Department of Electronic & Telecommunication Engineering
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Function Generator
Group 25

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EN 2091 Laboratory Practice and Projects

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Abstract

This report discusses the design process of an analog function generator, which our team designed for EN2091: Laboratory Practice and Projects. The analog function generator leverages the unique features of analog electronic components to effectively generate common types of signals. The designed analog function generator is capable of generating sinusoidal, triangular, saw tooth, and PWM waves with varying magnitudes, frequencies, and duty cycles.

This report includes the details on all the critical steps in the design process such as component value calculations, initial and final simulations, component selection, PCB designing, and enclosure designing. Moreover, it discusses the behavior of the sub systems and sub circuits, problems faced and the remedies for them, and the potential for future improvements.

Through this project our team gained a lot of experience on designing something with the careful manipulation of the knowledge on what we have already learnt. Other than that, the best practices of PCB designing, enclosure designing, project planning and management, etc. were learnt with hands-on experience.

Abbreviations and Acronyms

Op-Amp Operational Amplifier

PCB Printed Circuit Board

Contents

1 Introduction and Functionality

A function generator is a device that any electronic enthusiast or student must need in one point in their life. Such a device can generate different types of waves with varying magnitudes and frequencies and can be used to test other components and circuits such as their response to such waveforms.

For the Semester 3 module EN2091: Laboratory Practice and Projects, we selected to design an analog function generator. It was expected to be designed using analog electronic components only. As a result, we chose op amps, resistors, capacitors, etc. in order to realize our objective.

The function generator was expected to provide an amplitude variation from 0 to $10V$ and a frequency variation of 20Hz to 20kHz. Other than that, it was expected to drive at least a 50Ω load. Consequently, the maximum current that the device should support is calculated as follows.

$$V = RI$$
$$10 = 50 * I$$
$$I = 0.2A$$

All the PCB traces, components and other parameters were designed to support and withstand this $0.2A$ current.

The user is given knobs in the front interface to adjust amplitude, frequency, PWM duty cycle, and DC shift easily. There is a rotary switch which determines which kind of wave the function generator outputs, namely sinusoidal, triangular, saw tooth, and PWM. The device is supposed to be powered up using a DC jack that provides sufficiently high voltage to the device.

The basic functionality of the function generator is as follows.

- The power supply circuit takes DC (about $30V$) voltage and provides $\pm 12V$ and ground reference voltage.
- An op amp oscillator circuit generates a triangular waveform which is used as the base waveform.
- Triangular waveform is then used to generate saw tooth, PWM, and sinusoidal waveforms.
- Buffer circuits are used to isolate the triangular wave generation part from the rest of the circuit.
- A rotary switch is used to select the desired type of signal.
- The selected waveform is then passed through an amplifier.
- A DC shift can be added to the overall waveform as well.
- The resultant waveform is fed to a push-pull amplifier to provide the required power output.

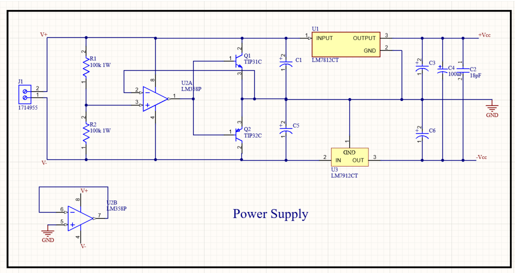
The functionality of each and every sub circuit is discussed in detailed in the following chapters.

2 System Architecture

The function generator consists of multiple sub-parts for waveform generation. First, a triangular wave is generated using an oscillator circuit which includes a Schmitt trigger circuit and an op amp comparator. Then, this triangular waveform is used as the base waveform for the other sub circuits to generate saw tooth, PWM, and sinusoidal waves.

Other than that, there is a separate circuit to power up the main circuit with +Vcc, -Vcc, and GND by taking only a DC input of sufficiently high voltage.

2.1 Power Sub Circuit

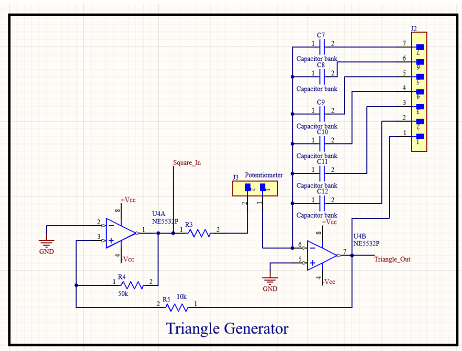


The circuit is designed to take a DC input of about 30V from an external power supply and split it into plus and minus 12V which are necessary to power up the op amps.[1] This circuit provides a ground reference that acts as the common ground to the rest of the circuit.

