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# Low Cost Electronic Measurement Device

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**Author Note:** The team consists of one CoE (Eric Rice), two EE's (Mandell Ross, Evan Spector) and one ISE (Gregg Martin). Professor Scott Craver and Professor Lindon Falconer have helped the team throughout the entire school year and deserve acknowledgement for making this project possible. The author of the essay can be reached by the email provided above or by phone at (914) 525-1140.

**Abstract:** Many high school students do not have access to tools that can help enhance their learning. Tools used to analyze signals such as oscilloscopes and spectrum analyzers are included as they are not very practical and many schools cannot afford them. Working with students from the University of West Indies, we have developed a device that is able to process signals and display the functions of the devices on an Android device. The device is able to convert audio signals to be processed and transmitted over Bluetooth, which displays the functions of the oscilloscope and spectrum analyzer on the Android device. Two sets of code are used with the Raspberry Pi and the Android device for the design to meet all of the listed requirements. With the device, teachers and students will be able to access an oscilloscope and spectrum analyzer with the measurement device and an Android product.

*Keywords:* Low Cost Measurement, Bluetooth Capabilities, Android device

## 1. Introduction

### 1.1 Initial Scope

The University of the West Indies at Mona would like to offer a low-cost solution for students learning about basic analog signals. This project will result in students being able to view signals via oscilloscope or spectrum analyzer on their personal Android phones. By connecting to the electronic measurement device's (EMD) BNC input, a Bluetooth connection will transfer signal data to the cell phone to be processed and displayed.

### 1.2 Problem Scope

The project entails designing hardware capable of processing signals for display by way of oscilloscope and spectrum analyzer on the Android operating system. The purpose is to provide a cost-efficient method to provide the functions these devices perform without the use of the bulky, expensive equipment.

### 1.3 Technical Review

The field in focus is mostly the educational environment in which oscilloscopes and spectrum analyzers are needed for demonstration in certain technical classes. However, these devices are very expensive and many inner city schools for example cannot afford to provide their students access to these devices. Schools across the world suffer from the lack of funding to provide students with tools to develop the conceptual foundation needed to understand complex subject areas. In 2012, it was recorded that 70% of teachers who worked in poorer area said that lack of funding was the largest issue in providing students the proper education. Also, 91% of teachers reported that they had access to personal technology such as computers but 78% said that they did not have the right level of technology (Barseghian, 2012). This technology has helped increase student motivation and helped account for a larger variety of learning styles.

Along with the lack of funding found in many schools, availability of technology in the classroom has not been able to meet the demand for it. With the integration of "blended learning" in which technology is used in sync with traditional teaching and 1-to-1 computing in which schools have been attempting to provide students with their own personal computers or tablets for learning. With the demand and the technology needed available, digital materials and applications have lagged as print still accounts for over 70% of the learning material used in the United States (Herold, 2016).

The Android application being developed will be able to provide the uses of an oscilloscope and spectrum analyzer. An oscilloscope is a tool that is used to view signal voltages usually plotted two-dimensionally across a period of time. This instrument can be very useful in high school physics classes for example as it allows students to conceptually understand concepts such as waves. The application will also allow for the function of a spectrum analyzer which measures the magnitude of a signal (y-axis) versus frequency (x-axis). The analyzer has similar uses as the oscilloscope and serves educational purposes to students within schools that can afford these instruments.

Currently, in order to provide these instruments to students, schools purchase the physical devices which each can costs a couple hundred dollars. With the constant development in technology, many physical books have been cut out and replaced with open-source pdf files for example. The Android application will serve this exact purpose. It will allow students to have access to these devices on their own technology whether it is their own personal phone or tablet or one provided by the school while saving schools and students money in the process.

## 1.4 Requirements

The goal of this project is to produce a portable oscilloscope and spectrum analyzer that can be utilized in an educational setting. This being the case, the system will be utilized more for demonstration purposes and therefore will not need to utilize bandwidths over 100 kHz {WCP30-001}. For the typical commercial oscilloscope, selection of the maximum frequency is based on the fact that these systems are capable of effectively measuring one fifth of the maximum frequency. That being said the system will be able to measure up to 20 kHz without signal distortion.

