Analog Kickdrum

EW-2: Project 2

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***Abstract*—The objective of this project is to build an analog kick drum circuit. It uses a transistor-based oscillator, simple RC envelope shaping, and a decay control to produce a low-frequency pulse when triggered. This includes pitch modulation through capacitor and resistor values, a trigger input, and output suitable for an external amp and 4Ω speaker. The design was tested on a breadboard, powered with ±12V, and tuned for a clean transient response. It's a practical and effective analog percussion circuit.**

I. Introduction

This project aims to design and implement a fully analog kick drum circuit that responds to external gate signals. It processes the gate using a TL081 op-amp-based gate-to-pulse converter, which sharpens the incoming signal into a short trigger pulse suitable for initiating the kick cycle. The design is modular, with each stage handling a specific aspect of sound generation and shaping.

The circuit is composed of the following key stages:

1) **Gate-to-Trigger Converter** – Converts an incoming gate signal into a short-duration trigger pulse using a TL081 configured as a comparator.
2) **Pitch Oscillator** – Generates the base low-frequency signal using a T-bridge oscillator topology, producing a decaying sine-like waveform.
3) **Pitch Envelope Stage** – Briefly modulates the oscillator's frequency at the start of the pulse, mimicking the natural pitch drop characteristic of kick drums.
4) **Decay Envelope Control** – Uses RC discharge networks to control how quickly the oscillator fades out, setting the overall length of the kick.
5) **Tone Control Stage** – Shapes the frequency response by attenuating highs and emphasizing low-end thump.
6) **Distortion/Clipping Stage** – Applies transistor-based clipping to add harmonic content and make the kick sound punchier or more aggressive.
7) **Driving the Speaker** - Reduces the distortion waveform, turning it into a valid input for the audio amplifier.

- **Final Implementation** – The full circuit was assembled on a breadboard, powered by a ±12V supply, and tested with an 4Ω speaker through an LM386 audio amplifier.
- **Presentation** - Link to Video

Performance was evaluated through both oscilloscope measurements and auditory testing. The final output produced a strong, percussive kick with tunable pitch, decay, and tonal character — all achieved using entirely analog circuitry.

II. Aim

1) **Supply Voltage:** ±12 V dual supply
2) **Input Square Pulse:** 5 V peak-to-peak
3) **Input Frequency:** 1 Hz (manual or low-rate triggering)
4) **Frequency Output:** 60–120 Hz fundamental (tunable)
5) **Load:** 4 Ω speaker
6) **Trigger Circuit:** TL081 gate-to-pulse converter
7) **Oscillator Core:** T-bridge sine wave oscillator
8) **Envelope Control:** Passive RC decay shaping
9) **Output Type:** AC-coupled audio signal

Note: To showcase waveform changes caused to the final output by each stage, we sweep all potentiometer ratios of said stage from 0.1 *(green)*, 0.5 *(blue)* & 0.9 *(red)* while keeping other ratios at 0.5.

III. Gate-to-Trigger Converter

A. Overview

The Gate-to-Trigger (GTT) converter is a crucial circuit in audio synthesis, converting a digital gate signal into a short, sharp trigger pulse for further processing by a trigger-based oscillator. This converter consists of two primary sections: a **high-pass filter** with a steep cutoff frequency and an **op-amp-based comparator**.

B. High-Pass Filter Section

The first stage of the GTT converter utilizes a high-pass filter designed to allow fast transitions of the input signal. When a gate signal is applied to the input capacitor, it generates a sharp voltage spike on the other side of the capacitor. This voltage quickly decays as the capacitor charges and ceases to pass further signal once it has stabilized. The rapid change in voltage generates the sharp, brief pulse that is essential for the next stage of triggering.

C. Comparator Section

The voltage spike generated by the capacitor is fed into an op-amp comparator circuit. The comparator is designed to trigger when the input voltage crosses a defined threshold. As the capacitor's voltage rises, the comparator's output shifts to **12V** for a brief moment, creating the **trigger pulse**. This pulse is sent to the next stage of the audio oscillator.

The comparator's output voltage is subsequently scaled down to around **1.4V** via a voltage divider to match the voltage requirements of the oscillator's input. This step ensures the correct signal amplitude for reliable oscillator triggering.

D. Diode Protection and Fixing Low-State Issues

During operation, the comparator's output will typically fall to **-12V** when the input signal is below the threshold. This is because the low supply voltage (in this case, -12V) causes the comparator to output a negative voltage when it is in the "low" state. However, this is not suitable for triggering the oscillator, which expects a ground-level (0V) signal for its low state.

To address this, a diode is placed at the non-inverting input of the op-amp. This diode prevents the comparator from being affected by excessively negative voltages during the capacitor's discharge phase, ensuring stable behavior. Additionally, a second diode is placed at the comparator's output to block the negative voltage when the output is low. This allows the trigger pulse to pass through while maintaining the voltage at ground level, as required for proper operation.

E. Operation Summary

In practice, the Gate-to-Trigger converter successfully takes a gate signal, generates a sharp voltage spike, and produces a clean, single trigger pulse. This pulse is passed to the oscillator's trigger input, where it activates the oscillator. The output is then clean and reliable, with only one trigger pulse generated per gate signal, rather than multiple undesired pulses.

F. Derivations and Calculations

1) Voltage Divider Calculation: The voltage divider used to scale down the 12V output from the comparator to 1.4V can be derived using the following formula:

$$V_{\text{out}} = V_{\text{in}} \times \frac{R_2}{R_1 + R_2}$$

where:
* $V_{\text{in}} = 12V$ * $V_{\text{out}} = 1.4V$
Substituting the desired output voltage:

$$1.4V = 12V \times \frac{R_2}{R_1 + R_2}$$

Solving for $\frac{R_2}{R_1+R_2}$:

$$\frac{R_2}{R_1 + R_2} = \frac{1.4}{12} \approx 0.1167$$

Therefore, the ratio of R_2 to the total resistance $R_1 + R_2$ must be approximately **0.1167** to achieve the desired output voltage of 1.4V.

2) Diode Voltage Drop: In order to effectively block the low-state voltage of -12V, the diodes used in the GTT converter need to have a low forward voltage drop. A typical silicon diode has a forward voltage drop of approximately **0.7V**. This ensures that when the output is negative, the diode will conduct, preventing any negative voltage from reaching the oscillator's input.