An op amp is used with negative feedback in the power sub circuit. It acts as a buffer which prevents the virtual ground from changing. Along with a duo of NPN and PNP transistors, two voltage regulators are used to regulate the voltage at the desired plus and minus voltages relative to the virtual ground.

The C2 and C4 capacitors are selected such that one having a relatively large capacitance(100μF) and the other having a relatively small capacitance (18pF). These capacitors help to reduce the noise in the circuit and the output.

2.2 Triangle Wave Generation



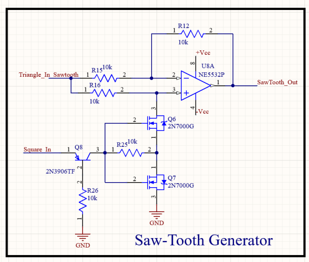
A system of two op amps with one having a positive and multiple feedback is used for the triangular wave generation. The initial stage acts as a stable multi-vibrator which gives a square-like signal which is then integrated to produce a triangular wave. In this case, as the frequency varies, different capacitances are needed to integrate the waveform effectively without significant distortions, and hence a capacitor bank is used to select the most appropriate capacitor for the required frequency range.
A potentiometer connected to the J3 pin changes the resistance which in turn changes the frequency where the multi-vibrator oscillates.

Following table include the capacitor ranges we have used.

Capacitor Value	Frequency Range
1μF	8 Hz - 250 Hz
100 nF	100 Hz - 850 Hz
10 nF	800 Hz - 10.5 kHz
1 nF	8 kHz - 48 kHz

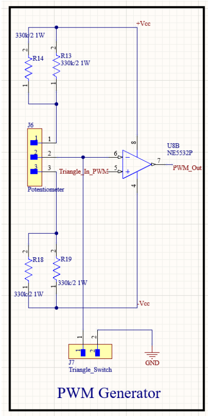
2.3 Saw Tooth Wave Generation

The basic functionality of the saw tooth wave generating sub circuit is to invert only a part of the triangular wave, thus making the resulting waveform appear as a saw tooth wave. This is achieved through comparing the triangular wave generated at the previous stage with the square-like wave which is also generated at the same previous stage.



When the ”Square-In” signal is low, the transistor network goes to the saturation region making the non-inverting terminal of the op amp pulled to ground. This causes the op amp to act as an inverting buffer. Similarly, when the ”Square-In” signal is high, the transistor network goes to the cut-off region making the non-inverting terminal of the op amp close to the supplied signal voltage thus acting as a non-inverting amplifier (unity gain buffer).

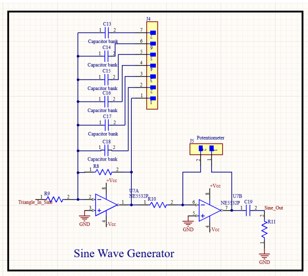
2.4 PWM Wave Generation



The Pulse Width Modulated (PWM) signal is generated by comparing the previously generated base triangular waveform with a reference voltage which determines the duty cycle. The reference voltage can be selected through a potentiometer which is connected to the +Vcc and -Vcc through some resistors that provides a little margin for the 1% and 99% duty cycles. The op amp comparator compares the triangular waveform with the reference voltage either driving the output voltage to the maximum or minimum possible voltages, giving a PWM signal.

Moreover, a separate switch is utilized to generate square waves (50% duty cycle) with minimum distortions than the previously mentioned ”square-like” wave. This switch will pull the reference voltage to the ground voltage, hence enabling to generate 50% duty cycle waves.

2.5 Sine Wave Generation



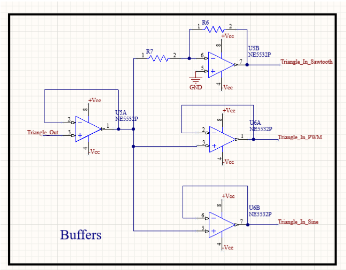
Sine wave generation is achieved by passing the triangular wave through an active filter circuit realized using op amps. The filter system allows only the low-frequency components of the triangular wave to pass through. This results in sinusoidal wave to be output. However, this approach does not generate perfect sinusoidal signals as the filters are not ideal and the lowest frequency component of different triangular waves change with the wave frequency. Nevertheless, with proper tuning of the active filter circuit with a variable capacitor back, this effect can be minimized beyond the noticeable level.