For the structure of the device, it shall be one channel and utilize a BNC connector {WCP30-002}. BNC connectors are utilized in situations where users want to make sure that a system receives as clear a signal as possible. The connectors are insulated thus protecting the coaxial cable and allowing clear signals to be picked up. Notably, since this is a device that is to be used for educational purposes, making this a one channel device will keep costs down and help maintain the portability of the system.

For the sake of accuracy, this system shall have a 10 or 16 bit resolution {WCP30-003}. Higher resolution lends itself to allow the system to better pick up small changes in the signal. For a system with 10 bit resolution, the voltage of the signal is split up into 1024 steps (and 65536 steps for the 16 bit). This allows for a more accurate and clear signal to be displayed on the android device as opposed to an 8 bit or less solution.

In order to maintain safe operation and to promote the durability of the electrical system, the device shall have a +/- 100V overprotection circuit {WCP30-004}. In the design, overprotection shall protect the analog to digital converter as well as any other electrical components from both voltage transients, and user input errors up to +/- 100V. In the grand scheme of the project, this will assist in extending the lifespan of the device for usage in schools.

The Spectrum Analyser component of the system shall operate with a 50 kHz maximum frequency {WCP30-005}. This frequency range is an adequate amount for students to observe and learn about the frequency response of signals. This range also keeps the cost of the system down because the signal will require much less filtering than its higher frequency counterparts.

The analyser shall have an autoscale function {WCP30-006}, which will allow users to see only the most relevant information. The autoscale functions on oscilloscopes are typically implemented utilizing trigger circuitry. This component will ensure that the image displayed on the Android device will be an accurate representation of the signal.

The analyser shall have an adjustable manual scale {WCP30-007} that will allow users to both attenuate, and adjust the display frequency on the android device. This feature, which will also utilize triggering, will assist students in understanding the form, function, and the components of the measured signals.

An important component that will add to the portability, and simplicity of usage for students will be that the EMD shall connect to an Android device via bluetooth {WCP30-008}. With the prevalence of cellular devices in the world today, this would provide a low cost solution that would make oscilloscope and spectrum analyzer functionality accessible to students.

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# 2. Design

## 2.1 Overview

The system is designed so that users can measure a given signal by way of BNC connector and display the signal via android device (Figure 1). At its core, the system allows the user to view both the signal itself and the signal's frequency response. This functionality allows users for example, to view and understand the performance of different circuits and their components. In terms of design flow, the input signal to be measured is attenuated and scaled down to a level that can be safely utilized by the analog to digital converter. After the signal is scaled down, it passes through an overprotection circuit which protects the ADC from any input or transient voltages that could potentially damage the device. From this point the signal is processed and sent to an Android device via Raspberry Pi bluetooth where it will be displayed on the designed application.

In order to power the module, the device will make use of the standard 120V wall power; potentially coupled with a battery pack (Figure 2). This will help maintain the portable nature of the device, and allow students to utilize multiple devices at once. In order to make this possible, another converter will be utilized to scale down the voltage to a safe level for the device.

### 2.1.1 Hardware Design

The hardware of this project will be centered around the use of a Raspberry Pi Zero W ("Adafruit MCP3008," 2008) development board and an Adafruit MCP3008 ADC ("BCM2835 ARM Peripherals," 2012). This particular variant of Raspberry Pi boards was chosen due to the low cost, built in Bluetooth capability (WCP-008), and relatively high processing speed. The use of a Raspberry Pi necessitated an external ADC, which led to the choice of the MCP3008 due to its low cost while meeting the designated bandwidth requirements. These parts will be connected utilizing the hardware SPI functionality that the two devices share. This connection methodology enables a slightly faster read time since there are fewer driver emulations between the two as opposed to emulating SPI with software or reading from the built in GPIO pins. The channel pin(s) of the ADC is/are connected to the positive terminal of a BNC connector, with the negative terminal tied to the Raspberry Pi ground.

On the input side of the device, in order to keep the input at a safe measurable range for the ADC, the signal is attenuated and is passed through an overvoltage protection circuit. This is done because the absolute maximum input voltage range for the channels is -0.6V to 7.6V. In order to protect the circuit we will remain at 5V and below, which in order to do so we must attenuate an input voltage of +100V by at least 26 decibels.

