

# Blood Pressure Tester

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**Abstract** — The blood pressure tester is an automatic, one-button device that utilizes the oscillometric blood pressure method, and 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 is connected to a ratio metric pressure sensor and transmits air pressure from the cuff with underlying air oscillations made by skin movement from artery movement. A filter and gain topology separates these air oscillations from the cuff pressure signal for use in an oscillometric algorithm which is implemented within the 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.

**Index Terms** — Wheatstone bridge, buck-boost, blood pressure monitor, upper arm occlusion cuff, wireless.

## I. INTRODUCTION

The ambulatory blood pressure tester will meet a growing need for distance and individual health monitoring. The final design of this device after being exhaustively tested; accurately processes raw patient data for blood pressure readings that are acceptable to medical device standards. Furthermore the device includes safety features such as the immediate release of cuff pressure upon pressing the same 'on,' push button to protect the patient from injury and to meet medical device regulations.

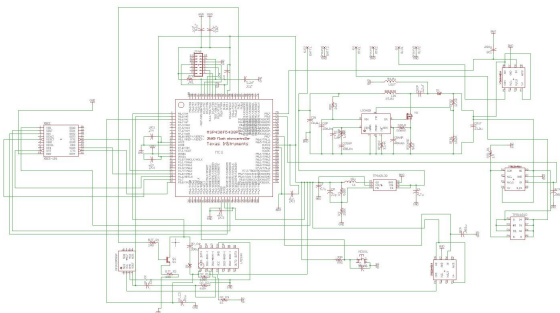


Fig. 1. Overall Schematics of the project.

## II. OSCILLOMETRIC METHOD

### A. Oscillometry

Distinct differences exist between two common methods of non-invasive blood pressure reading methods. The non-electronic Auscultatory Method, commonly 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. Occlusion of the artery and the re-entry of blood into the artery at a higher than systolic pressure creates turbulent blood flow oscillations that can easily be heard. Five phases of pressure are observed with a stethoscope, the phases, Korotkoff sounds, are recorded. The electronic Auscultatory Method, is based on the manual method differing by its indirect recording of pressure involving three sensors. One sensor is an air pressure transducer which senses the pressure in the occlusion cuff and converts it into a voltage signal. The other two sensors are microphones which transduce the Korotkoff Sounds into voltage. As blood pressure measurements are given in millimeters of mercury(mmHg) and pressure sensors usually are calibrated in pressure per square inch(psi), another conversion in the MCU 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. To meet the low power profile, the Auscultatory Method, is not utilized in the device. The Oscillometric Method, utilized in the blood pressure tester utilizes one air pressure transducing sensor. In this indirect method, the systolic and diastolic pressures are derived from a single cuff pressure value, through the use of an oscillometric algorithm. The specific voltage value is determined by finding the maximum pressure value and its point in time of a separate signal relaying the air oscillations in the cuff created by artery blood flow.

### B. Filter

The implementation of the Oscillometric Method, requires the use of filters in the the signal chain once the air pressure is converted to voltage. The pressure sensor connected to the occlusion cuff via a rubber tube; converts this air pressure into a mixed voltage signal. The MP3V5050GP ratiometric pressure sensor is based on the Wheatstone Bridge. The output voltage of the pressure sensor is related to the input voltage by the degree to which the air pressure bends the internal resistor. The signal is internally amplified and low pass filtered before exiting the pressure sensor. The mixed signal output is comprised of a higher amplitude DC signal and a lower amplitude AC signal that is separated by analog circuitry and amplified to a comparable voltage level of the DC signal before being converted digitally for processing and blood pressure calculation. The AC signal is filtered in the analog domain to obtain the peak values of the oscillation pulses, thereby lowering the amount of data to be processed to obtain a blood pressure reading. As the pressure sensor has internal low pass filtering, high frequency noise from the cuff is filtered out from the signal. Radio interference and other high frequency interference has not been found to cause errors in the pressure readings of this device. Further development may include implementing a second stage of analog low pass filtering for this purpose; if necessary. In this design, further noise filtering is carried out in the digital domain.