Following table include the capacitor ranges we have used.

Capacitor Value	Frequency Range
1μF	20 Hz - 300 Hz
100 nF	200 Hz - 1 kHz
10 nF	800 Hz - 8 kHz
1 nF	5 kHz - 48 kHz

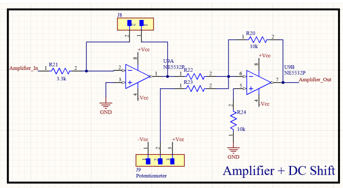
2.6 Buffers

A group of independent buffers are used to isolate the previously generated triangular wave from the rest of the circuit before submitting it to the other sub circuits. The main reason for this is to minimize the distortions and noise, while preventing any circuit backwardly affecting the generation of the triangular wave using the oscillator.



2.7 Amplifier and DC Shift Circuit

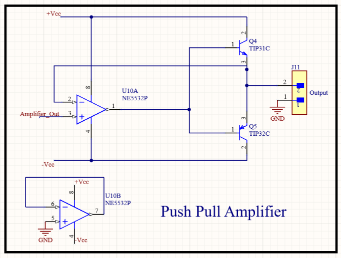
A variable resistance (potentiometer) connected to J8, changes the overall amplitude of the waveform. It uses an op amp amplifier circuit. Then, it is fed to one terminal of a summing amplifier circuit of which the second terminal is connected to a potentiometer. This potentiometer changes the voltage at the second terminal which will be added to the waveform, thus giving a DC shift to the waveform.



2.8 Push Pull Amplifier

In order to drive a load using the generated wave, it needs to have enough power to do so. To address this, the push pull amplifier is used.

Finally, a rotary switch is used to select the required waveform namely sinusoidal, triangular, saw tooth, and PWM to output.



3 Component Selection

3.1 Op-Amp Selection

Selecting the correct op-amp was crucial to achieve the given specifications. Since we had to generate waveforms upto 20,000Hz slew rate of the op-amp was very much important. High slew rates allows to handle rapid changes in the input. Therefore we have selected NE5532P op-amp which is having a slew rate of 9 V/us. Although we could have used a op-amp which is having a higher slew rate than this, due to the availability of the market we had to restricted for this op-amp.

Also a function generator requires a stable and low-noise amplification to produce clean and accurate waveforms.[2] The characteristics of having an Input Voltage Noise Density of $5nV\sqrt{Hz}$ and Input Noise Current Density of $2.7pA\sqrt{Hz}$ made NE5532P op-amp suitable for our application.

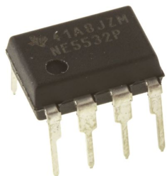


Figure 1: NE5532P

3.2 Transistor Selection

In the power supply circuit of the function generator we have used TIP31C and TIP32C due to its' current ratings. Since these two are in a push-pull configuration it provides an efficient operation and amplification.

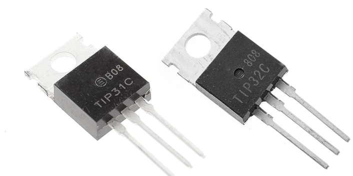


Figure 2: TIP31C TIP32C

Also we have used LM7812CT and LM7912CT as voltage regulators to get a fixed +12V and -12V respectively.

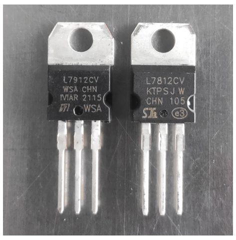


Figure 3: L7812 L7912

- In this project we had to generate waveforms for various frequencies. Since it could not be achieved by using one capacitor, we have used a capacitor bank.