G. LTSpice Simulation

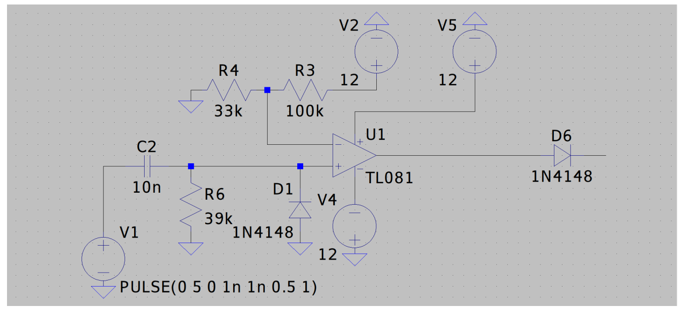

Fig. 1. LTSpice Circuit, Gate-to-Trigger Converter

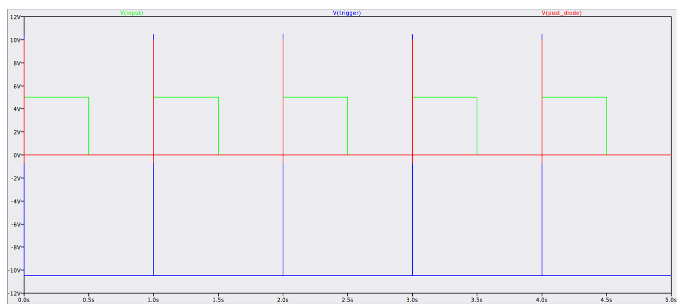

Fig. 2. Plots, Gate-to-Trigger Converter

- The LTSpice simulation of the Gate-to-Trigger Converter circuit confirms the generation of a sharp trigger pulse, with the expected voltage levels and timing characteristics.
- The output trigger pulse was observed to be approximately **1.4V**, in line with the voltage divider calculation.

H. Hardware Implementation

- The hardware test confirmed the expected behavior of the Gate-to-Trigger Converter, with the output trigger pulse generated reliably in response to the gate signal input.
- The use of diodes in the op-amp circuit prevented unwanted negative voltages from affecting the system's performance.
- Minor variations in supply voltage did not significantly affect the output, indicating good stability across typical analog rail tolerances.
- Thermal performance was stable under prolonged operation, with no noticeable drift in pulse width or voltage swing after several minutes of continuous triggering.

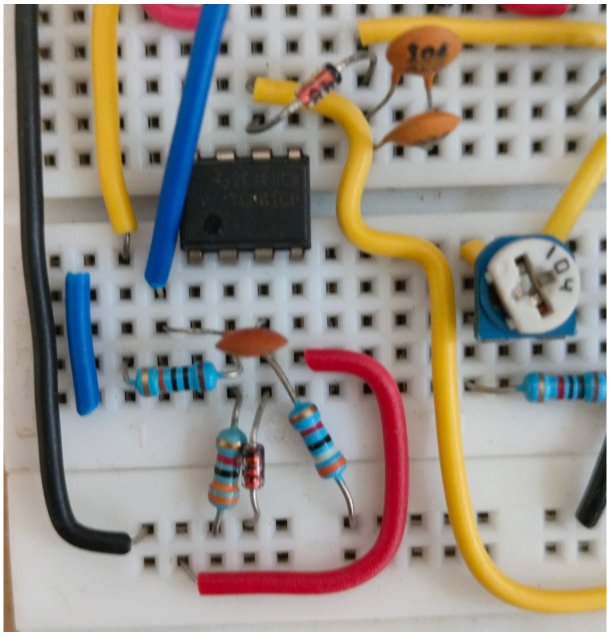

Fig. 3. Hardware Implementation, Gate-to-Trigger Converter

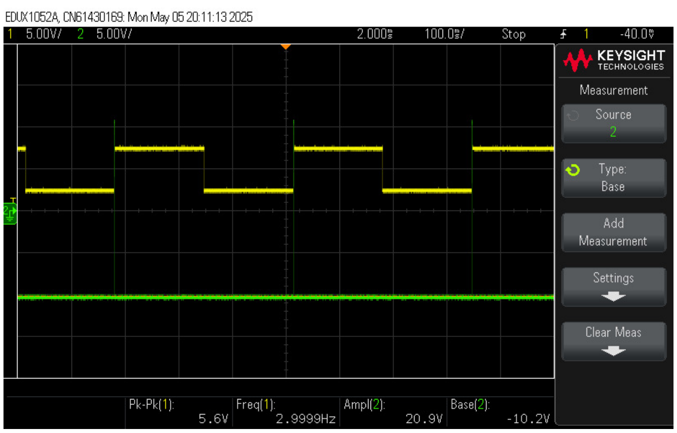

Fig. 4. DSO Waveform, GTT Pre-Diode

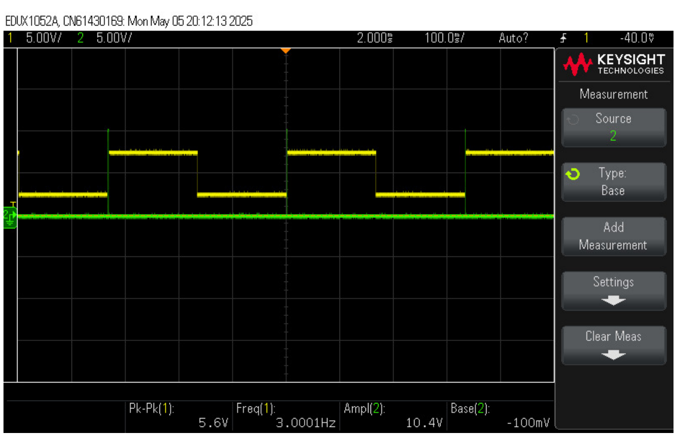

Fig. 5. DSO Waveform, GTT Post-Diode

IV. Envelope

A. Pitch Control Voltage (CV)

To introduce **voltage-controlled pitch modulation**, the core oscillator is adapted to respond dynamically to an external control voltage (CV). In analog synthesizers, pitch is typically tied to the oscillation frequency, which in turn depends on RC time constants. Thus, varying resistance in real-time enables pitch variation — a job best suited for a **voltage-variable resistor**.

1) NPN Transistor: A NPN transistor is inserted to act as this voltage-controlled element:

- Base is connected to the CV input via a 100kΩ resistor.
- Collector–Emitter path becomes the modulation point for current flow.

2) Operating Principle: :

- The transistor acts as a nonlinear resistor, with its Collector–Emitter current I_{CE} modulated by the base voltage V_{BE} (indirectly controlled by CV).
- An increase in CV raises V_{BE}, enhancing I_C according to the exponential relation:

$$I_C = I_S \cdot e^{\frac{V_{BE}}{V_T}}$$

  where I_S is the saturation current, and V_T is the thermal voltage ($\approx$ 26 mV at room temp).
- This enhanced conduction effectively lowers resistance, reducing the RC time constant, and thus increasing oscillation frequency — yielding a **higher pitch**.