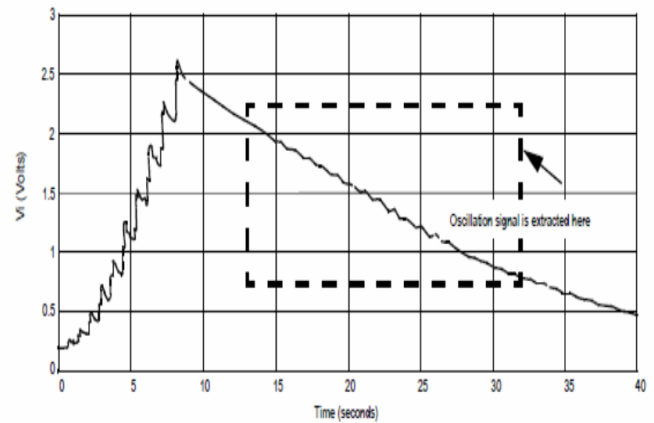
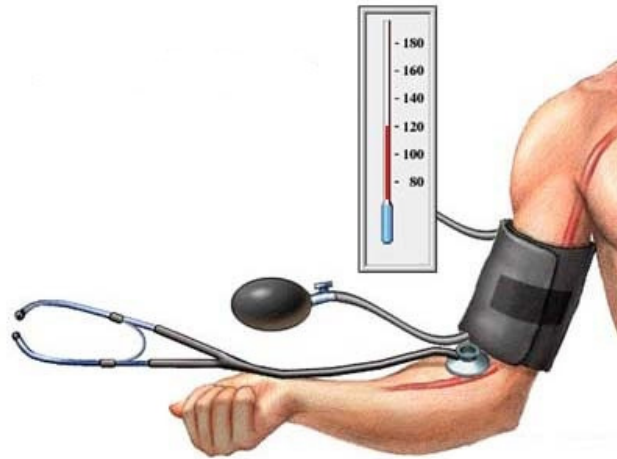
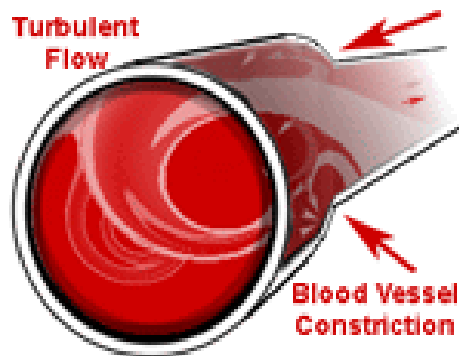


Fig. 2. Mixed DC / AC signal and its source, the occlusion cuff.



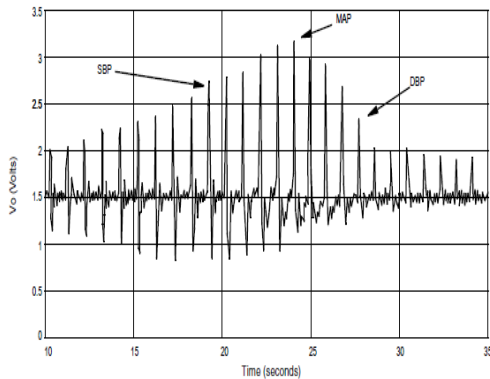


Fig. 3. Extracted AC signal and its source, artery movement causing air oscillations.



Fig. 4. The yellow line (top) represents the peak detection; the purple line (middle) represents the oscillation/pulse signal; the blue line (bottom) represents the cuff pressure decreasing.

### C.BP Calculation

As oscillations in the artery increase in amplitude during reintroduction of blood flow to the lower arm, the converted signal relaying this information is recorded. The peak of these oscillations is noted as the mean arterial pressure (MAP) pressure point in time to be related to the DC cuff pressure signal. 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 occurrence times are derived through taking a percentage the MAP before and after it occurs in time. The three points in time are correlated to the cuff pressure recording times.

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.

Equation (1) refers to the mean arterial pressure calculation.

$$\text{MAP} = \frac{1}{2} * \text{Systolic Pressure} + \frac{2}{3} \text{Diastolic Pressure} \quad (1)$$

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. Equation (2) refers to the calculations to find the systolic and diastolic pressures. These calculations refer to points in time on the DC pressure curve.

$$\begin{aligned} 0.54 * \text{MAP} &= \text{Systolic} \\ 0.72 * \text{MAP} &= \text{Diastolic} \end{aligned} \quad (2)$$

Because the Oscillometric method uses only one sensor and less circuitry, we have decided to utilize this method in the design of the blood pressure monitor 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 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.

### III. SYSTEM COMPONENTS

#### A. Power Source

There are several options for power source. The most common type of power source used in these devices is batteries. This project is going to be using four Alkaline AAA batteries. Each AAA Alkaline battery will generate 1.5V, has a cycle of 50-500, the approximate energy density (MJ/Kg) is 0.31, and the special characteristics are lower capacity and put out more voltage. The goal is provide enough power to the circuit without draining the battery too fast. So it shall be taken in consideration a topology known as boost-buck converter.

#### B. Power Regulators Buck/Boost

There are two types of power regulators being used 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- $\mu$ A quiescent current makes the TPS62122 an ideal choice in systems concerned over battery life. This topology is going to work perfectly for this project, since we are trying buck 4 - 6.6V to 3.3V to supply three loads. The loads that need to be supplied are the sensor, microcontroller and wireless. 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 100kHz and 1MHz 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 5 $\mu$ A and allows power supply sequencing. Internal soft-start limits the inrush current at start-up. This specific topology will be functioning as a buck and boost. The input ranges from 4 - 6.6V and the output will be a constant 6V. Furthermore, it will be supplying the motor and the valve.