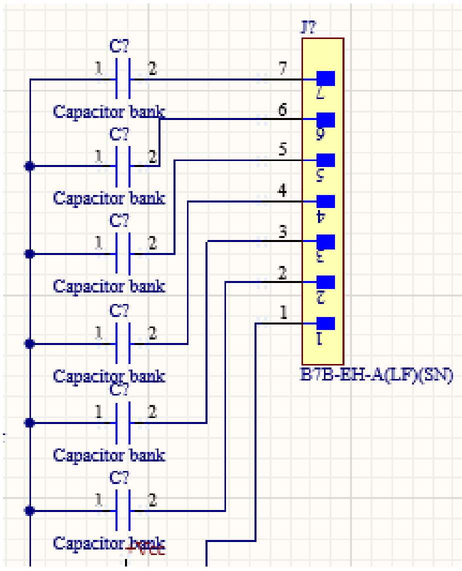


Figure 4: Capacitor Bank

4 PCB Design

PCB design has done using Altium Designer and it was done as a double layer PCB.

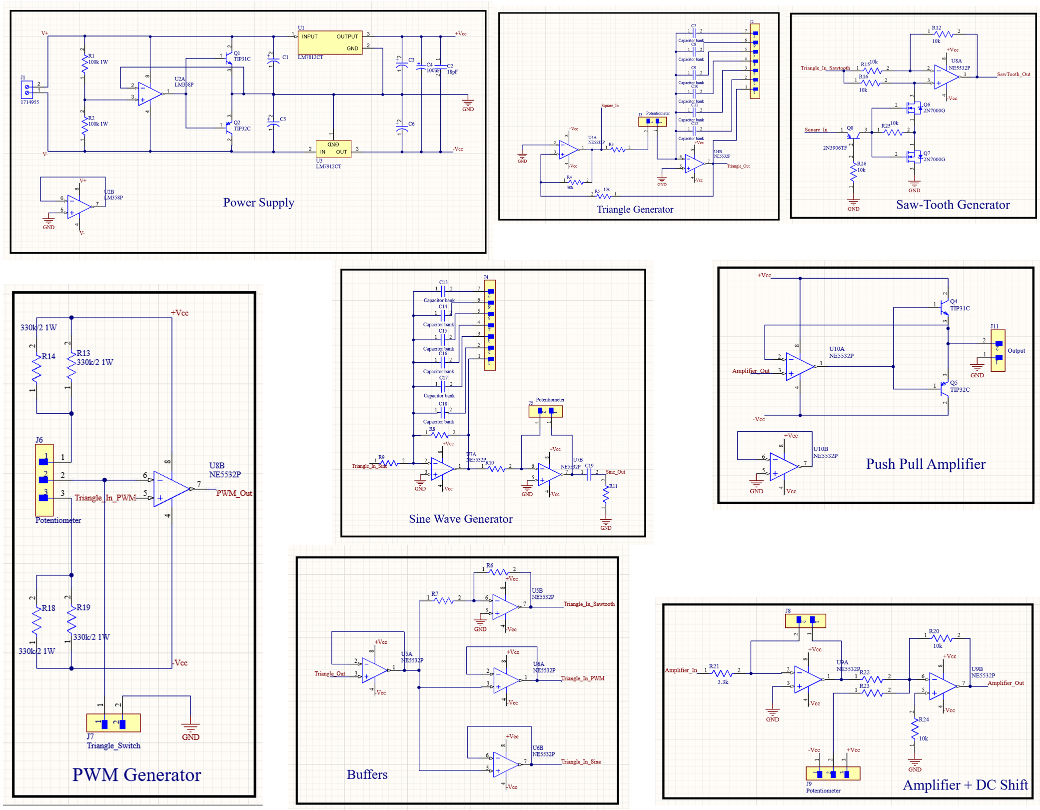


Figure 5: Schematic

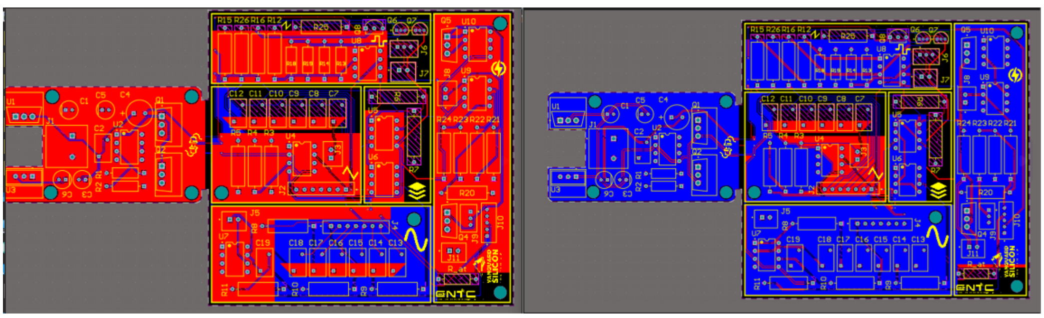


Figure 6: Top Layer & Bottom Layer

