Oscilloscope BoosterPack

To:

Client: Trey German, Texas Instruments

Supervisor: Dr. Yoder, Rose-Hulman Institute of Technology

From:

ECE462 Team 03

Thomas Tasch, Abel Woldemeskel,

Zachary Zdrojewski, and Ruoyu Zhuang

May 18, 2015

Executive Summary

For this project, we were responsible for designing and building an Oscilloscope BoosterPack for our client from Texas Instruments. This BoosterPack utilizes TI's LaunchPad in order to operate as a 2-channel oscilloscope. Our motivation for this project was to design an alternative, inexpensive oscilloscope as compared to the traditional oscilloscope. By using a color LCD touch screen, we incorporated the ability for users to manipulate the displayed waveforms, such as changing time and voltage divisions and running and stopping the display.

The project was divided into two major areas: the analog front-end and the touch screen interface. Our analog front-end was responsible for handling an input signal and altering the signal in order to meet the ADC's specifications for operation. The touch screen interface uses the signal from the front-end and converts it into a digital input for the touch screen to properly display. We were able to successfully build our front-end with breakout boards for its necessary components and display the signal onto our touch screen. However, we encountered a great amount of noise in the front-end, and the screen would display the subsequent noise. Our PCB design also generated noise in the signal on the screen. Recommendations for further improvements to this project would include finding and eliminating the source of the noise in the analog front-end and also incorporating additional functions to the touch screen, such as math functions and cursors.

1.0 Introduction and Project Overview

Our client for this project was Trey German from Texas Instruments, and he sought for an Oscilloscope BoosterPack that would provide a cheaper and efficient alternative to the traditional oscilloscopes used for measuring signals. This BoosterPack design would use TI's LaunchPad for powering its operation. The deliverables for this design project were a functioning BoosterPack prototype and a User's Manual. We were able to complete a functioning breadboard prototype with the touch screen display, but we endured issues with our PCB prototype with the display. This report will further explain the areas completed, the areas requiring future improvements, and additional tests used to evaluate the project's operation.

2.0 Accomplishments

In this section, you will find how our solution meets the requirements for our project. First, we provide our stakeholders and features of the project, along with the thorough solution descriptions and test data. These tests will thus determine the validity and functional solutions for our project.

2.1 Definition of Primary Stakeholders and Features

The Stakeholder Model is a clear and concise layout of all the stakeholders and features of our design product. Our stakeholders in Figure 1 range from both ends of the product's life span, including the manufacturer and the disposal company. Additionally, the listed features pertain to the cost and size of our final product among other desired features in Figure 2. Overall, this model helps us determine which features are desired more than others so that we can place more emphasis on these same desired features in our design process. Our stakeholder model is shown as Figure 3.

Stakeholder Name	Importance	Description
Users	highest	The end purchasers and consumers of the product
Technicians	moderate	The repairmen who fix and repair broken or damaged products
Client/Texas Instruments	highest	Company interested in developing a product additional to their LaunchPads
Manufacturers	moderate	Responsible for assembling a working product
Sales Department	moderate	The marketing company selling the product
Shipping Department	moderate	Delivers product from manufacturers to sales department
Universities	moderate	Students and faculty using the product for learning purposes
Recycle Companies	lowest	The company that handles the disposal of the product for recycling

Figure 1: Stakeholder Descriptions

Feature Name	**Feature Description**
Affordable	The BoosterPack final design must be less than $30 since it's a design requirement.
Durable	The BoosterPack should withstand constant vibrations and heat during shipping and everyday use.
Reparable	The product should be able to be repaired by a repairman examining the damaged BoosterPack.

Small Size and Weight	This design should be relatively small so it can attach to the TM4C1294XL LaunchPad for operation.
Efficient	The oscilloscope and operation of the product should perform its duties quickly with no delay.
Recyclable	Upon disposal of the product, it should be composed of all recyclable parts for a complete recycle.
Functional	The BoosterPack should be able to measure AC and DC voltages with two channels. These waveforms should display onto an LCD touch screen. The touch screen should display amplitudes and frequency, and should change s/div and V(or A)/div. The input voltage range should be between -15V to +15V at the BNC connector. The input impedance should be 1 MΩ.

