Department of Electronic and Telecommunication Engineering

University of Moratuwa

EN – 2090 Laboratory practice II

ANALOG FUNCTION GENERATOR

GROUP 20

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This is submitted as a partial fulfillment for the module
EN 2090: Laboratory Practice II
Department of Electronic and Telecommunication Engineering
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ABSTRACT

Function generator is an electronic device which generates various types of electrical waveforms over a broad range of frequencies. These devices can be used to generate waves with variable frequencies, amplitudes, offsets, and duty cycles for various experimental design purposes. Today most of the function generators are made using digital electronics components and these devices costs around $1000. This report talks about the overview of a signal generator, how to generate function using analog electronics, and changing its characteristics like waveform, modulation, frequency, and amplitude voltage.

CONTENTS

1. INTRODUCTION

The function generator can generate square, triangle, sawtooth, PWM and sine waveforms. Function generators can usually change their waveform frequency precisely among a wide range of values. Furthermore, they can even change their amplitudes and average DC values.

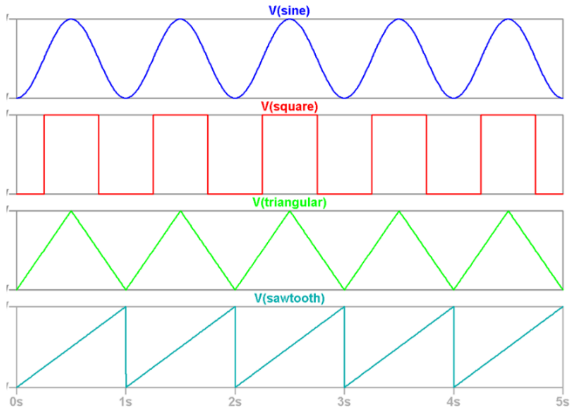


Figure 1 - Different types of waveforms

Some applications of function generator are sweep generation, AM/FM generation and Phase Locked Loops (PLLs).

In this report, we describe how we are going to build an analog circuit using transistors and op-amps and how we are going to change the frequencies and the amplitudes of the waveforms.

2. ELECTRONIC DESIGN

2.1 Design Specifications

In this project, we will fulfill the following specifications.

1. Function generator should be able generate sine, square, pulse width modulation, sawtooth, and triangular waves.
2. The output amplitude should be variable from 0V to 10V.
3. The output frequency should be variable from 20 Hz to 20000 Hz.
4. It should be able to drive at least a 50 Ohm load without significant waveform distortion or amplitude reduction.
5. PWM waveform should have a variable pulse width (1% to 99%).
6. The function generator should be able to give a DC shift to the waves.

2.2 Waveform Generation

2.2.1 Square Wave

The square wave as well as the triangular waves are combined together, which means that the output of one circuit acts as input of the other. The square wave was just the result of the comparator property of the Op-Amp used. The triangular wave was sent through the inverting input and a threshold voltage was set with the help of a feedback resistor and an input resistor. To change the frequency of the wave we are going to use a potentiometer in the place of R3 with a fixed resistor.

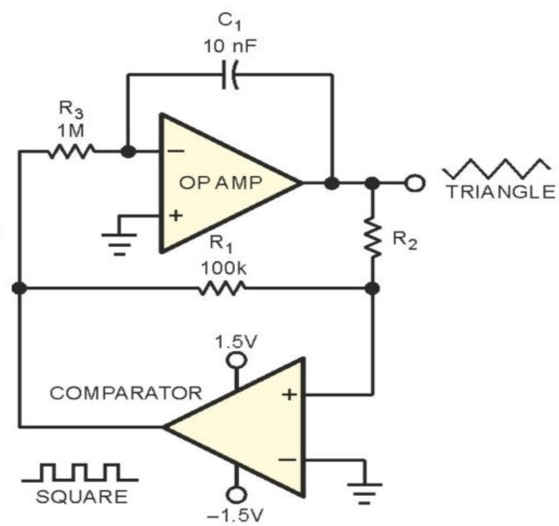


Figure 2 - Square & triangular waveform generating circuit

The solitary-comparator circuit uses a relaxation oscillator approach with the triangle approximation assuming an RC nature and by adding an integrator improves the triangle approximation. The circuit includes a hysteretic-feedback path as well as an RC or integrator feedback path comprising R3 and C1. The hysteretic-feedback path keeps changing the direction of the RC integrator and setting the new target voltage, and the RC integrator sets the rate of change toward the new target.

In the above circuit, we can calculate the frequency using the following equation.

$$f = \frac{1}{2\pi} \times \frac{R1}{R2} \times \frac{1}{(4 \times R3 \times C1)}$$

So, we are planning to change the frequency of the waveform using R3 resistor and C1 capacitor fixing the resistors R1 & R2.

2.2.2 Triangular Wave

As shown in the figure 2 the integral Op-Amp is used in generate triangular wave from square wave. The square wave output was input to the Op-Amp with a capacitance and an input resistor value which makes the Op-Amp to act as a desired integrator. The frequency of the wave can be changed in the same way by changing the frequency of the square wave.

