Indian Institute of Space Science and Technology

Function Generator

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SC19B091

Contents

Introduction

A function generator is a signal source that has the capability of producing different types of waveforms as its output signal. The most common output waveforms are sine-waves, triangular waves, square waves, and sawtooth waves. The frequencies of such waveforms may be adjusted from a fraction of a hertz to several hundred kHz.

A function generator has many practical electrical engineering applications. It is often used to produce different kinds of waveforms to test and debug various circuits and devices.

The purpose of this project is to make a function generator that can generate three different type of waveforms - a square wave, a triangle wave, and a sinusoidal wave using only analog components and circuitry. This circuit can be used to vary frequency in the range of 100-3200Hz using a potentiometer. The square wave generation is done using an Astable multivibrator. The triangle wave and the sine wave are generated using two integrators cascaded with the Astable Multivibrator.

Circuit Design

For the function generator, we need to design:

- An Astable Multivibrator for the square wave generation.
- An Integrator for the triangle wave generation
- An Integrator for the sine wave generation

For undistorted wave generation, we have to choose Opamp that has high slew rate so that the distortion will be less at high frequencies. The Opamp chosen should have good dynamic specifications to work at high frequencies i.e., the Opamp should be a high speed Opamp. The Opamp can be LT1818, LM7171, LT1357, TL081 etc.

We used LM741 in our calculations and simulations as it is cheap and easily available.

An Astable Multivibrator is an oscillator circuit that generates a free-running square output waveform using an RC timing network which is connected to the inverting terminal of the op-amp and a voltage divider network connected to the other non-inverting input of the op-amp. The power supply voltage is the source of oscillations. The op-amp functions as a comparator and keeps flipping its output between high and low due to hysteresis. When the capacitor charges and reaches a value, which is equal to the voltage at the positive input terminal of the op-amp, the output voltage becomes equal to that of the positive power supply voltage. Then, the capacitor starts discharging. When the capacitor discharges and reaches a value, which is equal to the voltage at the positive input terminal of the op-amp, the output voltage becomes equal to that of the negative power supply voltage.

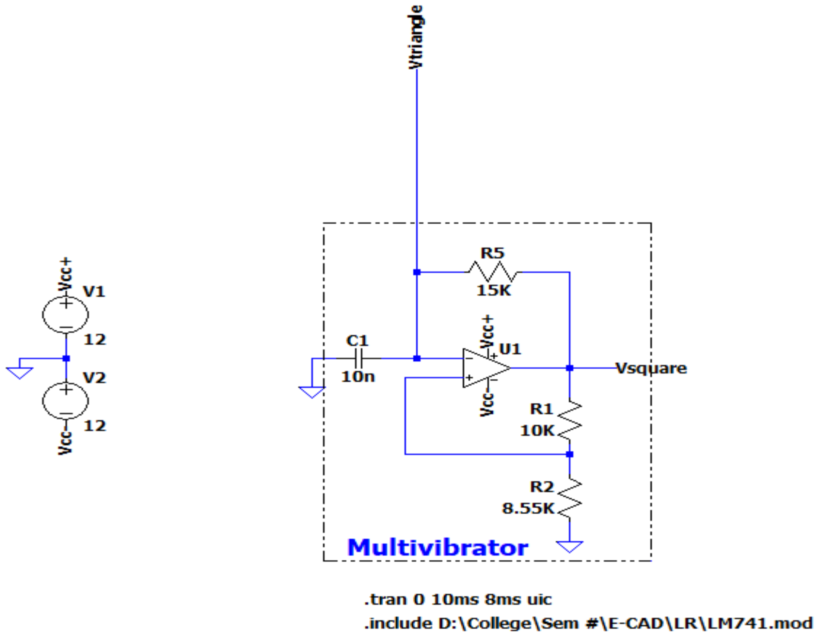
For the circuit, the values of C1, R1 and R2 are chosen to be: C1 = 10nF, R1 = 8kΩ, R2 = 10kΩ. A potentiometer X1 with a range upto 50kΩ is used in place of the resistance R. The potentiometer can be operated in the range of 12kΩ to 50kΩ. By varying the resistance of X1, the frequency can be varied from 100 – 3200Hz.

Initial designs:

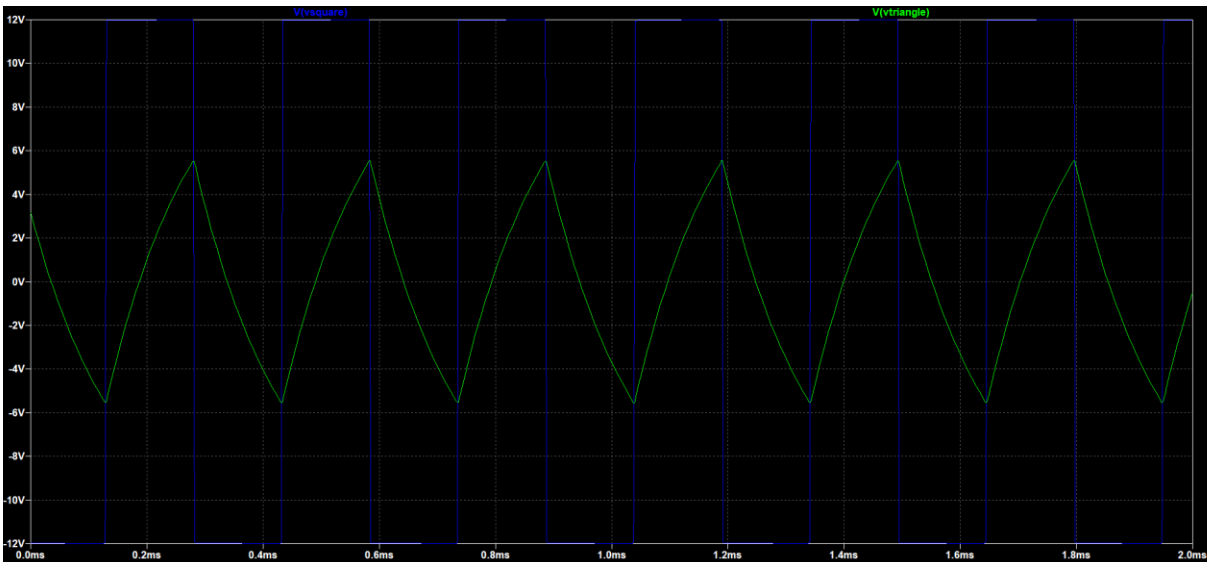
1. Obtaining Triangular and Square wave from Multivibrator

The initial design takes the advantage of the fact that the astable multivibrator can generate both triangular and square wave. We take the triangular wave and feed that into an integrator that approximately converts it into a sine wave.

Circuit diagram:



Simulation using L_TSpice:



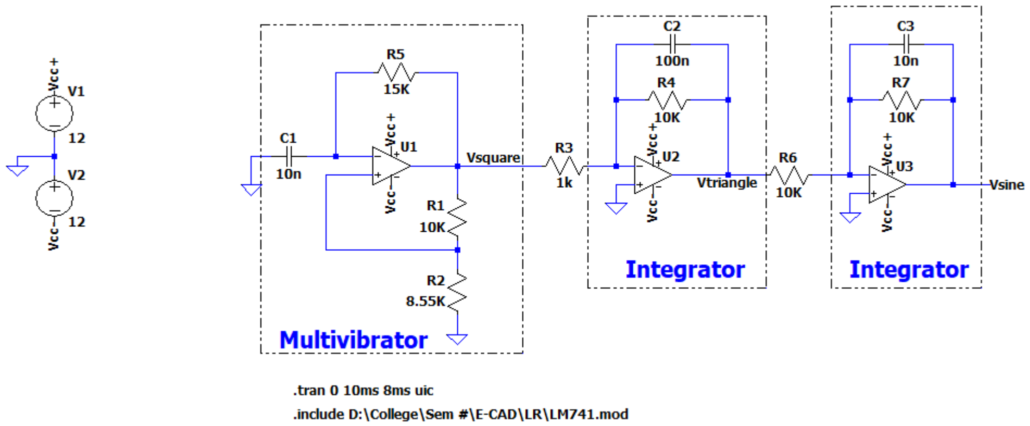
Problem:

a. The problem with this circuit is that the generated waveform is not fully linear it resembles the exponential function. As the charging and discharging of the capacitor are exponential functions.
b. The second problem that I faced is that when the triangular wave is cascaded or fed into the integrator it distorts or interferes with the square wave.

