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UNIVERSITY OF MORATUWA

EN2090: LABORATORY PRACTICE II

ANALOG FUNCTION GENERATOR

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Analog Function Generator

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***Abstract* – This report contains detailed information on generating a primary analog function generator that can generate a Sine, Saw-tooth, Square (with adjustable duty cycle), and a triangular waveform. These waveforms can be generated with adjustable amplitude, frequency, and DC offset. The Vpp can vary from 2V to 12V, and the frequency can be changed from 20Hz to 20kHz. The whole circuit was generated using only the analog electronics components like Op-Amps, transistors, resistors, and capacitors.**

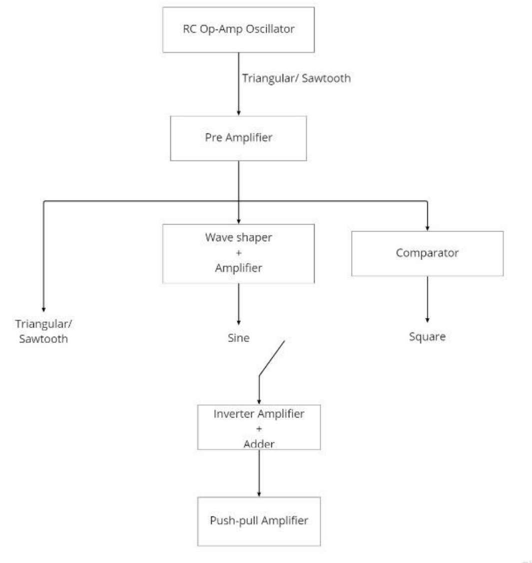
1. INTRODUCTION

In the early days, analog integrated circuits (Analog ICs) were used to generate the required functions. Later these analog ICs were replaced by the Direct Digital Synthesis chips. Our project expects to make a primary function generator using earlier used analog concepts to understand these electronic components better. In this project, a function generator was produced using op-amps, transistors, resistors, capacitors, and potentiometer only. These components are creatively used in order to generate a Sine, Saw-tooth, Square, triangular waveform with adjustable amplitudes, frequency, and DC shift. This report describes the circuits used to generate these waveforms and control their characteristics.

2. METHOD

The following block diagram shows the circuit sections used to generate the aforementioned waveforms and control their required characteristics.

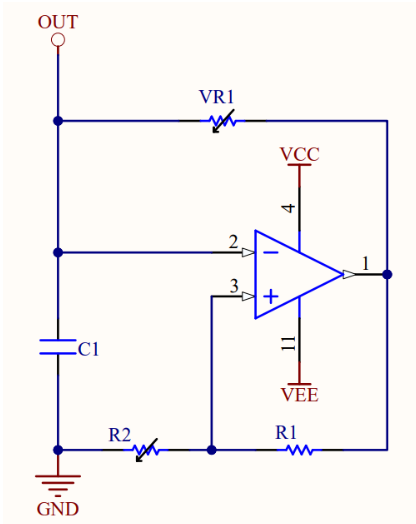
1. A triangular waveform is generated with an adjustable frequency from 20Hz to 20kHz.



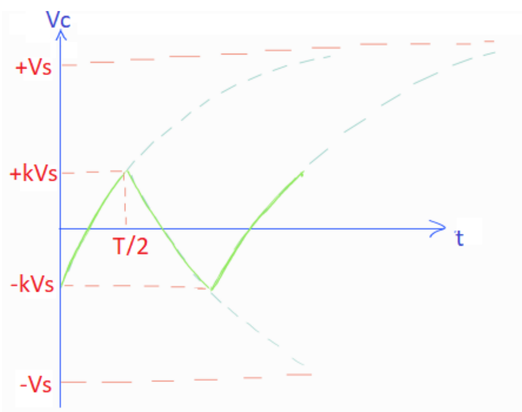
2. The saw-tooth waveform is generated by manipulating the triangular circuit in 1.
3. A square waveform is generated by passing the triangular waveform in 1 through a comparator.
4. A Sine wave is generated by sending the triangular waveform in 1 through a wave shaper.
5. The above waves are sent through an inverting amplifier+adder to give them a DC offset and the required amplitude.
6. The final generated waveform is sent through a push-pull amplifier before supplying it to a load.

2.1. TRIANGULAR WAVE GENERATION

Since the Op-amp is used in the positive feedback configuration, the output is either in the $+V_S$ or $-V_S$ saturated voltages.

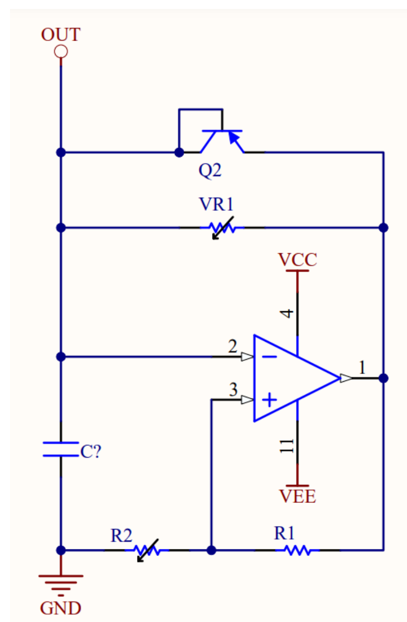


- Let's assume that the output is at $-V_s$ voltage. Then the $+V_{in}$ is at $-kV_s$ voltage. Where $k = \frac{R_2}{R_1+R_2}$. Then the capacitor C1 starts negatively charging. Due to this $-V_{in}$ voltage negatively increases. When it passes the $-kV_s$ the output shifts to the $+V_s$. Now the $+V_{in}$ is at $+kV_s$.