Figure 2: Feature Descriptions

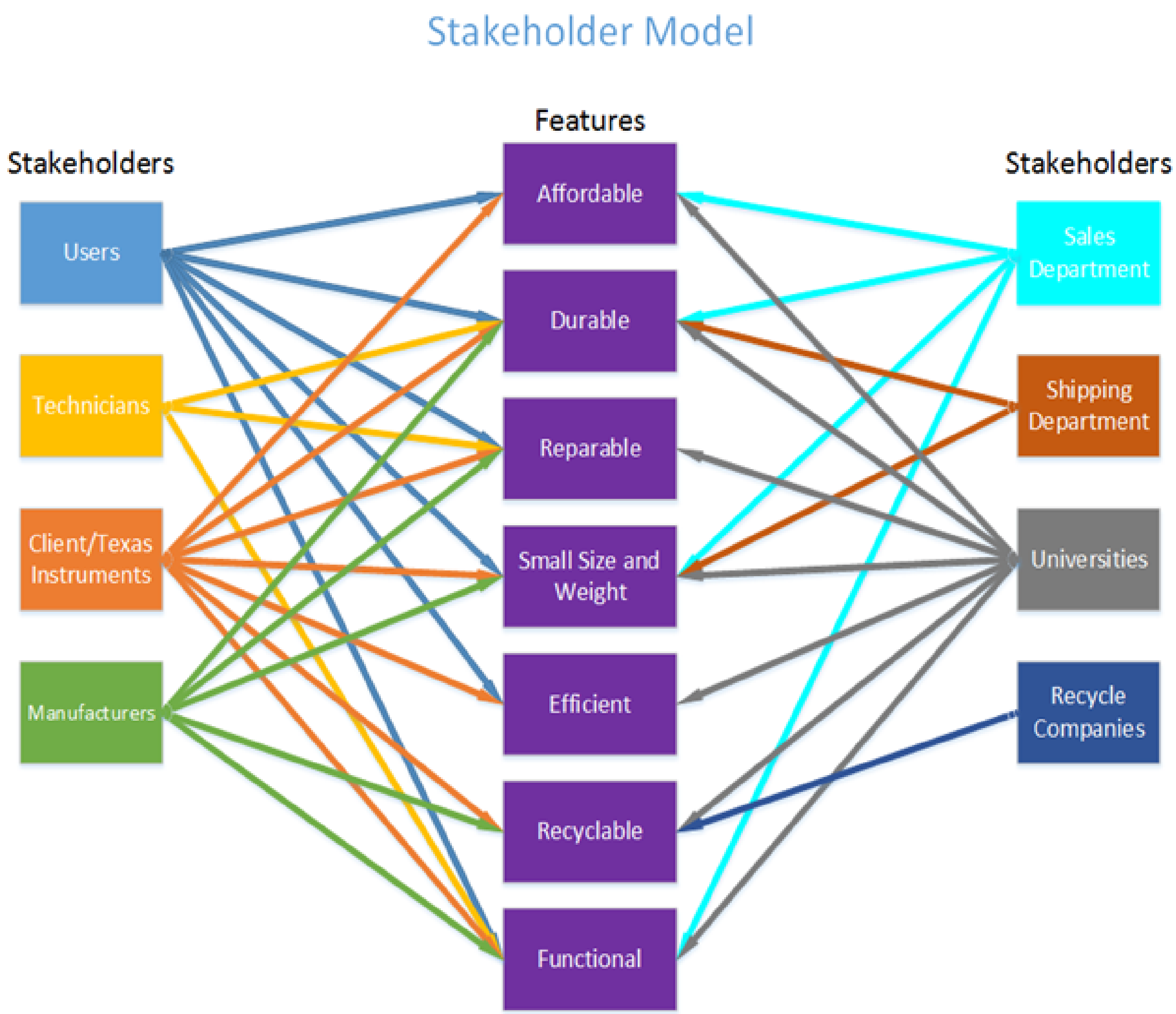


Figure 3: Stakeholder Model

Our primary stakeholders are Texas Instruments and users of the Oscilloscope BoosterPack. Texas Instruments is concerned with our design as our client, Trey German, is an employee who suggested the project to our advisor, Dr. Yoder. Also, we are using all TI components in our design except for the touchscreen. Users are our other primary stakeholder for they will use our product for everyday use, and they will be concerned about our design. For our primary features, our design should be ultimately affordable and functional. These two features directly affect the user, who will require a design they can easily purchase and a design that operates correctly as an oscilloscope for measurement. In comparison, the client is asking for a working product that provides a cheaper solution to other oscilloscopes.

2.2 Description of the Solution

The Domain Model seen in Figure 4 is used to give a general overview of what the oscilloscope will do and how it will do it. The oscilloscope being referred to here is comprised of both the BoosterPack and the TM4C1294XL LaunchPad. The actors are the outside factors that will influence the system, and the Input-Outputs (I/Os) of the system represent what is transmitted between the actors and the system. One major actor included that will interact with the system is the user. The user will be interfacing with the device through a set of user inputs, which will help the user set the oscilloscope to its desired settings. Other important actors include several electrical devices like the power supply and probe. The power supply is responsible for providing the power needed for the system. The probe is necessary so that the user can choose exactly what signal they want analyzed. Similar I/Os have been grouped together at three main interfaces. These include the mechanical interface, the information interface, and the electrical interface. The definitions for all of the actors and I/Os can be found in Figure 6.

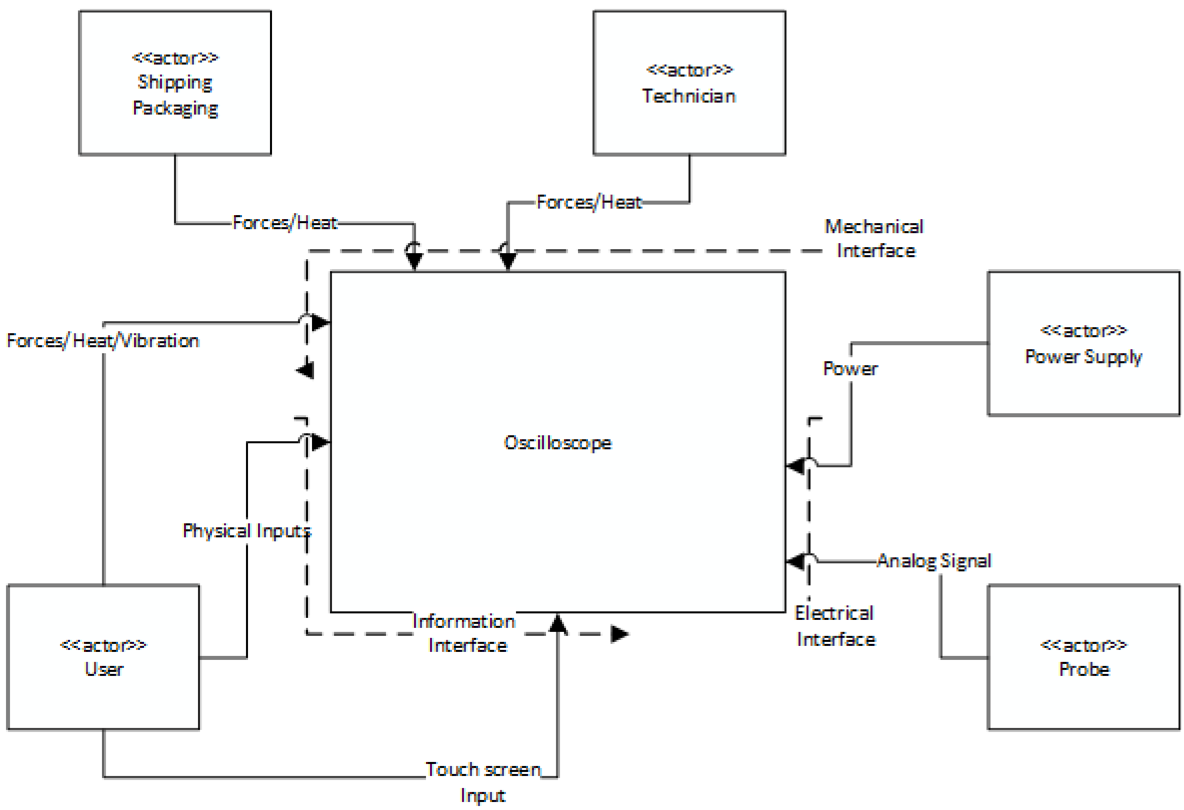


Figure 4: Domain Model for Oscilloscope

The Logical Architecture Model seen in Figure 5 helps visualize the behavior of the system. Several blocks are used to describe the behavioral elements of the oscilloscope. The power input goes to both the ADC, the TM4C1294XL LaunchPad, the touch screen, and the analog front end. The analog signal will go into the analog front end, where it is then modified to become the normalized analog signal, which will go into the ADC. After going through the ADC, the now digital signal is received by the TM4C1294XL LaunchPad. The TM4C1294XL LaunchPad is responsible for both receiving the digital signal and the desired settings from the user and then outputting this data onto the screen. The touch screen shows the relevant data a user would expect from an oscilloscope, and will also act as an input device that the user can use to manipulate the settings. The touch screen inputs help the user modify the oscilloscope to the desired purpose they want. The definitions for all of the behavioral blocks and internal I/Os can be found in Figure 6.

