EE 344: Electronic Design Lab

Project Report

Digital Oscilloscope

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Abstract

The aim of the project was to build a battery operated signal acquisition module which along with a PC can serve as a digital oscilloscope.

Wireless communication between the microcontroller and the PC is established using a Bluetooth module. Wireless communication isolates the PC from the signal voltage levels.

A GUI is developed for viewing the acquired signals, with controls for time scaling, voltage scaling, time shifting, voltage shifting as well as playing and pausing (RUN/STOP). Measurement tools for mean, max, min, peak-to-peak voltage and frequency have been provided.

It is usable for low frequency applications (upto 10 kHz) that can measure differential inputs and isolate various subsystems using wireless communication.

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1 Introduction

1.1 Background and Motivation

Oscilloscope is one of the most important tools in electrical engineers' toolbox, helping them analyze, debug and understand complex circuits by viewing voltage waveforms against time axis in a calibrated scale. A digital oscilloscope provides the facility for observing transient waveforms and has tools for measurement.

DSOs available in the market are expensive. Screens of the DSOs are the primary reason for their cost. Development of a signal acquisition module interfaced to a PC can result in a low-cost DSO.

The DSOs only provide the facility for acquiring single ended signals and are therefore not usable for differential inputs with large common mode. Developing a signal acquisition module with differential inputs can be used to realize a DSO with large common mode inputs. Such a DSO can be useful for applications with large common mode voltages. Bluetooth communication between the PC and DSO module can be used to provide electrical isolation.

The project serves as a proof of concept for DSO module. The signal bandwidth is limited to low frequency signals up to 10 kHz. This helped in completing the prototype by using a microcontroller with on-chip ADC and bread-boarding the circuit and later assembling it on a 2-layer PCB. The design can be later extended to larger bandwidth by using 4-layer PCB, amplifiers with larger bandwidth and high speed ADC.

1.2 Project Goals

As described in the section above, our major goals were

1. Providing differential voltage measurement in the DSO.
2. Providing GUI to the user on PC to provide DSO functionalities.
3. Establishing wireless communication between the PC and the micro-controller of the signal acquisition module.

1.3 Technical Specifications

1.3.1 Input Specifications

Single channel differential input with input impedance of 1 MΩ for both inputs.

Voltage Range	**Common Mode Voltage Setting**	**Gain**
-10 V to 10 V	C0	0.015
-1 V to 1 V	C1	0.15
-0.1V to 0.1V	C2	1.5

Differential Mode Voltage Setting	**Gain**
D0	4.33
D1	2.1
D2	1

Minimum differential mode peak-to-peak voltages at different common modes voltages[1] (assuming 20% tolerance to the noise getting added to the square wave signal)

$\mathbf{V}_{cm}$	$\mathbf{V}_{pp}(min)$
0 V	20 mV_{pp}
0.1 V	20 mV_{pp}
1 V	250 mV_{pp}
5 V	2.5 V_{pp}

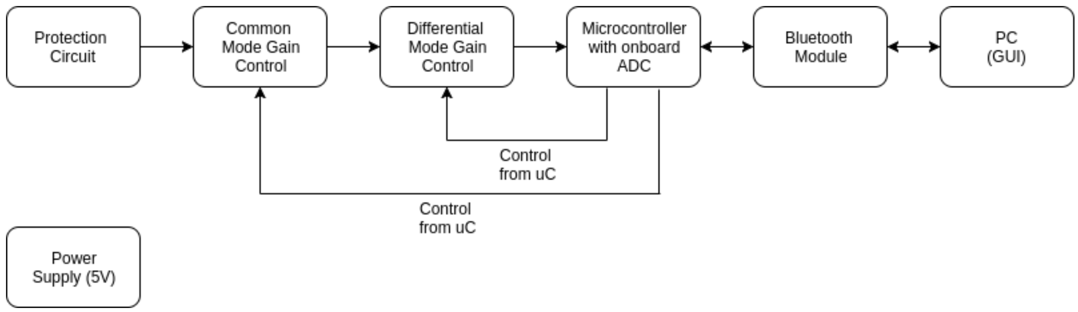
1.3.2 GUI Specifications

Time Scaling	200 μs to 5 s
Voltage Scaling	1 mV to 5 V
Trigger	Auto, Normal (+ve and -ve slope)
Automated Measurement Tools	Max, Min, Average, Frequency, Peak to Peak Voltage

[1] V_{cm} = 10 V and V_{pp}(min) lesser than 20 mV_{pp} could not be tested because of inability of AFG in WEL to provide the necessary waveforms

2 Project Design

2.1 Block Diagram



2.2 Subsystem Design

- **Power Supply** - The DSO module works on a 5 V supply. It can be provided using a power bank, a laptop or any other 5 V source. Power banks are usually capable of providing currents up to 2 A.