In the case of the overprotection circuitry, there are two methods under consideration. Beyond the device in Figure 4, there is the potential to utilize Schottky diodes in order to clamp a surge in voltage. This is because schottky diodes are known for having a low voltage drop across the devices therefore helping to maintain the quality of the signal. In this particular configuration they are used to clamp the input voltage into the ADC if the voltage exceeds the set threshold for the device; thus protecting the ADC from damage due to excess voltages from transients or user errors.

Once the input has been scaled, if there are signal frequencies higher than the specified requirement (WCP30-005) they must be filtered out. This will be implemented as a lowpass filter. A filter with cutoff frequency as specified by the requirement may be implemented in one of two main ways. The second way is discussed in Section 2.1.2. The first filter application is with analog circuit components as a two-pole op-amp circuit shown in. Simple changes to resistor and capacitor values allow the team to specify frequency values with equation 1 in Section 4. Depending on frequency response characteristics observed during testing, the circuit can be varied to account for gain and rolloff. To increase the accuracy of the filter, two of these circuits may be connected in series for a four-pole lowpass.

### 2.1.2 Software Design

A different approach to the implementation of a filter can be done in software. Once the raw signal data values have passed through the ADC and been transmitted via Bluetooth to the Android device, the signal exists in discrete time. Because of this, the Android app is able to have a digitally implemented low-pass filter. The benefit of this design is that its number of poles and zeros is limited only by the computing ability of the Android, meaning we can quantify and choose how closely it performs to ideal behavior. However, a very large downside is that a digital filter may not prevent aliasing caused by higher frequencies.

For this project, we will be creating two sets of software. One for the Raspberry Pi and one for the Android device. The Raspberry Pi code will be written in C to make use of the compiled nature of C code so that there is less overhead required by the system. The C code will make use of the Broadcom BCM2835 library and the Bluez Bluetooth library. The former will allow the code to interface with the hardware SPI defined previously. The latter allows for C control of the built in bluetooth hardware. The C code set will be run automatically on the Raspberry Pi so that there is no need to for the user to interface directly with the Raspberry Pi. The program will consist of a method of acquiring data from the ADC and a way to package and send the data over Bluetooth. A packet size will be determined based upon results of further testing of the graph update speed on the Android application. These two programs will be run as separate threads in a main constant loop, enabling the data to reach the Bluetooth device at a different rate than the ADC. This should allow for a maximized data capture rate as the data capture loop will not need to make space in the runtime to send the data to the Android device.

The Android code set will comprise of the standard set of Android application code, which means a collection of Java, XML, and others. The primary development will be completed in Java and XML as those two comprise the main parts of an Android application. The Android application will have the ability for the user to switch between a graphical oscilloscope view and a spectrum analyser view. The spectrum analyser will require more data processing before the graphical output can be displayed, as we need to run Fourier Transforms on the waveforms. The general composition of the program will consist of a method of acquiring a Bluetooth connection, one of dealing with data transfer, one to manage the graph display and some functions to manipulate the data.

Both systems operate around the Bluetooth connection . In the Raspberry Pi system, the ADC functionality isn't started until the Bluetooth connection is established. In the Android application, the app is inactive until the connection is established, which then enables the flow of data to the data processor and graph.

### 2.2 Use

The device is intended to assist in educating students on the properties, and uses of different circuits. It is also designed to make oscilloscope/spectrum analyzer technology accessible to students. In order to utilize the design, students must first download the application on their android device and sync the testing module to said device. At this point the user is able to use a test probe that is coupled with the module via BNC connection, to connect to any point in their circuit that they wish to view the signal. Once connected, the signal will be sent by way of bluetooth to the android device, where the signal will be auto-scaled so that students can view it. Once the signal is displayed, users will have the option of manually scaling the signal so that they can better understand its components.

## 3. Evaluation

### 3.1 Overview

The team has plans to test the device to ensure that each of the design requirements are met. Currently the team has a plan of seven tests (T001 – T007) which include testing for sampling speed, frequency analysis and functionality of the Android application. All of these tests have been planned to meet each of the requirements listed in the initial project proposal. Along with the technical requirements, the team was also able to keep the cost of the electronic device at a minimum. Overall, only an eigth of the $400 dollar budget was used allowing our device to be developed for purchase cheaply by our target audience. Therefore, the team is  well on track to achieving the goal and solving the issue of under funded schools in countries such as Jamaica.

