ASHESI UNIVERSITY COLLEGE

DESIGNING A LOW-COST EFFECT PEDAL FOR GUITARISTS IN GHANA WHO CANNOT AFFORD TO IMPORT EFFECT PEDALS

CAPSTONE PROJECT

B.Sc. Engineering

Godwin Adordie Jr.

2020

ASHESI UNIVERSITY COLLEGE

DESIGNING A LOW-COST SOLUTION FOR GUITARISTS IN GHANA WHO CANNOT AFFORD TO IMPORT EFFECT PEDALS

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University College in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical/Electronic Engineering.

Godwin Adordie Jnr.

2020

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

Candidate's Name:

Godwin Adordie Jr

Date:

May 29, 2020

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

………………………………………………………………………………………

Supervisor's Name:

………………………………………………………………………………………

Date:

………………………………………………………………………………………

Acknowledgements

To my supervisor, Dr Nathan Amanquah whose encouragement and academic advice helped me undertake this project.

Abstract

Music is a very important part of the Ghanaian society and it serves many purposes. In more recent times, the guitar has been one of the most widely used melodic instruments in music production. With the invention of the effect pedal, guitarists worldwide have been able to use a wider variety of tones to produce more complex and enjoyable music. In Ghana, however, these pedals need to be imported and this prevents a lot of guitarists from having a lot of tones to choose from which impedes their craft primarily because the cost of the pedal increases significantly while access to the pedal locally is restricted. Often software implementations of the effect pedals are used as substitutes for their hardware counterparts, but this comes at a cost of the reduction in tone quality. In this project, a low-cost effect pedal is designed and built to suit the needs of guitarists who cannot afford imported effect pedals.

Table of Content

Chapter 1: Introduction

Electric guitars and electric basses are instruments that have been around since 1930 and have been relevant in many styles and genres of music including pop, jazz, and heavy metal.

As the taste of music lovers changed, the need for players of such instruments to also change their tones arose. This led to an invention known as an effect pedal that was connected between the instrument and the output (e.g. A loudspeaker or amplifier). This invention could drastically alter the natural sounds produced by these instruments in real-time and give the user more options when playing.

1.1 Background

A large proportion of commercial music made in Ghana uses electric instruments. The music produced, however, requires several tones that the instruments cannot produce on their own and thus require the use of effects. Common ways of achieving these effects include software and effects pedals (analog or digital). Analog pedals, however, are still more preferred as compared to digital pedals and software because of their natural acoustic properties. [1]

1.2 Motivation

Access to effect pedals in Ghana is quite difficult primarily because of the price of the pedals. Consequently, bassists have been limited to a small range of sounds to work with.

This becomes very challenging for bassists because some of the most popular and widely patronized genres of music including hip hop, pop, jazz, and electronic music among others require certain specialized tones that cannot be naturally produced on the bass guitar.

Some bassists resort to alternative means of achieving these specialized tones. Some resort to software known as digital audio workstations (DAW's) to get the needed tones. Examples of the software include GarageBand, LogicPro, and Ableton Live. The overall cost of the software and other necessary equipment such as audio interfaces and cables is less than the cost of buying analog or digital pedals in the long run. However, there still exists that problem of the quality of the tone produced by the software. The tone produced by the software is only a simulation of what analog pedals should sound like and thus they do not sound as authentic. Others who cannot afford the original software also resort to cracked software which is illegal. Another problem associated with this alternative solution is that it cannot work without a computer (or laptop). Thus, any damage that renders the computer unusable can prevent this solution from working. Also, the software may not have a certain effect that the user requires.

Chapter 2: Related Work

2.1 Literature Review

The attempt to design a more cost-effective effect pedal has led to lots of research and implementations regarding real (and pseudo-real) time audio processing. A group attempted to create a digital multi-effect pedal on an Android platform [2].

The motivation for undertaking that project was to tackle the cost associated with effect pedals and corresponding complexity. The objective was to use digital signal processing methods to achieve their objective. An application with a graphical user interface was created to aid the user primarily in switching between different effect pedals and in controlling different parameters on each pedal such as the gain or tone levels. Effects were successfully implemented using digital signal processing algorithms, but the drawbacks included the inability to successfully implement this project in real-time because the Android API currently does not support real-time sampling. Hence, the algorithms were not properly integrated with the Android API. There also were issues with electrical grounding for the connection between the guitar and the Android device. What the API allowed was to take a sample of the audio input and store it temporarily for processing. This resulted in major latency issues that could not be solved easily and thus brought the project to a halt. The effects that were synthesized were reverberation, delay, flanging, distortion, and wah.

Another team designed a guitar combo that had both digital and analog effects that the user could choose from [3]. The combo included a speaker to produce the output, a signal amplifier and a power amplifier so that it could be used with ac power. The combo also had a graphical user interface designed with Java NetBeans with which the user could use to comfortably access the digital effects. Six analog effects and eight digital effects including octave up, tremolo, big muff and distortion were implemented for both designs.

This was done by designing different subsystems that would work together as one main system. Each subsystem was drawn as smaller block that were interconnected to form a bigger block diagram. They then analysed each subsystem and then designed each subsystem according to their requirements.

Circuits were designed for each of the analog effects using Graetz bridge rectifiers, positive feedback loops and clipping circuits among others. These circuits were built with electronic components such as potentiometers that would enable the user to change some aspect of the tone of their guitar by regulating the resistance at some point in the circuit.

The digital effects were then designed by using digital signal processing algorithms. A suitable multipurpose processor (TMS320C5515 eZdsp) was selected based on cost and performance parameters which were not disclosed. The various algorithms were then implemented in some undisclosed language. Communication with the computer was established using Java's Serial Port Communication library.

Lastly, a pre-amplifier system was designed to amplify the initial input signal before processing by either the analog or digital effects systems. Quality operational amplifiers were used in the design of the pre-amplifier which was designed in three stages. This helped to boost the signal voltage and then give it enough power to drive the loudspeaker.

Another project worked on designing a two-channel analog effect pedal with an in-built noise gate that would allow the user to have access to a variety of distortion and overdrive tones at the push of a button [4].

The first overdrive channel was named the "Madonna" channel. This channel was responsible for producing a less aggressive distorted guitar signal and could run with an already distorted signal to produce a high-gain distorted signal. The first stage of this channel was the soft-clipping stage. Silicon diodes were used to achieve this circuit because of its suitable characteristics. The second and final stage of this channel involved tone-shaping where a non-inverting amplifier circuit with a high-pass filter was built to achieve this purpose. A potentiometer was included in the circuit to allow the user to alter the tone.

The second channel was named the "Bishop" channel. This channel was responsible for producing a more aggressive distortion effect. However, unlike the first channel, this channel was not originally designed to run with already distorted signals because it would lead to loss of signal clarity. However, by adjusting the gain knob i.e. reducing the gain, the user can run this channel with an already distorted signal. This stage also employs potentiometers to enable volume, tone, and gain controls for user preferences. It also has clipping and tone-shaping stages similar to the "Madonna" channel. Both channels employed input and output buffers with unity gain for signal conditioning as well as for the elimination of potentially harmful DC voltages in the guitar signal.

The project had a few shortcomings, the first of which as that the second stage was not built with a volume and tone stage and so was set with fixed signal properties which meant that the user would not be able to alter their guitar signal. Also, there was no proper enclosure and printed circuit board layout, and this meant that the product was not fit for use by consumers in that unfinished state. There was no toggle feature which is considered a standard feature for all modern analog pedals. The toggle feature uses a mechanical three pole, double throw switch to allow the user to toggle between the use of different effects or to bypass the effect entirely.

2.1.1 Shortfalls identified in Literature Review

Based on the motivation for this project and the related work done by others, the most common reason for undertaking projects like these is cost. One of the most important objectives in the projects discussed in the literature review is to minimize the cost of the effect pedals so that users who are low-income or better can afford it.

In the second review, there were many effects implemented using analog and digital means as well as amplifier stages with a loudspeaker to produce the sonic output.

This is a very laudable project, but there are issues with mobility and storage because, with so many components in one product, the weight and volume of the product begin to increase, and thus moving it around becomes a problem. Also, finding a place to store the product may be worrisome. In this project, one of the important considerations would be to also minimize the weight and volume of the product as much as possible.

In the first and third reviews, a recurring challenge identified was the inability to build working prototypes. Thus, the sonic output could not be observed in real life. In this project, a working prototype is one of the markers for project success and so it must be implemented.

2.2 Commercial Products

Other commercial products such as GarageBand by Apple Inc. which are software implementations of classic analog pedals and amplifiers are available exclusively to owners of Apple computers and phones. However, such people would require extra hardware such as an audio interface to connect their instruments to the computer for software processing. Also, it means those who patronize Windows and other operating systems cannot have access to the software.

On the other hand, software for Windows users exist but they are also very pricey in addition to the fact that they would require extra hardware to connect the instrument to the computer. Software such as FL Studio and Ableton Live cost a minimum of $50 or GHC275 minus the cost of extra hardware.

Thus, the high cost of acquiring both hardware and software separately does not sit well with users who just need to practice or even play at some function. This is because of the increased time it takes to set up before using the system. The software-hardware combination is usually embraced by studios for recording since the software serves other useful purposes such as recording and track equalization.

Chapter 3: Requirements

3.1 Purpose

The product is supposed to produce a wide variety of other tones by altering the natural tone of an electric bass guitar. This allows the guitarist to have a lot of tools at their disposal and hence give them more flexibility when playing different genres of music. The product is intended for bass guitarists of any experience level (from beginners to professionals) who seek to explore other tones for any purpose at all (including practice, live performances, or even professional recordings).