- **Protection Circuit** - To protect the module from high input voltages, a protection circuit has been designed using diodes.

- **Common Mode Gain Control** - The common mode voltage of the inputs can vary between 0 to 10V. We provide common modes of voltage range of 100 mV, 1 V and 10 V with gain of 1.5, 0.15 and 0.015 respectively. Having a single gain (or attenuation) for all voltages degrades the signal with smaller amplitudes.

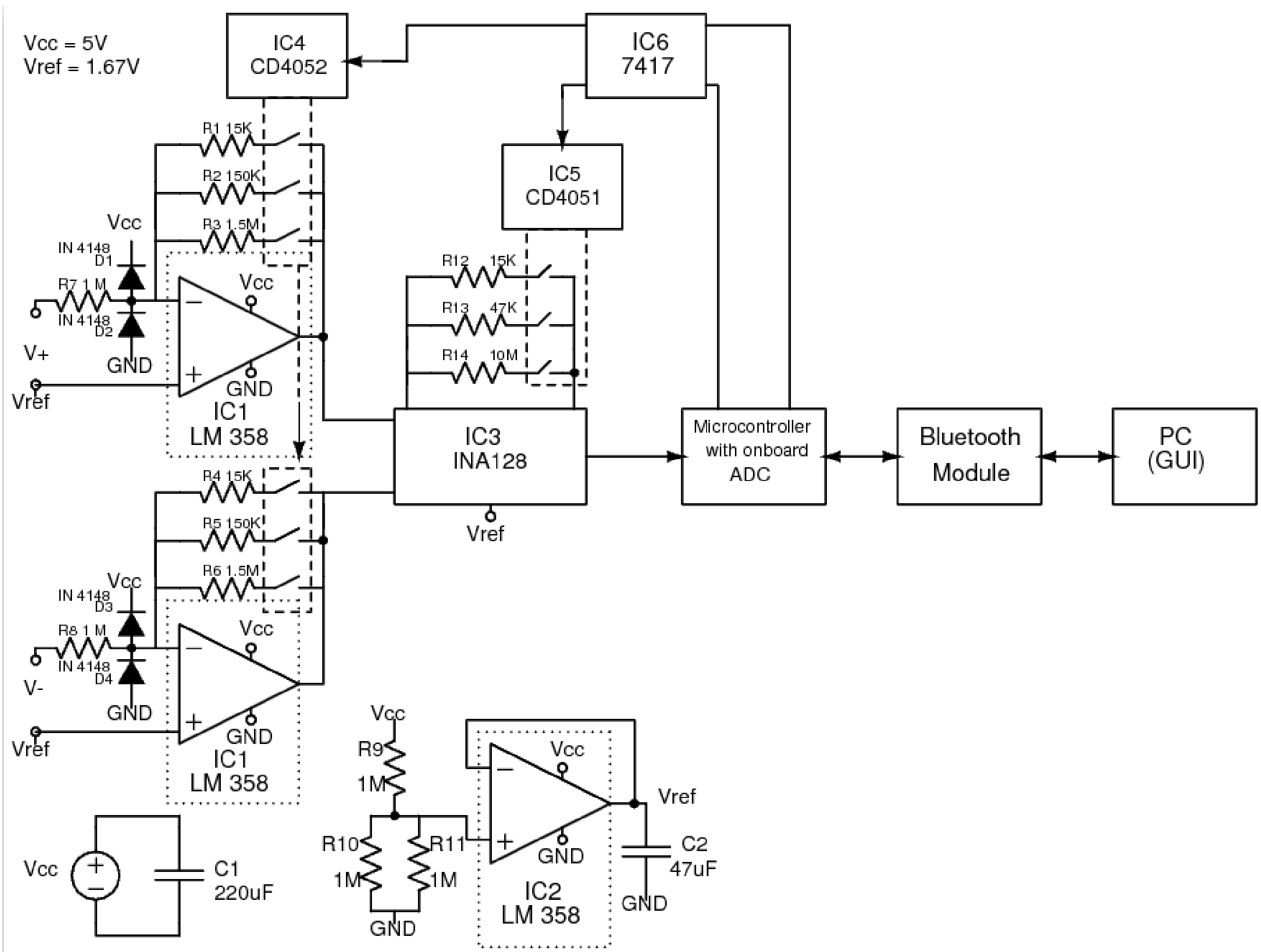
- **Differential Mode Gain Control** - The differential mode voltage of the inputs can also vary. We provide different gains viz. 4.33, 2.1 and 1 for different differential mode voltages. Having higher gains for signals that have higher attenuations in common mode control stage, improves the differential signal output.