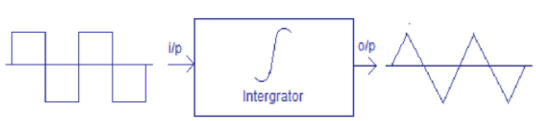


Figure 4- integrator

2.2.3 Sawtooth Wave

We plan to generate the sawtooth waveform from the same output pin where the triangular wave is generated. The only change made in the circuit is, if the non-inverting input of the Op-Amp is set to ground triangular wave is generated whereas if that is set to a potentiometer with a varying voltage a sawtooth waveform is generated. The modification is given below.

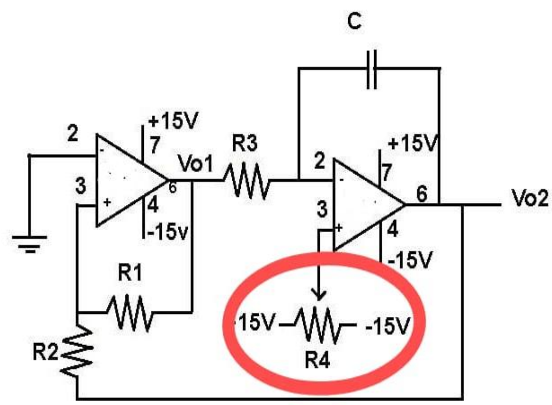


Figure 3 - Sawtooth generation circuit

2.2.4 PWM Wave

We plan to generate the PWM waveform from the triangular wave. A comparator is used to generate different duty cycles of PWM. We plan to give a reference voltage to inverting input at the same time we give the triangular wave to non-inverting input. If instantaneous voltage of the triangular wave is greater than the reference, output will be +Vs if less than reference, output will be -Vs. By changing the reference-voltage we give, we can change the duty cycle. For changing reference-voltage we plan to use a voltage divider circuit with a potentiometer.

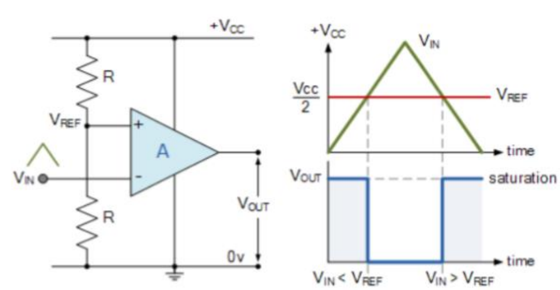


Figure 5 Comparator Circuit

2.2.5 Sine Wave

To obtain the sine waveform, we plan to use the Wein bridge oscillator circuit. The circuit is stabilized for controlling the gain. The Wein bridge oscillator has two capacitors, of which the values should be equal to each other. The frequency range is selected using these capacitors, while the variable resistor is used to obtain a specific frequency within the selected range.

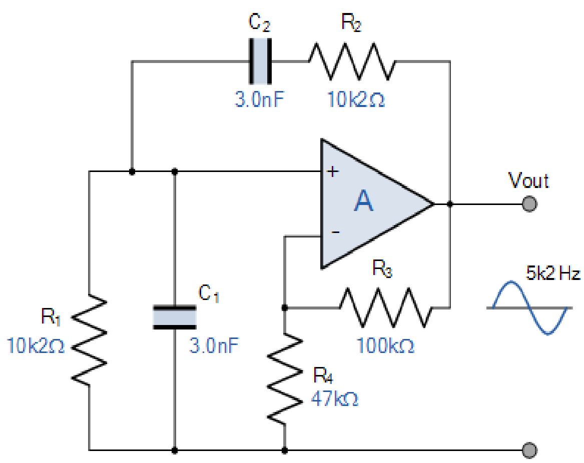


Figure 6 - Wein Bridge Oscillator

Hence, here is a frequency point where the maximum V_{out} can be occurred and it is known as oscillator resonance frequency(f_r) At f_r, Xc = R and phase difference between input and output is zero.

The circuit contains two RC pairs where in one R & C are in series and in the other the R & C are in parallel. Both the series and parallel RC combinations combined together to make a frequency dependent voltage divider. The output of the operational amplifier (op amp) is fed back to both the inputs of the op amp, through a feedback resistor to the inverting input and through the series RC combination to the non-inverting input. The whole combination generates a sine wave at the resonance frequency(f_r), given by the equation,

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

F_r -resonant frequency
R-Resistance
C- Capacitance
In this circuit, in series and parallel RC combinations, two resistors and two capacitors have to be of the same value.

2.3 Other Circuits

2.3.1 DC shift

We plan to add a DC offset to the generated waveform using an Op-Amp circuit. It is an inverting amplifier circuit. Input and a DC voltage is given to the inverting pin of the Op-Amp. DC voltage is controlled by the potentiometer.

2.3.2 Push Pull Amplifier

Class A

- One transistor always remains ON
- Distortions are minimum
- Amplified efficiency is 30%
- Same amount of load current to flow through even when there is no signal.

