Final Report of Senior Design Project
Spring 2011

The University of Minnesota
Department of Electrical and Computer Engineering

Ambulatory Blood Pressure Monitor

Prepared by: Derek Berger, Kangyu Qiu, Negin Mokhtari, & Shreya Goenka
Advisors: Prof. Giannakis & Larry Beaty

EXECUTIVE SUMMARY

A goal of the Halberg Chronobiology Center is to obtain an Ambulatory Blood Pressure Monitor suitable for long-term use, encourage its use on a massive scale to obtain measures in health, and to encourage the development of diagnostic, prevention and treatment techniques.

The Halberg Chronobiology Center believes that changes in blood pressure cycles can be used to prevent and treat hypertension, heart attack, stroke, kidney disease, retinopathy, and other major handicapping and fatal diseases. Measurements of blood pressure cycles can be analyzed if they are continued for at least 7 days with automatic ambulatory monitoring that is easily available for everyone. This will enable people to receive treatment who would never be treated, reduce the debilitating side-effects of unnecessary medication, make visible critical symptoms that do not occur during physician visits, detect the onset of the vascular diseases which often do not have easily visible symptoms, and greatly reduce the enormous health care cost of catastrophic events by preventing them.

The Phoenix Project will develop the monitor. It will focus on product development and launch. The Phoenix Measurement Program will encourage the monitor to be used to obtain measures of normal health. It will focus on public health and policy. The Phoenix Clinical Program will encourage the use of the monitor in diagnosis, prevention and treatment. It will focus on clinical practice and services.

Our design was aimed at making improvements on an already existing design by adding an additional sensor at each measurement location and adding a differential amplifier on the output. A main issue with the current prototype is the susceptibility to motion artifacts (e.g. arm movement.) Our design would use both sensors at each location and pass both through a differential amplifier where it would act as a subtracter and eliminate the commonalities between the two signals. In this case the motion artifacts from arm movements.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Introduction

Figure 1 shows a simplified block diagram of the overall blood pressure monitor system. Our design fits into the sensor portion of the design and is a very key component in the overall system. Our design is aimed at improving an already existing design. The improvements will aid the IEEE Phoenix team in deciding what sensor technology to pursue in future full system design.

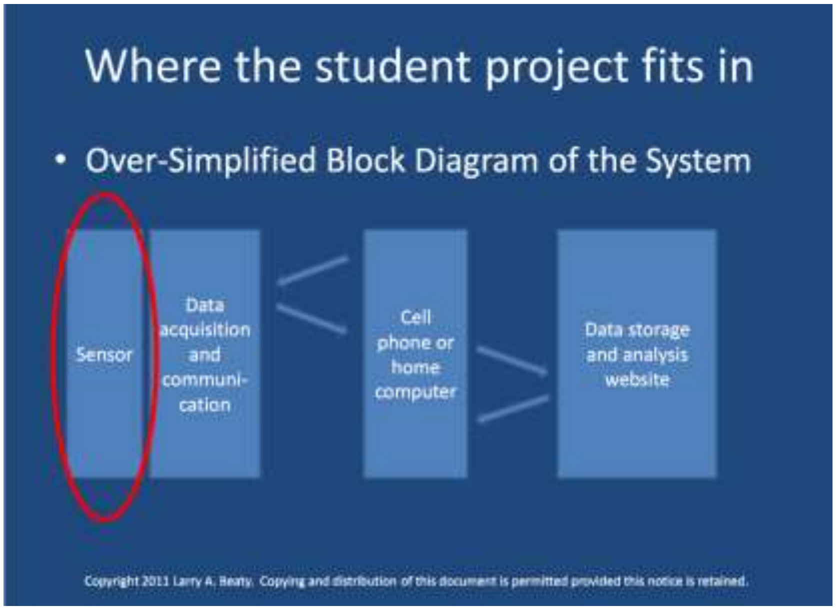


Figure 1 - System Block Diagram

1.2 Motivation and Goals

Current methods for continuously monitoring blood pressure require the use of inflatable cuffs, pumps, and electronics similar to the automatic systems used in clinics and pharmacies. These methods are awkward, intrusive, and not conducive for wearing 24 hours a day for a week. Therefore, the idea is to design and construct a monitor system that would be comfortable enough to wear for 24 hours a day, and cost effective enough to use at home.

The senior design group intends to improve the sensor portion of the monitor to help meet the following full system demands:

- <u>Inexpensive</u>

The price of the monitor should be less expensive than the blood pressure cuff and less expensive than a wrist watch, less than $100.

- <u>Unobtrusive</u>

The monitor should be able to be placed on a patient so that they can forget about it and not have to worry about it.

- <u>Easy to Use</u>

The monitor should be easier to use than current devices relying on the blood pressure cuff while providing measurements of equal accuracy.

- Week of Blood Pressure Measurements

The monitor should record measurements at least every half hour for at least 7 days.

2. MISSION STATEMENT

2.1 Introduction

The Ambulatory Blood Pressure monitor is meant to be worn 24 hours a day and 7 days a week. An important issue with the current prototype is that the patient must remain completely still for the sensor to pick up the blood pressure measurement. Thus, a remedy to this movement issue became our goal for this project.

2.2 Problem statement

The sensor portion of the Ambulatory Blood Pressure monitor is very susceptible to motion artifacts generated by the arm. The sensor portion needs to produce accurate waveforms at least every half-hour. The method for calculating the blood pressure is based on the Chen et. al, US Patent No. 6,599,251 which states that the arterial pulse delay is proportional to blood pressure. The equation is expressed as,

$P = a + b \ln(T)$

where T - Time delay in milliseconds
a,b - constants dependent on each subject.

Figure 2 shows a blood pressure waveform with the systolic and diastolic blood pressure levels which can be used to calculate the pulse pressure. To measure the time delay, two different waveforms from two different locations from the heart need to be measured. In our design this was the wrist and the elbow.

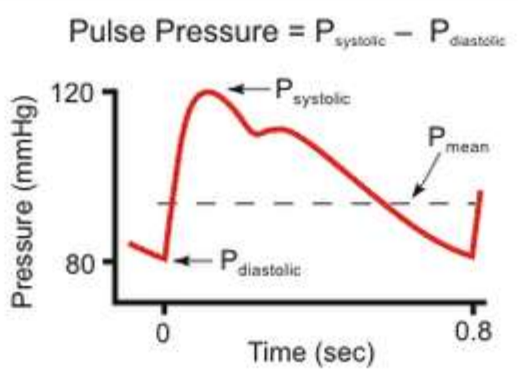


Figure 2 - Blood Pressure waveform

2.3 Design specifications

Specification	As of 2/17/11	As of 5/3/11	Desired Specs.
Price	Under $100	Same	The cheaper the better
Size	Small enough to be	Same	The smaller the better

	worn 24/7		
Accuracy	Within +/- 3mmHg	Same	N/A
Piezoelectric Sensor	FLDT-028K	SDT1-028K	N/A
Power Supply	3.3V	Same	Battery Powered

3. METHODS OF SOLUTION

3.1 Introduction

There are three main components of our design. They are the sensors, the circuit, and the PCB. A flow chart of our design can be seen in Figure 2. The National Instruments DAQ USB-6009 was used with NI LabView to record the waveforms we received. For more information on the DAQ and LabView see Appendix 3.