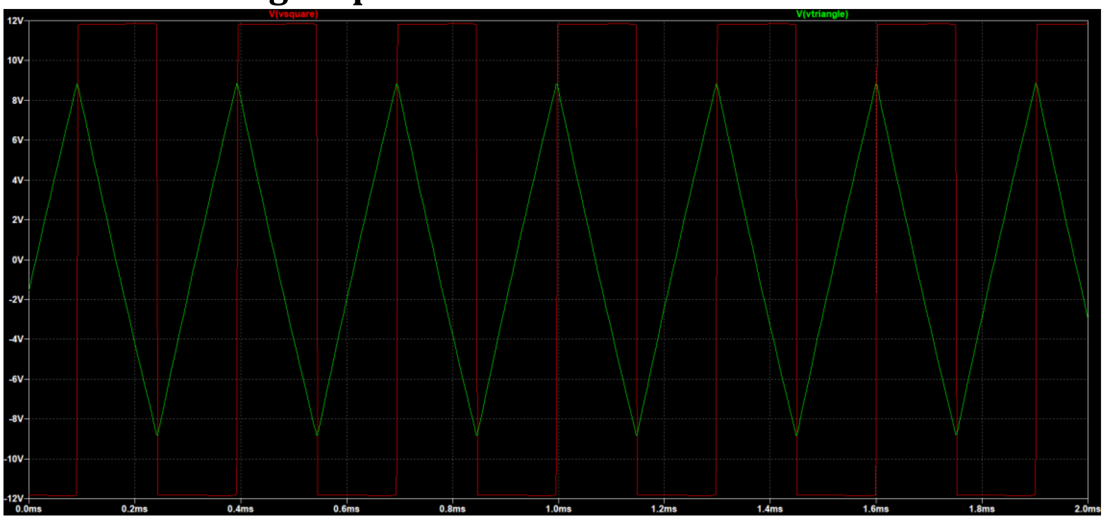
2. Using two integrators

The above problem can be solved by using two integrators instead of one the first integrator transforms the square wave into a triangular wave with decrease in the amplitude that is because the gain of the integrator is inversely proportional to the frequency. We can adjust the amplitude by using the amplifying properties of the Opamp and use it as a non-inverting amplifier.

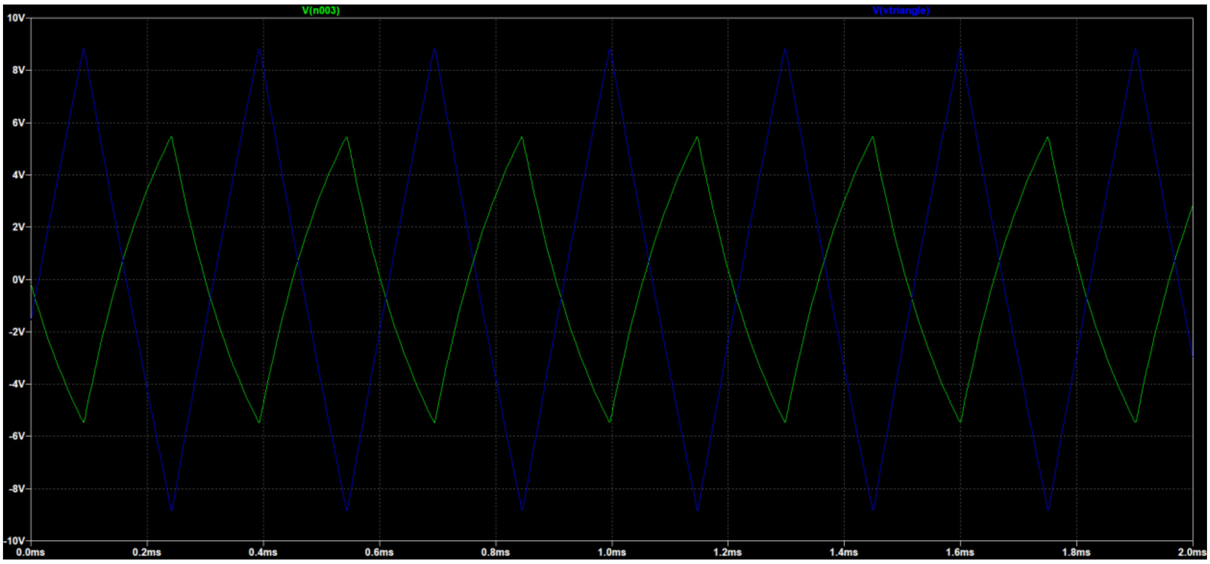
Circuit Diagram:



Simulation using LTSpice:



The above circuit gives a fairly linear triangular wave. We can also see or observe the difference between the triangular wave generated by both the circuits as shown below:



Problems:

As we increase the frequency or design the circuit for operation at higher frequencies, we face mainly three problems:

a. Distorted Wave
b. Amplitude decrease
c. DC shift

Solutions:

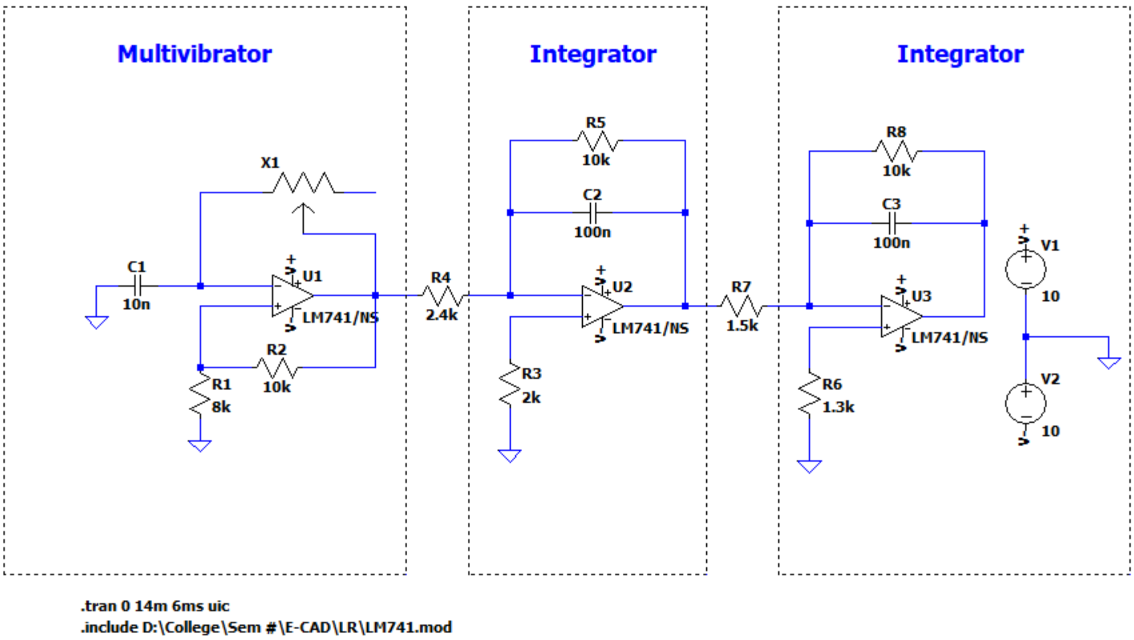
The distortion in the wave is due to the fact that at high frequencies the dynamic characteristics of the Opamp came into picture. We can eliminate this problem by using high speed opamps that has high slew rate and should have low bias currents to decrease the DC shift.

We can either select Opamp with low bias current or by using method of bias current compensation.