Class B

- The two identical transistors are connected in such a way that each transistor is operating per each half cycle.
- Efficiency is about 50%, greater than of class A
- Q point of the transistor is located at its cut off region

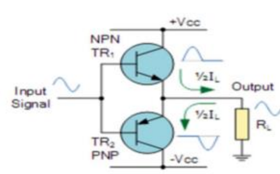


Figure 7 - Class B

Class AB

- The efficiency is about 50%
- Conduction angle is between 180 and 360
- Low crossover distortion
- In here both transistors are on between -0.7v and 0.7v
- High linearity like class A amplifier

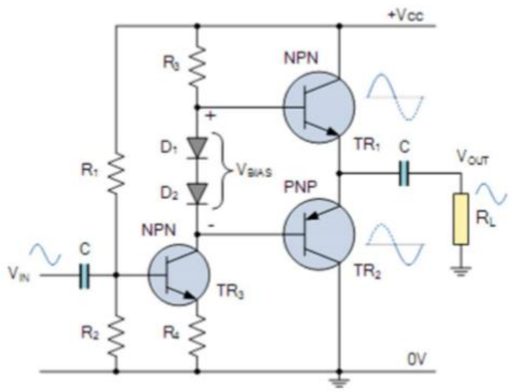


Figure 8 - Class AB

We are going to design the amplifier circuit in three stages.

Inverting amplifier stage -To obtain a variable amplitude
Voltage buffer stage - To maintain the stability
Push pull amplifier stage – To produce high current

2.3.3 Power Supply Circuit

We have to create +12V and -12V DC power supply to perform our expected task. Since the function generator is a laboratory equipment and it is used for a long time, we planned to supply the voltage using an AC power supply. We are going to use a step-down transformer of 15V, a rectifier bridge and LM7812 and LM7912 regulators for this purpose.

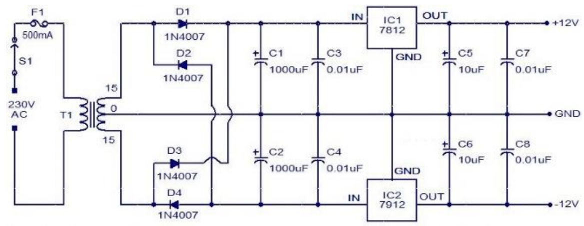
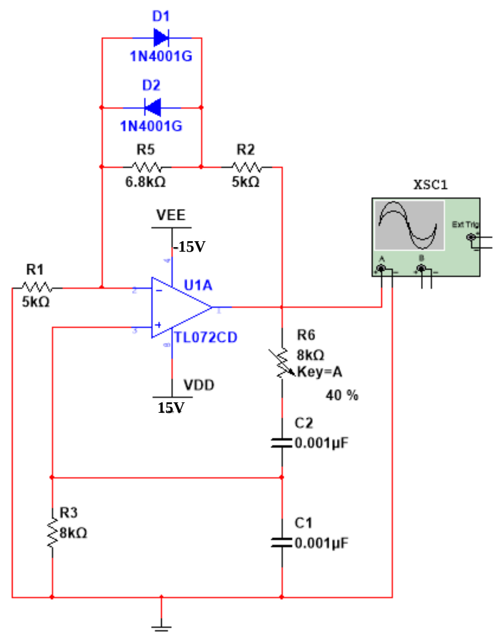


Figure 9 - Power Supply Circuit

3. SIMULATIONS

3.1 Sine Wave



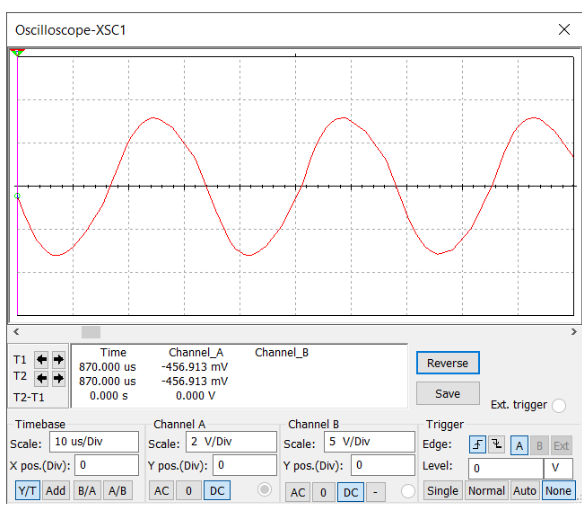
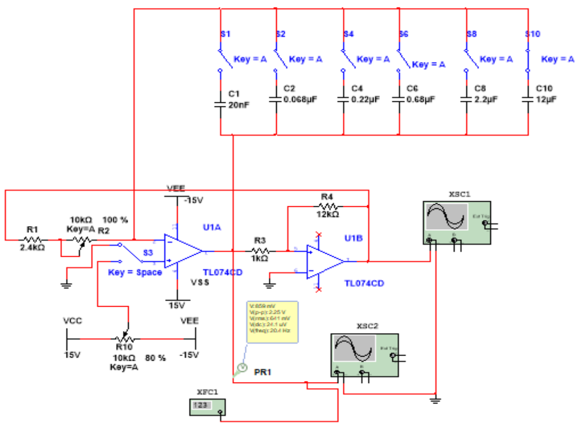