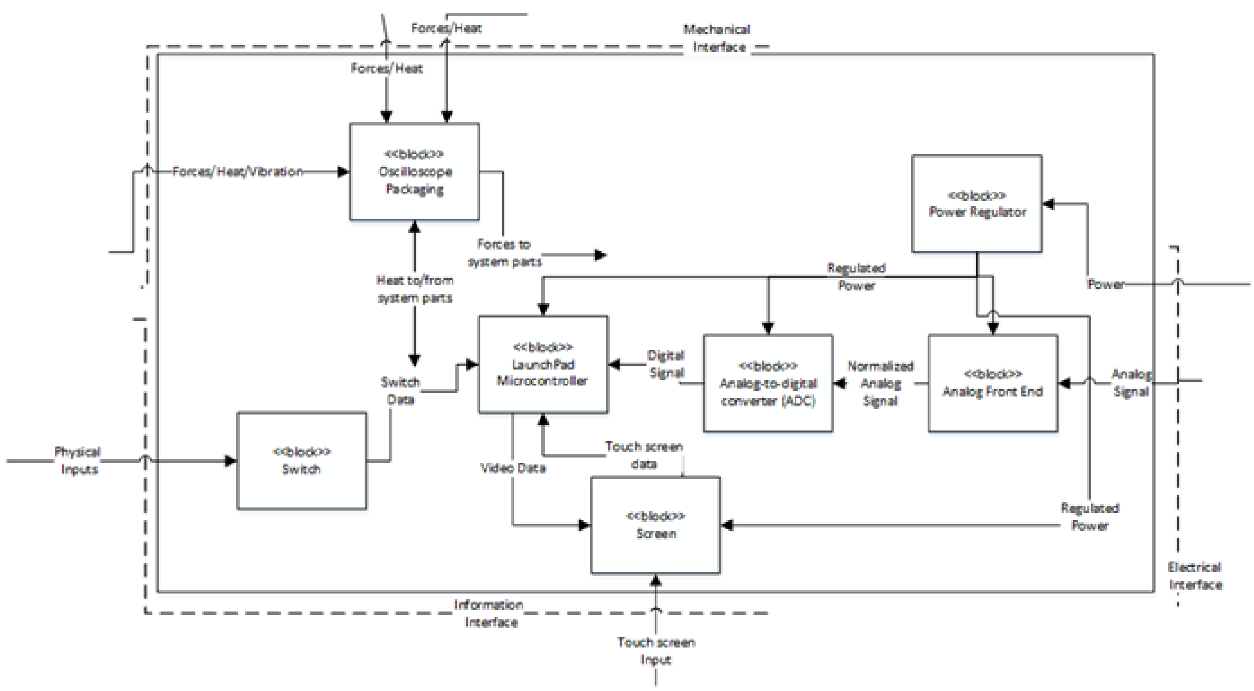


Figure 5: Logical Architecture Model for Figure 4

Domain Model	
Actor Name	**Definition**
Probe	**The 10x probe with a BNC connector that will connect to the part of the circuit that is being investigated.**
Screen	**This is the color LCD touch screen that will display the investigated signal along with all the settings for the oscilloscope. It will also act as an input which the user can use to control the settings of the oscilloscope.**
Power Supply	**This is the power source for the oscilloscope. It will be supplied from the micro USB port.**
User	**This is the person using the device to help measure signals on their circuit.**
Shipping Packaging	**This is the packaging that will go around the device along with any vehicles used to transport the device from manufacturing to distribution.**
Technician	**This is the person who will be making repairs on the device. An action taken by the Technician to consider is the heat from the solder.**
I/O Name	**Definition**
Analog Signal	**This is the signal that is being determined by the probe's positioning in the circuit. It will come from either of the two channels.**
Power	**This consists of the electrical energy coming from the external power supply.**
Forces/Heat/Vibration	**This is the mechanical forces and heat that the device will encounter from physical matter.**
Physical Input	**This is the input coming from the user via the power switch.**
Touch Screen Input	**This is the input coming from the user to the touch screen, i.e. the act of the user placing his/her finger somewhere on the screen.**

Logical Architecture	
Block Name	**Definition**
Oscilloscope Packaging	**This is the physical structure that will house the oscilloscope and keep all of the system parts in place.**
Power Regulator	**This is the power regulator that will convert the power received from the micro USB port to the various voltage levels needed for each device.**
Analog Front-End	**This consists of the various analog components needed to change the voltage level of the incoming signal to that of what is appropriate for the ADC.**
Analog-to-Digital Converter (ADC)	**This is the ADC that will convert the analog signal into a data signal that the TM4C1294XL LaunchPad can handle effectively.**
Switch	**This is the switch that will control whether the oscilloscope should be powered on or off.**
Screen	**This is the touch screen that will display the measured signal and receive inputs from the user. These inputs change the settings of the oscilloscope.**
TM4C1294XL LaunchPad	**This is the Texas Instruments TM4C1294XL LaunchPad required to receive and analyze all the input data and output this data in a way that the user will be able to understand.**
Internal I/O Name	**Definition**
Normalized Analog Signal	**This is the analog signal after being manipulated by the analog front-end so that the ADC can read the signal correctly.**
Digital Signal	**This is the converted analog signal that is now digital.**
Video Data	**This is the data describing how the display on the screen should look in order to properly inform the user about what the device is measuring.**

Touch Screen Data	**These are the electrical signals coming from the screen that describe where and when certain parts of the screen were touched by the user.**
Switch Data	**This is the data coming from the power switch that describes how the power was manipulated.**
Heat to/from System Parts	**This is the heat that will transfer to and from system parts as a result of dispersed energy from the system components and external heat sources.**
Forces to System Parts	**These are the forces exerted by the oscilloscope packaging onto the various components located within the oscilloscope.**

Figure 6: Definitions of Blocks and I/Os from Domain and Logical Architecture Models

This design was made to optimize the primary features. High end components were used in the analog front end design in order to achieve optimal performance, but each component was used to its full potential in order to minimize the cost. For example, the Digital Variable Gain Amplifier (DVGA) within the analog front end was used as both the programmable gain amplifier and the single to differential converter. The LaunchPad was also designed to be used to its full potential. It performed the main functions such as acquiring data from the Analog to Digital Converter (ADC) and controlling all of the oscilloscope settings based on the touch screen inputs. It also provided the bit clock for the ADC, the digital inputs for all of the analog front end components, and the power for the entire system. By using the power provided from the LaunchPad, the need for an external power supply was eliminated, thus reducing the cost.

Much of the functionality of the project can be based on how well the touch screen correctly displays signals. The use of a touch screen eliminated the need for numerous physical inputs such as buttons or dials, thereby reducing the complexity of the interface and keeping the cost to a minimum. The touch screen offers several ways to manipulate the signal such as changing the horizontal or vertical scale division, adjusting the trigger level, and allowing the user to choose the acquire mode to be either normal or averaging.

2.3.0 Data and Verification of Requirements

2.3.1 Switchable Attenuator

Requirement:

In order to receive large peak-to-peak input voltages as sine/square/ramp waveforms, the oscilloscope must have an attenuator to properly decrease the peak-to-peak input voltage in order to meet the requirement for the ADC. The ADC (ADS4222) in our design requires a maximum of 1 Volt peak-to-peak. As a result, our attenuator at the input of our front-end analog design must be able to recognize how much attenuation is needed to meet this ADC requirement. Our design uses the OPA4872 since it has a large bandwidth (500 MHz) and it can use a resistive ladder with 2-bit logic to control its four stages of attenuation.

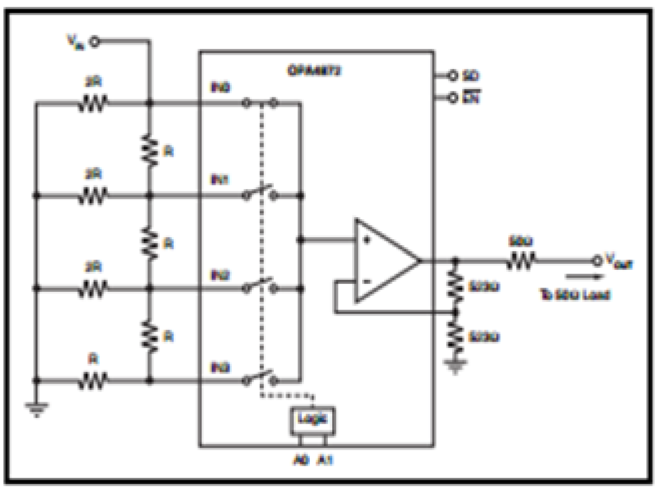
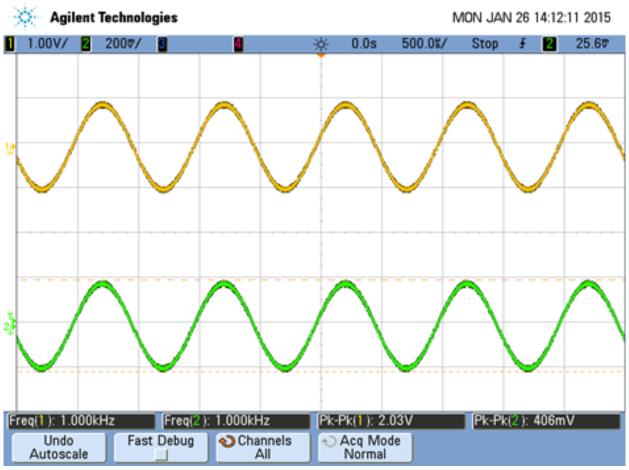