3) Waveform Distortion: :

- In the absence of CV, the oscillator produces a near-pure sine wave.
- With CV applied, the transistor introduces asymmetric current conduction due to the mismatch between forward-active and reverse-active current handling (typically $\sim$ $400\,\mu$A vs. $15\,\mu$A).
- This asymmetry bends the waveform into a **soft sawtooth**, which is musically expressive and contributes to the percussive character of a kick drum.

B. Pitch Envelope Generation

To animate the pitch over time to give the kick a sense of attack and decay, we introduce a simple attack-decay envelope generator based on a capacitor-resistor network:

- A **220nF capacitor** acts as the temporal storage element.
- A trigger pulse charges this capacitor quickly via a forward-biased diode (near-instant attack).
- The capacitor then discharges slowly through a potentiometer (defining decay rate).

1) Voltage Across Capacitor:

- Let the capacitor charge instantly to V_{max} and decay through resistance R_{decay}. The voltage over time is:

$$V(t) = V_{\text{max}} \cdot e^{-\frac{t}{RC}}$$

  where $RC = 220\,\text{nF} \cdot R_{\text{pot}}$.

2) *Buffering:*

- An NPN transistor is used in an emitter-follower (common-collector) configuration to buffer the envelope voltage:
  - Collector tied to V_{CC}
  - Emitter outputs envelope voltage via a 100kΩ resistor
- This ensures low output impedance and prevents the capacitor from discharging prematurely due to the load.

C. Pitch Limiting and Depth Control

1) *Possible Excessive Frequency Issue:*

- Without constraints, the envelope CV can drive the oscillator pitch into excessively high frequencies, losing musicality.
- In order to prevent this, two more controls are added:
  - A 2kΩ resistor to ground at the transistor output sets a lower bound on effective resistance, capping the frequency near 250 Hz.
  - A 10kΩ potentiometer in the CV path controls the **modulation depth**, i.e., how much the envelope affects the pitch.

2) *Observed Issue:*

- The decay curve, while exponential, may sound abrupt due to rapid capacitor discharge in later stages.
- The return to base pitch lacks smoothness, creating a jarring effect rather than a natural glide.

D. Smoothing the Envelope

To soften the pitch glide and enhance musical phrasing, a passive RC low-pass filter is added between the envelope generator and the oscillator's CV input:

- A capacitor connects the CV node to ground via a diode.
- A 1MΩ resistor links this filtered output to the oscillator's control point.

1) *Dynamic Behavior:*

- During envelope **attack**, the capacitor charges quickly, injecting voltage into the oscillator's CV input.
- During **decay**, the 1MΩ resistor slows the capacitor's discharge.

2) *Correct Topology Consideration:*

- The resistor must terminate at the transistor's **collector**, not ground. This ensures:
  - When the collector voltage is **high**, it drives base current, increasing pitch.
  - When the collector is **low**, it naturally prevents over-discharge and holds some residual charge, making the tail gentler.

3) *Design Note:*

- Increasing the capacitor value in this filter further slows transitions, useful for deep sub-bass kicks where a long pitch glide is desirable.

E. LTSpice Simulation

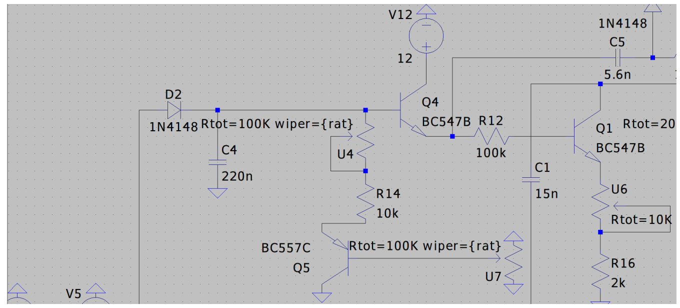

Fig. 6. Envelope Control Circuit Simulated in LTSpice

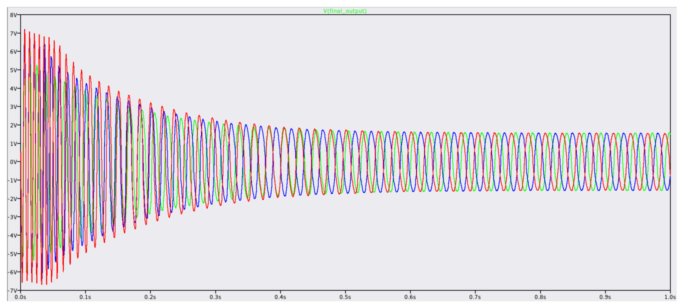

Fig. 7. Simulated Envelope Voltage Over Time

F. Hardware

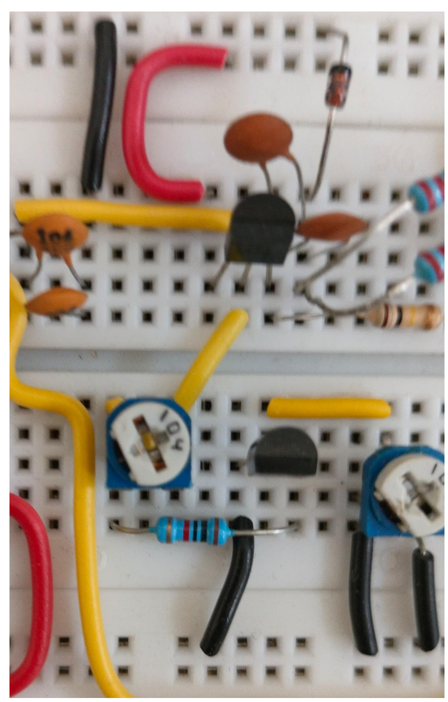

Fig. 8. Breadboard Implementation of Envelope Stage

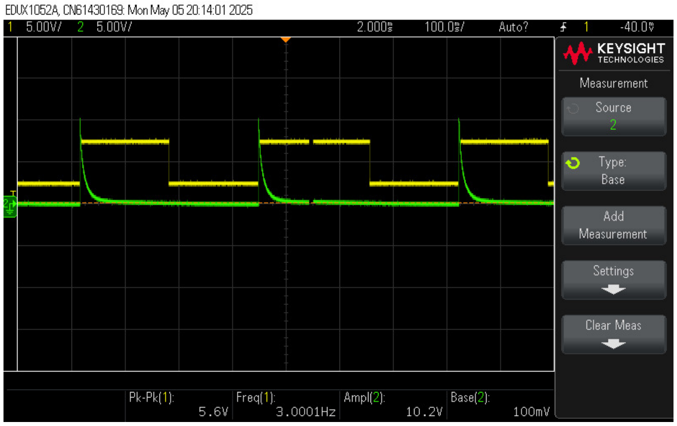

Fig. 9. DSO Waveform, Envelope Capacitor Discharge

V. Pitch

A. Oscillator Frequency and Pitch Fundamentals

- The core pitch of the analog kickdrum is determined by the frequency of its oscillator. For a typical oscillator, the frequency depends on how fast a timing capacitor charges and discharges through a resistor.
- The basic expression for frequency is:

$$f = \frac{1}{2RC \ln\left(\frac{V_+}{V_+ - V_{\text{th}}}\right)} \tag{1}$$

  where:
  - R is the timing resistance,
  - C is the timing capacitance,
  - V_+ is the supply voltage,
  - V_{th} is the threshold voltage for switching.
- In simpler RC oscillators (like a Schmitt trigger-based design), frequency simplifies to:

$$f \approx \frac{1}{RC} \tag{2}$$

- This shows clearly: **lower resistance** $\rightarrow$ **faster charging** $\rightarrow$ **higher frequency** $\rightarrow$ **higher pitch**.

B. Voltage-Controlled Pitch Modulation

To dynamically modulate pitch, we replace the static resistor with a **voltage-controlled resistor**. In this circuit, an NPN transistor plays that role.

1) Configuration:

- Base connected to control voltage (CV) through a 100kΩ resistor.
- Collector tied to the oscillator's discharge path.
- Emitter toward ground (or low-potential node in the RC timing path).
- As the CV increases:
  - Base-emitter junction turns on more strongly,
  - Collector-emitter path conducts more current,
  - Effective resistance drops,
  - Capacitor charges/discharges faster,
  - Pitch increases.

2) Deriving Resistance Modulation:

- The collector-emitter resistance (R_{CE}) of the transistor depends on I_C (collector current), which is exponentially related to V_{BE}:

$$I_C = I_S e^{\frac{V_{BE}}{V_T}} \tag{3}$$

  where:
  - I_S is the saturation current,
  - V_T is the thermal voltage ($\approx 26\,\text{mV}$ at room temp).
- So small changes in CV (which affect V_{BE}) lead to large exponential changes in I_C—and thus to effective pitch modulation. This non-linearity is part of what gives the analog kick its characteristic sound.

C. Effect of CV on Waveform Character

- In absence of CV
  - Oscillator outputs a nearly pure sine wave.
- As CV increases,
  - Transistor conducts more,
  - The envelope of oscillation becomes steeper on one side,
  - This asymmetry introduces harmonic content,
  - Waveform shifts toward a soft sawtooth.
- Distortion arises due to asymmetric behavior of the transistor-
  - Forward active mode: $\sim$400μA current,
  - Reverse active mode: $\sim$15μA current,

  The difference is significant, and that asymmetry becomes musically expressive rather than electronically problematic.

D. Pitch Envelope Coupling

To allow temporal shaping of pitch, the control voltage is not static—it's driven by an envelope generator. The smoothed envelope output (discussed in the previous section) is routed to the base of the transistor.

So, instead of a sudden jump in pitch, we get:

- A rapid rise in pitch (via envelope attack),
- A slow glide back to base pitch (via envelope decay).

This gives the kick a punch at the start, followed by a deeper thump sound.

E. Pitch Limiting and Envelope Depth Control

- A 2kΩ resistor is placed between the transistor's emitter and ground. This sets a floor on R and thus a ceiling on f.
- Frequency Cap: Assuming $C = 0.1\,\mu$F, and $R_{\text{min}} = 2\,k\Omega$:

$$f_{\text{max}} = \frac{1}{RC} = \frac{1}{2 \times 10^3 \times 0.1 \times 10^{-6}} = 5000\,\text{Hz} \tag{4}$$

- In practice, parasitics and nonlinearities lower this; the measured cap is around 250 Hz, suitable for kick frequencies.
- To control modulation depth:

- A 10kΩ potentiometer is placed between the envelope output and the base of the transistor.
- This scales how much the envelope affects pitch.