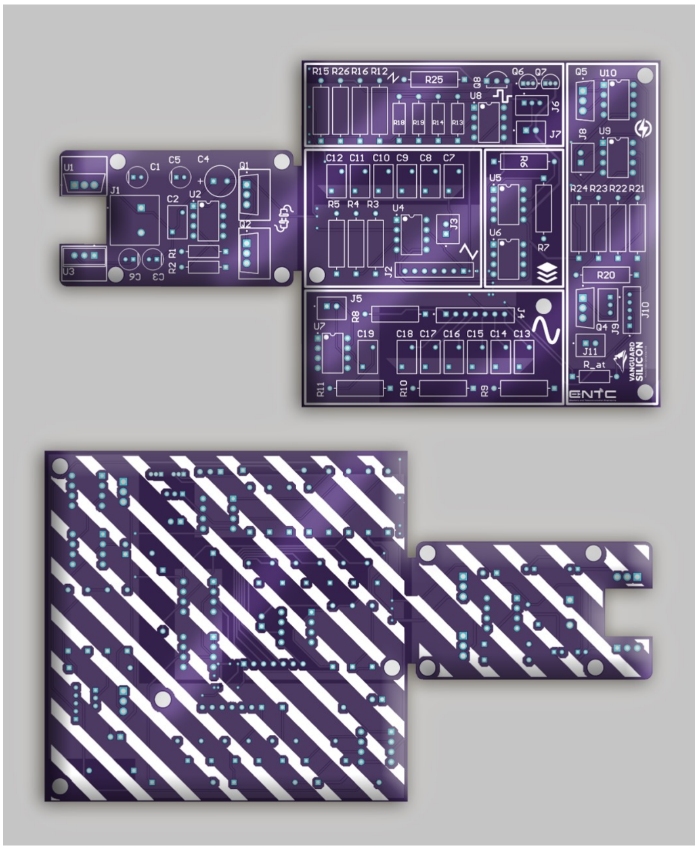


Figure 7: Final Design

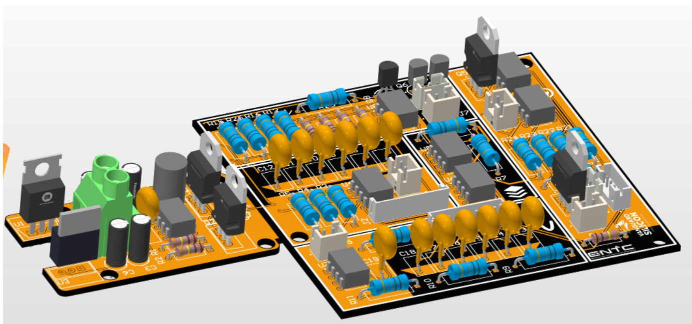
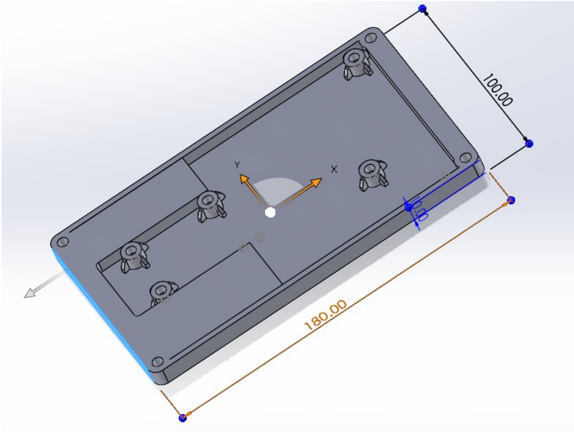
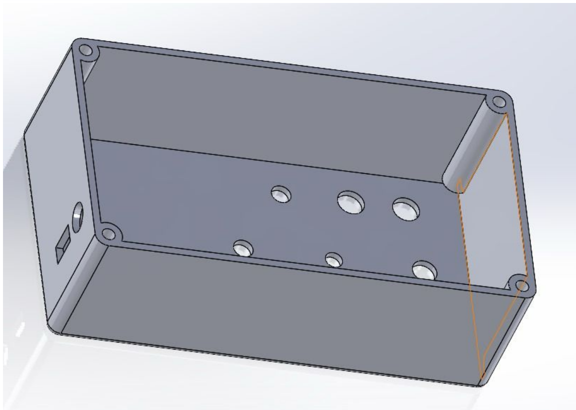


Figure 8: 3D View

5 Enclosure Design

Enclosure design is done using SOLIDWORKS.





