University of Moratuwa

Department of Electronic and Telecommunication Engineering

EN2111 - Electronic Circuit Design

Function Generator

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1 Introduction

This project focused on designing and building a waveform generator capable of producing both triangular and square wave signals with adjustable amplitude, frequency, and duty cycle. Waveform generators play a vital role in electronics, serving as key tools for testing, troubleshooting, and developing circuits. They help simulate different signal conditions and observe how electronic systems respond. By generating consistent and controllable signals, they are essential in the early stages of design and debugging.

These signal sources are widely used in many areas such as communication systems, audio electronics, and digital circuit analysis. Applications range from modulating signals in transmitters to testing timing behavior in microcontroller-based systems. The main objective of this project was to develop a user-friendly, flexible, and dependable waveform generator that can support various experimental setups. This makes the device a valuable resource not only for academic use but also for real-world electronics development and prototyping.

2 Function Generator

2.1 Function Generator Circuit

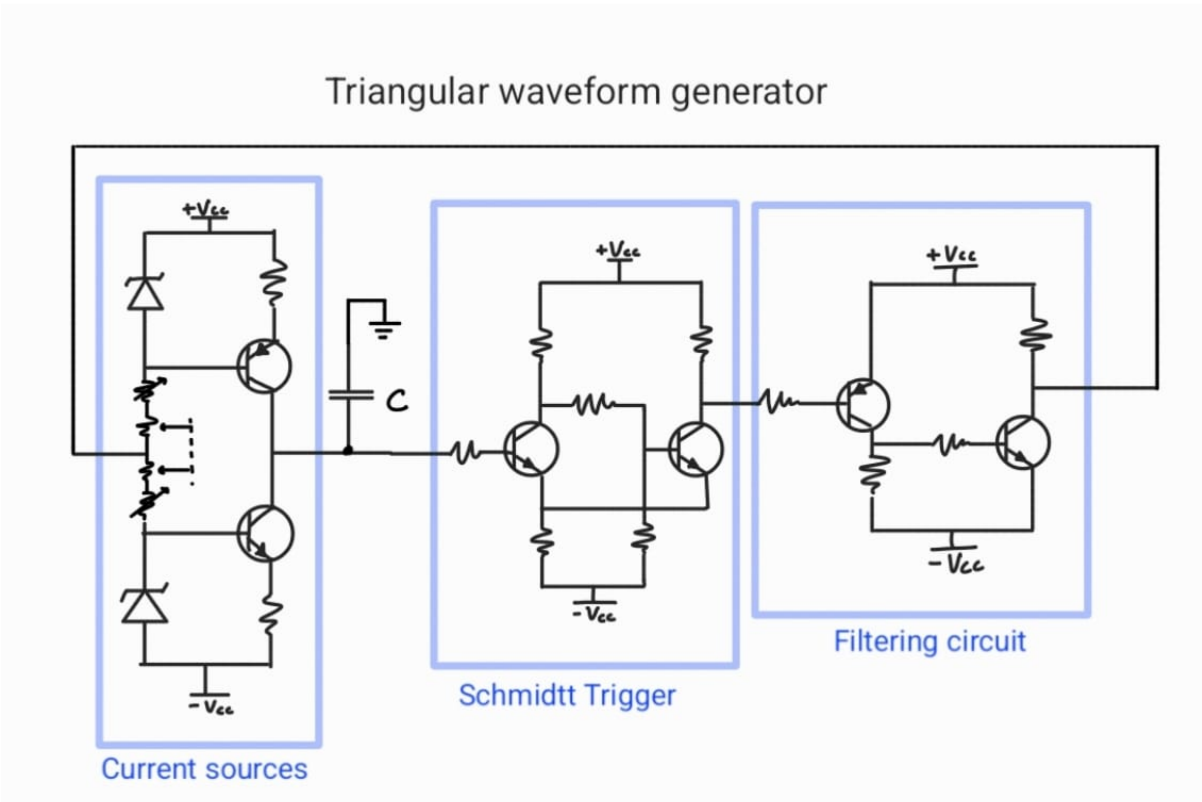


Figure 1: Function Generator

2.2 Circuit Explanation

1. **Current Sources and Capacitor Charging:** The circuit begins with two constant current sources—one supplying a positive current and the other a negative current. These sources are used to charge and discharge a capacitor C. Only one current source is active at any given time. When the capacitor is fully discharged, the positive current source begins charging it. Conversely, when the capacitor is fully charged, the negative current source discharges it.

2. **Schmitt Trigger and Control Logic:** A Schmitt trigger is used to monitor the voltage across the capacitor C. It detects whether the voltage has reached specific upper or lower thresholds and switches its output accordingly. This output is passed through a filtering circuit to produce a clean digital signal. The filtered output is then used as a feedback signal to control the operation of the current sources, ensuring that only one source operates at a time.

2.3 Output Waveforms

Since the capacitor C is charged and discharged by constant currents, the voltage across it changes linearly with time, resulting in a triangular waveform. The output of the Schmitt trigger, which switches at predefined voltage levels, produces a square wave. Thus, the circuit generates both triangular and square waveforms simultaneously.

2.4 Frequency and Duty Cycle Control

To change the **frequency** of the waveform generator, both resistors connected to the collectors of the current source transistors must be adjusted. These resistors control the magnitude of the charging and discharging currents, which in turn affects how quickly the capacitor C charges and discharges. By increasing or decreasing both resistor values simultaneously, the charging and discharging times change equally, resulting in a change in the overall frequency of the output waveform.