F. LTSpice Simulation

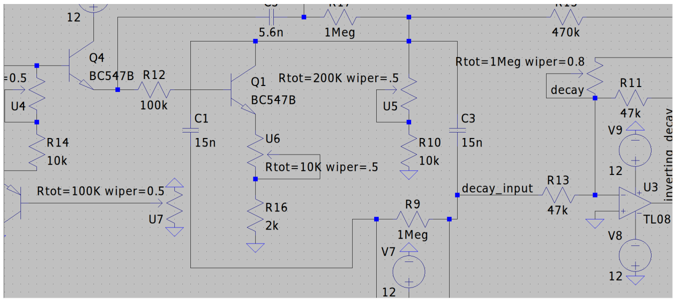

Fig. 10. Pitch Control Circuit Simulation

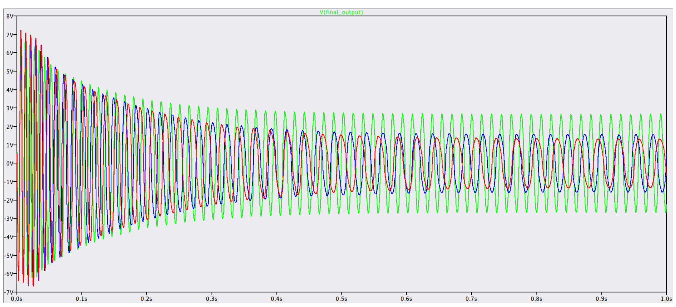

Fig. 11. Pitch Response to Envelope CV

G. Hardware Implementation

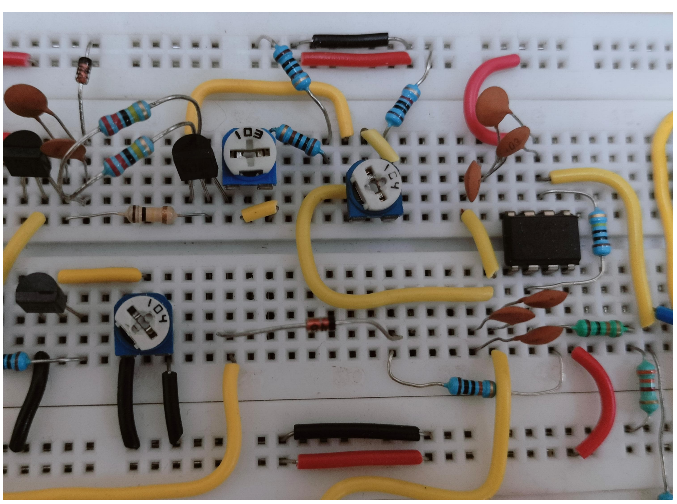

Fig. 12. Breadboard Implementation, Pitch Section

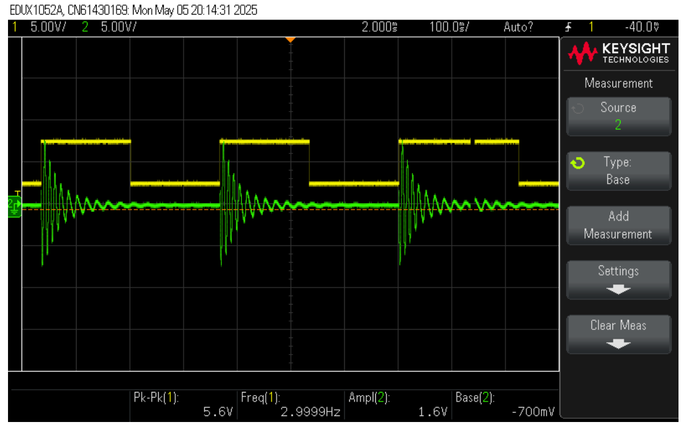

Fig. 13. DSO Waveform, Pitch Stage

VI. Decay

A. Theory and Design Ideas

The initial decay of the kick drum output was observed to be too short. The goal was to extend the decay duration without altering the fundamental pitch of the oscillator. To approach this, we evaluated two theoretical methods:

1) Reduce energy loss per oscillation cycle (i.e., increase the oscillator's Q factor).
2) Inject energy back into the oscillation loop (positive feedback).

The first method, reducing energy loss, was impractical in this context:

- Increasing the value of the bridge resistor (across the timing capacitor) reduces damping but also lowers the oscillation frequency, unintentionally lowering pitch.
- The decay time extension achieved through resistance change was marginal.
- The resistor value in the baseline design was already optimized for pitch.

Therefore, we implemented **controlled positive feedback** to reinforce oscillations, thereby increasing the decay time without affecting pitch.

B. Positive Feedback Implementation

- An op-amp was configured as an inverting buffer and added as a feedback path:
  - **Input:** Connected to the kick drum output (oscillator output).
  - **Output:** Connected to the midpoint between two capacitors in the oscillator via a large resistor (in the range of 100kΩ to 1MΩ).
- This configuration introduces phase-inverted feedback into the RC oscillator loop. The mechanism is as follows:
  - When the oscillator output voltage increases, the buffer output decreases, pulling the capacitor node lower.
  - This forces the main oscillator op-amp to push harder, reinforcing the rising edge of the waveform.

- The same effect occurs in reverse when the output falls.
- This additional current path adds energy to each oscillation cycle, resulting in sustained oscillations and thus a longer decay envelope.

C. Decay Time Derivation

- In the absence of feedback, the oscillator envelope decays exponentially due to energy loss in the resistive elements:

$$V(t) = V_0 e^{-t/\tau}, \quad \text{where} \quad \tau = RC \text{ (in RC-based circuits)} \tag{5}$$

- With positive feedback, the effective damping resistance is reduced. Let R_{eff} represent the equivalent resistance accounting for feedback. Then:

$$\tau_{\text{eff}} = R_{\text{eff}} C \tag{6}$$

- If we define gain of the feedback path as G, then the effective damping resistance becomes:

$$R_{\text{eff}} = \frac{R}{1 - G} \tag{7}$$

- Assuming $G < 1$, we observe that increasing G increases τ_{eff}, i.e., longer decay.

D. Decay Control Mechanism

To make the decay adjustable, a potentiometer was placed in the feedback loop of the buffer op-amp to control gain G:

- **Higher gain:** More feedback, higher τ, longer decay.
- **Lower gain:** Less feedback, shorter decay.

By varying resistance in the feedback loop, we modulate how much energy is re-injected per cycle.

E. Linearising Potentiometer Response

- A linear potentiometer does not yield a linear perception of decay because decay is an exponential function of time constant. The initial feel of the control was abrupt and nonlinear.
- To address this, a $47\text{k}\Omega$ resistor was added in parallel with the potentiometer to approximate a reverse-logarithmic response:

$$R_{\text{parallel}} = \left(\frac{1}{R_{\text{pot}}} + \frac{1}{47k\Omega} \right)^{-1} \tag{8}$$

- This modification compresses the resistance range at higher values, allowing finer control over longer decay times and smoothing the overall feel of the knob.

F. Result

The final configuration achieved a wide, controllable decay range, short and punchy at one extreme, long and sustained at the other, without affecting pitch or waveform integrity. Feedback remained below the self-oscillation threshold to avoid instability.

