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Function Generator

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Contents

Abstract

In this report, we have outlined the design process for an analog function generator. The entire design was constructed using analog components such as op-amps, transistors, capacitors, resistors, etc. The report provides details on the production of sine, square, triangular, and sawtooth waves, with amplitude variation from 0V to 10V, frequency ranging from 20Hz to 20kHz, and a variable duty cycle for PWM waves from 1% to 99%. Additionally, the report includes PCB designs, enclosure designs, and suggestions for future improvements that can be implemented.

1 Introduction and Functionality

In our project, we aimed to design a versatile function generator employing basic analog circuits and components such as transistors, resistors, potentiometers, op-amps, and capacitors. The function generator is intended to produce sine, square, triangular, and sawtooth waves, with amplitude variation from 0V to 10V, frequency ranging from 20Hz to 20kHz, and a variable duty cycle for PWM waves from 1% to 99%. For square wave generation, we utilized an op-amp Schmitt trigger exploiting hysteresis. PWM wave generation involved modulating a triangle waveform through integration of a square wave with a DC offset. Frequency variation was achieved by adjusting resistor and capacitor values. Op-amps, specifically NE5532, were chosen for their high slew rate and sufficient bandwidth. Complementary symmetric transistors and MOSFETs were employed for balanced operation and efficient amplification. Additionally, a dedicated power supply circuit capable of generating a 12V dual power supply was designed to meet the requirements of the op-amps.

2 Requirements

The given requirements were met in the design of the function generator.

- **Waves:** square / triangle / sawtooth / sine
- **Amplitude variation:** 0V – 10V
- **Frequency variation:** 20Hz – 20kHz
- **Variable duty cycle for PWM wave:** 1% - 99%
- **Should be able to drive a 50Ω minimum load.**

3 Calculations and design

3.1 Square wave generation

We constructed a square wave generator utilizing an op-amp Schmitt trigger. This device exploits the hysteresis property of the Schmitt trigger, using a positive feedback to generate a square wave. The input triangle wave is applied to the non-inverting terminal of the Schmitt trigger. Initially in a stable state, the trigger transitions when the rising edge of the triangle wave surpasses the upper threshold, causing the output to switch states. Conversely, when the falling edge of the triangle wave crosses the lower threshold, the output reverts to its original state. This process repeats, resulting in the continuous generation of a square wave as the triangle wave oscillates.

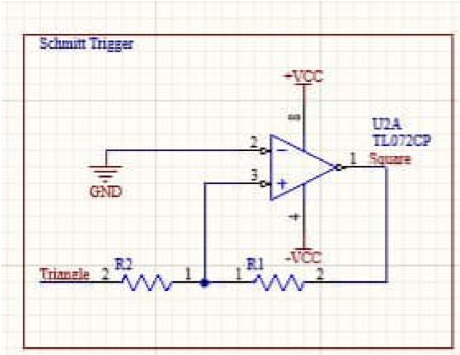

Figure 1: Schmitt trigger

3.2 PWM wave generation

The duty cycle variation is achieved by varying the voltage level between -Vs and +Vs of the noninverting terminal of the integrator. In generating a PWM wave, a triangle waveform, created through integration of a square wave, is modulated by a DC offset. This offset, applied to the non-inverting terminal, shifts the triangular waveform, influencing the duty cycle and producing a precisely controlled PWM output with varied average voltage.

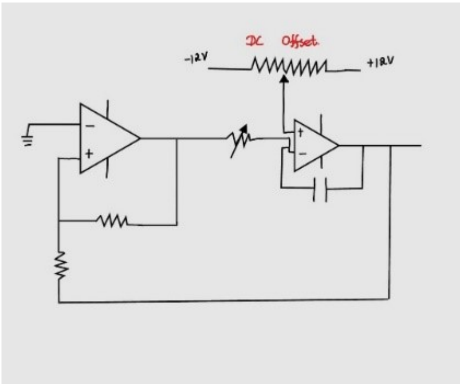

Figure 2: PWM wave with DC offset

3.3 Saw-tooth Wave Generation

To design a sawtooth wave generator, utilize an operational amplifier (op-amp) configured as an inverting amplifier. Employ a Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) as a switch in conjunction with the op-amp. Connect a resistor from the input signal to the MOSFET gate, allowing the capacitor to charge through the MOSFET when it is on. Implement a feedback network with resistors to set the gain of the inverting amplifier. This cyclical process results in a sawtooth waveform.