- Then, the capacitor starts discharging. The above graph shows the voltage of the capacitor from this point onwards. It is equal to $-V_{in}$
- Then, the capacitor fully discharges and starts to charge positively. When it exceeds $+kV_s$ output again shifts to $-V_s$.
- This cycle continuously repeats.
- By changing the R_2, the k value is kept very small. Since the capacitor is operating only within a small portion of the entire charge-discharge curve of the capacitor, it can be considered almost linear.
- By changing the VR1 resistor value, the speed of the capacitor being charged and discharged is changed. By using this, the frequency of the generated triangular waveform can be adjusted.
- The output received here is very small, so it is sent through an amp.

2.2. SAW-TOOTH WAVE GENERATION

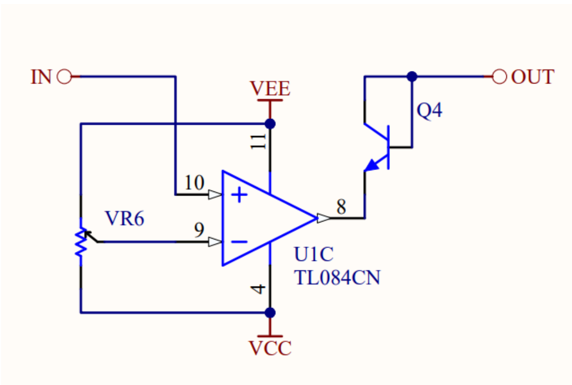


The saw-tooth wave is generated using the same methodology used to generate the triangular wave. Here, the first half of the triangular waveform is removed by quickly charging the capacitor from $-kV_s$ to $+kV_s$ via bypassing the VR1 resistor.

- To accomplish this, a transistor is used as a diode. (The reason for using a transistor instead of a diode has been explained in discussion).
- Selector switch used to connect this transistor across VR1.
- Since half of the triangular wave is cut-off, the frequency range is doubled to

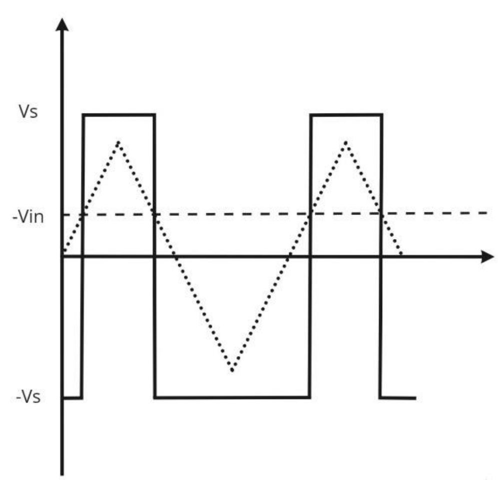
40Hz - 40kHz. Parallel capacitors are attached using a selector switch to bring it back to the required range.

2.3. SQUARE WAVE GENERATION



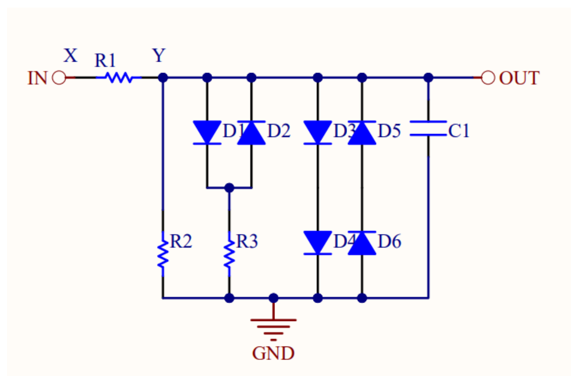
The triangular wave is passed through a comparator to get a square wave. A comparator output $-V_s$ if the value is lower than the comparing voltage and output $+V_s$ if the value is higher. The comparing voltage, $-V_{in}$ is adjusted through the VR6 variable resistor.

- By adjusting this comparing voltage, the portion of the output waveform having $+V_s$ can be changed, altering the duty cycle. The following graph shows how increasing the $-V_{in}$ reduces the duty cycle and vice versa.



- The square wave output received through the comparator has is is two levels at $+V_s$ and $-V_s$. But it required to have a square wave varying from 0 to $+V_s$. Since the waveform is sent through an inverting amplifier, the positive half of the above wave is removed.
- To remove the positive half cycle, a transistor is used as a diode to clip the positive half.