G. LTSpice Simulation

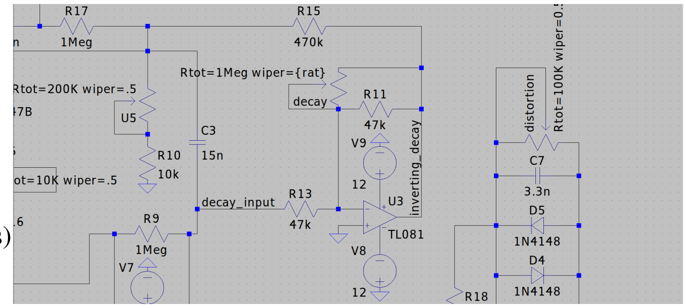

Fig. 14. Circuit Simulation of the Decay Block

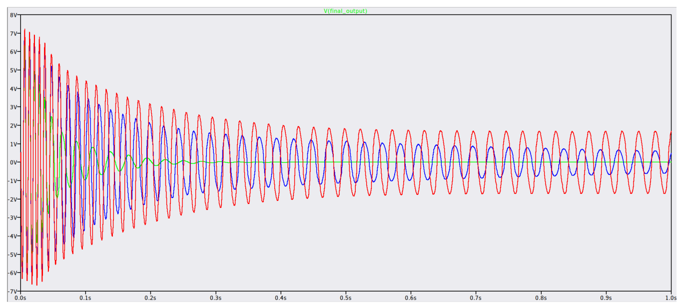

Fig. 15. Simulated Output Showing Extended Decay via Feedback

H. Hardware Implementation

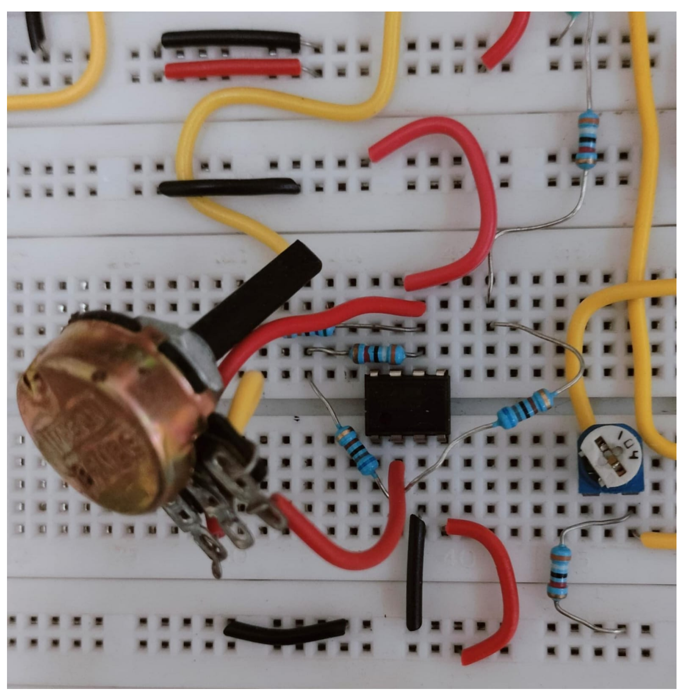

Fig. 16. Breadboard Implementation, Decay Block

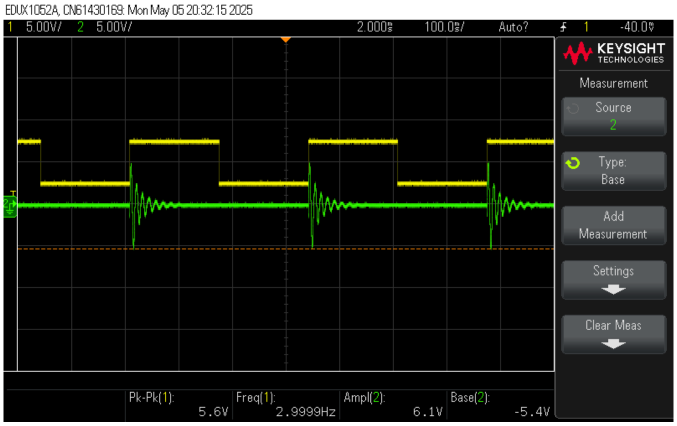

Fig. 17. DSO Waveform, Decay Stage *(Inverts Pitch Output)*

VII. Tone & Distortion

A. Purpose

The purpose of this stage is twofold:

- To attenuate the initial high-frequency transient (click) produced by the oscillator.
- To provide better harmonic functioning via soft clipping, without affecting the core low-frequency content.

B. Tone Control: Low-Pass Filter Design

A passive first-order low-pass RC filter was placed directly after the kick output. The filter's role is to attenuate high-frequency transients without significantly affecting the fundamental frequency.

1) Cutoff Frequency Derivation:

- For a standard RC filter:

$$f_c = \frac{1}{2\pi RC}$$

2) Tone Knob:

- The tone knob is a variable resistor, which controls R in the equation above. Based on the implemented component values:
  - **Max tone (min R)**: $R = 1\,\mathrm{k}\Omega$, $C = 0.68\,\mu\mathrm{F}$

$$f_c = \frac{1}{2\pi \cdot 1\,\mathrm{k}\Omega \cdot 0.68\,\mu\mathrm{F}} \approx 234\,\mathrm{Hz}$$

  - **Min tone (max R)**: $R = 10\,\mathrm{k}\Omega$

$$f_c \approx 23\,\mathrm{Hz}$$

- Thus, the filter provides user-controllable attenuation of high-frequency components from the kick signal.

3) Observations:

- Increasing resistance lowers the cutoff, reducing more click.
- However, it also increases output impedance, which causes signal loss and undesirable interaction with the following stage.

C. Buffer and Distortion Stage

- To resolve the output impedance issue and optionally introduce distortion, the signal passes through an inverting op-amp stage with a diode-clipped feedback path.
- The circuit is a standard inverting amplifier with a non-linear feedback network:

$$V_{\text{out}} = -\left(\frac{R_f}{R_{\text{in}}}\right) V_{\text{in}}$$

  Where:
  - $R_{\text{in}} = 10\,\mathrm{k}\Omega$
  - $R_f = 10\,\mathrm{k}\Omega + \text{potentiometer}$
  - Two anti-parallel diodes (1N4148) clip the output symmetrically at $\approx \pm 0.6\,\mathrm{V}$
- The buffer ensures a consistent output level regardless of the tone knob setting. Once the op-amp output exceeds the diode threshold, clipping occurs.

D. Distortion Smoothing (RC Feedback Filter)

- To control the character of distortion, a capacitor is added in parallel with the diode/potentiometer network. This forms an RC filter within the feedback loop.
- **Smoothing Effect** Let:

$$f_{\text{clip}} = \frac{1}{2\pi R_f C_f}$$

  Where:
  - R_f is the feedback resistance during clipping (typically set by the potentiometer).
  - C_f is the feedback capacitor (e.g., $4.7\,\mathrm{nF}$).
- A smaller C_f shifts the cutoff higher, allowing more high-frequency content into the feedback—resulting in harsher, brighter distortion. A larger C_f reduces the high-frequency gain in the feedback loop, smoothing the waveform.