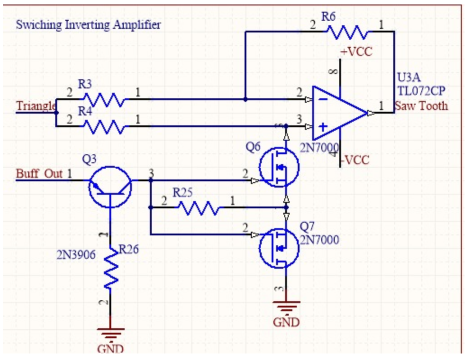

Figure 3: Saw tooth wave generating circuit

3.4 Triangle Wave Generation

Triangle Waves are generated by connecting integrator circuit at the output of schmitt trigger. Let the output of the schmitt trigger is at a +vsat , the integrator continuously integrates the signal until the output voltage reaching a specific threshold level. Upon crossing this threshold, the Schmitt trigger switches its output to -Vsat. The integrator then proceeds to integrate this -Vsat signal for a finite duration. By repeating this process generates a triangular waveform in the circuit.

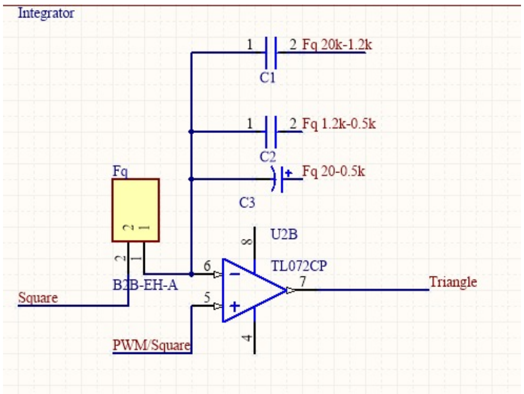

Figure 4: Designing of triangular circuit

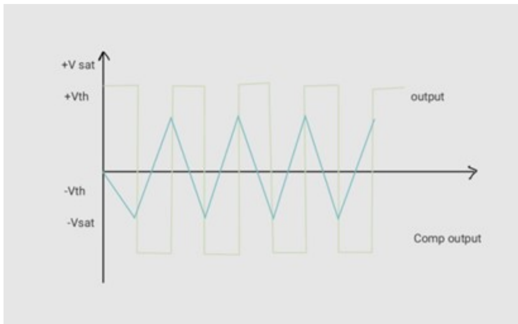

Figure 5: Triangle wave

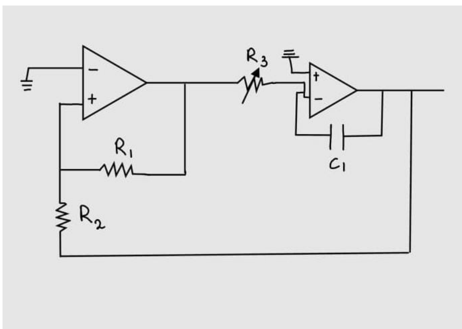

Figure 6

$$V_+ = \frac{R1}{R1+R2}V_X + \frac{R2}{R1+R2}V_{\text{sat}} \tag{1}$$

$$V_+ = 0 \tag{2}$$

$$V_{\text{out1}} = -\frac{R2}{R1} \cdot V_{\text{sat}} \tag{3}$$

$$V_{\text{out2}} = \frac{R2}{R1} \cdot V_{\text{sat}} \tag{4}$$

$$V_{\text{PP}} = 2\frac{R2}{R1} \cdot V_{\text{sat}} \tag{5}$$

$$V_{\text{PP}} = -\frac{1}{R3C1}\int_0^{T/2} V_{\text{in}}(t)\,dt \tag{6}$$

$$f = \frac{R_1}{4R_3R_2C_1} \tag{7}$$

Amplitude

$$V_{\text{PP}} = 2\frac{R2}{R1} \cdot V_{\text{sat}} \tag{8}$$

frequency

$$f = \frac{R_1}{4R_3R_2C_1} \tag{9}$$

4 Changing frequency in regions

The frequency is varied by changing a resistor value and capacitor value. We have used four capacitors (connected to the integrator) to cover the range of 20Hz to 20kHz. To finely change frequencies in each region, a variable resistor was used