Figure 7: 2-Bit High Speed Attenuator with Switchable Resistive Ladder Input

A0	A1	$\overline{EN}$	SD	V_{OUT}
0	0	0	0	IN0
1	0	0	0	IN1
0	1	0	0	IN2
1	1	0	0	IN3
X	X	1	0	High-Z, I_Q = 3.4mA
X	X	X	1	High-Z, I_Q = 1.1mA

Figure 8: Truth Table for Logic Inputs A0 and A1



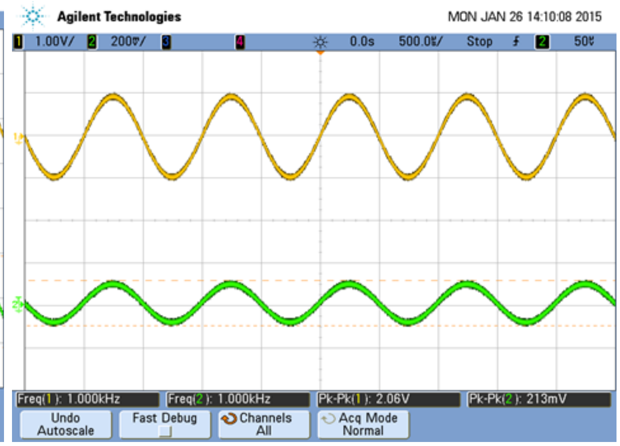
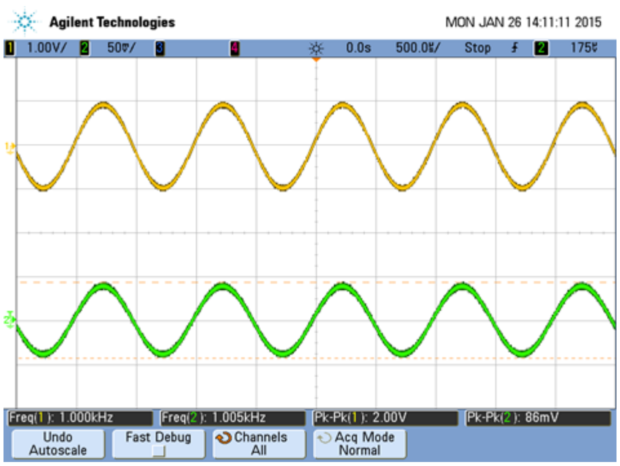


Figure 9: Logic 00 Input and Output

Figure 10: 01 Logic Input and Output



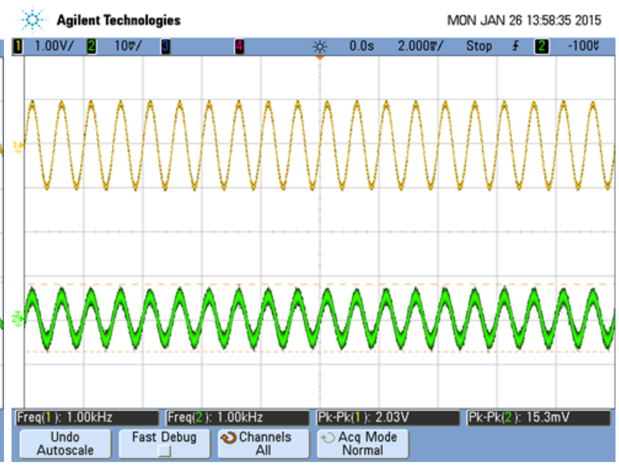


Figure 11: 10 Logic Input and Output

Figure 12: 11 Logic Input and Output

Verification Result:

From Figures 9, 10, 11, and 12, we can see all four logic attenuation stages attenuating the input signal to be our output. From the aforementioned figures, the outputs' peak-to-peak values decrease with the increase in digital logic. In each plot, the topmost yellow waveform resembles the 1k Hz sine wave with 2.00 Volts peak-to-peak, while the bottommost green waveform resembles the attenuated output of the

OPA4872, the attenuator. All scope captures have both frequencies and peak-to-peak voltages for the input and output waveforms at the bottom of the plots.

From logic 00 to 01 to 10 to 11, the attenuation output works by reducing the input by 5, 10, 23, and 132 respectively to each aforementioned logic code. This was calculated by dividing the input peak to peak voltage by the output peak to peak voltage. The attenuation increments are not as we envisioned as we were expecting to see the 00 digital input produce an output equal to the input waveform, the 01 digital input produce an output attenuated to be 1/2 the input, the 10 digital input produce an output attenuated to be 1/4 the input, and the 11 digital input produce an output attenuated to be 1/8 the input. Instead, all digital input combinations gave us outputs that were all attenuated with no clear ratios, but we are not worried because we can use the DVGA (digital variable gain amplifier) to increase the gain of the signal if needed. One issue we had while testing was that there were significant noise during the procedure. Be sure to add bypass capacitors to limit this noise during the OPA4872's operation.

2.3.2 ADC Verification

Requirement:

Our project needs an analog-to-digital converter (ADC) to convert the analog signal inputs to a digital signal output and transfer the digital signal to a touchscreen to display waveforms. The ADC (ADS4222) can take two differential analog signals and convert the differential signals to a 12 bit 2's complement digital signal output. There is a 0.95 V offset added to the input signals. The positive and negative analog signal inputs can swing from 0.5 V above the offset and -0.5V below the offset.

Verification Result:

IN +	IN -	OUTPUT	Measurement Value	Calculated Value
1.45 V	0.45 V	0111 1111 1111	1 V	1 V
0.95 V	0.95 V	0000 0001 0101	0 V	0.0101 V
0.95 V	0.95 V	0000 0001 1010	0 V	0.0127 V
1.45 V	0.95 V	0100 0001 0000	0.5 V	0.5080 V
1.45 V	0.95 V	0100 0000 1011	0.5 V	0.5056 V
1.45 V	0.65 V	0110 1000 1001	0.8 V	0.8173 V
1.45 V	0.65 V	0110 1000 1010	0.8 V	0.8178 V
0.45 V	1.45 V	1000 0000 0000	-1 V	-1 V

Figure 13: ADC Verification Table Results

When the positive input is 1.45 V and the negative input is 0.45 V, the ADC has a maximum positive output binary number. When positive input is 0.45 V and negative input is 1.45 V, the ADC has maximum negative output binary number. There are some small variation during some input values. The differential value of the analog inputs can be translated back from the digital output value. When the result is a positive number, the formula is {(the decimal value) x (1/2047)}. When the result is a negative number, the formula is {(the negative of 2's complement value in decimal) * (1/2047)}.

2.3.3 Digitally Controlled Variable Amplifier (DVGA)

Purpose: The main purpose of the DVGA in this design is to control the gain/amplitude of the signal by amplifying the signal in case the displayed signal is too small.

The working principle is that when all digital pins are low, then D3, D2, D1, and D0 are 0. The DVGA amplifies by 26 dB (20x), whereas each digital pin represents a 6dB decrease from this.