- **Microcontroller** - For prototyping purposes, the on board ADC of Tiva TM4C123G microcontroller is used. The ADC is used here to sample at rates up to 0.1 MSPS. The samples are sent to the PC via bluetooth module. This isolates the analog front-end from the PC. Bluetooth communication happens at a rate of 115200 bits/s.

- **Graphical User Interface** - The GUI displays the differential of the inputs. GUI provides information about the signal like max, min, average, frequency and peak-to-peak voltage. It also provides the user to control the common mode and differential mode gains to improve the waveform displayed. Following controls are provided in the GUI:
  - Time per division control
  - Voltage per division control
  - Play and Pause control
  - Channel On and Off control
  - Trigger level control
  - Trigger slope options
  - Simple auto-trigger control
  - Common mode controls
  - Differential mode controls
  - Averaged waveform option

3 Project Implementation

3.1 Circuit Diagram



3.2 List of Components Used

Following components were used in making of our project:

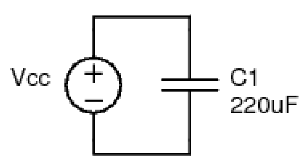
- Tiva TM4C123G Microcontroller
- Bluetooth Module HC-05
- LM 358 Low-Power, Dual-Operational Amplifiers
- CD 4051/4052 CMOS Analog Multiplexer/Demultiplexer With Logic-Level Conversion
- INA128 Differential Input Instrumentation Amplifier
- SN7417 Hex Buffers and Drivers With Open-Collector High-Voltage Outputs

All components were provided by Wadhwani Electronics Laboratory, Electrical Engineering Department, IIT Bombay.

3.3 Battery

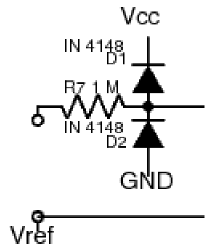
We use 5V power bank to provide 5 V supply to various sub-systems of our design. The circuit draws around 150 mA of current. The power bank has a current rating of 2 A. If using other supplies, care must be taken about the current specifications.

A decoupling capacitor of value 220 μF is connected in parallel to the supply and on the PCB, supply voltage traces were of 32 mils to reduce the noise in the signal.



3.4 Protection Circuit

The protection circuit is implemented using IN4148 diodes. The peak forward repetitive current specification of IN4148 is 500 mA. Therefore, the circuit is protected for voltages up to 0.5 A $\times$ input resistance (1 MΩ) which is 0.5 MV.

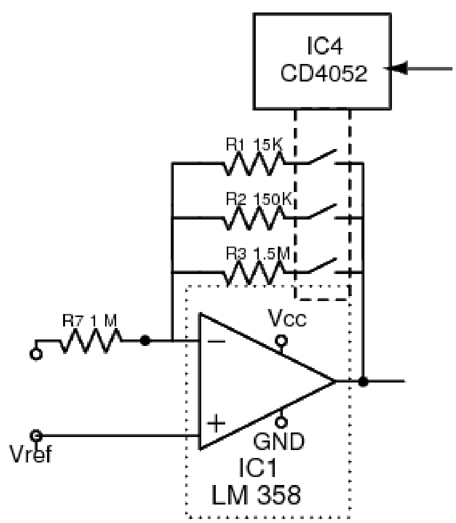


3.5 Common Mode Gain Control

Common mode gain control is implemented using two inverting operational amplifiers. The gain is controlled according to the mode set by the user on GUI. The mode specifies the range of the common mode input voltage.