3.2 Scope

The product is a bass effect pedal. It will receive electric bass signals as input, process the signal (analog or digital processing) depending on what function the user selects, and then produce an output electric signal which is the preferred tone as predetermined by the user. It will enable the user to alter different parameters of the tone to their preference (e.g. Tone, Volume, Gain, etc.). These parameters, however, vary from one tone to the next. The product will also enable the user to tune their instrument to a preferred frequency.

The product can be used by bass guitarists for practice, live performances or recordings. The product should primarily be cheaper than other similar products on the market (less than $50). It should also possess user-friendly functions. The product should have a reasonable weight (less than 800g). The product should enable the user to provide power to it using different means (eg.1x 9V battery or 6x 1.5V batteries). The product should also have minimal noise present in the output signal unless the noise originates from the input signal. The product should finally be able to indicate which effect(s) the user is engaging at every point in time.

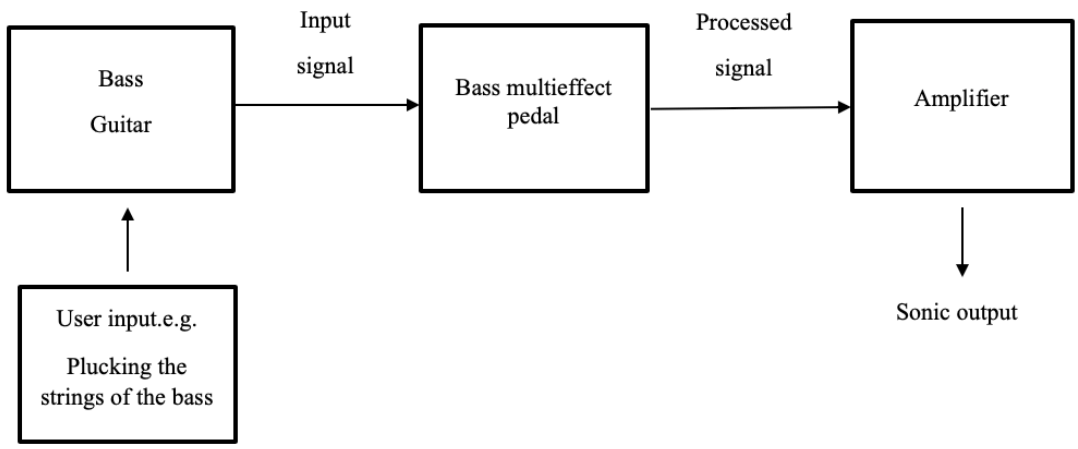

Figure 1. A block diagram showing the how the product would fit in the larger system.

3.3 Definitions

- User – Any person who engages the product directly.
- Customer – Any person who purchases the product but does not necessarily use the product.
- Product – The bass multieffect pedal
- Electric bass – A stringed melodic instrument that uses electronics to produce musical notes of lower frequencies than ordinary acoustic guitars. It also uses thicker strings to also achieve the lower frequencies.
- Amplifier – A device that amplifies the electric signal from any electric instrument and produces the output through a speaker. It usually has a frequency equalizer to shape the tone of the sound.
- Tone – A steady, periodic sound.

- Latency – A short period of delay between when a signal enters the system as an input and when it emerges as an output
- Audiophile - a person who is especially interested in high-fidelity sound reproduction.
- Effects unit/pedal – An electronic device that alters the sound of an electric instrument or audio source.
- Waveform – A graph showing the amplitude of a sound wave with respect to time.
- Octave – Frequencies which are integral multiples of a fundamental frequency.
- Combo – An amplifier unit with a loudspeaker attached to it. It is usually used as at output medium for electric guitars and basses.

3.4 Product Perspective

The product is not standalone and cannot be used by itself. It must be connected between a bass guitar and an amplifier. Thus, it receives input from the bass guitar and then sends the processed signal to an amplifier to produce the sound. Hence, for the product to function properly within this setup, it must satisfy certain requirements including:

1) The output signal must be above the threshold for input signals by a combo.
2) It must be able to detect signals within a defined range of voltage values.
3) The product should not produce any other signal apart from the output signal e.g. internally generated noise.
4) The product must not produce any audible latency unless the intentionally selects an effect whose properties cause the output signal to be delayed.
5) The chassis for the product should be made of diecast aluminium.
6) All circuit components must be assembled on a printed circuit board.

3.5 Hardware Interface

The product will provide only two female ¼" TRS female ports to serve as input ports and output ports respectively. This is because ¼" TRS and TTRS interfaces are now the standard interfaces for most modern electric instruments. The product will also have knobs that allow the user to alter the properties of the sound signal based on their preference. The product will also have a knob that will allow the user to engage and disengage the preferred effect pedal.

3.6 Operations

While operating the product, the user should be able to do the following:

1) Select/disengage one or more desired effects.
2) Adjust the knobs to subjectively alter the properties of the output sound.
3) Easily move the product around.

When the product is not engaged, although connected, it should only send the original input signal to the amplifier.

3.7 User Characteristics

The intended users of this product should have had reasonable experience working with electric instruments. No necessary level of education is required of them.

3.8 Constraints

In the process of designing and building the product, the following factors are going to bring about some form of limitation in the product. These include:

1) Method of implementation: The bass effects can be realized using digital signal processing or analog circuits. However, due to the nature of the waveforms of some effects, they are best implemented using digital signal processing to achieve that sound waveform. For the same reason, others are best implemented using analog circuits. This reduces the number of effects that are available to the user because it means that the cost of implementation would have to increase if all effects were to be implemented.
2) Noise from the input signal: Noise from the input signal is going be amplified after being processed. This noise cannot be eliminated by the bass effects pedal and can cause loss of signal clarity when played through the amplifier.
3) The overall cost of materials: This project is intended to be as cost-effective as possible while ensuring that quality is not compromised. This will therefore be a determinant in selecting components and materials. The total budget for this project was given to be $50 and based on the cost analysis done, the maximum number of effects that can be supported is 3 effects.
4) The size of the product: The product is required to be light and small enough so that users can easily carry it around and easily store it. This immediately places a cap on the number of components that are going to be used in its design as well the weight of these components.

3.9 Assumptions

It is assumed that the user will provide all necessary power requirements for the proper functioning of the product. It is also assumed that the user has access to a bass guitar, an amplifier and the cables required to connect all the devices together including the product.

3.10 Performance Requirements

The product should have the following static and dynamic features pertaining to user interaction:

1) It must have one input port and at least one output port.
2) It must support only one electric instrument.
3) It must process all continuous time signals within a certain voltage threshold (analog voltage signals between 0-2V maximum amplitude).
4) It must produce no noise in the output signal.
5) It must audibly alter the tone of an input signal based on selected effect(s).
6) It must allow the guitar signal to bypass the effect when the effect is not engaged.
7) It must be easily movable and storable.

The effects to be produced are **Octave Up and Distortion/Fuzz**

Octave Up: This effect alters the guitar signal by doubling the frequency of the signal, thus giving the audience the impression that higher octaves are being played.

Distortion/Fuzz: This effect alters the guitar signal giving the audience the impression of a distorted, aggressive and noisy guitar signal.

3.10.1 Other Effects

There are several other effects that exist and are used by guitarists [5]. Some of these include:

Phaser Effect: This effect shifts the input effect by some phase angle and then mixes it with the original signal to give the audience the impression of a sweeping sound.

Chorus: This effect produces different tones of the same input signal and then mixes it with the original signal to give the impression of several sounds converging (as with a choir).

Wah-Wah Effect: This effect enables the user to glide smoothly between frequencies using an envelope filter to create an onomatopoeic "wah" sound.

TalkBox: This effect allows the user to apply speech sounds unto the notes played by the guitar, thus producing an output of somewhat melodious speech or singing.

Vibrato: This effect gives the audience the impression of a timed, pulsating change of pitch

Delay/Echo: This effect alters the original signal such that the audience gets the impression that the signal is echoing or repeating itself at fixed time intervals.

Chapter 4: Design

The chassis would also contain openings for fastening of screws when the chassis is closed shut. Inside the chassis would house all electrical components. The chassis would have openings which would serve the following purposes:

1. Input ports for a ¼” TS (tip-sleeve) or TRS (tip-ring-sleeve) male jack from the bass guitar since it is one of the modern standard interfaces for audio inputs and outputs.
2. Output ports which would also utilize ¼” TS or TRS male jacks from the effect pedal to the output amplifier or another effect pedal.
3. Potentiometers which would be fitted with knobs to allow the user to easily alter their sound to their preference.
4. A power jack input, which would power the circuit using a 9V DC wall adapter.
5. A toggle switch or 3PDT switch which would allow the user to bypass the effect.

4.1 Circuit Schematics

4.1.1 Distortion Circuit Introduction

The distortion effect is a harsh, aggressive sounding version of input signal. It is as a result of the non-linear distortion of a signal or waveform. This distortion is often achieved by increasing the gain of the input signal to the maximum allowable levels of the amplifier. This is achieved by using a two-stage common emitter configuration [6] . This setup is based on the design by R.G Keen in 1998 [7].