The amplitude decreases because of the reason that the gain of integrator is inversely proportional to the frequency. As we increase the frequency the amplitude decreases. We can rectify this problem by using an amplifier stage.

We can design the circuit for any frequency but instead of replacing the resistors we can add a potentiometer that manages the frequency of output wave. We can also control the amplitude of the waves by adding a amplifier stage and feeding the desired wave to the amplifier.

3. Final Circuit:

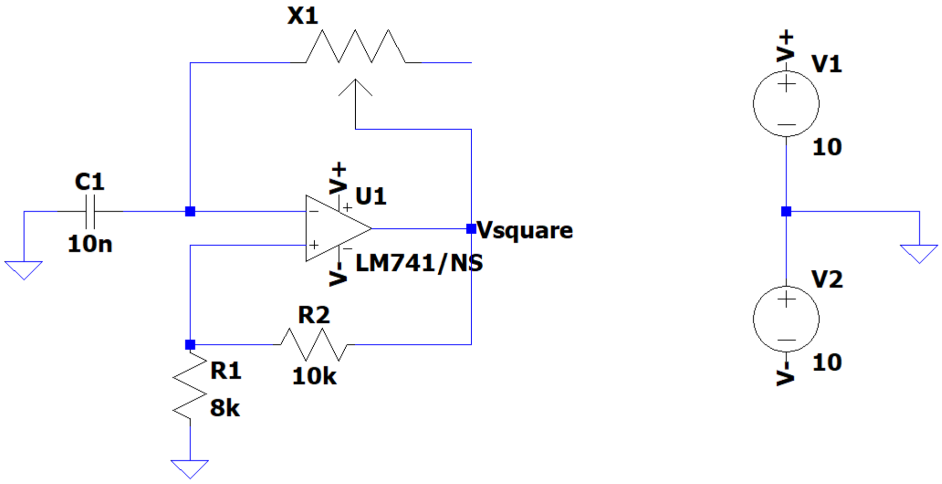


Working:

The circuit uses an astable multivibrator for the generation of a square wave. The source of generation of the wave is the electrical noise that is present in the circuit due to the thermal excitation of the electrons. The circuit picks up these vibrations and amplifies them to a desired level and the Opamp acts as a comparator that flips its voltage between low and high and the circuit continues to generate the wave due to hysteresis loop and the saturation of the Opamp. The generated square wave is then fed into an integrator that transforms the generated square wave into a triangular wave the generated triangular wave is then fed into another integrator that transforms it into a parabolic function but as the time step is fairly small, we can neglect the higher terms in the series expansion of sine and our generated parabolic functions is approximately resembles the sine wave.

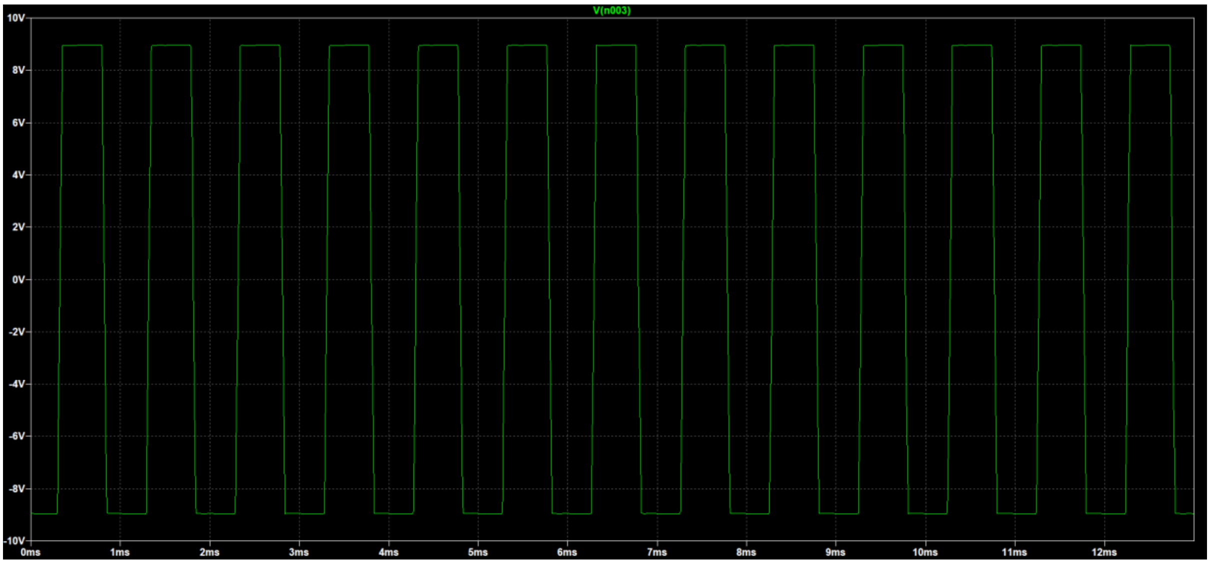
1. Square Wave Generation: Astable Multivibrator

Circuit Diagram:




```
.tran 0 15m 2m
.include D:\College\Sem #\E-CAD\LR\LM741.mod
```

Simulation result:



The square wave is generated using an astable multivibrator whose frequency can be controlled using the equation:

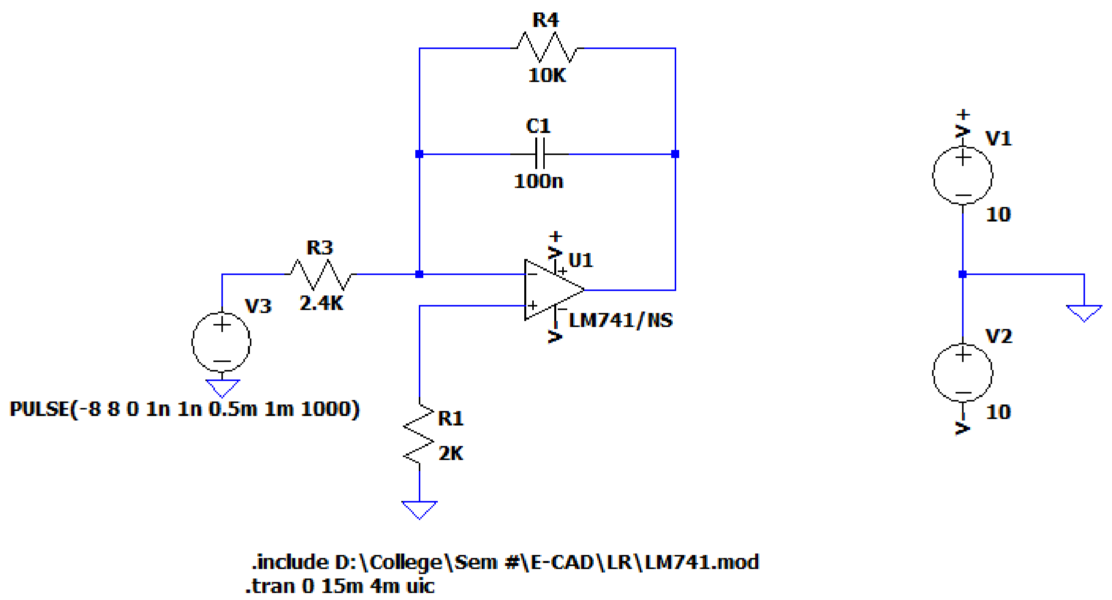
$T=2X_1C_1 \ln[1+2R_1/R_2]$ .... (1)

We can select any values of X_1, C_1, R_1 and R_2 which satisfies the above equation and gives us the desired frequency.