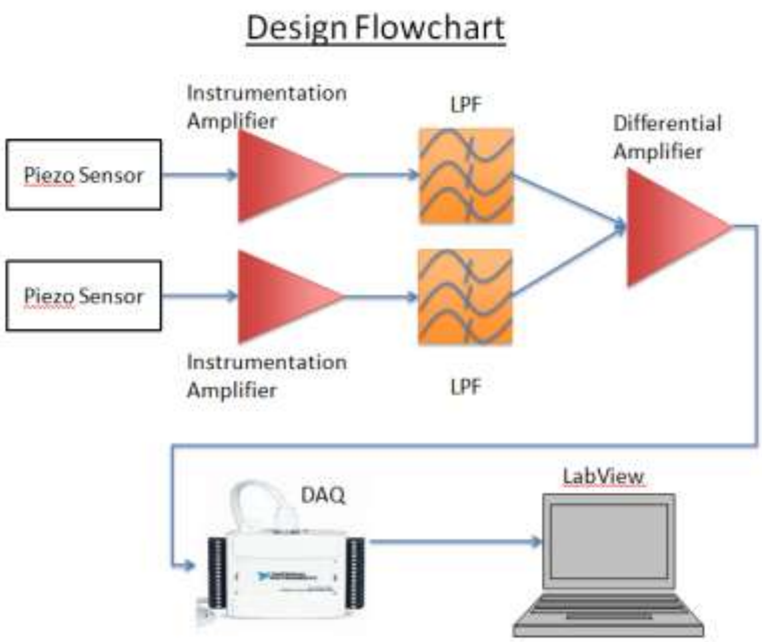


Figure 3 - Design Flowchart

3.2 Our Design

3.2.1 The Sensor

In our design two different piezoelectric sensors were tested and evaluated, the Measurement Specialties SDT1-028K Piezoelectric Sensor and the Measurement Specialties FLDT-028K Piezoelectric Sensor. Both sensors have their advantages and disadvantages and will be further discussed in Section 4 - Results. Figure 4 and Figure 5 show the design of the different sensors. As you can see in Figure 4 the SDT1 has a shielded lead attached to the pad of the sensor whereas the FLDT sensor has a laminated lead which contains a piezoelectric element within the lead for improved sensitivity.

Figure 4 - Measurement Specialties SDT1-028K Piezoelectric Sensor

Figure 5 - Measurement Specialties FLDT-028K Piezoelectric Sensor

Piezoelectric sensors were chosen because of their ability to be cut and designed into virtually any shape and size, their relatively low cost, and their robustness. Along with these benefits, one of our group members was familiar with using piezoelectric pressure sensors which eliminated time needed to explore and understand a different sensor technology. Figure 6 depicts an example of what the sensor arrangement of our design would look like on a subject. Unlike previous designs which only used one sensor at each location, we proposed using two sensors at each location. One sensor would be placed directly on the location of measurement and the other sensor would be placed in close proximity where it would detect just the motion artifacts and any extraneous noise present in the system. Both signals would then be amplified and fed through a differential amplifier with unity gain which acts as a subtracter and eliminates the commonalities between the two signals leaving just the blood pressure waveform.

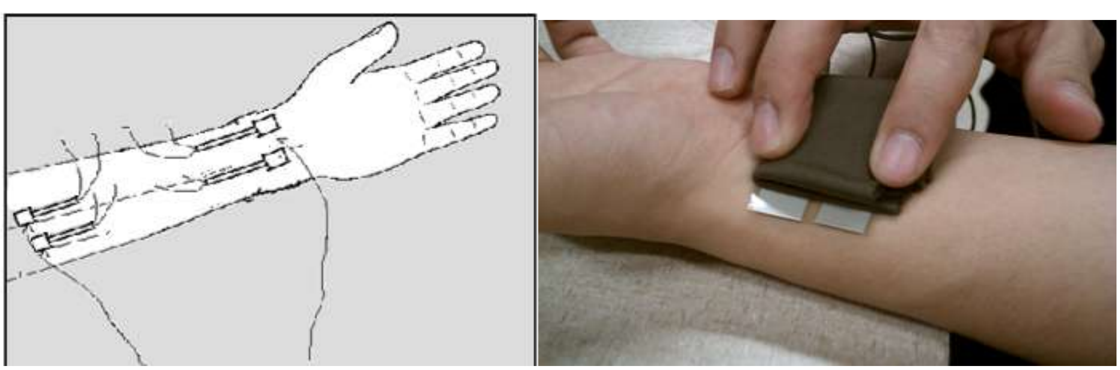


Figure 6 - Two sensors at each location

3.2.2 The Circuit

The circuit we used is shown in Figure 7. The circuit is powered by three AAA batteries which are regulated with STMmicroelectronic's LE33CZ regulator to provide a stable 3.3V to the circuit. The circuit has a low pass filter with a cutoff frequency of 12-13Hz and the DC gain is approximately +30dB. A piezoelectric sensor operating at a low frequency has a very high input impedance and therefore to eliminate loading effects a comparable input impedance needed to be achieved at the input amplifiers. Also, at low frequencies (< 1 kHz) a piezoelectric sensor behaves like a voltage source in series with a capacitance therefore any load connected to the sensor will form a high pass filter. In this design the input capacitance was 10nF, therefore we chose in input resistor of 10 MOhms which formed a high pass corner frequency of 1.6Hz. A differential amplifier configured with unity gain is connected to the output of both sensor amplifiers which provides the aforementioned signal commonality rejection.