2.4. SINUSOIDAL WAVEFORM GENERATION



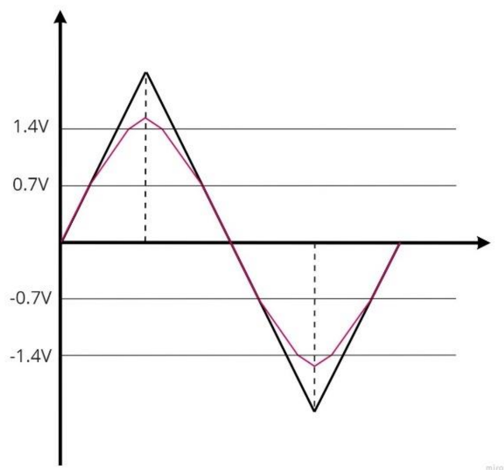
The triangular waveform generated above is sent through a waveshaper to make a sine wave. Here the triangular wave is partitioned at three voltages, and the slopes were adjusted at each stage.

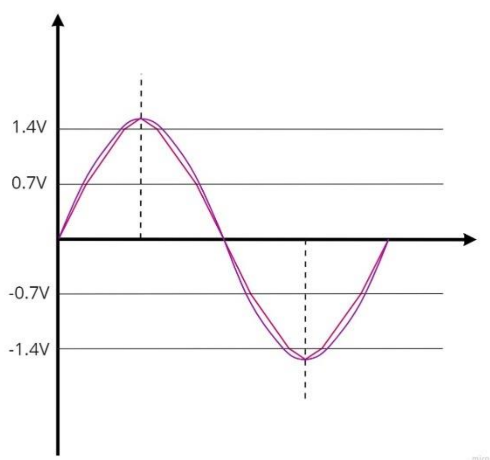
- The V_{pp} voltage of the triangular wave at X is too large for the waveshaper. So, the V_{pp} is adjusted to the required level by sending through a potential divider (R1, R2).
- Output wave traces a similar shape to the triangular wave at point Y until it exceeds 0.7V since the current doesn't have any other path to discharge.
- When the voltage at Y increases beyond 0.7V, the current can discharge through the D1 diode in the positive half cycle and D2 through the negative half cycle. So, the slope of the output wave after

0.7V reduces more than that of the original triangular wave.

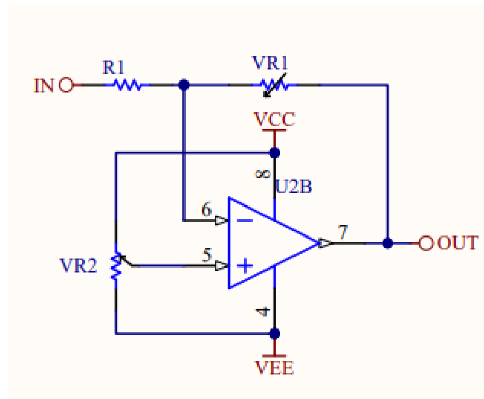
- Due to using the R3 resistor, the voltage at Y can increase above 0.7V since the R3 resistor can generate voltage difference across itself.
- When the voltage at Y increases above 1.4V, the current has two additional paths to pass the positive half cycle, and D2 and D5, D6 during the negative half cycle. So, the output slope further reduces above 1.4V.
- Then, the generated shape is smoothed using the C1 capacitor as a low pass filter.

The original amplitude reduced triangular wave, the partitioned wave before the capacitor, and the final sine wave are shown belove in the graph.





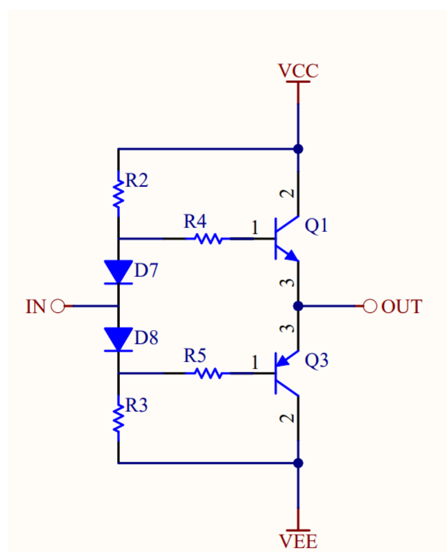
2.5. INVERTING AMPLIFIER



An Op-amp in an inverting amplifier configuration is used to amplify the selected waveform. An inverting amplifier is better suited here than a non-inverting amplifier since the outputs should be amplified and attenuated.

- A DC offset is also given at the output stage using the same Op-amp in the summing configuration.
- The amplitude of the output is adjusted by changing the amplification factor by adjusting the VR1 variable resistor.
- The DC offset is changed by changing the $+V_{in}$ by adjusting the VR2 variable resistor.

2.6. PUSH-PULL AMPLIFIER



The push-pull circuit amplifies the current at the output stage to drive a load without distortion in the waveform. Here a class AB amplifier is used for better efficiency in output power.

A complimentary pair of NPN and PNP transistors are used in the circuit.

The NPN transistor drives the output during the positive half cycle of the wave, while the PNP transistor is turned off. Similarly, during the negative half cycle of the wave, the PNP transistor drives the output while the NPN transistor is turned off.

Both transistors are kept biased by the two diodes, preventing crossover distortion.

3. CALCULATIONS AND THE COMPONENT SELECTION

To get the required specifications, some suitable components were needed to be selected. This was done by doing some calculations and by referring to the datasheets. The main components selected are Op-amp, transistors, capacitors, and resistors.