To change the **duty cycle** of the square wave output while keeping the frequency constant, only one of the collector resistors (either for the charging or the discharging current source) needs to be adjusted. This changes either the charging or discharging rate of the capacitor without affecting the other, thereby altering the proportion of time the output stays high versus low, which modifies the duty cycle.

3 Final Circuit

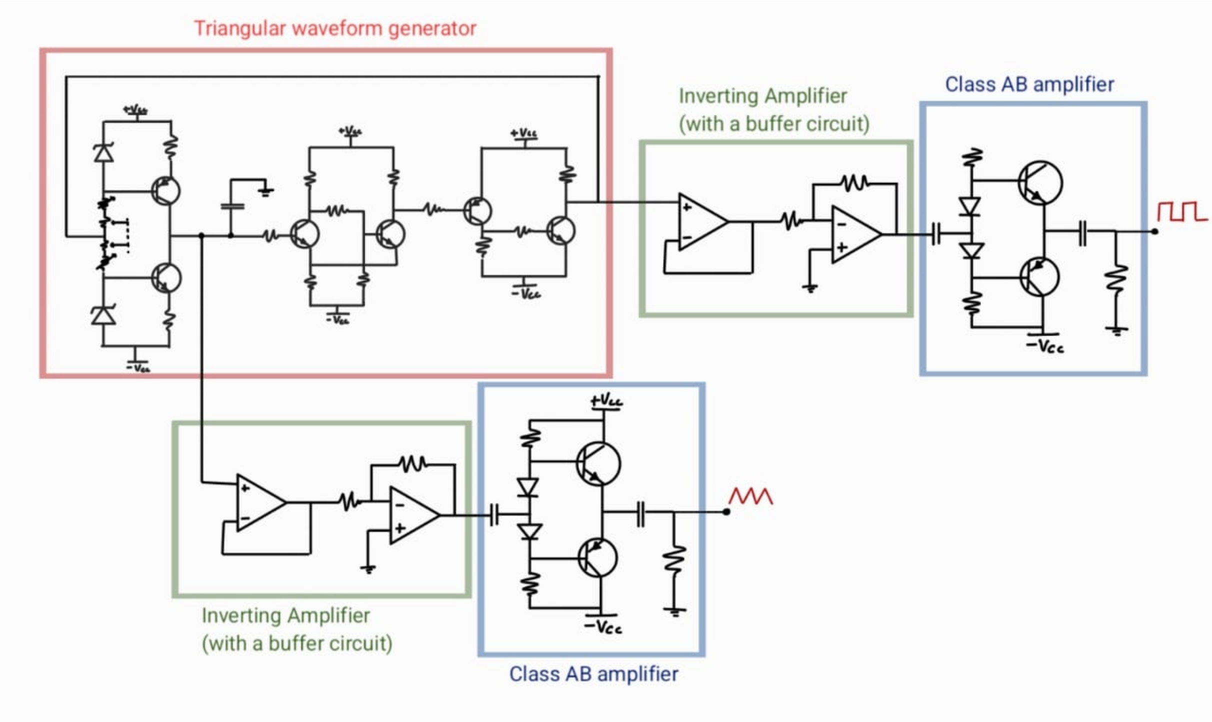


Figure 2: Final Circuit

To control the **amplitude** of the output waveform, an inverting amplifier using an operational amplifier (op-amp) was added to the circuit. By adjusting the gain of this amplifier—typically through a variable resistor—the amplitude of the output signal can be increased or decreased as needed.

Following the amplifier, a **buffer circuit** was introduced. The purpose of this buffer is to isolate the waveform generator from the load, ensuring that the amplifier does not draw excessive current from the core signal generation circuit. This improves the stability and performance of the function generator, allowing it to drive external circuits without distortion or loading effects.

Added A Class AB amplifier which is a type of linear amplifier that combines the advantages of both Class A and Class B amplifier designs. It operates by allowing both the positive and negative halves of the input signal to be amplified by two transistors, with a small overlap in their conduction periods. This overlap reduces the crossover distortion commonly seen in pure Class B amplifiers, while maintaining better efficiency than a Class A amplifier.