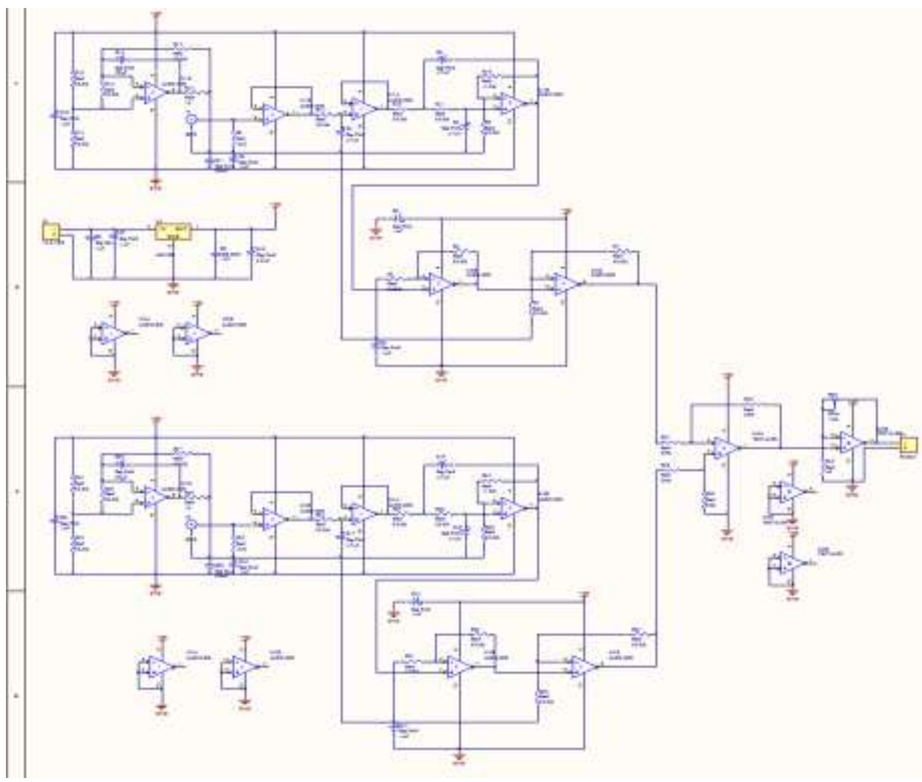


Figure 7 - Design Schematic

3.2.3 The PCB

The PCB was 12.3cm x 10.3cm, included both signals at each location, and was constructed using the Altium Designer Summer 09 software. The layout can be seen in Figure 8. Both sensors were attached using BNC receptacle connectors (J1 and J3) and the battery power was connected using a two pin right angle through hole connector (J2.) The red traces are top layer routed and the blue traces are bottom layer routed. The output is measured from the two pin connector P1.

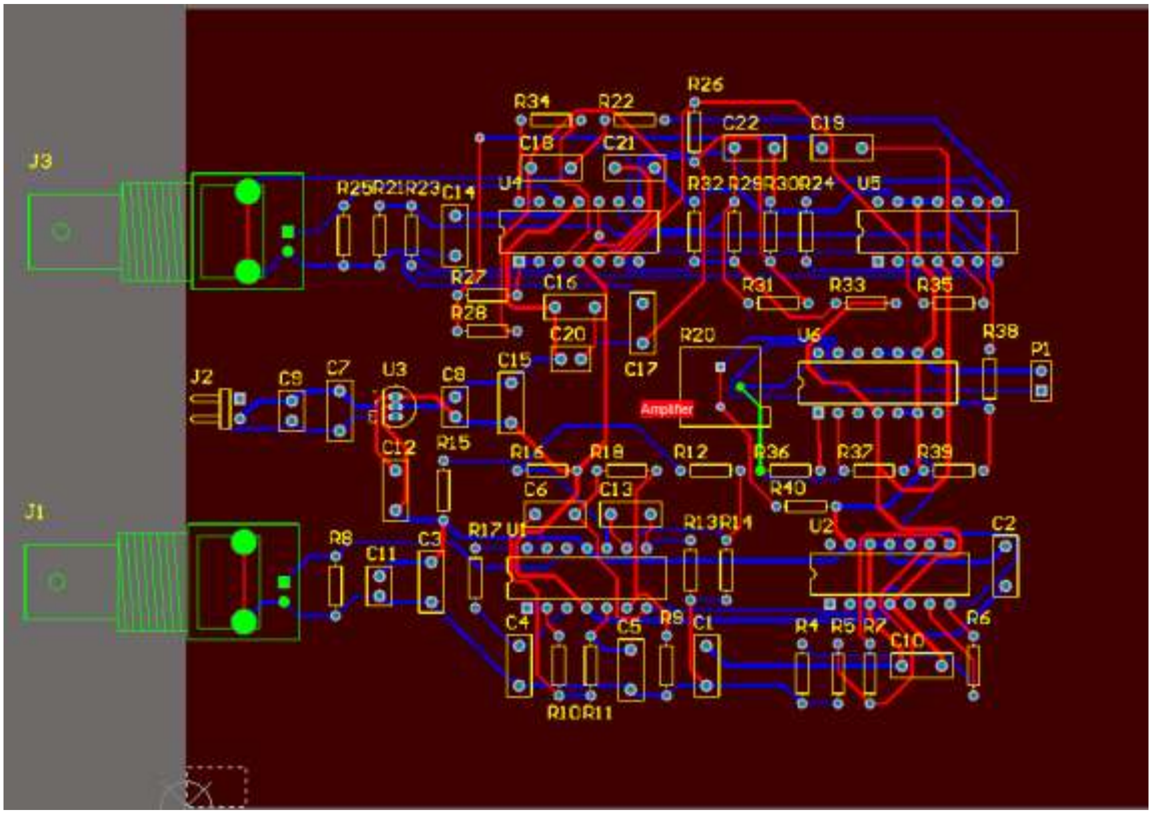


Figure 8 - Design PCB

3.3 Alternative Approach/Design Trade Offs

Alternative approaches and trade offs were explored and discussed in our project but because of the limited time we had, we made a best judgment call and decided to pursue a design which we were certain we could finish.

Some alternative methods were using a different sensor technology such as Infrared sensors but because of our limited experience with the technology and more familiarity with piezoelectric we chose to pursue the latter.

Using a charge amplifier instead of an instrumentation amplifier was also discussed but again because of the limited experience with charge amplifiers and more experience with instrumentation amplifiers we chose the latter.

4. RESULTS

4.1 Introduction

Though we did not get the results we were expecting, we still received a waveform from which the blood pressure could be calculated, as seen in Figure 9.

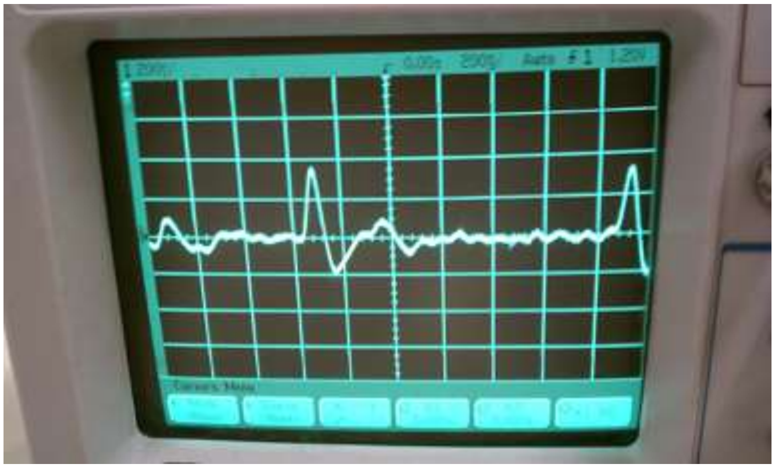


Figure 9 - Differential amplifier output using SDT1 sensor

As we can see the waveform seems to be flattening out after the peaks. We expected to receive a waveform closer to that of Figure 2. This is most likely due to the way that the piezoelectric sensor is detecting the movement of the skin from the blood pressure pulse. After the initial pulse from the blood pressure wave moving through the veins, the skin stops moving and thus the piezoelectric sensor does not produce a voltage. This makes it more difficult to calculate the diastolic blood pressure because it is harder to find the trough of the wave forms, unlike that of Figure 2. We found that when coupling the sensors to the skin some sort of backing was needed as seen in Figure 6. This helped eliminate any motion artifacts produced from the fingers pressing down on the sensor and it helped provide a constant pressure across both sensors.