E. LTSpice Simulation

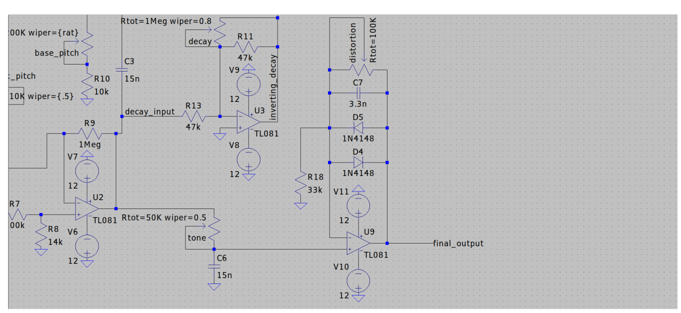

Fig. 18. LTSpice Circuit, Tone & Distortion

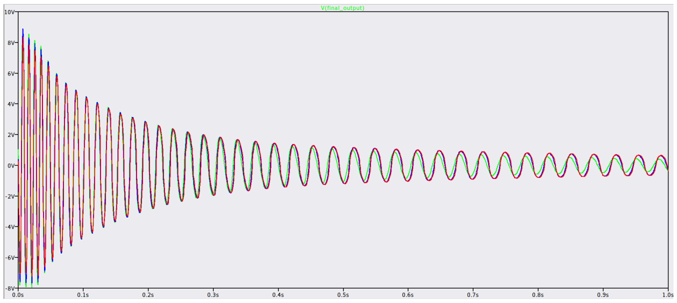

Fig. 19. LTSpice Simulation, Tone & Distortion

F. Hardware Implementation

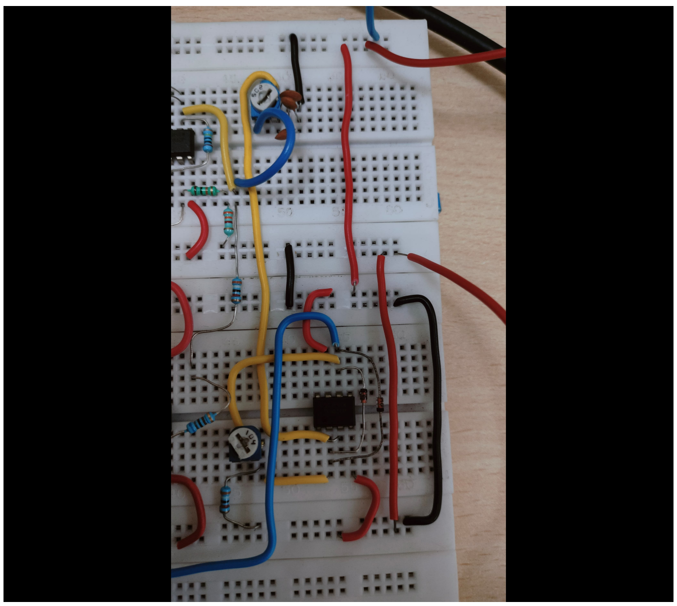

Fig. 20. Breadboard Implementation, Tone & Distortion

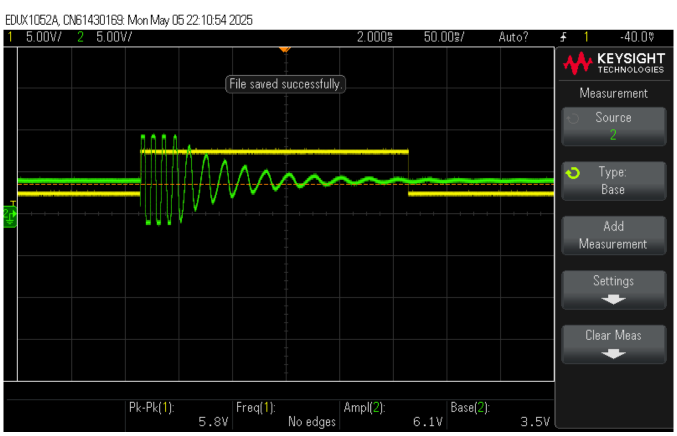

Fig. 21. DSO Waveform, Tone & Distortion *(Initial Clipping Control)*

VIII. Problems Faced

1) **Unreliable Oscillation and Triggering:** In the initial testing of the trigger and pitch stage, the oscillator didn't start reliably every time. This was traced back to improper biasing and resistor-capacitor combinations that didn't consistently produce the expected pulse. We had to tweak several component values to make sure the circuit always triggered and that trigger led to a decaying sinusoid.
2) **Excessive Output from Distortion Stage:** The distortion stage ended up pushing out a signal of nearly 10V peak-to-peak which is way too much for the LM386 audio amplifier to handle directly. When connected, this caused major clipping, noise, and even temporary muting. To fix this, we added a non-inverting UA741 op-amp as a pre-attenuation stage, bringing down the gain by a factor of 13 using a 13k and 1k resistor. This conditioned the signal to a safe level for the LM386 input.
3) **Breadboard-Level Noise:** Throughout testing, we faced issues like random noise and weird waveform glitches. Most of these stemmed from breadboard limitations — loose connections, parasitic capacitances, and messy wiring. Adding bypass capacitors near the op-amps power rails and simplifying the layout helped reduce the noise, but some interference remained inevitable in a breadboard prototype.
4) **Mismatch Between Simulation and Hardware Behavior:** LTSpice simulations often looked clean and predictable, but in real hardware, things like supply rail limits, transistor biasing, and non-ideal diode behavior created noticeable differences. This required us to make several real-time adjustments like changing op-amps or resistor values that weren't obvious from simulations alone.

IX. Final Circuit

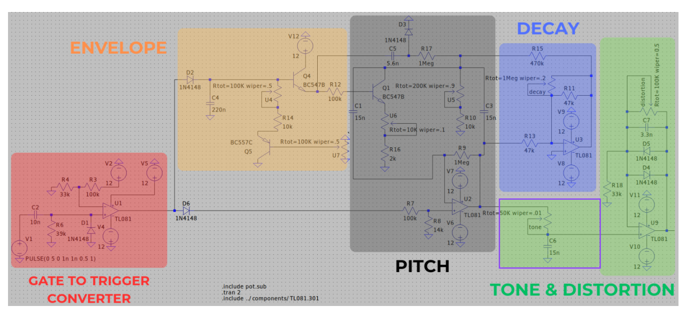

Fig. 22. Final Circuit Stages

The final circuit was designed to drive a 4-ohm speaker using the LM386 audio amplifier IC. The output from the distortion stage initially had a peak-to-peak voltage of around 10V, which was too high for the LM386 to handle properly. To resolve this, we used a non-inverting UA741 operational amplifier to attenuate the signal before it was fed into the LM386.

A. Amplification and Gain Control

1) Gain Control Problem: The distortion stage produced a signal with a peak-to-peak voltage of 10V, which exceeded the input voltage range of the LM386. To prevent clipping or distortion, we first used a non-inverting UA741 amplifier to scale down the signal to an acceptable level for the LM386 to handle.

2) Non-Inverting Amplifier with UA741: A non-inverting amplifier was implemented using the UA741 op-amp. The gain of this amplifier was set by the resistors $R_1 = 1\text{k}\Omega$ and $R_2 = 13\text{k}\Omega$, which resulted in a gain of $1/13$:

$$\text{Gain of non-inverting amplifier} = \frac{R_1}{R_2} = \frac{1\text{k}\Omega}{13\text{k}\Omega} = \frac{1}{13}$$

This attenuation reduced the 10V peak-to-peak signal to a level that the LM386 could handle without issues. The scaled signal was then fed into the LM386 for further amplification.

3) LM386 Amplification: The LM386 has a default gain of around 20, which is sufficient for driving a 4Ω speaker. With the signal already reduced by the UA741, the LM386 amplified it further, providing enough power to drive the speaker effectively.