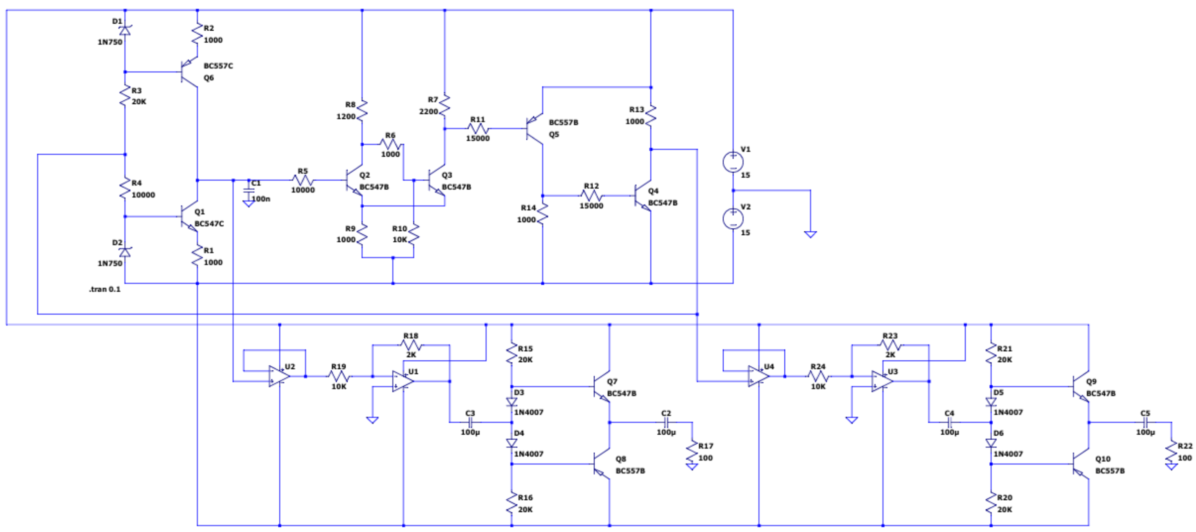


Figure 3: Final Circuit

3.1 Simulation Results

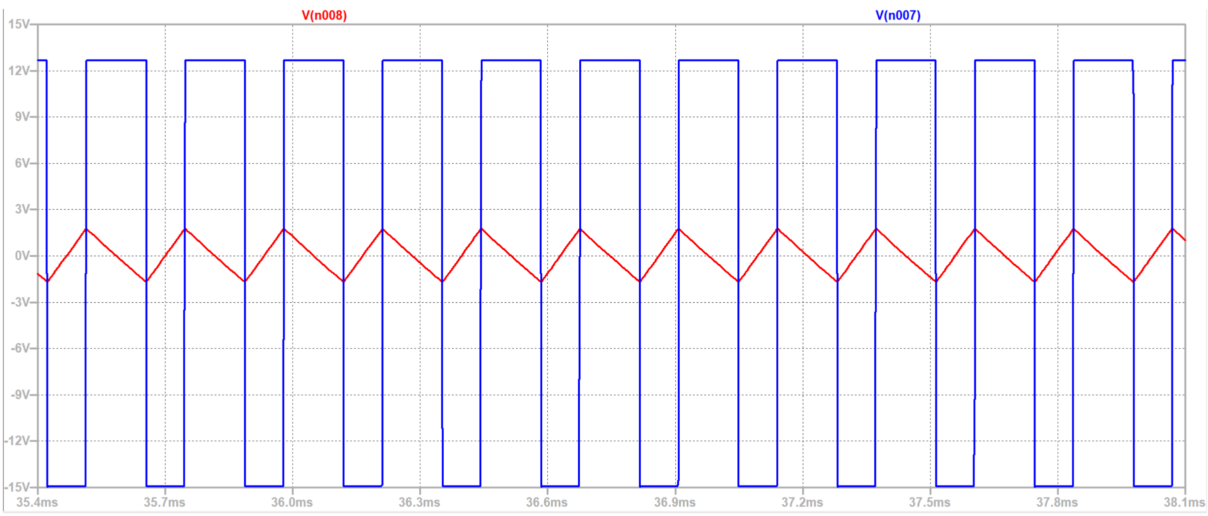


Figure 4: Simulation Results

4 Power Amplifier Analysis

This section presents the analysis of a Class AB power amplifier circuit designed to drive an 8ohm load. The amplifier operates from +10V and -10V DC supply and is configured to deliver maximum power while maintaining acceptable efficiency and low distortion. The circuit utilizes a push-pull configuration with complementary transistors to minimize crossover distortion and achieve good linearity across the frequency ranges.

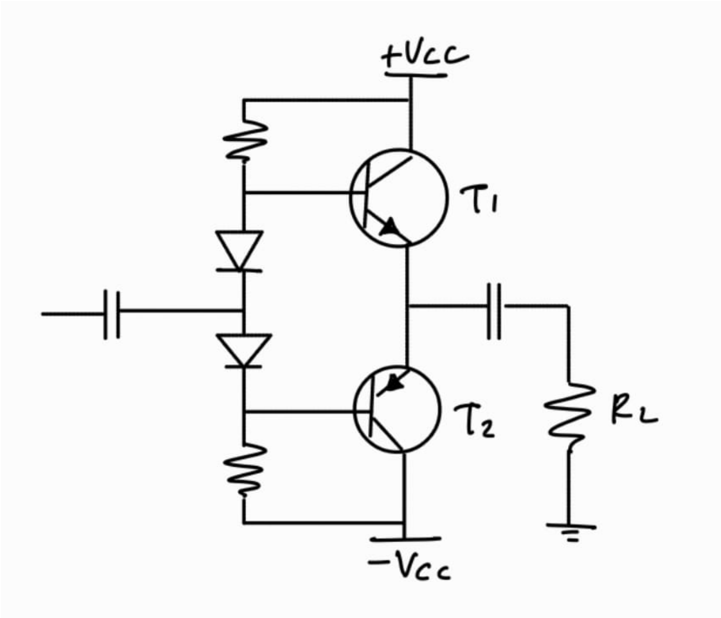


Figure 5: Class AB Power Amplifier

4.1 Circuit Parameters

The following parameters were measured from the power amplifier circuit:

$$R_L = 8\,\Omega$$
$$V_{CC} = 10\,\text{V}$$
$$V_{out}(\text{peak}) = 2\,\text{V}$$