4.2 Discussion of Results

As was stated previously, we did not receive the results we expected from our design but we were still able to receive a waveform from which measure the blood pressure would be possible. We tried different piezoelectric sensors and found that our proposed sensor did not perform as well as others. Figure 10 shows the SDT1 sensor input to the differential amplifier and as we can see there are clearly defined peaks which represent the systolic blood pressure. This signal has been amplified by 40dB and passed through a passed through a low-pass filter with a cutoff frequency of 12-13Hz.

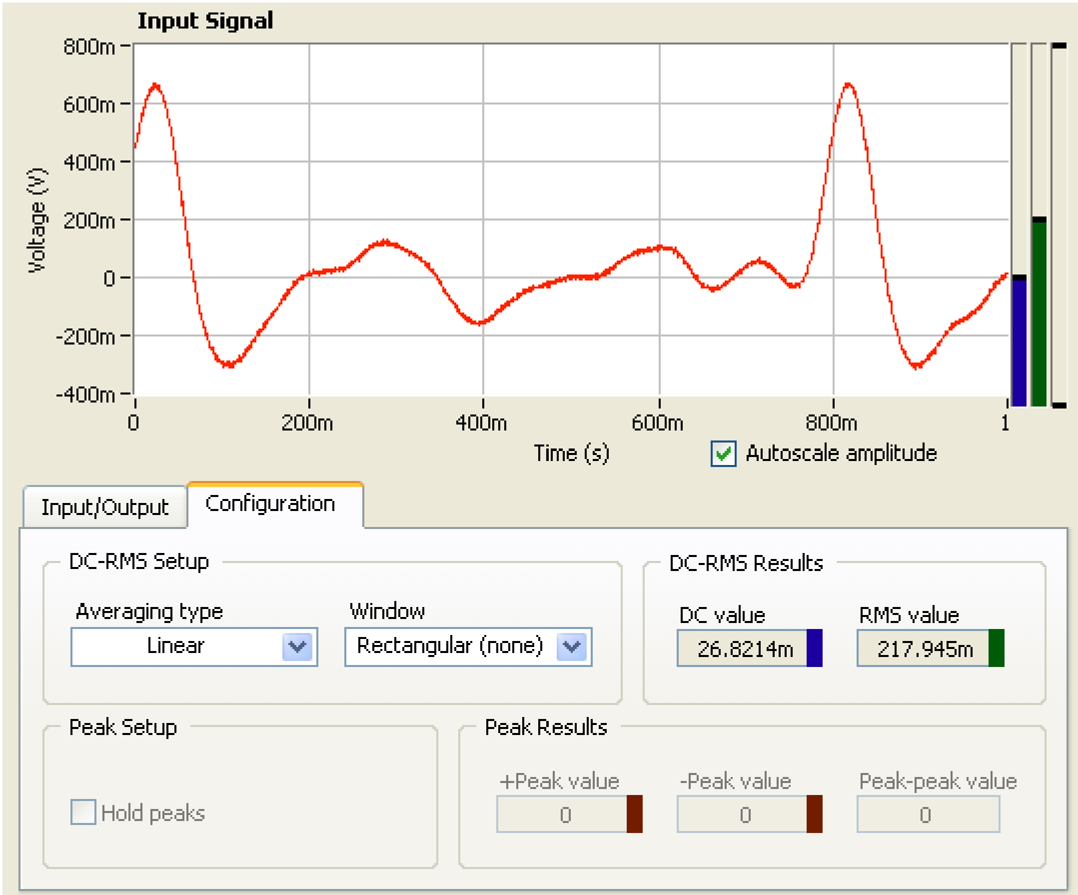


Figure 10 - SDT1 sensor input to differential amplifier

Looking at Figure 11, the output of the differential amplifier we can see that there definitely some attenuation happening. This is most likely due to the close proximity of the two sensors at the one location. The sensor designated to just pick up the motion artifacts is most likely picking up some of the skin movement from the pulse and once both signals are passed through the differential amplifier any commonalities will be canceled out. There are still clear systolic peaks but again we still have a hard time determining the diastolic blood pressure. Also, as we can see there is a reduction in overall noise from that of Figure 11, therefore the differential amplifier seems to be doing its job in reducing some of the EMI noise generated from the sensors. However, movement of the arm caused the output to become completely unstable and unusable for calculating the blood pressure, the subject still needs to remain completely still.

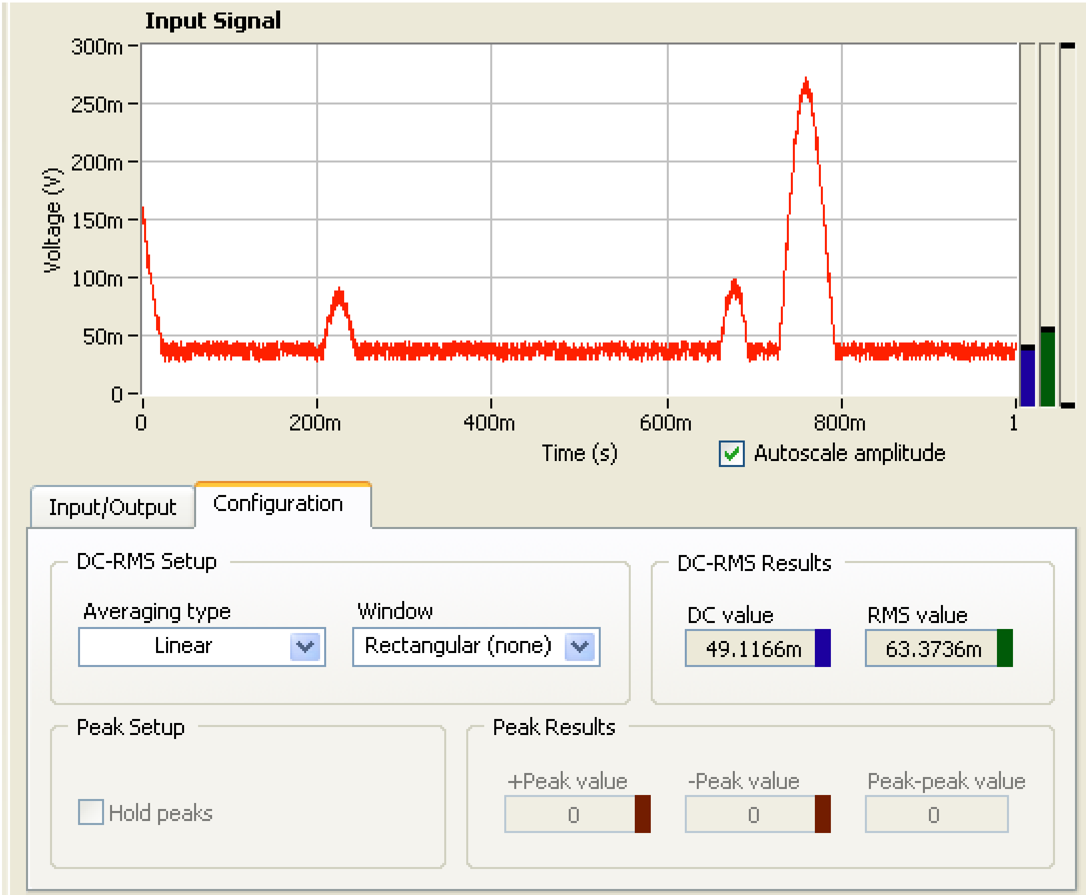


Figure 11 - Differential amplifier output using SDT1 sensors

Figure 12 depicts the input to the differential amplifier when using the FLDT sensor. When compared with the waveform of Figure 10 from the SDT1 sensor, the FLDT seems to be as stronger signal but at the same time noisier or more sensitive for that matter. This was unexpected because our initial design proposed to use the FLDT sensors because of they were more sensitive. We found that even when the subject would breathe, the sensor would detect the movement. This was most likely due to the fact that the FLDT sensor is a laminated sensor where the leads are a piezoelectric element as well as the pad (see Figure 5.) This forced the subject to remain even more still than when using the SDT1 sensors. After running tests on both sensors we determined that the SDT1 sensors gave us the best results and therefore were are sensor of choice for this design.