Gain (or attenuation) is adjusted such that the output voltage of the op-amps will be nearly equal to permissible input voltage values for the instrumentation amplifier. This will ensure high SNR of the differential output.

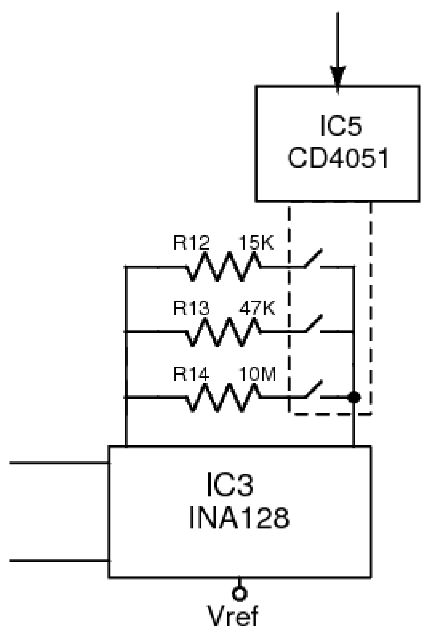
We used LM358 operational amplifiers. The variable resistance of the op-amps is controlled digitally by switching modes of analog multiplexer CD4052, according to the user-specified voltage range. CD4052s minimum high input voltage is 3.5V which is supplied by 7417 buffer connected to the microcontroller. We perform ganged operation of changing gains for both the inputs simultaneously using CD4052.



3.6 Differential Mode Gain Control

Differential mode gain control is implemented using INA128 instrumentation amplifier. The gain is controlled by varying R_g of the amplifier. Gain equation is $G = 1 + 50\ k\Omega/R_G$.

The variable resistance is controlled digitally by switching modes of analog multiplexer CD4051, according to user specified voltage range for the differential input.



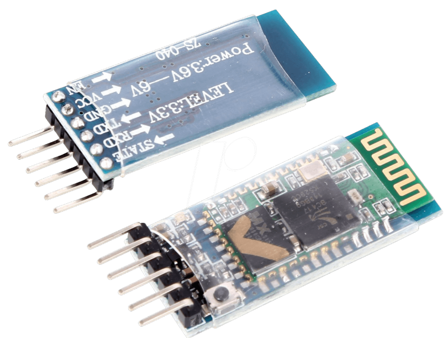
3.7 Microcontroller

The microcontroller is receiving input from the on-board ADC. It is communicating with the PC via the Bluetooth module. We don't do any signal processing in the controller. All the samples are sent to the PC for processing. We used TIVA-TM4C123G microcontroller operating at frequency of 80MHz. Microcontroller is programmed to respond to 'instructions' from the PC, for example, 's' means that micro-controller should sample 400 times and send samples to PC, 'd2' means differential mode should be set to 2, 'f1000' means sampling frequency should be set to 1000 and so on. Sampling routine implemented is (current implementation using $n = 400$):

Consecutive Sampling

```
initialize variables
when timer overflows:
  sample 'n' samples
  send 'n' samples via Bluetooth
```

3.8 Bluetooth Module



Bluetooth module HC-05 is used to transmit data wirelessly, sampled by the micro-controller, to PC. The baud rate we've used is 115200 bit/s. The sampled values are converted to string and ended with end-line character. This strings when received by PC, are separated by the end-line character and converted back into integers for further processing.

3.9 Graphical User Interface

GUI has two windows viz. panel and display. Panel (as shown in figure 1) contains all the controls which are explained below. Display (as shown in figure 2) is the window where waveform is observed. Record length used is 400 out of which 200 samples are displayed on screen.
GUI has following buttons and sliders:

- *Auto-connect*: automatically searches for a COM ports and connects to the first one available.
- *Find Available COM Ports*: finds all the available COM ports and adds them to drop-down menu above it.
- *Connect*: connects to the available COM port selected in drop-down menu to the left of it.