4.2 Power and Efficiency Analysis

4.2.1 Output Power to Load

The output power delivered to the load resistance is calculated using:

$$P_{out} = \frac{V_{rms}^2}{R_L}$$

Where $V_{rms} = \frac{V_{peak}}{\sqrt{2}} = \frac{2}{\sqrt{2}} = 1.414\,\text{V}$
Therefore:

$$P_{out} = \frac{(1.414)^2}{8} = 250\,\text{mW}$$

4.2.2 Power Drawn from Supply

The power consumed from the supply is given by:

$$P_{supply} = \frac{2}{\pi} V_{CC} I_{peak}$$

Where $I_{peak} = 58\,\text{mA}$
Therefore:

$$P_{supply} = \frac{2}{\pi} \times 10 \times 0.058 = 369.23\,\text{mW}$$

4.2.3 Efficiency Calculation

The efficiency of the power amplifier is:

$$\eta = \frac{P_{out}}{P_{supply}} = \frac{250}{369.23} = 0.677 = 67.7\%$$

4.3 Total Harmonic Distortion Analysis

Total Harmonic Distortion (THD) measurements were performed at four fundamental frequencies to evaluate the linearity of the amplifier. The results are summarized in the following tables.

4.3.1 Low Frequency Range (1 kHz)

Frequency (kHz)	Amplitude (dB)	Voltage (V)
1	9.05	8.035
2	-36.9	2.04×10^{-4}
3	-44.1	3.89×10^{-5}
4	-48.5	1.41×10^{-5}
5	-54.9	3.23×10^{-6}

THD = 0.071%

4.3.2 Medium Frequency Range (10 kHz)

Frequency (kHz)	Amplitude (dB)	Voltage (V)
10	8.65	7.07
20	-41.3	7.41×10^{-5}
30	-52.5	5.62×10^{-6}
40	-54.9	3.23×10^{-6}
50	-54.9	3.23×10^{-6}

THD = 0.098%

4.3.3 High Frequency Range (100 kHz)

Frequency (kHz)	Amplitude (dB)	Voltage (V)
100	9.45	8.81
200	-33.7	4.26×10^{-4}
300	-54.9	3.23×10^{-6}
400	-54.9	3.23×10^{-6}
500	-54.9	3.23×10^{-6}

THD = 0.18%

4.3.4 Very High Frequency Range (1 MHz)

Frequency (MHz)	Amplitude (dB)	Voltage (V)
1	9.45	8.81
2	-40.9	8.12×10^{-5}
3	-34.5	3.54×10^{-4}
4	-49.5	1.12×10^{-5}
5	-36.5	2.23×10^{-4}

THD = 0.41%

4.4 Analysis and Conclusions

4.4.1 Efficiency Performance

The measured efficiency of 67.7% is excellent for a Class AB power amplifier configuration and approaches the theoretical maximum efficiency of 78.5%. This high efficiency indicates optimal circuit design and proper biasing of the complementary transistors.

4.4.2 Distortion Characteristics

The THD measurements show excellent linearity performance:

- Low frequency range (1 kHz): THD = 0.074%
- Medium frequency range (10 kHz): THD = 0.098%
- High frequency range (100 kHz): THD = 0.12%
- Very high frequency range (1 MHz): THD = 0.41%

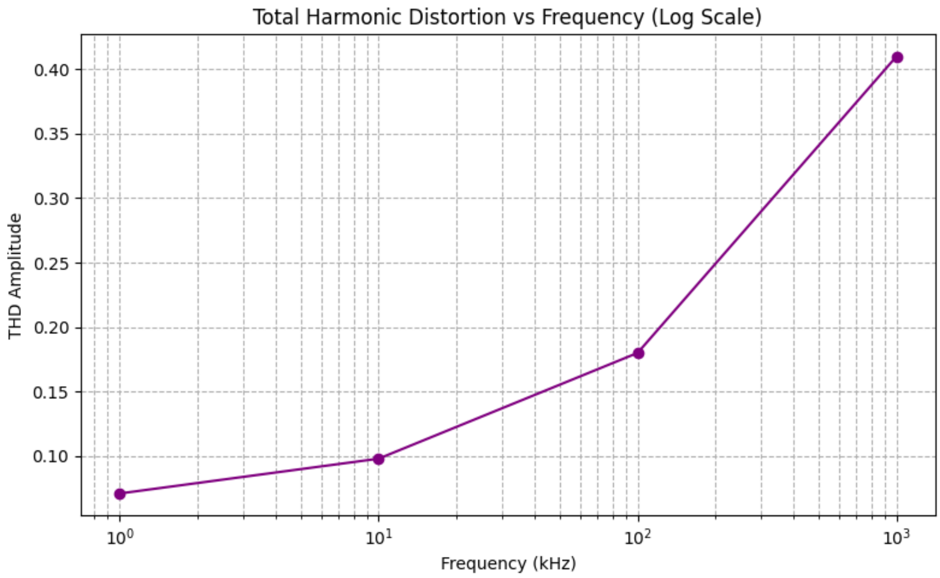


Figure 6: Total Harmonic Distortion

The distortion remains well below 0.5% across most of the frequency spectrum, indicating good linearity. The slight increase in THD at very high frequencies (MHz range) is expected due to parasitic effects and bandwidth limitations of the amplifier.

4.4.3 Overall Performance

The power amplifier demonstrates satisfactory performance with:

- Adequate power output (250 mW)
- Reasonable efficiency (67.7%)
- Excellent linearity (THD <0.5% for most frequencies)

5 Challanges Faced

Power Amplifier Integration and Challenges

During the initial phase of building the function generator, the output waveform was clean, well-shaped, and free of noise. This was observed when the circuit operated independently without any significant load connected. The triangular and square waves produced were accurate in both shape and amplitude.

