)	

Table 3.3.4.7-- *(App A: CC2520 [5])*

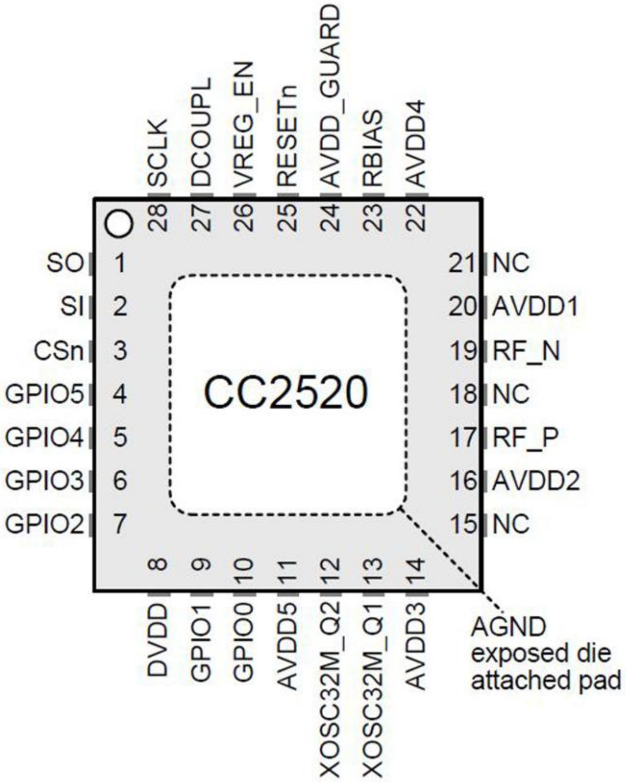


Figure 3.3.4.5: CC2520 Pin Configuration – Courtesy of Texas Instruments

Pros
· Low power wireless sensor networks
· Wide supply range: 1.8V-3.8V
· 6 configurable IO pins
· Automatic CRC
· Fast data rate
· Good radio
· Very small
· Low operating voltage

Table 3.3.4.8A--*(App A: CC2520 [5])*

Cons
· Uses 2.4 GHz ZigBee
· Inexperienced programming

Table 3.3.4.8B--*(App A: CC2520 [5])*

Transceiver Summary:

A quick overview of each transceiver that could be used in the wireless portion of the blood pressure tester is good since it will show the most important comparisons of each possible transceiver which will help decided what transceiver will be used on the design portion of the wireless section of the blood pressure tester.

CC1101 vs. CC2500 – Comparing both the CC1101 and the CC2500; there is not a lot different about these two transceivers, for example both of these transceivers are 4x4 with 20 pins in size, are very low power and very low cost, and have very similar pin layouts. However, the CC1101 has something that the CC2500 does not have. For example, the CC1101 has a frequency range of 300-348MHz, 387-464MHz if using the 27MHz crystal, the lower frequency limit for this band is 392MHz, and 779-928MHz. The CC2500 has a frequency range of 2400-2483.5 MHz, for this project the frequency range that the CC2500 offers is not an ideal range for this project since there could be some problems with congestion in that range as stated above.

Also, the CC1101 has the option to attach the CC1190 for a range extender for the 850-950 MHz range, giving the option to enhance the RF performance of the CC1101, vs. the CC2500 does not have this option, so in comparing these two transceivers the CC1101 is by far a better choice for this project. Mainly for the option of better RF performance and being able to perform in a different frequency range that is not in the 2.4 GHz range.

CC1101 vs. CC2420 – Comparing both the CC1101 vs. the CC2420; there are some differences in a few things when comparing these two transceivers. For starters the CC2420 has a lot more pins and options than the CC1101, the CC2420 come ZigBee-ready when the CC1101 does not. These two transceivers are again very low cost and very low power, however, the CC2420 is substantially bigger than the CC1101. The CC2420 measuring at 7x7 mm with 48 pins when the CC1101 is at 4x4 with 20 pins. This made a huge impact when deciding what transceiver to use since one of the main goals of the blood pressure tester was to make the PCB design as compact as possible.

Knowing this it automatically put the CC2420 in a low option for this project. The CC2420 similar to the CC2500 operates in the 2400-2483.5 frequency range when the CC1101 operates in the 300-348MHz, 387-464MHz if using the 27MHz crystal, the lower frequency limit for this band is 392MHz, and 779-928MHz. Again the CC1101 also has the option to operate with the CC1190 for a range extender for the 850-950 MHz range, giving the option to enhance the RF performance. Where the CC2420 does not come with that option, so again given the fact that the CC2420 is substantially bigger than the CC1101, the CC2420 come ZigBee-ready which is unnecessary for this project, and the fact that the CC2420 operates in the 2.4GHz rang giving it a better chance than the CC1101 to get in a congested frequency. For the Blood Pressure Tester, the CC1101 still had a better chance of being the right transceiver for this project.

CC1101 vs. CC2520 - Comparing both the CC1101 and the CC2520; there are some differences in a few things when comparing these two transceivers. For starters, the CC2520 is very similar to the CC2420; the CC2520 also comes ZigBee-ready, and operates in the 2.4 GHz range. The CC1101 again operates in the 300-348MHz, 387-464MHz if using the 27MHz crystal, the lower frequency limit for this band is 392MHz, and 779-928MHz. Again the CC1101 also has the option to operate with the CC1190 for a range extender for the 850-950 MHz range, giving the option to enhance the RF performance.

These two transceivers are again both very low cost and both very low power making it and obsolete advantage since most Texas Instruments components are low cost and low power. When it comes to size the CC1101 is again a better option since it will take up the least amount of real state on the PCB board measuring at 4x4 with 20 pins and the CC2520 measuring at 5x5 with 28 pins. With the frequency range on the CC2520 being 2.4GHz and the fact that it is going to be taking up more room on the PCB layout. It is an easy choice to say that the CC1101 was the obvious transceiver that the Blood Pressure Tester should use when comparing these two transceivers.

Conclusion – After further research done in senior design II, the xbee module was the final deciding factor for this project. Since it was easily put it on our PCB design and the support for this module was great. Easy to use and it worked flawlessly in the project. Concluding the decision to use the xbee module for the wireless portion of this project.

3.3.5 Display

After the MCU is able to identify the Mean Arterial Pressure (MAP) according to its peak voltage, it applies the necessary algorithm to find the systolic and diastolic measurements and these results are transmitted wirelessly to a display. The two best options to display these measurements were to display it in a Texas Instruments Experimenter Board or display it in a display located in a remote computer. These options are described below:

MSP430F5438 Experimenter Board – This experimenter board is a development platform for the latest generation of MSP430 MCUs developed by Texas Instruments. This board has a 138x110 dot-matrix LCD for rich user interfaces and it is compatible with many TI low-power RF evaluation modules.

Features:

Power Supply sources:

- USB
- FET
- 2x AA batteries

5-position joystick (up, down, left, right, push down)
2 push buttons
2 LEDs
138x110 grayscale, dot-matrix LCD
3-Axis Accelerometer (ADXL330)
Microphone (Amplified by TLV2760)
3.5mm audio output jack (Features TPA301, 350mW Mono Audio Power Amplifier)
Support for TI Low Power RF Wireless Evaluation Modules and eZ430-RF2500T. Currently supported modules: - CC1100/CC1101EMK – Sub-1GHz radio - CC2500EMK – 2.4 GHz radio - CC2420/CC2430EMK – 2.4 GHz 802.15.4 radio - CC2520/CC2530EMK – 2.4 GHz 802.15.4 radio
USB connectivity for data transfer
JTAG header for real-time, in-system programming

MSP430F5529 Experimenter Board – This board was developed by Texas Instruments and is compatible with many TI low-power RF wireless evaluation modules. This board has integrated USB, and more memory and leading integration for application such as energy harvesting, wireless sensing and automatic metering infrastructure.

Features:

USB Development Platform
5-pad capacitive touch strip (button or slider functionality)
microSD Card Slot with 1GB card included
102x64 grayscale, dot-matrix LCD with backlight
4 push buttons (2x User Configured Pushbuttons, 1x Reset Pushbutton, 1x USB Bootstrap Pushbutton)
3 general purpose LEDs, 5 LEDs for capacitive touch buttons, and 1 LED Power indicator
Scroll wheel/Potentiometer
Integrated EM headers allow support for TI Low Power RF Wireless Evaluation Modules and eZ430-RF2500T. Currently supported modules: - CC1100/CC1101EMK - Sub-1GHz radio - CC2500EMK - 2.4 GHz radio - CC2420/CC2430EMK - 2.4 GHz 802.15.4 radio - CC2520/CC2530EMK - 2.4 GHz 802.15.4 radio

Integrated eZ-FET for Spy-Bi-Wire (2-wire JTAG) programming and debugging
JTAG header for full 4-sire JTAG programming and debugging
Multiple power supply options, including USB, JTAG, batteries, or external power supply
Easy access to F5529 I/O pins for prototyping. Port mapping available for additional flexibility

As cost was a major factor in the design of this project, table 3.3.5.1 shows the price of the experimenter boards mentioned previously (MSP430F5438 Experimenter Board and MSP430F5529). This connector is compatible with different wireless designs that utilize the transceivers that are being discussed in section 3.3.4 (Transceivers).

	MSP-EXP430F5438	MSP-EXP430F5529
Price (US$)	**149**	**149**

Table – 3.3.5.1: Price of Experimenter Boards – (App A [28], [29])

<u>BP Monitor Display:</u> this option displays the systolic and diastolic measurements in a display designed by the team members. This option is able to send the measurements from the MCU to a display located at a remote computer. The design for the display is shown below in Fig. 3.5.5.1.

Fig. 3.5.5.1: BP Monitor Display

As showed in figure above, the BP Monitor display is able to show the status of the operation (Started, Aborted, Reading in Progress, Time out) depending on which step the program is executing at that moment. The display is also able to show the systolic and diastolic measurements, as well as detect with an asterisk (*) when the program senses a heartbeat.

After analyzing all the alternatives shown above, the best option for our project was to display the systolic and diastolic measurements in the BP Monitor Display as it is more convenient for someone to see more details about the execution of the program and which state is being executed at that moment.

3.3.6 Analog signal processing

The signal obtained from a pressure sensor of this size is in the 0 – 2.8V range. As it is a mixed signal which contains both DC and a far lower amplitude AC signal, the complete mixed signal must be filtered for noise, amplified, and filtered further to obtain two signals, after which the AC signal is amplified again.

The noise contained in the signal is not only from the electronics of the device but also from movement of the patient when the skin and cuff may slip and cause friction.

The mixed signal is filtered through an internal noise filter of the MP3V5050GP pressure sensor. The output of the pressure sensor is split into two. One output is sent through a high pass and gain filter topology to cut off frequencies lower than 0.8Hz and to amplify the low power signal to the 0-2.1V range. The high pass filtered signal is split into two. One part of the high pass filtered signal is sent to one channel of the analog to digital converter of the MCU. This channel on the analog to digital converter relays oscillation pulse signals to the MCU for detection of blood flow. The second output of the high pass filter is sent to a peak holding circuit to detect and output only the peaks of the pulses. The output of this peak detecting circuit is sent to a second channel of the analog to digital converter. There are less data points existing in the peak signal in comparison to the pulse signal. For calculation of the highest amplitude of the pulses and when it occurs, it is a much simpler calculation to find the highest of a few peak signals than to find the highest amplitude of thousands of data points within the pulses. The other pressure sensor output which is not high pass filtered is sent directly to the analog to digital converter of the MCU to relay the pressure of the cuff.

The DC and AC parts of the signal carry different information regarding the pressure. The DC signal is a constant monitor of the air pressure within the cuff. The DC signal's peak is when the cuff is at maximum air pressure. At this point there should be no blood flow. As the release valve is turned on the air pressure in the cuff will decrease by 5mmHg per second. Soon after this point, blood will start to flow in the arm covered by the cuff. The AC signal reflects oscillations inside of the cuff caused by pulses created by arterial walls flexing from blood flow. During the immediate return of blood to the artery that had been occluded by the cuff, the blood returns in pulses and not in a smooth linear flow. The pulses will increase significantly until the maximum amplitude of these pulses is reached. Afterwards the pulses become significantly diminished in amplitude until they are so faint that they are undetectable. After this point the artery is in its normal pressure state. The peak of the pulse string is determined as the mean arterial pressure (MAP). A calculated percentage of the MAP is known to be the systolic point that is before the MAP in time. A portion of the MAP, after the MAP peak that occurs is calculated to find the diastolic point in time. The two data sets of DC and AC signals are correlated and the points in time registered as systolic and diastolic correspond to pressure measurements in mmHg from the DC signal. The systolic pressure over the diastolic pressure is patient's blood pressure reading. This calculation is completed by the program utilizing an oscillometric algorithm within the microcontroller unit.

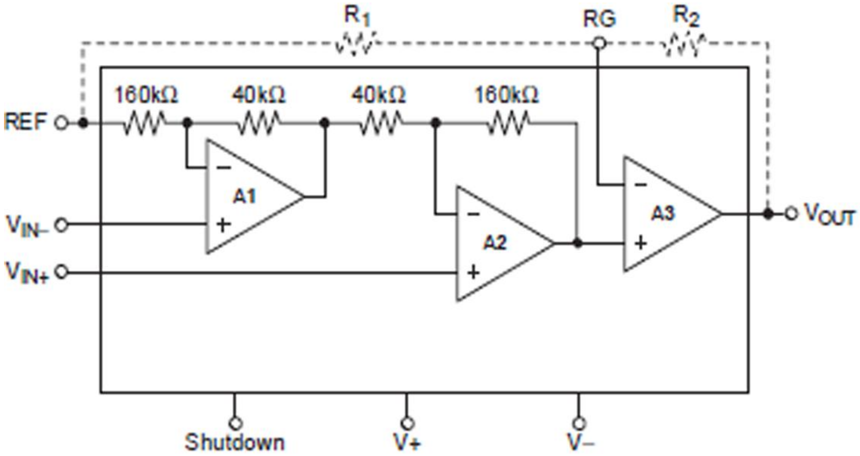


Figure – 3.3.6.1
Texas Instruments INA321
AppA [24]

The gain of the INA321 instrumentation amplifier can be adjusted from its internal gain of 5 volts based on the resistance of the external resistors.
Voltage out = (Vin+-Vin-)*Gain; Gain = 5 + 5(R2/R1)

After exiting the high gain DC instrumentation operational amplifier the signal is split. One part of the signal is directly connected to channel A of the analog to digital converter, on the WS-AFE board, if the device is to be built without the use of the WS-AFE board the analog to digital converter would be located on the same board as the microcontroller unit. The DC signal is sent to channel A of the analog to digital converter so that the DC component of the pressure signal which represents the pressure of the cuff can be monitored, recorded and used in calculating the blood pressure.

The other part of the mixed signal goes to a 0.8Hz second order high-pass filter to remove the DC component. Once the network coefficient (a_{11}) of a 2^{nd} order Butterworth High Pass filter is determined as well as a desired passing frequency (0.8Hz), the resistance and capacitance values to obtain this passing frequency in a filtering circuit can be calculated by deriving an equation from the transfer function of a 2nd order High Pass Butterworth Filter as follows:

$$H_{HPF}(S)=\frac{S^2}{S^2+S\left(\frac{C_2+C_3}{(R_8+R_9+R_{10})C_2C_3}\right)+\frac{1}{(R_8+R_9+R_{10})(R_{17}+R_{18}+R_{19})C_2C_3}}$$

$$R_8+R_9+R_{10}=\frac{C_2+C_3}{C_2C_3\alpha_{11}\omega_c}=\frac{0.1+0.1}{0.1\times0.1\times1.414\times0.8\times2\pi}=1.41M\Omega$$

$$R_{17}+R_{18}+R_{19}=\frac{1}{(R_8+R_9+R_{10})C_2C_3\omega_c^2}=\frac{1}{1.41M\Omega\times0.1\times0.1\times(0.8\times2\pi)^2}=2.86M\Omega$$

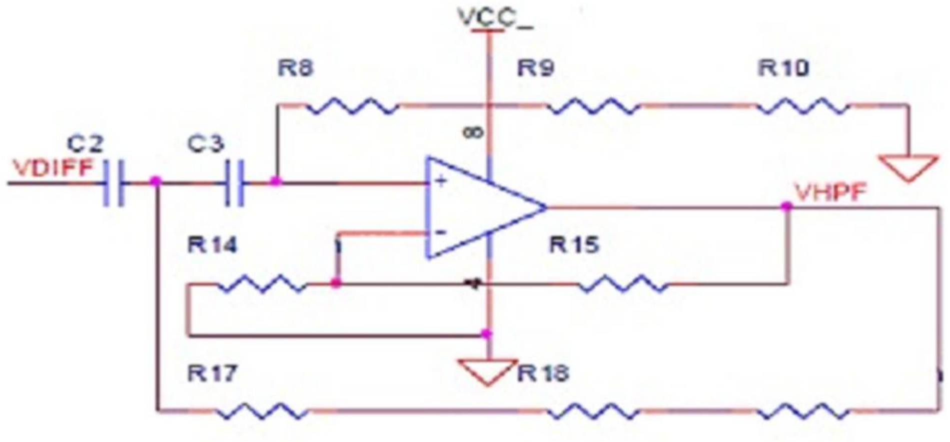


Figure – 3.3.6.2
0.8Hz second order high pass-filter utilizing
Texas Instruments OPA2835 operational amplifier AppA [22]

With the DC component of the signal removed, the AC component of the signal is much weaker than the DC portion of the mixed signal originally was. The AC signal is so weak that it must be amplified in the range of 10 times of its original amplitude so that it can be used. This is done through the use of the OPA2835 operational amplifier being used for gain. If Rs is selected to be 1 kOhms and Rf is selected to be 10000 kOhms because of the relation Gain >> Rf/Rs, the gain of the AC signal will be in the range of 10.

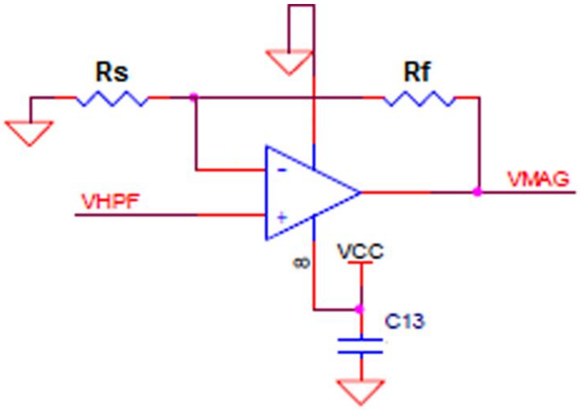


Figure – 3.3.6.3
Gain amplification circuit utilizing
Texas Instruments OPA2835 operational amplifier
AppA [22]

Amplification of the weak AC signal introduces other problems because amplifying the AC signal also amplifies the noise artifacts of the machine and human noise. And therefore this must be filtered out to avoid errors in blood pressure readings. Therefore the amplified AC signal is sent to a a 2nd order Butterworth Low Pass filter. The 38Hz second order low-pass filter will filter high-frequency noise and frequency interference and adjust the signal in the range of 0 to 5V for use in the blood pressure readings as well as in the triggering circuit.

Once the network coefficient (a_{11}) of a 2nd order Butterworth Low Pass filter is determined as well as a desired passing frequency (38Hz), the resistance and capacitance values to obtain this passing frequency in a filtering circuit can be calculated by deriving an equation from the transfer function of a 2nd order Low Pass Butterworth Filter as follows:

$$H_{LPF}(S)=\frac{\frac{1}{(R_{31}+R_{32})R_{29}C_8C_{11}}}{S^2+S\left(\frac{R_{31}+R_{32}+R_{29}}{(R_{31}+R_{32})R_{29}C_{11}}\right)+\frac{1}{(R_{31}+R_{32})R_{29}C_8C_{11}}}$$

$$R_{31}+R_{32}=\frac{\alpha_{11}}{\omega_c C_8}=\frac{1.414}{38\times 2\pi\times 0.1\mu F}=59.3k\Omega$$

$$R_{29}=\frac{1}{(R_{31}+R_{32})C_8C_{11}\omega_c^2}=\frac{1}{59.3\times 0.1\times 0.1\times(38\times 2\pi)^2}=29.3k\Omega$$

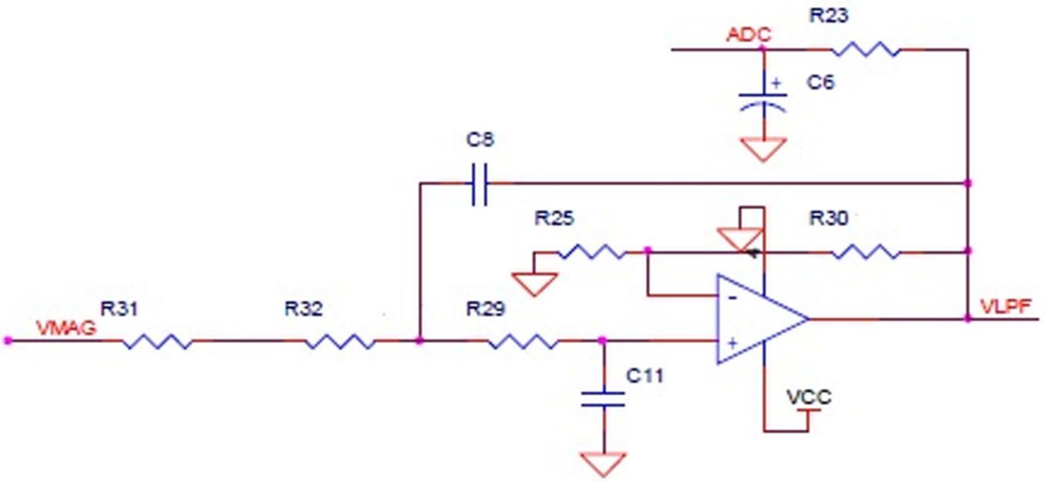


Figure – 3.3.6.4
AppA [22]

After low pass filtering the AC signal is split. One part of the filtered AC signal is sent to a pulse rate trigger circuit for generating trigger pulses that starts the analog to digital converter module operation. The pulse rate trigger circuit will utilize the LM139-N National Semiconductor (now Texas Instruments) voltage comparator requiring a supply voltage within the range of 2 - 36 volts and a supply current of 0.8mA. This low power comparator maintains the device’s low power profile. The other part of the AC signal is sent to channel B of the analog to digital converter for calculating the amplitude of AC signal.

The AC signal passed through the 38Hz 2nd order Low Pass Butterworth filter will be connected to the input of the positive side of the comparator LM139-N. The reference voltage with V_{DD}=3.3 V, will be input to the negative side. The points in time when the AC signal is greater than the reference voltage will induce the LM139-N to output a high signal. When the AC signal is lower than the reference voltage the LM 139-N will output a low signal. This low and high output will create a pulse rate for the starting the ADC module. The reference voltage is determined by choosing resistance values for R_{24} and R_{22} and taking into account the supply voltage.

$$V_{CMPREF} = V_{DD} \times \frac{R_{24}}{R_{22} + R_{24}} = 3.3V \times \frac{R_{24}}{100k + R_{24}}$$

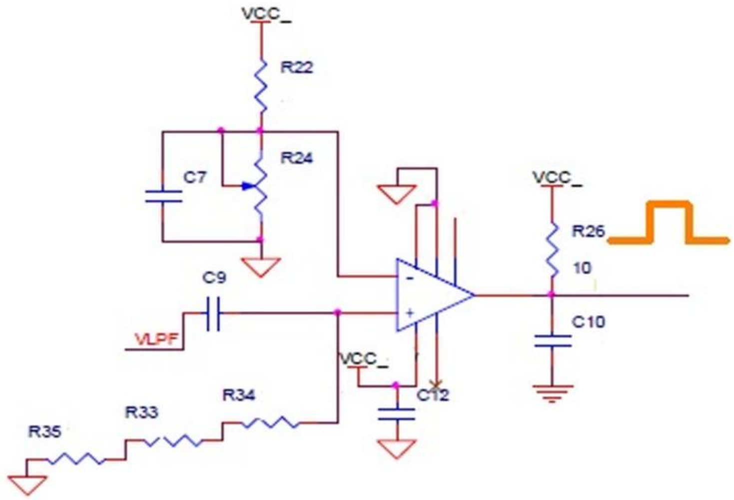


Figure – 3.3.6.5
Voltage differential comparator utilizing
LM139-N National Semiconductor comparator
AppA [22]

The DC and AC parts of the signal carry different information regarding the pressure. The DC signal is a constant monitor of the air pressure within the cuff. The DC signal's peak is when the cuff is at maximum air pressure. At this point there should be no blood flow. As the release valve is turned on the air pressure in the cuff will decrease by 5mmHg per second. Soon after this point, blood will start to flow in the arm covered by the cuff. The AC signal reflects oscillations inside of the cuff caused by pulses created by arterial walls flexing from blood flow. During the immediate return of blood to the artery that had been occluded by the cuff, the blood returns in pulses and not a smooth flow. The pulses will increase significantly until the maximum amplitude of these pulses is reached. Afterwards the pulses become significantly diminished in amplitude until they are so faint that they are undetectable. After this point the artery is in its normal pressure state. The peak of these pulses is determined as the mean arterial pressure (MAP). A tested percentage of the MAP is known to be the systolic point that is before the MAP in time. A portion of the MAP, after the MAP peak occurs is calculated to find the diastolic point in time. The two data sets of DC and AC signals are correlated and the points in time registered as systolic and diastolic correspond to pressure measurements in mmHg from the DC signal. The diastolic pressure is subtracted from the systolic pressure to determine the patient's blood pressure. This calculation is completed by the program utilizing an oscillometric algorithm within the microcontroller unit.

The signal obtained from a pressure sensor of this size is in the 0 – 2.8V range. As it is a mixed signal which contains both DC and a far lower amplitude AC signal, the complete mixed signal must be filtered for noise, amplified, and filtered further to obtain two signals, after which the AC signal is amplified again.

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The mixed signal is filtered through an internal noise filter of the MP3V5050GP pressure sensor. The output of the pressure sensor is split into two. One output is sent through a high pass and gain filter topology to cut off frequencies lower than 0.8Hz and to amplify the low power signal to the 0-2.1V range. The high pass filtered signal is split into two. One part of the high pass filtered signal is sent to one channel of the analog to digital converter of the MCU. This channel on the analog to digital converter relays oscillation pulse signals to the MCU for detection of blood flow. The second output of the high pass filter is sent to a peak holding circuit to detect and output only the peaks of the pulses. The output of this peak detecting circuit is sent to a second channel of the analog to digital converter. There are less data points existing in the peak signal in comparison to the pulse signal. For calculation of the highest amplitude of the pulses and when it occurs, it is a much simpler calculation to find the highest of a few peak signals than to find the highest amplitude of thousands of data points within the pulses. The other pressure sensor output which is not high pass filtered is sent directly to the analog to digital converter of the MCU to relay the pressure of the cuff.

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4.0 Project Hardware and Software Design Details

4.1 Software and Hardware Diagrams

Hardware Block Diagram

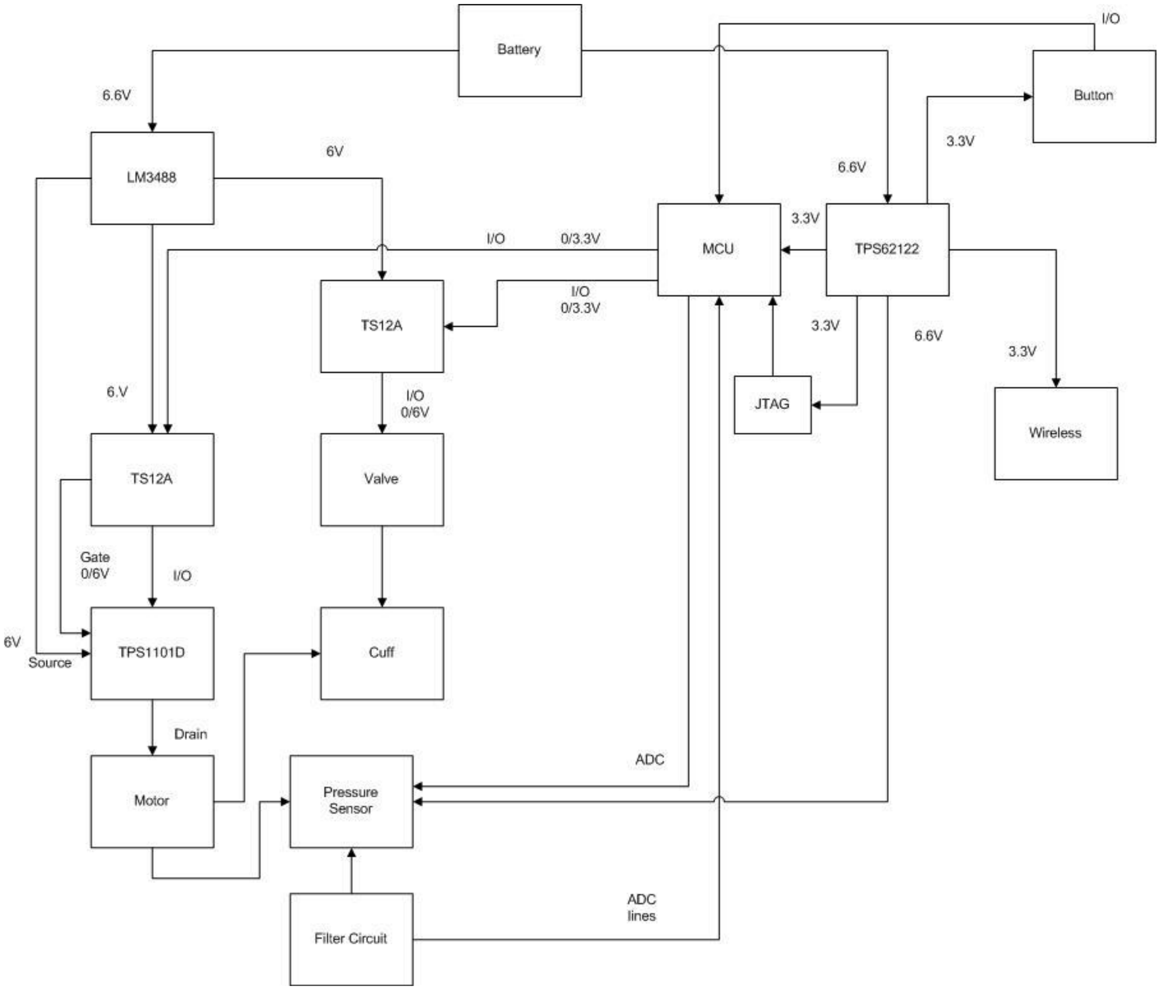


Fig. 4.1.1 Hardware Block Diagram

The hardware block diagram shows how all the major components of the project will be related and from where it receives input and where it sends the output. As shown in Figure 4.1.1, the main components of the system are: the motor, valve, cuff, MCU, pressure sensor and wireless. The system also integrates two voltage regulators (TPS62122 and LM3488). The TPS62122 regulator regulates the voltages coming to the Motor and the Valve, while the TPS62122 regulator regulates the voltages entering the JTAG, the pressure sensor, the wireless, the start button, and the MCU. The system integrates three switches; the first TS12A controls another switch TPS1101D that controls the motor and the last switch controls the valve. There is also a filter circuit that is implemented in the pressure sensor so there is the elimination of noise in the system.