#### C. 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 is going to prevent the battery from draining too fast because the MCU (MSP430F5438) will not have to send a constant high signal to keep the switch normally open. This CMOS switch can operate 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 will vary 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 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  $\mu$ A, 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 ultra 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 an 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 pinout common with other P-channel MOSFETs in SOIC packages.

#### *D. 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 1mW Chip 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 (30 m), Outdoor RF line-of-sight Range up to 300 ft (90 m), a Transmit Power Output (software selectable) 1mW (0dBm), the RF Data Rate is 250,000 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 <10 $\mu$ A. Some general information regarding the Xbee that is being utilized is the Operating Frequency ISM 2.4 GHz, Dimensions 0.960" x 1.087" (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.

#### IV. MECHANICAL COMPONENTS

This blood pressure Tester is going to require 2 mechanical components: the motor and the valve. The model of the motor is P54A02R 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 will successfully pump air into the cuff in a short period of time without any concerns. The valve is a high frequency solenoid and has the following specifications: rated voltage is DC6V/DC12V, rated current is 60mA/45mA, exhaust time is max. 6.0 seconds from 300mmHg reduce to 15mmHg at 500CC tank, resistance is  $100\Omega \pm 10\%$ / $270\Omega \pm 10\%$ , 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.

#### V. 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.

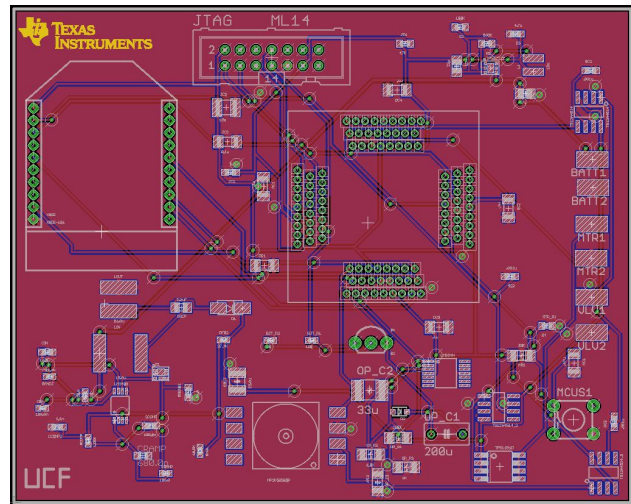


Fig. 1. PCB Layout of Blood Pressure Tester

#### VI. CONCLUSION

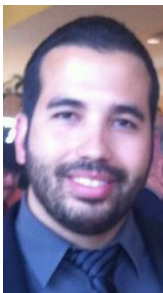
CONCLUSION – The blood pressure monitoring device designed and built involves various fields of engineering. While each section or module has individually been tested in simulation and then with a physical prototype for expected output based on known inputs before being assembled and tested as a whole; no one part is more essential than the other. Each person of the group will be involved in making sure that the module that they are responsible for is working as expected before the modules are connected for a complete device. While every module has been tested as a group effort, every module has been managed by an individual. The choice of each part of this device has been critical to meet the specifications and objectives of the project. Meeting the objectives of

the project has helped ensure that the device is a working blood pressure tester that can further developed for a variety of applications.

#### ACKNOWLEDGMENT

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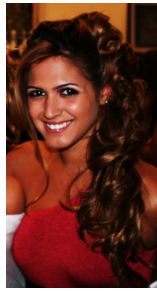
#### THE ENGINEERS



Brandon Sbert is currently a senior at the University of Central Florida and graduating with a BS in Electrical Engineering on May 3, 2012. Upon graduation Brandon has accepted a job offer from Texas Instruments working in the Technical Sales program starting June 18th 2012.



Ricardo Wheeler is graduating from the University of Central Florida with a Bachelor's degree in Electrical Engineering in May 2012. Upon graduation, he intends to pursue a career in Power/Green Energy Systems. He will be taking the Fundamentals of Engineering exam in October, and then he will work towards Professional Engineer licensure.



Bianca C. Belmont, is an international student from Brazil that is currently a senior at the University of Central Florida and will receive her Bachelor's degree in Computer Engineer in May of 2012. She plans to pursue a double major in Computer Science right after her graduation and her Master's degree also at the University of Central Florida. Her current interests relate to applications engineer and sales programs.



A.Raj Bose, currently an engineering student at the University of Central Florida, is graduating with a Bachelor of Science in Electrical Engineering along with a minor in International Engineering, which included participation in a long term engineering study abroad program in Rio de Janeiro, Brazil. With interests in Power/Energy Systems and Acoustics, Raj plans to gain international work experience in these exciting fields. Preparing for the Fundamentals of Engineering exam, he intends to work towards Professional Engineering licensure.

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