Figure 10 - Sine Wave Simulation

3.2 Triangular, Square, Sawtooth, & PWM



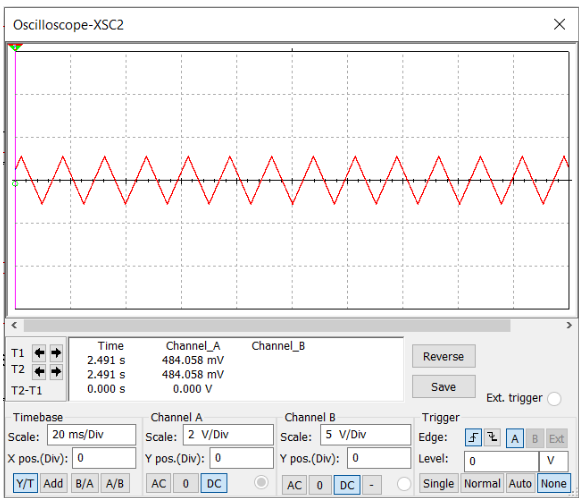


Figure 11 - Triangular Wave Simulation

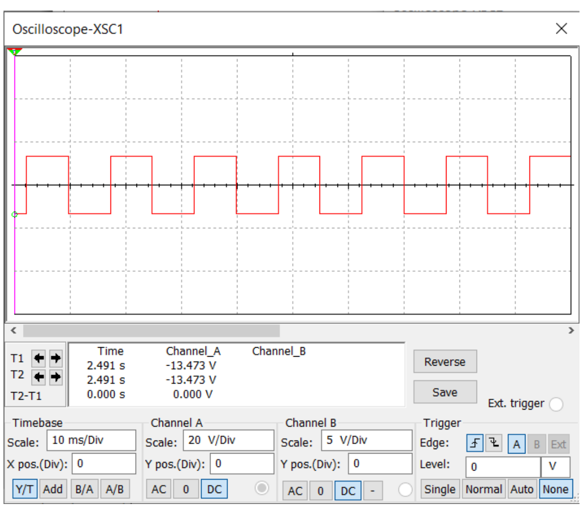


Figure 12 - Square Wave Simulation

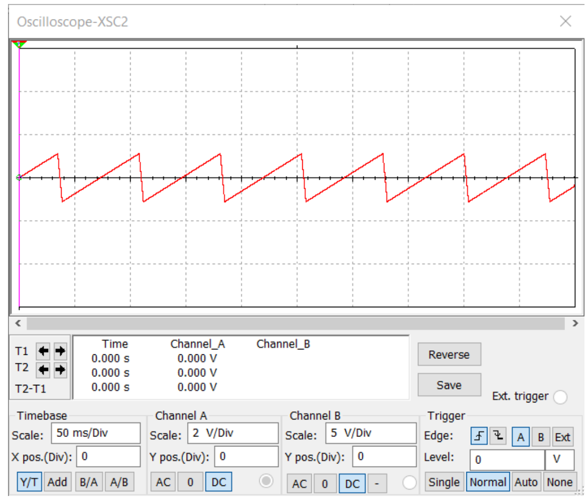


Figure 13 - Sawtooth Wave Generation

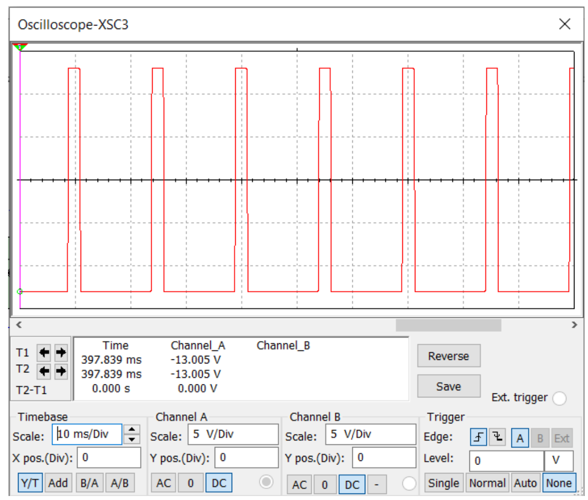
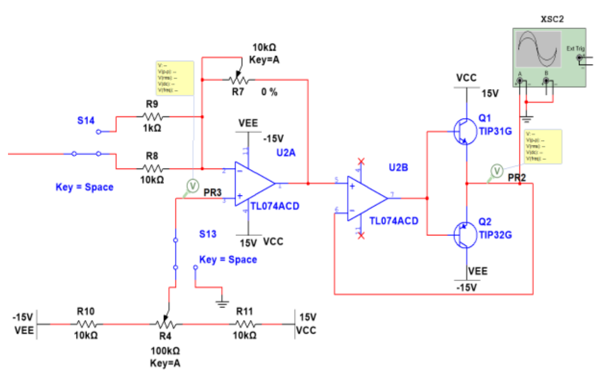