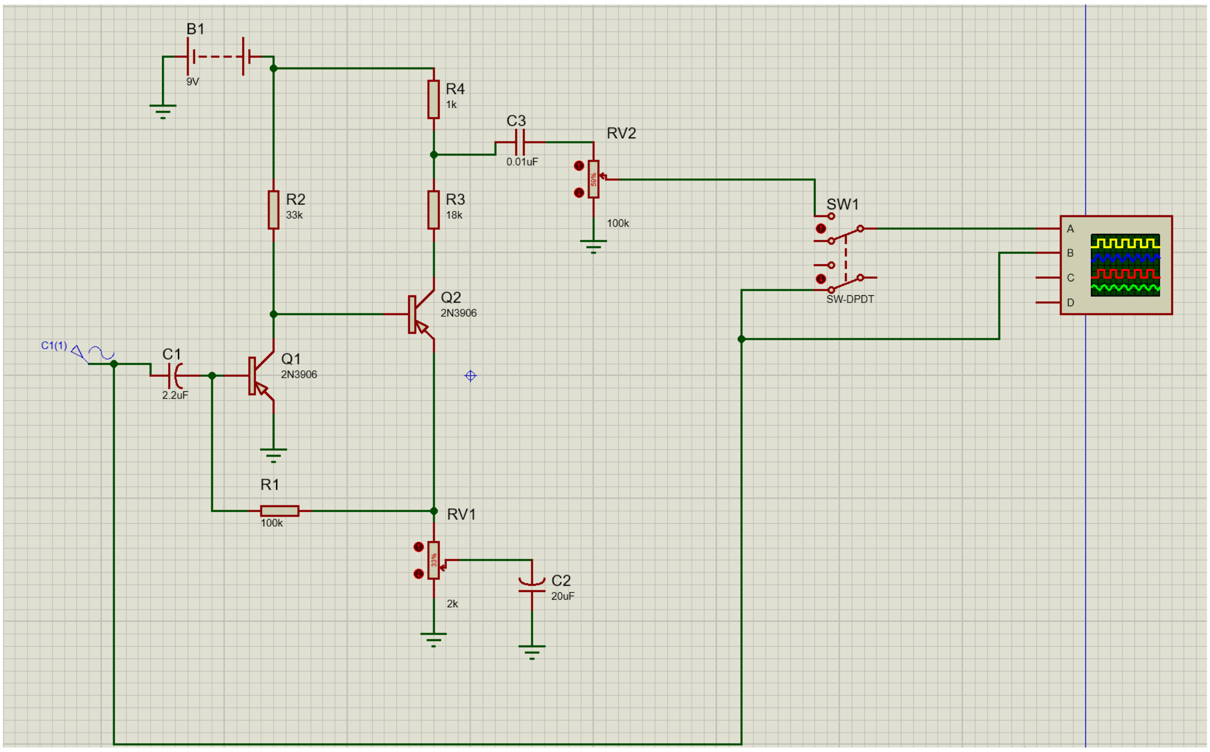

Figure 2. The circuit schematic for the Distortion effect designed in PROTEUS 8.

4.1.2 Bill of Materials / Choice of Materials for Distortion

COMPONENT	QUANTITY	UNIT PRICE	LINK TO PRODUCT
0.01µF ceramic capacitor	1	$ 0.0520	Click here to visit Invent Electronics
2.2 µF polarized capacitor	1	$ 0.0520	Click here to visit Invent Electronics
47 µF polarized capacitor	2	$ 0.0690	Click here to visit Invent Electronics
1kΩ resistor	1	$ 0.0170	Click here to visit Invent Electronics
18kΩ resistor	1	$ 0.0076	Click here to visit AliExpress
33kΩ resistor	1	$ 0.0350	Click here to visit GeekElectronics
100kΩ resistor	1	$ 0.0170	Click here to visit Invent Electronics
10kΩ potentiometer	1	$ 0.1700	Click here to visit Invent Electronics
100kΩ potentiometer	1	$ 0.1700	Click here to visit Invent Electronics
2N3906 PNP transistor	2	$ 0.0470	Click here to visit Jumia
Total		$ 0.9346	

Table 1. Bill of Materials for Distortion circuit. NB: Delivery charges are not included

The ideal choice for the transistor would have been a germanium transistor since it is believed by many audiophiles believe that they sound better when used in distortion circuits than silicon transistors [8] i.e. It has been widely accepted although it is not quite yet an industrial standard. However, there is very little scientific proof to back the claims. However, germanium transistors were out of stock and thus a silicon transistor was used instead. Any silicon transistor would work provided the other components are properly connected. The other passive components were chosen based on the transistor configuration that was used to achieve the distortion.

4.1.3 Distortion Circuit Breakdown

The first stage has the input signal is fed to a DC blocking capacitor (C1) directly to the base of Q1, with the emitter grounded and a single collector resistor (see Figure 2). This drives a load which is the base of the second stage which is directly coupled.

The second stage acts as a common emitter amplifier. Hence its output voltage must follow the collector at Q1 although it will not have the same value due to the base-emitter voltage drop of Q2 . The resistor R1 is a feedback resistor that passes that passes a current that is proportional to the first transistor's collector voltage and feeds it to the base of Q1. The effect of this is that provides the highest possible gain from a transistor which is good for distortion [7].

The second stage has its base directly coupled to the collector of Q1. The gain of the second stage is determined by the ratio of the AC load in the collector to the AC load on the emitter. The AC collector load is just the sum of the AC resistors while the emitter load is the portion of the potentiometer RV1 not shorted to ground through the 20uF capacitor. Thus, RV1 determines the varies the gain of the second transistor.

The capacitor C3 determines the bass response of the output signal. Thus, the higher its value, the more bass is present in the output signal. The resistors R3 and R4 determine the output level of the signal.

4.1.4 Octave Up Introduction

The Octave Up effect essentially produces an output signal which is an octave above the input signal passed to it. A note whose frequency twice the frequency of another note is said to be an octave above that note. Thus, the Octave Up effect essentially doubles

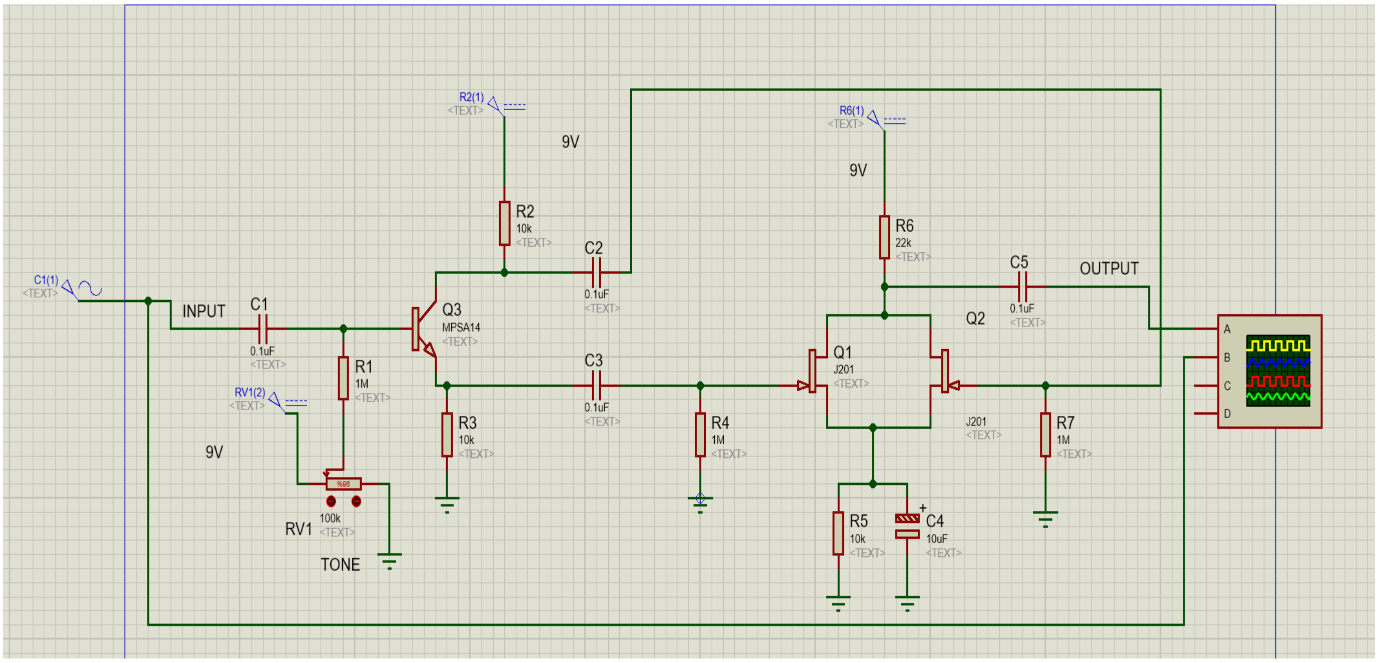

Figure 3. The circuit schematic for the Octave Up effect designed in PROTEUS 8

the frequency of any signal passed to it. The setup is based on the design by Tim Escobedo [9]

4.1.5 Bill of Materials / Choice of Materials for Octave Up

The MPSA 13 transistor was chosen because of its high gain (especially current gain) properties which is very useful since the long-tailed pair configuration produces a significant reduction in signal gain. Although a Darlington transistor can be constructed from more than one transistor, choosing the MPSA13 means having fewer components in the circuit schematic and a corresponding reduction in the overall cost of

COMPONENT	QUANTITY	UNIT PRICE	TOTAL COST	LINK TO PRODUCT
0.01 µF ceramic	4	$ 0.0520	$ 0.2080	Click here to visit Invent Electronics
10 µF polarized	1	$ 0.0690	$ 0.0690	Click here to visit Invent Electronics
10 kΩ resistor	3	$ 0.0350	$ 0.1050	Click here to visit GeekElectronics
22 kΩ resistor	1	$ 0.0350	$ 0.0350	Click here to visit GeekElectronics
100 kΩ resistor	1	$ 0.1700	$ 0.1700	Click here to visit Invent Electronics
1 MΩ resistor	3	$ 0.1700	$ 0.5100	Click here to visit Invent Electronics
100 kΩ potentiometer	1	$ 0.1700	$ 0.1700	Click here to visit Invent Electronics
MPSA 13 Darlington	1	$ 0.0159	$ 0.0159	Click here to visit AliExpress
PN4393 N-Channel	2	$ 0.2820	$ 0.5640	Click here to visit AliExpress
			Total = $ 1.8469	

Table 2. Bill of Materials for OctaveUp circuit. NB: Delivery charges not included

the components, although the difference may be negligible. The PN4393 JFET was chosen as a substitute for a J201 JFET which was not readily available. The 1MΩ and 0.1µF values were chosen to create a high pass filter whose cut-off frequency would be determined in subsequent sections.