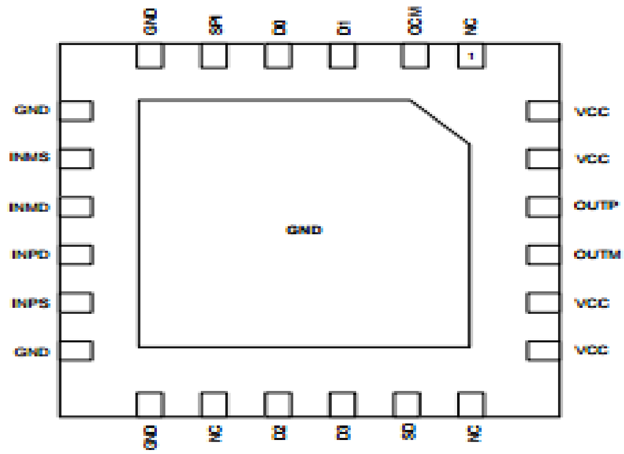


Figure 14: Pin Layout of LMH6881

Table 2. Amplifier Gain for All Control Pin Combinations

CONTROL PINS LOGICAL LEVEL IN PARALLEL MODE					
D3	D2	D1	D0	DECIMAL VALUE	AMPLIFIER VOLTAGE GAIN [dB]
1	X	1	X	10 - 15	6
1	0	0	1	9	8
1	0	0	0	8	10
0	1	1	1	7	12
0	1	1	0	6	14
0	1	0	1	5	16
0	1	0	0	4	18
0	0	1	1	3	20
0	0	1	0	2	22
0	0	0	1	1	24
0	0	0	0	0	26

Figure 15: Various Combinations of Digital Pins for DVGA

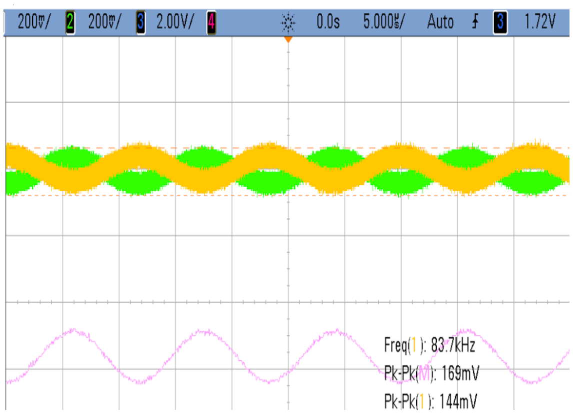
Test input signal:- 100mV Peak-peak. Sine wave.

Cases	Vin(peak-peak)	Vout(Peak-peak)	Expected(dB)	Measured(dB)
case 1	100mV,sine	144 mV	6	3.2
case 2	100mV,sine	156 mV	8	3.86
case 3	100mV,sine	188 mV	10	5.48
case 4	100mV,sine	213 mV	12	6.57
case 5	100mV,sine	244 mV	14	7.75
case 6	100mV,sine	294 mV	16	9.37
case 7	100mV,sine	356 mV	18	11.03
case 8	100mV,sine	725 mV	20	17.2
case 9	100mV,sine	770 mV	22	17.73
case 10	100mV,sine	730 mV	24	17.27
case 11	100mV,sine	830 mV	26	18.38

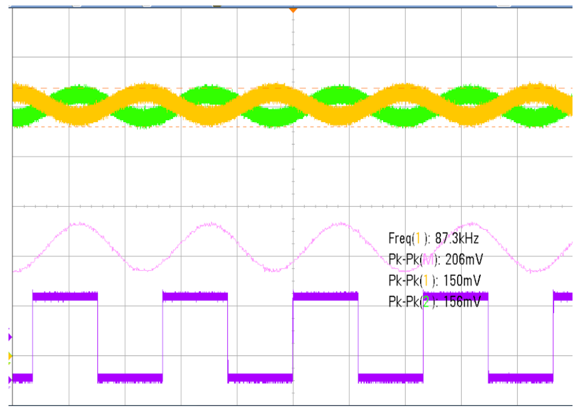
Fig. 15.2 Expected and measured voltage gains of Lmh6881(digitally controlled voltage gain amplifier)

Each of the 11 combinations from Figure 15 were tested and the results are summarized below in Figure 16.
The following screenshots are measured outputs of the DVGA(LMH6881). The input to the DVGA is 100mV sine wave(just for testing purposes).

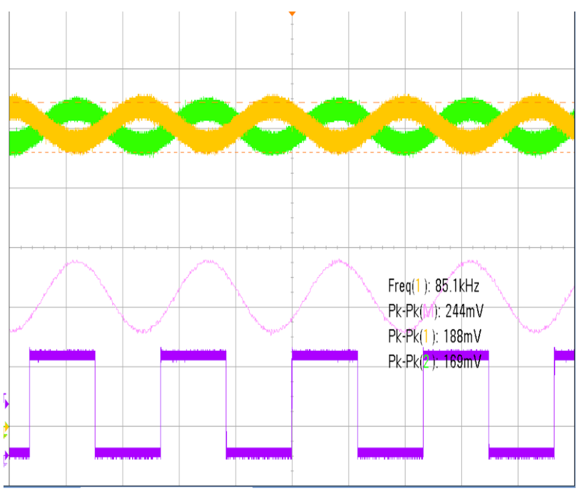
Case 1.



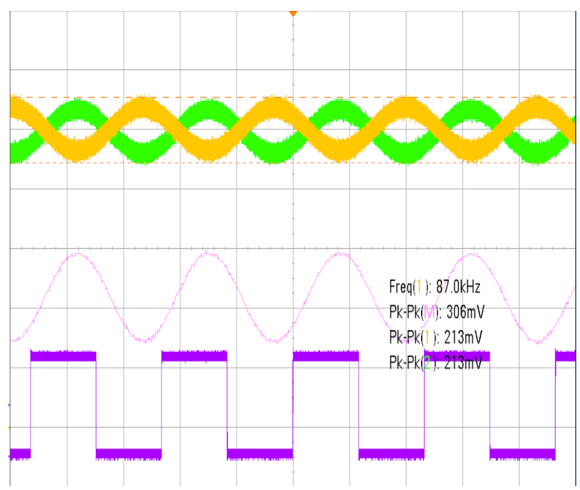
Case 2.



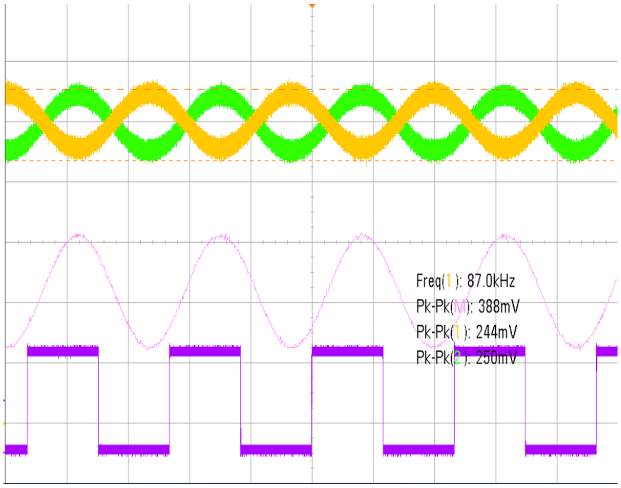
Case 3.