6 Software Simulation and Hardware Testing

For simulations we have used Multisim and LTSpice.

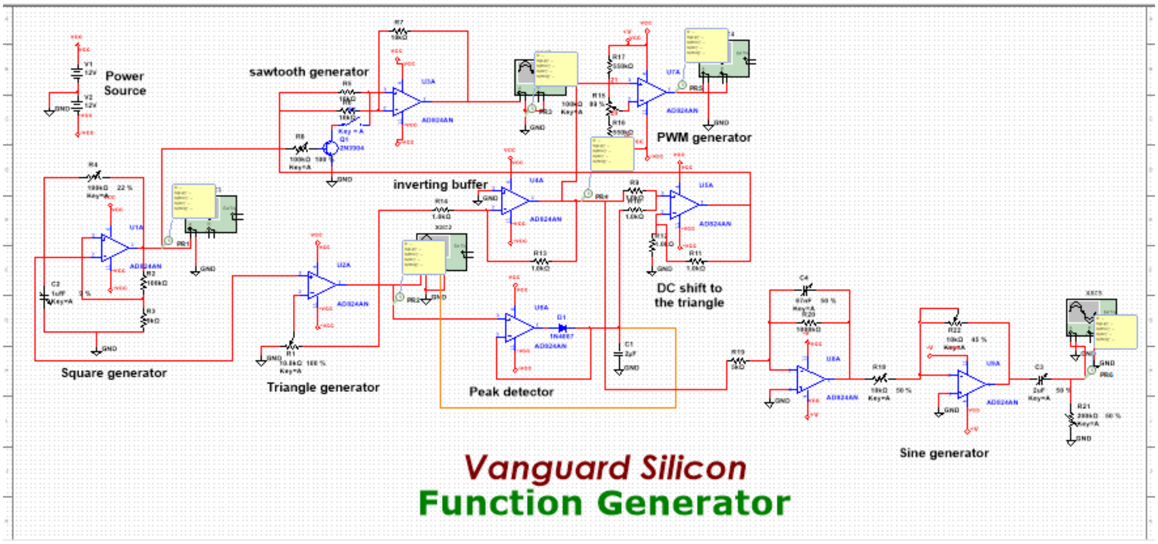


Figure 9: Main Circuit

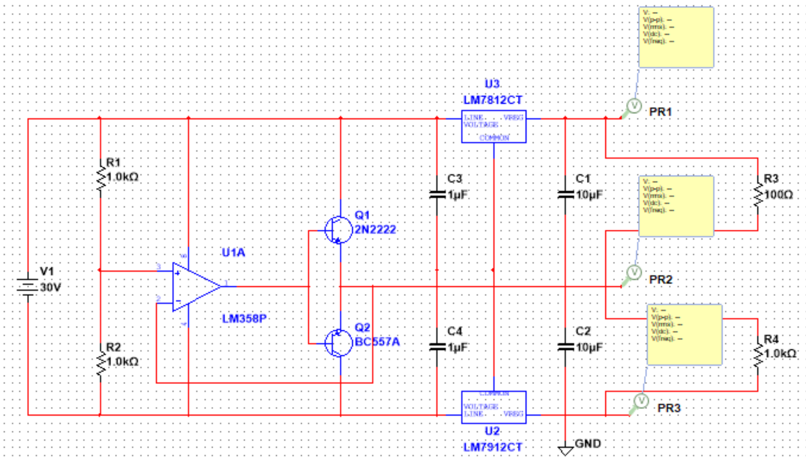
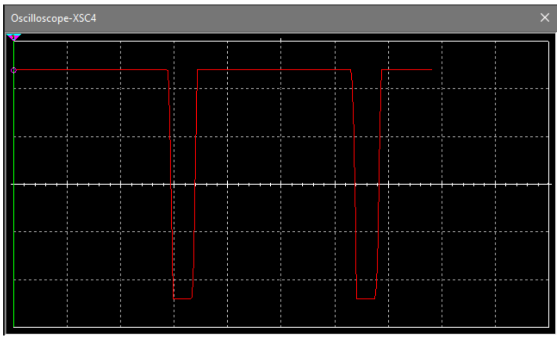
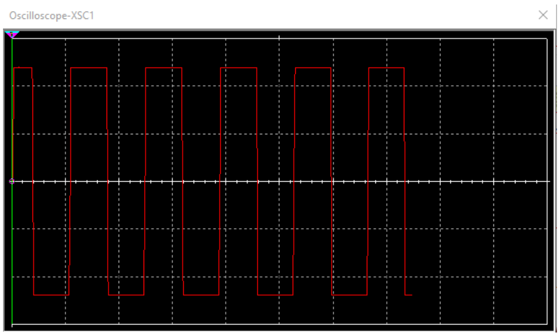