Frequency range	**capacitor value**
20Hz - 500Hz	1μF
500Hz - 1.2kHz	100nF
1.2kHz - 20kHz	10μF

Table 1: capacitor values needed for each range

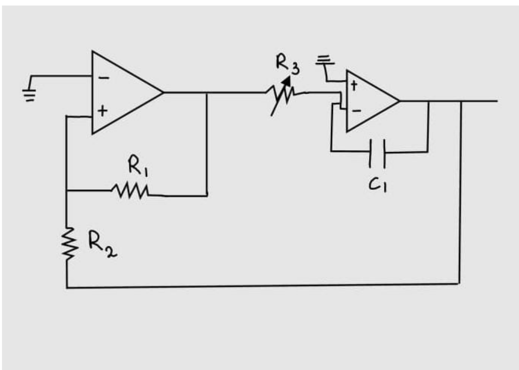

Figure 7: Multisim Schematic Diagram

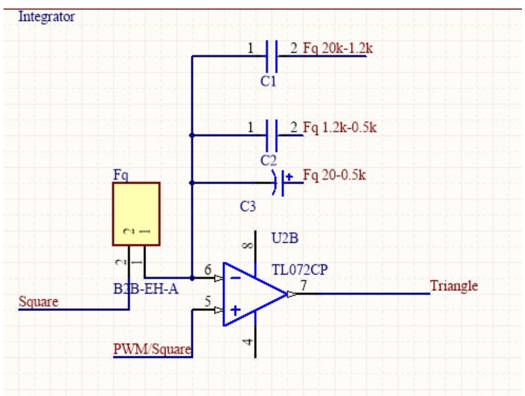

Figure 8: Capacitor bank

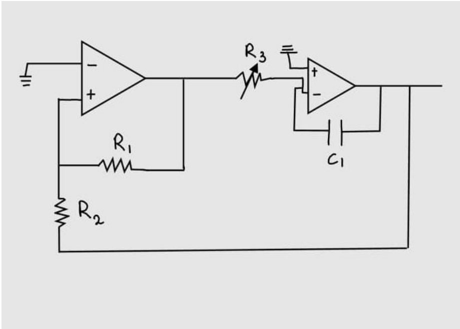

Figure 9: Schmitt trigger

$$V_+ = \frac{R1}{R1+R2}V_X + \frac{R2}{R1+R2}V_{\text{sat}} \tag{10}$$

$$V_+ = 0 \tag{11}$$

$$V_{\text{out1}} = -\frac{R2}{R1}\cdot V_{\text{sat}} \tag{12}$$

$$V_{\text{out2}} = \frac{R2}{R1}\cdot V_{\text{sat}} \tag{13}$$

$$V_{\text{PP}} = 2\frac{R2}{R1}\cdot V_{\text{sat}} \tag{14}$$

$$V_+ = 0 \tag{15}$$

$$V_{\text{PP}} = -\frac{1}{R3C1}\int_0^{T/2} V_{\text{in}}(t)\,dt \tag{16}$$

$$f = \frac{R_1}{4R_3R_2C_1} \tag{17}$$

5 Selection of components

5.1 Op-Amp selection

For all implementations, the op-amps that were used were NE5532. NE5532 op-amp has a slew rate of 8V/µs. Such a high slew rate is needed since sawtooth and square wave forms becomes distorted in higher frequencies. The bandwidth of the Op-amp is 10MHz. It is enough to generate the frequency range required (20Hz-20kHz).

5.2 Transistor selection

Two complementary symmetric transistors, TIP31C (npn) and TIP32C (pnp), were used in the push-pull circuit to achieve balanced operation, reducing distortion and enabling efficient amplification of both the positive and negative halves of the input signal. Both transistors have a maximum collector current of 3A; since the circuit should support a maximum current of 200mA (10V/50Ω), these transistors were deemed suitable for the circuit. In the generation of the sawtooth wave, a switching circuit was implemented using two 2N7000 MOSFETs and a 2N3906 (pnp). The maximum collector current of the 2N3906 is 200mA, which is within the acceptable range and does not exceed the circuit's maximum supported current.

6 Power supply

Since each op-amp requires a 12V dual power supply, a power supply circuit capable of generating a dual 12V power supply was designed. The power supply is designed using both a negative voltage regulator and a positive voltage regulator, along with an op-amp buffer and a push-pull circuit.