- *Run/Stop*: run and stop the display respectively. (Internally it stops sending the instruction for sampling.)
- *Disconnect*: disconnect from the COM port being used.(To be used only after stopping the sampling using 'Stop' button.)
- *Common and Differential Modes*: to select the common and differential mode.
- *Time Scale*: Adjust the time per division for the display. (Internally, it changes the sampling rate.)
- *Voltage Scale*: Adjust the voltage per division of display.
- *Trigger Point*: Adjust the trigger point on display.
- *Time shift*: Move the waveform left and right on display to observe out-of-screen region.
- *Average/Max/Min/Pk-Pk*: Average, maximum, minimum and peak-to-peak voltage from waveform. These include the complete record length and not just what is displayed.
- *Frequency*: Displays the frequency of the waveform. It internally uses the trigger point and trigger type mentioned and counts the number of crossings to calculate frequency.
- *Auto Trigger*: Triggers the currently displayed waveform. It uses the mentioned trigger type and brings the trigger level to average of the waveform.
- *Positive/Negative Slope*: Select the type of trigger to use.
- *Average 1/2/4/8/16/32/64*: How many samples to take in while averaging the waveform. 1 means there is no averaging.
- *White sub-panel*: The white sub-panel at the bottom of panel shows a log of activities in bluetooth connection.

Display has a black background, 5 vertical and 5 horizontal divisions in thin white lines. On the left bottom side, it shows the voltage per division. And to the left of it, is the time per division. Waveform appears in green coloured line, trigger level in red-coloured line. The time and voltage zero-levels are displayed in thick white lines.

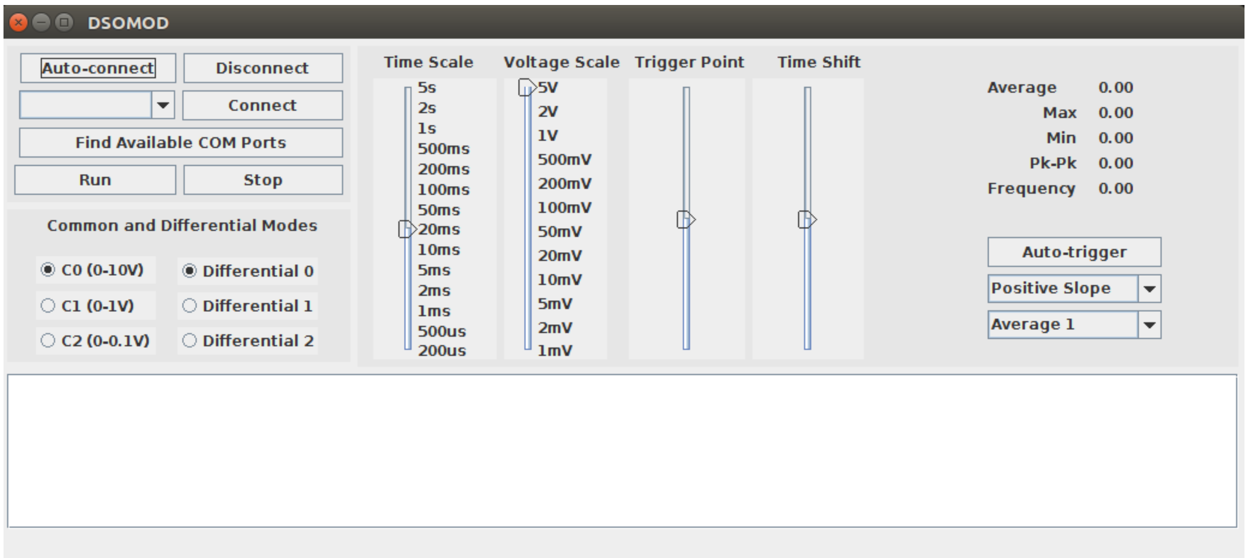


Figure 1: GUI Panel

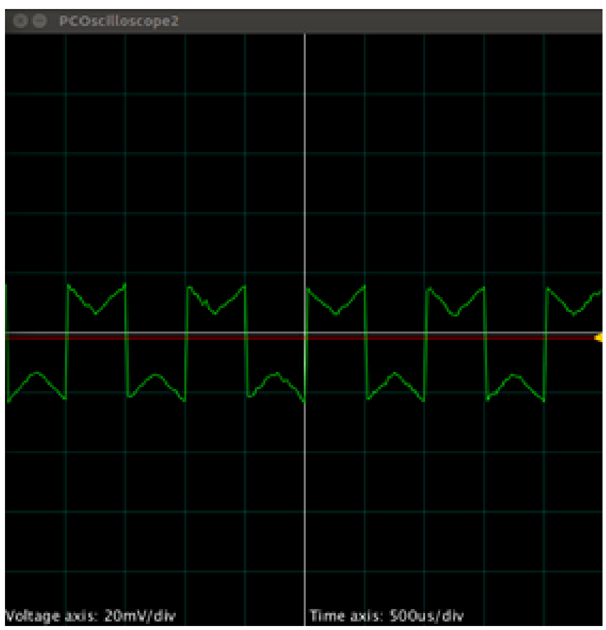


Figure 2: GUI Display

4 Performance Evaluation

Testing conditions :