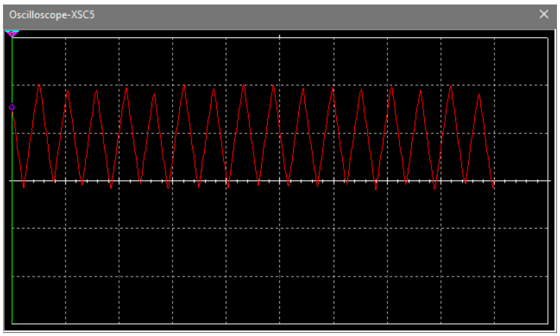
Figure 10: Power Supply Circuit



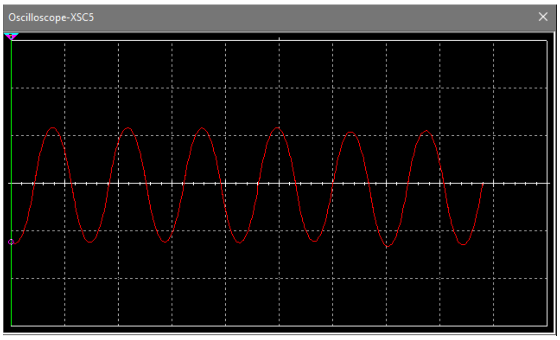
(a) PWM Wave



(b) Square Wave



(c) Triangle Wave



(d) Sine Wave

7 Conclusion & Future Works

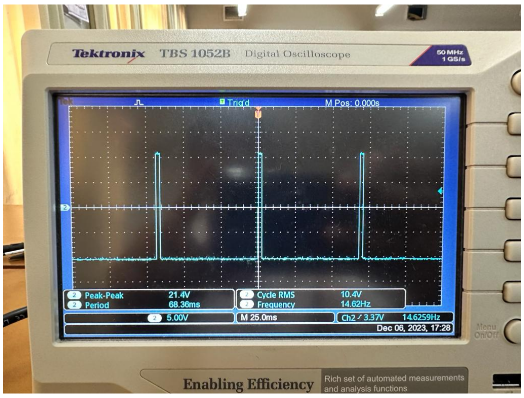
Waveform	Achieved Maximum Frequency
Triangle	42 kHz
Saw Tooth	22 kHz
PWM	25 kHz
Sinusoidal	21 kHz

To enhance the function generator's performance and usability, the following improvements are proposed:

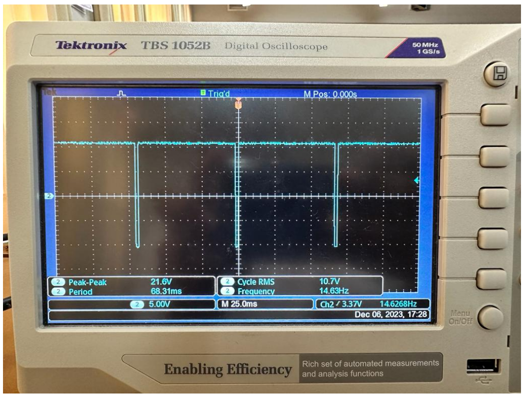
- Upgrading op-amps with higher slew rates to surpass the 20kHz frequency limit, enabling the generation of higher frequency waveforms.
- Implementing higher-order filters, like fourth or fifth-order configurations, in sine wave generation to attain greater precision and accuracy in waveform production.
- Integrating an LCD screen to display waveform details such as amplitude, frequency, and DC shift, thus enhancing user interaction and convenience.
- Replacing existing voltage regulators with a more efficient switch-mode power supply to improve power efficiency, reducing the need for a 30V input to produce a 12V output.
- Exploring development opportunities for the function generator to operate using AC voltage, expanding its compatibility with various power sources and increasing versatility.