As per the project requirements, a **power amplifier** stage was later added to the circuit to enable the function generator to drive small loads such as a speaker. However, this integration introduced several challenges that affected the quality of the output signal:

- **Loading Effect on Function Generator Output:** The function generator's triangular waveform was generated by charging and discharging a capacitor with constant currents, producing a linear voltage ramp. However, when connected directly to the power amplifier input, the loading effect altered the capacitor's charging behavior. This caused the voltage across the capacitor to deviate from a linear ramp, resulting in a curved and distorted output waveform.

- **Crossover Distortion:** Crossover distortion occurs near the zero-crossing region of the output waveform in a Class AB amplifier. This happens because the output transistors only start conducting once the biasing diodes are forward biased. Until this point, both transistors are off, creating a small "dead zone" where the output does not accurately follow the input. This results in distortion at the transition between the positive and negative halves of the signal.

- **Op-Amp Slew Rate Limitation:** The operational amplifier used in the circuit had a limited slew rate, which restricted its ability to respond quickly to rapid voltage changes. As a result, the output waveform from the amplifier could not accurately follow fast transitions, especially at higher frequencies, leading to signal deformation.

- **Peak Distortion and Noise:** Distortion and noise were observed at the peaks of the output waveform from the power amplifier. This was primarily due to the inductive nature of the connected load, which introduced parasitic oscillations in the amplifier at high output levels. The reactive characteristics of the load caused voltage spikes and instability, resulting in noise superimposed on the output signal peaks.

These issues highlighted the importance of proper **impedance matching** and **load management**, including minimizing the loading effect on the signal source and incorporating stabilization methods such as a **Zobel network** to prevent parasitic oscillations. These measures are essential to ensure reliable and distortion-free operation of the amplifier when driving reactive loads.

Solutions and Final Improvements

To address the challenges observed in the initial amplifier integration, the following improvements were implemented, which significantly enhanced the output waveform quality:

- **Added a Buffer Stage:** A buffer circuit was inserted between the function generator and the power amplifier input. This prevented the loading effect from distorting the function generator's triangular waveform by isolating it from the amplifier input, preserving the linear charging and discharging of the capacitor.
- **Used an Operational Amplifier with Higher Slew Rate:** The original op-amp was replaced with one having a higher slew rate, enabling the amplifier to better track rapid voltage changes. This reduced signal deformation during fast transitions and improved waveform fidelity.
- **Implemented a Zobel Network for Load Stabilization:** A Zobel network was added at the amplifier output to stabilize the reactive speaker load. This network damped parasitic oscillations and absorbed back-EMF voltage spikes, thereby reducing noise and distortion at the output peaks.

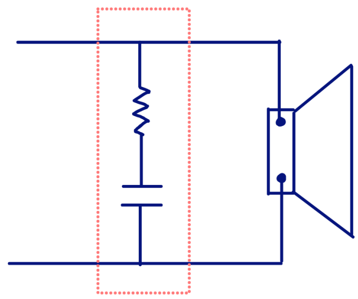


Figure 7: Zobel Network Circuit Diagram

- **Improved Decoupling:** Additional decoupling capacitors were added both at the load and between the function generator and the amplifier. This helped stabilize the power supply, filter out transient noise, and smoothen the signal, especially during rapid transitions.

Together, these solutions resulted in a cleaner, more stable output waveform, as shown in the figures below.