The input signal is fed to a DC blocking capacitor (C1). A bias voltage is set by the potentiometer RV1 which controls the tone of the signal (see Figure 3). The signal is fed into the base of the transistor Q3, a Darlington transistor that doubly amplifies the signal but causes a 180° phase shift between the output at the emitter and the output of the collector . C2, R7 and C3, R4 form high pass filter configurations which block frequencies below 15.9 *Hz* and feeds the signal from the collector and emitter respectively of Q3 as the inputs of the long-tailed paired configuration.

$$High\ pass\ filter\ cutoff\ frequency, f_{cutoff} = \frac{1}{2\pi RC}$$

$$R = 1 * 10^{6}\ \Omega \qquad C = 0.01 * 10^{-6} F$$

$$f = \frac{1}{2\pi * 1 * 10^{6} * 0.01 * 10^{-6}} = 15.915\ Hz$$

The significance of this cut-off frequency is that since the human audio range is between 20*Hz* and 20k*Hz* [9], it would prevent the attenuation of any frequencies within the range.

The long-tailed paired configuration consists of the JFETs Q1 and Q2, R6,R5, and C4. It amplifies the difference in the input signals while simultaneously suppressing in-phase parts of the signal [11]. Since the input signals are 180° out of phase, one signal reaching its positive peak will correspond to the other reaching its negative peak. Thus, these two signals are only in phase when their amplitude is zero. At this point the output signal is constant but maximum every half cycle of the inputs. During the other half cycle, where the inputs are not in phase, the output signal reaches its minimum peak when either input signal reaches its maximum. Thus, the output signal essentially has twice the frequency of the input signal. C5 improves the bass response of the output signal which can be improved by increasing its value .

Chapter 5: Testing and Results

5.1 Simulations

The circuit schematics were designed and simulated in PROTEUS 8 to check whether they would yield the desired results before any actual implementation was made. For the Octave Up schematic, the MPSA13 was not available in the simulation software and this meant that meant that a suitable substitute (MPSA14) had to be used. According to the datasheets published by the manufacturers, ON Semiconductor, both transistors have the same properties although the MPSA14 [12]. Thus, no changes to the signal due to the change in transistor model are expected. All simulations were tested with a sine wave of 1V amplitude, 0° phase angle and varying frequencies of 100 Hz, 200Hz,500Hz and 2kHz. Adjustments were also made to the oscilloscope window to accommodate graphs that did not fit within default oscilloscope parameters.

A sine wave was chosen as the input signal to represent the signal that a guitar would produce. It must be noted, however, that a guitar signal is more complex and consists of a sum of multiple signals. An assumption is made in this case that any changes to the sine wave would be equally observed on a real guitar signal.

5.1.1 Simulation of Distortion Effect

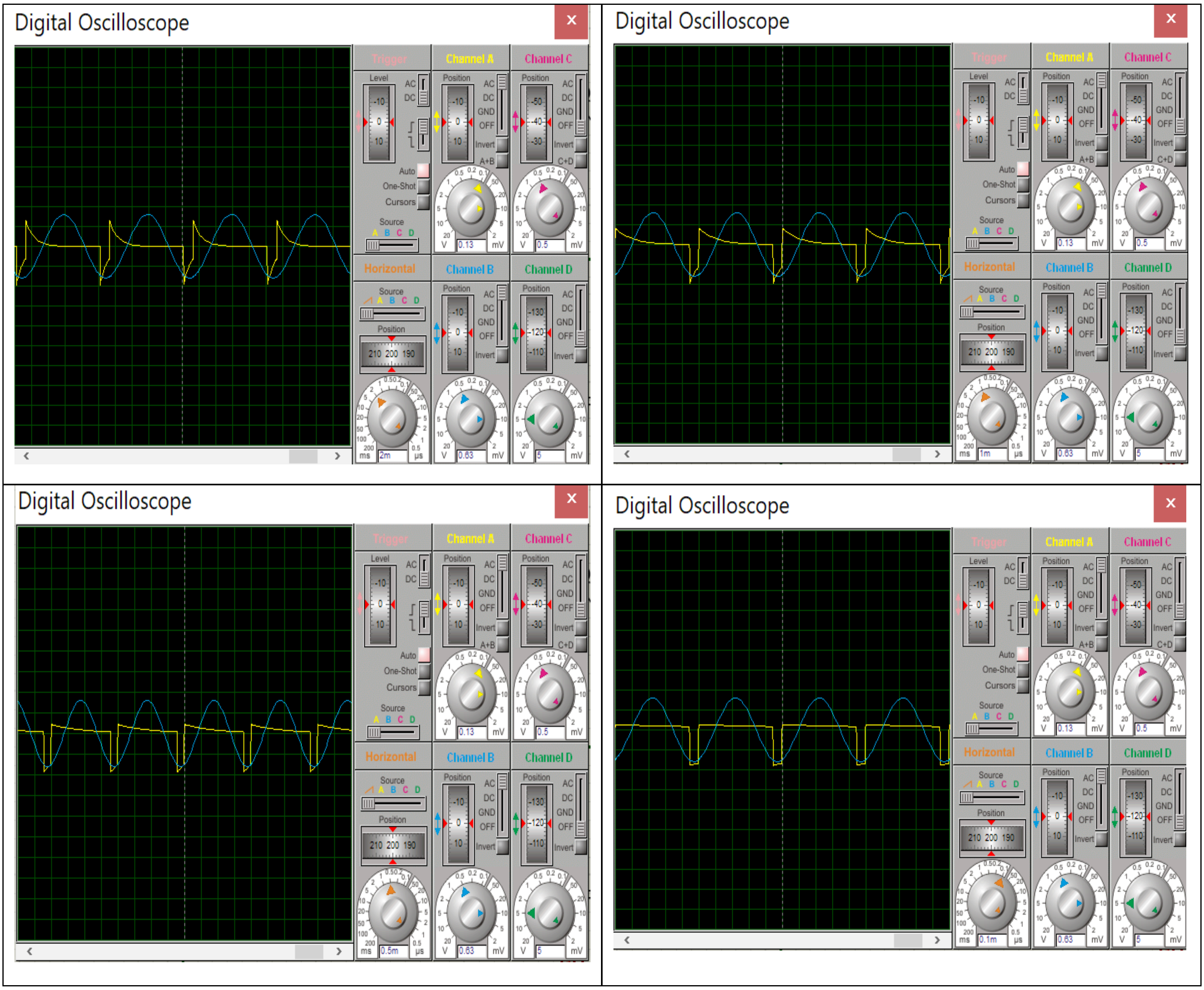

Figure 4. Waveforms showing the input signals (blue) and the distorted output signal (yellow) after simulation. Input signal frequencies are 100*Hz,* 200*Hz,* 500*Hz and* 2*kHz respectively.*

Table 3 shows the parameters of the digital oscilloscope that resulted in the waveforms above. These parameters were adjusted to make the waveforms visible for measurements to be taken. The amplitudes of the input and output signals were measured to give indications of whether the input signal was being amplified or attenuated.

	Input Signal (Blue)	Output Signal (Yellow)
Amplitude (*V*)	1	0.15
Frequency (*Hz*)	100	100
Y - axis intervals (*V/division*)	0.13	0.63
Time base (*ms*)	2	2
Offset (*V*)	0	0
	Input Signal (Blue)	Output Signal (Yellow)
Amplitude (V)	1	0.1
Frequency (Hz)	200	200
Y - axis intervals (V / division)	0.13	0.63
Time base (ms / division)	1	1
Offset (V)	0	0
	Input Signal (Blue)	Output Signal (Yellow)
Amplitude (V)	1	0.05
Frequency (Hz)	500	500
Y - axis intervals (V / division)	0.13	0.63
Time base (ms / division)	0.5	0.5
Offset (V)	0	0
	Input Signal (Blue)	Output Signal (Yellow)
Amplitude (V)	1	0.025
Frequency (Hz)	2000	2000
Y - axis intervals (V / division)	0.13	0.63
Time base (ms / division)	0.1	0.1
Offset (V)	0	0

Table 3. Table showing graph parameters for Distortion simulation

5.1.2 Results of Distortion simulation

The blue waveform represents the input signal and the yellow waveform represents the output signal (see Figure 4). The simulations show clipping of the peaks and troughs of the output waveform. Also, there is a reduction of the amplitude of the output waveform. This can be attributed to the negative feedback circuit (see Figure 2). Negative feedback circuits have characteristic gain reducing properties [13]. It can also be observed that both the input and output are in phase.