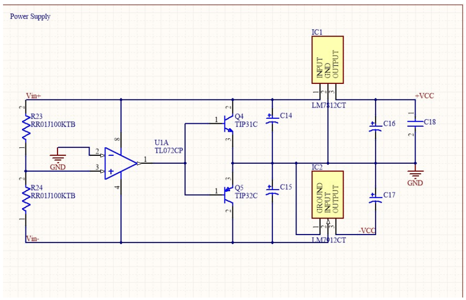

Figure 10: Power supply

7 Push Pull Output with Voltage Buffer

The amplifier output is sent to a buffer with a push-pull output stage designed to enhance current drive, utilizing a complementary pair of NPN and PNP transistors. The op-amp buffer removes

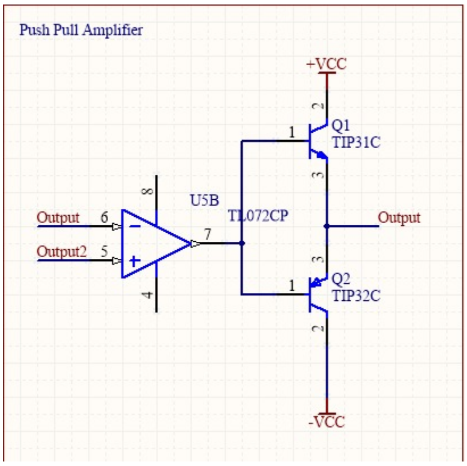

Figure 11: circuit for push pull

crossover distortion in the push-pull amplifier. In a standard push-pull configuration, when the instantaneous amplitude is small, both transistors remain off, leading to distortion. However, in this circuit, the absence of negative feedback in such situations causes the op-amp output to saturate. As a result, one of the transistors turns on, preventing distortion. The buffer also maintains a unity gain.

8 Simulation & Testing

Creating electronic circuits involves a challenging and time-consuming process. To guarantee the final product aligns with the desired specifications, it is crucial to simulate and test the circuit before progressing to the manufacturing phase of the printed circuit board (PCB). The circuit design was simulated and validated for functionality using the National Instruments (NI) Multisim software. After simulating and optimizing the circuit's performance, it was implemented on a breadboard, and waveform analysis was conducted with an oscilloscope. This visual representation of the circuit's signals enabled the identification of any disparities between the simulated and actual results.

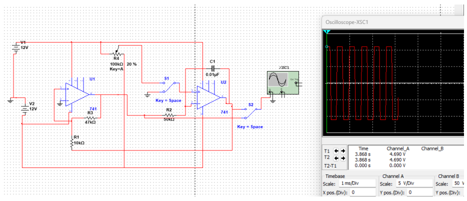

Figure 12: Simulation in multisim

9 Amplitude variation and DC offset

In the common amplifier, a summing amplifier with DC offset to efficiently handle input signals. This summing amplifier was designed to sum multiple input waveforms while accounting for a specific DC offset, enhancing the amplifier's adaptability. Specifically for square wave signals, it integrated an inverting amplifier as a gain reduction stage. This additional layer of gain reduction ensures that the square wave signal is appropriately shaped and scaled before being routed to the common amplifier. a common inverting amplifier which will allow amplitude variation between 0-12 V. The wave amplitudes are adjusted to the same level before sending through this amplifier to maintain consistency.

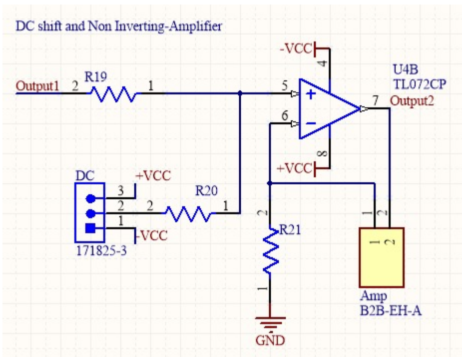

Figure 13: Amplitude and DC offset variation circuit

9.1 Amplitude variation of square wave

Since the square wave generated by the Schmitt trigger oscillates between +12V and -12V, we have utilized an inverting amplifier to enable variation of the amplitude in the range of 0V to 10V by attenuating the wave.