Software Block Diagram

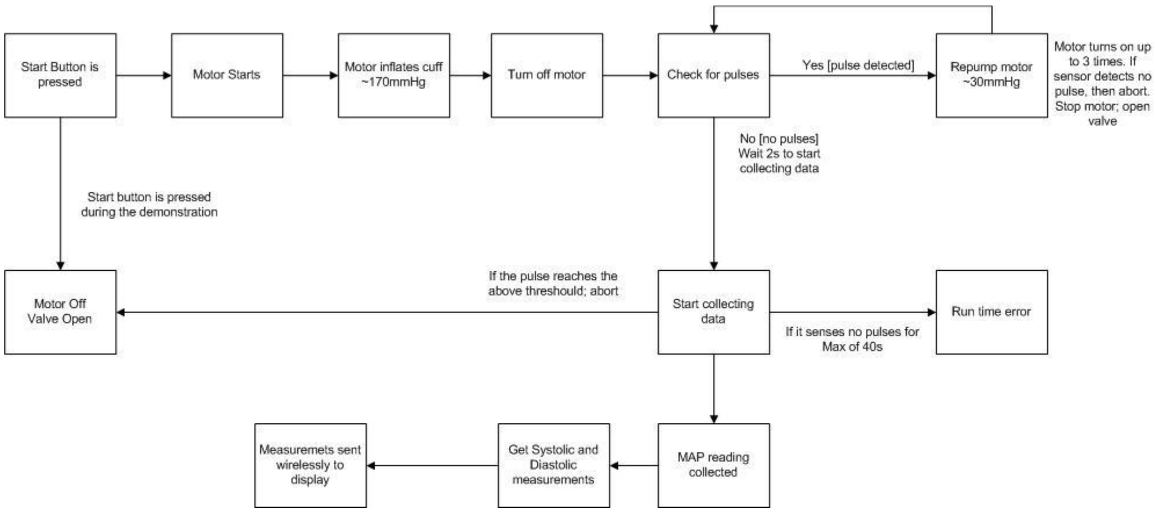


Fig. 4.1.2

The software block diagram showed in Fig. 4.1.2 shows the sequence of events relating the software design of the project. All the programming for this project is done in C language and it was used Code Composer Studio v5.1 as the compiler and developer of the program. As shown in the software block diagram above, the program starts when the Start Button is pressed; when this happens, the motor turns on until the cuff pressure reaches about 170mmHg; the next step is to check the if the sensor senses any pulses (if it does, then turn the motor back on so the cuff pressure is increased by about 30mmHg; this step is performed for at most 3 times). If the sensor senses no more pulses for 2 seconds, it means that there is no more blood flow in the person’s arm and the program can start collecting and recording the pulses (data). If the sensor doesn’t sense any pulses for 40 seconds, then it occurs a run time error and the valve opens up and the system is turned off; also if the person does any sudden movements during the collection of data, then the program is able to detect that high increase in the pulse and the motor turns off and the valve is opened up (error detection). If the data is collected with success and no errors are detected, then the program is able to determine the Mean Arterial Pressure (MAP) and apply the algorithm to find the systolic and diastolic measurements. The last step is to send the data wirelessly to a display located at a computer.

4.2 Hardware Subsystems

4.2.1 Blood Pressure Sensor

The Freescale Semiconductor MP3V5050GP piezoresistive ratio metric pressure sensor was the pressure sensor utilized in this device. It maintains the device's low profile by only needing 3.0V and 7mA to operate correctly. It outputs a maximum voltage of 2.82V and has a pressure range of 0 -7.25 psi. This is more than sufficient to cover the range of human blood pressure values as it represents 0 to 375mmHg.

4.2.2 WS-AFE

The WS-AFE was considered for this project because it serves as an instrumental amplifier. The WS-AFE is an analog-front-end targeting weight measurement followed by a 16bit, 128sps. The weight measurement chain includes an instrumentation amplifier, with gain set by an external resistor, followed by the 16bit ADC, a 6bit DAC for offset correction and a circuit to drive the external bridge/load cell with a fix 1.7V voltage. This voltage is tied to the reference voltage of the ADC, therefore becoming de-facto a ratiometric measurement. The device operates from 2V to 3.6V (supporting, for instance, a CR2032 battery), specified from -15^{o}C to 60^{o}C range and delivered in TQFP-80 form.

Features:

Weight Scale Front-end:
Bridge supply: - 1.7V, 20mA LDO single output with enable/disable (50ms switching time). - Voltage tied to ADC reference (ratiometric).
Instrumentation amplifier internal feedback resistors trimmed to +/-5%.
Gain setting through single external resistor. 100ppm/C (without accounting for ext. resistor).
58nVrms input referred noise from 0.1Hz to 2Hz (G>180, gain resistor noise not included).
6b, +/-6.5uA offset correction DAC.
Best fit linearity (ADC included): +/-0.01%.
Supply current: 200uA typical, 400uA maximum.
ADC:
16bit, 128sps.
Power: 150uA typical, 200uA maximum.
RoHS Compliant and Green.

Table – 4.2.2.1: Features of WSAFE

Table 4.2.2.1 shows the terminal/bond pad description. There are several pins that are not connected, because they would not add any functionality to the project. The instrumentation pins amplify differential inputs for each of the 4 weight scale channels, provide gain setting resistor for the instrumentation amplifier, reference voltage, supply (3.3V), and a clock to latch input data.

Number	Name	I/O	Description
1, 6, 9, 14, 21, 32, 45, 60, 77	AVSS		Ground
2, 3, 4, 5, 10, 11, 12, 13	INP1, INM1 to INP4, INM4	I	Instrumentation amplifier differential inputs for each of the 4 weight scale channels.
7, 8	INPR, INMR		Connection of gain setting resistor for the intr. Amplifier
15, 51	AAUX	I	Auxiliary inputs to the ADC
16	VLDO	O	LDO output to supply the bridge/s (~1.7V)
17	VREF	O	Reference voltage (connect 470nF to ground)
18, 46, 80	AVDD		Supply (3.3V)
8	NC		Do not connect
9	NC		Do not connect
22, 23, 24, 25, 26, 27	NC		Do not connect
28, 29, 30, 31	NC		Do not connect
33, 34, 35, 36, 37, 38	NC		Do not connect
39, 40, 41, 42	NC		Do not connect
47, 48	NC		Do not connect
49, 50	NC		Do not connect
53	/RST	I	0: Reset, 1: Normal operation
54	/STE	I	SPI enable. 0: shift data in, 1: disable.
56	SDOUT	O	Serial data output
57	SDIN	I	Serial data input
58	SCLK	I	Clock to latch input data (negative edge latch)
59	RDY	O	Data ready
79	CLK	I	1MHz
43, 44, 52, 55, 61- 69, 70-76, 78	NC		Do not connect

Table 4.2.2.2: Terminal bond/pad description – Courtesy of Texas Instruments

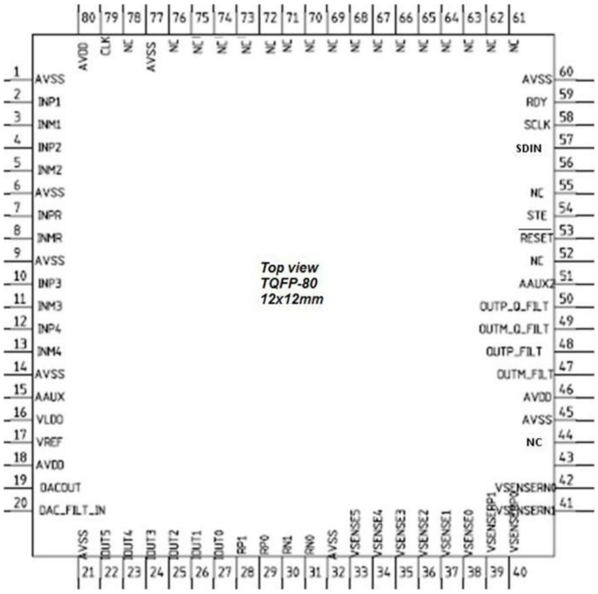


Figure 4.2.2.1: WSAFE pin layout – Courtesy of Texas Instruments

Table 4.2.2.2 shows the absolute maximum ratings of the WSAFE. Stresses above those listed under absolute maximum ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied Exposure to absolute maximum rated conditions for extended periods may degrade device reliability. All voltages referenced to VSS. VCORE is for internal device usage only. No external DC loading or voltage should be applied.

Parameter			Range	Unit
	Voltage applied at VCC to VSS		-0.3 to 4.1	V
	Voltage applied to any pin		-0.3 to VCC + 0.3	V
	Diode current at any device pin		+/-2	mA
T_J	Maximum operating junction temperature		TBD	˚C
T_{stg}	Storage temperature range		-25 to 65	˚C
	Storage humidity		10 to 95	% (Rh)
	ESD Ratings	HBM	2000	V
		CDM	1000	V

Table 4.2.2.3: Absolute Maximum ratings – Courtesy of Texas Instruments

After power up, the device needs to be RST to get all the internal registers to their default state. This can be done by applying a zero pulse in the /RST line for more than 20ns, after 5ms of power being stable. After 30ns, the first access can be initiated (first falling edge of STE, see below).The serial interface lines are:

- STE: SPI interface enable/latch, active low
- SDIN: serial data in
- SDOUT: serial data out
- SCLK: serial clock in. Device latches the data on the falling edge. Outputs the data on the rising edge (so the external receiver will have to latch on the falling edge).

The data packet (between falling and rising edge of STE) is 24 bits long and it is shifted in serially in SDIN with MSB first. The 8 MSB represent the address of the register being accessed and last 16 bits (LSB) represent the data to be stored or read from that address. Of the 8 bits address, the lower 5 bits are the real address <20:16> bits. <21> is the read/write bit:

- “0” defines a write operation of the 16 data bits <15:0> into the register defined by the <20:16> address.
- “1” triggers a read operation of the register defined by the <20:16> address. The data is output in SDOUT with every rising edge of SCLK. At the same time, data in SDIN is shifted inside the 16 data bits of that given register. In fact, there is a bug on the device that will actually write the shifted data in DIN into the register being read. The read value in SDOUT will still be the correct one, but the register will hold the new data (from SDIN) into it after the write operation is finished.

Also obtained information about the ADC Data Result which would be very useful to the implementation of the WS-AFE in this design. This ADC Data Result provides information about what is stored in each bit of the address.

Address 0x00 - Register storing most recent conversion data, in 2’s complement, with MSB in Bit[15] and LSB in Bit[0]. The ADC Control Register is address 0x01:

15	14	13	12	11	10	9	8
ADC_CONV_MODE	ADC_INP_MUX_SELECT				ADC_PGA		

7	6	5	4	3	2	1	0
ADC_PDN	ADC_DATA_RATE			COMP_MODE	COMP_LATCH	COMP_QUE	

Bit[15]: ADC_CONV_MODE: trigger conversion (write) and status report (read)**.** The bit has different functions when written or read, and as such, will not read what is written to it. Write: 0 = No effect.1 = Single shot conversion mode.By default the ADC is powered down (bit 1[7]=1). Writing a “1” here (1[15]) will trigger one ADC conversion before returning to power down again. If a zero is written in ADC_PDN (1[7]) the ADC will be in continuous mode, taking samples continuously, and the value written in this bit (ADC_CONV_MODE, 1[15]) will have no effect. Read: 0 = Device is currently performing a conversion. 1 = Device is not currently performing a conversion. In single-shot mode, once 1[15] is asserted, the bit will read '0', indicating that a conversion is currently in progress. Once conversion data is ready, the bit returns ‘1’ and the ADC powers down. In continuous conversion mode, once a conversion has been completed, the WSAFE places the result in the conversion register (ADC_DATA_RESULT, 0[15:0]) and immediately begins another conversion. Reading this bit (1[15]) has no meaning. When conversion is finalized, the RDY pin may be asserted (see application information for more details).

Bit[14:11]: ADC_INPUT_MUX_SELECT: ADC input mux and reference selection. These bits select which of the inputs of the multiplexer (right in front of the ADC) are connected to the input of the ADC, and what is the level driving the ADC reference. The inputs to the multiplexer come from the peripheral blocks, through a first multiplexer controlled by PERIPHERAL_SEL (16[4:0]). Selection of reference between power supply or input pin is done with bit[14].

ADC_INPUT_MUX_SELECT[14:11]	ADC AINP, AINM	ADCREF
0000 (default)	AI1, AI2	AVDD
0100	AI1, AVSS	AVDD
0101	AI2, AVSS	AVDD
0110	AI3, AVSS	AVDD
0111	AI4, AVSS	AVDD
1000	AI1, AVSS	AIN3
1001	AI1, AVSS	AIN3
1010	AI2, AVSS	AIN3
1011	AVDD, AVSS	AIN3

Table – 4.2.2.4: Address Bits related to ADC AINP, AINM

Bit[10:8]: ADC_PGA. Gain select: These bits select one of six different PGA settings.

CONFIG[10:8]	PGA gain
000	½
001 (default)	1
010	2

011	4
100	8
101	16
110	16
111	16

Table – 4.2.2.5: Bits related to the PGA gain

Bit[7]: ADC_PDN. ADC Powerdown**.** ADC is power down when the bit is high (default after powering up the device).Read/Write: 0 = Continuous conversion mode, 1 = Shutdown mode (default).

Bit[6:4]: Conversion rate: Conversion rate select bits. These bits select one of eight different conversion rates. Table assumes an input clock of 1MHz.

CONFIG[6:4]	**Sample rate (sps)**
000	8
001	16
010	32
011	64
100 (default)	128
101	250
110	475
111	862

Table – 4.2.2.6: Bits related to the sample rate

Bit[3]: Comparator mode**:** Comparator mode select bit. This bit toggles the comparator between normal comparator mode (“0”) and window comparator mode (“1”). In normal comparator mode, the comparator triggers only when the measured voltage is greater than the upper threshold value (COMP_HIGH_LEVEL). In window comparator mode, the comparator triggers when the measured voltage increases above the upper threshold or decreases below the lower threshold (COMP_LOW_LEVEL). Read/Write: 0 = Comparator (default), 1 = Window Comparator. The output of the comparator may be routed to the RDY pin. See application information for more details.

Bit[2]: Comparator latch**:** Toggles the comparator between being transparent or latched. When latched, the bit will remain asserted until a successful SMB alert response is initiated from the master even if the analog inputs are no longer triggering the comparator. When transparent, the alert pin will relax from assertion when analog inputs are no longer triggering the comparator. Read/Write: 0 = Transparent (default), 1 = Latched.

Bit[1:0]: Fault Queue: Dual function bits. Sets the number conversions required to trigger the comparator or disable the comparator.

CONFIG[1:0]	**Fault queue**
00	1st fault
01	2nd fault
10	3rd fault
11 (default)	Comparator disabled

Table – 4.2.2.7: Bits related to the Fault queue

For the computer low level design, the address that is responsible for it is address 0x02. Bit [15:0]: Low level trigger point stored in 2’s complement with MSB in Bit[15] and LSB in Bit[0]. Its default value is 1000 0000 0000 0000b. For the computer low high design, the address that is responsible for it is address 0x03. Bit [15:0]: High level trigger point stored in 2’s complement with MSB in Bit[15] and LSB in Bit[0]. The default value is 0111 1111 1111 1111b.

The first address that controls the device is address 0x09. Bit [0]: Enable Weight Scale. 0: power down weight scale circuit; 1: power up weight scale circuit. Bit [1]: Enable Body Composition: 0: power down body composition circuit; 1: power up weight scale circuit. Bit [2]: Enable Bias Generator: 0: power down bias generation circuit; 1: power up bias generation circuit. Bit [3]: Powerdown DAC: 0: power up DAC; 1: power down DAC. Bit [12]: LDO_MODE_SELECT: By default (value 0), when measuring weight, the LDO output is connected to LDO pin, and when measuring impedance the LDO is connected to the VREF pin. Nevertheless, a value of 1 inverts this behavior. Bit [14]: PULL-UP/DOWN: 0 (default): disconnects the internal pull-up or pull-down resistors on the digital pins to save power if these are not needed. 1: enables the internal pull-up or pull-down resistors. Table shows a summary of the functionality of each bit for this address.

15	14	13	12	11	10	9	8
X	Pull-up/down	X	LDO_MODE_SELECT	X	X	X	X

7	6	5	4	3	2	1	0

X	X	X	X	DAC Powerdown	Enable Bias Generator	Enable Body Composition	Enable Weight scale

The address responsible for the weight scale control is address 0x0D. Bit[14:13] INA stage 2 gain setting: sets the gain of the 2nd stage of the INA, from 1 to 4. 00: Gain = 1; 01: Gain = 2; 10: Gain= 3; and 11: Gain = 4. Table shows a summary of the functionality of each bit for this address. Bit [5:0] Offset correction DAC setting: sets the value for the DAC used to correct the input offset, usually dominated by the bridge offset (see application section). This is done at the 2nd stage. The offset correction at the output of the first stage is given by OFFSET_DAC_VALUE * 31.2mV. Notice that OFFSET_DAC_VALUE is a number from -32 to 31, in 2's complement.

15	14	13	12	11	10	9	8
X	INA_STG2_GAIN		X	X	X	X	X

7	6	5	4	3	2	1	0
X	X	OFFSET_DAC_VALUE					

The second address that controls the device is address 0x0F. Bit [7], Bit [0] battery monitor is used to monitor the supply value. Once enabled by writing the register bits 15[7] and 15[0] to logic 1's, the supply 3 V is routed to AAUX2 input of the ADC. Programming the peripheral select bits (10[4:0]) to 1001, AAUX2 is routed to the AI2 mux input of the ADC. For 00: Monitor disabled, for 11: monitor enabled. Bit [2:1] Bridge select: Selects one of the 4 differential input pairs to the instrumentation amplifier. For 00: bridge 1 (INP1, INM1) connected to the input of the instrumentation amplifier. For 01: bridge 2 (INP2, INM2) connected to the input of the instrumentation amplifier. For 10: bridge 3 (INP3, INM3) connected to the input of the instrumentation amplifier. 11: bridge 4 (INP4, INM4) connected to the input of the instrumentation amplifier.

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
BAT_MON1	X	IQ_DEMOD_CLK_DIV_FAC			BRIDGE_SEL		BAT_MON0

The address responsible for the ADC control register is address 0x10. Bit [6:5] ADC reference select: selects the reference for the ADC: For 00: ADCREF connected to VLDO, and VREF- to GND and it is used for ratiometric weight scale measurement. For 11: ADCREF connected to VREF (internal voltage reference generator) and it is used for impedance measurement. Bit [4:0] Peripheral select: selects what signal conditioning blocks are connected to the AI1, AI2 multiplexer inputs of the ADC. For 00000: Connect weight scale instrumentation amplifier outputs (outp/outm) to ADC mux inputs AI1/AI2. For 00011: connect body composition meter outputs OUTP_FILT/OUTM_FILT to ADC mux inputs AI1/AI2.For 00101: connect body composition meter outputs OUTP_Q_FILT/OUTM_Q_FILT to ADC mux inputs AI1/AI2. For 01001: connect AAUX1 to ADC mux input AI1. ADC mux input AI2 is unknown (floating), therefore an appropriate option would need to be selected in ADC_INPUT_MUX_SEL <3:0> = 0100 or 1001 to convert AI1 with respect to GND. For 10001: connect AAUX2 to ADC mux input AI2. ADC mux input AI1 is unknown (floating), therefore an appropriate option would be chosen in ADC_INPUT_MUX_SEL<3:0> = 0101 or 1010 to convert AI2 with respect to GND. For 11001: connect AAUX1 to ADC muc AI1 and AAUX2 to ADC mux input AI2. All other combination of bits is not valid.

15	14	13	12	11	10	9	8
X	X	X	X	X	X	X	X

7	6	5	4	3	2	1	0
X	ADC_REF_SEL		PERIPHERAL_SEL				

Regarding the WS-AFE application, the circuit needs to be analyzed inside the WS-AFE so can understand how it works and how all the other components are connected to it. Figure 4.2.2.2 shows a top level view of the portion of the front-end devoted to weight scale measurement.

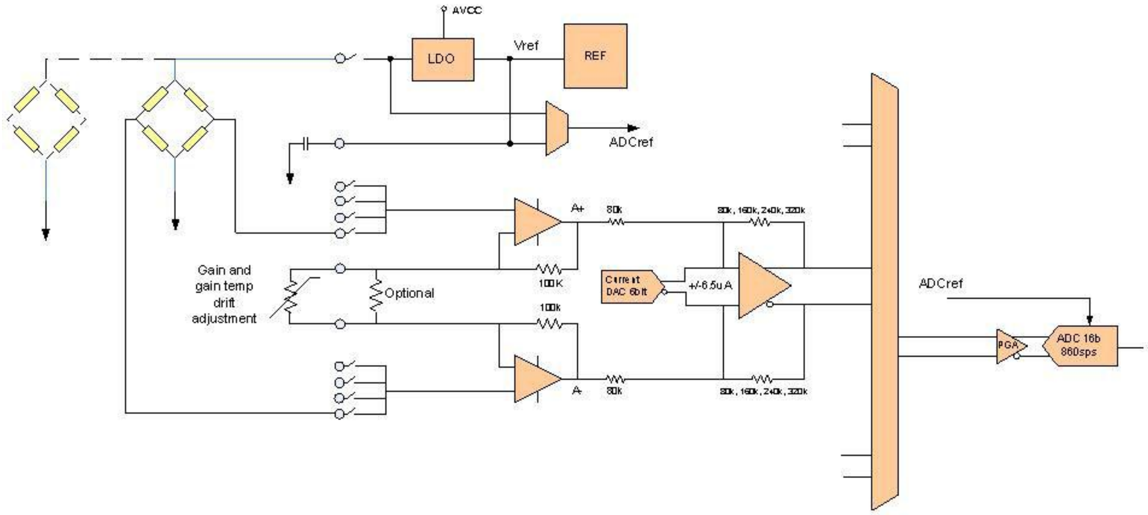


Figure 4.2.2.2: WSAFE circuit – courtesy of Texas Instruments

An internal reference source provides a constant voltage of 1.7V at the VLDO output to drive the external bridge. The output of the bridge is connected to an instrumentation amplifier (first stage). The first stage gain is set by the external resistor and the 100k (+/-5%) feedback resistors as:

$$G=2*(1+100k/Rext)$$

The output of the first stage (terminals A+ and A-) cannot get closer than 0.25V to the supply rails to avoid non-linearity. Therefore, as device is rated for 2V supply, every terminal (A+ and A-) will be limited to 0.25V to 1.75V. Also notice that each output of the first stage (A+ or A-) swings around the common mode set by the bridge common mode. For instance, if the supply of the bridge is 1.7V, the common mode would be about 0.85V. User should set the gain of the first stage as large as possible, to minimize the effect of noise addition from the next stages, but without saturating the first stage, including not only the input signal but also its offset. As an example, let's assume a bridge powered from 1.7V with 1.5mV/V sensitivity and a potential offset between -4mV and 4mV. Worst case, the maximum signal would be 4mV of offset plus 1.7*1.5mV/V= 2.55mV of signal, for a total of 6.55mV. The bridge common mode is ~0.85V. The maximum excursion is 0.85V-0.25V=0.6V (bottom rail) single ended, on each output (A+ or A-), therefore, +/-1.2V differentially at the output of the first stage before it saturates. This means that the first stage can have up to 1.2V/6.55mV = 183 gain.

The 2nd stage gain is controlled by the feedback resistor R_f which can take 4 possible values (80k, 160k, 240k and 320k). As the gain is R_f/80k, the gain setting can be 1, 2, 3 or 4. The offset correction is implemented in the 2nd stage with a 6b differential DAC, where each output is mirror of the other and can output or sink up to 6.5uA. The effect at the output of the second stage is to add up to +/-6.5uA*2*R_f. This is equivalent (referring this to the input of the 2nd stage by dividing by its gain) to a voltage at the input of the 2nd stage (A+/A-) up to +/-6.5uA*2*80k=+/-1V. Notice that this has no effect avoiding the first stage saturation. As the offset correction DAC is a 6bit DAC, the offset compensation step is 2V/2^6=31.2mV when referred to the input of the 2nd stage.

Going back to the above example, the swing at the output of the 1st stage corresponding only to the potential offset range will be 183 * +/-4mV = +/-0.732V. This can be completely removed at the output of the 2nd stage by the offset correction (as it has a +/-1V range) except for a maximum error of 31.2mV. Notice that as the signal swing will be only in the positive direction, they aim at setting the zero of the signal at some negative point in the range, such a way, that the excursion of the signal is centered around zero. This practice maximizes the gain applicable down the chain without saturation. After offset removal, the excursion of the signal, i.e., the maximum differential swing left at stage 1 (due to the signal) is 2.55mV * 183 = 0.466V. Therefore, going back to the offset correction topic, the aim is of an offset correction at the setting of zero of the signal at -0.46/2=-0.23V at the output of stage 1. For instance, if the input offset produced 0.732V at the output of the stage 1, 0.732 + 0.23 = -0.96V would be applied on the offset correction. The output signal of stage 2 goes to the input of an analog multiplexer and it is routed to a PGA followed by a 16bit ADC with external reference. The reference is connected to the voltage applied to the bridge (ratiometric). In our example, the bridge is powered from 1.7V and therefore, the ADC range will be +/- 1.7V. With a PGA setting of 2, the input range of the PGA is +/-0.85V. Therefore, stage 2 gain could be set to round (0.85/0.233) = 3 to utilize as much as possible the full ADC range.

Another part of the WSAFR is the digitizer. The digitizer block includes an analog multiplexer, a PGA and a 16b sigma delta ADC. For battery/VCC monitoring, an internal 1/3 resistor divider is included which enables the measurement using only one reference setting (1.5V) for any battery voltage, simplifying the monitoring routine.

The WSAFE is equipped with a customizable comparator that can issue an alert on the RDY pin. This feature can significantly reduce external circuitry for many applications. The comparator can be implemented as either a traditional comparator or a window comparator via the COMP_MODE bit in the ADC_CONTROL_REGISTER (1[3]). When implemented as a traditional comparator (1[3]=0), the RDY pin asserts (goes low, i.e., active low by default) when conversion data exceed the limit set in the high threshold register (COMP_HIGH_LEVEL, 3[15:0]). The comparator then de-asserts when the input signal falls below the low threshold register value (COMP_LOW_LEVEL, 2[15:0]). See Figure 4.2.2.3 for more details:

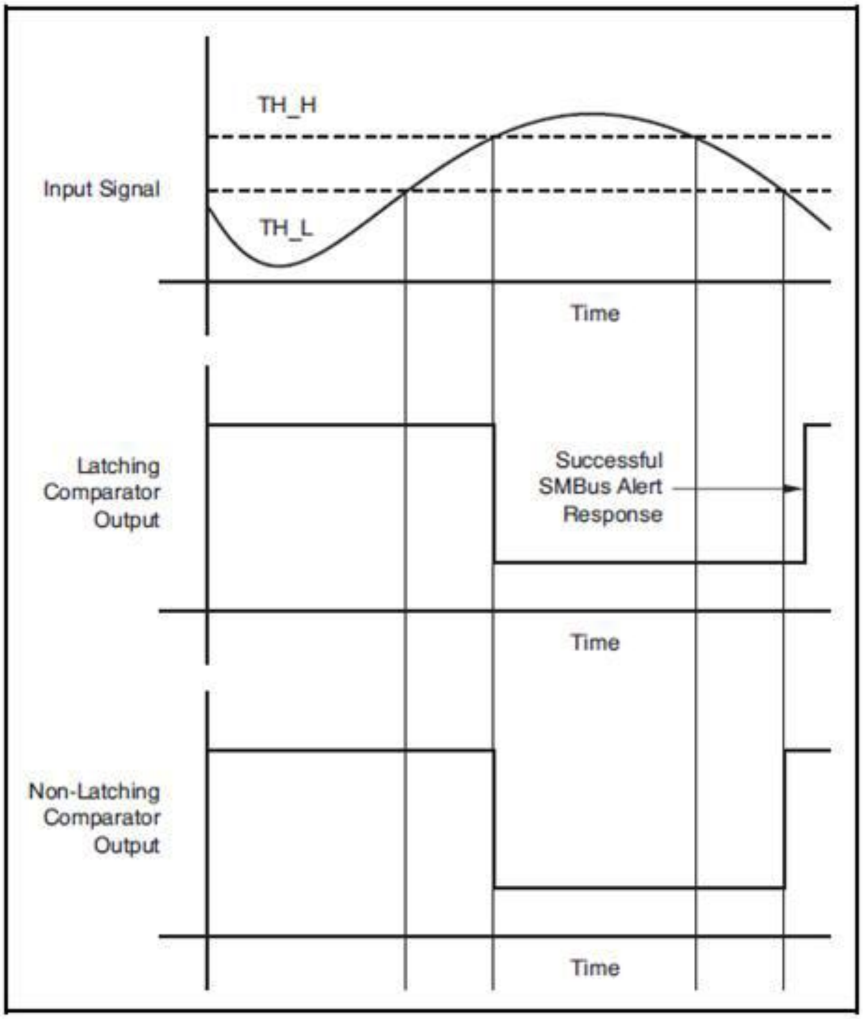


Figure 4.2.2.3: Comparators of the input signals – Courtesy of Texas Instruments

In window comparator mode (1[3]=1), the RDY pin asserts if conversion data exceed the high threshold register or fall below the low threshold register. See Figure for more details:

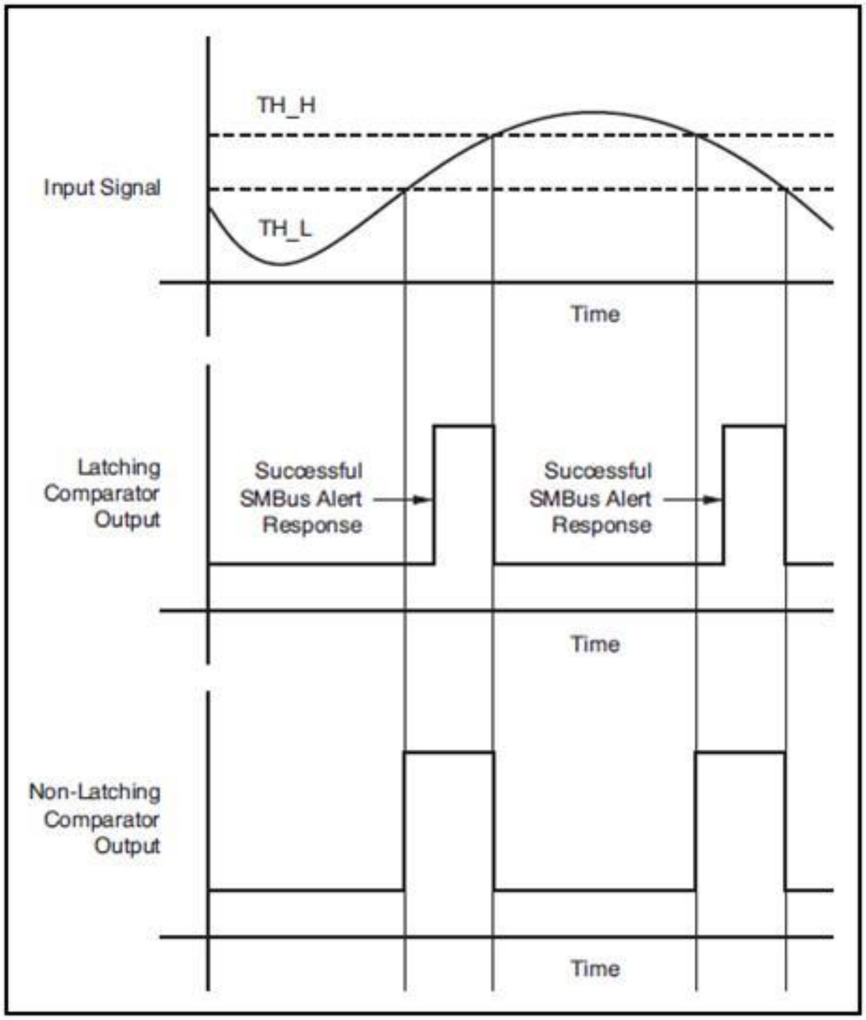


Figure 4.2.2.4: Comparators of the input signals – Courtesy of Texas Instruments

In either window or traditional comparator mode, the comparator can be configured to latch once asserted by the COMP_LATCH bit in the ADC_CONTROL_REGISTER (1[2]). This setting causes the assertion to remain even if the input signal is not beyond the bounds of the threshold registers. This latched assertion can be cleared by issuing an SMBus alert response or by reading the conversion register, ADC_DATA_RESULT (0[15:0]). The COMP_POL bit in the Config register configures the ALERT/RDY pin as active high or active low.