5.1.3 Simulation of Octave Up effect

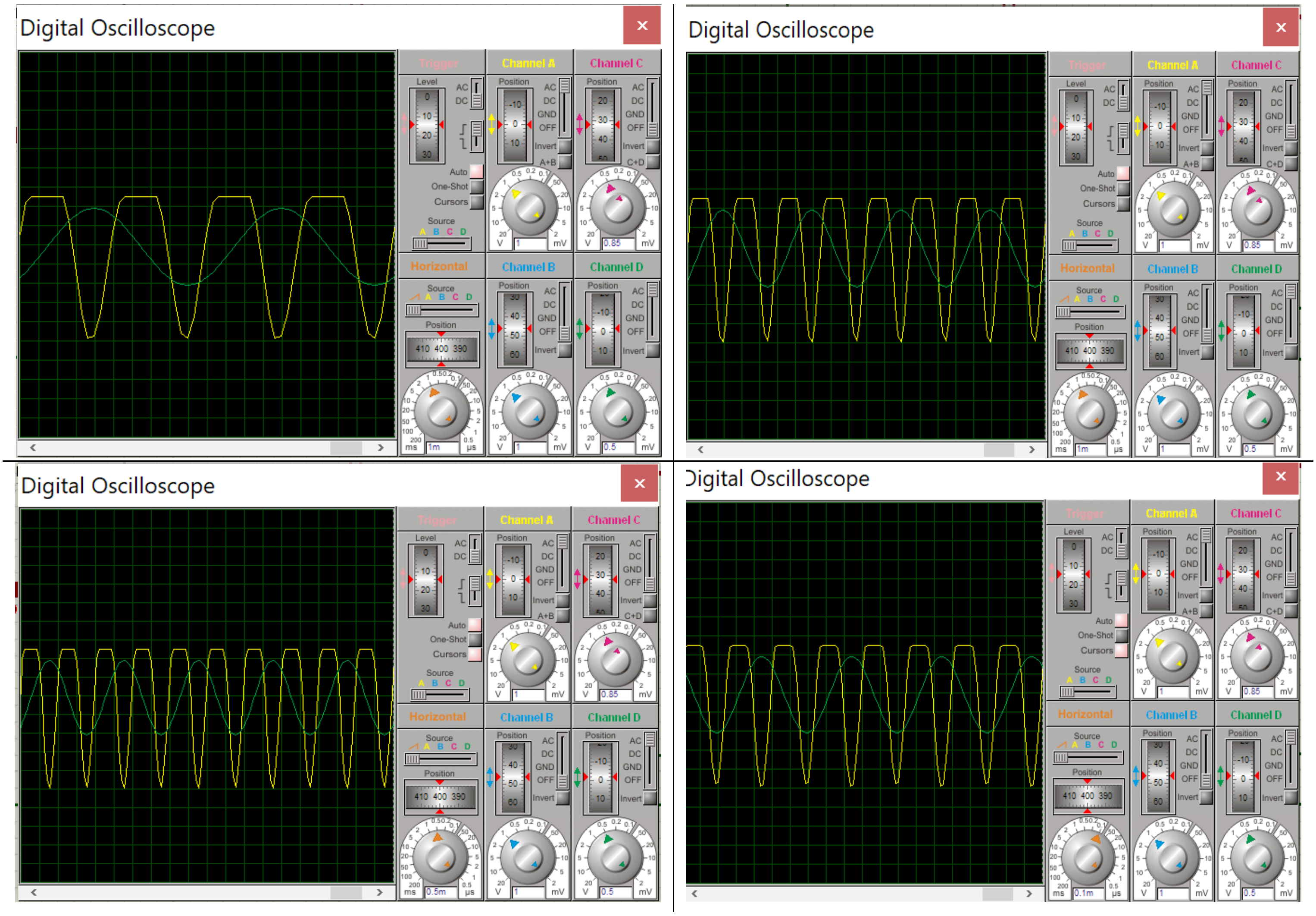

Figure 5. Waveforms showing input signals (green) and octave output signal (yellow) after simulation. Input signal frequencies are 100*Hz*, 200*Hz*, 500*Hz* and 2000*Hz* respectively

Table 4 shows the parameters of the digital oscilloscope that resulted in the waveforms above. These parameters were adjusted to make the waveforms visible for measurements to be taken. The amplitudes of the input and output signals were measured to give indications of whether the input signal was being amplified or attenuated.

	Input signal (Green)	Output signal (Yellow)
Amplitude (*V*)	1	2.5
Frequency (*Hz*)	100	200
Y-axis interval (*V / division*)	0.5	1
Time base (*ms*)	1	1
Offset (*V*)	0	0
	Input signal (Green)	Output signal (Yellow)
Amplitude (*V*)	1	2.5
Frequency (*Hz*)	200	400
Y-axis interval (*V / division*)	0.5	1
Time base (*ms*)	1	1
Offset (*V*)	0	0
	Input signal (Green)	Output signal (Yellow)
Amplitude (*V*)	1	2.5
Frequency (*Hz*)	500	1000
Y-axis interval (*V / division*)	0.5	1
Time base (*ms*)	0.5	0.5
Offset (*V*)	0	0
	Input signal (Green)	Output signal (Yellow)
Amplitude (*V*)	1	2.5
Frequency (*Hz*)	2000	4000
Y-axis interval (*V / division*)	0.5	1
Time base (*ms*)	0.1	0.1
Offset (*V*)	0	0

Table 4. Table showing graph parameters for OctaveUp simulation.

5.1.4 Results of OctaveUp simulation

The green waveform on the graph represents the input signal while the yellow waveform represents the output waveform (See Figure 5). It can be observed that the output waveform has twice as many cycles as the input waveform. This means that the output waveform has twice the frequency of the input waveform. Also, the input is out of phase with the output by 180°. This can be attributed to the phase splitter configuration of Q3 (See Figure 3) [13]. Common emitter configurations have the output (the collector) being out of phase with the inputs by 180°.

Also, the peaks of the output signal can be observed to be clipped, although very slightly. This suggests that there could be some distortion in the signal due to the increase in gain. However, it is not known whether the distortion enough to be audibly perceptible in a real signal. It also important to note that this distortion can be controlled by the potentiometer RV1 (see Figure 3).

5.2 Breadboard implementation

The circuit schematics were implemented on a breadboard in order to test the circuit for any deviations from the simulation environment. It must be noted that simulations use ideal conditions in computing circuit outputs which may differ from real life implementations for a few reasons.

The Analog Discovery 2 was used to generate the sine wave used as the input and to display the output waveform. Some components in the schematic were not readily available hence suitable substitutes were used. These components include PN4393 in place of J201 in simulation and MPSA13 instead of MPSA14 in simulation for the Octave Up effect. These substitutes were not available in PROTEUS 8 either, but they worked in the breadboard setup. For the Distortion effect the 2kΩ potentiometer, RV1 (see Figure 2), which was not readily available was replaced with a 10k potentiometer which was the closest available resistance value. The effects were tested at different frequency values of 100*Hz*, 200*Hz*, 500*Hz* and 2*kHz* (see Figure 5).

5.2.1 Breadboarding the Distortion effect

The parts used in breadboarding this effect are displayed in Table 5.

Component	Quantity

0.01µF ceramic capacitor	1
2.2µF electrolytic capacitor	1
47µF electrolytic capacitor	2
1kΩ resistor (0.25 W)	1
18kΩ resistor (0.25 W)	1
33kΩ resistor (0.25 W)	1
100kΩ resistor (0.25 W)	1
10kΩ potentiometer	1
100kΩ potentiometer	1
2N3906 PNP Transistor	2
Analog Discovery 2 Kit	1
Breadboard	1

Table 5. Table showing components used in breadboard implementation of Distortion effect.

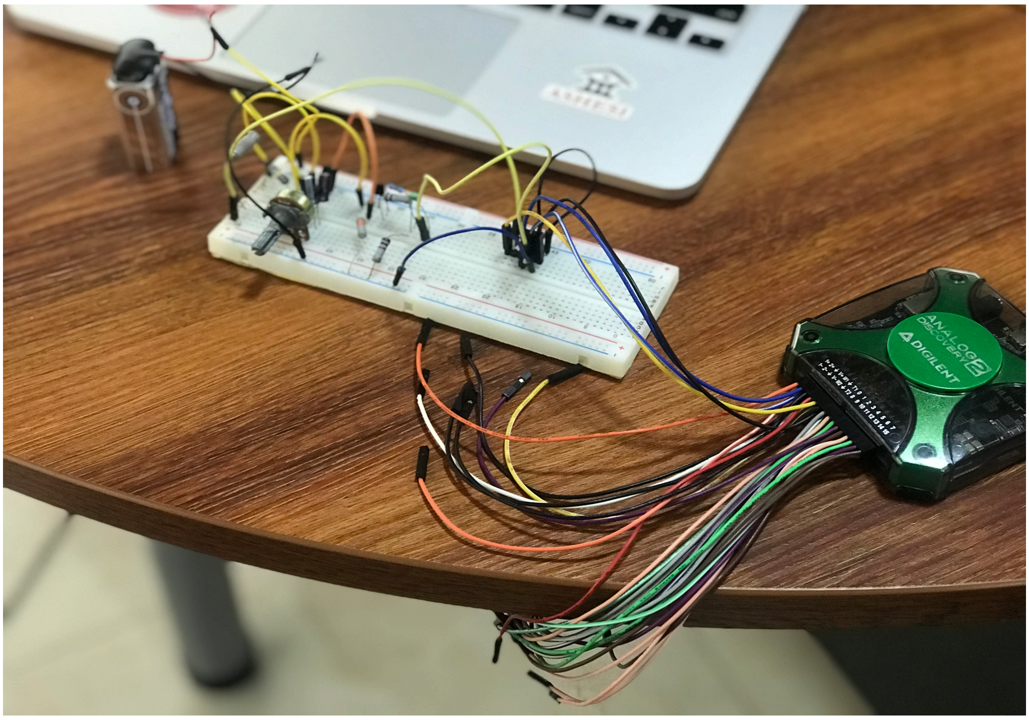

Figure 6. Image showing circuit components on a breadboard for Distortion.