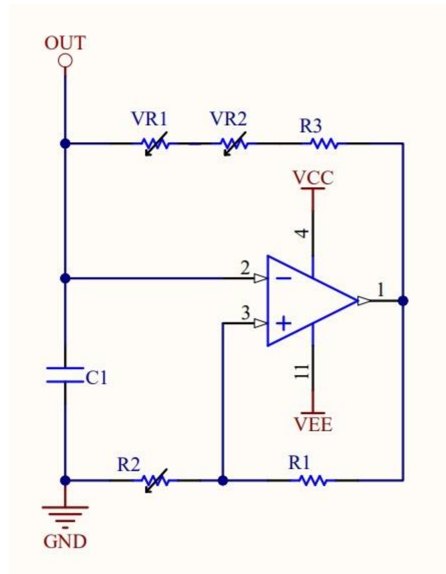
3.1. OP-AMP SELECTION

Five Op-amps were required for the whole circuit, where three of them were used as amplifiers, one as a comparator and the other as an oscillator to generate the triangular waveform. For this TL08X series Op-amp ICs are selected. The main reasons for this are,

- Having a low noise.
- Having a high slew rate of 13 V/µs which was an essential factor in square wave generation.
- Having a Gain Bandwidth Product (GBP) of 4MHz, which is enough to create a 200 maximum gain and a 10V peak-peak output waveform within the required bandwidth of 20kHz.

$$Maximum\ Gain = \frac{4x10^6}{20x10^3} = 200$$

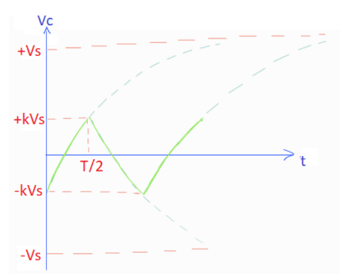
3.2. CAPACITOR AND VARIABLE RESISTORS SELECTION



Selecting a proper C1 capacitor is essential in getting a linear triangular waveform, and selecting VR1 and VR2 variables are essential in changing the waveforms within the required bandwidth. The voltage across the C1 capacitor, V_c can be calculated as,

$$V_c = V_s - \left(V_s - (-kV_s)\right)e^{-\frac{t}{RC}}$$

$$\Rightarrow V_c = V_s(1 - (1 + k)e^{-\frac{t}{RC}})$$



Substitute $t = \frac{T}{2}$, where $V_c = kV_s$

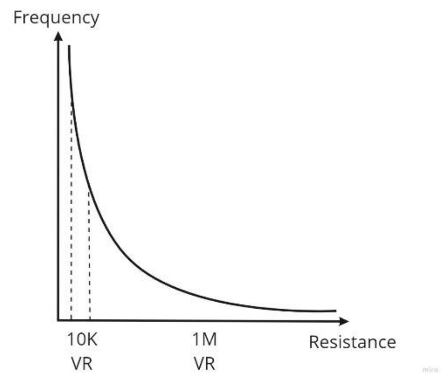
$$\Rightarrow kV_s = V_s(1 - (1 + k)e^{-\frac{T}{2RC}})$$

$$\Rightarrow T = 2RC.\ln\left(\frac{1 + k}{1 - k}\right)$$

$$\Rightarrow f \; \alpha \frac{1}{R}$$

The above circuit was tested by observing the waveform while keeping k at a small value. Then it was observed that selecting $C = 0.27\mu F$ is suitable. Then substituting this C to the above equations, the variable resistor was selected as 1M.

Here, since the frequency changes drastically in the lower resistance values, as shown in the graph, two variable resistors are connected in series to change the frequency accurately. 10K resistor for fine-tuning frequencies at higher values and 1M for lower frequencies.



3.3. TRANSISTOR SELECTION

This function generator is required to power up a load of 50Ω and the generated waveforms are required to have an amplitude of 10V peak to peak. Depending on this, power and current requirements can be calculated as follows.

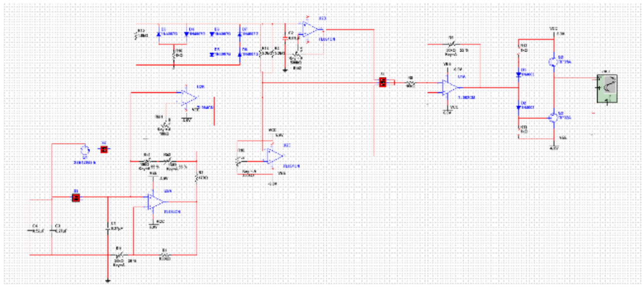
$$Maximum\ Current = \frac{10V}{50\Omega} = 200mA$$