The comparator can be configured to activate the RDY pin after a set number of successive readings exceed the threshold. The comparator can be configured to wait for one, two, or four readings beyond the threshold before activating the RDY pin by changing the COMP_QUE bits in the ADC_CONTROL_REGISTER (1[1:0]). The COMP_QUE bits can also disable the comparator function.

Regarding the RDY PIN as conversion ready PIN, the RDY pin can also be configured as a conversion ready pin. This mode of operation can be realized if the MSB of the high threshold register is set to '1' (3[15]=1) and the MSB of the low threshold register is set to '0' (2[15]=0). The COMP_POL bit continues to function and the COMP_QUE bits can disable the pin. However, the COMP_MODE and COMP_LATCH bits no longer control any function. When configured as a conversion ready pin, RDY continues to require a pull-up resistor. When in continuous conversion mode, the WSAFE provide a brief (~8µs) pulse on the RDY pin at the end of each conversion. When in single-shot shutdown mode, the RDY pin asserts low at the end of a conversion if the COMP_POL bit is set to '0'.

4.2.3 Microcontroller

The microcontroller is among the most important components of the system, therefore when the choice was made for this project all the major features of each MCU were taken into consideration as you can see in the table 4.2.3.1.

MSP430	**FG439**	**FG4618**	**FG479**	**FR5739**	**F5438A**
Freq (MHz)	8	8	8	24	25
Flash (KB)	32	116	60	-	256
FRAM (KB)	-	-	-	16	-
SRAM (B)	2048	8192	2048	1024	16384
ADC	12-bit SAR	12-bit SAR	16-bit Sigma Delta	10-bit SAR	12-bit SAR
USCI	USART (1)	USCI_A (1) USCI_B (1)	USCI_A (1) USCI_B (1)	USCI_A (2) USCI_B (1)	USCI_A (4) USCI_A (4)
Approx. Price (US$)	6.60 | 1ku	8.35 | 1ku	6.20 | 1ku	2.45 | 1ku	4.55 | 1ku

Table 4.2.3.1: Comparison of important parameters

After comparing all the MSP430s, the most appropriate MCU to be used in the project was the MSP430F5438A because it has all the features that led the project to accomplish all its goals and objectives. Those features include a reasonable amount of Flash memory to store temporary data, 12-bit Digital to Analog converter, OpAmp, and 2KB of RAM. This MCU is able to receive information from the Analog to Digital Converter Circuit, process the data, and send it, wirelessly, to the display. Besides all those characteristics, this is a low cost, easy to use, MCU.

4.2.4.1 Wireless Design:

For this project is a display that is used, the laptop display. Below is the design for the wireless portion on the actual PCB that was designed, and the pin locations to the MCU.

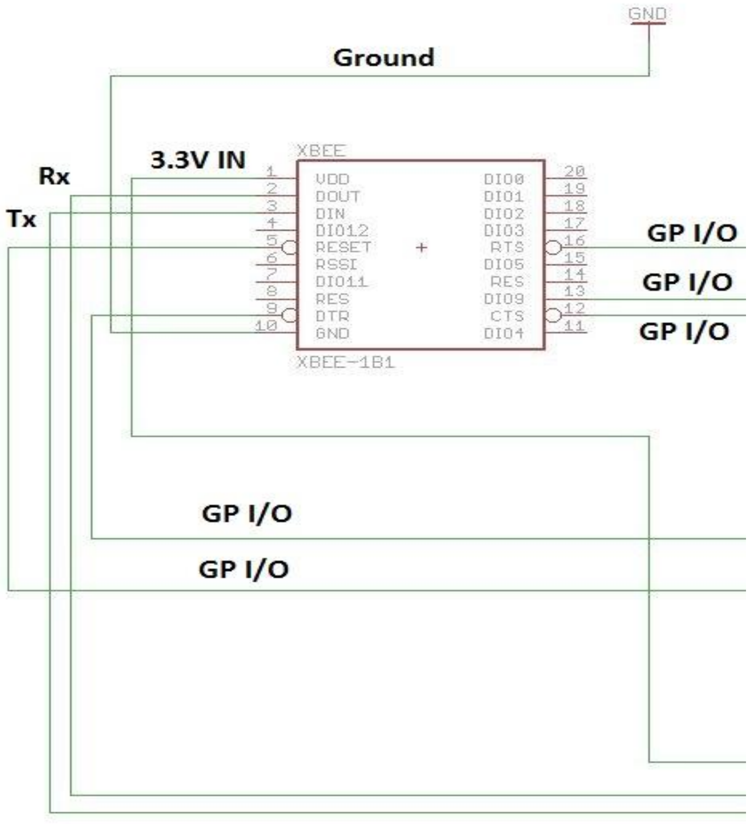


Figure 4.2.4.1.1 – Personal Image

Now you can see some of the other options that could have been a part of this design but ultimately were not used in this project. Let’s start with an option from the CC2500 Transceiver which is known to be very similar to the CC1101;

however it does not operate in the same frequency. Take a look at the design Texas Instruments has provided for the design of the CC2500 circuit at frequency 2.4GHz.

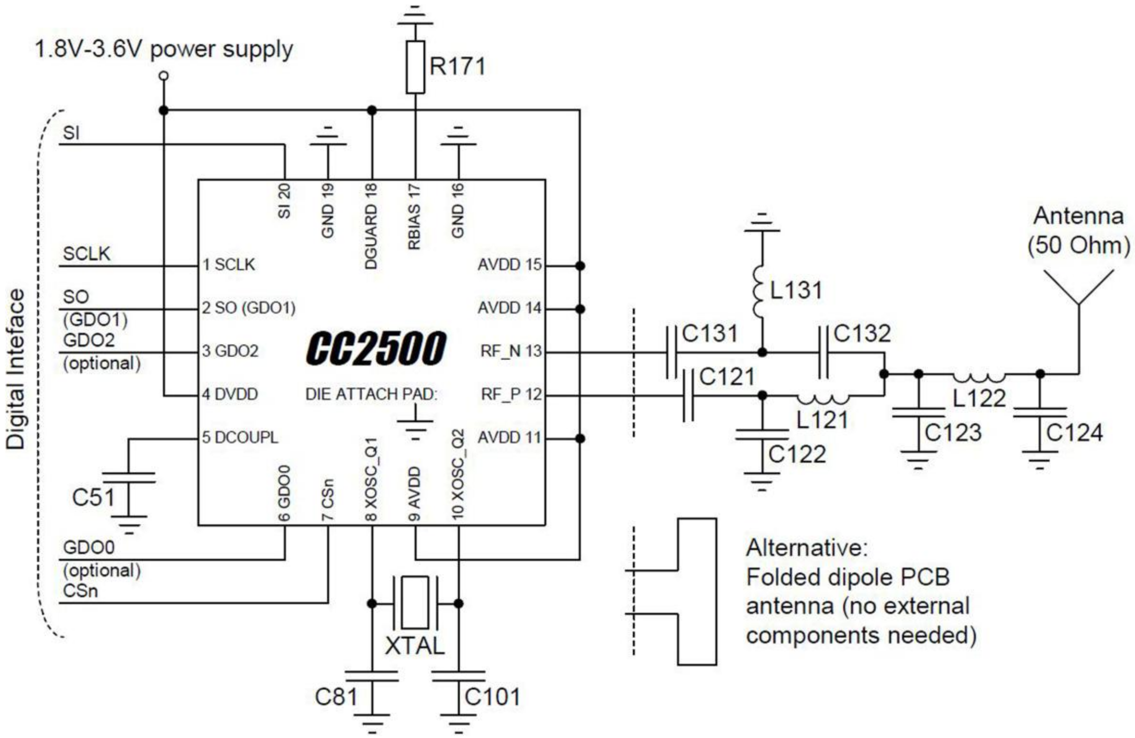


Figure 4.2.4.1.2: Courtesy of Texas Instruments

As you can see from the pin placements that it is pretty much identical to the CC1101 pin placement, however with the frequency being held at such a commonly used frequency this project could run into so potential problems with congestion issues.

The parts that were used in this system were capacitors and inductors and some other components. To get a better understanding of what each of these components are the description of each one is as follows; for the C51 component it is a Decoupling capacitor for on-chip voltage regulator to digital part. For the C81/C101 they are both crystal loading capacitors. For C121/C131 they are both RF balun DC blocking capacitors. For C122/C132 They are both balun/matching capacitors. For C123/C124 they are both RF LC filter/matching capacitors.

Now getting into the inductors and other components, let’s start with the L121/L131 which are both RF balun/matching inductors (inexpensive multi-layer type). The L122 is an RF LC filter inductor (inexpensive multi-layer type). The resistor R171 is a resistor for internal bias current reference. *(App A: CC2500 [3])*

Each value of each component is important to understand to see how the system works. Taking a look at the capacitors first, the C51 is a 100nF ±10%, 0402 X5R, the C81 is a 27pF ±5%, 0402 NPO, and the C101 is also a 27pF ±5% 0402 NPO.

Continuing with more capacitors, the C121 is a 100nF ±5% 0402 NPO, the C122 is a 1.0pF ±0.25pF, 0402NPO, the C123 is a 1.8pF ±0.25pF, 0402 NPO, the C124 is a 1.5pF ±0.25pF, 0402 NPO, the C131 is a 100pF ±5%, 0402 NPO, and the C132 is a 1.0pF ±0.25pF, 0402 NPO. Taking a look at the inductors this system starts with the L121 a 1.2 nH ±0.3 nH, 0402 monolithic, the L122 a 1.2 nH ±0.3 nH, 0402 monolithic, and the L131 a 1.2 nH ±0.3 nH, 0402 monolithic. Taking a look at the other components of this system, it starts with the R171 a 56 kΩ ±1%, 0402, and the XTAL a 26.0 MHz surface mount crystal. *(App A: CC2500 [3])*

All in all the CC2500 system is very similar to the CC1101, however the only negative thing that could be said about it for this project is the fact that it works in a potentially problematic 2.4 GHz frequency rage. So this makes this particular system useless for The Blood Pressure Tester. Again making the CC1101 the lead contender for this particular project when it comes to using the wireless portion to send the blood pressure results to the display on the experimenters' board

Looking at another option for the Blood Pressure Tester, the CC2420 transceiver with another suggested circuit design from Texas Instruments was option. Was interesting to see how each pin is used in this particular design since the CC2420 uses about 48 pins, but obviously not all the pins are used for this design. The circuit show in (Figure 8) is a typical application circuit with transmission line balun for single-ended operation. The first pin and the last pin are shown with big arrows in the picture in order to see where they are. The count of the pins are in order going counter clockwise, you can reference the table above in order to know exactly what every pin is doing and to see what pins are used. By looking at this Figure it's seen that there are multiple inductors and capacitors that make up this particular design in order to make this system work. It is important to know what each and every one of these smaller components are doing and to see how they are helping this particular design. A more detailed description of the components is going to be described in the writing below the (Figure 4.2.4.3) system schematic.

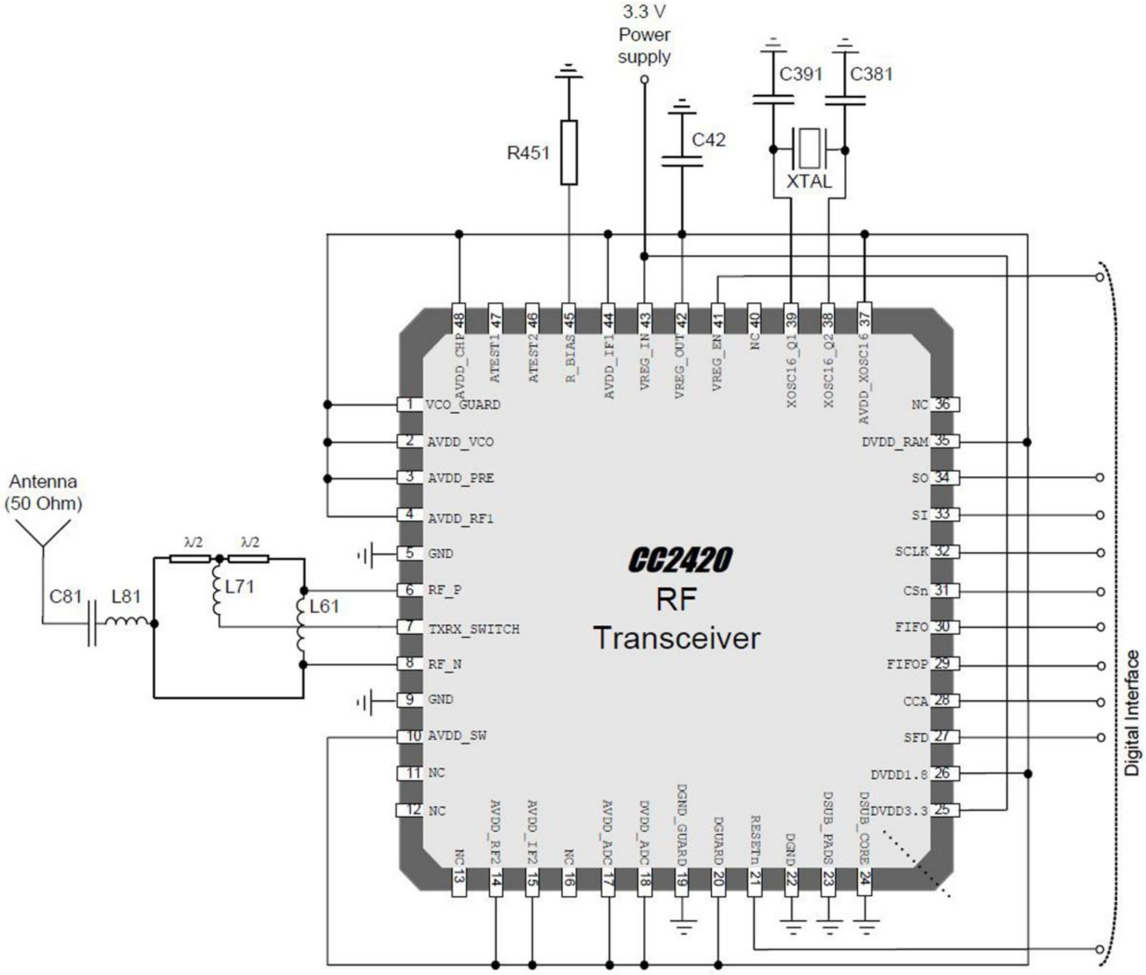


Figure 4.2.4.3 – CC2420 - Courtesy of Texas Instruments

Each component on this design for the CC2420 is a specific thing not specified in this schematic. Listed below is what each component is and what it does, and what the value of each component is.

Starting with capacitors, C42 is a voltage regulator load capacitance, C61 is a Balun and match, C62 is a DC black to antenna and match, C71 is a Front-end bias decoupling and match, C81 is another Balun and match. C381 is a 16MHz crystal load capacitor, C391 is also a 16MHz crystal load capacitor. *(App A: CC2420 [3])*Taking a look at the Inductors, the L61 is a DC bias and match, the L62 is also a DC bias and match, L71 is another DC bias and match, L81 is a Balun and match. Some miscellaneous components include a resistor R451 which is a Precision resistor for current reference generator, and the XTAL is a 16MHz crystal. *(App A: CC2420 [4])*

The table below shows what each component value is in the particular circuit design for the single ended output, transmission line balun.

Item	**Single ended output transmission line balun**
C42	10 µF, 0.5Ω < ESR < 5Ω
C61	Not used
C62	Not used
C71	Not used
C81	5.6 pF, +/- 0.25pF, NP0, 0402
C381	27 pF, 5%, NP0, 0402
C391	27 pF, 5%, NP0, 0402
L61	8.2 nH, 5%, Monolithic/multilayer, 0402
L62	Not used
L71	22 nH, 5%, Monolithic/multilayer, 0402
L81	1.8 nH, +/- 0.3nH, Monolithic/multilayer, 0402
R451	43 kΩ, 1%, 0402
XTAL	16 MHz crystal, 16 pF load (CL), ESR < 60 Ω

Table 4.2.4.1--*(App A: CC2420 [4])*

There are a couple designs that are suggested by Texas Instruments using the C1101 transceiver. This first design is an option of a design that is a typical application and evaluation Circuit 315/433 MHz (excluding decoupling capacitors).

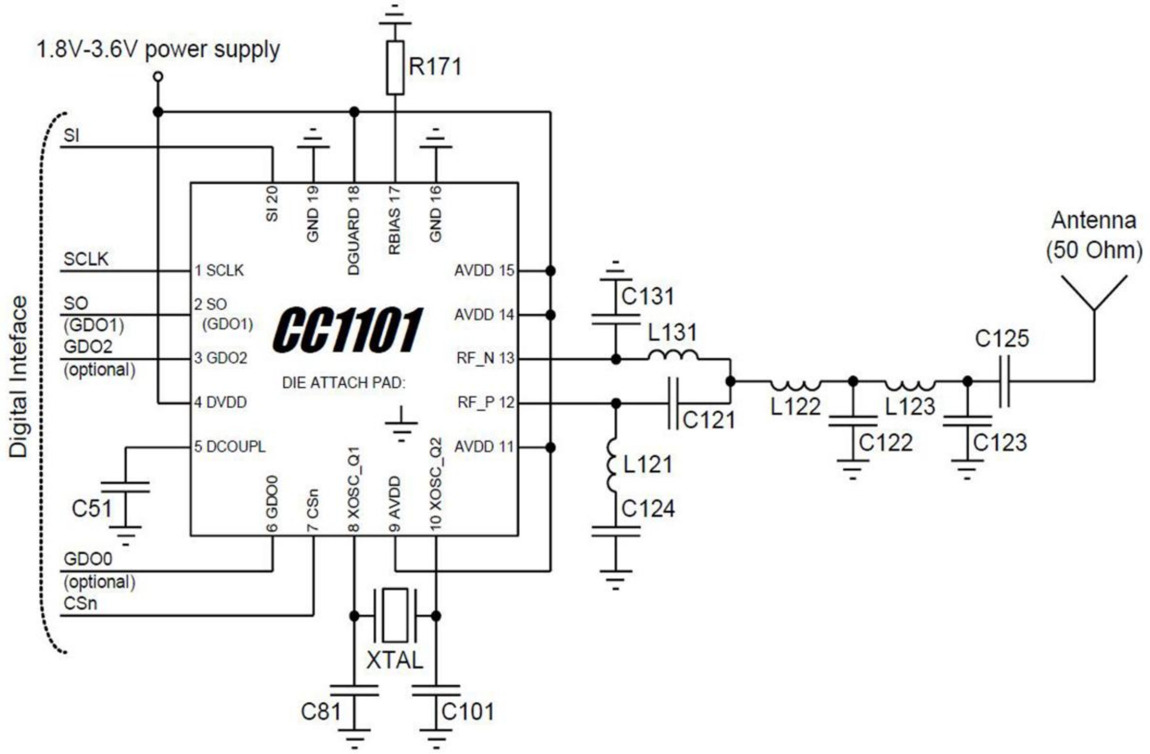


Figure 4.2.4.4: CC1101 – Courtesy of Texas Instruments

The table below will tell you what pins are being utilized in this design in order for the wireless communication to work. To reference what each pins function is, you may references the pin descriptions discussed above.

Pin#	**Pin Name**		**Pin#**	**Pin Name**
1	SCLK		11	AVDD
2	NOT USED		12	RF_P
3	NOT USED		13	RF_N
4	DVDD		14	AVDD
5	DCOUPL		15	AVDD
6	NOT USED		16	GND
7	CSn		17	RBIAS
8	XOSC_Q1		18	DGUARD
9	AVDD		19	GND
10	XOSC_Q2		20	SI

Table 4.2.4.2--*(App A: CC1101 [2])*

As you can see from the table above, not every single pin was used for this design. The “NOT USED” pins in this recommended design were left as optional.

The design itself does not seem too difficult to recreate on a custom designed PCB board.

Another option with the CC1101 is this recommended circuit by Texas Instruments which is a typical application and evaluation circuit 868/915 MHz frequency. Reference the picture below to see the potential schematic of the custom PCB board. This schematic is the top runner for the choice in what design will be used in The Blood Pressure Tester. It’s in the frequency range desired for this project and it has a development kit provided by Texas Instruments in order to provide appropriate testing for the wireless part, so the re-designed portion can be compared to a working a functioning wireless application design using the CC1101 transceiver. *(App A: CC1101 [2])*

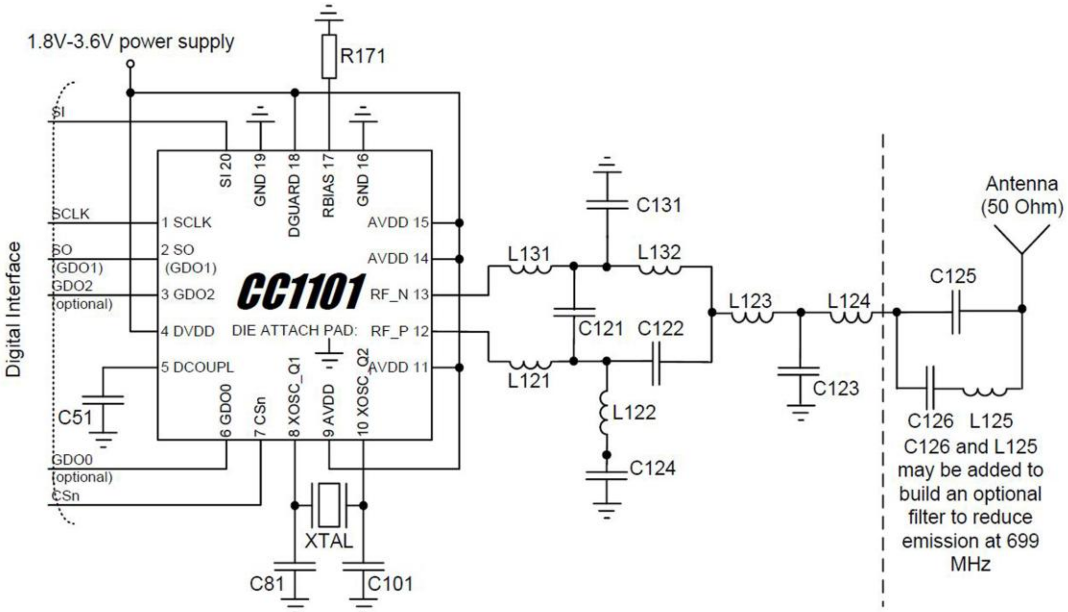


Figure 4.2.4.5: CC1101 – Courtesy of Texas Instruments

As you can see from this image all of the same pins were used as in the previous circuit design. However, there is a more complicated circuit connected to the RF_N and RF_P pins and attached directly to the antenna. This is due to the different range in frequency the two circuits hold. In the first circuit the range was 315/433 MHz and in this design the range is 868/915 MHz. *(App A: CC1101 [2])*

There are a lot of smaller components i.e. inductors and capacitors that make up both designs. The table listed below will describe what these component values are.

Component	Value at 315MHz	Value at 433MHz	Value at 868/915MHz
C51	100 nF ± 10%, 0402 X5R		
C81	27 pF ± 5%, 0402 NP0		

C101	27 pF ± 5%, 0402 NP0		
C121	6.8 pF ± 0.5pF, 0402 NP0	3.9 pF ± 0.25pF, 0402 NP0	1.0 pF ± 0.25pF, 0402 NP0
C122	12 pF ± 5%, 0402 NP0	8.2 pF ± 0.5pF, 0402 NP0	1.5 pF ± 0.25pF, 0402 NP0
C123	6.8 pF ± 0.5pF, 0402 NP0	5.6 pF ± 0.5 pF, 0402 NP0	3.3 pF ± 0.25 pF, 0402 NP0
C124	220 pF ± 5%, 0402 NP0	220 pF ± 5%, 0402 NP0	100 pF ± 5%, 0402 NP0
C125	220 pF ± 5%, 0402 NP0	220 pF ± 5%, 0402 NP0	12 pF ± 5%, 0402 NP0
C126			47 pF ± 5%, 0402 NP0
C131	6.8 pF ± 0.5pF, 0402 NP0	3.9 pF ± 0.25pF, 0402 NP0	1.5 pF ± 0.25pF, 0402 NP0
L121	33 nH ± 5%, 0402 monolithic	27 nH ± 5%, 0402 monolithic	12 nH ± 5%, 0402 monolithic
L122	18 nH ± 5%, 0402 monolithic	22 nH ± 5%, 0402 monolithic	18 nH ± 5%, 0402 monolithic
L123	33 nH ± 5%, 0402 monolithic	27 nH ± 5%, 0402 monolithic	12 nH ± 5%, 0402 monolithic
L124			12 nH ± 5%, 0402 monolithic
L125			3.3 nH ± 5%, 0402 monolithic
L131	33 nH ± 5%, 0402 monolithic	27 nH ± 5%, 0402 monolithic	12 nH ± 5%, 0402 monolithic
L132			18 nH ± 5%, 0402 monolithic
R171	56 kΩ ± 1%, 0402	Koa RK73 series	
XTAL	26.0 MHz surface mount crystal		

Table 4.2.4.3 -- *(App A: CC1101 [2])*

There are a few recommendations that Texas Instruments has given if one is planning to create one of these circuit designs on a PCB board. For starters, the top layer of the PCB board should be used for signal routing, and open areas should be filled with metallization connected to ground using several vias. When soldering the chip onto the PCB one must use the area under the chip for grounding and should be connected to the bottom ground plane with several vias for good thermal performance and sufficiently low inductance to ground. When the project will implement the recreated circuit on The Blood Pressure Tester's PCB board, the bottom line of the design is that it must stay consistent with what Texas Instruments has provided. Since this senior design group has no actual experience with designing an RF circuit, the best route to take is to look at something that has already been done and proven to work then recreate it exactly how it is. Or else the project could run into some serious problems with "noise" that the signal creates and a load of other potential problems that could be created if the circuit was not created exactly the way it was supposed to be made. *(App A: CC1101 [2])*

Again the actual design that the project used was an xbee module connected to the designed PCB board and another module connected to the laptop USB port.

Conclusion - Having a wireless display is an important aspect of the project; it is needed so that the person viewing the patient's' blood pressure has the freedom to view it from the comfort of wherever they want to be in the building. For example, if a doctor wanted to know the patient's' blood pressure in a room on the other side of the building, he/she could just tell the nurse in charge of that patient to take it and he could see the results at a display in his office, such as his/her computer instantly. The wireless solution utilized is the XBee 1mWChip Antenna - Series 1 (802.15.4) one of the more popular choices from Digi. This particular module uses the 802.15.4 stack which is the basis for Zigbee and makes it into a simple to use serial command set. It's basically a simple point to point (anything with a serial port) wireless Communication device. For this particular design it has one module attached to the printed circuit board (PCB) designed. Also, another module is attached to a USB cable which is then attached to a laptop computer. The module attached to the PCB receives the calculated blood pressure data from the MCU and communicates with the Xbee attached to the laptop which will display the calculated results in a systolic/diastolic form (two different numbers) on the laptop screen on a simple graphical user interface (GUI). The specifications this particular Xbee operates with is it has an Indoor/Urban Range of up to 100 ft (30m), Outdoor RF line-of-sight Range up to 300 ft(90 m), a Transmit Power Output (software selectable) 1mW (0dBm), the RF Data Rate is250,000 bps, 1200 bps-250 kbps (non-standard baud rates also supported), and receiver sensitivity is -92 dBm (1% packet error rate). Some power requirements for the Xbee, is the supply voltage requires 2.8-3.4V, Transmit Current (typical) 45mA (@3.3V), the Idle/Receive Current (typical) 50mA (@3.3V), and the Power-down Current is<10uA. Some general information regarding the Xbee that is being utilized is the Operating Frequency ISM 2.4 GHz, Dimensions 0.960" x1.087" (2.438cm x 2.761cm), Operating Temperature -40 to 85 degrees C (industrial), and Antenna Operations is integrated whip, chip or U.FL Connector, RPSMA connector.