5.2.2 Results of breadboarding the Distortion effect

The results of breadboarding the Distortion circuit are shown in Figure 7. The frequencies of the input signals were the same as the frequencies used in the simulation.

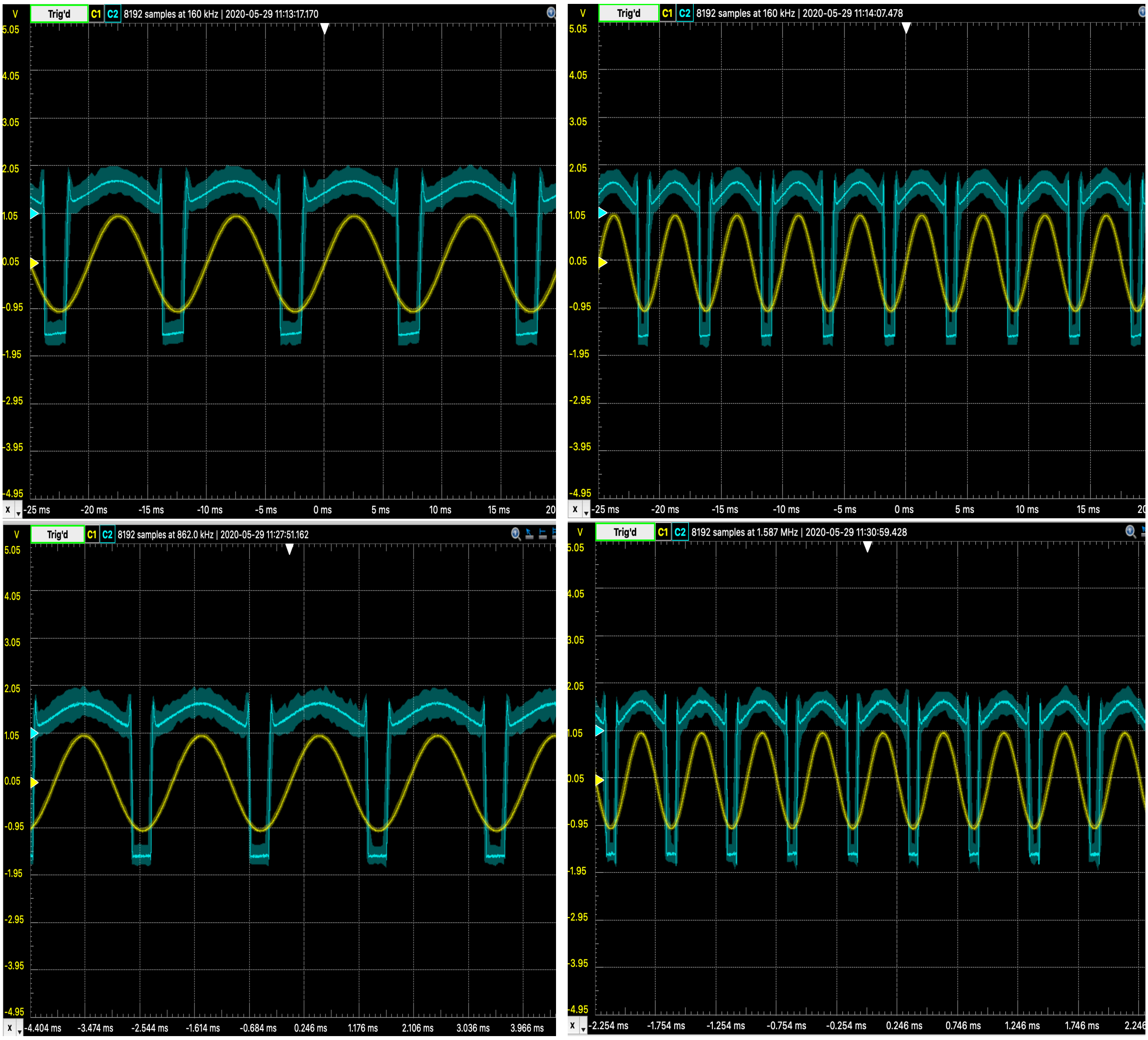

Figure 7. Waveforms showing input signal (yellow) and output signal (blue) after breadboarding Distortion effect. Input signals used had frequencies of 100Hz, 200Hz, 500Hz and 2kHz respectively.

Table 6 shows the parameters of the signal and graph window at each frequency

	Input signal (Yellow)	Output signal (Blue)
Amplitude (*V*)	1	0.032
Frequency (*Hz)*	100	100
Y-axis interval (*V / division*)	1	0.02
Time base (*ms*)	5	5
Offset (*V*)	-0.05	0.02
	Input signal (Yellow)	Output signal (Blue)
Amplitude (*V*)	1	0.032
Frequency (*Hz)*	200	200
Y-axis interval (*V / division*)	1	0.02
Time base (*ms*)	5	5
Offset (*V*)	-0.05	0.02
	Input signal (Yellow)	Output signal (Blue)
Amplitude (*V*)	1	0.032
Frequency (*Hz)*	500	500
Y-axis interval (*V / division*)	1	0.02
Time base (*ms*)	1	1
Offset (*V*)	-0.05	0.02
	Input signal (Yellow)	Output signal (Blue)
Amplitude (*V*)	1	0.032
Frequency (*Hz)*	2000	2000
Y-axis interval (*V / division*)	1	0.02
Time base (*ms*)	0.5	0.5
Offset (*V*)	-0.05	0.02

Table 6. Table graph parameters for Distortion breadboard implementation

From the waveforms in Figure 7, the output waveform (in blue) bears some resemblance to the waveform obtained in simulation (see Figure 4). A slight variation in the two graphs can be observed with the clipping of the peak of the output waveform. It can be observed that the peak is still rounded as opposed to a more flattened shape as shown in the simulation. This can be attributed to the battery voltage depleting due to a depletion of its charge. The voltage drop caused the signal to not reach saturation and hence the clipping could not occur at the peaks. However, the output signal appears to be clipped at the troughs. Figure 8 shows the value of the voltage across the battery terminals and how it was tested.

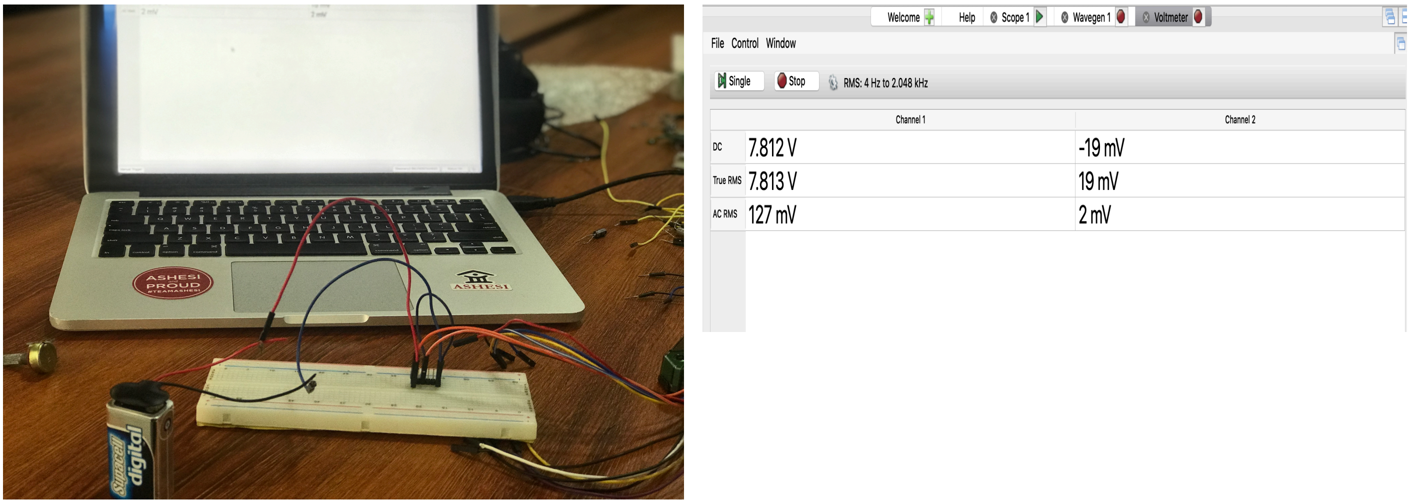

Figure 8. Image showing setup for battery voltage testing (left) and the voltage across the terminals of the battery as measured by the Analog Discovery kit (right)

5.2.3 Breadboarding the OctaveUp effect

The parts used in breadboarding this effect are displayed in the table below:

Component	Quantity
10kΩ resistor (0.25 W)	3
22kΩ resistor (0.125 W)	1
1MΩ resistor (0.125 W)	3
100kΩ potentiometer	1
0.01µF ceramic capacitor	4
10µF electrolytic capacitor	1
MPSA 13 Darlington transistor	1
PN4393 N-Channel JFET	2
9V alkaline battery	1
Analog Discovery 2 Kit	1

Breadboard	1

Table 7. Table showing the components used in breadboard implementation of OctaveUp effect.