(a) Enclosure

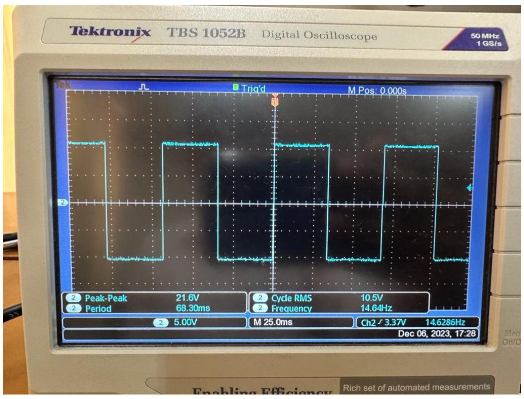
(b) Enclosure



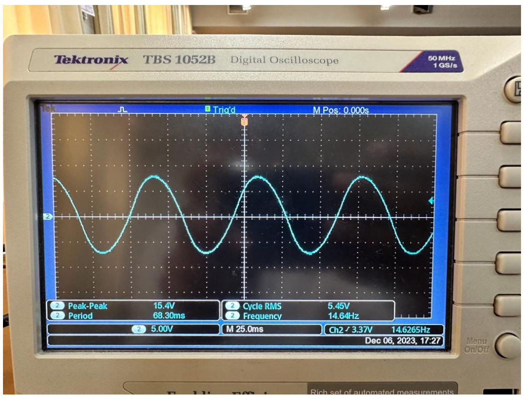
(c) PWM Wave 1% Duty



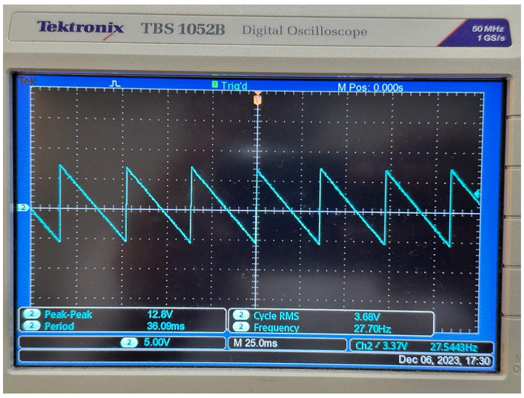
(d) PWM Wave 99% Duty



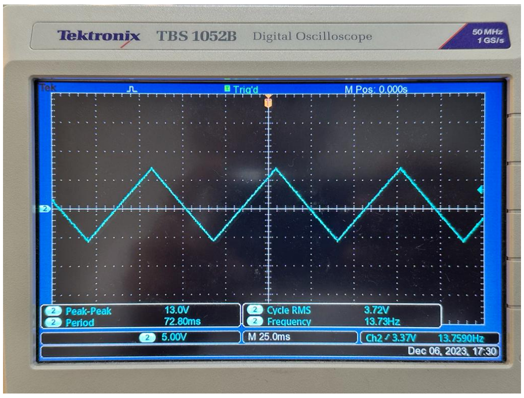
(e) Square Wave (50% Duty)



(f) Sine Wave



(a) Saw Tooth Wave



(b) Triangle Wave

8 Contribution of Group Members

Name	Task
BASNAYAKE B.Y.N	Circuit Implementation, Simulations, Debugging
DE ZOYSA A.K.N	Circuit Implementation, PCB design
JAYATHISSA R.M.K.C	Circuit Implementation, Enclosure Design
RATNAYAKE R.M.L.H	Circuit Implementation, PCB Design, Enclosure Design

Acknowledgment

References

[1] Instructables. Function generator. [Online]. Available: https://www.instructables.com/Function-Generator/

[2] Learning About Electronics. Function generator circuit. [Online]. Available: http://www.learningaboutelectronics.com/Articles/Function-generator-circuit.php