Although the project may seem overly technical, it relates to Industrial/Systems Engineering as the team is creating a system in order to fix a problem in the world. Many applications already developed require an actual oscilloscope to be connected to an Android device via network or physically connected by a LAN, USB, or GPIB cord as the team's device does not require this as the EMD functions as the oscilloscope/spectrum analyzer. Also many other applications are functioning at a bandwidth in the 20-30 kHz range as the device developed by the team currenly runs at 110 kHz. The application developed by the team will also have a dual functionality as both a oscilliscope and spectrum analyzer that is absent from any other Android application.

### 3.2 Future Plans

Testing is currently being performed. All of the requirements will be met. The team has constantly been in contact with Professor Lindon Falconer to ensure our design met all the requirements and his expectations. There is one current issue with the transmission speeds over Bluetooth and the team is looking into alternatives such as Wifi direct to speed up the device. There are plans for the team to travel to University of West Indies to present our product that will eventually be integrated into the high schools in that area.

## 4. Equations

$$f_c = 1/(2 * pi * sqrt(R_1 * R_2 * C_1 * C_2)) \tag{1}$$

## 5. Figures And Tables

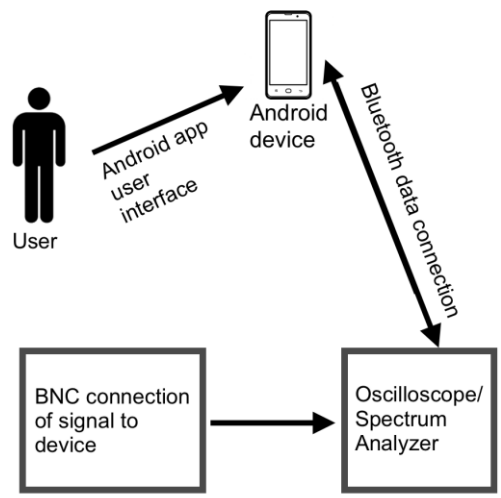


Figure 1. Top level design flow

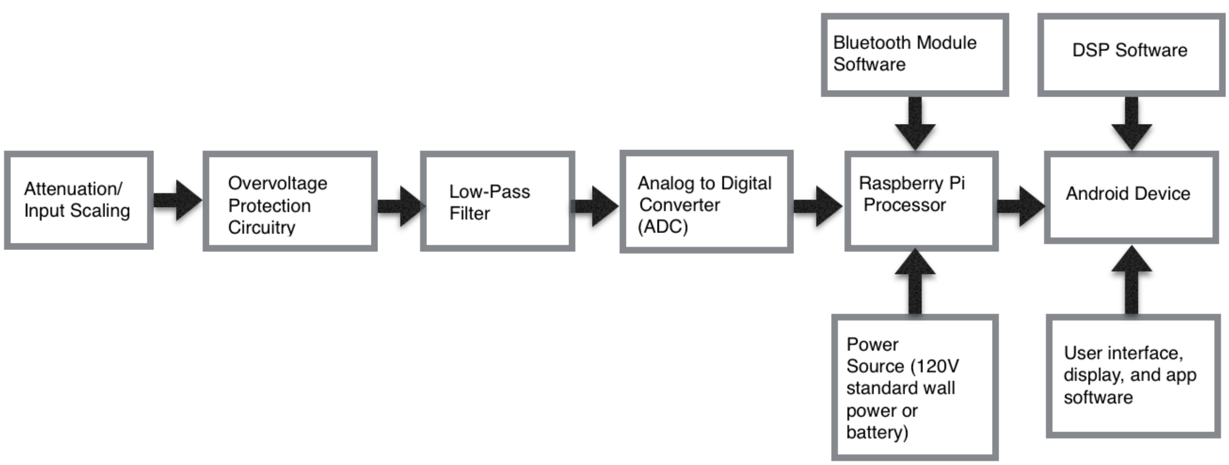


Figure 2. System Flow Chart

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