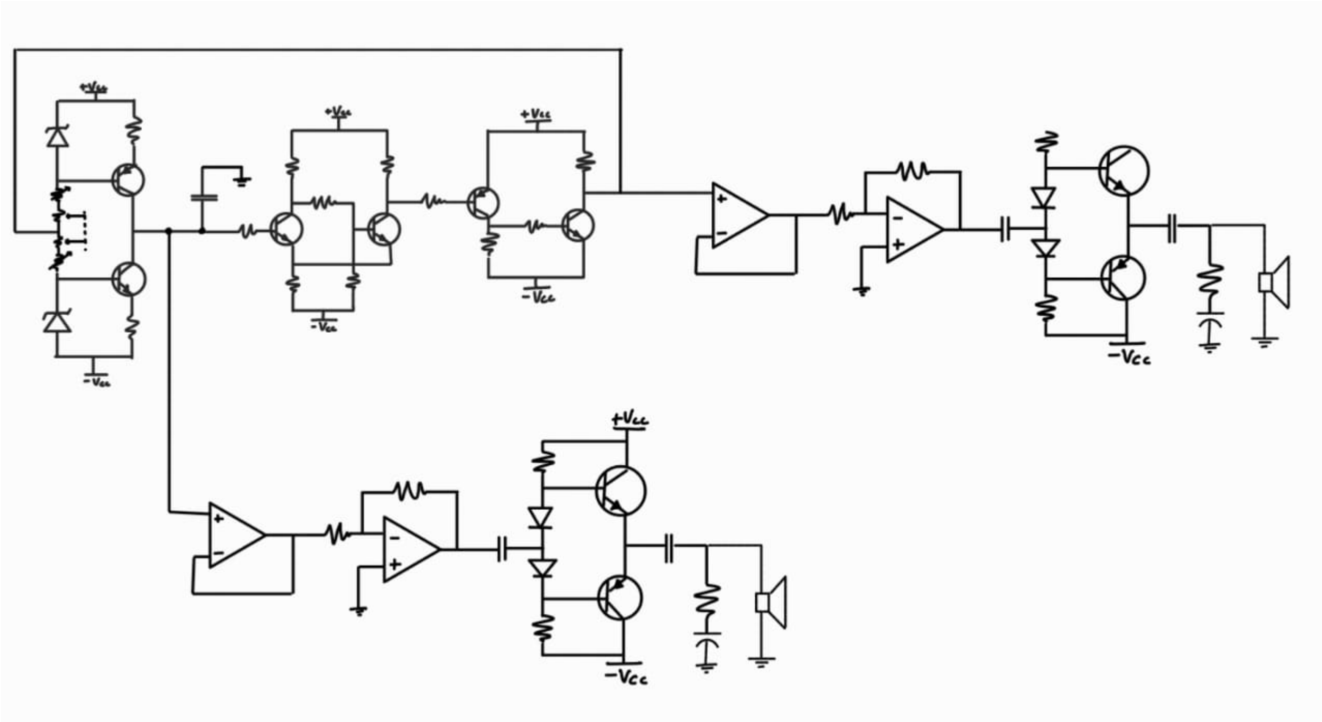
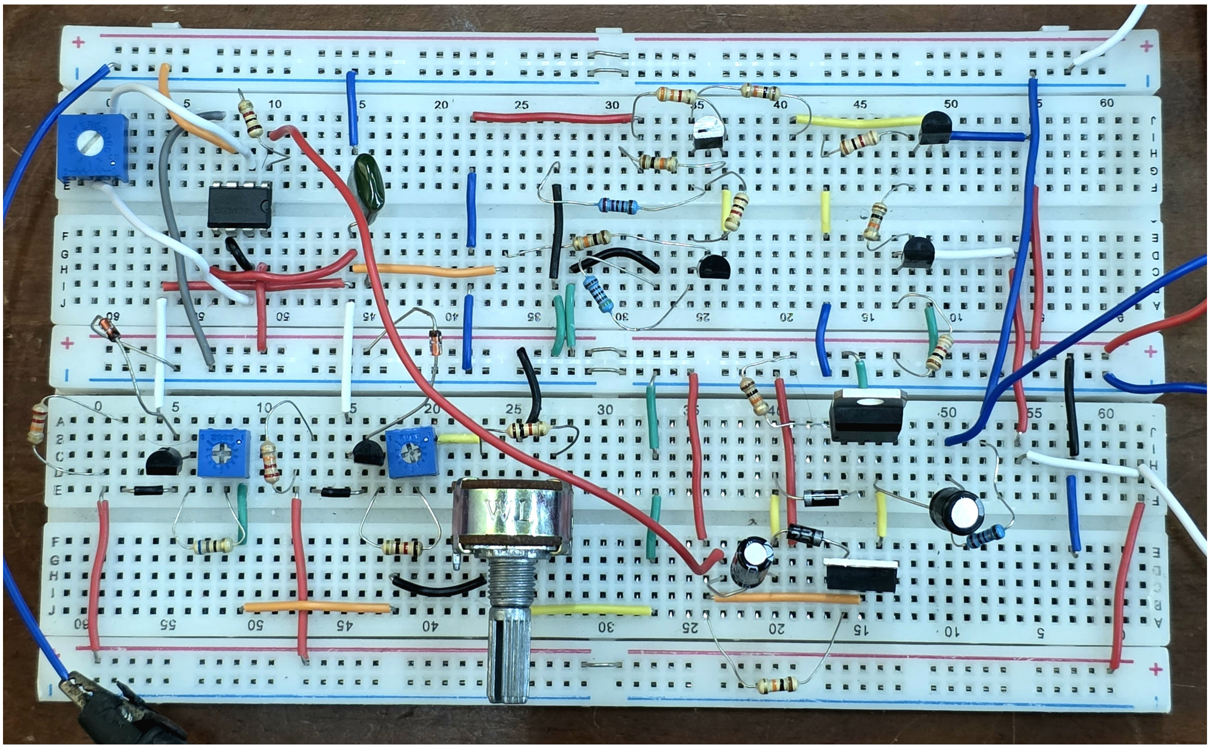