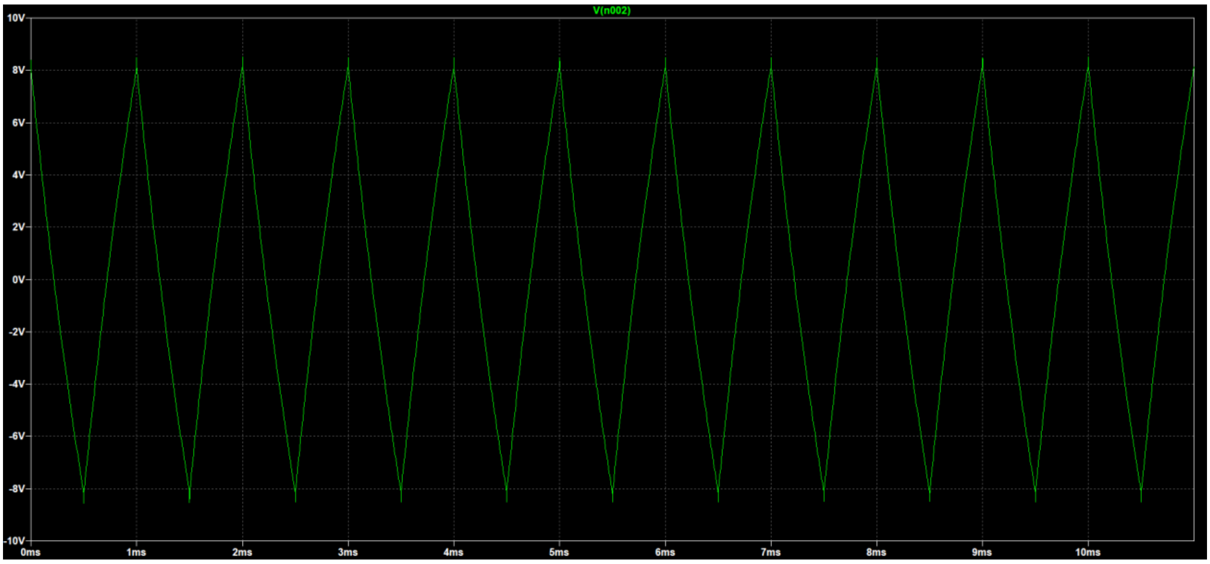
We can easily derive the equation 1 by using the charging and discharging equation of the capacitor.

2. Triangular Wave Generation: Integrator

Circuit Diagram:



Simulation result:



The triangular wave is generated by feeding the square wave into an integrator.

For the integrated wave to resemble a triangular wave the time constant of integrator or its cut-off frequency should be much less than the frequency of square wave

For the triangular circuit to work as an integrator $f >> f_c$

Where, f is frequency of triangular wave and f_c is given by:

$f_c = 1/(2\pi R_4 C_1)$

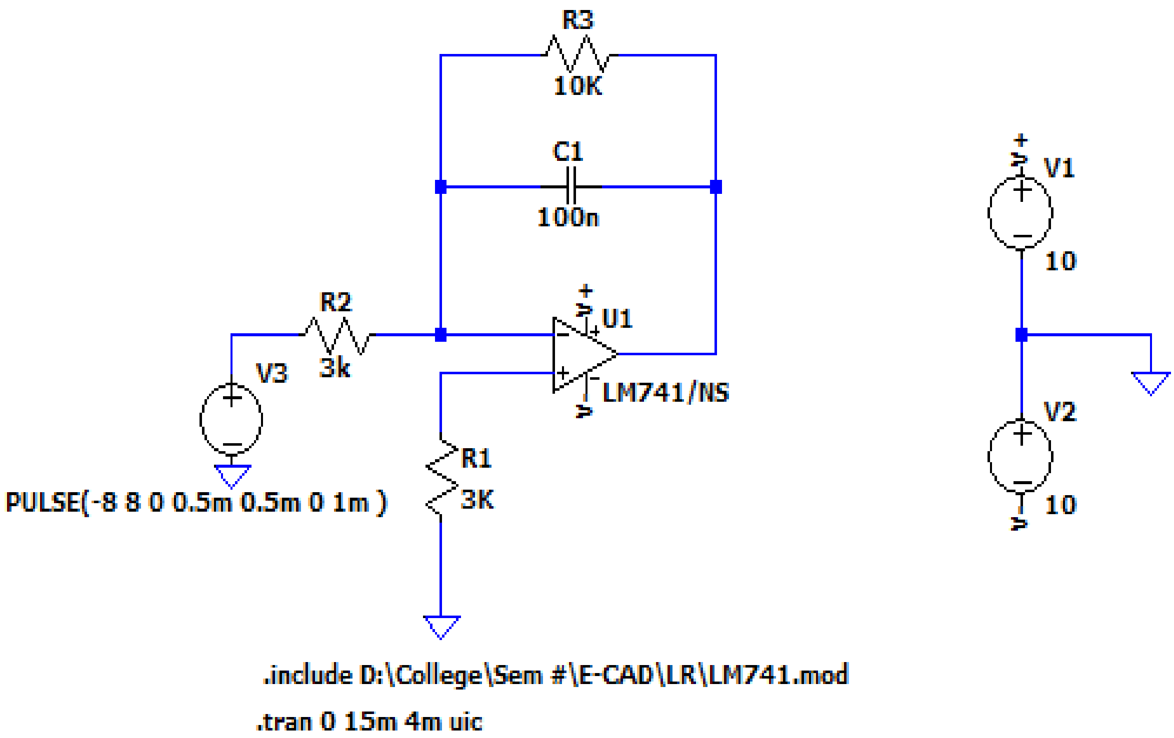
We can easily derive the equation of cut-off frequency by finding the transfer function of the integrator which is given by:

$H(\omega) = 1/(\omega R_4 C_1)$

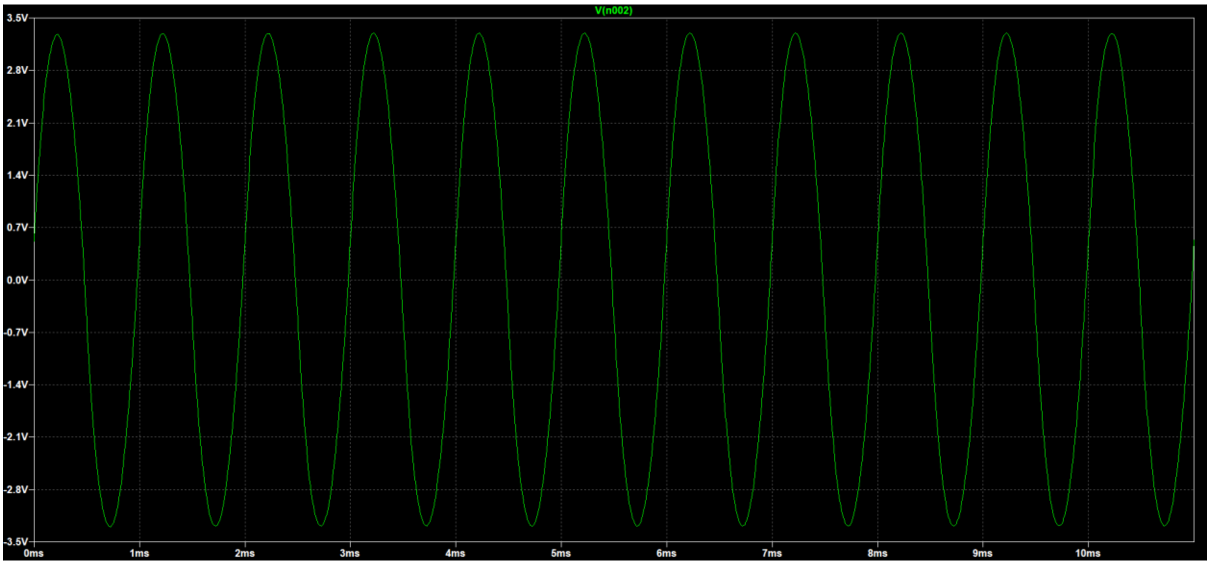
Here, we can see that the transfer function or gain is inversely proportional to the frequency. On increasing the frequency, the gain decreases significantly.

The generated triangular wave is then fed into another integrator stage

3. Sine Wave Generation: Integrator



Simulation result:



The sine wave is generated by using the triangular wave that we obtained from the output of the integrator and feeding it into another integrator.

For the wave to resemble a sine wave the cut-off frequency of the integrator should be much lesser than the frequency of triangular wave. The integrated wave is a parabolic function that resembles the sine function.