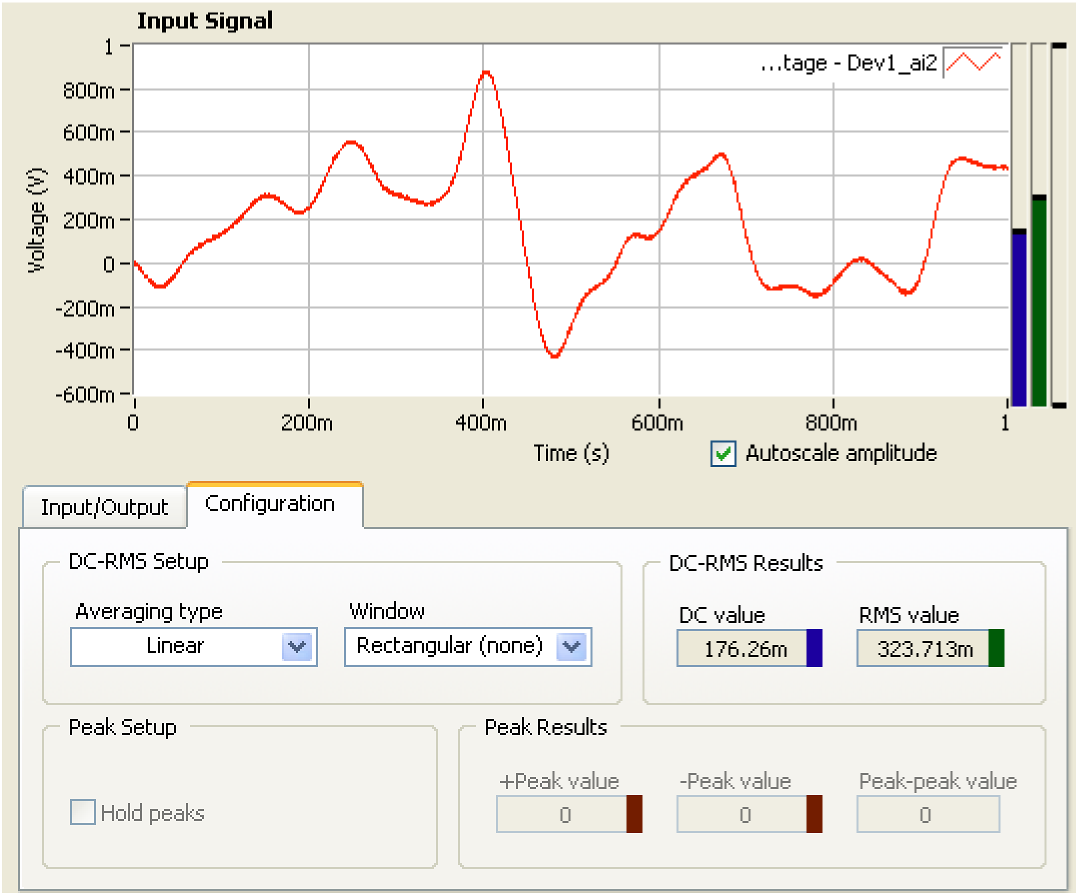


Figure 12 - FLDT sensor input to differential amplifier

Now looking at Figure 13 we can again see that there is some attenuation from that of Figure 12. This is again most likely due to the sensor designated to pick up just the motion artifacts from the arm is also picking up some of the movement of the skin from the pulse. However, when comparing Figure 13 and Figure 11 we can see that the signal from the FLDT sensor is stronger by approximately 400mV. However, the signal of Figure 13 seems to be noisier as well. The differential amplifier again seems to be doing it's job by reducing some of the noise seen in Figure 12 but there still appears to be some getting into the resulting signal. This is most likely due to the fact that because the FLDT sensors are so extra sensitive to motion that there may be exclusive disturbances generated in each of the sensors laminated leads that are propagating to the output.