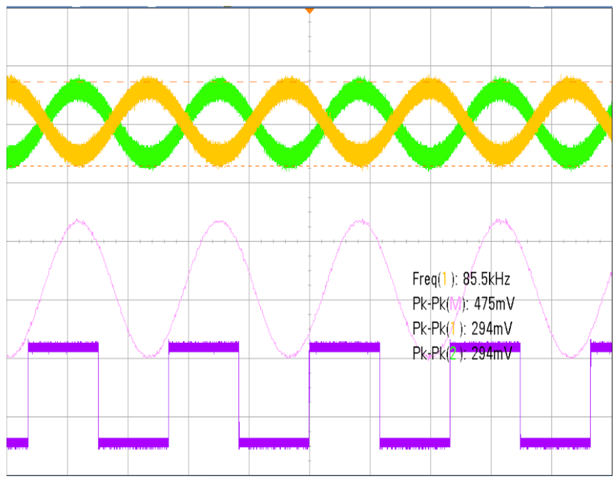
Case 4.



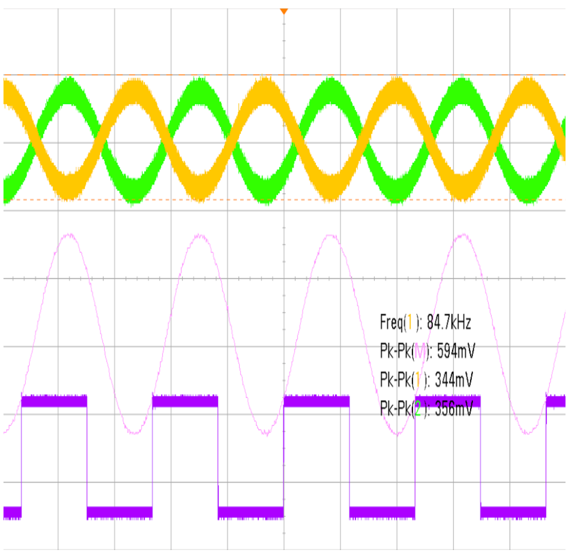
Case 5.



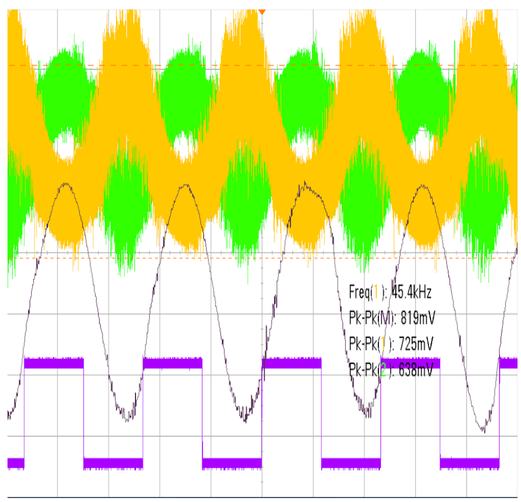
Case 6.



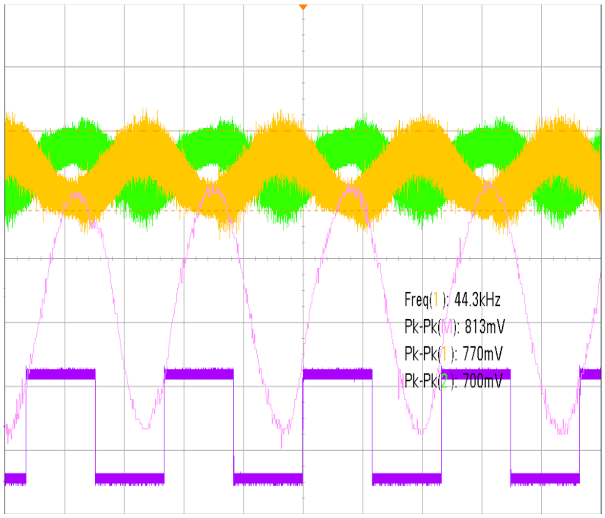
Case 7.



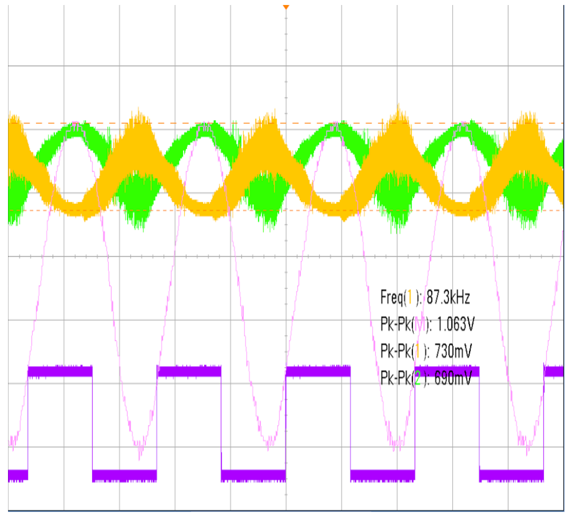
Case 8.



Case 9.



Case 10.



Case 11.

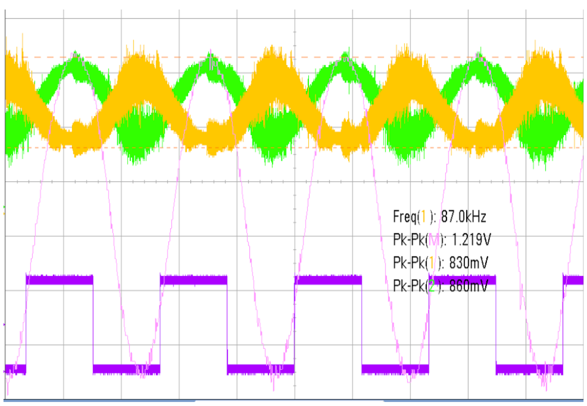


Figure 16: 11 Combinations for DVGA Testing Results

From the above data gathered, the DVGA amplifies the signal depending on the combination of the digital inputs. Those digital inputs are then controlled by the user using the touch screen. However, we have also noticed that the degree of the amplification is not accurate as expected from the datasheet (From Table 15.2, differences between measured and expected voltage gains could be anywhere between 3dB - 8dB off). We believed this to be satisfactory since we were still able to display small amplitude signals on the screen. The differences between what we measured and what we expected forced us to carefully calibrate each voltage division in the final design so that accurate readings were displayed on the screen.

3.0 Project Plan and Timeline

In the fifth week of ECE460, we developed an initial plan to map our progress. In order to finish our completed design in a timely manner, we planned to complete our design process by the end of ECE461 in the winter quarter and complete our documentation during ECE462 in the spring quarter. Our initial flowchart for our planned progress is presented below with descriptions of the tasks.