Design Calculation for 1KHz frequency

For square wave generator,

$T=2X_1C_1 \ln[1+2R_1/R_2]$ for f=1KHz → $T=1/f=1ms$

$1ms=2X_1C_1 \ln[1+2R_1/R_2]$

Selecting standard values of $X_1 = 5K\Omega$ and $C_1=0.1\mu F$

- ➔ $\ln[1+2R_1/R_2] =1$
- ➔ $R_1/R_2 =0.8591$

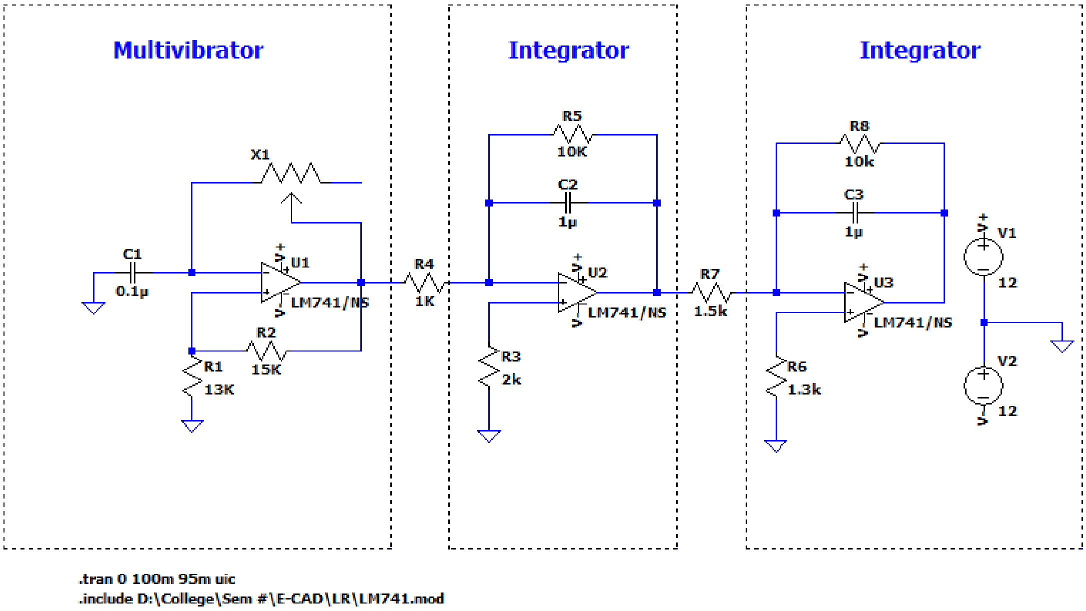
Taking $R_1=13K\Omega$ and $R_2=15K\Omega$

For the triangular circuit to work as an integrator $f >> f_c$

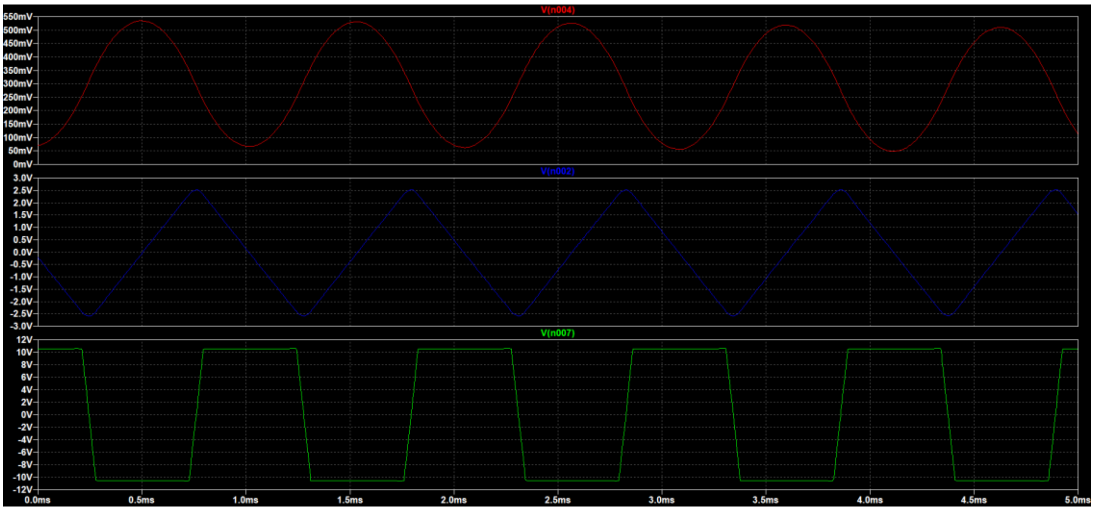
- ➔ But here f=1KHz and $f_c =1/(2\pi R_5C_2)$
- ➔ Let $C_2 =1\ \mu F$
- ➔ And R_5 should be greater than 160Ω therefore, $R_5=10K\Omega$

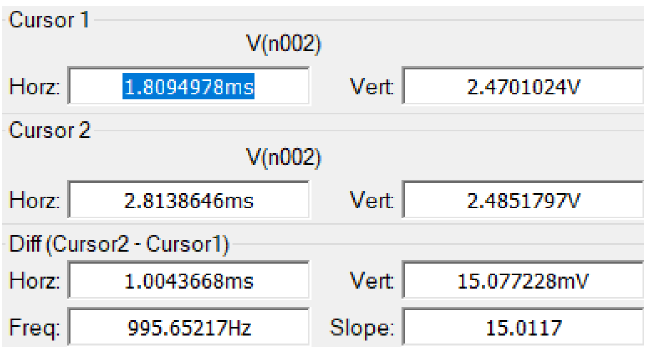
Using values R_8 and C_3 for the sine wave stage same as R_5 and C_2 respectively.

Circuit for 1KHz frequency:



Simulation result of the above circuit:





The measured frequency came out to be 995.65217Hz.

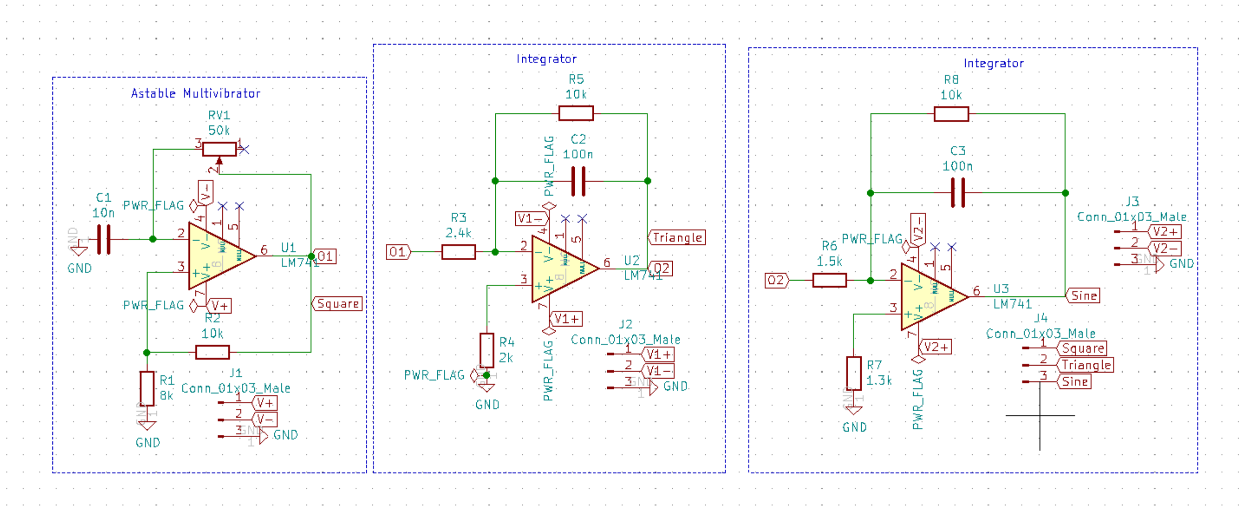
Result

Our designed circuits meet our requirement to generate a Square, a triangular Wave and a sine wave Outputs. But we observe that there is some error in the frequency of the output, it is due to the use of real Op-Amps. We also discussed the problems and the plausible and applicable solutions. By using LM741 we can obtain frequencies ranging from 100 Hz to 3200Hz. We can further increase the frequency range by using high speed Opamps as discussed earlier.