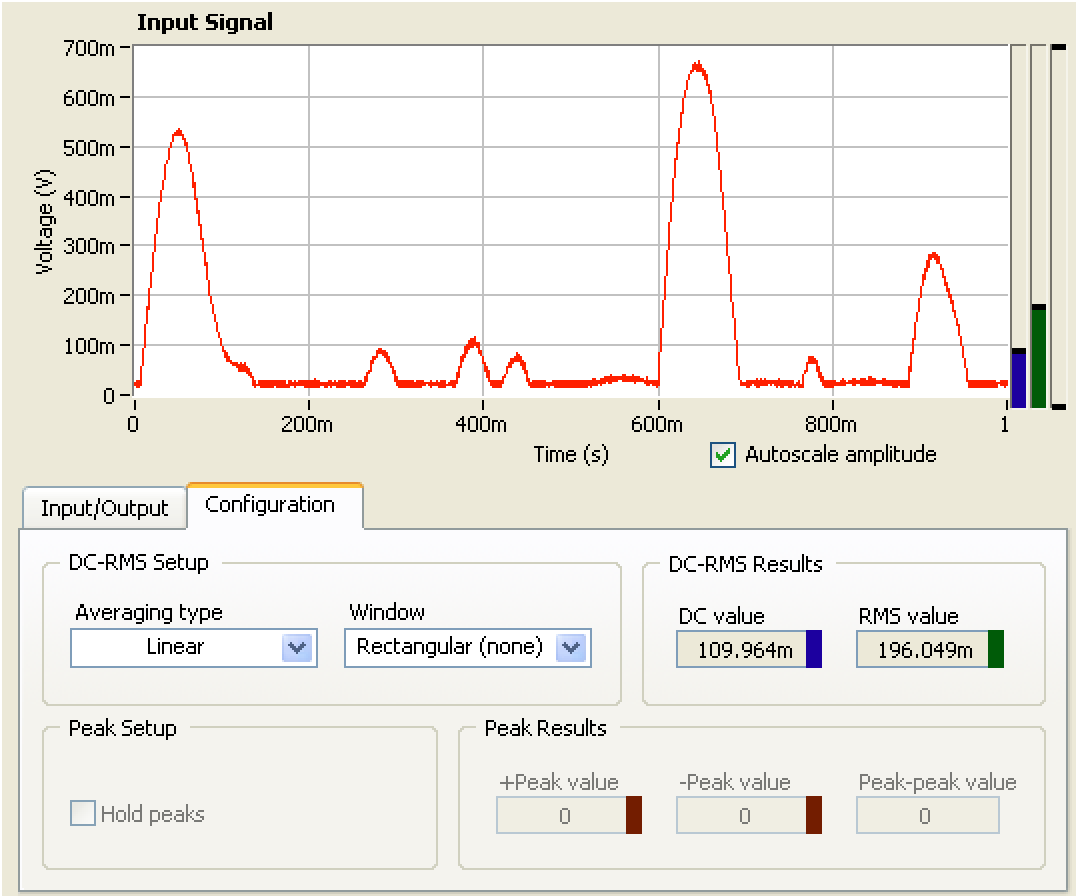


Figure 13 - Differential amplifier output using FLDT1 sensors

Final thoughts: Based on our results we can conclude that the Measurement Specialties SDT1-028K Piezoelectric Sensors seem to perform better in our design than the Measurement Specialties FLDT-028K Piezoelectric Sensors. The FLDT sensor has a larger output but along with that comes more susceptibility to motion artifacts. The differential amplifier seems to be performing as expect, in that it reduces some of the unwanted noise included in the signals but it seems to be attenuating the signals by roughly a factor of 2. Also, the diastolic blood pressure is still difficult to detect whereas the systolic blood pressure can still be found quite easily.

5. ADMINISTRATIVE

5.1 Introduction

Going into this project we were allotted $300 from the University and should we have needed extra funding we could have requested more from our sponsors. Because this design is part of an open source initiative we agreed that any of our final results, information, and documentation would be readily available for our customer, the IEEE Phoenix Team to use as they see fit.

5.2 Cost Analysis

Being that one of our goals for this project was to keep the prototype under $100 we did not feel much pressure in exceeding this budget limit. The most expensive part of our project was undoubtedly the PCB which was $50.00. With that being said, the price of the PCB and all other components totaled to $93.10. However, due to some of our complications throughout this project an extra $10.34 was spent on emergency parts and components.

When speaking with our customer about our final product and what it would take to complete our original design, we estimated it would take about another four to six weeks being that we know what went wrong and how we could fix them. As for materials, given that we had access to the proper equipment, we would need another PCB, replacement amplifiers, and some passive components that had been damaged from the previous attempt. We estimated this would cost another $58.00 for the PCB, amplifiers and passive components. However, after speaking with some fellow engineering peers we decided that we would order a new PCB from a different supplier which charges $33.00 for a two-layer board of superior quality compared with our original. The complete bill of materials can be found in Appendix A.

5.3 Risk Analysis

As was stated in our initial design proposal our design ran the risk of not improving the existing prototype at all. However, this was by no means a failure because this design was something no one had tried before and our customer now possesses some valuable information about what could be built upon in the future. The following section describes this in further detail.

The approach we took to this project, like all projects has varying degrees of risk associated with specific parts of the project. In what follows is an analysis of the different aspects of our design and their associated risk level from highest risk to lowest risk.

The design solution we proposed was something no one has ever tried before and like anything that is new, it ran the risk of not really being a solution at all.

Our design was to placed on a PCB which varying degrees of risk associated with it. For example, traces could be incorrectly routed, the quality of the board may be sub par from what is expected. The design of a PCB needs to be handled with great care because unlike a breadboard or protoboard components and traces cannot be easily corrected.

Even though this aspect may be very low risk, for this particular project, it is worth mentioning. There is a chance that the components ordered for the design may not be correct.

For example, a 20 pack of 20 kOhm resistors could end up having two 20 Ohm resistors instead of 20 kOhm.

6. CONCLUSIONS

6.1 Introduction

Our final design has some very useful information associated with it. As was stated by our customer in the beginning, we want something from which we can make better decisions on a final product. We discovered some piezoelectric sensors respond better than others, the motion artifacts generated by the arm are still too strong for piezoelectric sensors, and other sensor technologies may want to be explored. Although we did not completely meet our final goals, we still have a waveform from which it would be capable to measure blood pressure using the pulse wave velocity method.

6.2 Expansion and Improvement

Based on our results we learned that there are many different aspects which could be built upon and improved. In what follows is an analysis of what could be built upon and improved for future designs.

As we found in our results, the differential amplifier seems to be working in the fact that it is subtracting out the commonalities between the two signals but the response to motion artifacts still needs some improvement. The ability to move around while wearing the device continues to be a goal of this product.

The sensitivity to the motion artifacts may stem from the piezoelectric sensors themselves therefore, we suggest that it may be worthwhile to look into using different sensor technologies for the design. Some possibilities might be Infrared sensors, acoustic sensors, and even magnetics. Although, we believe that the use of acoustic sensors would be still be susceptible to the motion artifacts generated from arm movement. However, we feel that IR sensors may be viable solution because they may not be as sensitive to the motion artifacts because IR would not be sensing skin movement but instead the inflation and deflation of the vein or artery. Another technology which we only briefly discussed would be magnetics. Though there is much research to be done on this type of sensor technology, it may be worthwhile to research different types of magnetic sensors and how they could be used.

Based on some of the issues we ran into with our PCB and just the sheer size of our schematic, future designs may want to look into using all-in-one chips. Although all-in-one chips are usually more expensive, they save on time, space, and components. For example, the AD623 and AD625 are all-in-one instrumentation amplifiers which can be programmed using a single external resistor for gains of 1-1000 and 1- 10,000. This would surely shrink the size of the overall circuit but at an increased price.

We concluded that the FLDT piezoelectric sensors were almost too sensitive for this application. The leads on the FLDT sensors also contained piezoelectric elements along with the detection pad and therefore were contributing to the susceptibility to the motion artifacts. The subject's breathing or just touching the table that the arm was resting on was enough to create unwanted motion artifacts in the signals. A possible solution would be to reduce the overall length of the FLDT sensor leads or make sure they are firmly held in place on the subjects arm.

An issue that was consistently apparent in our design was successfully coupling the piezoelectric sensors to the skin. We discovered that some sort of backing was needed to apply a constant pressure over both sensors when they were placed on the skin. We believe that the coupling to the skin could be improved if the sensors were applied to the skin with some sort of coupling gel. For example, Parker Laboratories Aquasonic Ultrasound Gel would be a good candidate and it is readily available. We believe this could help reduce any sonic vibration or noise generated in the system along with maintaining a strong coupling to the subject's skin.

A definite solution for the reduction of size would be to create a PCB with all surface mount components. Our prototype used all through hole components which take up much more space and are sometimes more expensive.

6.3 Valuable Experience Gained

During the course of this project there were definitely some very valuable lessons learned about what it takes to be a successful engineer and successful team member. Some lessons we were warned about all semester but it would seem that some lessons just cannot be stressed enough, they need to be experienced to get the full effect.

One of the most valuable lessons was the fact that not everything will play out according to plan. In the initial stages of our design process we had, what we thought to be, a nicely laid out plan to accomplish all our goals for the project. Things progressed nicely for the first few months but there came a time when the results we were hoping for were not as expected and our group was sent into what we called a "panic mode." There were some very unexpected and costly variables that ended up playing into our project which taught us that we should essentially double the amount of time planned for certain key steps of the project.