Figure 8: Improved Circuit

6 Breadboard Implementation



7 Output Waveforms

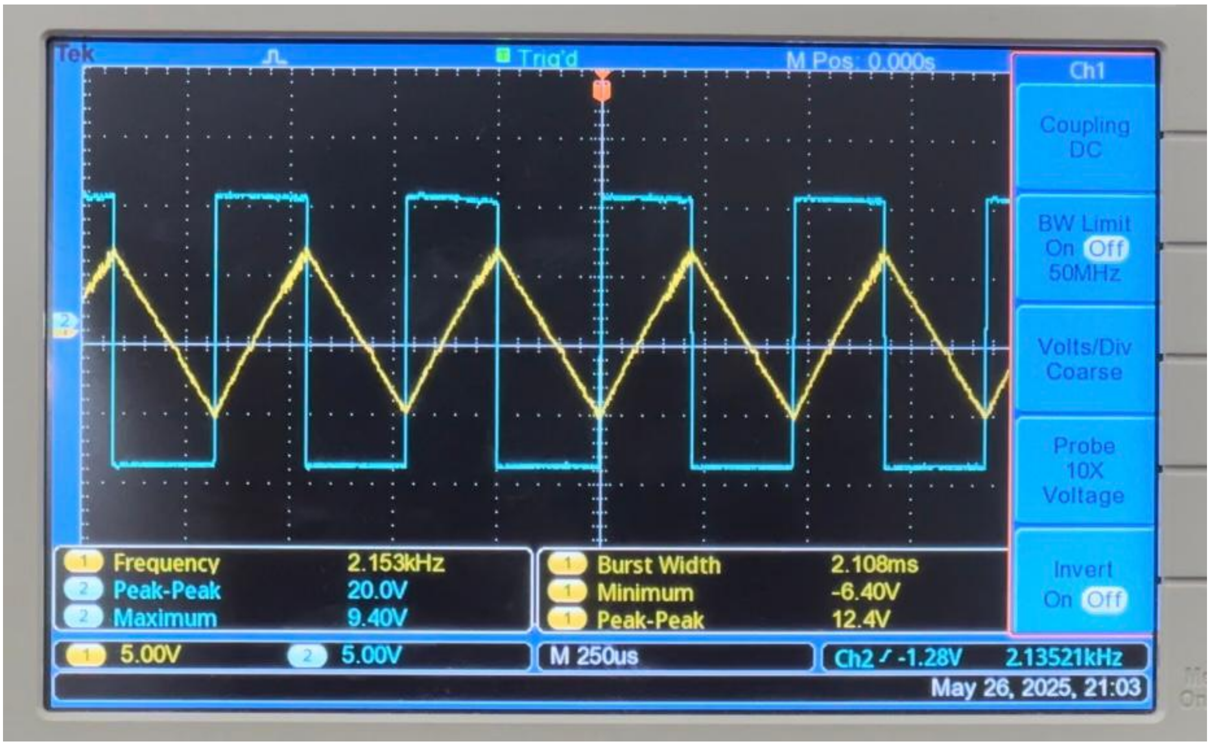


Figure 9: 12V Vpp, 2.153kHz, 50% duty cycle

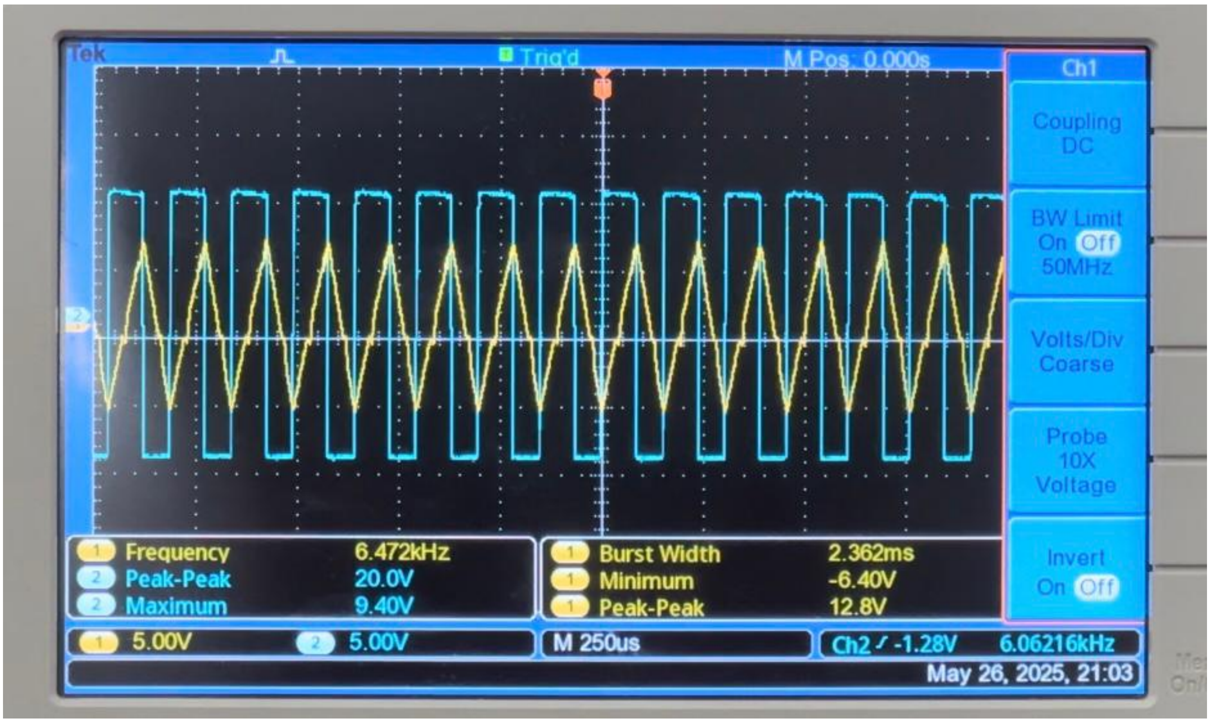