4.2.5 Display summary

The main objective of the display is to show two measurements taken from the patient: the systolic measurement (in mmHg) and the diastolic measurement (in mmHg). The display receives information sent by the MCU, wirelessly, and displays it in a window called BP Monitor. The display used in this project is also able to display the status of the operation (started, aborted, reading in progress, time out) as well as an asterisk that reflects the detection of a heartbeat. The reason why this option was chosen over the MSP-EXP430F5529 and the MSP-EXP430F5438 was that there was no need to add an extra cost to the project since a display was designed according to the necessities of the project and it could be accessed from any computer that has its executable. Figure 5.3.1 shows a comparison between the displays that are in experimenter board and the display designed for the project. As you can see, Figure 4.2.5A has a much better resolution that Figure 4.2.5.B, but the final decision was to use the display showed in Figure 4.2.5.C.; once again, this display is available to any computer that has access its executable file.

Figure 4.2.5A: Display of MSP-EXP430F5438 *(App A [30])*

Figure 4.2.5B: Display of MSP-EXP430F5529 *(App A [31])*

Figure 4.2.5C: Display of BP Monitor

4.3 Software

There are several programming languages, such as C++, C, C#, Java, JavaScript, and PHP that could be implemented in this project but it noticed during research that the microcontroller used (MSP430F5438A) supports C language, therefore, most of the programming was done in C language. During the development of this project, there were different functions developed to perform different tasks and these functions were called by the main function of the program. The program created for the microcontroller is able to turn on/off the blood pressure monitor, open/close the valve, receive the data from the blood pressure circuit, process this information, and send the data wirelessly to the display. Code Composer Studio v5.1 software, developed by Texas Instruments, and was used to program the MSP430F5438A. As mentioned previously, the microcontroller receives input data from the blood pressure circuit.

The microcontroller is responsible for processing the data and checking if the systolic and diastolic measurements are within the expected range. There are several factors that can influence these measurements, such as age, gender and height. In children, the normal ranges are lower than for adults. As you get older, the systolic measurement tends to rise and the diastolic measurement tends to fall. The program is able to process the data received and check if the results are within the expectations. Besides showing the systolic and diastolic measurements, the display is able to show the status of the program at that moment (started, reading in progress, time out, aborted), and finally it is able to display an asterisk that represents the detection of the person’s heartbeats. Table 4.3.1 shows the different functions that were created and that are called by the main function of the program.

Function	Description – summary
Init_pulse (void)	Init_pulse – is able to detect the first pulse
Pulse_detect (void)	Pulse_Detect – is able to detect when the pulses are increasing and decreasing
Map_detect (void)	Map_detect – register all the pulses and then records the peak pulse (this is the mean arterial pressure)
Get_cuff_pressure (void)	Get_cuff_pressure – gets the pressure of the cuff relating the pump up
sendReading ()	sendReading – sends the systolic and diastolic readings wirelessly to the display

Table 4.3.1: Shows the functions of the project

A complete description of the functions is given below:

Init_pulse (void): this function does the setup for readings. This function also applies an algorithm to check after the motor pumps up, how long it looks for a pulse, and then it returns the reading.

Pulse_detect (void): this function assumes a 120Hz data; applies a low filter; detects the pulse above the noise threshold; it is able to detect if the slope is up or down; record the history of edges; resets the timer, and if it doesn't see a pulse during a certain period, then the reading is done.

Map_detect (void): this function applies an error detection, in which if it records a pulse that is higher the threshold set, then it aborts the execution. For example, if someone moves his/her arms too much, the system is able to detect, and the microcontroller sends a signal to turn open the valve and abort the operation.

Get_cuff_pressure (void): this function gets the cuff pressure relating to the pump up and returns its value.

SendReading (): this function is responsible for sending the systolic and diastolic measurements, as well as the status of the system and the detection of a heartbeat represented by an asterisk.

It is important to understand how the sequence of events performed by the system works. After the microcontroller and system initializes, if the Start button is pressed once the microcontroller sends a voltage to turn the motor on and close the valve. If the Start button is pressed again during the procedure, then the motor is turned off and the valve is open (safety procedure). The motor stays on until the cuff pressure reaches about 170mmHg (this number is set in the program, and therefore can be changed according to the needs of the project). Then, the motor turns off and the sensor checks if there is any pulses, if it does, then the motor turns on again for about 20mmHg (this can be done at most 3 times); if the sensor doesn't sense any more pulses (it means that here is no more blood flow), then there is need to turn on the motor again, and the MCU starts to collect the data (pulses). After this collection is done, the algorithm to find the systolic and diastolic measurements is applied (it uses only the Mean Arterial Pressure as a value to make the calculations). Finally, this information is sent wirelessly to a display located at a remote computer. This display is able to show the systolic and diastolic measurements, as well as the status of the procedure at a certain moment (started, abort, reading in progress, and time out). The time out error occurs when the sensor detects no pulses after about 40 seconds).

As the functions were previously defined, pseudo codes for each function needed to be created. The pseudo code is an artificial and informal language that helps the programmer to develop algorithms for each function. It also helps the programmer to have an idea how all the components of the system work together to perform the required tasks. The program consists of a main program that is responsible for calling all the functions in the system.

// Main program

At this moment, all the parameters are equal to zero;

```
       //examples
        int button_pressed = 0;                // button pressed
       int pump_up = 0;                        // doing pump up

WDTCTL = WDTPW + WDTHOLD; // Stop watchdog timer

//Enable and set the pins for the wireless module and communication
//Enable the pins used in the microcontroller
     P9OUT &= ~BIT6;                          // P9.6 motor
     P2REN |= BIT5;                           // enable internal pull up, P2.5
     P9OUT &= ~BIT7;                          //P9.7 valve
     P8OUT &= ~BIT7;                         // P8.7 transducer power

while(1)
       {
              if(!PUSH_BUTTON)
              {
                     //if the button is pressed
                     //stops the reading
                     //sends an abort if reading was going on and we pressed
                      the button to stop it
              }
              else
              {      // button released
                     if(button_pressed == 1)
                     {
                    //if the button was pressed before and now it is released
                     if((reading_abort == 0) && (reading_in_progress == 0) )
                            {      //if no reading is in progress than start the
                                  Reading
                            }

                            reading_abort = 0;
                     }
              }
              if(reading_in_progress == 1)
              // the reading is in progress
              // this group is pulse detect
                     if(sensor_working == 1)
                     {
                    // look to see if pulse, this should be over a short
                    period of time
                    // if no pulse set to re pump, only allow this to occur 2
                    times then shut down.
              Else
              {
              // shut down pulse detect
              }
             //computes the value
             SYS = (MAP * 0.55) + ( MAP / 1.3 );
             DIA =  (MAP * 0.85);
```

```
            sendReading (SYS,DIA);
}
```

Figure 4.3.2: Pseudo code that explains the main component
Figure 4.3.2 – Pseudo code for the main function

```
void init_pulse(void)
{
      // setup for reading
      //after it pumps up, apply equation that indicates how long it is
looking for a pulse, returns the reading
      pd_pulse = 0;
}
```

Figure 4.3.3: Pseudo code for the init_pulse fn

```
int pulse_detect(void)
{
      val = A6avg;

      // this routine will assume 120 hz data
      // may need to low pass here
      // compare a6 to threshold
      if ( val > PULSE_THRESHOLD) //pulse detect above the noise threshold
      {
            // track level above threshold
            // find direction change
            if( val > pd_last_val)
            {
             // slope is up
            }

            else
            {      // slope is down
            }
      }
      return pd_found_pulse;
}
```

Figure 4.3.4: Pseudo code for the pulse_detect function

```
void init_reading(void)
{
      //set an array to store the pulses detected
      // set up pulse for start of reading
      //sets the timer until it reaches the time where we start seing pulses
      MAP = 0;
}
```

Figure 4.3.5: Pseudo code for init_reading function

```
void map_detect(void)
{
      if (val > threshold)  //
```

```
	{
		//abort when the person moves the arm too much above the value
		set
		VALVE_OPEN;
	}

	if(pd_pulse)
	{
		// we have a pulse
		// cuff pressure is pulse pressure; store the values at an array
		// look for peak value at center of arrau

		MAP = cuff_Pres;
	}
}
```

Figure 4.3.6: Pseudo code for the map_detection function

```
// pressure routines
int get_cuff_pressure(void)
{
	//get the pressure of the cuff relating to the pump up
	// return the pressure here
	return (int) cuff_Pres;
}
```

Figure 4.3.7: Pseudo code for the get_cuff_pressure function

```
void sendReading()
{
	sendByte (ourReading.header);
	sendByte (ourReading.systolic);
	sendByte (ourReading.diastolic);
	sendByte (ourReading.checksum);
}
```

Figure 4.3.8: Pseudo code for the sendReading function

5.0 Design Summary of Hardware and Software

5.1 Microcontroller

After doing an extensive research of the different types of microcontrollers that were available, the project uses the MSP430. This microcontroller was designed and developed by Texas Instruments and it is able to receive, process, and transmit data successfully. There are several different types of MSP430 experimental boards, and below, is a summary of characteristics of the five different MCUs that would best suit the necessities to design and develop the blood pressure monitor.

MSP430FG439: Ultralow power MCU that consists of five low power modes and it is optimized to achieve extended battery file in portable measurement applications. Table 5.1.1 shows some of the parameters of the MSP430FG439.

	MSP340FG439
Frequency (MHz)	**8**
Flash (KB)	**60**
SRAM (B)	**2048**
GPIO	**48**
Timers 16-bit	**2**
Watchdog	**Yes**
Brown Out Reset	**Yes**
SVS	**Yes**
USART	**1**
DMA	**Yes**
Comparators	**Yes**
Temp Sensor	**Yes**
ADC	**12-bit SAR**
LCD Segments	**128**
Pin/Package	**80 LQFP**
Approx. Price (US$)	**6.60 | 1ku**

Table 5.1.1: Parameters of MSP430FG439

MSP430FG4618 – Ultralow power microcontroller that features a 16-bit RIS CPU, 16-bit registers and a digitally controlled oscillator (DCO) that allows a wake-up from low-power modes to active mode in less than 6 µs. Table 5.1.2 shows some of the parameters of the MSP430FG4618.

	MSP430FG4618
Frequency (MHz)	**8**
Flash (KB)	**116**

SRAM (B)	**8192**
GPIO	**80**
Timers 16-bit	**1**
Watchdog	**Yes**
Real-time clock	**Yes**
Brown Out Reset	**Yes**
SVS	**Yes**
USART	**1**
USCI_A	**1**
USCI_B	**1**
DMA	**Yes**
Multiplier	**16x16**
Comparators	**Yes**
Temp Sensor	**Yes**
ADC	**12-bit SAR**
LCD Segments	**160**
Pin/Package	**100LQFP**
Approx. Price (US$)	**8.35 | 1ku**

Table 5.1.2: Parameters of MSP430FG4618

MSP430FG479 – Ultralow power microcontroller that has a configuration of two 16-bit timers, a basic timer with a real-time clock, a high performance 16-bit sigma-delta A/D converter, and two universal serial communication interface. Table 5.1.3 shows some of the parameters of the MSP430FG479.

	MSP430FG479
Frequency (MHz)	**8**
Flash (KB)	**60**
SRAM (B)	**2048**

GPIO	**48**
Timers 16-bit	**2**
Watchdog	**Yes**
Brown Out Reset	**Yes**
SVS	**Yes**
USCI_A	**1**
USCI_B	**1**
Comparators	**Yes**
Temp Sensor	**Yes**
ADC	**16-bit Sigma Delta**
LCD Segments	**128**
Pin/Package	**80LQFP**
Approx. Price (US$)	**6.20 | 1ku**

Table 5.1.3: Parameters of MSP430FG479

MSP430FR5739 – Ultralow power microcontroller that has different sets of peripherals targeted for various applications. Its architecture, FRAM, and peripherals, combined with seven low-power modes, are optimized to achieve extended battery life in portable and wireless sensing applications. Table 5.1.4 shows some of the parameters of the MSP430FR5739.

	MSP430FR5739
Frequency (MHz)	**24**
FRAM (KB)	**16**
SRAM (B)	**1024**
GPIO	**33**
Timers 16-bit	**5**
Watchdog	**Yes**
Real-time clock	**Yes**
Brown Out Reset	**Yes**

SVS	**Yes**
USCI_A	**2**
USCI_B	**1**
DMA	**Yes**
Multiplier	**32x32**
Comparators	**Yes**
ADC	**10-bit SAR**
ADC Channels	**14**
Pin/Package	**38TSSOP, 40VQFN**
Approx. Price (US$)	**2.45 | 1ku**

Table 5.1.4: Parameters of MSP430FR5739

	MSP430F5438A
Frequency (MHz)	**25**
FRAM (KB)	**-**
SRAM (B)	**16384**
GPIO	**87**
Timers 16-bit	**3**
Watchdog	**Yes**
Real-time clock	**Yes**
Brown Out Reset	**Yes**
SVS	**Yes**
USCI_A	**4**
USCI_B	**4**
DMA	**Yes**
Multiplier	**32x32**

Comparators	**-**
ADC	**12-bit SAR**
ADC Channels	**16**
Pin/Package	**100LQFP, 113BGA MICROSTAR JUNIOR**
Approx. Price (US$)	**4.55 | 1ku**

Table 5.1.5: Parameters of MSP430F5438a

Once again, after comparing all the MSP430s, the microcontroller that best suited the project was the MSP430F5438A. The features that are present in the MCU are enough to receive, process, and send the data to display located at a remote computer, besides being a low cost, compact, easy to use microcontroller.

5.2 Wireless:

Having a wireless display is an important aspect of the project; it is needed so that the person viewing the patient's' blood pressure has the freedom to view it from the comfort of wherever they want to be in the building. For example, if a doctor wanted to know the patient's' blood pressure in a room on the other side of the building, he/she could just tell the nurse in charge of that patient to take it and he could see the results at a display in his office, such as his/her computer instantly. The wireless solution utilized is the XBee 1mWChip Antenna - Series 1 (802.15.4) one of the more popular choices from Digi. This particular module uses the 802.15.4 stack which is the basis for Zigbee and makes it into a simple to use serial command set. It's basically a simple point to point (anything with a serial port) wireless Communication device. For this particular design it has one module attached to the printed circuit board (PCB) designed. Also, another module is attached to a USB cable which is then attached to a laptop computer. The module attached to the PCB receives the calculated blood pressure data from the MCU and communicates with the Xbee attached to the laptop which will display the calculated results in a systolic/diastolic form (two different numbers) on the laptop screen on a simple graphical user interface (GUI). The specifications this particular Xbee operates with is it has an Indoor/Urban Range of up to 100 ft (30m), Outdoor RF line-of-sight Range up to 300 ft(90 m), a Transmit Power Output (software selectable) 1mW (0dBm), the RF Data Rate is250,000 bps, 1200 bps-250 kbps (non-standard baud rates also supported), and receiver sensitivity is -92 dBm (1% packet error rate). Some power requirements for the Xbee, is the supply voltage requires 2.8-3.4V, Transmit Current (typical) 45mA (@3.3V), the Idle/Receive Current (typical) 50mA (@3.3V), and the Power-down Current is<10uA. Some general information regarding the Xbee that is being utilized is the Operating Frequency ISM 2.4 GHz, Dimensions 0.960” x1.087” (2.438cm x 2.761cm), Operating Temperature -40 to 85 degrees C (industrial), and Antenna Operations is integrated whip, chip or U.FL Connector, RPSMA connector.

5.3 Mechanical:

5.3.1 Power:

There are several options for power source. The most common type of power source used in these devices is batteries. The disposable batteries consist of one or more electrochemical cells that convert stored chemical energy into electrical energy. Also, the rechargeable batteries are called storage battery which consists of a group of one or more electrochemical cells. They are known because of their secondary cells because their electrochemical reactions are electrically reversible.

There are several differences and pros and cons of each pick. Disposable batteries are said to be largely used for powering low voltage devices that are not used often. Disposable batteries (primary batteries) come with different chemical agents known as Carbon Zinc being one of the most common ones. Carbon Zinc works best in low energy depleting devices. Other chemical agents are Alkaline, Super Alkaline, Air Alkaline, Lithium, Silver Oxide and Zinc Air. One of the most popular batteries is the alkaline which come in all the standard sizes. The alkaline batteries include the flat round type that work well in often-used medium to high energy depleting items. There are super alkaline batteries that last longer for high used devices which can include medical apparatus and photo equipment. Table 5.3.1.1 will provide the comparisons of common battery types.

Common Battery types						
	Alkaline	Carbon Zinc	Lithium (BR)	Lithium (CR)	Lithium-Thionyl Choride	Zinc Air
Anode (-)	Zinc	Zinc	Lithium	Lithium	Lithium	Zinc
Cathode (+)	Manganese dioxide	Manganese dioxide	Carbon monofluoride	Manganese dioxide	Sulfur-oxygen chlorine	Oxygen

Nominal Voltage (V)	1.5	1.5	3	3	3.6	1.4
Approximate Energy Density (MJ/Kg)	0.5	0.13	1.3	1	1.04	1.69
Special Characteristics	Long shelf life, supports high to medium-drain application	Economical in cost per hour for low current consumption	Wide temperature operation, high internal impedance, low pulse current	Good pulse capabilities, stable voltage during discharge	Low self-discharge rate, can support 20-year battery	High energy density, battery life of weeks to months

Table 5.3.1.1

Furthermore, another great choice is rechargeable batteries (secondary batteries). Nickel Cadmium (Ni-Cads) is the most commonly purchased rechargeable battery. The con is that the disposal of these batteries is really hazardous to the environment because of the toxic metals in the batteries. There are also nickel metal hydrides (NiMH) that have good performance and are less toxic to the environment. Alkaline batteries can replace the disposable batteries normally used, are less costly than the Ni-Cad and hold a longer charge but have a shorter life span than NiMH. There are some examples of the main types of rechargeable batteries which are Nickel-Cadmium, Nickel-Metal Hydride, Nickel-Zinc, Lithium Ion and Rechargeable Alkaline Batteries. Typical uses of the main types of rechargeable batteries include: NiCad is used for low-drain applications such as electronics (power tools, especially for blood pressure monitors), toys, cordless and wireless telephone and emergency lighting. NiMH batteries are used in electric vehicles, cordless wireless phones, digital cameras, remote controlled racing toys and others. NiZn is used in high drain applications such as flashlights, outdoor equipment and cameras. Li-ion batteries are easy to manufacture in different shapes and are used in laptops, cell phones, PDAs, camcorders, digital cameras among other devices. Rechargeable Alkaline batteries are used in low drain applications such as CD/MD/MP3 players, toys, electronic games, cameras, flash lights, remote controls. Table 5.3.1.2 will provide the comparisons of rechargeable batteries.

Rechargeable Batteries					
	Alkaline	Li-ion	NiZn	NiMH	NiCad
Cycles	50-500	1200	100-500	500-100	1500
Voltage (V)	1.5	3.6	1.7	1.2	1.2
Approximate Energy Density (MJ/Kg)	0.31	0.58	0.22	0.11-0.29	0.14-0.22
Special Characteristics	lower capacity, put out more voltage	one of the best energy densities	shelf life is long, environmentally green	shelf life is short	suffers from the memory effect

Table 5.3.1.2

Below will show the best options for this project after analyzing those two previous tables 5.3.1.1 and 5.3.1.2.

1. The cheapest was considered.
2. For voltage, this project cannot exceed more than 6V, so it required four AAA batteries.
3. Environmental issues, quality and safety issues are always of concern. It was considered battery without or less as possible high toxicity.
4. Memory effect refers to having damage when not discharge completely and charged completely. Then in high discharge rate with no damage, meaning that the system can be discharged completely and have no damage to it, in this case there is no real preference, but recharging without complete drain damage for this project researching without complete drain damage would be what the clients would probably do since they would not want to have their system “dead” until they would have to charge it all over again. This is very important.
5. Not really a tragic concern if self-discharge is that important since the battery was charged often.
6. For cycles, since this is medical equipment, the one with the most amounts of cycles was most convenient.

The advantages of using rechargeable batteries are many which include performance and durability. Since rechargeable batteries as their name mentions can be recharged many times, the total performance life exceeds that of disposable batteries by a really considerable amount. Furthermore, because they are rechargeable it will save the client money allowing the patient to recharge the batteries several times. It is very important to be environmentally conscious and since the life time of these batteries is so much longer than the disposable ones they reduce the amount of hazardous waste due to batteries. The rechargeable batteries with no hazardous can be disposed in regular landfills and those with hazardous waste can be recycled. , are satisfying the client needs and reducing the waste of batteries which is successfully helping the environment.

After several runs, the four AAA batteries did not generate enough power to support the whole circuit. The goal is to provide enough power to the circuit without draining the battery too fast. So it was taken in consideration a topology known as boost-buck converter. Before going through the comparison description of boost-buck converter, it shall be necessary to understand the concept of electric power.

Electric power is the rate at which electric energy is transferred by an electric circuit. The SI unit of power is the watt. Also, Electric power, like mechanical power, is represented by the letter P in electrical equations. The term wattage is used colloquially to mean "electric power in watts." In direct current resistive circuits, electrical power is calculated using Joule's law:

$$P = IV$$

P is the electric power, V the potential difference, and I the electric current. In the case of resistive (Ohmic, or linear) loads, Joule's law can be combined with Ohm's law (I = V/R) to produce alternative expressions for the dissipated power:

$$P = I^2 R = \frac{V^2}{R},$$

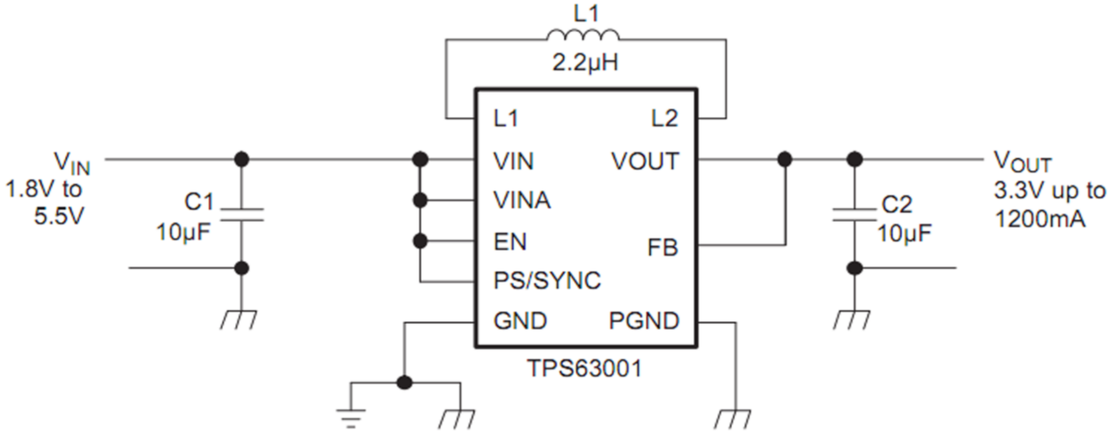
R is the electrical resistance.

There is a boost-buck topology built by TI (Texas Instruments) known as TPS63001 which would work for this project at first. The TPS6301 device provide a power supply solution for products powered by either a two-cell, three-cell or even four-cell alkaline, NiCd or NiMH battery, or a one-cell Li-Ion or Li-polymer battery. Output currents can go as high as 1200 mA while using a single-cell Li-Ion or Li-Polymer Battery, and discharge it down to 2.5V or lower. The buck-boost converter is based on a fixed frequency, pulse-width-modulation (PWM) controller using synchronous rectification to obtain maximum efficiency. At low load currents, the converter enters Power Save mode to maintain high efficiency over a wide load current range. The Power Save mode can be disabled, forcing the converter to operate at a fixed switching frequency. The maximum average current in the switches is limited to a typical value of 1800 mA. The output voltage is programmable using an external resistor divider, or is fixed internally on the chip. The converter can be disabled to minimize battery drain. During shutdown, the load is disconnected from the battery. The device is packaged in a 10-pin QFN PowerPAD ™ package measuring 3 mm × 3 mm (DRC). The table 5.3.1.3 is providing the features. (APP B [15])

Features
Up to 96% efficiency
1200 mA Output Current at 3.3 V in Step Down Mode (VIN= 3.6V to 5.5V)
up to 800 mA Output Current at 3.3V in Boost Mode (VIN > 2.4V)
Automatic Tansition between Step Down and Boos mode
Device Quiescent Current less than 50 µA
Input Voltage Range: 1.8V to 5.5V
Fixed and Adjustable Output Voltage Options from 1.2V to 5.5V
Power Save Mode for Improved Efficiency at Low Output Power
Forced fixed frequency Operation and Synchronization possible
Load Disconnect During Shutdown
Over-Temperature Protection

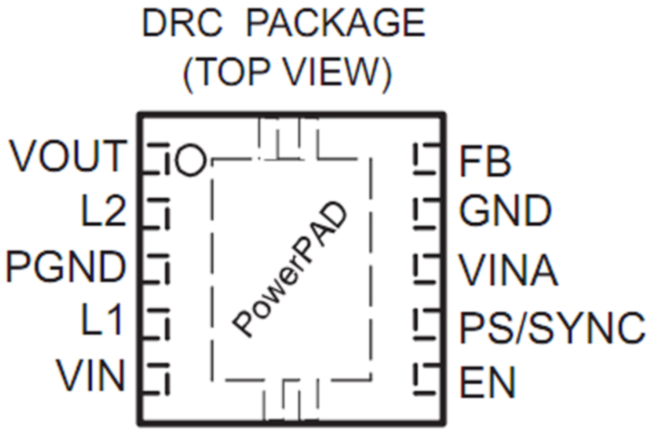
Table 5.3.1.3 (APP B [15])

The picture 5.3.1.1 is showing the schematic of TPS6301. The input is from 1.8V to 5.5V and the Output is 3.3V up to 1200 mA. This topology is going to work perfectly for this project, since the boost 3V to 3.3V to supply the amplifiers.



Picture 5.3.1.1(APP B [15])

Right below the picture 5.3.1.2 is showing the pin assignments and the table 5.3.1.3 is showing the description of each pin.



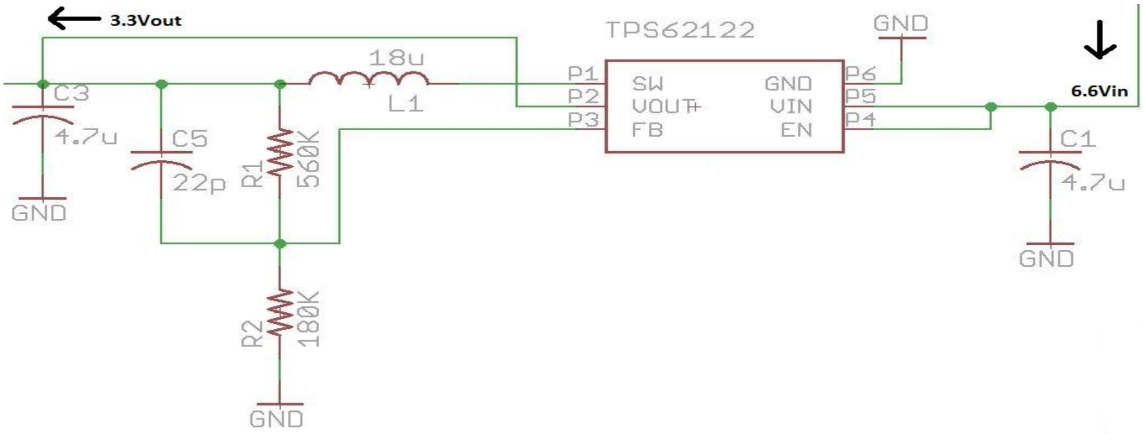
Picture 5.3.1.2 (APP B [15])

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
EN	6	I	Enable input. (1 enabled, 0 disabled)

FB	10	I	Voltage feedback of adjustable versions, must be connected to VOUT on fixed output voltage version
GND	9		Control / logic ground
PS/SYNC	7	I	Enable / disable power save mode (1 disabled, 0 enabled, clock signal for synchronization)
L1	4	I	Connection for Inductor
L2	2	I	Connection for Inductor
PGND	3		Power ground
VIN	5	I	Supply voltage for power stag
VOUT	1	O	Buck-boost converter output
VINA	8	I	Supply voltage for control stag
PowerPAD			Must be soldered to achieve appropriate power dissipation. Should be connected to PGND

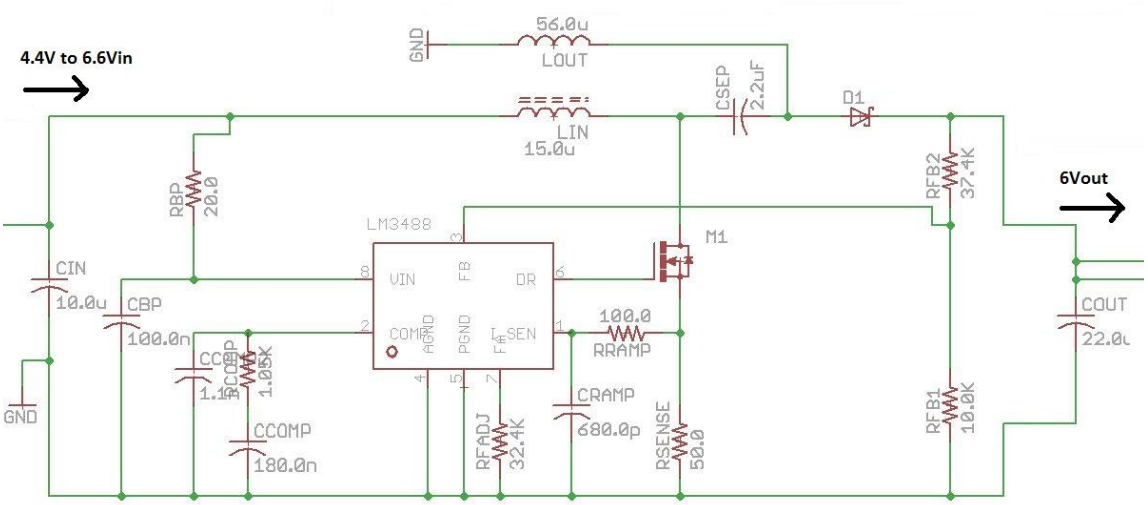
Table 5.3.1.3 (APP B [15])

After some research and changes, it was decided to use four AAA batteries instead of two. Consequently the total output of the power source turned out to be 6V; Therefore, the topology TPS6301 was neglected because it can only handle a total of Vin=5.5V. Two different types of power regulators were implemented in this project. They are known as TPS62122 and LM3488. First, TPS62122 has an input from 3.6V to 15V and the output is 3.3V, and the current can reach up to 1200 mA. Also, it has a highly efficient solution (up to 96% efficiency) capable of driving 75-mA loads. Its 11-µA quiescent current makes the TPS62122 an ideal choice in systems concerned over battery life. This topology worked perfectly for this project, as the objective was to buck 4 - 6.6V to 3.3V to supply three loads. The loads that needed to be supplied were the sensor, microcontroller and wireless. The picture 5.3.1.4 below is the final schematic of the power regulator used in this project.