The "panic mode" taught us what I believe to be a very real engineering lesson that I feel all engineers should know. That lesson being, to keep in touch with the customer and knowing when to get in touch with them when the product is not coming together as planned. There came a time in this project when our design needed some serious rework and our group was essentially banging our heads against the wall trying to figure out how we could still deliver what the customer wanted. Though we probably should have went to the customer earlier, instead of just giving up or making something up, we still went and met with the customer where we all figured out a new plan of action.

There is a saying, "Measure twice, cut once." For this particular project it seemed to be a recurring theme. When purchasing a large amount of 20 kOhm resistors from the ECE Depot two of them turned out to be just 20 Ohms which caused all of our amps on the PCB to saturate causing us to believe something was wrong with our PCB. Of course we did not figure this out until we took each component off the PCB and measured them individually. This was simply a variable we did not even imagine would play a role in our design. Also, because of the poor quality of the PCB we purchased, when removing components from the board the pads and traces sometimes come off with the component. When looking back at the PCB we noticed that two of the traced had been routed incorrectly. If we had taken another look at the PCB before sending it in or had a peer review of it before sending it in we would have had a better chance of catching the mistake. Of course we did not have enough time to order another PCB which forced us to put everything back on a breadboard.

6.4 Acknowledgements

This project would not have been possible without the contribution and help of the IEEE Phoenix Team. This project required certain knowledge for the physiology of blood flow

through the human body and the Phoenix Team was always more than willing to clear up and confusion about the subject. We were allowed access to use their equipment such as the National Instruments DAQ USB-6009 and laptop with LabView software. Special thanks goes out to Larry Beaty and Steven James of the IEEE Phoenix team, without their guidance and help, this project would not be where it is today.

Appendix A: Timeline

Figure 14 and Figure 15 show the original proposed timeline and our new, reworked timeline if we were to go back and do the project all over again. There are some clear differences between the two, particularly when it comes to testing we essentially doubled the time. Unfortunately, we learned this the hard way. We found that it would have been much wiser to have overestimated the time required than to have assumed everything would go according to plan.

Task	Week3		Week4		Week5		Week6		Week7	
	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday
Pick A Sensor										
Schematics		Derek ->Filter, Kangyu ->Amp								
Simulations		Shreya + Negin -> Sensor Array								
Peer Review										
Order Parts									Assuming all parts fro	
Test On Protoboard										
Test Sensor Array										
PCB										
TEST On PCB										
TEST On Arm										
Final report/ Presentation										

Task\	Week8		Week9		Week10		Week11	
	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday
Pick A Sensor								
Schematics								
Simulations								
Peer Review								
Order Parts								
Test On Protoboard								
Test Sensor Array								
PCB		Depending on board shop						
TEST On PCB								
TEST On Arm								
Final report/ Presentation								

Task\	Week12		Week13		Week14		Week15	
	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday
Pick A Sensor								
Schematics								
Simulations								
Peer Review								
Order Parts								
Test On Protoboard								
Test Sensor Array								
PCB								
TEST On PCB								
TEST On Arm								
Final report/ Presentation								

Figure 14 – Original Timline

Task	Week3		Week4		Week5		Week6	
	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday
Pick A Sensor								
Schematics								
Simulations								
Peer Rewiew								
Order Parts								
Test On Protoboard								
PCB								
TEST On PCB								
TEST On Arm								
Final report								

Task	Week7		Week8		Week9		Week10	
	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday
Pick A Sensor								
Schematics								
Simulations								
Peer Rewiew								
Order Parts								
Test On Protoboard								
PCB								
TEST On PCB								
TEST On Arm								
Final report								

Task	Week11		Week12		Week13		Week14		Week15	
	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday	Tuesday	Thursday
Pick A Sensor										
Schematics										
Simulations										
Peer Rewiew										
Order Parts										
Test On Protoboard										
PCB										
TEST On PCB										
TEST On Arm										
Final report										

Figure 15 – New Timeline

Appendix B: Bill of Materials

Count	RefDes	Description	Value	Value2	Manufacturer	Part Number	Distributer	Dist Part	Price
1	-	Battery Holder 6" flying lead	3 cell	AAA	Keystone	2480K	Digikey	2480K	$ 1.88
2	J1	BNC receptacle	PC mount	RA	Amphenol	31-5431-2010	Digikey	ARF1065NW-ND	$13.16
2	C13	Cap, monolithic ceramic	22 pf	50V	Murata	RPE5C1H220J2K1Z03B	Digikey	490-3709-ND	$ 0.96
2	C1	Cap, monolithic ceramic	.1 uF	25V	Murata	RDER71E104K0K1C03B	Digikey	490-5380-ND	$ 0.88
2	C2	Cap, monolithic ceramic	.1 uF	25V	Murata	RDER71E104K0K1C03B	Digikey	490-5380-ND	$ 0.88
2	C3	Cap, monolithic ceramic	.1 uF	25V	Murata	RDER71E104K0K1C03B	Digikey	490-5380-ND	$ 0.88
2	C7	Cap, monolithic ceramic	.1 uF	25V	Murata	RDER71E104K0K1C03B	Digikey	490-5380-ND	$ 0.88
2	C8	Cap, monolithic ceramic	.1 uF	25V	Murata	RDER71E104K0K1C03B	Digikey	490-5380-ND	$ 0.88
2	C12	Cap, monolithic ceramic	.1 uF	25V	Murata	RDER71E104K0K1C03B	Digikey	490-5380-ND	$ 0.88
2	C4	Cap, monolithic ceramic	.47 uF	25V	TDK	FK18Y5V1E474Z	Digikey	445-4807-ND	$ 0.66
2	C5	Cap, monolithic ceramic	.47 uF	25V	TDK	FK18Y5V1E474Z	Digikey	445-4807-ND	$ 0.66
2	C6	Cap, monolithic ceramic	.47 uF	25V	TDK	FK18Y5V1E474Z	Digikey	445-4807-ND	$ 0.66
2	C9	Cap, tantalum	1.0 uF	20V	AVX	TAP105K020SCS	Digikey	478-1833-ND	$ 0.92
2	C10	Cap, tantalum	2.2 uF	16V	AVX	TAP225K016SCS	Digikey	478-1868-ND	$ 0.88
2	C11	Cap, tantalum	6.8 uF	16V	AVX	TAP685K016SCS	Digikey	478-1919-ND	$ 0.65
1	J2	Header, male pins	2pin	0.1"	TE Connect	2-644803-2	Digikey	A30924-ND	$ 0.34
1	-	Header, female	2pin	0.1"	TE Connect	3-641536-2	Digikey	A31101-ND	$ 0.19
2	R1	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K0	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R5	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K1	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R6	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K2	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R7	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K3	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R9	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K4	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R10	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K5	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R11	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K6	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R12	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K7	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R14	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K8	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R15	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K9	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R16	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K10	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R17	Resistor, 1%	20.0K	1/8W	Stackpole	RNF18FTD20K11	Digikey	RNF18FTD20K0CT-ND	$ 0.30
2	R4	Resistor, 1%	2.00K	1/8W	Stackpole	RNF18FTD2K00	Digikey	RNF18FTD2K00CT-ND	$ 0.30
2	R8	Resistor, 5%	10M	1/4W	Stackpole	CF14JT1M00	Digikey	CF14JT1M00CT-ND	$ 0.16
2	R13	Resistor, 1%	10	1/4W	Stackpole	RNF14FTD10R0	Digikey	RNF14FTD10R0CT-ND	$ 0.30
2	R18	Resistor, 1%	11.8K	.40W	Vishay	SFR2500001182FR500	Digikey	PPC11.8KYCT-ND	$ 0.36
1	R19	Potentiometer	10K	1/4W	Bourns	3310Y-001-103L	Digikey	3310Y-001-103L-ND	$ 2.56
5	U1	IC, op-amp	-	-	STM	TS27L4CN	Digikey	497-2254-5-ND	$ 5.30
5	-	sockets	-	-	TE Connect	2-641609-1	Digikey	A24808-ND	$ 3.40
1	U3	Voltage Regulator	3.3V	100mA	STM	LE33CZ-TR	Digikey	497-4258-1-ND	$ 0.88
Total									**$43.10**