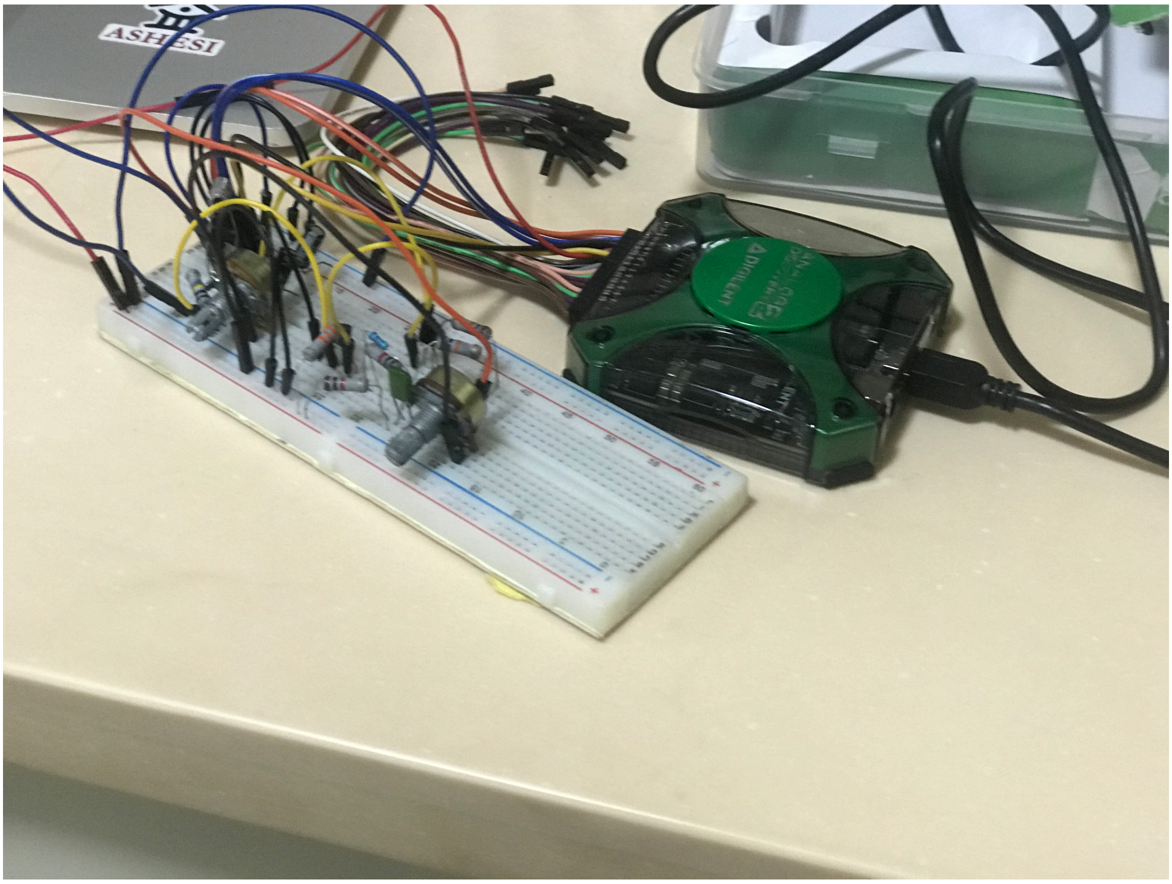

Figure 9. Image showing setup of OctaveUp circuit with components on a breadboard.

5.2.4 Results of breadboarding the OctaveUp effect

The output of the circuit as detected by the Analog Discovery kit is shown in Figure 10:

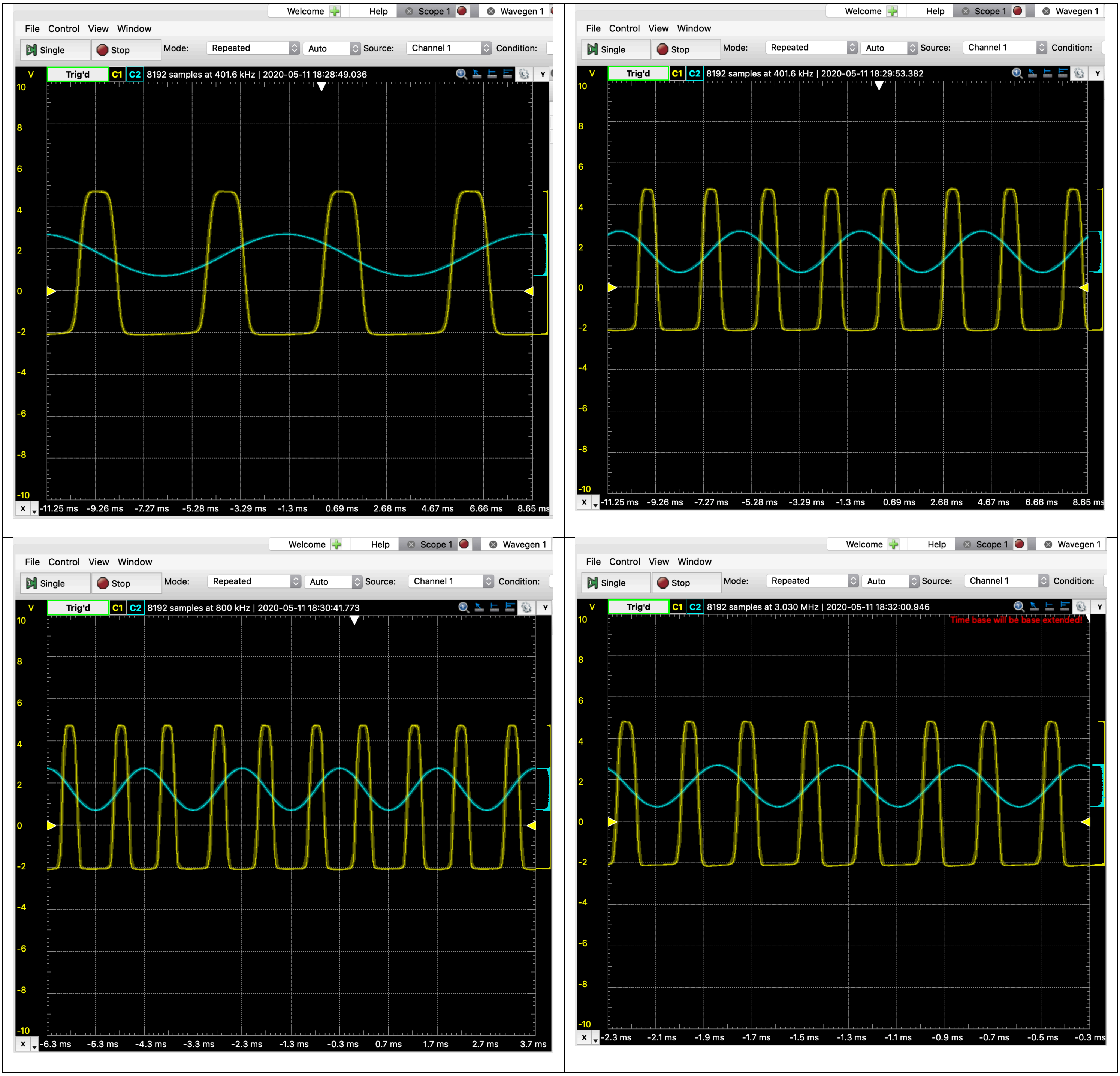

Figure 10. Waveforms showing the input signal (blue) and the output signal (yellow) after breadboarding Octave up effect. Input signals used had frequencies of 100Hz, 200Hz, 500Hz and 2kHz respectively.

Table 8 shows the various parameters of the signal and the graph window at each frequency.

	Input signal (Blue)	Output signal (Yellow)
Amplitude (*V*)	1	3.5
Frequency (*Hz)*	100	200
Y-axis interval (*V / division*)	2	2
Time base (*ms*)	2	2
Offset (*V*)	0	0
	Input signal (Blue)	Output signal (Yellow)
Amplitude (*V*)	1	3.4
Frequency (*Hz)*	200	402
Y-axis interval (*V / division*)	2	2
Time base (*ms*)	2	2
Offset (*V*)	0	0
	Input signal (Blue)	Output signal (Yellow)
Amplitude (*V*)	1	3.4
Frequency (*Hz)*	500	1005
Y-axis interval (*V / division*)	2	2
Time base (*ms*)	1	01
Offset (*V*)	0	0
	Input signal (Blue)	Output signal (Yellow)
Amplitude (*V*)	1	3.4
Frequency (*Hz)*	2000	4000
Y-axis interval (*V / division*)	2	2
Time base (*ms*)	0.2	0.2
Offset (*V*)	0	0

Table 8. Table showing graph parameters for OctaveUp breadboard implementation.

Figure 10 shows how the frequency of the output signal doubles after being processed by the OctaveUp circuitry. There is also a slight clipping of the peaks of the signal in both simulation and breadboard implementations (see Figure 5 &10). This is as a result of the large gain provided by the Darlington transistor (Q3 in Figure 3). The result of this is that some distortion is likely to occur. However, seeing that the type of clipping is linear, even and slightly reduces the amplitude of the signal, it may not present itself to be a problem as it may be barely audible.

Also, the output signal is out of phase with the input signal due to the phase splitter configuration of Q3 (see Figure 3). This, however, does not have any physical implications on the signal.