Figure 14 - PWM Wave Generation

3.3 DC Shift & Amplification



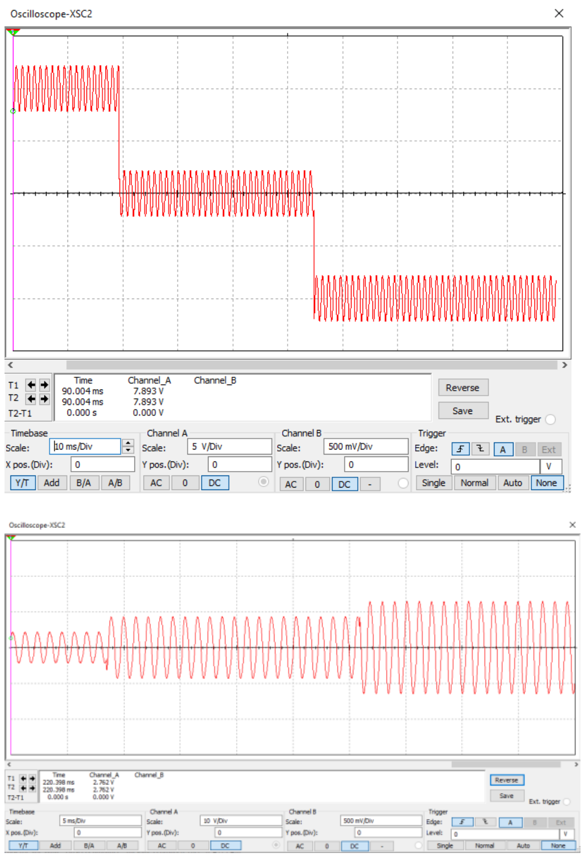


Figure 15 - shift Simulation

4. CALCULATIONS

4.1 Triangular, Sawtooth and Square Wave Calculation

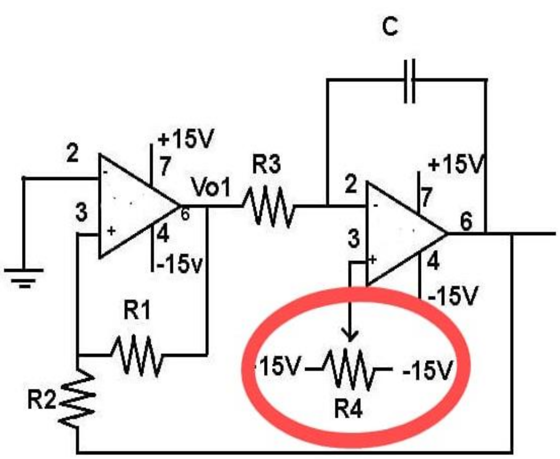


Figure 16 -Wave Form Generation Circuit

- For 20Hz,

  R3 = 6.2kΩ R2 = 2.4kΩ
  R4 = 1kΩ R5 = 12kΩ

$$20 = \frac{12}{1} \times \frac{1}{4 \times (6200+2400) \times C1}$$

  C1 = 17.44 μF

- For 20kHz,

  R3 = 0kΩ R2 = 2.4kΩ
  R4 = 1kΩ R5 = 12kΩ

$$20000 = \frac{12}{1} \times \frac{1}{4 \times (2400) \times C1}$$

  C1 = 0.0625 μF

4.2 Sine Wave Calculation

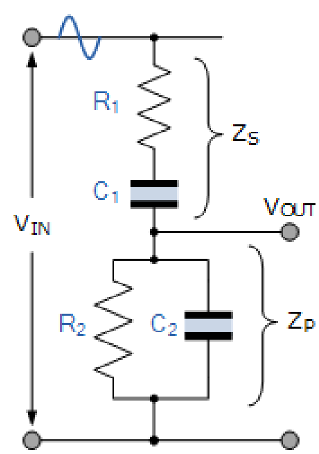


Figure 17 -Sine Wave Generation Circuit

For example, we can take R1=R2=12kΩ, C1=C2=3.9nF and the supply frequency f=3.4kHz.

- For Series Combination

$$R = 12k\Omega, \text{ but } X_C = \frac{1}{2\pi fC}$$

$$\therefore X_C = \frac{1}{2\pi \times 3.4kHz \times 3.9nF} = 12k\Omega$$

$$Z_S = \sqrt{R^2 + X_C^2} = \sqrt{12000^2 + 12000^2}$$

$$\therefore Z_S = 16{,}970\Omega \text{ or } 17k\Omega$$

- For Parallel Combination

$$R = 12k\Omega, \text{ and } X_C = 12k\Omega$$

$$\frac{1}{Z} = \frac{1}{R} + \frac{1}{XC} = \frac{1}{12000} + \frac{1}{12000}$$

$$\therefore Z = 6000\Omega \text{ or } 6k\Omega$$

$$R = 6k\Omega, \text{ and } X_C = 6k\Omega \text{ (Parallel)}$$

$$Z_P = \sqrt{R^2 + X_C^2} = \sqrt{6000^2 + 6000^2}$$

$$\therefore Z_P = 8485\Omega \text{ or } 8.5k\Omega$$

- Z Out of Voltage Divider

$$Z_{OUT} = \frac{Z_P}{Z_P + Z_S} = \frac{8.5k\Omega}{8.5k\Omega + 17k\Omega} = 0.333 \text{ or } \frac{1}{3}$$

- Then,

Vout = Zout x Vin

Vout = $\frac{1}{3}$ x Vin

Above values are used to show how 1/3 comes and We will change the resistor values for the circuit while we will be testing the circuits according to the results.

4.2.1 Wein Bridge Oscillator

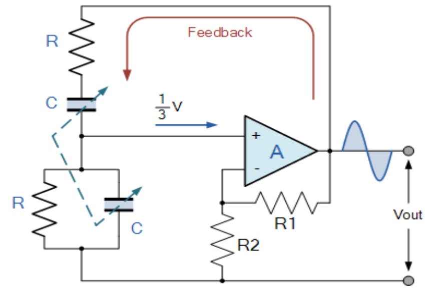


Figure 18- Wein Bridge Oscillator

Output voltage gain of non-inverting amplifier (Av) $= 1 + \frac{R_1}{R_2} = \frac{V_{out}}{V_{in}}$

To get the oscillation output, Av ≥ 3

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

We have to vary the frequency from 20Hz-20000kHz. We have choose C1,C2 as 1nF to achieve maximum 20kHz frequency.