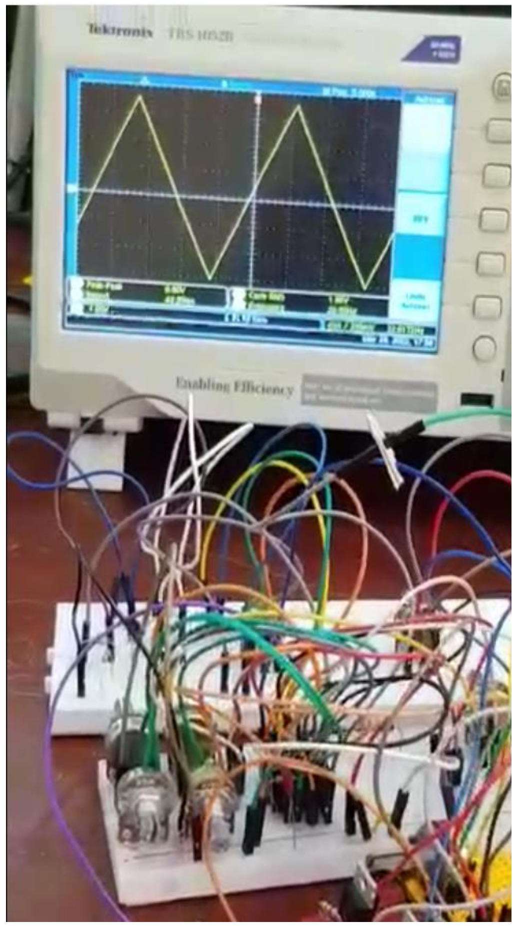
$$Maximum\ Power = \frac{(10V)^2}{50\Omega} = 2W$$

Depending on these requirements and the lack of components in the local shops, the most suitable complementary pair available were TIP31 (NPN) and TIP32(PNP). Although these components have more than the required ratings, these had to be used in the project.

4. SIMULATION AND TESTING

The circuits were first designed using NI Multisim, and these were tested through simulations. Then the simulated circuits were tested on the breadboards. According to the physical testing, some circuits were required to be redesigned.

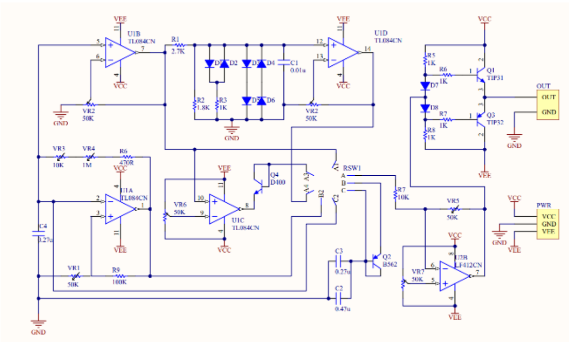


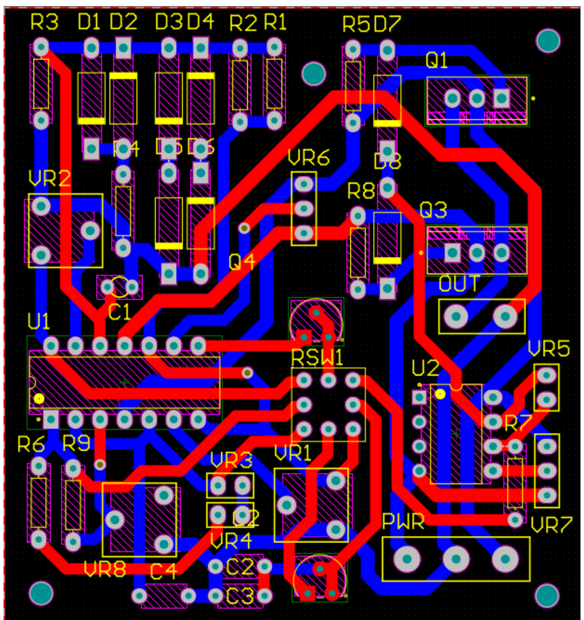


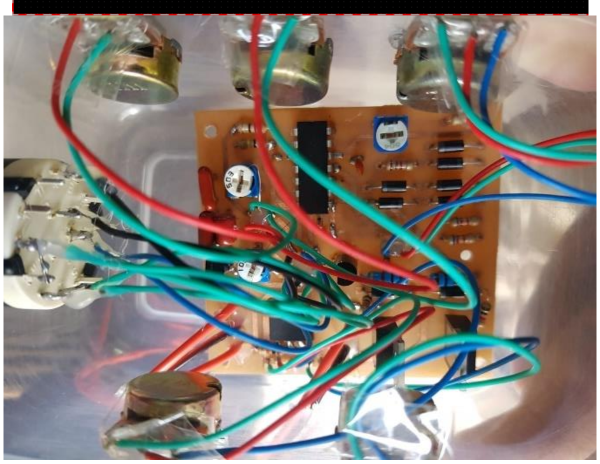
5. RESULTS

5.1. SCHEMATIC AND PCB

After testing the breadboard circuits, the PCB is designed using Altium software.

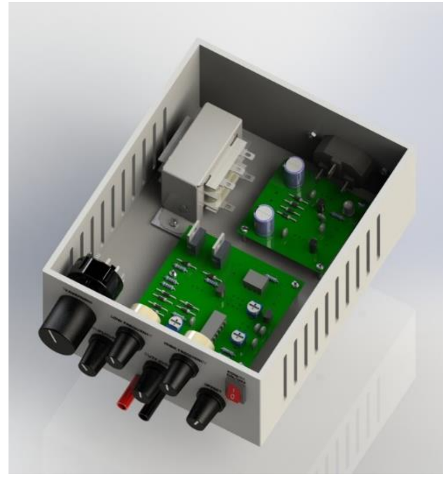






5.2. ENCLOSURE DESIGN

A 3D enclosure was designed using Solid Works.