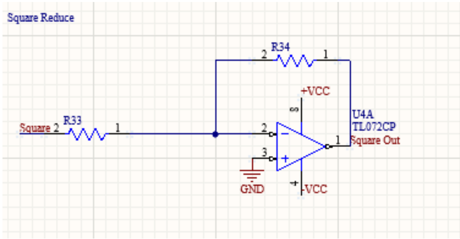

Figure 14: Amplitude and DC offset variation circuit

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10 PCB Design

PCB design has done using Altium Designe. It was designed as a double layer PCB.

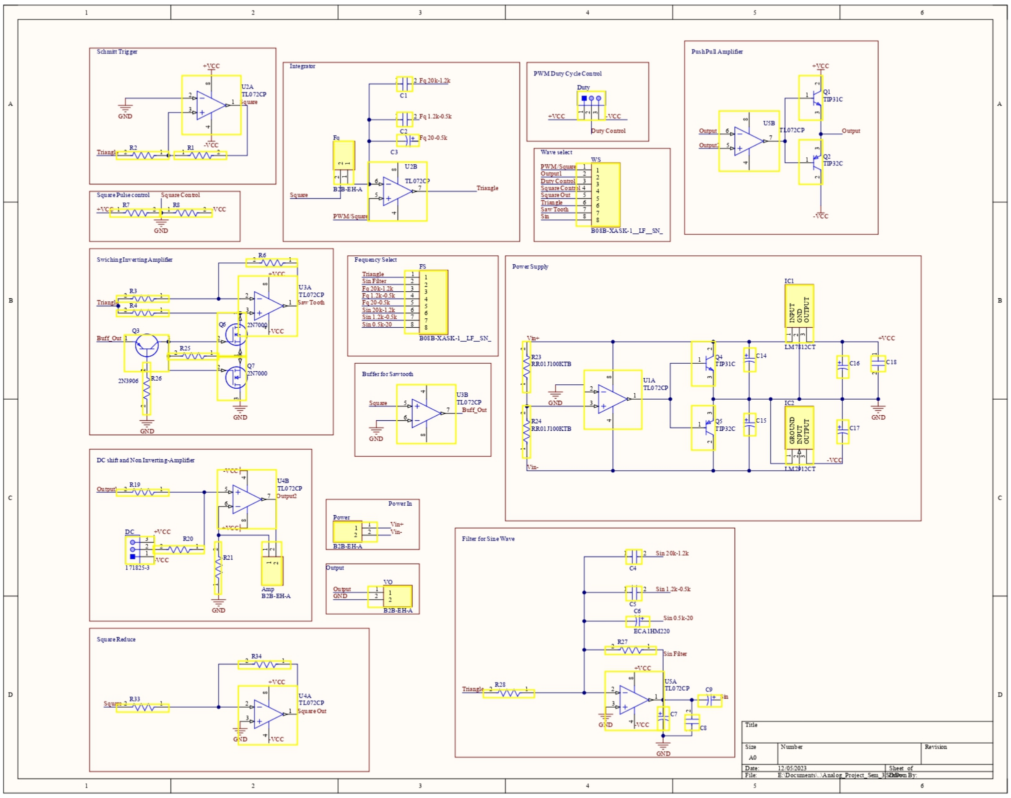


Figure 15: PCB Schematic

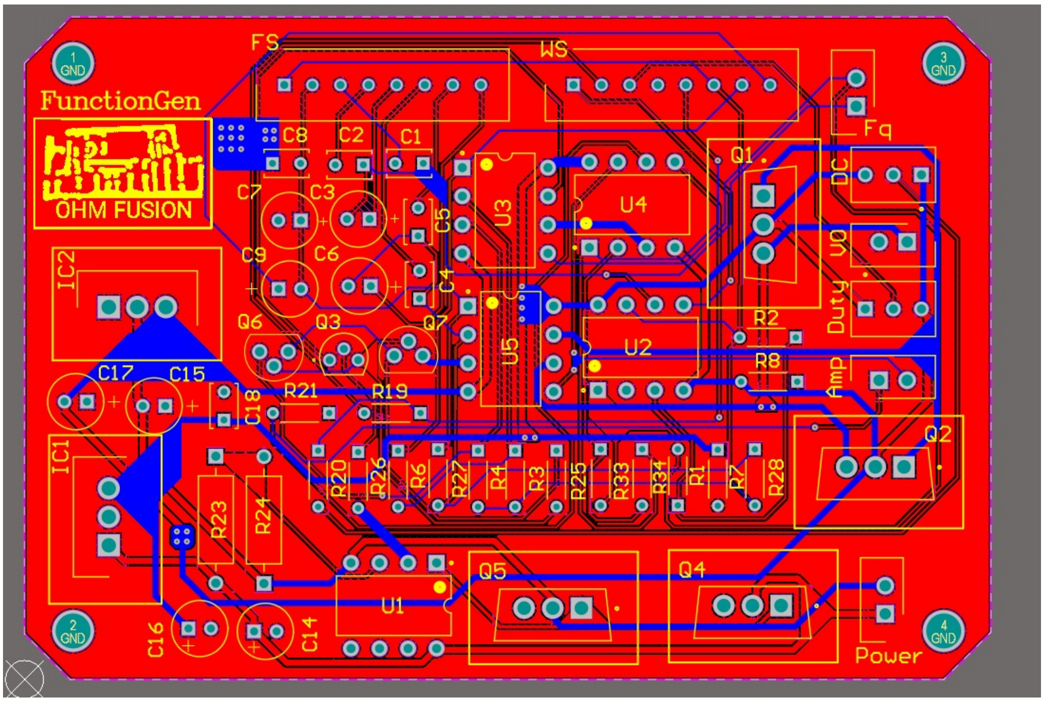


Figure 16: PCB routing

11 Enclosure Design

Enclosure design was created using Solidworks software.

Figure 17: Enclosure

Figure 18: User interface

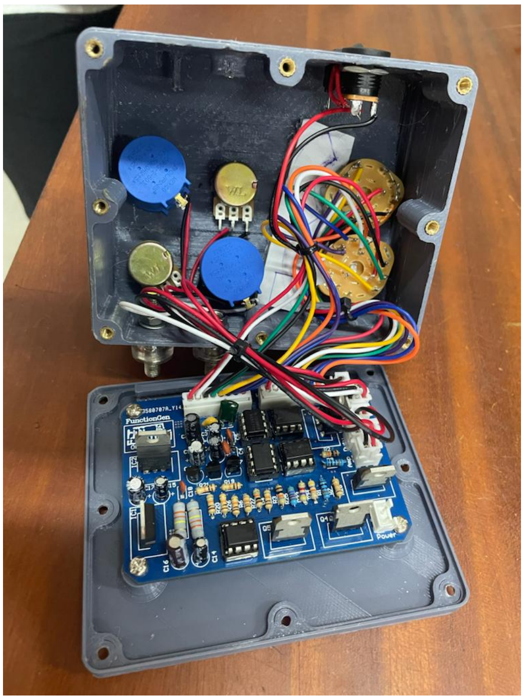
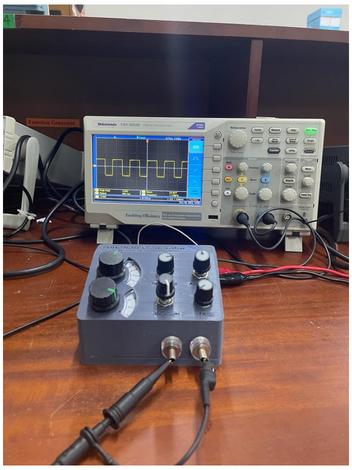


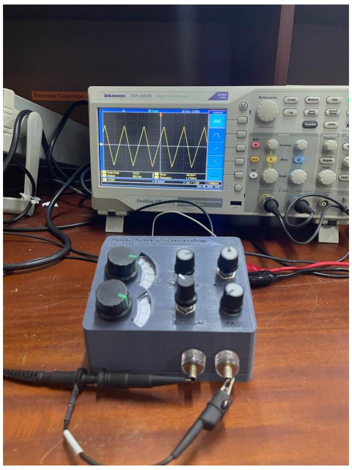
Figure 19: Assembly

Figure 20: Enclosure

12 Hardware Testing



(a) Square Wave



(b) Triangle wave

(c) Sine

(d) PWM wave

13 Future improvements

In our project, we encountered distortion in the generated sawtooth wave. While this issue could have been addressed through additional testing, unfortunately, time constraints prevented us from doing so. In the generation of the sine wave, we employed a low-pass filter. However, a more effective approach would have involved using higher-order filters to completely eliminate any potential further distortions in the sine wave.

14 Contribution of Group Members

- **210212N:** Prototyping, Assembly
- **210215C:** Enclosure design, Documentation
- **210216F:** Prototyping, Documentation
- **210205V:** PCB design, Enclosure design, Assembly

15 References

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