B. Gain Calculation

- The overall gain of the circuit was the product of the UA741 and LM386 gains:

$$\begin{aligned}\text{Total Gain} &= \text{Gain of UA741} \times \text{Gain of audio amp}\\ &= \frac{1}{13} \times 18\\ &= 1.38\end{aligned}$$

- This final gain allowed the signal to be audible through the speaker while maintaining clarity and avoiding distortion.

C. LTSpice Simulation

The LTSpice simulation below shows the complete final circuit. We analyzed waveforms at each stage to verify the expected behavior and ensure that the signal was properly scaled and amplified.

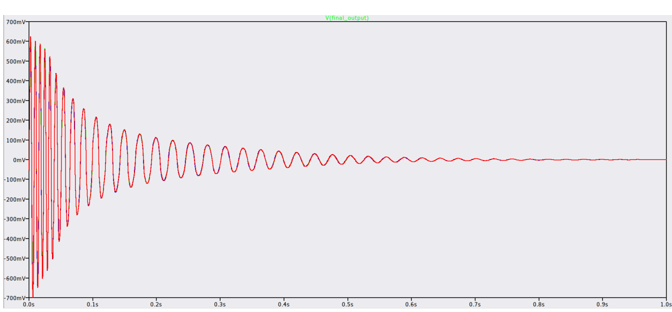

Fig. 23. Final Waveform *(Attack, sustain (decay) & frequency controls)*

D. Hardware Implementation

The final circuit was implemented on a breadboard. The non-inverting UA741 amplifier successfully attenuated the signal, and the LM386 amplified it to drive the 4-ohm speaker. The circuit produced a clean, audible sound without distortion.

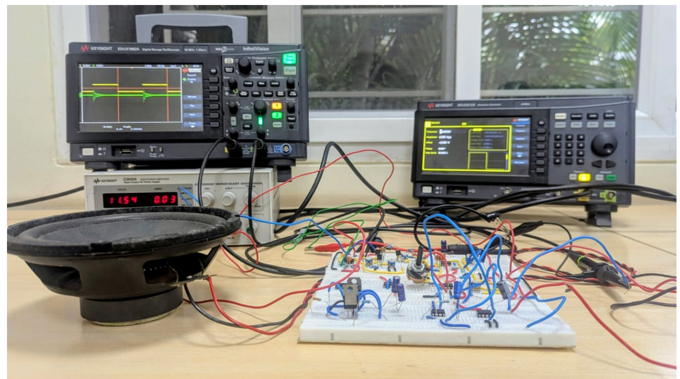

Fig. 24. Final Project Setup (Hardware)

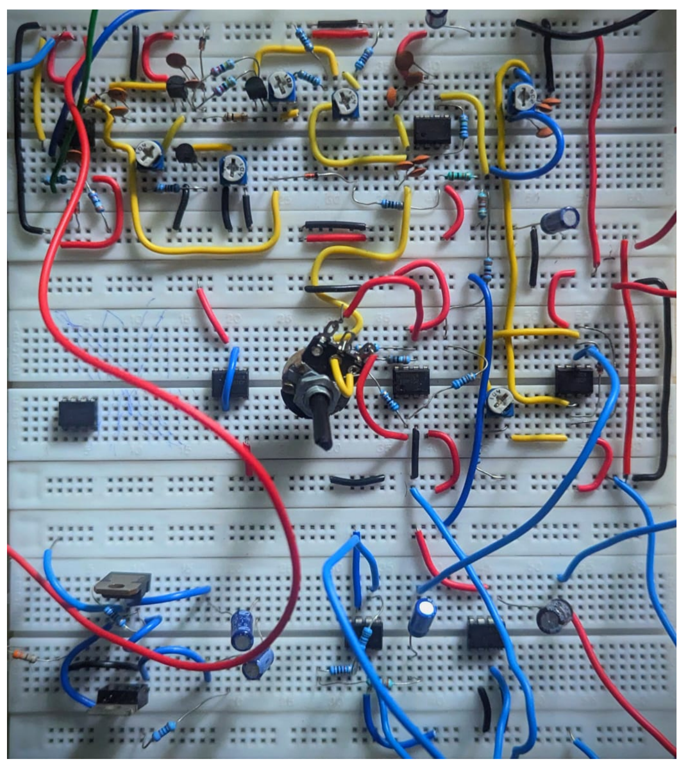

Fig. 25. Final Breadboard Implementation

E. Results and Analysis

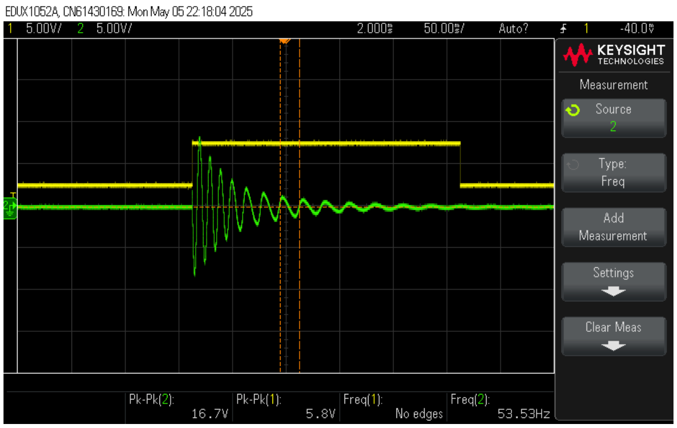

Fig. 26. DSO Waveform, Final Output

Upon testing the final implementation, the sound output from the speaker was clean and clear. The gain control mechanism successfully attenuated the distortion stage signal to a safe level for the LM386, while the overall gain provided sufficient volume.

1) Waveform Analysis: The final waveform from the speaker output was analyzed using an oscilloscope. The waveform showed no clipping or distortion, confirming that the signal amplification was within the expected range.

2) Speaker Performance: The speaker produced an audible sound with adequate volume, and the tone was clear with no noticeable distortion, demonstrating the effectiveness of the gain reduction and amplification stages.

F. Conclusion

The final circuit brought together all the key functional blocks: tone control, distortion generation, pitch envelope, decay control, and audio amplification, into a cohesive and working audio system. In essence, the project achieved its goals: designing an efficient analog kick drum circuit, inspired by Roland. The circuit remains open to further tuning and enhancements, but its current form stands robust and functional.

X. Acknowledgements

We would like to express our sincere gratitude to:

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- **Professor K Madhava Krishna** for his mentorship and encouragement in tackling technical challenges.
- The **Teaching Assistants** for their continuous assistance in troubleshooting and refining the implementation.

XI. References

- LM386 IC Audio Amplifier Circuit
- Classical R-C Oscillator Article
- How to Mix Kick Drum - Sage Audio
- ADSR Explained - Native Instruments