1. Signals $V_{cm} + V_{ac}$ and V_{cm} are applied to our module.

2. V_{ac} is a square wave with peak-to-peak voltage V_{pp} and frequency 500 Hz.

Reported Quantities:

1. Minimum V_{pp}[2] : The minimum peak-to-peak voltage such that the noise is not more than 20% of applied V_{pp}.

2. Maximum V_{pp}[3] : The maximum peak-to-peak voltage such that the module still operates in linear region.

We can measure a difference signal of 20 mV_{pp} (and posibly lower voltages) reliably when V_{cm} = 0 V and measure a difference signal of 2.5 V_{pp} reliably when V_{cm} = 5 V. The performance of the module is good at low common mode voltages but is not as good at higher common mode voltages.

The detailed performance under differet test conditions is provided in the following subsections.

4.1 Test with $V_{cm} = 0$ V

Common Mode Gain	Differential Mode Gain	Maximum V_{pp}	Minimum V_{pp}
0.015	4.33	20 (+)	2.2
0.015	2.1	20 (+)	6
0.015	1	20 (+)	10
0.15	4.33	2.5	0.3
0.15	2.1	4.3	0.75
0.15	1	6.6	1
1.5	4.33	0.250	0.020 (-)
1.5	2.1	0.430	0.050
1.5	1	0.650	0.100

[2] The V(-)in the table indicates that the testing function generator could only supply V and V_{pp} is possibly lower than V

[3] The V(+)in the table indicates that the testing function generator could only supply V and the Maximum V_{pp} is possibly greater than V

4.2 Test with $V_{cm} = 0.1$ V

Common Mode Gain	Differential Mode Gain	Maximum V_{pp}	Minimum V_{pp}
0.015	4.33	20 (+)	2.5
0.015	2.1	20 (+)	5
0.015	1	20 (+)	9
0.15	4.33	2.3	0.3
0.15	2.1	4.2	0.6
0.15	1	6.4	0.9
1.5	4.33	0.080	0.020 (-)
1.5	2.1	0.250	0.060
1.5	1	0.450	0.100

4.3 Test with $V_{cm} = 1$ V

Common Mode Gain	Differential Mode Gain	Maximum V_{pp}	Minimum V_{pp}
0.015	4.33	18 (+)	2.2
0.015	2.1	18 (+)	5
0.015	1	18 (+)	10
0.15	4.33	1.7	0.25
0.15	2.1	3	0.5
0.15	1	4.6	0.85
1.5	4.33	saturation	saturation
1.5	2.1	saturation	saturation
1.5	1	saturation	saturation

4.4 Test with $V_{cm} = 5$ V

Common Mode Gain	Differential Mode Gain	Maximum V_{pp}	Minimum V_{pp}
0.015	4.33	10 (+)	2.5
0.015	2.1	10 (+)	5
0.015	1	10 (+)	10
0.15	4.33	saturation	saturation
0.15	2.1	saturation	saturation
0.15	1	saturation	saturation
1.5	4.33	saturation	saturation
1.5	2.1	saturation	saturation
1.5	1	saturation	saturation

5 Conclusion

5.1 Summary

We were able to build a proof of concept for a DSO module that achieved the following objectives:

- Capable of measuring differential signals for frequencies up to 10 kHz
- Has a GUI for displaying waveforms and controlling the output that can be used on Ubuntu operating system.
- Has Bluetooth communication between the personal computer and the analog front-end.

5.2 Suggestions for Further Work

- The performance of the module (minimization of amplitude of differential signal that can be measured at higher common mode voltages) could be improved by using rail to rail operational amplifiers and rail to rail instrumentation amplifiers.
- Having an ADC which can measure voltages between 0 to 5 V instead of 0 to 3.3 V and can operate at higher frequencies will also improve the performance and the frequencies that can be measured.
- Equivalent sampling can also be implemented to measure signals of higher frequencies. More channels could be added to the module using multiple ADCs.