Picture 5.3.1.4

Second, LM3488 is a versatile Low-Side N-FET high performance controller for switching regulators. It is suitable for use in topologies requiring low side FET, such as boost, flyback, SEPIC, etc. Moreover, the LM3488 can be operated at extremely high switching frequency in order to reduce the overall solution size. The switching frequency of LM3488 can be adjusted to any value between 100 KHz and 1 MHz by using a single external resistor or by synchronizing it to an external clock. Current mode control provides superior bandwidth and transient response, besides cycle-by-cycle current limiting. Output current can be programmed with a single external resistor. The LM3488 has built in features such as thermal shutdown; short-circuit protection and over voltage protection. Power saving shutdown mode reduces the total supply current to 5µA and allows power supply sequencing. Internal soft-start limits the inrush current at start-u. This specific topology was functioning as a buck and boost. The input ranges from 4 - 6.6V and the output will be a constant 6V. Furthermore, it was supplying the motor and the valve. The picture 5.3.1.5 below is the final schematic of the power regulator used in this project.



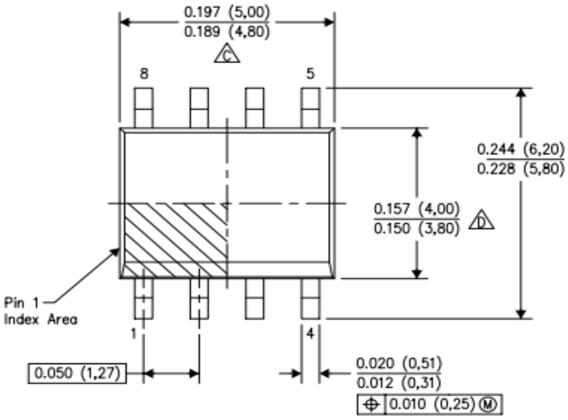
Picture 5.3.1.5

One major concern of this project was the voltage not being enough or too high to support all the components on the PCB (Printed Circuit Board) since it used four AAA batteries. After some research, the boost-buck converter which is built by TI (Texas Instruments) was the perfect fit for this project. Those topologies provide a great capability of stepping up or down the voltage. The goal of this project is to keep battery cycle as long as possible.

5.3.2 Switches:

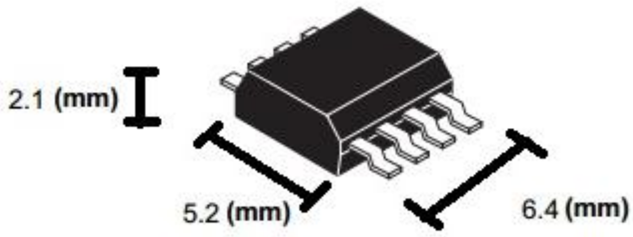
There are two switches being used in this project, and they are known as TS12A4514 and TPS1101PWR. The TS12A4514 is a single pole/single throw (SPST), low-voltage, single-supply CMOS analog switches, with very low switch ON-state resistance. The TS12A4514 is normally open (NO). This switch prevents the battery from draining too fast because the MCU (MSP430F5438) does not have to send a constant high signal to keep the switch normally open. This CMOS switch operates continuously with a single supply between 2V and 12V. Each switch can handle rail-to-rail analog signals. The OFF-leakage current maximum is only 1 nA at 25°C or 10 nA at 85°C. All digital inputs have 0.8-V to 2.4-V logic thresholds, ensuring TTL/CMOS-logic compatibility when using a 5-V supply.The TS12A4514 construction is typical of most CMOS analog switches, except that they have only two supply pins: V+ and GND. V+ and GND drive the internal CMOS switches and set their analog voltage limits. Reverse ESD-protection diodes are internally connected between each analog-signal pin and both V+ and GND. One of these diodes conducts if any analog signal exceeds V+ or GND. Virtually all the analog leakage current comes from the ESD diodes to V+ or GND. Although the ESD diodes on a given signal pin are identical and, therefore, fairly well balanced, they are reverse biased differently. Each is biased by either V+ or GND and the analog signal. This means their leakages varies as the signal varies. The difference in the two diode leakages to the V+ and GND

pins constitutes the analog-signal-path leakage current. All analog leakage current flows between each pin and one of the supply terminals, not to the other switch terminal. This is why both sides of a given switch can show leakage currents of the same or opposite polarity. There is no connection between the analog-signal paths and V+ or GND. V+ and GND also power the internal logic and logic-level translators. The logic-level translators convert the logic levels to switched V+ and GND signals to drive the analog signal gates. The picture 5.3.2.1 below is the switch TS12A4514.



Picture 5.3.2.1

The TPS1101 is a single, low-rDS(on), P-channel, enhancement-mode MOSFET. The device has been optimized for 3V or 5V power distribution in battery-powered systems by means of the Texas Instruments LinBiCMOS process. With a maximum VGS(th) of –1.5 V and an IDSS of only 0.5 µA, the TPS1101 is the ideal high-side switch for low-voltage, portable battery-management systems where maximizing battery life is a primary concern. The low rDS(on) and excellent ac characteristics (rise time 5.5 ns typical) of the TPS1101 make it the logical choice for low-voltage switching applications such as power switches for pulse-width-modulated (PWM) controllers or motor/bridge drivers. The ultrathin thin shrink small-outline package or TSSOP (PW) version fits in height-restricted places where other P-channel MOSFETs cannot. The size advantage is especially important where board height restrictions do not allow for a small-outline integrated circuit (SOIC) package. Such applications include notebook computers, personal digital assistants (PDAs), cellular telephones, and PCMCIA cards. For existing designs, the D-packaged version has a pin out common with other P-channel MOSFETs in SOIC packages. The picture 5.3.2.2 below is the switch TPS1101.



Picture 5.3.2.2

5.3.3 Motor:

Micro air pump powered by an electric motor is a non-complex device, but the application of it has revolutionized the world of industry. Most electric motors or electric machines operate through the interaction of magnetic fields and current-carrying conductors to generate force. There are several types of electric motors powered by an AC (alternating current) or DC (direct current) electric motor. The conversion of electrical energy into mechanical energy was demonstrated by the British scientist Michael Faraday in 1821. In 1827, Hungarian physicist Ányos Jedlik started experimenting with devices he called "electromagnetic self-rotors". Although they were used only for instructional purposes, in 1828 Jedlik demonstrated the first device to contain the three main components of practical direct current motors: the stator, rotor and commutator. The device employed no permanent magnets, as the magnetic fields of both the stationary and revolving components were produced solely by the currents flowing through their windings.

Industrial processes were no longer limited by power transmission using line shafts, belts, compressed air or hydraulic pressure. Instead every machine could be equipped with its own electric motor, providing easy control at the point of use, and improving power transmission efficiency. Electric motors applied in agriculture eliminated human and animal muscle power from such tasks as handling grain or pumping water. Furthermore, electric motors still play a very important part in furnishing power for all types of domestic and industrial applications. Their versatility, dependability, and economy of operation cannot be equaled by any other form of motive power. (APP A [7])

In an electric motor the moving part is called the rotor and the stationary part is called the stator. Magnetic fields are produced on poles, and these can be salient poles where they are driven by windings of electrical wire. A shaded pole contains an inductor to delay the phase of the magnetic field for that pole.

A commutator switches the current flow to the rotor windings depending on the rotor angle.

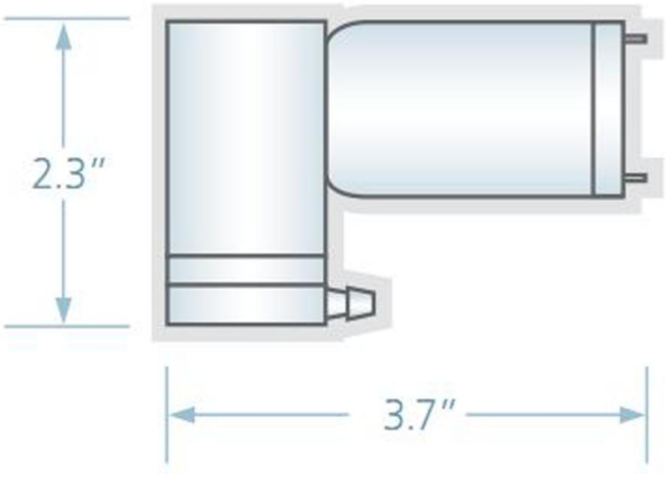
A DC motor is powered by direct current, although there is almost always an internal mechanism (such as a commutator) converting DC to AC for part of the motor. An AC motor is supplied with alternating current, often avoiding the need for a commutator. A synchronous motor is an AC motor that runs at a speed fixed to a fraction of the power supply frequency, and an asynchronous motor is an AC motor, usually an induction motor, whose speed slows with increasing torque to slightly less than synchronous speed. Universal motors can run on either AC or DC, though the maximum frequency of the AC supply may be limited. (APP A [6])

The purpose of the micro air pump or micro motor is to provide enough pressure to the cuff, so the patient can successfully test his/her own blood pressure or a nurse can test the blood pressure of the patient. Micro air pump has an extraordinary size and can generate the perfect amount of power to execute a blood pressure test without any concerns. Also, about 95% of the power being generated by the four AAA batteries is supporting the micro air pump once it is turned on when both switches TS12A4514 and TPS1101PWR are closed.

The features of the micro air pump are very important to this project because it shall be small enough to keep the project compact, easy to mount and provide maximum durability. Furthermore, the motor shall have the rated voltage capacity of 6V because the power will be provided by four AAA batteries.

There are several types of micro air pumps in the market, consequently makes the decision more challenging. All the details about the micro air pump motor are being considered. There are about five motors which are being considered for this project. They are known as #SP-8000, #AP-2P01, #AP-2P02PA, #AP-3P04 and #P54A02R. For this project, it was chosen the motor #P54A02R.

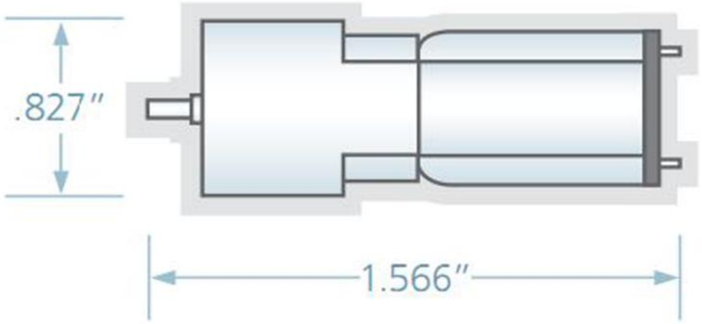
First, the #SP-8000 micro air pump has a design single diagram, positive displacement. The ports are 3/16” barb. It is FAA approved (D016C). This motor has no valve, but it was not an issue for this project because a different valve was used to deflate the cuff. Voltage range is 12 or 24 VDC. Power consumption is less than 1 amp. Electrical connections are spade type terminals. Maximum output pressure is 20 PSI (1.38 Bar) which is beyond the expectations for this project. The vacuum is 18 inHg (457 mmHg); also the motor is permanent magnet DC. Another concern is the size of this micro air pump which is 38.1x57.9x102.6 mm. The duty cycle is 1000 hours @ 100%, a duty cycle which is very impressive. After analyzing the specifications of this motor, the conclusion is that this motor is over powering the system and the size is a concern. The picture 5.3.3.1 of the motor is below. (APP A [9])



 # SP-8000

Picture 5.3.3.1 (APP B [5])

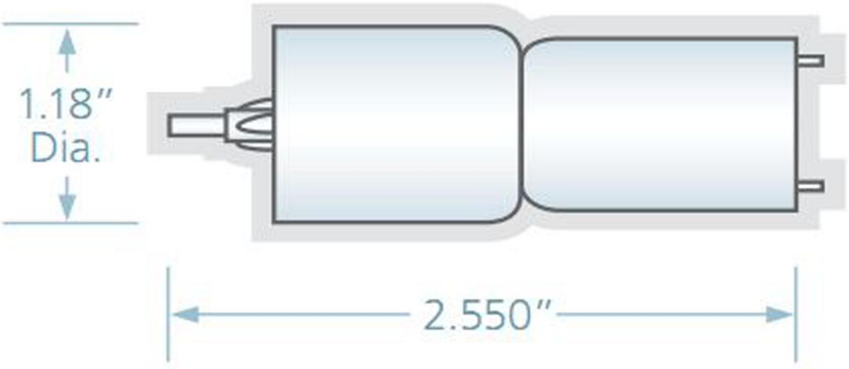
Second, the #AP-2P01 micro air pump has a design rotary diaphragm, ideal for battery powered applications, and this is very important for this project. The ports are 3 mm outlet. This micro air pump has a suction and discharge valve, which was not necessary for our purpose. Voltage range is nominal 3 VDC, 2.0 – 3.0 VDC. Power consumption is maximum 460 mA. This micro air pump does have some noise which is <60 dBA @ 10 cm, but this is not compromising the effectiveness of the project. Maximum output pressure is 6.76 PSI (350 mmHg) which is reasonable to accomplish the goals of this project. The pressure drop is <2 mmHg/min from 300 mmHg, and can provide more control when the cuff is being deflated. The size of this micro air pump is being taken in consideration because it is very compact, and size is 39.78x11.99x21.00 mm. The duty cycle is tested to 30.000 operations, and it shall be very satisfactory for the project. The picture 5.3.3.2 of the motor is below. (APP A [9])



 # AP-2P01

Picture 5.3.3.2 (APP B [5])

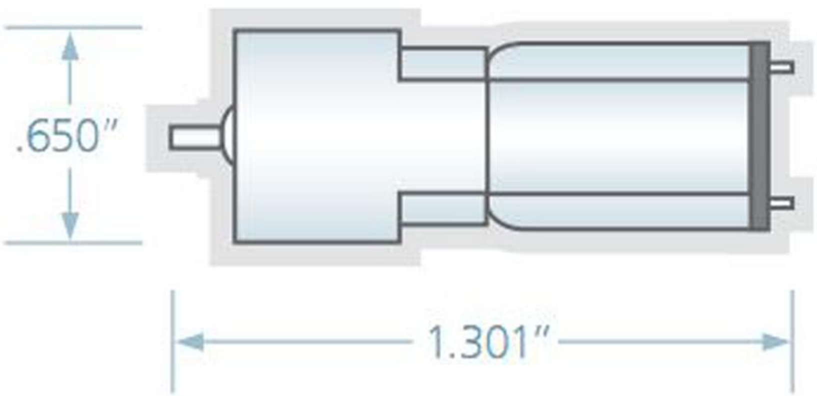
Third, the #AP-3P04 micro air pump also has a rotary diaphragm, ideal for battery powered applications. The ports are 4 mm outlet. The valve of this micro air pump is also a suction and discharge type valve. Voltage range is nominal 12 VDC; this motor is requiring more energy than the power source best suited for the project and the increased size well exceeds the designed scope of the project. Power consumption is maximum 270 mA. This micro air pump also does have some noise which is <55 dBA @ 10 cm. Electrical connections are terminals extended from top to pump. Maximum output pressure is 11.0 PSI (570 mmHg) which is too powerful to accomplish the goals of this project; it could damage the cuff or even injure the patient. The pressure drop is <3 mmHg/min from 525 mmHg; the speed of deflation is too high, and it does not provide enough time for the sensor to get an accurate response. Also as mentioned before, the size being 64.77x30.00mm is too big for the project. The duty cycle is tested to >80.000 operating cycle which is very convenient. The picture 5.3.3.3 of the motor is below. (APP A [9])



 # AP-3P04

Picture 5.3.3.3 (APP B [5])

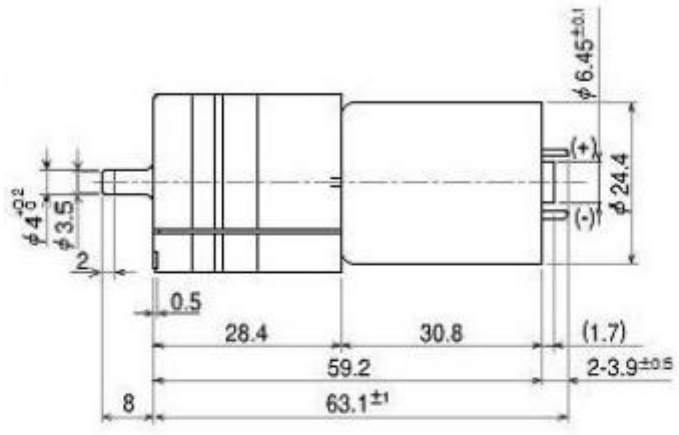
Four, the #AP-2P02PA is also a rotary diaphragm micro air pump and ideal for battery powered applications. The ports are 3 mm outlet. This micro air pump also has a suction and discharge type valve. Voltage range is nominal 3 VDC, 1.9 – 3.1 VDC. Power consumption is maximum 320 mA. This micro air pump also does have some noise which is <60 dBA @ 10 cm. Electrical connections are terminals extended from top to pump. Maximum output pressure is 6.76 PSI (350 mmHg) which is reasonable to accomplish the goals of this project. The pressure drop is <2 mmHg/min from 300 mmHg, and it does provide more control when the cuff is being deflated. The size of this micro air pump is the main key for this project, and the size is 33.04x10.01x16.51 mm. The duty cycle is tested to 30.000 operations, and it is very satisfactory for the project. Indeed, this micro air pump has strong similarities comparing to the #AP-2P01, but what makes this specific motor a great fit to this project is simply the dimensions. The picture 5.3.3.4 of the motor is below. (APP A [9])



 # AP-2P02A

Picture 5.3.3.4 (APP B [5])

Five, the motor #P54A02R was the chosen to be used in this project. This motor has the following specifications: cylinders is 3, rated voltage is DC6V, flow (No Load) is 1.8L/min, current (No Load) is 170mA, max current is 290mA, max pressure is 95KPa, noise is 50dB, life is 71 hours, and life test condition is rated voltage - 500ml volume pressurizing from 0 to 40KPa - 1 cycle (8.5 sec ON, 7 sec OFF). It does successfully pump air into the cuff in a short period of time without any concerns, and it is compact enough to satisfy the objectives of this project. The picture 5.3.3.5 of the motor is below.



#P540A2R - Picture 5.3.3.5

The microcontroller is sending a high signal to switch TS12A4514 to turn on, and then it turns on the switch TPS1101PWR, after those steps the micro air pump does start pumping air into the cuff though a latex T-tube. It does keep the micro motor pumping air until the cuff reaches the desired pressure which was 170 ~ 200 mmHg.

It is a very simple procedure, but the intentions of this project are to maintain the technical concepts as simple as possible. Furthermore, electrical wires were used to connect the micro air pump to the PCB (printed circuit board). It was required only two wires to assemble the circuit.

There is another issue which can potentially cause serious problems in the future after using several times the micro air pump. The pollution in the air is the main issue. The environment is very important when the blood pressure test is being executed. Smoking must be avoided around the micro air pump while it is being used and outdoors because the presence of pollution is respectively high. It seems to be simple, but after using the micro air pump several times without any type of protection or filter, it can clog up the T-tube. Indeed, that is not acceptable.

After taking care of those procedures, the micro air pump is working without any concerns and for a long period of time.

5.3.4 Valve:

A valve is a device that regulates, directs or controls the flow of a fluid (gases, liquids, fluidized solids, or slurries) by opening, closing, or partially obstructing various passageways. Valves are technically pipe fittings, but are usually discussed as a separate category. In an open valve, fluid flows in a direction from higher pressure to lower pressure. Valves are used in a variety of contexts, including industrial, military, commercial, residential, and transport. The industries in which the majority of valves are used are oil and gas, power generation, mining, water reticulation, sewerage, chemical manufacturing. In daily life, most noticeable are plumbing valves, such as faucets for tap water. Other familiar examples include gas control valves on cookers, small valves fitted to washing machines and dishwashers, safety devices fitted to hot water systems, and valves in car engines. Valves vary widely in form and application. Sizes typically range from 0.1 mm to 60 cm. Special valves can have a diameter exceeding 5 meters. For this particular project a micro valve will be used to support this biotechnology project. Although the valve is named as a Micro, it still does not modify the way it will control the fluid. All the mechanical process and philosophy of the valve remain similar. Valve cost ranges from simple inexpensive disposable valves to specialized valves costing thousands of US dollars per inch of diameter. Disposable valves may be found inside common household items including mini-pump dispensers and aerosol cans.

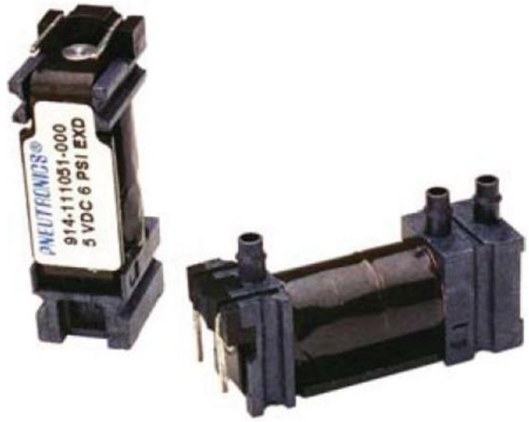
The micro air valve has a major importance in this project as part of the micro air pump because it controls the amount of air being pumped into the cuff. If there was not a valve to control the amount of air being pumped into the cuff, the patient could potentially hurt him/her self, and consequently it would cause bruises and intense pain. The micro valve is working together with the micro sensor and the micro air pump. Once the sensor does not feel any vibration on the cuff which means that the blood flow has stopped, it does alert the micro controller to send a low signal to the switches TS12A4514 and TPS1101PWR which are controlling the micro air pump to turn off, and sends a high signal to the switch TS12A4514 which is controlling valve to turn on (to open).

There are several types of micro valves in the market, consequently makes the decision more challenging. All the details about the micro valves are being taken in consideration. There are about six valves which are being considered for this project. They are known as SRS (manifold mounted plastic solenoid valve), Ten-X (10mm solenoid valve), Ten-X Le (low energy digital solenoid valve), X-Valve (8mm universal solenoid valve) and KSV05B (Solenoid Valve). For this project, the micro valve known as KSV05B was used because it fits perfectly to the goals of this project. There are some clarifications to understand why the KSV05B has been chosen compared to the others described below.

First is SRS, the 10mm SRS Series plastic solenoid valve converts a digital electrical signal into a digital pneumatic output. The SRS Valve is constructed of engineering thermoplastics and non-corrosive metals to exceed the specifications demanded by critical applications in the life sciences. The valve type is 2 or 3 way normally closed, 2 or 3-Way Normally Opened or 3-Way Distributor. The operating environment is from 32 to 131 Fahrenheit (0 – 55 Celsius). The dimensions of this micro valve are: Length 1.5 in (38.1 mm), Width 0.394 in (10 mm), Height 0.61 in (15.49 mm), Weight .23 oz (6.57 grams), and the voltage range is 5V. Also, the power is 0.5 to 1.0 Watt. The internal volume is 0.0016 in^3 (0.0267 cm^3). The leak rate is <0.016 sccm (bubble tight). The response is <30 msec cycling (2 Watts). The pressure 0 to 20 psig (0.13 MPa), and vacuum is 0-27 in Hg (0.09 MPa). The porting is Manifold mount; Gasket supplied. It is recommended a filtration of 40 micron. Indeed, the features of this specific micro valve are very interesting, but it is not the best option to accomplish the goals of this project. Below is the picture 5.3.4.1 of the micro valve. (APP A [10])

Picture 5.3.4.1 (APP B [4])

Second is Ten-X, this micro valve is a 10mm solenoid valve with a 2 or 3-way NO/NC and distributor design. Ten-X delivers repeatable "energized" and "de-energized" response times, low power, and flow capability to meet the specific performance requirements of medical devices. The media of the valve is non-reactive gases. The operating environment is from 32 to 122 Fahrenheit (0 – 50 Celsius). The dimensions of this micro valve are: Length 1.26 in (32 mm), Width 0.39 in (10 mm), Height 0.63 in (16 mm), and Weight 0.39 oz (10.7 grams). The internal volume is 0.0080 in^3. The leak rate is 0.016 sccm of air (Silicone), and this provides enough control during the deflation of the cuff. The power is 0.5 or 1.0 Watt; it is the same as the previous valve. The response is <5 msec cycling (Silicone) or <20 msec cycling (Viton & EPDM). The pressure which is very important is up to 6 psig (0.04 MPa), and the minimum flow is 8 lpm @ 6 psi (0.04 MPa). Also, the porting is Barbs for 0.078" I.D tubing and Manifold mount with gasket. This micro valve does have a decent potential, but still is not the best option for this project because it is more than necessary to accomplish the objectives of this project based on its features. Below is the picture 5.3.4.2 of the micro valve. (APP A [10])

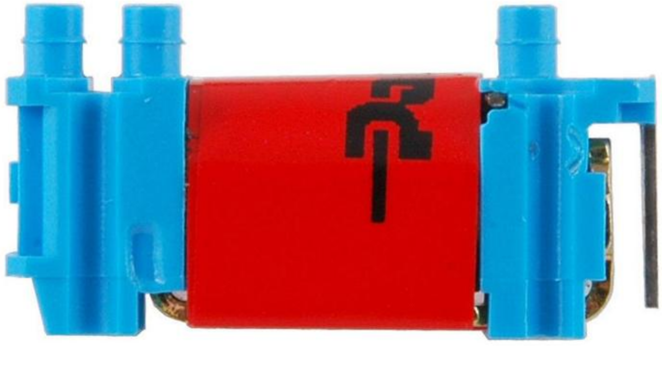


Picture 5.3.4.2 (APP B [4])

Third is Ten-X Le, this micro valve is an electro-magnetic poppet valve designed to provide the highest performance available for the package size. The quiet, lightweight 10-mm wide valve can be used as a standalone with tube connections PC or in multi-station manifold mount set-ups. Integrated drive electronics featuring efficient pulse width modulation (PWM) circuit technology consume minimal power. The valve type is 2 or 3-way Normally Closed, 30 psi, 2 or 3-way Normally Opened, 30 psi or 3-way Distributor, 20 psi. The media is non-reactive gases. The operating environment is from 32 to 122 Fahrenheit (0 – 50 Celsius) continuous duty. The dimensions of this micro valve are: Length 1.3 in (33.1 mm), Width 0.39 in (10 mm), Height 0.61 in (15.5 mm), and Weight 0.42 oz (12 grams). The internal volume is 0.0080 in^3 (0.131 cm^3). The leak rate is <0.02 sccm of air max; since the leak is higher than 6 psi, it affects the sensor reading because the air escapes from the cuff too fast. The power is 0.5 Watt (with PWM circuit); this is very important because it is actually possible to control the air flow out of valve though the B PWM output waveform. The response is <20 msec cycling. The pressure goes from 0 to 30 psi (0.20 MPa). The porting is Barbs for 0.078" I.D tubing: Manifold mount with gasket. This micro valve has a great potential, but the dimensions are slightly bigger than expected for this project. Below is the picture 5.3.4.3 of the micro valve. (APP A [10])

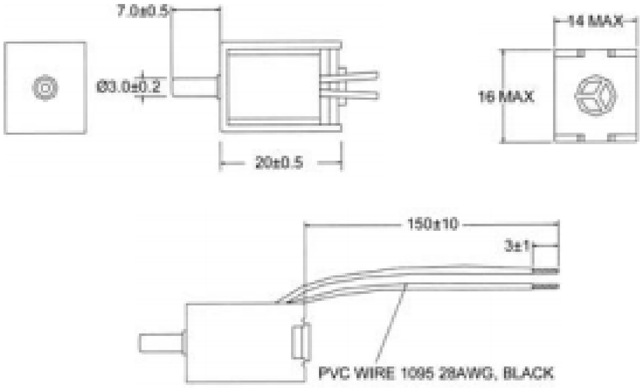
Picture 5.3.4.3 (APP B [4])

Four is X-Valve, this micro valve is a two or three-way universal solenoid valve measuring just 8mm in width. The X-Valve's unitized body incorporates its functional features in a single glass-reinforced, PBT (Polybutylene Terephthalate) molded body. The media is non-reactive gases. The operating environment is from 32 to 122 Fahrenheit (0 – 50 Celsius). The dimensions of this micro valve are: Length 0.92 in (24 mm), Width 0.31 in (7.9 mm), Height 0.35 in (9 mm), and Weight 0.16 oz (4.5 grams). The internal volume is 0.0045 in^3 (7.71 grams). The porting is Universal barbs for 1/16" I.D. tubing (1/32" Wall Max.) and Manifold mount with X-seal. The leak rate is <0.016 sccm (6 psi Silicone). The response is <20 msec full cycle (Silicone, FKM). The pressure is 0 to 6 psi (0.04 MPa), and minimum flow is 4 lpm @ 6 psi (0.04 MPa). It needs to use the B PWM output waveform to the speed of deflation. This valve has a great potential, but it is not the best fit. Below is the picture 5.3.4.4 of the micro valve. (APP A [10])



Picture 5.3.4.4 (APP B [4])

Five is KSV05B, the micro valve is a high frequency solenoid and has the following specifications: rated voltage is DC6V/DC12V, rated current is 60mA/45mA, and exhaust time is max. 6.0 seconds from 300mmHg reduce to 15mmHg at 500CC tank, resistance is 100Ω±10%/270Ω±10%, and leakage is max. 3mmHg/min from 300mmHg at 500CC tank, insulation level is A, and apply for air. This product is applicable to Arm-type electric blood pressure monitor, Air passage switch control, air massage products, and other products need deflation or exhausting. This micro valve was the chosen one for this project because of its features. Below is the picture 5.3.4.5 of the micro valve.