$$R = \frac{1}{2\pi \times 20kHz \times 1nF}$$

$$= 7.957k\Omega \approx 8k\Omega$$

We have choose C1,C2 value as 1uF to achieve minimum 20Hz frequency.

$$f = \frac{1}{2\pi \times 8kHz \times 1\mu F}$$

$$= 19.89Hz \approx 20Hz$$

To begin the sinusoidal oscillation Av ≥ 3; We Assumed R4 as 5kΩ. Then,

$$1 + \frac{R_3}{R_4} \geq 3$$

$$1 + \frac{R_3}{5k\Omega} \geq 3$$

$$R_3 \geq 10\text{k}\Omega$$

We need to use some methods to be stabilizing the amplitude of the oscillations. If the voltage gain of the amplifier is too small the desired oscillation will decay and stop. If it is too large the output will saturate to the value of the supply rails and distort. We have used feedback diodes to stabilization of amplitude.

5. OP AMP SELECTION

When choosing an op amp, we must consider the main requirements. They are,

- Input offset voltage
- Input impedance
- Input leakage current
- Common mode rejection ratio
- Open loop gain
- Bandwidth
- Maximum output slew rate
- Output source and sink current limits
- Noise figure

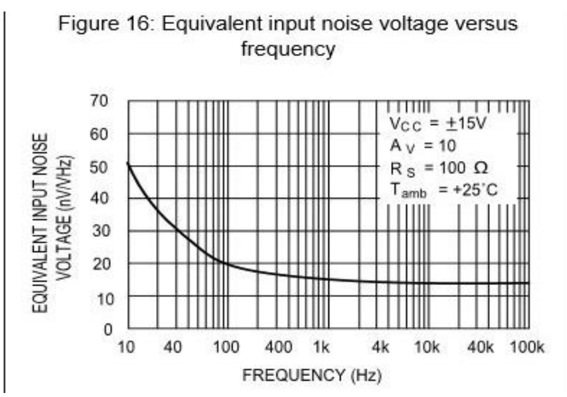


Figure 20 - Equivalent Input Noise Voltage

But needed requirements differ from application to application. We want to find an op amp with better features for the function generator circuits. We choose TL072 and LM741 to generate waveforms.

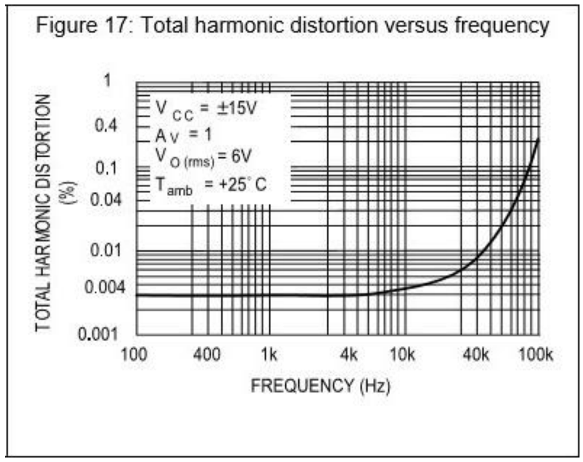


Figure 19 -Total Harmonic Distortion

These two figures show how the noise input voltage and harmonic distortions change with respect to the frequency. Hence, both noise effect and harmonic distortions increase when frequency is increased. We have to change the frequency from 20Hz-20000Hz, and it is suitable to stop all scenarios that can generate noise as well as harmonic distortions. We choose TL072 on the fact of low noise and low harmonic distortions. There are number of noise sources within an op amp such as resistor noise, current noise, and KT/C noise. Reduction of resistors as well as covering the non-used pins of op-amps may help to reduce the noise effects and harmonic distortions.

6. ROTARY SWITCH

For the selection of different frequencies of the waveforms, and for the selection of the waveform. we are going to use rotary switches in our design. A rotary switch is a switch in which the contacts are changed when the spindle is rotated in either a clockwise or an anticlockwise direction. We are going to use 1 pole 12-way rotary switch for this purpose, and we can change the frequency values by changing the capacitor values.