Appendix C: Equipment List

Technical Sales
United States
(866) 531-6285
info@ni.com

NI USB-6009

14-Bit, 48 kS/s Low-Cost Multifunction DAQ

- 8 analog inputs (14-bit, 48 kS/s)
- 2 analog outputs (12-bit, 150 S/s); 12 digital I/O; 32-bit counter
- Bus-powered for high mobility; built-in signal connectivity
- OEM version available
- Compatible with LabVIEW, LabWindows/CVI, and Measurement Studio for Visual Studio .NET
- NI-DAQmx driver software and NI LabVIEW SignalExpress LE interactive data-logging software

Overview

The National Instruments USB-6009 provides basic data acquisition functionality for applications such as simple data logging, portable measurements, and academic lab experiments. It is affordable for student use and powerful enough for more sophisticated measurement applications. For Mac OS X and Linux users, download the NI-DAQmx Base driver software and program the USB-6009 with LabVIEW or C.

To supplement simulation, measurement, and automation theory courses with practical experiments, NI developed a USB-6009 Student Kit that includes a copy of the LabVIEW Student Edition. These kits are exclusively for students, giving them a powerful, low-cost, hands-on learning tool. Visit the NI academic products page at http://www.ni.com/academic/measurements.htm for more details.

For faster sampling, more accurate measurements, calibration support, and higher channel count, consider the NI USB-6210 and NI USB-6211 high-performance USB data acquisition devices.

Every NI USB data acquisition device includes a copy of NI LabVIEW SignalExpress LE so you can quickly acquire, analyze, and present data without programming. In addition to LabVIEW SignalExpress, USB data acquisition modules are compatible with the following versions (or later) of NI application software – LabVIEW 7.x, LabWindows™/CVI 7.x, or Measurement Studio 7.x. USB data acquisition modules are also compatible with Visual Studio .NET, C/C++, and Visual Basic 6.

Specifications

Specifications Documents

- Specifications (3)
- Data Sheet

Specifications Summary

General	
Product Name	USB-6009

- **For more information on LabView and its capabilities we recommend visiting:**

  http://www.ni.com/labview/whatis/

Appendix D: Parts Information

TS27L4C,I,M

PRECISION VERY LOW POWER CMOS QUAD OPERATIONAL AMPLIFIER

- VERY LOW POWER CONSUMPTION : **10µA/op**
- OUTPUT VOLTAGE CAN SWING TO GROUND
- EXCELLENT PHASE MARGIN ON CAPACITIVE LOADS
- STABLE AND LOW OFFSET VOLTAGE
- THREE INPUT OFFSET VOLTAGE SELECTIONS

N
DIP14
(Plastic Package)

D
SO14
(Plastic Micropackage)

P
TSSOP14
(Thin Shrink Small Outline Package)

DESCRIPTION

These devices are low cost, low power quad operational amplifiers designed to operate with single or dual supplies. These operational amplifiers use the ST silicon gate CMOS process allowing an excellent consumption-speed ratio. These series are ideally suited for low consumption applications.

Three power consumptions are available allowing to have always the best consumption-speed ratio:

- I_{CC} = 10µA/amp.: TS27L4 (very low power)
- I_{CC} = 150µA/amp.: TS27M4 (low power)
- I_{CC} = 1mA/amp.: TS274 (standard)

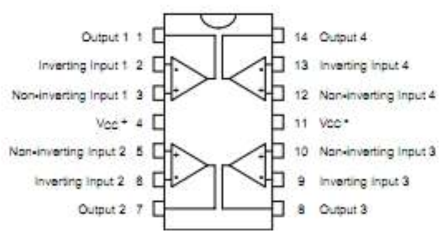
These CMOS amplifiers offer very high input impedance and extremely low input currents. The major advantage versus JFET devices is the very low input currents drift with temperature (see figure 2).

ORDER CODE

Part Number	Temperature Range	Package		
		N	D	P
TS27L4C/AC/BC	0°C, +70°C	•	•	•
TS27L4I/AI/BI	-40°C, +125°C	•	•	•
TS27L4M/AM/BM	-55°C, +125°C	•	•	•
Example : TS27L4ACN				

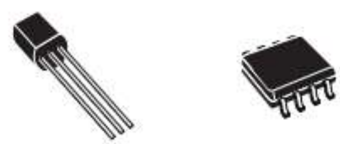
N = Dual In Line Package (DIP)
D = Small Outline Package (SO) - also available in Tape & Reel (DT)
P = Thin Shrink Small Outline Package (TSSOP) - only available in Tape & Reel (PT)

PIN CONNECTIONS (top view)



LExxAB
LExxC

Very low drop voltage regulators with inhibit



TO-92 SO-8

Features

- Very low dropout voltage (0.2 V typ)
- Very low quiescent current (typ. 50 µA in OFF MODE, 0.5 mA in ON MODE, no load)
- Output current up to 100 mA
- Output voltages of 2.5; 2.7; 3; 3.3; 3.5; 4; 4.5; 4.7; 5; 8 V
- Internal current and thermal limit
- Only 2.2 µF for stability
- Available in ± 1 % (A) or ± 2 % (C) selection at 25 °C
- Supply voltage rejection: 80 dB (typ.)
- Temperature range: -40 to 125 °C

Description

The LExxAB and LExxC are very low drop voltage regulators available in SO-8 and TO-92 packages and in a wide range of output voltages.

The very low drop voltage (0.2 V) and the very low quiescent current make them particularly suitable for low noise low power applications and specially in battery powered systems.

They are pin to pin compatible with the older L78Lxx series. Furthermore in the 8 pin configuration (SO-8) they employ a shutdown logic control (pin 5, TTL compatible). This means that when the device is used as a local regulator, it's possible to put in stand by a part of the board even more decreasing the total power consumption. In the three terminal configuration (TO-92) the device is even in ON STATE, maintaining the same electrical performances. It needs only 2.2 µF capacitor for stability allowing room and cost saving effect.

Table 1. Device summary

Part numbers		
LE25AB	LE35C	LE47AB
LE27AB	LE35AB	LE50C
LE30C	LE40C	LE50AB
LE33C	LE45C	LE80C
LE33AB	LE45AB	LE80AB