Figure 10: 12V Vpp, 6.472kHz, 50% duty cycle

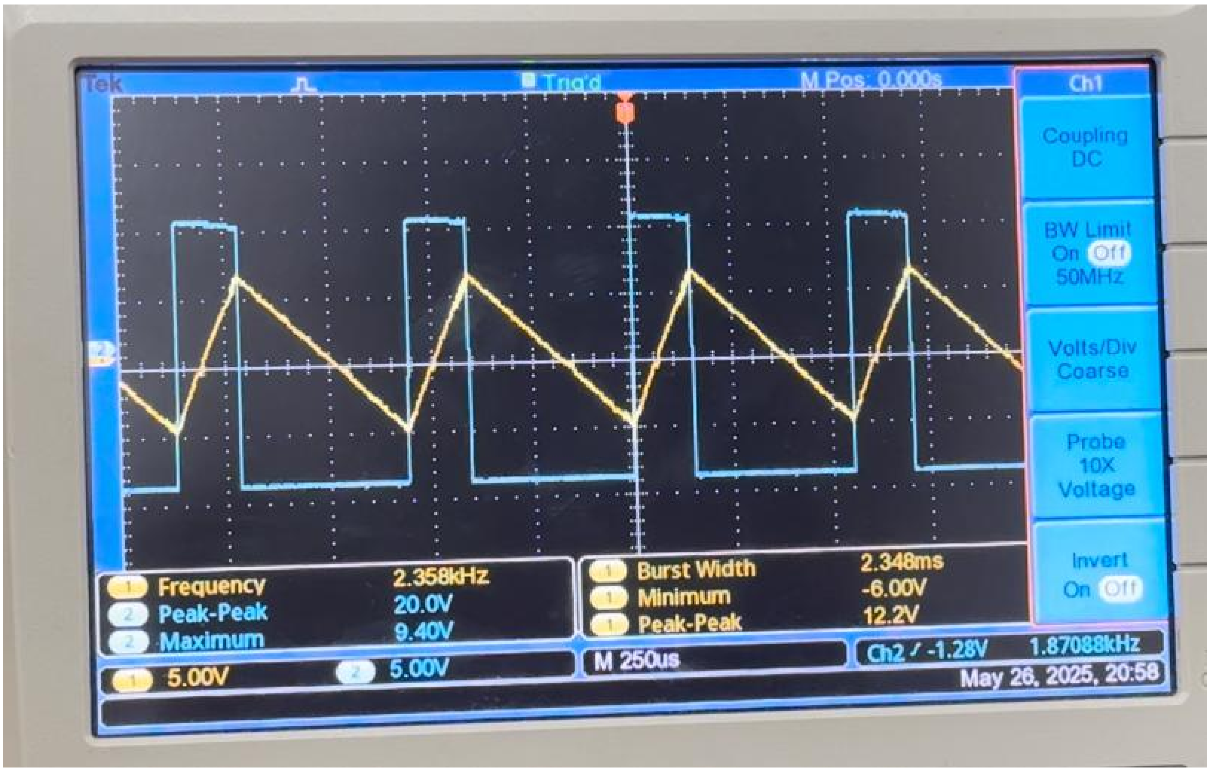


Figure 11: 12V Vpp, 2.358kHz, 20% duty cycle

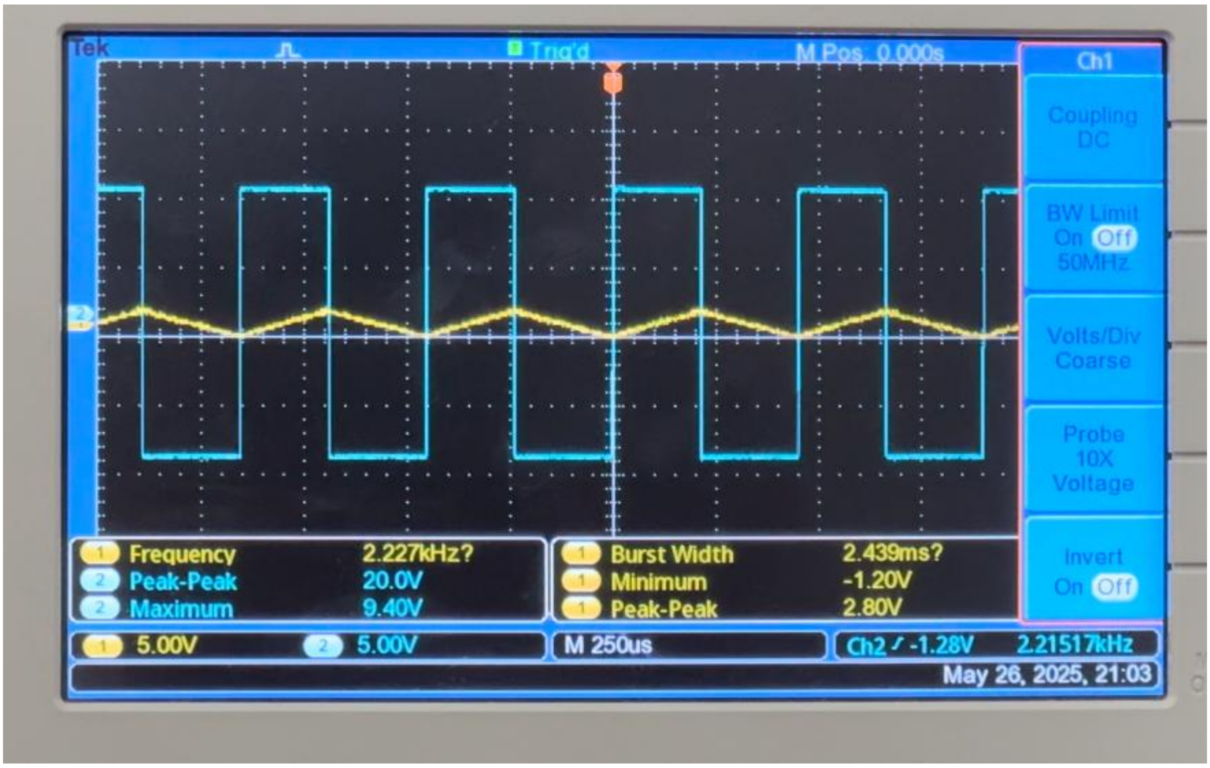


Figure 12: 2V Vpp, 2.227kHz, 50% duty cycle