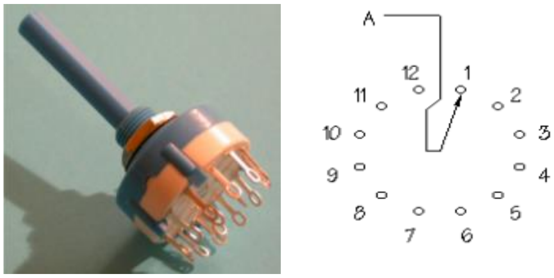


Figure 21 -Rotary Switch

7. SCHEMATIC DESIGNS

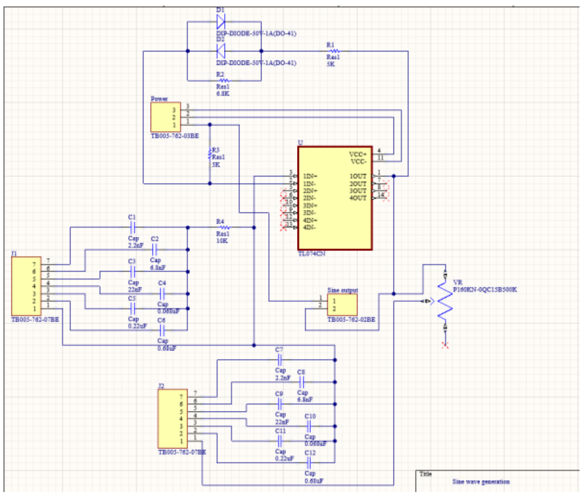


Figure 22 – Sine Wave Schematic

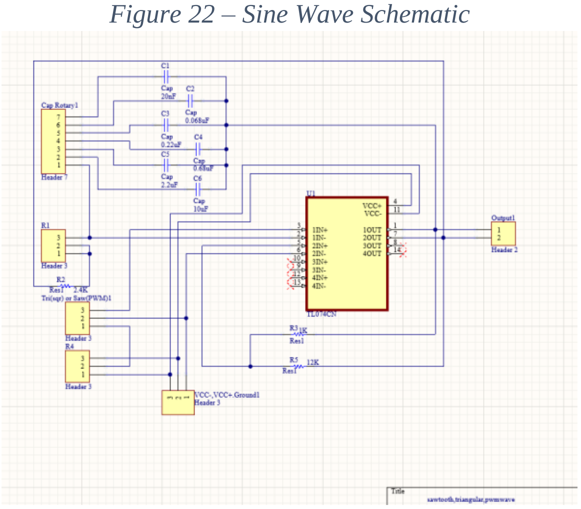


Figure 23 – Sawtooth, Triangular, Square, & PWM Wave Schematic

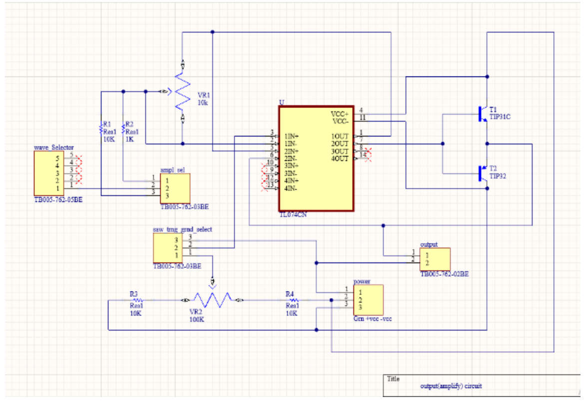


Figure 24 – Output Circuit Schematic

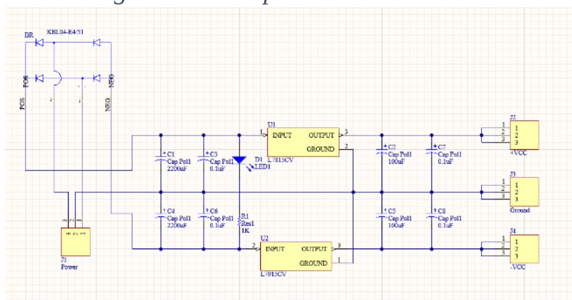


Figure 25 – Power Supply Circuit Schematic

8. LAYOUTS

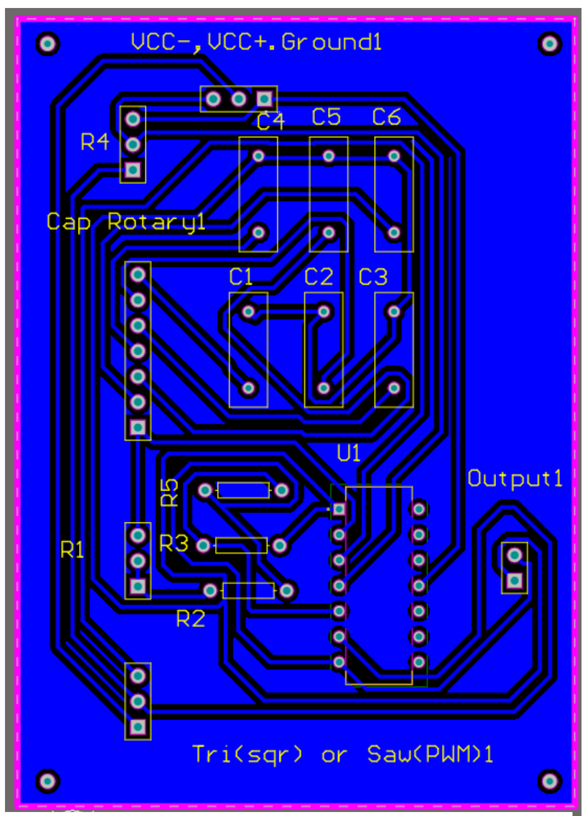


Figure 26 – Sawtooth, Triangular, Square, & PWM Wave 3D

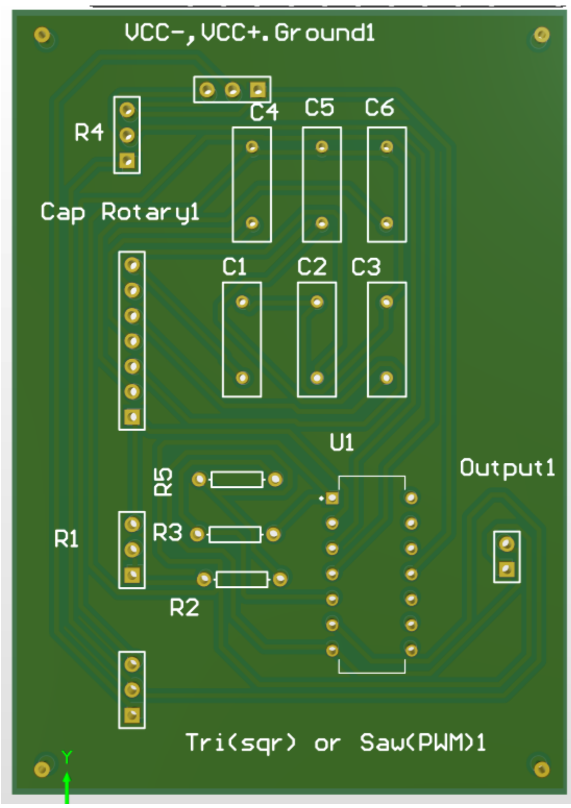