5.3. FINAL OUTCOMES

- Can generate four standard waveforms:
  1. Sine wave
  2. Triangular wave
  3. Sawtooth wave
  4. Square wave.

- The following features can be adjusted independently of each other,
  1. Adjustable 20Hz – 20kHz frequency range
  2. Square Wave has an adjustable duty cycle range of 2% - 98%.
  3. Adjustable amplitude from 0 – 10V Vpp.
  4. Adjustable offset.

- Can drive a maximum output current of up to 200mA.

- Compact portable design.

- Can operate with a 230VAC power supply or a 10VDC dual power supply.

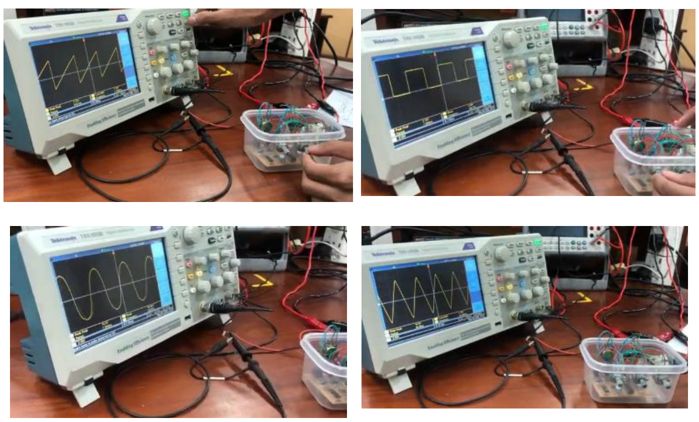
- Triangular Wave
  Frequency range: 20Hz-20KHz
  V_{pp} range: 3.5V-14V

- Sawtooth Wave
  Frequency range: 15Hz-15KHz
  V_{pp} range: 2V-12V

- Square Wave
  Frequency range: 20Hz-3KHz
  V_{pp} range: 1.5V-8V
  Adjustable duty cycle: 2% - 98%

- Sine Wave
  Frequency range: 20Hz-3kHz
  V_{pp} range: 1.5V-14V

The following diagrams show the PCB circuit's oscilloscopes readings for four waveforms.

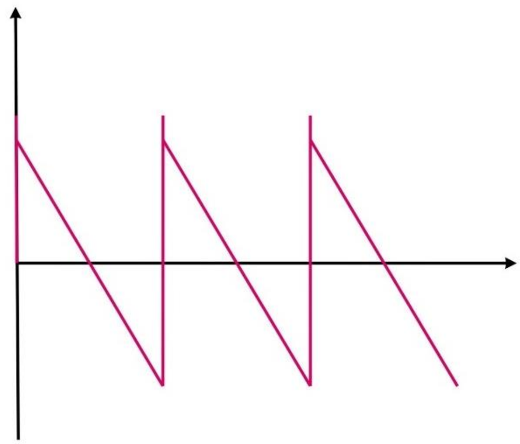


6. DISCUSSION

When generating the saw-tooth wave by short-circuiting the variable resistor using a diode in triangular wave generation circuit, it is observed that a small spike appears at the tip of the saw-tooth wave, as shown in the graph belove.

The spike mentioned above was not appearing when connecting its collector and the base using a transistor as a diode.

When a diode is forward biased, it has a small depletion layer. When it suddenly reverses bias, a small number of charges passes through to widen the depletion layer, even though the component is in the reverse-bias mode. This causes a sudden voltage drop of the capacitor. This is the reason for the small spike. But in a transistor, the depilation layer widening is low since the middle



layer is narrow. So, the number of charges passing through at the beginning of the reverse biasing is low. So, the spike is negligible.

This same concept is used when removing the positive part of the square wave.

7. CONCLUSION

By observing the results of the designed analog function generator, it is evident that we can generate the triangular wave, saw-tooth wave, square wave, and the sine wave with variable amplitudes and frequencies to an acceptable accuracy by using Op-amps.

8. REFERENCE

[1]. Instructables. (2017, October 29). Analog Function Generator. https://www.instructables.com/Function-Generator/

[2]. Floyd, T. L. (2011). Electronic Devices (Electron Flow Version) (9th Edition) (9th ed.) [E-book]. Pearson.

[3]. transistor TIP31 datasheet - Ates Compon. (2022). Retrieved 7 May 2022, from https://www.web-bcs.com/transistor/tc/ta/TIP31.php

[4]. transistor TIP32 datasheet - Ates Compon. (2022). Retrieved 7 May 2022, from https://www.web-bcs.com/transistor/tc/ta/TIP32.php