Picture 5.3.4.5

Six is the Mechanical Valve, this valve is a simple plastic with a rubber in it which maintains a slower linear deflation rate. It is optimal for pressure sensor sampling. This valve actually delays the speed of deflation so the sensor can collect some data before the valve KSV05B opens up to deflate the cuff completely. This valve was the best solution to help the sensor to collect enough data for an accurate result, and it does not require power. Below is the picture 5.3.4.6 of the micro mechanical valve.

Picture 5.3.4.6

Table 5.3.4.1 is providing the prices of each micro air valves.

COSTS	
SRS	~ $47
Ten-X	$37
Ten-X Le	$46
X-Valve	~$47
KSV05B	$50
Mechanical Valve	$5

Table 5.3.4.1

Even though the KSV05B is not the cheapest, it still is the best choice to make this project work properly.

This specific micro solenoid air valve is providing the work required for this project without any concerns. The electrical connection is very simple as well. It requires only two wires which are connected to the bottom of the micro solenoid air valve, and then the wires are connected directly to the PCB (Printed Circuit Board). The speed of deflation is very critical for this project because it can affect tremendously on the precision of the blood pressure test.

When the microcontroller sends a high signal to the switch TS12A4514 to close it, it then turns the valve on, or in other words, opens the valve, the microcontroller also keeps the sensor on at all time until the cuff has been deflated. Once there is no air flowing in the tube, the sensor sends an analog signal to the microcontroller to open the switch TS12A4514 to turn off the valve (close the valve) and the sensor. Then it starts doing the calculations.

The valve has to be always working properly with the sensor because if there is a difference on the speed of deflation, it compromises the blood pressure test. If that occurs, the patient has to reset the machine and start all over again. This is very inconvenient and worthless.

5.3.5 Cuff:

The cuff is an integral part of the blood pressure tester project and is one of the most important components. The cuff is normally placed smoothly and snugly around an upper arm, at roughly the same vertical height as the heart while the subject is seated with the arm supported. It is essential that the correct size of cuff is selected for the patient. When too small a cuff results in too high a pressure, while too large a cuff results in too low a pressure, so it comes in four sizes, for children up to obese adults. Also, it is made of a non-elastic material, and the cuff used is about 20% bigger than the arm. The cuff is inflated until the artery is completely occluded. Then, the sensor takes action sensing the brachial artery at the cuff; the microcontroller controls the valve which slowly releases the pressure in the cuff. As the pressure in the cuffs falls, a pulsation sound is heard when blood flow first starts again in the artery. The pressure at which this sound began is known and recorded as the systolic blood pressure. Furthermore, the cuff pressure is further released until the sound can no longer be heard. This is recorded as the diastolic blood pressure. There are two main blood pressure flows such as systolic blood pressure and diastolic blood pressure. Below are the definitions of each blood flow.

Systolic blood pressure - is the amount of pressure that blood exerts on vessels while the heart is beating. In a blood pressure reading (such as 120/80), it is the number on the top.

Diastolic blood pressure – is the pressure in the bloodstream when the heart relaxes and dilates, filling with blood. In a blood pressure reading (such as 120/80), it is the number on the bottom.

Most people think of a blood pressure (BP) cuff as simply, “just a cuff.” However, there are actually a number of BP cuffs that have been developed to meet the varying needs of patients and medical facilities. In an effort to shed more light on the different cuffs available for use, here is some detailed information on each type, how they are used and the typical environment in which each are used.

Reusable Cuffs: The most popular and common cuff on the market today is the reusable cuff. These cuffs are usually made out of a nylon material, which is a great material for durability, longevity, and easy cleaning. These cuffs are used on multiple patients every day, and can be found in almost any doctor’s office or hospital where there is a low risk for spreading infectious diseases. Typically, the sizes for the reusable cuffs range from Infant to Thigh (8 cm to 50 cm circumference).

Disposable Cuffs: Disposable cuffs are the second most common cuff on the market and are quickly becoming popular as there is a growing concern for hospital acquired infections (like MRSA and C-diff). Hospitals are turning toward disposable cuffs as a first line of defense to reduce the risk of hospital acquired infections (HAI). Disposable cuffs are typically made out of polyester or vinyl. These cuffs are single-patient-use or limited-use cuffs and common throughout emergency rooms, operating rooms, intensive care units, and neonatal units where infection control is a concern. Typically, the sizes for disposable cuffs range from Neonate #1 to Thigh (3 cm to 50 cm circumference).

D-Ring Cuffs: Putting on a “typical” blood pressure cuff (reusable or disposable cuff) yourself can be difficult. D-ring cuffs were designed to be self-applied and make it easier to take your own blood pressure without assistance. D-Ring cuffs are typically used for the home-monitoring and self-application environments. Also, a D-Ring cuff is a standard type of blood pressure cuff that you would usually see in your doctor’s office. It is a cuff where the user loops one end of the cuff through a metal ring, then fastens it to the arm.

Specialty Cuffs: SunTech Medical has two patented specialty-use blood pressure cuffs, the Orbit and Orbit-K cuff. These cuffs were designed specifically for ambulatory blood pressure monitoring and exercise stress testing environments, respectively. These cuffs have a built-in elastic sleeve that gently hugs the arm to keep the cuff in place, whether it be for an extended period of time or running/walking on a treadmill or ergo meter.

There is also a different way of taking the blood pressure instead of the expandable cuff, and that is known as the Wrist Cuff. A wrist cuff is similar to an upper arm cuff; however you can wrap it around your wrist instead of your upper arm. Wrist blood pressure monitors can be accurate if used exactly as directed. However, according to the American Heart Association, it's best to use a home blood pressure monitor that measures blood pressure in your upper arm. Devices for the upper arm are also easier to check for accuracy than are wrist monitors.

Wrist blood pressure monitors are extremely sensitive to body position. To get an accurate reading when taking your blood pressure with a wrist monitor, your arm and wrist must be at heart level. Even though, it's thought that because of differences in the width of the arteries in your forearm, and how deep the arteries are under your skin, blood pressure measurements taken at the wrist are usually higher and less accurate than those taken at your upper arm.

It's actually very common for blood pressure readings taken at home on any type of monitor to be different from those taken at your doctor's office. If you have a wrist blood pressure monitor, it's suggested to take your blood pressure monitor to a doctor's appointment. Your doctor can then check your blood pressure with both a standard upper arm monitor and a wrist monitor in the correct position in the same arm to check your wrist blood pressure monitor's accuracy.

Related to the high probabilities of having an inaccurate result using the wrist cuff, the expandable cuff is going to be used in this project to avoid inaccurate results.

After all those definitions, the D-Ring Cuff did satisfy the objectives and goals of this project. D-Ring Cuff is easy to use and does not require assistance. This way, this project can successfully be used for home-monitoring and self-application environments. Below is a picture 5.3.5.1 of a D-Ring Cuff.

Picture 5.3.5.1 (APP A [6])

D-ring cuffs come in different sizes of small, standard and large. It is important to pick out the right size cuff based on your individual arm circumference. Expandable Cuff is a pre-formed upper arm cuff that expands to fit both regular and large sized arms. It is designed to ensure more comfortable, accurate readings. There is a reasonable standard expandable D-Ring cuff which has a circumference between 9” to 13” – 22 to 32 cm which is being used for this project. It is very important to use the appropriate size cuff for your arm in order to get accurate measurement results when using your home blood pressure monitor. If you use the wrong sized cuff, you are likely experiencing inaccurate readings, inconsistent readings and error messages from the device. To determine your arm size, use a cloth tape measure and place midway between your elbow and your shoulder around the circumference of your upper arm.

Wrap the tape measure evenly around your arm. Do not pull the tape tight. Note the precise measurement in inches. Following those procedures it shall be easy to determine which size cuff is best for you. Below is a small table 5.3.5.1 with the arm sizes. (APP A [11])

D-Ring Upper Arm Cuff Sizing	
Small adult cuff	fits upper arm with circumference between 7-9 inches
Standard adult cuff	fits upper arm with circumference between 9-13 inches
Large adult cuff	fits upper arm with circumference between 13 and 17 inches

Table 5.3.5.1

Most of the people do not know how to put the cuff on correctly, below is providing the correct steps to be taken when using D-Ring cuff.

When the cuff is assembled correctly, the hook material is on the outside of the cuff loop and the metal d-ring is not touching your skin. If the cuff is not assembled, pass the end of the cuff furthest from the tubing through the metal D-Ring to form a loop. The smooth cloth should be on the inside of the cuff loop.

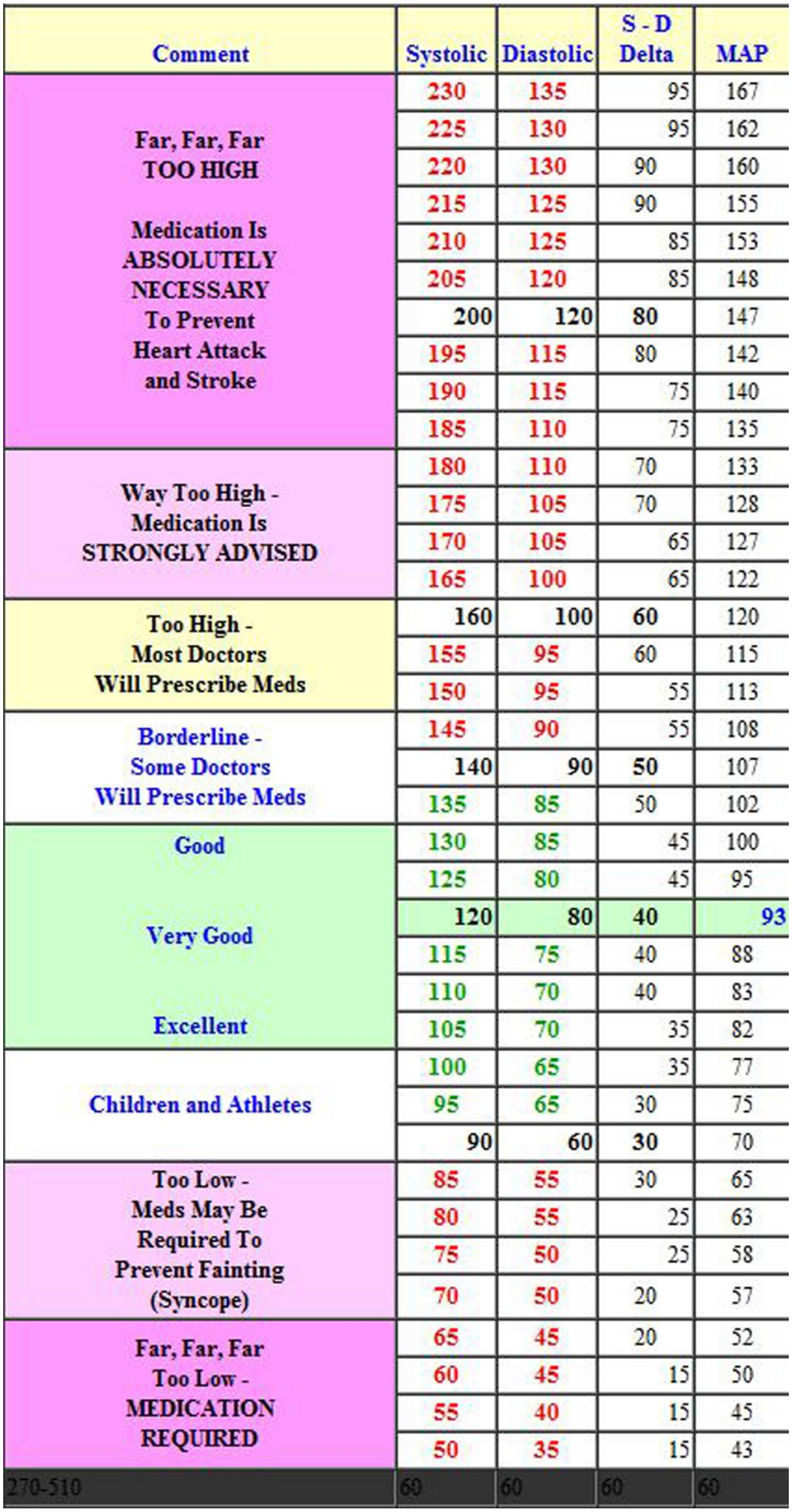
1. Remove tight fitting clothing from your upper arm.
2. Sit in a chair with your feet flat on the floor. Rest your left arm on a table so that the cuff is at the same level as your heart. Turn the palm of your hand upward.
3. Put your left arm through the cuff loop. The bottom of the cuff should be approximately one-half inch above the elbow. The cuff tab shall lie over the brachial artery on the inside of the arm. The cuff tube should run down the center of the arm even with the middle finger.
4. Secure the cuff around your arm. Pull the cuff so that the top and bottom edges are tightened evenly around your arm.

5. Make sure the cuff is wrapped firmly in place. You should be able to fit your index finger between the cuff and your arm easily.
6. Relax your arm and place your elbow on the table so that the cuff is at the same level as your heart.
7. Be sure there are no kinks in the air tubing.

Also, there are some activities that must be taken right before a blood pressure test. Such as, avoid eating, drinking alcohol or caffeinated beverages, and smoking, exercising and bathing for 30 minutes prior to taking a measurement. It is also best to rest for 15 minutes before starting the measurement. Avoid taking a measurement during stressful times. Take the measurement in a quiet place. Furthermore, it is recommended that the patient takes his/hers blood pressure measurement at the same general times each day (for example, once in the morning and once at night) for comparison purposes. Following those activities properly, the results are very accurate.

This cuff must provide great flexibility to execute the test on several people regardless to their arm size or age. Also it is fairly easy to attach the air plug to the air tube. This cuff must be light and comfortable, so the patients do not wound his/herself during the whole process of the test. The cost of the D-ring cuff is really affordable. It costs only $13.95 at amazon website.

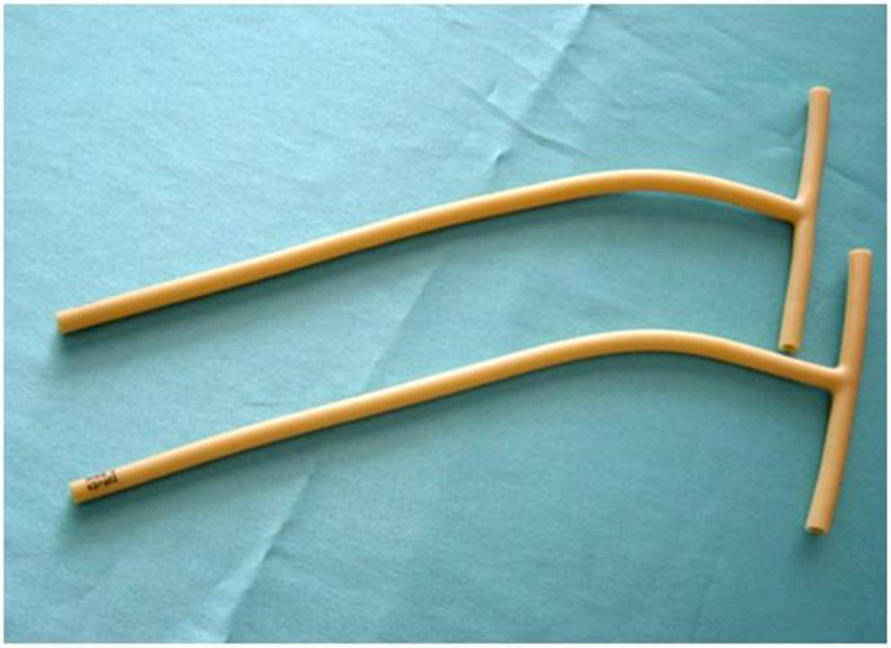
This cuff shall be strong enough to support a pressure of 170 ~ 200 mmHg because any leak could potentially pop the cuff, and consequently it does severely wound the patient. Even though it is a simple device, it has to be in perfect shape at all times during its usage. Right below is the blood pressure chart 5.3.5.1.



Comment	Systolic	Diastolic	S - D Delta	MAP
Far, Far, Far TOO HIGH Medication Is ABSOLUTELY NECESSARY To Prevent Heart Attack and Stroke	230	135	95	167
	225	130	95	162
	220	130	90	160
	215	125	90	155
	210	125	85	153
	205	120	85	148
	200	**120**	**80**	147
	195	115	80	142
	190	115	75	140
	185	110	75	135
Way Too High - Medication Is STRONGLY ADVISED	180	110	70	133
	175	105	70	128
	170	105	65	127
	165	100	65	122
Too High - Most Doctors Will Prescribe Meds	**160**	**100**	**60**	120
	155	95	60	115
	150	95	55	113
Borderline - Some Doctors Will Prescribe Meds	145	90	55	108
	140	**90**	**50**	107
	135	85	50	102
Good	130	85	45	100
	125	80	45	95
Very Good	**120**	**80**	**40**	**93**
	115	75	40	88
	110	70	40	83
Excellent	105	70	35	82
Children and Athletes	100	65	35	77
	95	65	30	75
	90	**60**	**30**	70
Too Low - Meds May Be Required To Prevent Fainting (Syncope)	85	55	30	65
	80	55	25	63
	75	50	25	58
	70	50	20	57
Far, Far, Far Too Low - MEDICATION REQUIRED	65	45	20	52
	60	45	15	50
	55	40	15	45
	50	35	15	43
270-510	60	60	60	60

Blood Pressure Chart 5.3.5.1 (APP B [3])

Another part of the cuff is the tube. It was used a latex T-tube with a diameter of 3mm. This diameter of the T-tube is very important because it must connect very tightly to the motor, cuff and the valve to avoid any air leak. If there is any crack on the tube, it potentially compromises the results of the blood pressure test. After some discussions and researches, it was decided to do not keep the sensor on the cuff, so the T-tube was the solution to solve the challenge. The main reason why a T-tube has been chosen is because the sensor is located at the T section. It is a strategic location because it will be able to sense the pressure on the cuff when the motor is pumping air into the cuff, and also it is able to sense all the air coming out of the cuff once the valve has been opened. Therefore, it provides a very accurate result. Picture 5.3.5.2 is an example of the T-Tube.



Picture 5.3.5.2 (APP B [2])

6.0 Project Test Plans

6.1 Hardware

The major function of the hardware testing is to be completely sure that the hardware will accomplish the expected characteristics prior to integrating the each hardware with the main design. The first procedure is physically putting the hardware through similar physical conditions to analyze how it is handling them, which may include such things as position, temperature, proper voltage, or proper current. After it is determined the functions of the hardware, then it must be determined that the hardware is working at its full potential. The hardware's output characteristics based on its inputs must be tested against a reliable outside source. Furthermore, the tests were executed several times to make sure the hardware was working properly. Even after the hardware has been connected, it was tested by connecting it to the software and ensuring that the hardware outputs to the software as expected at all times.

Testing

- The sensor was tested individually to ensure that it works properly; i.e. whether it turns on and off when supplied power.
- The micro air pump was tested individually to ensure that it works properly; i.e. whether it turns on and off when supplied power. Also, to ensure that the pressure being produced by the micro air pump is related to specifications.
- The micro valve was tested individually to ensure that it works properly; i.e. whether it turns on and off when supplied power. Also, to ensure that the pressure being released by the valve is related to the specifications.
- The cuff was tested individually to ensure that it works properly; i.e. whether it is being inflated or deflated.
- Each light element was tested to ensure that the lights function properly when supplied with the proper voltage.
- The boost-buck converter was continuously tested throughout the project. Multimeter leads were consistently applied to the input and output terminals to make sure that the voltages were accurate and regulated.
- After all components were installed, power was supplied to all of the individual components from the power management system to ensure that power requirements have been met. This also includes testing that there was sufficient voltage to all elements so that they behave as expected. LEDs and the LCD had to be lit with proper luminance.
- Also to ensure that the four AAA batteries are providing enough power to the units such that their output characteristics remain within the provided margin of error.
- Microcontroller was properly configured and tested sending signal to each component on the PCB board individually.
- After the microcontroller had been configured, the wireless component was tested. It sent some data from to microcontroller to the PC’s display.

When all the tests were successfully executed, the next step was to assemble the parts. The challenge was to analyze how the components were functioning once they were connected.

6.2 Software Testing

After all the components of the project were brought together there was a full understanding on how the system works before proceeding to start testing the software to make sure that all the functions are performing according to requirements. Each major part of the project was independently tested to avoid wasting time trying to figure out which function was not working properly. The main purpose of doing software testing was to make sure that each function was working independently and that it works when all the functions are put together. During this stage, error checks were performed and corrected as soon as possible. This stage is was very critical because it showed us if the project would perform as planned.

Different types of software were tested during this stage. These tests were dynamic testing, static testing, unit testing, system testing, integration testing, and stability testing. For the dynamic testing, the entire system was tested, which means that all the functions created were tested together to see how the system was performing; for the static testing, the code was developed, line by line, function by function, always verifying if there is any error in the code; for the unit testing, each component of the system was tested separately. This type of testing gave the ability to identify which functions were incorrect without having to go through all of the functions at the same time; for the system testing. The system met every requirement that was set during the design of the project; the system testing ensured that the system functioned accordingly and it met every requirement of the project; and finally, the stability testing made sure that the code runs consistently, independently of how many times it needs to run.

To run the tests mentioned previously, Code Composer Studio (CCStudio) Integrated Development Environment (IDE) v5 was used. Code Composer Studio™ (CCStudio) is an integrated development environment (IDE) for Texas Instruments' (TI) embedded processor families. It comprises a suite of tools used to develop and debug embedded applications. It includes compilers, source code editor, project build environment, debugger, profiler, simulators, real-time operating system and many other features. The intuitive IDE provides a single user interface taking you through each step of the application development flow. Most of the components are from Texas Instruments, including the MCU, so it is important to have access to an easy to use compiler, that is user friendly and that has all the tools that will be necessary to complete all tasks. This IDE is based on the Eclipse open source software framework which offers an excellent software framework for building software development environments and it is becoming a standard framework used by many embedded software vendors. CCStudio combines the advantages of the Eclipse software framework with advanced embedded debug capabilities from TI resulting in a compelling feature-rich development environment for embedded developers. Code Composer Studio supports running on both Windows and Linux PCs, which worked perfect for this project, since all of us have access to Windows PCs.

6.3 Wireless Testing

In order to start testing the wireless portion of The Blood Pressure Tester, the first step taken was getting an entire development kit from Texas Instruments Inc. This provided the prototyping with the exact idea of what this wireless portion supposed to work, and behave. It was important to get an idea of how the actual functioning wireless communication works, so when the re-designed PCB of the wireless circuit that is going on The Blood Pressure Tester is ready to test there will be a functioning wireless circuit to compare it to.

The testing portion done was with the xbee device attached to the redesigned pcb then testing the connection with the other module attached to the laptop. This way it was known that a connection was being sent/received and now it could be working properly as you can see from the picture below.

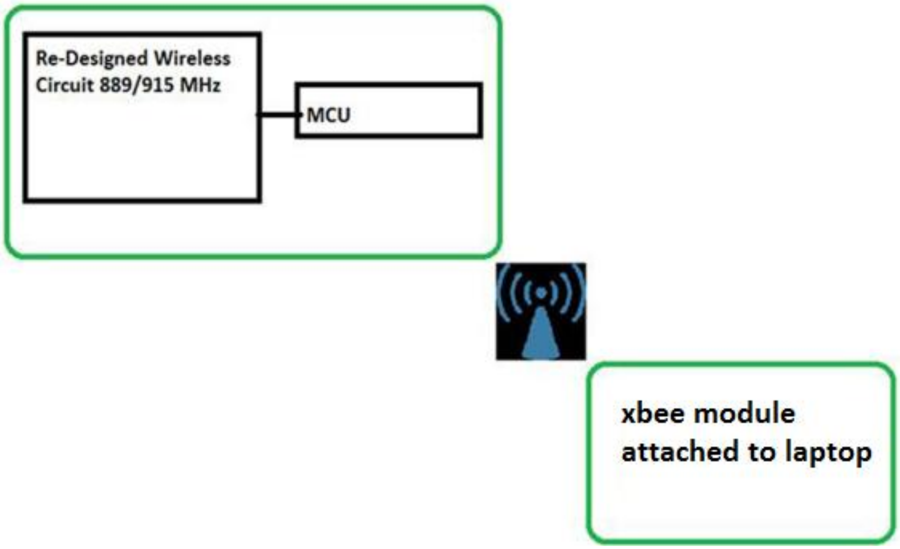


Figure 6.3.1: Testing procedure

So as you can see from (Figure 6.1) it can be seen what exactly needs to be done in order to start an appropriate testing procedure for the wireless portion for this project. The re-designed wireless circuit is already known as from the discussions above. To connect the wireless circuit to the MCU is simply connecting the appropriate pins as stated above, to each other in order for the two components to communicate effectively.

Once these two components were communicating effectively the MCU was programmed to send a “dummy” packet to the wireless circuit for it to send it to the wireless circuit on the laptop, this is because since the MCU could potentially cause some sort of wireless interruption due to “noise” it was good idea to test how the wireless circuit will act like when it has a MCU operating close to it.

Everything else on The Blood Pressure Tester PCB board is turned off except the MCU when the wireless device is operating. This is because if there at many components on while the wireless portion is on, it could cause a lot of interrupts in the wireless transmission because most components add noise to their surrounding areas. Noise can definitely cause some issues with transmitting data wirelessly. Noise is a summation of unwanted or disturbing energy from natural and sometimes man made sources. Since this project has a lot of a lot of noise generating components, it is a good thing that most of the components will be turned off during the time of wireless transmission.

Once it was known what the transmission signal is supposed to look like when see how the pre-made wireless circuits work, it was simple to see what to look for once the re-designed circuit was made and the testing began. For example, say the signal the working wireless circuits form the development kit produces something like what is show in (Figure 6.2)

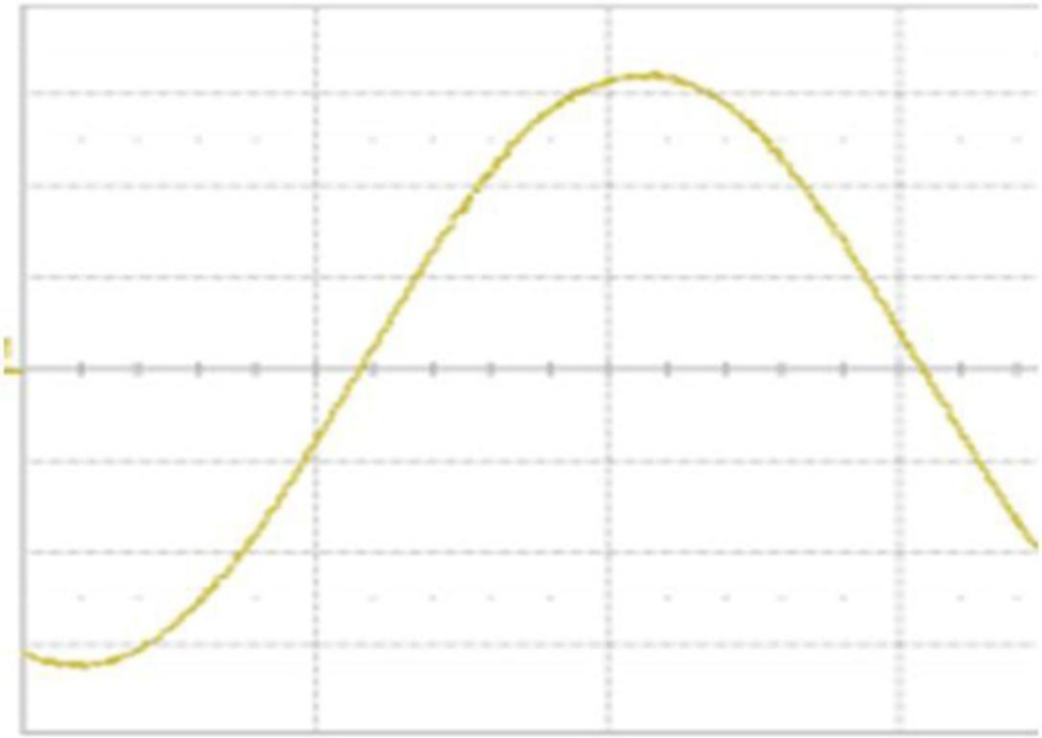


Figure 6.3.2: Wireless Signal – Courtesy of Texas Instruments

It was known what to look for when the re-designed circuit started communicating with the wireless part on the MSP430F5438. This made the wireless testing complete and ready to be put on the final PCB for The Blood Pressure Tester. Some pseudo code on how the MCU will be communicating with the wireless component is below.

```
//Checkrecieve (Packet_sent, Packet Received)
```

//Check packet sent, check packet received
If < packet has been sent flag YES
Else
Return 0;
If<packet received flag YES
Else
Return 0;

7.0 Safety Protocol:

The safety protocol, or in other words, safety precautions are very important, and they shall be carefully followed when setting up and using the blood pressure monitor in order to avoid any type of injury. Below is providing some examples of safety information.

- Contact your physician specific information about your blood pressure. Self-diagnosis and treatment using measurement results may be dangerous.
- Do not confuse self-monitoring with self-diagnosis. This unit allows you to monitor your blood pressure.
- Do not begin or end medical treatment based solely on the measurements of the device. Consult a physician for treatment advice.
- If you are taking any medication, consult your physician to determine the most appropriate time to measure your blood pressure. Never change a prescribed medication without consulting your physician.
- The blood pressure monitor is intended for adult use only.
- Dispose of the device and components according to applicable local regulations. Unlawful disposal may cause environmental pollution.
- Do not use wireless devices near the blood pressure monitor because it may result in an operational failure.
- Use four “AAA” batteries with the device to do not damage the unit.
- Do not subject the monitor to strong shocks, such as dropping the unit on the floor.
- Keep any liquid away from the device.
- Keep the monitor in a clean and safe location.
- The material of the cuff must be in a good shape and very comfortable to prevent the arm from getting injured once it is being inflated.