Figure 27 – Sawtooth, Triangular, Square, & PWM Wave 3D

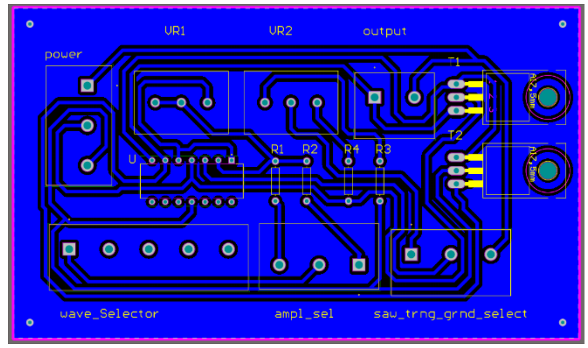


Figure 30 – Output Circuit Layout

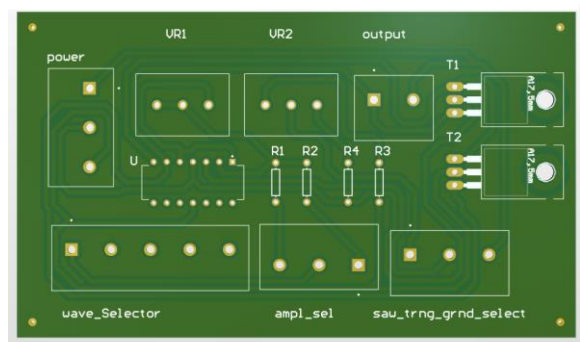


Figure 31 – Output Circuit 3D

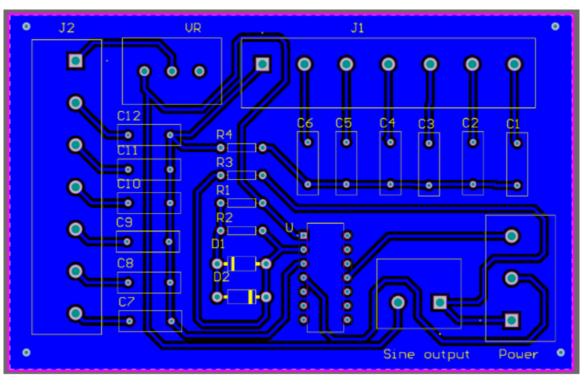


Figure 28 – Sine Wave Layout

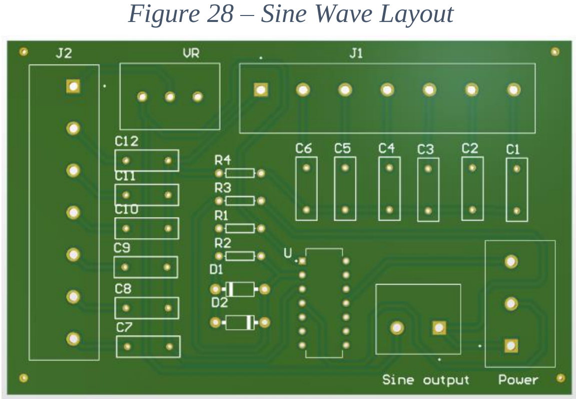


Figure 29 – Sine Wave 3D

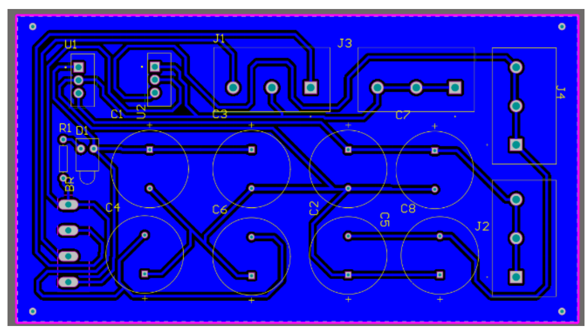


Figure 32 – Power Supply Circuit Layout

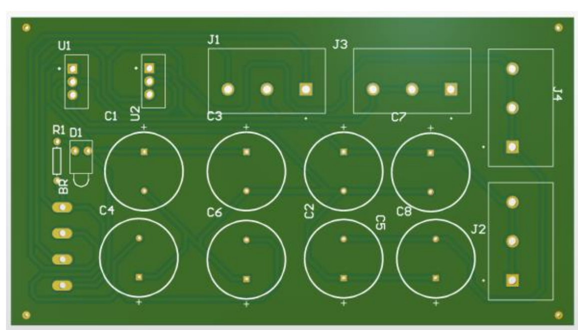


Figure 33 – Power Supply Circuit 3D

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