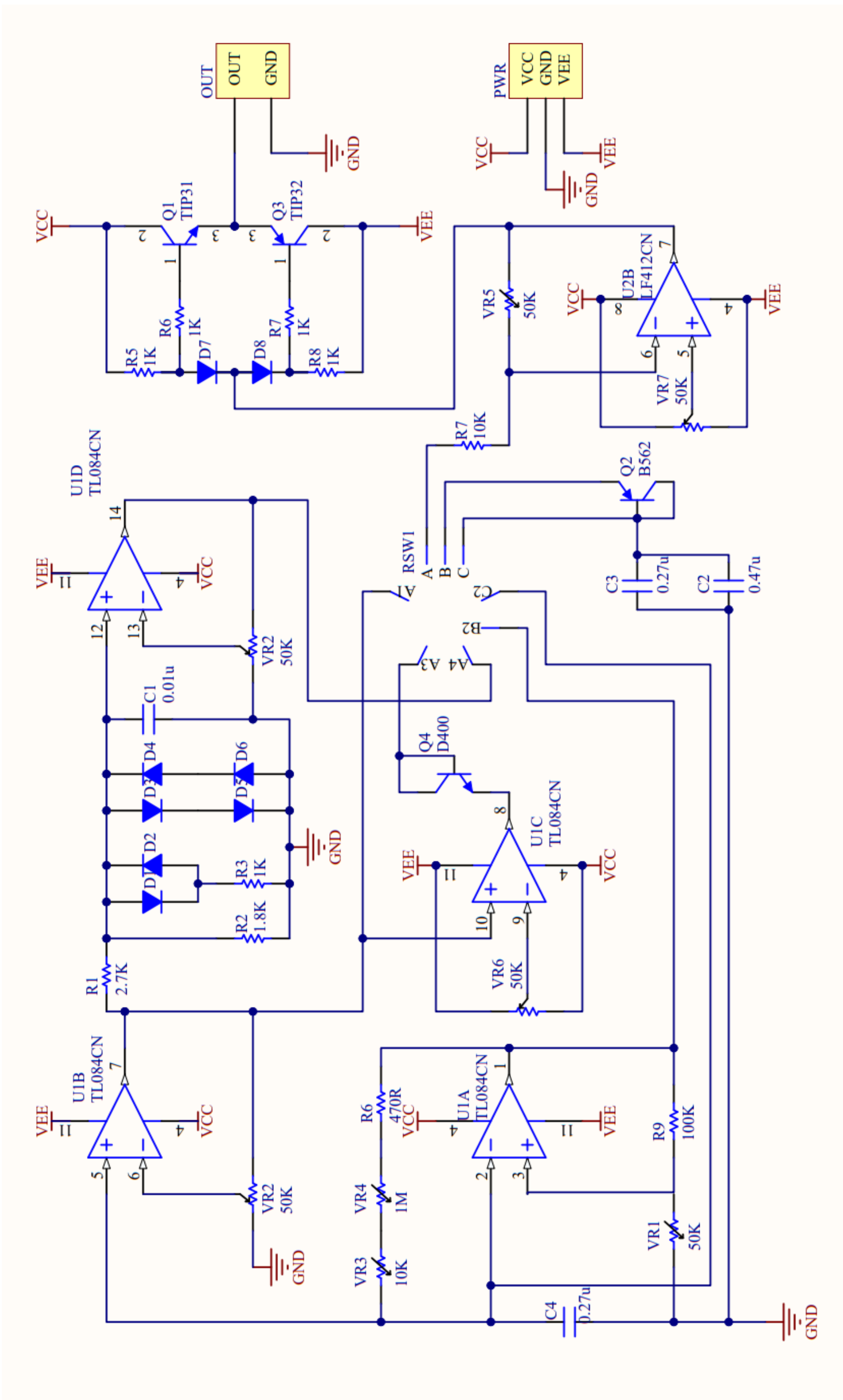
[5]. TL084CN Datasheet (PDF) - Motorola, Inc. (2022). Retrieved 7 May 2022, from https://www.alldatasheet.com/datasheet-pdf/pdf/5778/MOTOROLA/TL084CN.html

9. CONTRIBUTION

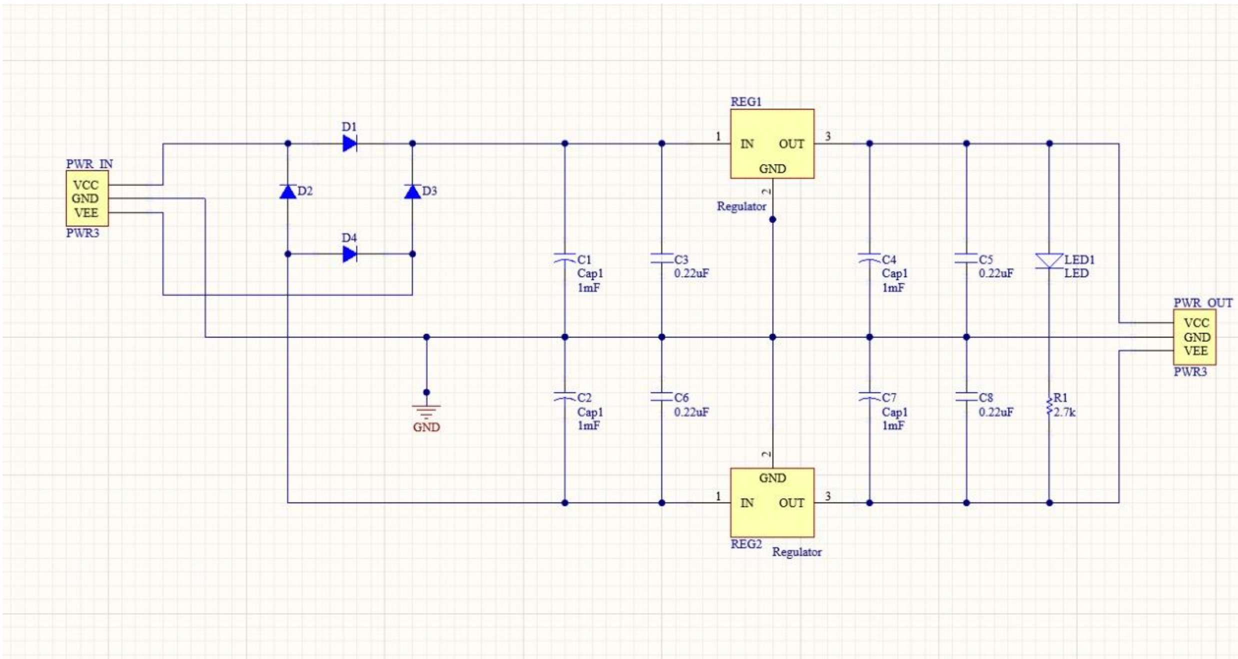
Index	Name	Contribution
190012X	Abeysinghe A.L.R.	Power Supply, Square wave generation part
190014F	Abeysinghe W.A.M.S.Y.	Sine wave generation part, Soldering
190018V	Abeywickrama K.C.S.	Triangular generation part, PCB designing
190021A	Adikari A.M.A.D.	Final amplifier, Enclosure designing