There is some specific technical safety protocol as well. If the cuff pressure exceeds 300 mmHg, the unit automatically deflates; also there is a button on the device which turns on/off the device, once the button is pressed for the second time, it sends a signal to the microcontroller, and the microcontroller stops the micro air pump and immediately opens the valve to deflate the cuff to avoid any injury. Once this button has been pressed for the second time, the microcontroller erases the data of the previous test and resets the whole system, and then it starts the blood pressure test all over again.

Another safety protocol is the non-auscultatory mercury-free sphygmomanometers. It uses the oscillometric technique to measure the blood pressure based on changes in the artery pulsation during cuff inflation and deflation. These different options to the mercury sphygmomanometer are easy to use. They do not use the auscultation technique, and it is easier to train users. Furthermore, patients are using more of them for home blood pressure monitoring and also almost exclusively for 24-hour ambulatory blood pressure monitoring. They do not require a lot of maintenance, costs is reasonable to the additional capabilities of the device. Indeed, the alternatives to Hg sphygmomanometers have hugely different levels of reliability.

Vibration is another concern. The vibration potentially affects the performance of the blood pressure monitor. It can also damage one of the components in the system while it is being used. It is recommended that the blood pressure test is executed in an empty and quiet room.

8.0 Project Summary and Conclusion:

Hardware Block Diagram

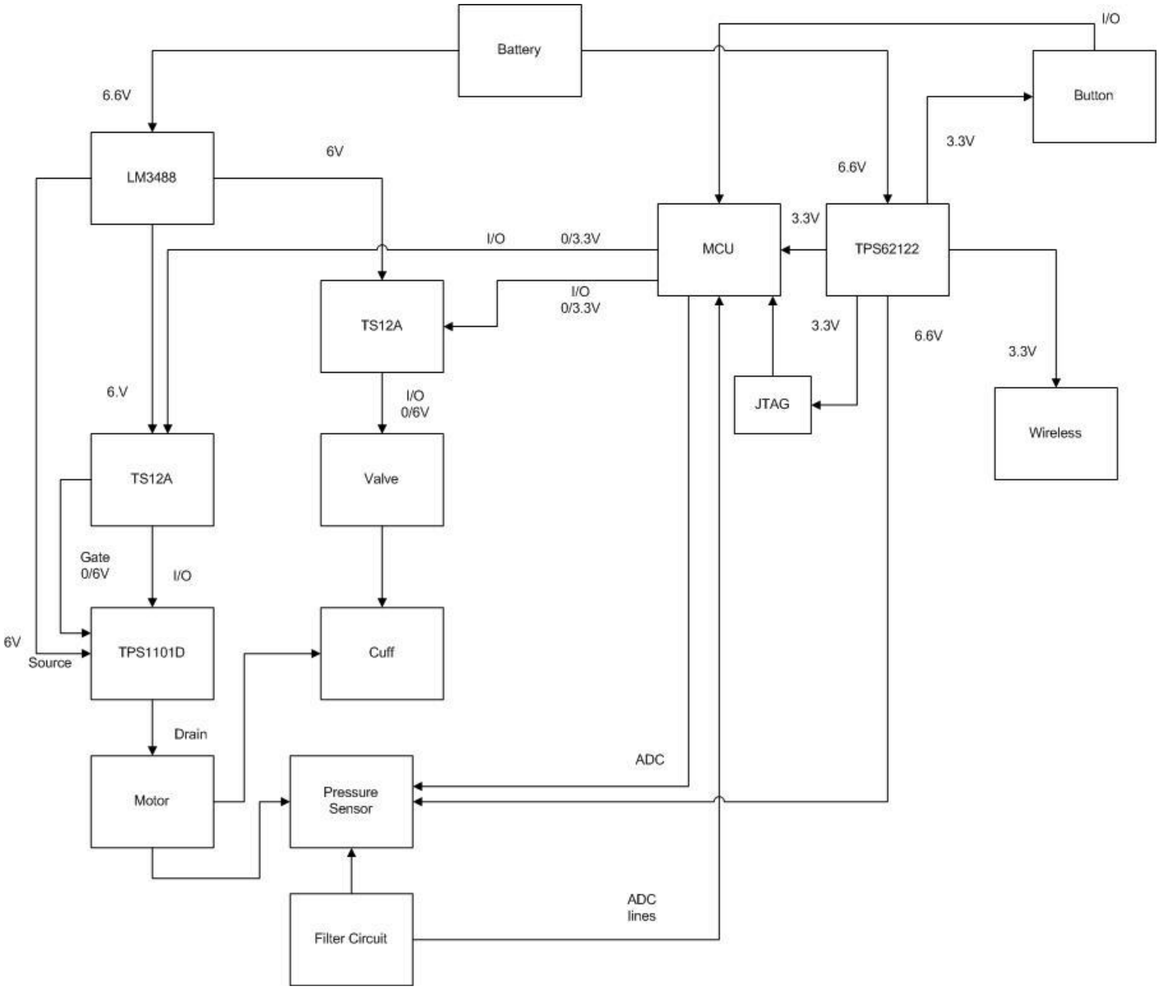


Fig. 8.1 Hardware Block Diagram

The hardware block diagram shows how all the major components of the project are related and from where it receives input and where it sends the output. As shown in the diagram, the battery (composed of 4AAA batteries) provides 6V to voltage regulators (LM3488 and TPS62122) that regulates the voltage to 3.3V which is the voltage supported by the MCU; The TPS62122 regulator regulates the voltages coming to the Motor and the Valve, while the TPS62122 regulator regulates the voltages entering the JTAG, the pressure sensor, the wireless, the start button, and the MCU. The system integrates three switches; the first TS12A controls another switch TPS1101D that controls the motor and the last switch controls the valve. There is also a filter circuit that is implemented in the pressure sensor so there is the elimination of noise in the system. There is also a start button that starts the entire system, or if pressed again, aborts the procedure. All the information collected is sent wirelessly to a display located at a remote computer.

Software Block Diagram

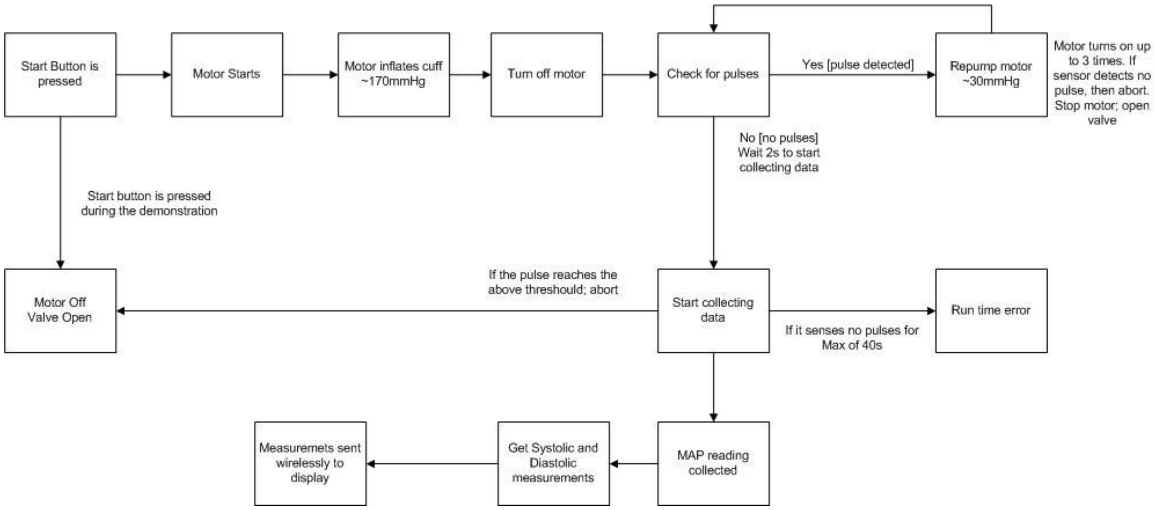


Fig. 8.2 Software Block Diagram

The software block diagram shows how the programs for the main components are related. All the programming for this project was done in C language and used Code Composer Studio v5.1, from Texas Instruments, to compile and run the program. As shown in the Fig. 8.2, if the demonstration runs with success, the MCU is able to collect the data (Mean Arterial Pressure – MAP) and apply the algorithms to find the systolic and diastolic measurements and send the results wirelessly to the BP Monitor display.

Oscillometric Blood Pressure Method – The blood pressure monitoring and reading method utilized in this device is the oscillometric method. It is not a direct method of blood pressure measurement and therefore requires analog filtering and data interpretation by a MCU as well as pressure conversion calculations before a blood pressure reading can be displayed. In this method the systolic and diastolic pressures are derived from an algorithm which uses data from a pressure sensor that converts mechanical air pressure inside the occlusion cuff as well as oscillations of arterial blood flow due to reintroduction to the artery after being cut off. The pressure sensor converts this air pressure into a mixed voltage signal by utilizing a Wheatstone Bridge resistor configuration. The mixed signal is comprised of AC and DC signals that must be separated by analog circuitry before being converted digitally for processing and blood pressure calculation. As oscillations in the artery increase in amplitude during reintroduction of blood flow, the converted signal relaying this information is recorded. The peak of these oscillations is noted as the mean arterial pressure or MAP, pressure point. During the pressure decrease in the cuff, the oscillations will become increasingly significant, until maximum amplitude of these oscillations defines the average blood pressure or MAP. The DC voltage signal relays the cuff pressure. The AC signal is the voltage signal relaying the oscillations within the cuff that are caused by the artery flexing upon blood flow reintroduction. Flexing of the artery during introduction of blood flow produces turbulent oscillating blood flow instead of a laminar smooth flow that is normal to the artery. The point in time in which the MAP occurs is recorded. The systolic and diastolic points' occurrence times are derived through taking a percentage of the MAP before and after. The three points in time are correlated to the cuff pressure recording. The points in time of the AC signal are correlated to the DC signal's pressure values at the noted times. This is how pressure reading is derived in the oscillometric blood pressure method.

Microcontroller - Between all the MSP430 designs, the one used in the project was the MPS430F5438A. The features of this specific MCU are enough to receive, process, and send the data to BP Monitor display located at a remote computer. It also maintains the low power and low cost profile of the blood pressure monitor. This microcontroller is directly powered so that it can initiate the power management boosting converter. Furthermore it controls all aspects of the system including powering on and off the motor, the valve, the pressure sensor, as well as the wireless. Furthermore it does all the data calculations and processing.

Power System –. This device utilizes four AAA batteries as the project specifications specify that the device must run on 6 volts. Environmental issues, quality and safety issues are always of concern. For this reason the battery that was considered was the one with the least toxicity. Memory effect refers to having damage when the batteries are not discharged and charged completely. As individuals are less likely to completely run the rechargeable batteries down before recharging, having a device run automatic discharge cycles will help maintain battery life. The four AAA batteries generate more than enough power to support the whole circuit. The objective is to provide proper power to all parts of the system. This is done with a boost-buck converter. The boost-buck topology built by TI (Texas Instruments) TPS62122 and LM3488 provide a power regulator solution for products powered by either a two-cell or three-cell alkaline, NiCd or NiMH battery, or a one-cell Li-Ion or Li-polymer battery. Output currents can go as high as 1200 mA while using a single-cell Li-Ion or Li-Polymer Battery, and discharge it down to 2.5V or lower. The buck-boost converter is based on pulse-width-modulation (PWM) controller using synchronous rectification to obtain maximum efficiency. At low load currents, the converter enters Power Save mode to maintain high efficiency over a wide load current range. All parts of the device are sufficiently powered.

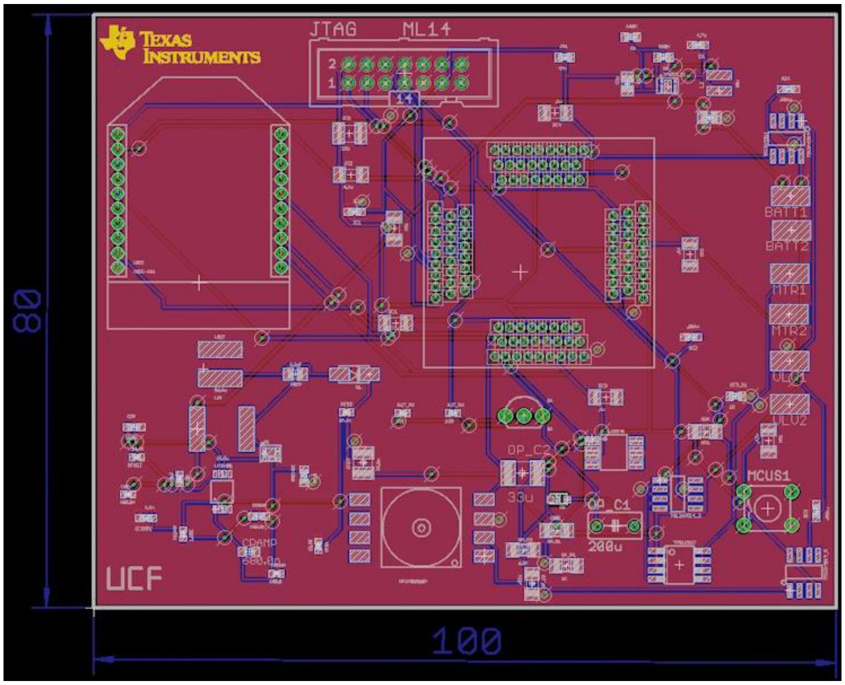
Pressure sensor- The Freescale Semiconductor MP3V5050GP piezoresistive ratio metric pressure sensor was the pressure sensor utilized in this device. It maintains the device's low profile by only needing 3.0V and 7mA to operate correctly. It outputs a maximum voltage of 2.82V and has a pressure range of 0 - 7.25 psi. This is more than sufficient to cover the range of human blood pressure values as it represents 0 to 375mmHg.

Wireless – Having a wireless display is an important aspect of the project; it is needed so that the person viewing the patient's' blood pressure has the freedom to view it from the comfort of wherever they want to be in the building. For example, if a doctor wanted to know the patient's' blood pressure in a room on the other side of the building, he/she could just tell the nurse in charge of that patient to take it and he could see the results at a display in his office, such as his/her computer instantly. The wireless solution utilized is the XBee 1mWChip Antenna - Series 1 (802.15.4) one of the more popular choices from Digi. This particular module uses the 802.15.4 stack which is the basis for Zigbee and makes it into a simple to use serial command set. It's basically a simple point to point (anything with a serial port) wireless Communication device. For this particular design it has one module attached to the printed circuit board (PCB) designed. Also, another module is attached to a USB cable which is then attached to a laptop computer. The module attached to the PCB receives the calculated blood pressure data from the MCU and communicates with the Xbee attached to the laptop which will display the calculated results in a systolic/diastolic form (two different numbers) on the laptop screen on a simple graphical user interface (GUI). The specifications this particular Xbee operates with is it has an Indoor/Urban Range of up to 100 ft (30m), Outdoor RF line-of-sight Range up to 300 ft(90 m), a Transmit Power Output (software selectable) 1mW (0dBm), the RF Data Rate is250,000 bps, 1200 bps-250 kbps (non-standard baud rates also supported), and receiver sensitivity is -92 dBm (1% packet error rate). Some power requirements for the Xbee, is the supply voltage requires 2.8-3.4V, Transmit Current (typical) 45mA (@3.3V), the Idle/Receive Current (typical) 50mA (@3.3V), and the Power-down Current is<10uA. Some general information regarding the Xbee that is being utilized is the Operating Frequency ISM 2.4 GHz, Dimensions 0.960" x1.087" (2.438cm x 2.761cm), Operating Temperature -40 to 85 degrees C (industrial), and Antenna Operations is integrated whip, chip or U.FL Connector, RPSMA connector.

Display – The main objective of the display is to show two measurements taken from the patient: the systolic measurement (in mmHg) and the diastolic measurement (in mmHg). The display receives information sent by the MCU, wirelessly, and displays it in BP Monitor display located at a remote computer. The display used in this project was designed to show, not only the two measurements in mmHg, but also the status of the operation and the detection of heartbeats. The reason why this option was chosen over the MSP-EXP430F5529 and the MSP-EXP430F5438 was the convenience of designing our own display and to maintain our cost efficiency. Figures 4.2.5A, 4.2.5B and 4.2.5C show a comparison between the displays that are in experimenter board and the display designed specifically for this project. The final decision was to use the BP Monitor to display all the results and the status of the system at a specific moment.

Software – After researching about the most common programming languages, such as C, C++, C#, Java, JavaScript and PHP, the most appropriate language to be used in this project was the C language. This language is supported by the microcontroller that was used in this project (MSP430F5438A) and all other components. To accomplish all requirements, different functions were created that were responsible for performing specific tasks. The pseudo code mentioned in section 4.3 shows how the program will perform each function. To check if the functions are written correctly, separate software tests were performed during each addition of a different component and they were classified as following: dynamic testing, static testing, unit testing, system testing, integration testing, and stability testing. For each test case, the code was checked to make sure that it worked for each component independently, as well as for the entire system. To perform these tests, Code Composed Studio (CCStudio) Integrated Development Environment (IDE) v5 was used to compile and run the program, which is an integrated development environment (IDE) for Texas Instruments' embedded processors.

PCB- The final printed circuit board (PCB) design for this project is a simple two-layer board utilizing the software EAGLE to design the schematic along with the PCB. Due to different current consumptions from different components pulling current to work at the same time or individually, the trace widths of each trace on the PCB had to be carefully calculated in order to allow the correct amount of current to go through the traces leading to each component. the gap between traces along with the gap between the ground plane and traces were carefully calculated in order to avoid overlapping of traces and throughout the process of using Eagle. This PCB consists of mainly surface mount components directly soldered onto the PCB itself. It was decided to make the PCB as compact as possible in order to fit a 3" x 4" area it was decided to apply small surface mount components. However, the MCU is not directly connected to the PCB, an adapter that fits the MCU is soldered directly onto the PCB. This was decided to avoid any JTAG programming issues that may rise in the case of a miss connection to the MCU from the JTAG on the PCB. That way if this type of error were to arise, the MCU can be easily removed and programmed somewhere else then place back into the adapter instead of having to de-solder the 100-Pin MCU and re-soldering it over and over again for debugging. Along with the MCU adapter, the Xbee has header pins attached to the designed PCB in order to have easy access to the Xbee module itself. In the case of the module getting damaged since RF equipment can be very sensitive, the headers give the option to easily remove and replace this part with no soldering involved.



-Personal Image of the Eagle designed PCB

CONCLUSION – The blood pressure monitoring device designed and built involved various fields of engineering. While each section or module was individually tested in simulation and then with a physical prototype for expected output based on known inputs before being assembled and tested as a whole; no one part is more essential than the other. Each person of the group was involved in making sure that the module that they were responsible for worked as expected before the modules were connected for a complete device. While every module will be tested as a group effort, every module had a manager. The choice of each part of this device was critical to meet the specifications and objectives of the project. Where needed, part decisions were changed through the project cycle to better meet the objectives and goals of the project. By meeting the objectives of the project, the device can be further developed for future applications.

Appendix: A (Reference)

[1] Federal Communications Commission, "Code of Federal Regulations: Title *47," Federal Communications Commission,* October 2008. [Online], Available: http://www.fcc.gov. [Accesses: Nov. 15, 2011].

[2] Texas Instruments, "CC1101 Low-Power Sub-1 GHz RF Transceiver". *Texas Instruments.[Online]* Available: www.ti.com. [Accessed: Nov. 29, 2011].

[3] Texas Instruments, "CC2500 Low-Cost Low-Power 2.4 GHz RF Transceiver". *Texas Instruments.[Online]* Available: www.ti.com. [Accessed: Nov. 29, 2011].

[4] Texas Instruments, "CC2420 2.4 GHz IEEE 802.15.4/ZigBee-ready RF Transceiver". *Texas Instruments.[Online]* Available: www.ti.com. [Accessed: Nov. 29, 2011].

[5] Texas Instruments, "CC2520 2.4 GHz IEEE 802.15.4/ZIGBEE RF Transceiver". *Texas Instruments.[Online]* Available: www.ti.com. [Accessed: Nov. 29, 2011].

[6] Streetdirectory, "Understanding Electric Motors and Their Uses," [Online], Available: http://www.streetdirectory.com/travel_guide/115541/technology/understanding_electric_motors_and_their_uses.html, [Accessed: Nov. 11, 2011].

[7] Priestelectric, "The History of Electric Motors," [Online], Available: http://www.priestelectric.com/electric-motors, [Accessed: Nov. 11, 2011].

[8] Samsung, "S3P8245, ARM Blood Pressure Monitor," July 2010, [Online], Available:http://www.samsung.com/global/business/semiconductor/products/microcontrollers/downloads/S3P8245_ARM_Blood_Pressure_Monitor_AN_REV000.pdf, [Accessed: Nov. 13, 2011]

[9] Smartproducts, "AP Micro - Air Pump," @ 2005-2011 [Online], Available: http://www.smartproducts.com/pumps_series_ap_micro_air_pumps.php, [Accessed: Nov. 14, 2011].

[10] Parker, "Micro Solenoid Valve," 2011[Online], Available: http://www.parker.com/portal/site/PARKER/menuitem.7100150cebe5bbc2d6806710237ad1ca/?vgnextoid=f5c9b5bbec622110VgnVCM10000032a71dacRCRD&vgnextfmt=EN&vgnextdiv=&vgnextcatid=2934892&vgnextcat=UNIVERSAL+STYLE&Wtky=VALVES, [Accessed: Nov. 14, 2011].

[11] ncbi, "A short history of blood pressure measurement," v.70(11); Nov 1977 [Online], Available: http://en.wikipedia.org/wiki/Sphygmomanometer, [Accessed: Nov. 17, 2011].

[12] consumerreports, “Home Medical Supplies,” September 2011 [Online], Available: http://www.consumerreports.org/health/healthy-living/home-medical-supplies/blood-pressure-monitors/blood-pressure-monitor/overview/blood-pressure-monitor-ov.htm, [Accessed: Nov. 17, 2011].

[13] trustyourhearttoomron, “Automatic Blood Pressure Monitor,” September 2011 [Online], Available: http://www.trustyourhearttoomron.com/pdf/Upper%20Arm %203%20series/bp710_im_eng_09152010.pdf, [Accessed: Nov. 17, 2011].

[14] aandd, “Automatic Blood Pressure Monitor,” September 2005 [Online], Available: http://www.aandd.jp/products/manual/medical/tm2655.pdf, [Accessed: Nov. 17, 2011].

[15] Texas Instruments, "96% Buck-Boost Converter with 1.7A Current Switches, 3.3V fixed Output voltage in 3x3”. *Texas Instruments.[Online]* Available: www.ti.com. [Accessed: Nov. 29, 2011].

[16] “Omron 1500PRO Ultra Premium Blood Pressure Monitor” January 2011, [Online],

Available: http://www.healthchecksystems.com/bpdigital.htm, [Accessed Nov. 28, 2011]

[17] **“**Measurement and Mechanism of Pulsus Paradoxus,” April 2007, [Online], Available: http://jama.ama-assn.org/content/297/16/1810/F3.expansion, [Accessed Nov. 28, 2011]

[18] “Oscillometric Method,” September 2003, [Online], Available: http://www.blood-pressure-hypertension.com/how-to-measure/measure-blood-pressure-8.shtml, [Accessed Nov. 30, 2011]

[19] “Oscillometric Method – Phillips,” November 2008, [Online], Available: http://www.patientsafety.gov/alerts/AL10-11-PMD_-_White_Paper_-_NIBP_Mean_Only_Readings.pdf, [Accessed Dec 1, 2011]

[20] “NOAA pressure conversions,” July 2009, [Online], Available: http://www.wrh.noaa.gov/slc/projects/wxcalc/formulas/pressureConversion.pdf[Accessed Dec 2, 2011]

[21] “Automated Digital Blood Pressure Meter,” March 2007, [T.I. PDF document]

[22] Samsung, “S3P8245, ARM Blood Pressure Monitor,” July 2010, [Online], Available: http://www.samsung.com/global/business/semiconductor/products/microcontrollers/downloads/S3P8245_ARM_Blood_Pressure_Monitor_AN_REV000.pdf, [Accessed: Nov. 13, 2011]

[23] ncbi, “A short history of blood pressure measurement,” v.70(11); Nov 1977 [Online], Available: http://en.wikipedia.org/wiki/Sphygmomanometer, [Accessed: Nov. 17, 2011].

[24] “Texas Instruments INA 321”http://www.ti.com/lit/ds/symlink/ina321.pdf, 2011 [Accessed Nov 22, 2011]

[25]“ASDXLDO,“[Online],Available:http://content.honeywell.com/sensing/prodinfo/pressure/008141_2_en_w.pdf,[Accessed: Nov 28, 2011]

[26]“MPS-3117,”[Online],

Available:http://www.metrodyne.com.tw/datasheets/en/MPS/MPS-3110series.pdf, [Accessed” Nov. 28, 2011]

[27]“ADP1,”[Online],Available:http://pdf1.alldatasheet.com/datasheet-pdf/view/90541/ETC/ADP1101.html, [Accessed: Nov 28, 2011]

[28] Texas Instruments, “MSP430F5438 Experimenter Board “. Texas Instruments [Online] Available: http://www.ti.com/tool/msp-exp430f5438 [Accessed: Nov 30]

[29] Texas Instruments, “MSP430F5529 USB Experimenter’s Board”. Texas Instruments [Online] Available: http://www.ti.com/tool/msp-exp430f5529&DCMP=capacitivetouch&HQS=Other+PR+capacitivetouch-msp-exp430f552 [Accessed: Nov 30]

[30] Texas Instruments, “MSP430F5438 Experimenter Board “. Texas Instruments [Online] Available: http://www.ti.com/tool/msp-exp430f5438 [Accessed: Nov 30]

[31] Texas Instruments, “MSP430F5529 USB Experimenter’s Board”. Texas Instruments [Online] Available: http://www.ti.com/tool/msp-exp430f5529&DCMP=capacitivetouch&HQS=Other+PR+capacitivetouch-msp-exp430f552 [Accessed: Nov 30]

[32] Samsung Electronics, “S3P8245 ARM Blood Pressure Monitor”. Samsung Electronics [Online] Available: http://www.samsung.com/global/business/semiconductor/products/microcontrollers/downloads/S3P8245_ARM_Blood_Pressure_Monitor_AN_REV000.pdf [Accessed: Dec 1]

Appendix: B (Permissions)

[1]http://www.ti.com/corp/docs/legal/copyright.shtml?DCMP=TIFooterTracking&HQS=Other+OT+footer_copyright
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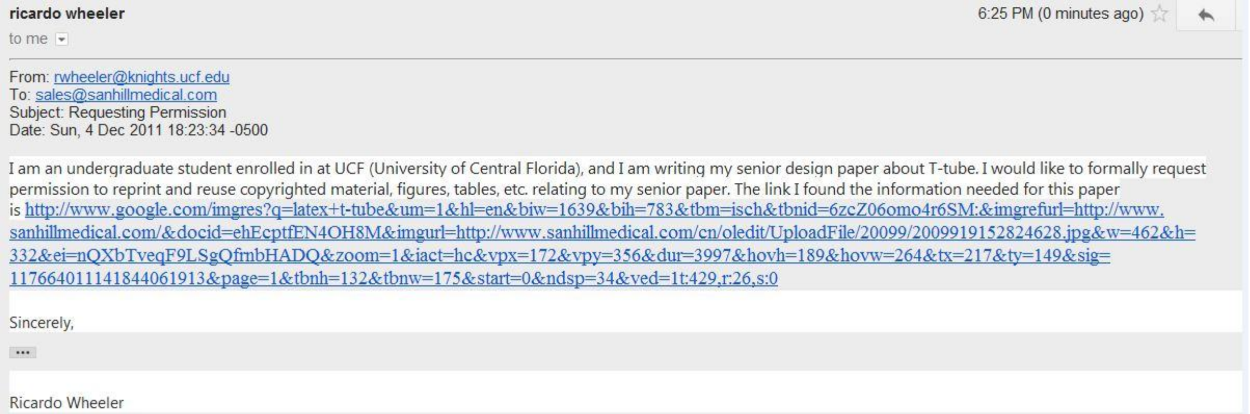

ricardo wheeler
to me
6:25 PM (0 minutes ago)

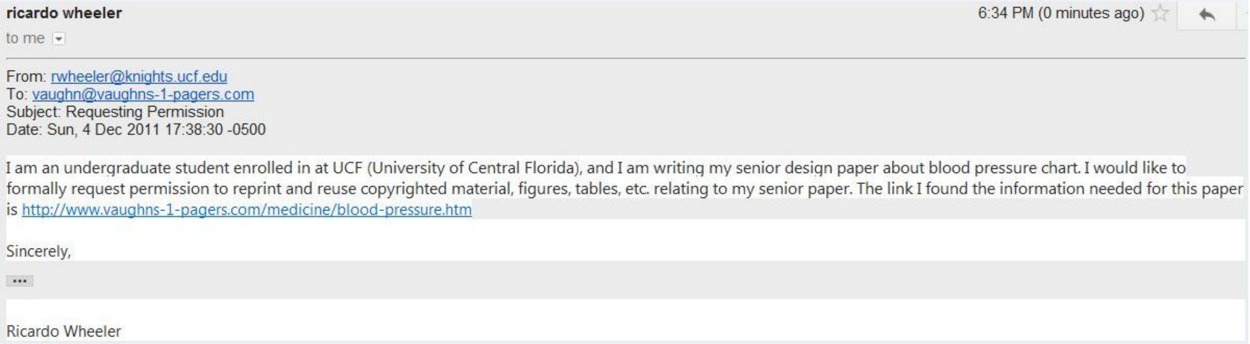
From: rwheeler@knights.ucf.edu
To: sales@sanhillmedical.com
Subject: Requesting Permission
Date: Sun, 4 Dec 2011 18:23:34 -0500

I am an undergraduate student enrolled in at UCF (University of Central Florida), and I am writing my senior design paper about T-tube. I would like to formally request permission to reprint and reuse copyrighted material, figures, tables, etc. relating to my senior paper. The link I found the information needed for this paper is http://www.google.com/imgres?q=latex+t-tube&um=1&hl=en&biw=1639&bih=783&tbm=isch&tbnid=6zcZ06omo4r6SM:&imgrefurl=http://www.sanhillmedical.com/&docid=ehEcptfEN4OH8M&imgurl=http://www.sanhillmedical.com/cn/oledit/UploadFile/20099/2009919152824628.jpg&w=462&h=332&ei=nQXbTveqF9LSgQfmbHADQ&zoom=1&iact=hc&vpx=172&vpy=356&dur=3997&hovh=189&hovw=264&tx=217&ty=149&sig=117664011141844061913&page=1&tbnh=132&tbnw=175&start=0&ndsp=34&ved=1t:429,r:26,s:0