PCB Design

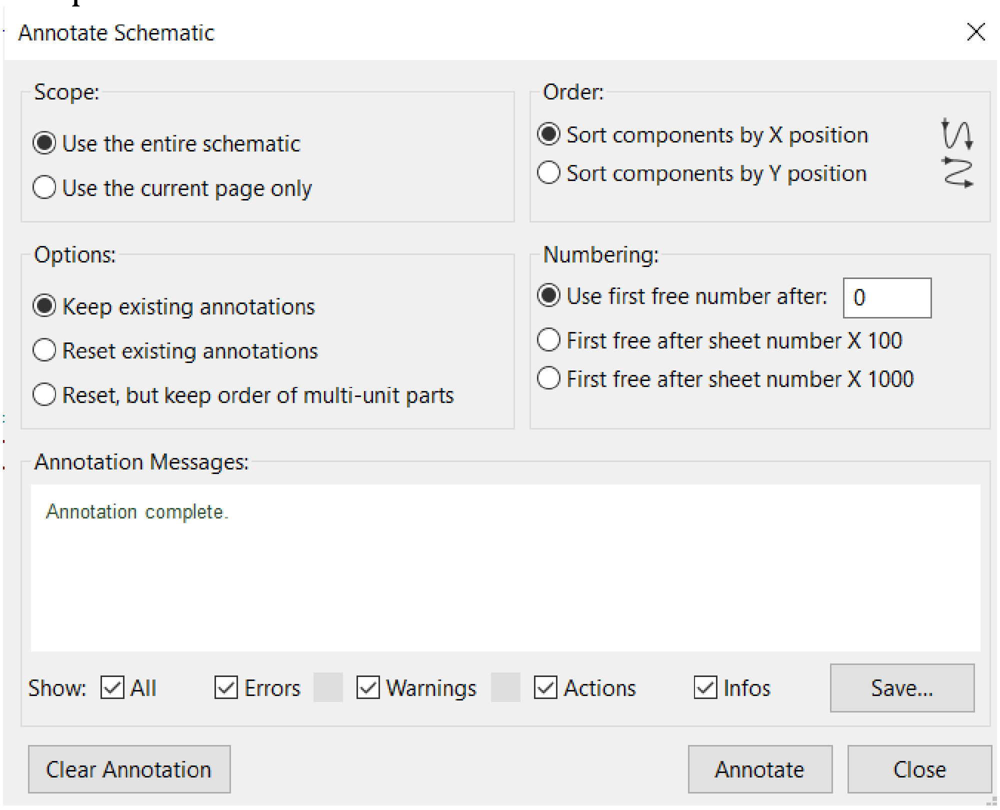
Following are the steps to design the PCB on Kicad:

1. Draw the Schematic of the circuit



2. Annotate the components

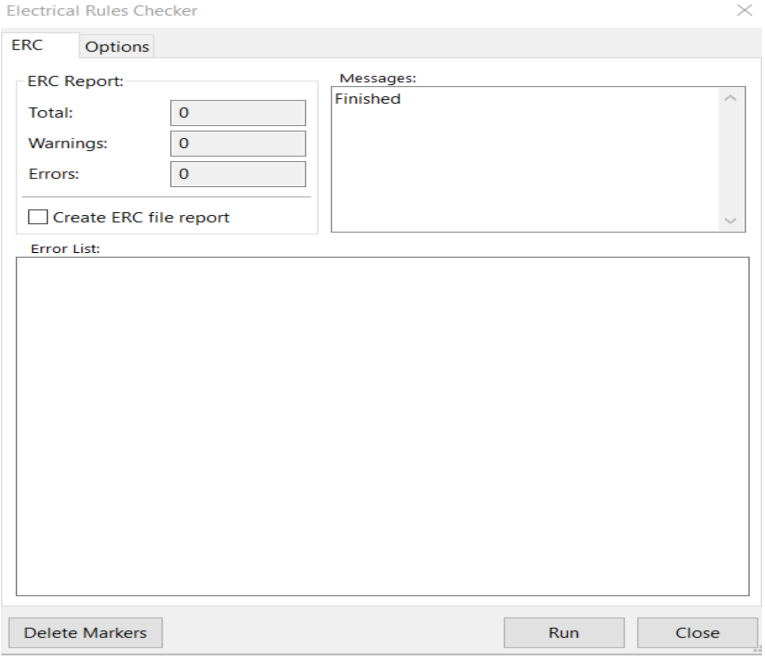
i. Click on the  symbol which is present on the top taskbar
ii. A window will pop up click on Annotate to annotate the components in the schematic.



3. Perform the electrical rules check

i. Click on the  button on the top taskbar

ii. A window will pop up click on Run

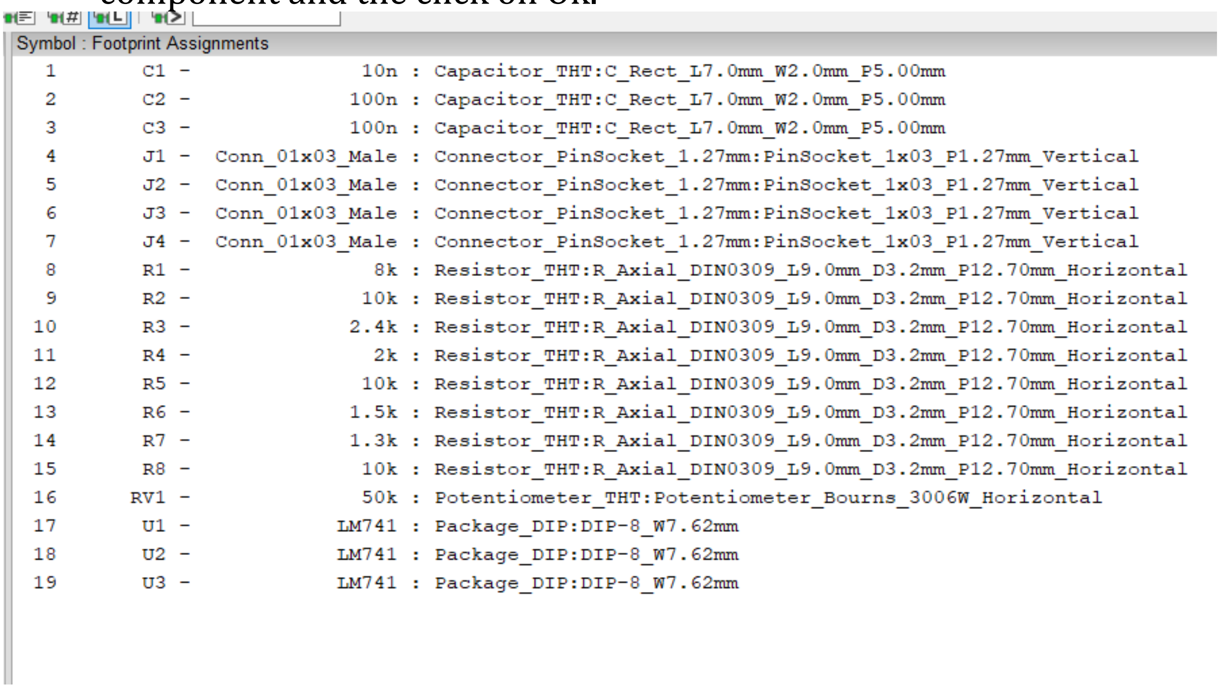


iii. If any errors are there they will be marked by green arrow on the schematic.

4. Assign footprints to the components

i. Click on the  button on the top taskbar

ii. A window will pop up assign the footprints to each and every component and the click on Ok.