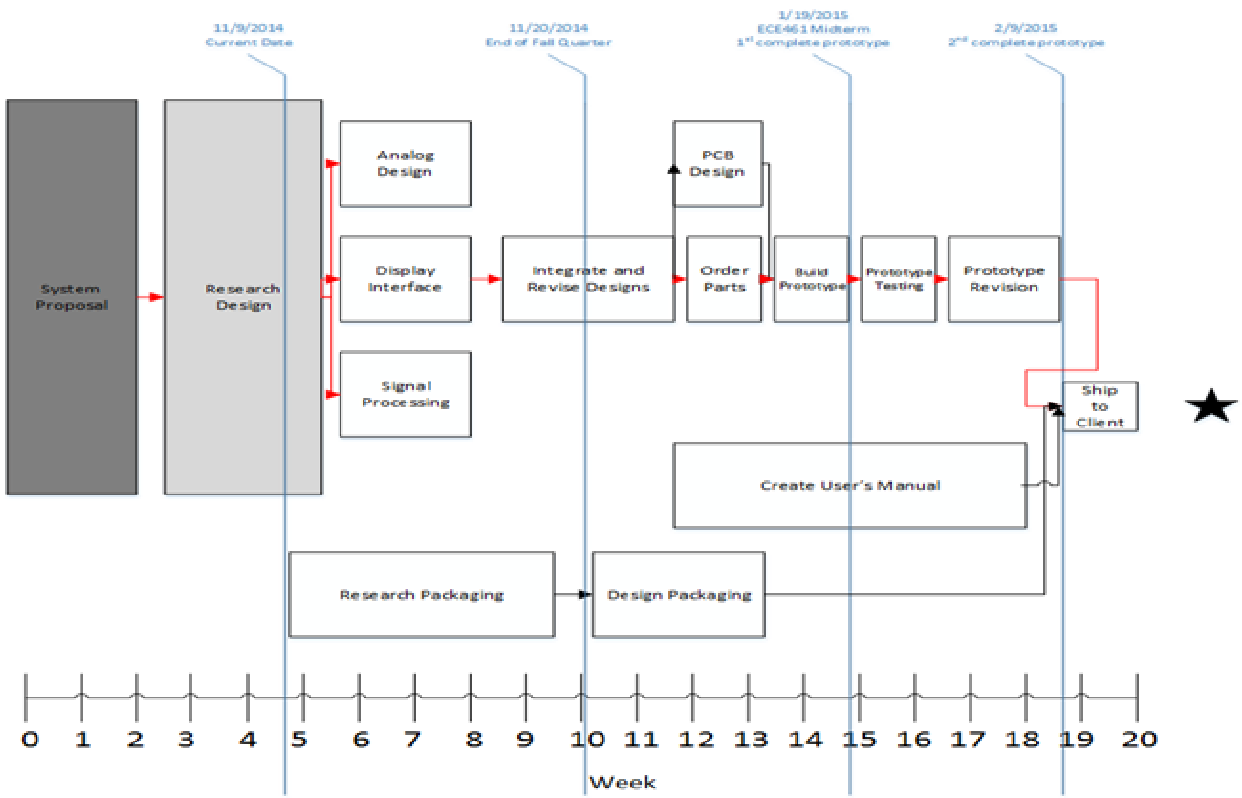


Figure 17: Project Flowchart

Block	**Description**
System Proposal	During this period, the expectations from the client are verified and a system level description of our project is created.
Research Design	Various designs of oscilloscopes are researched, and each aspect is inspected to determine its functionality.
Analog Design	All of the front-end analog components necessary between the probe tip and the ADC are determined.

	This design will make the required manipulations on the signal so that the ADC can function properly.
Display Interface	Communication between the screen and display is figured out. The programming needed to display a signal on the screen and receive inputs is completed.
Signal Processing	The programming required to store and analyze the digital signals received from the ADC will be formed.
Integrate and Revise Design	All of the separate design aspects of the oscilloscope will be integrated together. The newly integrated design will be revised based on input from other colleagues, and an agreed-upon complete design will have been constructed.
PCB Design	The various components from the revised design will be arranged onto a PCB.
Order Parts	This is the time required to buy and ship the parts needed.
Build Prototype	During this time, the prototype will be built according to our designs.
Prototype Testing	The prototype will be rigorously tested to make sure everything functions as planned and suggestions for more optimal designs are brought forth.
Prototype Revision	Based on problems or weak areas detected during testing, the prototype will be revised to fix these issues.
Research Packaging	Various packaging solutions for our product will be researched.
Design Packaging	The design of our packaging will be determined and verified during this time.

Create User's Manual	The manual, which describes how to correctly connect the oscilloscope to the LaunchPad as well as operate it, is written.
Ship to Client	This accounts for the time required to ship our product to the client.

Figure 18: Project Timeline Definitions

From the timeline, we first planned to complete the system proposal and then research possible designs for our BoosterPack. Afterwards, we would split as a group and individually research the analog design, touch screen, and signal processing for our project. By the end of the fall quarter, we would come together as a group and start combining our designs together to form our first prototype. In the meantime, we would begin building the initial PCB for the front-end analog. Once we had our first prototype, we would test it to produce a working oscilloscope. Next, we would revise our prototype and incorporate additional features to our touch screen, such as measuring frequency and magnitude. After testing our product, we would have our final design for our client.

In comparison to our actual progress, we deviated from the initial timeline by extending our time used to order parts. Our time needed to receive breakout boards to test our analog front-end design took an unexpected amount of time, delaying our process by about two weeks longer than expected. Since the components we needed to solder onto the breakout boards, such as the ADC component ADS4222, were miniscule, none of us were experienced enough nor had the necessary equipment to solder the boards. As a result, we contacted Jay Sotak from Rose-Hulman Ventures, as advised by our client who recently worked at Ventures, to complete the task for us for free. Looking back, we could have spent the extra money to have the boards produced online, which we did eventually when some components needed replaced in our design. If we spent more money, we would have received the boards quicker than waiting for a volunteer to solder them for us. Additionally, we could have still used Jay Sotak's help if we instead accounted for the longer wait period by planning to have the boards completed before Thanksgiving break.

Once we received these boards, we began testing our analog design for the oscilloscope. Again, we encountered issues when we were ready to send our PCB design after testing to an online fabrication service that would build and solder our entire front-end analog PCB design. In order to complete the PCB and solder every component for us with a seven-day completion, the final cost was near $1500.00. Instead, we chose the $900.00 option for the same task with a nine-day completion. This long wait period pushed us back further into the spring quarter, delaying our expected completion of the final prototype. To account for this issue in the future, we could have tried completing our front-end analog sooner in order to not delay the PCB order, slowing down our progression for the final prototype. In order to not deviate from our schedule in the future, we could use more money in our budget to order the PCB earlier. However, in the interest of conserving our budget for us, we had to order the PCB for less money.

When we were testing our breakout boards, we spent longer than expected trying to eliminate noise in our signals. We used at least a week trying to reduce the noise when we noticed its effects on our project. To recognize this issue in the future, we would add bypass capacitors across our front-end. This would limit the noise in our front-end, allowing for less noise appearing on our touch screen. As a result, we added bypass capacitors across the power supply pins to ground to reduce the noise.

4.0 Recommendations

After several quarters spent working on the BoosterPack, we were unable to incorporate a working oscilloscope onto a final PCB prototype. We also were unable to reach MHz on our oscilloscope. Moving forward, we would recommend designing a functional PCB that can measure and display signals on its touch screen in the range of 20 MHz. Durable, small size, and functional features would be satisfied features from our stakeholder model if the PCB was designed properly. With a PCB, it is more durable than the breakout boards wired together by numerous wires and cables. A PCB is also smaller in size than the intertwining wires used for the breakout boards. Furthermore, a PCB would be entirely functional when compared to the breakout boards. The breakout boards are prone to noise and interference from other electrical equipment, but the PCB provides a reliable and functional board. From our design, the PCB prototype encountered additional noise from the analog front-end. To complete our project, the next steps needed would require the design and testing of a PCB for the BoosterPack and eliminate the noise accumulated onto the display screen.

5.0 Going Further Material

This section provides analyses on various material that was considered during the project or that was considered after the completion of the project. The following sections are Standards, Manufacturability and Safety, System Failure Mode, Societal Impact, Economic Impact, and Environmental Impact.

5.1 Standards

For our design, we encountered several standards as we used Texas Instrument components. To connect our BoosterPack to a TI LaunchPad, we used the model LaunchPad TM4C1294XL Rev. C, which also had a standard USB connection of a micro USB. Additionally, to display our waveform signals on a touch screen, we used the touch screen model EB-LM4F120-L35.