Sincerely,

Ricardo Wheeler

[3]


ricardo wheeler
to me
6:34 PM (0 minutes ago)

From: rwheeler@knights.ucf.edu
To: vaughn@vaughns-1-pagers.com
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Sincerely,

Ricardo Wheeler

[4]

ricardo wheeler

6:35 PM (1 minute ago)

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To: ppfinfo@parker.com
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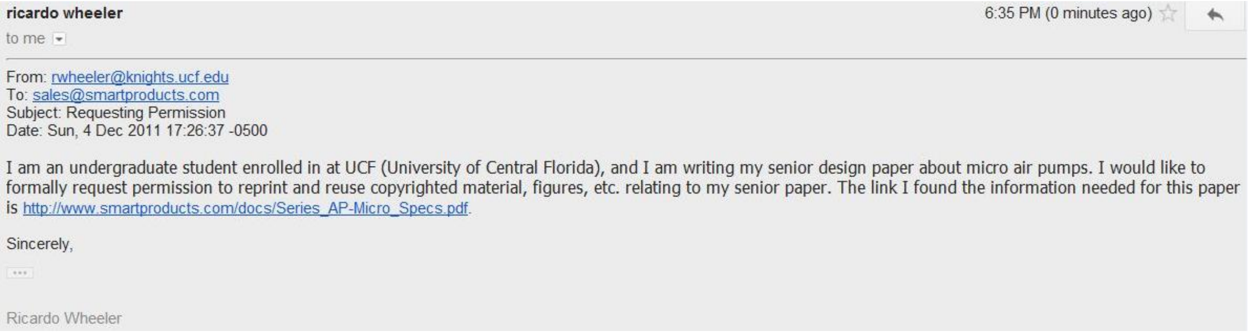
Sincerely,

Ricardo Wheeler

[5]



ricardo wheeler

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Sincerely,

Ricardo Wheeler

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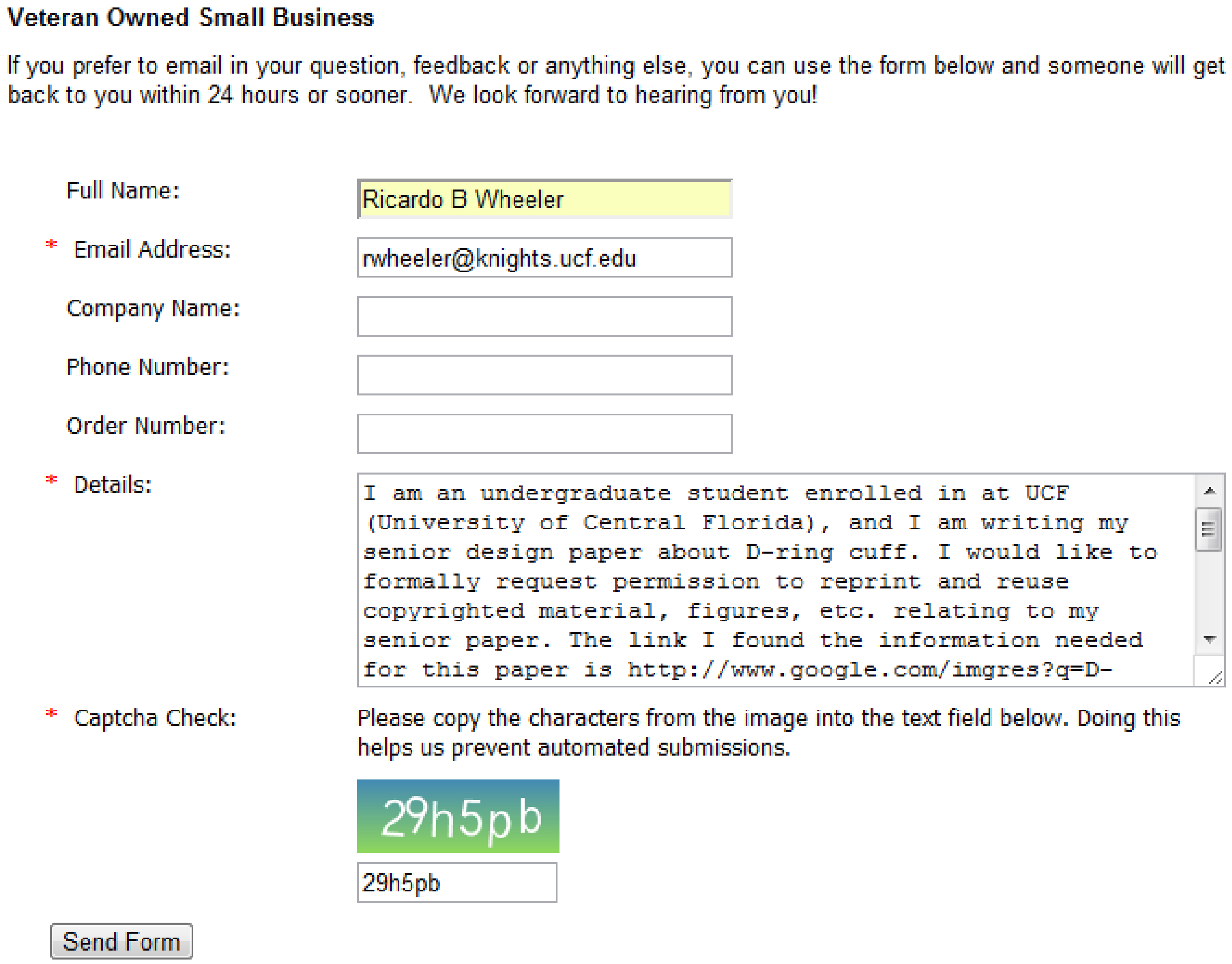
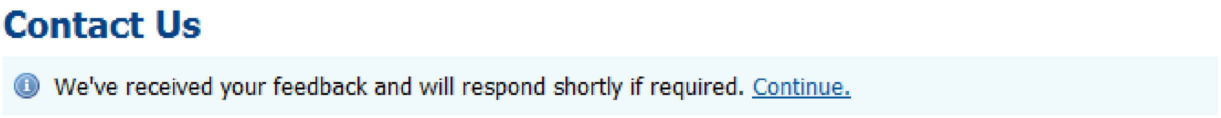


Veteran Owned Small Business

If you prefer to email in your question, feedback or anything else, you can use the form below and someone will get back to you within 24 hours or sooner. We look forward to hearing from you!

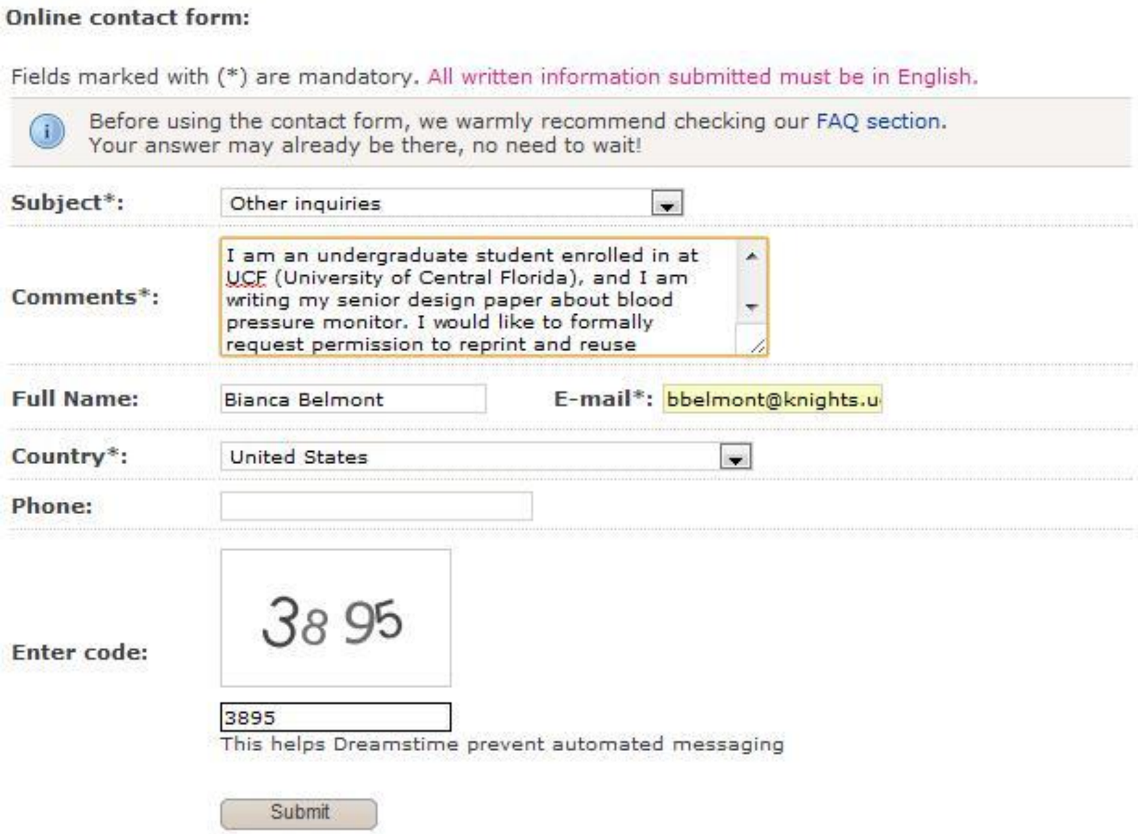
Full Name:	Ricardo B Wheeler
* Email Address:	rwheeler@knights.ucf.edu
Company Name:	
Phone Number:	
Order Number:	
* Details:	I am an undergraduate student enrolled in at UCF (University of Central Florida), and I am writing my senior design paper about D-ring cuff. I would like to formally request permission to reprint and reuse copyrighted material, figures, etc. relating to my senior paper. The link I found the information needed for this paper is http://www.google.com/imgres?q=D-
* Captcha Check:	Please copy the characters from the image into the text field below. Doing this helps us prevent automated submissions. 29h5pb 29h5pb



Contact Us

We've received your feedback and will respond shortly if required. Continue.

[7]



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Fields marked with (*) are mandatory. All written information submitted must be in English.

Before using the contact form, we warmly recommend checking our FAQ section.
Your answer may already be there, no need to wait!

Subject*: Other inquiries

Comments*: I am an undergraduate student enrolled in at UCF (University of Central Florida), and I am writing my senior design paper about blood pressure monitor. I would like to formally request permission to reprint and reuse

Full Name: Bianca Belmont

E-mail*: bbelmont@knights.u

Country*: United States

Phone:

Enter code: 3895

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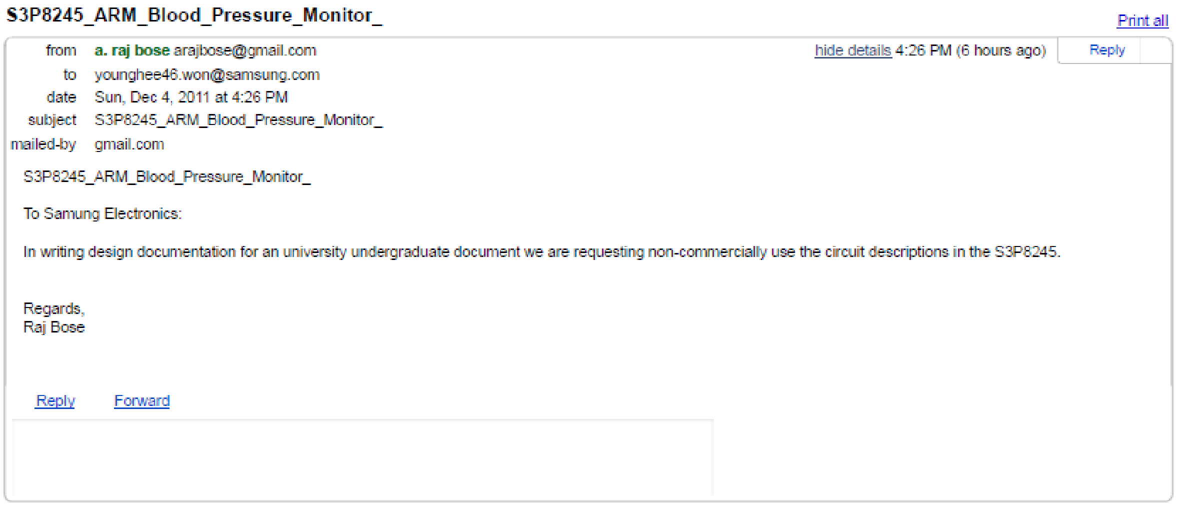

S3P8245_ARM_Blood_Pressure_Monitor_

from **a. raj bose** arajbose@gmail.com
to younghee46.won@samsung.com
date Sun, Dec 4, 2011 at 4:26 PM
subject S3P8245_ARM_Blood_Pressure_Monitor_
mailed-by gmail.com

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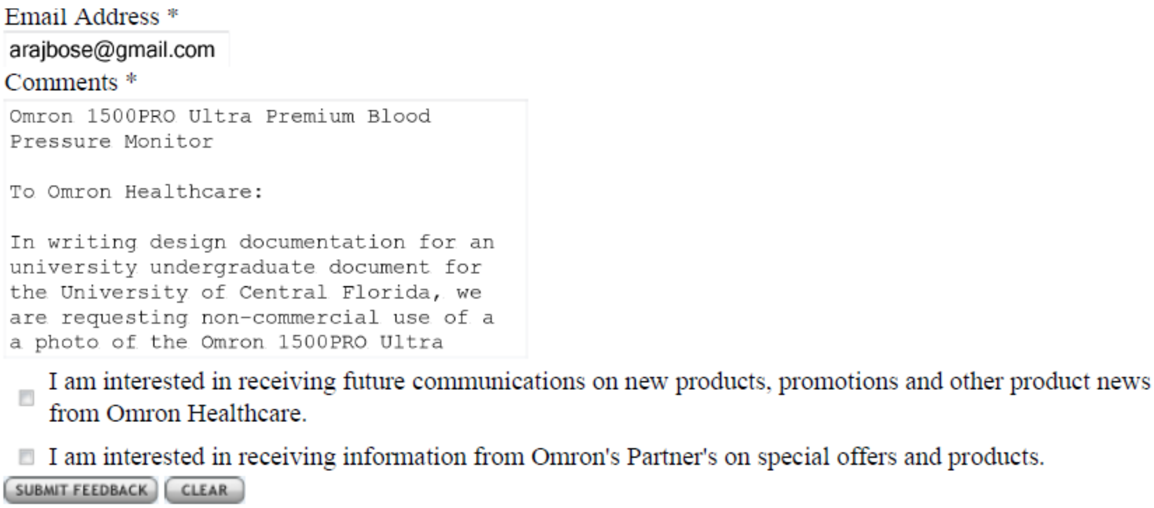
S3P8245_ARM_Blood_Pressure_Monitor_

To Samung Electronics:

In writing design documentation for an university undergraduate document we are requesting non-commercially use the circuit descriptions in the S3P8245.

Regards,
Raj Bose



Email Address *
arajbose@gmail.com
Comments *

Omron 1500PRO Ultra Premium Blood Pressure Monitor

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☐ I am interested in receiving future communications on new products, promotions and other product news from Omron Healthcare.

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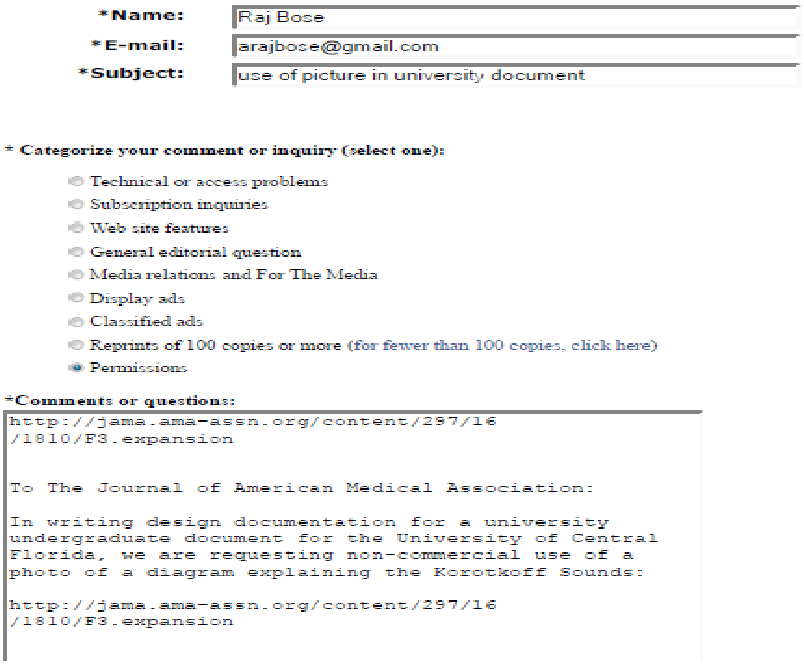

*Name: Raj Bose
*E-mail: arajbose@gmail.com
*Subject: use of picture in university document

* Categorize your comment or inquiry (select one):

○ Technical or access problems
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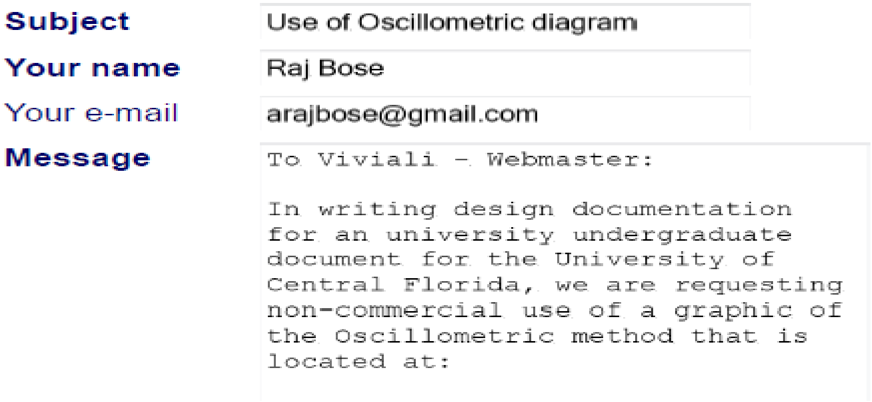

Subject Use of Oscillometric diagram
Your name Raj Bose
Your e-mail arajbose@gmail.com
Message To Viviali - Webmaster:

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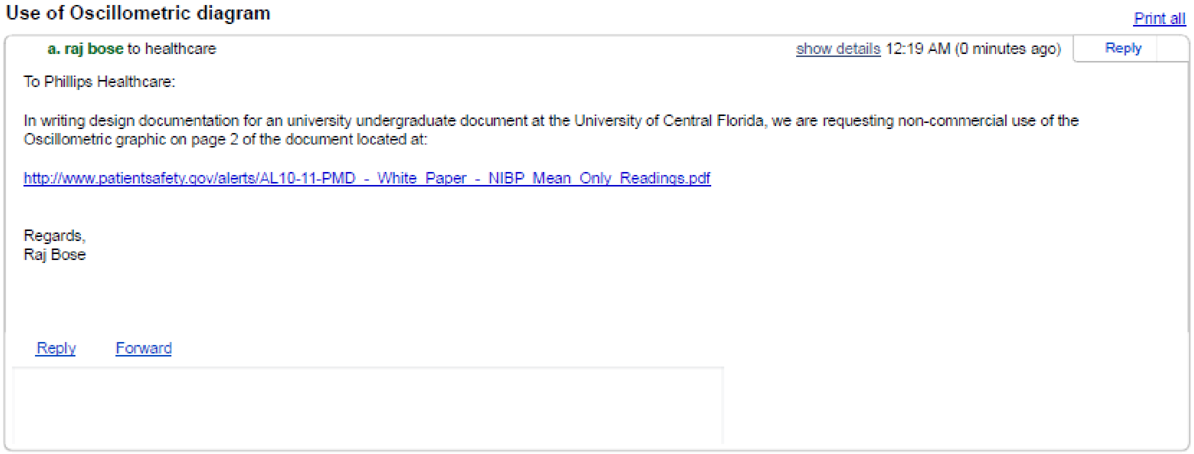

Use of Oscillometric diagram

a. raj bose to healthcare 12:19 AM (0 minutes ago)

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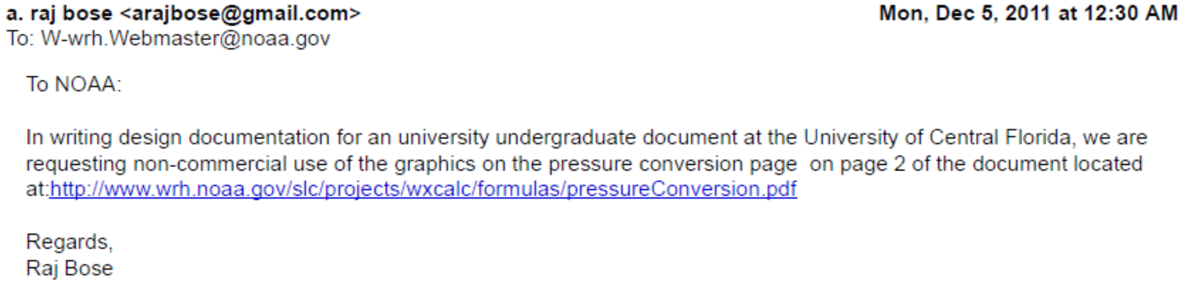
http://www.patientsafety.gov/alerts/AL10-11-PMD_-_White_Paper_-_NIBP_Mean_Only_Readings.pdf

Regards,
Raj Bose



a. raj bose <arajbose@gmail.com> **Mon, Dec 5, 2011 at 12:30 AM**
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To NOAA:

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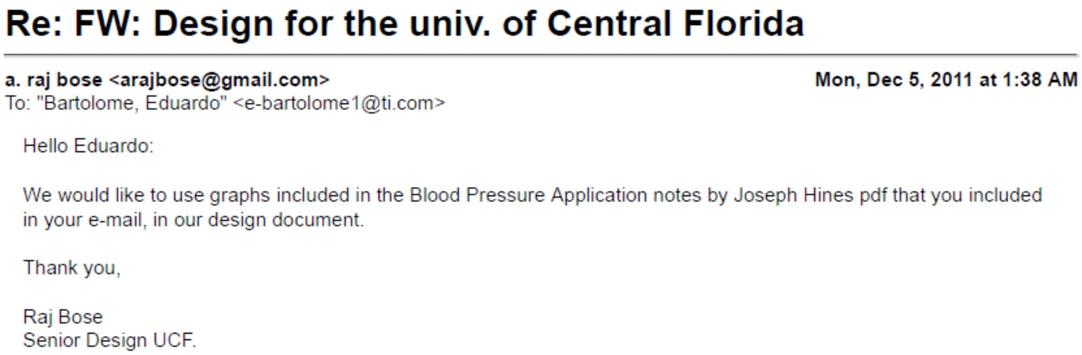
Regards,
Raj Bose



Re: FW: Design for the univ. of Central Florida

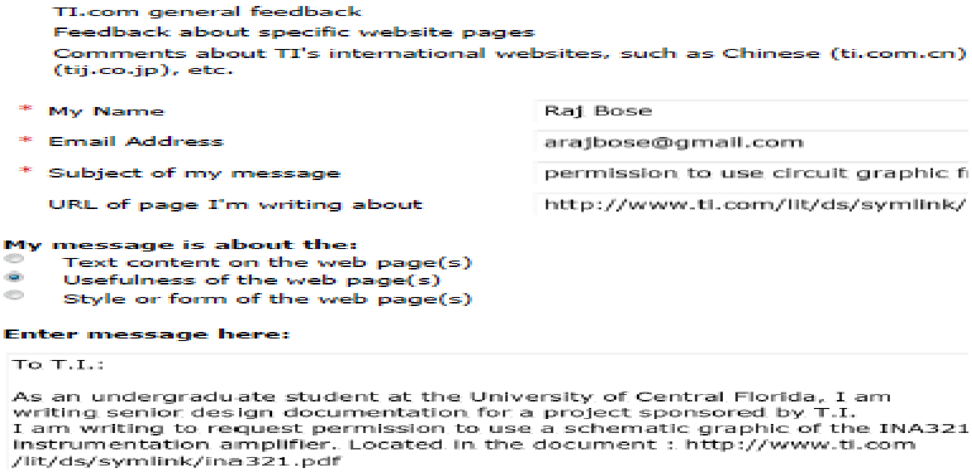
a. raj bose <arajbose@gmail.com> **Mon, Dec 5, 2011 at 1:38 AM**
To: "Bartolome, Eduardo" <e-bartolome1@ti.com>

Hello Eduardo:

We would like to use graphs included in the Blood Pressure Application notes by Joseph Hines pdf that you included in your e-mail, in our design document.

Thank you,

Raj Bose
Senior Design UCF.



○ TI.com general feedback
○ Feedback about specific website pages
○ Comments about TI's international websites, such as Chinese (ti.com.cn) (tij.co.jp), etc.

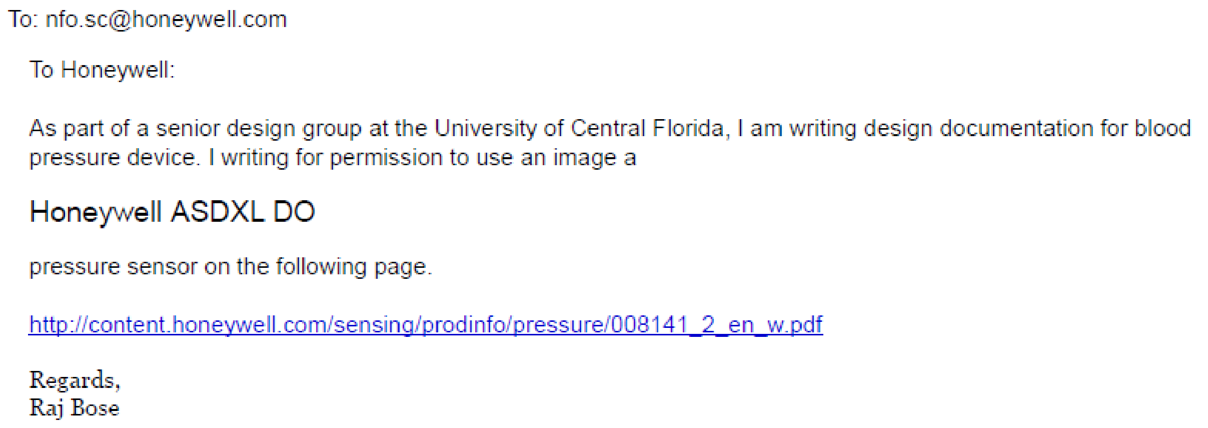
* My Name	Raj Bose
* Email Address	arajbose@gmail.com
* Subject of my message	permission to use circuit graphic f
URL of page I'm writing about	http://www.ti.com/lit/ds/symlink/

My message is about the:
○ Text content on the web page(s)
● Usefulness of the web page(s)
○ Style or form of the web page(s)

Enter message here:

To T.I.:

As an undergraduate student at the University of Central Florida, I am writing senior design documentation for a project sponsored by T.I.
I am writing to request permission to use a schematic graphic of the INA321 instrumentation amplifier. Located in the document : http://www.ti.com /lit/ds/symlink/ina321.pdf



To: nfo.sc@honeywell.com

To Honeywell:

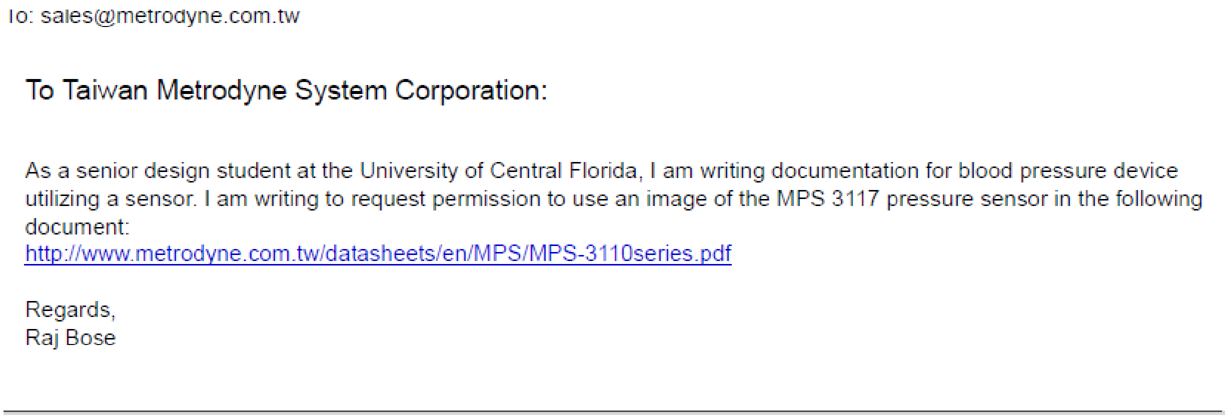
As part of a senior design group at the University of Central Florida, I am writing design documentation for blood pressure device. I writing for permission to use an image a

Honeywell ASDXL DO

pressure sensor on the following page.

http://content.honeywell.com/sensing/prodinfo/pressure/008141_2_en_w.pdf

Regards,
Raj Bose



Io: sales@metrodyne.com.tw

To Taiwan Metrodyne System Corporation:

As a senior design student at the University of Central Florida, I am writing documentation for blood pressure device utilizing a sensor. I am writing to request permission to use an image of the MPS 3117 pressure sensor in the following document:
http://www.metrodyne.com.tw/datasheets/en/MPS/MPS-3110series.pdf

Regards,
Raj Bose

Io: webmaster@jri.co.jp

To Matsushita Electric Works:

I am senior design student at the University of Central Florida, writing documentation for senior design project for a blood pressure device.
I am writing to request the permission to use an image of the ADP1 pressure sensor in the document.
The image is located at http://pdf1.alldatasheet.com/datasheet-pdf/view/90541/ETC/ADP1101.html

Regards,
Raj Bose