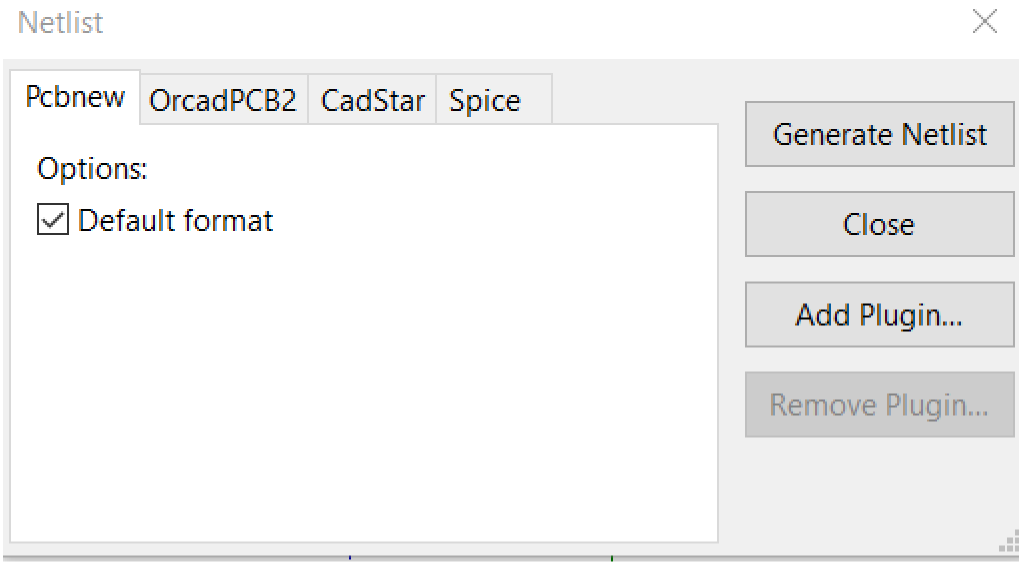
Symbol : Footprint Assignments

1	C1	-	10n	:	Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
2	C2	-	100n	:	Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
3	C3	-	100n	:	Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
4	J1	-	Conn_01x03_Male	:	Connector_PinSocket_1.27mm:PinSocket_1x03_P1.27mm_Vertical
5	J2	-	Conn_01x03_Male	:	Connector_PinSocket_1.27mm:PinSocket_1x03_P1.27mm_Vertical
6	J3	-	Conn_01x03_Male	:	Connector_PinSocket_1.27mm:PinSocket_1x03_P1.27mm_Vertical
7	J4	-	Conn_01x03_Male	:	Connector_PinSocket_1.27mm:PinSocket_1x03_P1.27mm_Vertical
8	R1	-	8k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
9	R2	-	10k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
10	R3	-	2.4k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
11	R4	-	2k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
12	R5	-	10k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
13	R6	-	1.5k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
14	R7	-	1.3k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
15	R8	-	10k	:	Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
16	RV1	-	50k	:	Potentiometer_THT:Potentiometer_Bourns_3006W_Horizontal
17	U1	-	LM741	:	Package_DIP:DIP-8_W7.62mm
18	U2	-	LM741	:	Package_DIP:DIP-8_W7.62mm
19	U3	-	LM741	:	Package_DIP:DIP-8_W7.62mm

5. Generate the netlist

i. Click on the  button on the top taskbar

ii. A window will pop up click on generate Netlist and save it to desired folder and click on save