For the components used in our front-end analog, there are standards for the storage temperatures for each part. The ADC, ADS4222, and the Digital Variable Gain Amplifier (DVGA), LMH6881, require the storage temperature to be -65°C to +150°C. The switchable attenuator, OPA4872, requires the storage temperature to be -65°C to +125°C. These components also have standards for their respective ESD protection limits for human body model, or commonly known as human use. For example, the ADS4222 specifies 2 kV maximum for the ESD rating, the LMH6881 specifies 1 kV maximum, and the OPA4872 specifies 1.3 kV maximum. In comparison, the negative voltage converter used in our analog front-end has a maximum output of 2.0 Amps. These standards resemble only some of the standards and specifications found in their respective datasheets on TI's website, which is www.ti.com [11].

5.2 Manufacturability/Safety

In terms of manufacturability, we strictly used TI's components in our design. As a result, our choice to use only TI parts makes our project's design very appealing to our client, who is an employee from TI. If our client wishes to reproduce our project in the future, then it will be feasible as the components are already made available to our client. The only part we used that was not under TI's name was the touch screen. This screen was found online, and we decided to use it as a BoosterPack attachment to our own Oscilloscope BoosterPack. Touch screen BoosterPacks were not available from TI; thus, we were able to use models found elsewhere.

For our project in terms of safety, the front-end analog components heat-up very quickly upon turning the power on. These components could cause burns to a user's hand if the front-end analog parts are handled during operation. To accommodate this safety issue for the future, we could create a protective case for the entire BoosterPack in order to shield the user from potentially burning their hands.

5.3 System Failure Mode Analysis

As we have progressed through our design for the Oscilloscope BoosterPack, we have been able to identify various failure modes that could cause system failure, either soon or immediately. First, when testing our front-end analog design with the breakout boards, we found some pins on our boards that were shorted together when they should not have been together. For example, the negative power and ground pins on one of our initial breakout boards for the DVGA were found shorted together, thus current-limiting our DVGA during operation and causing the system design to fail. This occurred from the first time we tested the board until we noticed the shorted pins, and it resulted in a non-functional board. To find this error, we noticed that the DC power supply was current-limiting our board when attempting to provide +5Volts to the board. By using the continuity test on a DMM, we observed that the negative power and ground pins were shorted together by solder that we were unable to remove successfully. We then had to replace the board entirely with a new component and new breakout board.

Second, for user error, we accidentally would connect negative and positive power backwards on the breakout boards, causing our system design to fail. This error would cause the breakout boards to produce clipped waveforms or small waveforms in terms of amplitude. With this error, we risked damaging the breakout boards' operations. If we would leave the power supplies connected backwards for several minutes, then our boards would be damaged permanently. To detect the error in our boards' operations, we would see if the output waveforms were properly attenuated or had proper gain due to our digital inputs from the touch screen. If we did not see the expected signals, then we would double-check our breakout boards' connections. Once we found the user error and connected the power supplies correctly, our system would be fixed.

5.4 Societal Impact

Our project can have a societal impact on the future of oscilloscopes. Oscilloscopes, in general, are expensive for universities and companies to purchase and use. It is possible that this design could be used by TI to develop enough oscilloscopes to sell at a reduced price compared to other available oscilloscopes. Additionally, universities could use our project design to save money and provide learning tools for its students. This impact will not be immediate, but it could develop more with additional testing in the near future.

5.5 Economic Impact

Similar to our project's societal impact, our Oscilloscope BoosterPack could have an economic impact in the future. Our design utilizes a cheaper layout that could potentially save money when compared to other brand name oscilloscopes available on the market. Stakeholders, such as TI and universities, would be interested in our design because it could save them money to purchase our design project. TI could build and develop this oscilloscope design on a large scale and sell them at a reduced price. Thus, universities could save money and purchase these oscilloscopes for learning purposes.

5.6 Environmental Impact

For our project design, it could subsequently impact the environment during its life cycle. In our analog front-end, we incorporated a PCB to maintain a functional, reliable design. PCB's can affect the environment due to their need to be recycled [9]. In general, the boards use a copper-clad material with phenolic plastic. If the boards are neglected and not recycled, they will not be able to decompose quickly in the environment; subsequently, they need to be processed correctly at the end of their life cycle. Upon recycling the boards after their use, a spray water should be used to limit the odor and dust in the air from spreading when the boards are properly crushed and destroyed. It is imperative to recycle PCB's and our oscilloscope design in order to limit the amount of pollution in our environment for the future.

6.0 Bibliography

[1] Thomas Tasch. ADC Digital Control. December 4, 2014. "Research Memo" section of binder.
The purpose of this research memo is to determine the best way for the LaunchPad microcontroller to control the DVGA located in the analog front end.

[2] Zachary Zdrojewski. Research Memo on Analog ADC Drivers. October 24, 2014. "Research Memo" section of binder.
This memo was created to understand the operation and purpose of an ADC driver.

[3] Thomas Tasch. ADC Selection. October 19, 2014. "Research Memo" section of binder.
This memo shows the specifications for various Analog to Digital Converters (ADC) and the decision matrix used to determine which ADC was best for our project.

[4] Thomas Tasch. Data Acquisition. October 14, 2014. "Research Memo" section of binder.
The purpose of this research memo is to determine the best way for the LaunchPad microcontroller to retrieve the digital data from the Analog-to-Digital Converter (ADC) and how to store this data into the microcontroller.

[5] Zachary Zdrojewski. Research Memo on Oscilloscope Front-End Analog. October 15, 2014. "Research Memo" section of binder.
This memo was created to gather more information on the individual components for our oscilloscope front-end design.

[6] Abel Woldemeskel. Oscilloscope Analog Front End design Independent Study Summary. October 13, 2014. "Research Memo" section of binder.
This memo gives an overview of the working principle for our oscilloscope.

[7] Zachary Zdrojewski. Packaging Research Memo. November 10, 2014. "Research Memo" section of binder.
This research memo was made to find various design methods for the packaging of our completed BoosterPack.

[8] Ruoyu Zhuang. Touch Screen Memo. October 14, 2014. "Research Memo" section of binder.
This memo describes how the touch screen will be implemented on the BoosterPack to make our oscilloscope a user friendly device.

[9] Link.springer.com, ‘Printed Circuit Board Recycling Process and Its Environmental Impact Assessment’, October 2007, Volume 34, Issue 9-10, 1030-1036. [Online]. Available: http://link.springer.com/article/10.1007%2Fs00170-006-0656-6.

This article gave insight on the general risks found by the end of a PCB’s life cycle.

[10] Ti.com, 2015. [Online]. Available: http://www.ti.com.

This website provided all datasheets for our analog components, helping us implement our analog design for the project.

Processors.wiki.ti.com, 'Creating IoT Solutions with the TM4C1294XL Connected LaunchPad Workshop - Texas Instruments Wiki', 2015. [Online]. Available: http://processors.wiki.ti.com/index.php/Creating_IoT_Solutions_with_the_TM4C1294XL_Connected_LaunchPad_Workshop.

This is a workshop from TI that teaches users how to become familiar with the TM4C1294XL LaunchPad and Code Composer Studio.

TivaWare™ Peripheral Driver Library User's Guide, 1st ed. Austin, TX: Texas Instruments, 2014, pp. 201-232,253-289,585-608.[Online]. Available: http://www.ti.com/lit/ug/spmu298a/spmu298a.pdf

This document provides detailed explanations of all the functions available from the driver library designed to help with TivaWare peripherals.