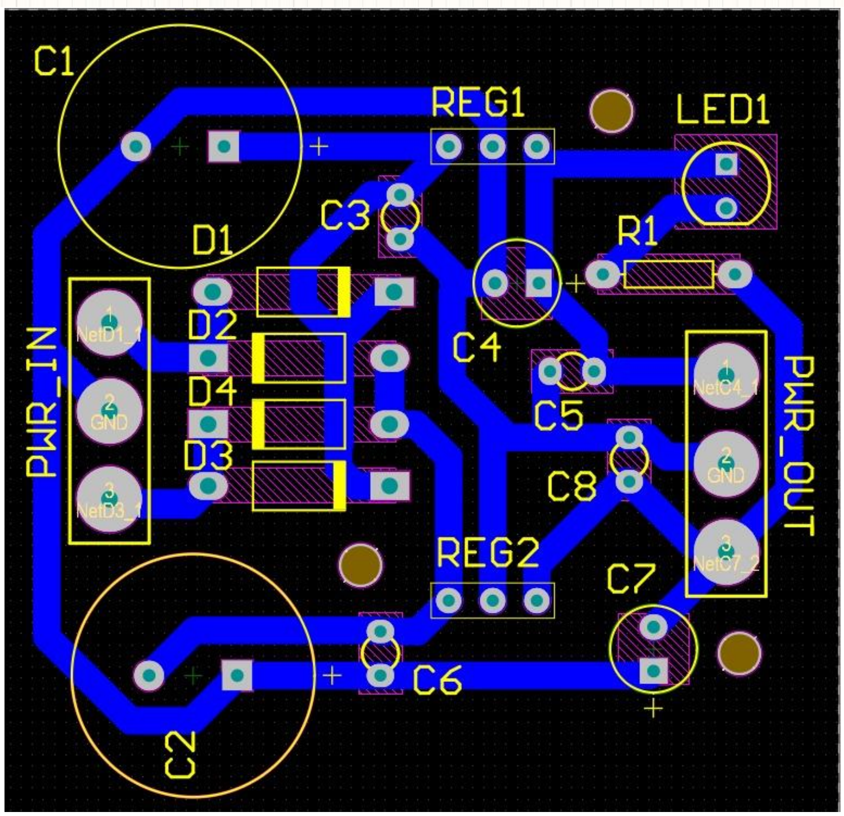
APPENDIX

a. Full Circuit Diagram



b. Power Supply





c. Datasheet

Analog Function Generator

The CYLA2 gives the power to generate four different signals at an affordable price, from 20Hz to 20kHz frequency range. With four standard waveforms, square wave, triangular wave, sawtooth wave, and sine wave you can create the signal you need to exercise your design thoroughly.

1. Specifications

- Can generate four standard waveforms:
  5. Sine wave
  6. Triangular wave
  7. Sawtooth wave
  8. Square wave.

- The following features can be adjusted independently of each other,
  5. Adjustable 20Hz – 20kHz frequency range
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  7. Adjustable amplitude from 0 – 10V Vpp.
  8. Adjustable offset.

- Can drive a maximum output current of up to 200mA.

- Compact portable design.

- Can operate with a 230VAC power supply or a 10VDC dual power supply.

2. General Characteristics

- Triangular Wave
  Frequency range: 20Hz-20KHz
  Amplitude range: 3.5V-14V

- Sawtooth Wave
  Frequency range: 15Hz-15KHz
  Amplitude range: 2V-12V

- Sine Wave
  Frequency range: 20Hz-3kHz
  Amplitude range: 1.5V-14V

- Square Wave
  Frequency range: 20Hz-3KHz
  Amplitude range: 1.5V-8V
  Adjustable duty cycle: 2% - 98%

d. GitHub Link

https://github.com/KCSAbeywickrama/Function-Generator