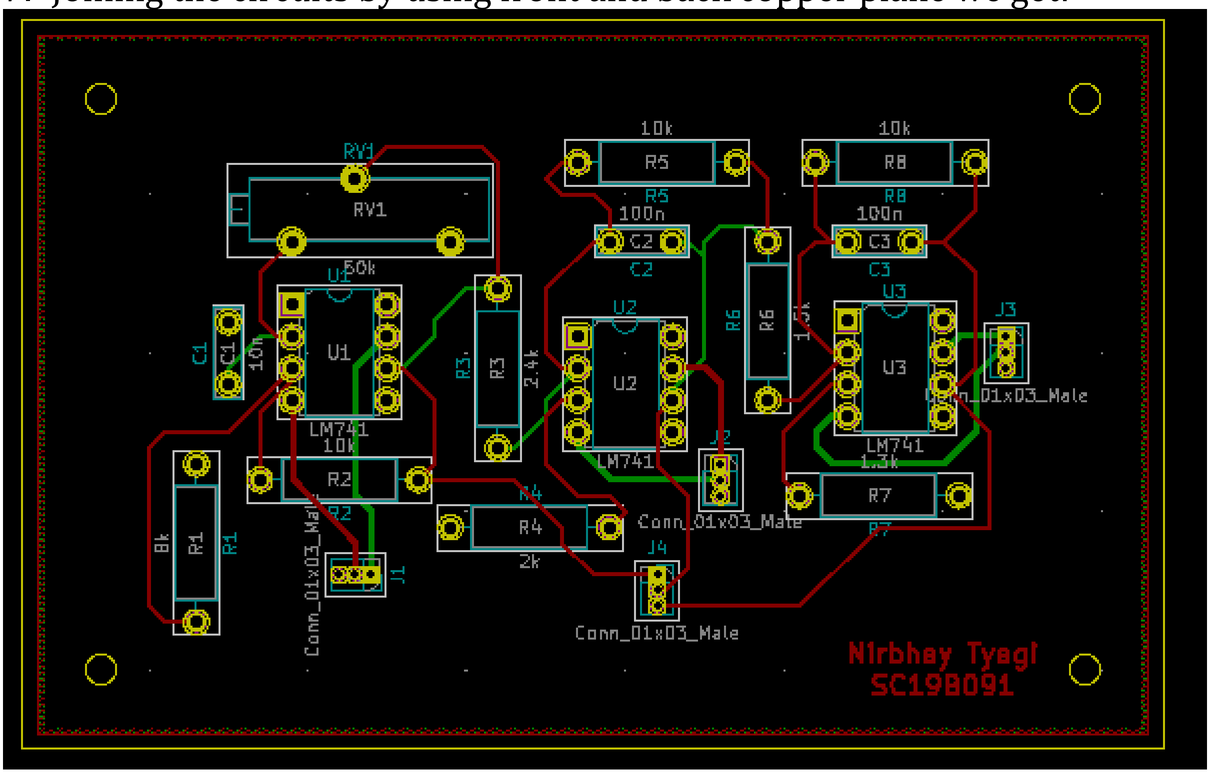


6. Designing the PCB

i. Open the working folder on KiCad and click on PCBnew

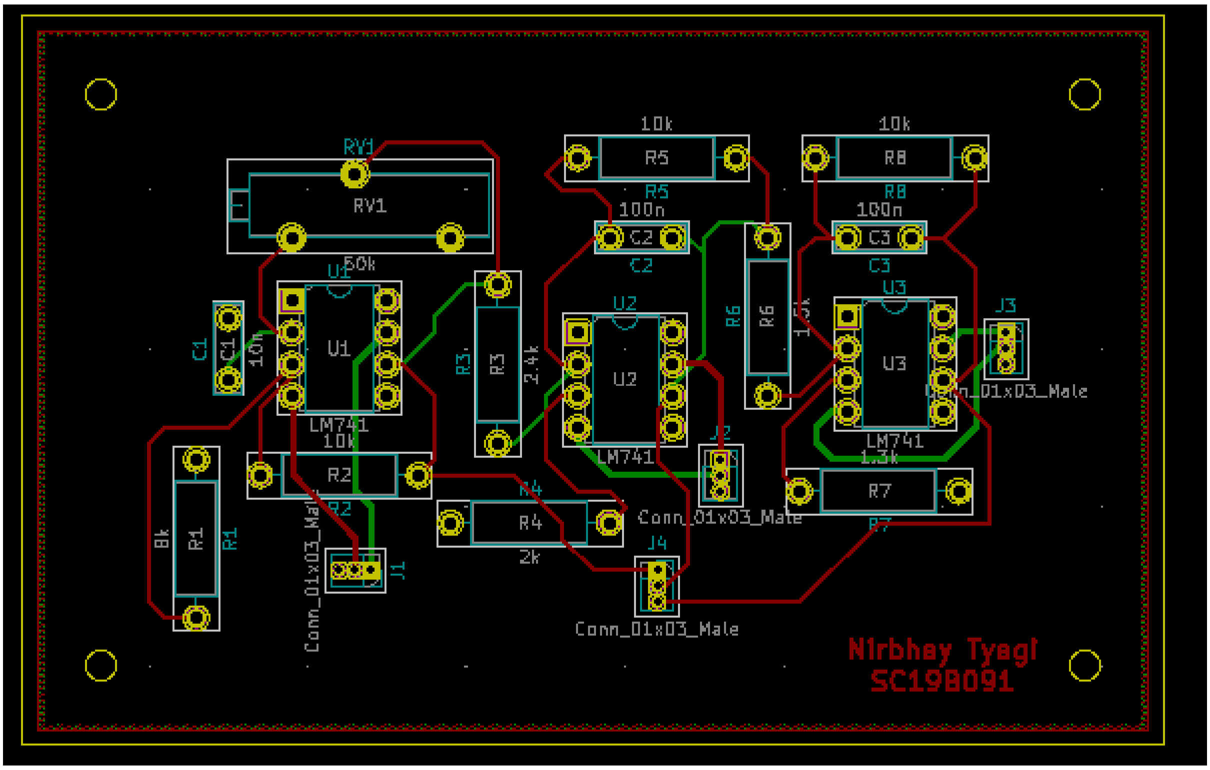
ii. For using the circuit connections in PCBnew, we can use the generated netlist by clicking  and then browsing the PCB location and then by click Update PCB.

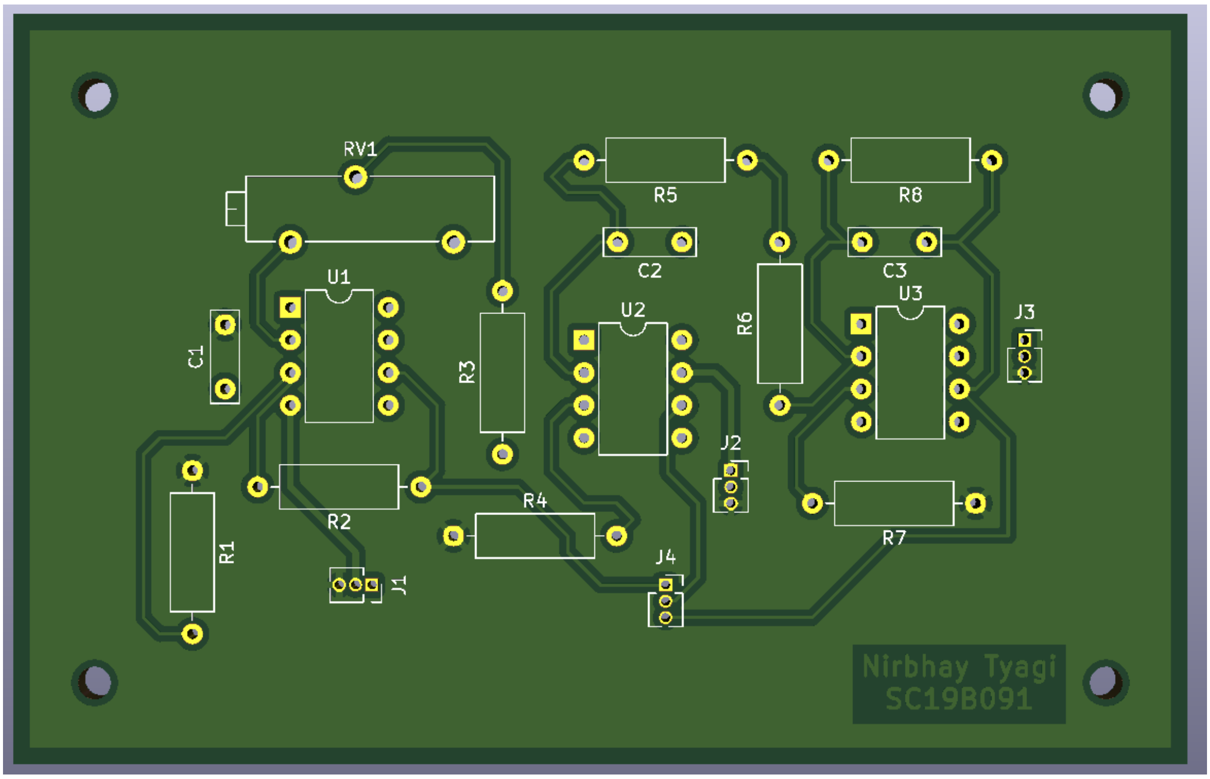
7. Joining the circuits by using front and back copper plane we get:



8. Perform the electrical rules check
9. Generate the Gerber files

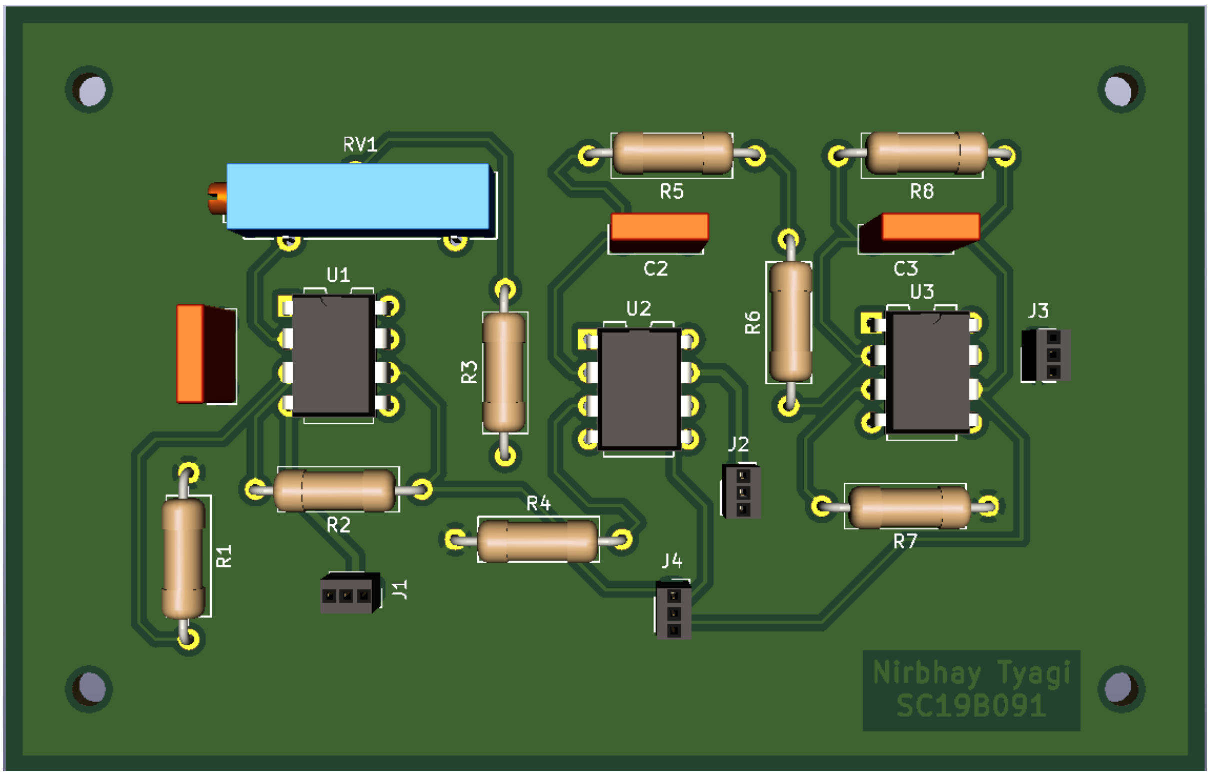
PCB Footprint Layout





3-D View of PCB with components

Top View



Back View