Figure 11 shows a comparison between the simulated effect and the breadboarded effect. From the parameters in Table 4 and Table 6, once can observe that the amplitude of the output signal on the breadboard is about 1.4 times higher than in simulation. Though untested, it may be attributed to the increase in the JFET gain due to changes in JFETs. This can be said because the JFET is the only component that differs between simulation and breadboard implementation. (see Q1 and Q2 in Figure 3). The PN4393 was used in place of the J201 transistor. The use of MPSA14 in simulation and MPSA13 on the breadboard is not expected to have any noticeable effect on the signals because according to the manufacturers, they have the same characteristics.

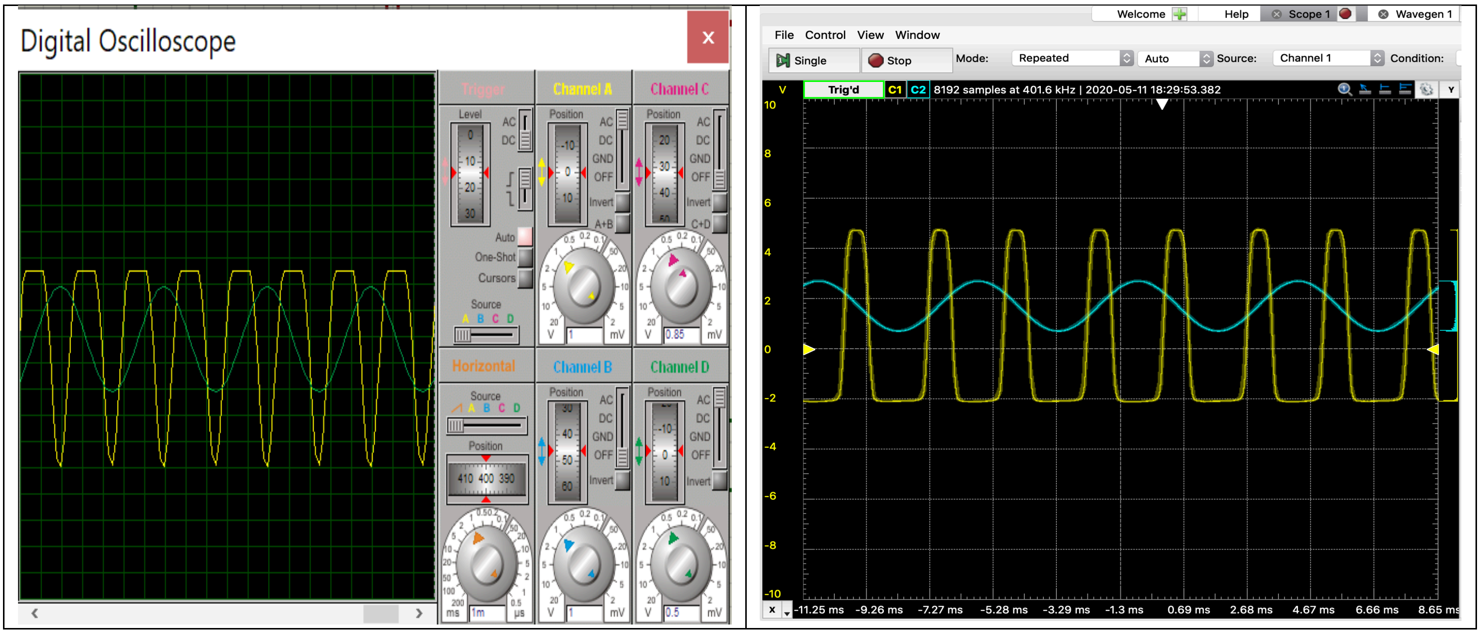

Figure 11. Images showing waveforms in simulation (left) and waveforms after breadboard implementation.

Chapter 6 : Recommendations, Future Works and Conclusion

6.1 Achievements

From the objectives set in Section 3.4, the following are the key accomplishments of this project:

- No noise was present in the output signal : From the waveforms in Chapter 5 (see Figure 7 and Figure 10), it can be observed that the output signal is clean and has no jagged or rough edges (which are indicative of some noise) for the range of frequencies for which it was tested. In effect, the user is assured of clean and quality audio.
- Support for only one electric instrument : From the circuit design and the breadboard implementation, one can observe that only one input signal is allowed

into the circuit for processing. The impact of this is having more input signals increases the likelihood of producing unwanted noise in the output signal.

- The effect audibly alters the tone of the original input signal : From the shape waveforms in Chapter 5, we may conclude that the tone of input signal will in fact be altered audibly and will produce the desired effect for user convenience.
- The effect can process continuous time signals between 0 – 2V (maximum amplitude) : Based on the simulation and breadboard implementations, we can conclude that this condition is satisfied since all input signals had an amplitude of 1V. The maximum amplitude was set at 2V although the effects can handle signals with larger amplitudes.

6.2 Future Works and Recommendations

To improve upon this project, the following are a few things to consider :

- A chassis or enclosure to house the circuitry : Standard electronic equipment usually has some housing that not only adds aesthetic value to the product but also protects the circuit from external agents that could potentially damage it.
- Dual power supply system : The effect pedal is typically used where there is access to ac power. Thus, it would be prudent to design a system that takes advantage of that environment. However, in case one cannot access ac power, it would be very beneficial for a user to be able to switch to a 9V battery or similar.
- Train effects system : This is a feature that allows multiple effects to be engaged at the same time. As the project stands now, it is untested whether more than one effect can be engaged to produce a combined effect. However, it would be an additional feature that users may find useful.

- True-bypass feature : This is a feature that allows the user to engage or disengage the effect, thus toggling between their original guitar sound and the effect output.

6.3 Conclusion

The average Ghanaian guitarist may not be able to afford the pedals on the market currently. However, this project has the potential to create a foundation for a professional yet low-cost product to satisfy the needs of these guitarists. This project is a potential job creation avenue for individuals who want to assemble circuits as a business in Ghana.

References

[1] Sound Unsound, “Analog Versus Digital Guitar Pedals,” Sound Unsound, 15 April 2020. [Online]. Available: https://sound-unsound.com/analog-versus-digital-guitar-pedals/. [Accessed 12 March 2020].

[2] K. Elfenbein, M. Loh and A. Kriegel, “TapBoard: Android-Based Digital Multi-Effect Pedal,” Carnegie Mellon University, Pittsburgh, Pennsylvania, 2012.

[3] A. Chen, A. Hernandez, B. Delose and R. John, “Guitar Amplifier with analog and digital effects systems,” University of Central Florida, Orlando, Florida, 2013.

[4] D. Breuer, “"Dual Peaks" Analog Guitar Distortion Effects Pedal,” California Polytechnic University, San Luis Obispo, 2018.

[5] Burton Guitar Repair, “Circuit Snippets,” GuitarHQ, 2013. [Online]. Available: http://www.jiggawoo.eclipse.co.uk/guitarhq/Circuitsnippets/snippets.html. [Accessed 27 November 2019].

[6] Electronics Notes, “Transistor Common Emitter Amplifier,” Electronics Notes, [Online]. Available: https://www.electronics-notes.com/articles/analogue_circuits/transistor/transistor-common-emitter-configuration.php. [Accessed 8 May 2020].

[7] R. Keen, “Technology of the Fuzz Face - Frame Definition,” 1998. [Online]. Available: http://www.geofex.com/article_folders/fuzzface/fffram.htm. [Accessed 11 May 2020].

[8] T. Wempe, “Why is germanium considered better than silicium for audio applications?,” Research Gate, 2014. [Online]. Available: Why is germanium considered better than silicium for audio applications?. [Accessed 8 May 2020].

[9] T. Escobedo, “Circuit Snippets,” GuitarHQ, [Online]. Available: <http://www.jiggawoo.eclipse.co.uk/guitarhq/Circuitsnippets/snippets.html>. [Accessed 8 May 2020].

[10] Engineering Libre Texts, “The Differential Amplifier,” 7 July 2019. [Online]. Available: https://eng.libretexts.org/Under_Construction/Map%3A_Operational_Amplifiers_and_linear_Integrated_Circuits_(Fiore)/1%3A_Introductory_Concepts_and_Fundamentals/1.6%3A_The_Differential_Amplifier. [Accessed 19 April 2020].

[11] ON Semiconductor, “ MPSA13, MPSA14 Darlington Transistors. 4th ed. [ebook],” 2007. [Online]. Available: <http://www.onsemi.com> . [Accessed 8

May 2020].

[12] Electronics Tutorials, “Negative Feedback Systems,” [Online]. Available: https://www.electronics-tutorials.ws/systems/negative-feedback.html. [Accessed 2020 May 8].

[13] F. Rice, “Transistors as amplifiers and switches,” 2019. [Online]. Available: http://www.sophphx.caltech.edu/Physics_5/Experiment_6.pdf. [Accessed 2020 May 11].

[14] Analog Devices, “Differential Amplifiers,” 6 June 2017. [Online]. Available: https://wiki.analog.com/university/courses/electronics/text/chapter-12. [Accessed 23 February 2020].

[15] P. Horowitz and W. Hill, “The Art of Electronics,” Cambridge University Press, New York, 2015.

[16] “The Technology of the Fuzz Face,” 1998. [Online]. Available: http://www.geofex.com/article_folders/fuzzface/fffram.htm. [Accessed 20 January 2020].

[17] R. Elliott, “Power Amplifier Design Guidelines,” 27 December 2006. [Online]. Available: https://sound-au.com/amp_design.htm#s10. [Accessed 19 April 2020].