Project Title

Project report submitted in partial fulfillment of the degree of
Electronics and Communication Engineering

For the course

Design Lab 1

Barnabh Chandra Goswami
19UEC161

Department of Electronics and Communication Engineering
The LNM Institute of Information Technology, Jaipur

17 September 2020

Abstract

In this project we will design a **Function Generator with a single output**, that is, it can give you one waveform at a time. The Function Generator which we are designing in this project after completion will be able to produce 4 fundamental wave-forms which are Square Wave, Triangular Wave, Sinusoidal Wave and Sawtooth Wave.
In the starting we will first describe the theories regarding our Function Generator Circuit which involves a decent knowledge about **Astable Multivibrator, Integrator and LM324 IC,** we will discuss how they are made and how they work, we study their basics so that we can apply it finally in our Function Generator Circuit.
Then we will talk about the components which are required in making Function Generator. Finally, after this our real work starts which is designing the Function Generator. As per our previous knowledge and basics we gained in this, we will cascade the LM324's and try to check the outputs from each branch of LM324, you can say that this will be periphery of our project, the main real analysis we will do in that respective section.
So now we have got an idea about this, after this we will talk about the cases how and when we will get the distortion or perfection in the output? What should be the value of resistors and capacitors in the circuit? What could happen when we put the wrong values?
For designing this circuit, we will use an online simulation tool called ***Proteus 8 Professional***. The reference path of all the images and circuit diagrams which we will use in later section will be given just below them and some of them are of Proteus also (observation that will be taken from my laptop), after that in our result we will see our desired outputs one by one and also take all output at once. We will describe some problems which we will face (maybe) and if so, we will discuss their solutions also.
At last like an ordinary report we will write our conclusions and future work, and then provide references of some contents to you.

Contents

List of Figures

1 MOTIVATION

As my Project title suggests **“Function Generator with a Single Output”**, it will give you the Square wave, Triangular wave, Sinusoidal wave and finally the Sawtooth wave one at a time in the Oscilloscope. Any viewer who wants to test this can see the waves they required at output by just using the Switch i.e. Square mode, Triangular mode, Sinusoidal mode and Sawtooth mode.

I have taken this project because I thought that this will be the best opportunity to analyse the Interior of Function Generator (roughly) which we used to see every time in our Electronics Lab in Universities or Collages, since it is widely and commonly used in Electronics among students and researchers also.

Well indeed my circuit was not that much in detail i.e. having Frequency Controller, Amplitude Controller, DC Offset etc. My work in this project basically shows you the main fundamental waves generating from my Function Generator.

Now if I talk about my approach, I use the LM324’s as a fundamental component in this. Why? Because at the present time I think I feel most comfortable with LM324 in IC’s and I have also studied this IC very well rather than other IC’s like 555 timers, L293D etc. The circuit is also quite understandable to me. Hence due to these reasons I think that the use of LM324 IC will be perfect for me.

There are also many other ways to make a basic Function Generator like: -

- We can make a Function Generator with the help of LM7812 and LM7912 IC’s.
- We can make a Function Generator with the help of IC 555 Timer also.
- We can make a Function Generator with the help of ICL8038 Signal generator, with this it will become quite easy to make a simple Function Generator.
- We can make a Function Generator with the help of IC XR2206 which is a monolithic generator and like IC8038 it provides a very simple function generator with only a few external components.
- And we can make a Function Generator through IC 741 Op-Amp or LM324(which will be used in this one).

Here we describe the components by which they can be made easily, there are other methods also.

At last I am greatly motivated to work in this project because it provides me the extra knowledge about working of Function Generator which might help me future also. And since I feel

I know the basics of the circuits used in this Function Generator (like Astable Multivibrator, Integrator, Differentiator etc), that's why I feel that I can shoot it.

2 Proposed Solution

2.1 About Function Generator

So many of the experiments in our collages or universities workplace build use of oscilloscopes and Function generators as a result of it's helpful to find out their general operation. because the Function Generators produces signal sources which give a identifiable voltage applied over a identifiable time, like a "Sinusoidal wave", "Triangular wave" or "Square wave" signal etc.

A Function generator has several sensible applied science applications, it is usually necessary to supply completely different styles of wave-forms to check and rectify various electronic circuits and devices.

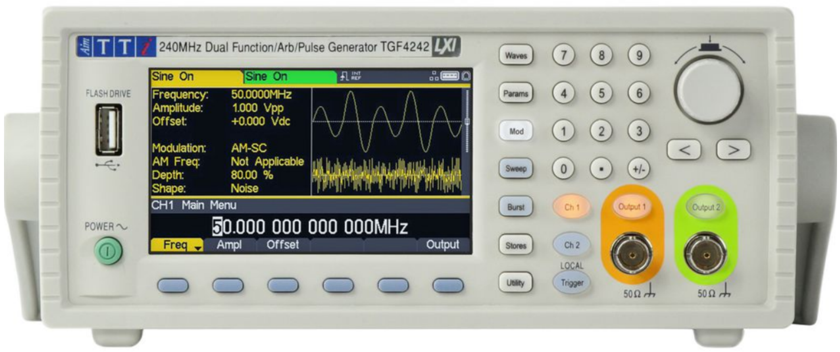

Figure 2.1: Function Generator

My **outline** in making Function Generator looks like this: -

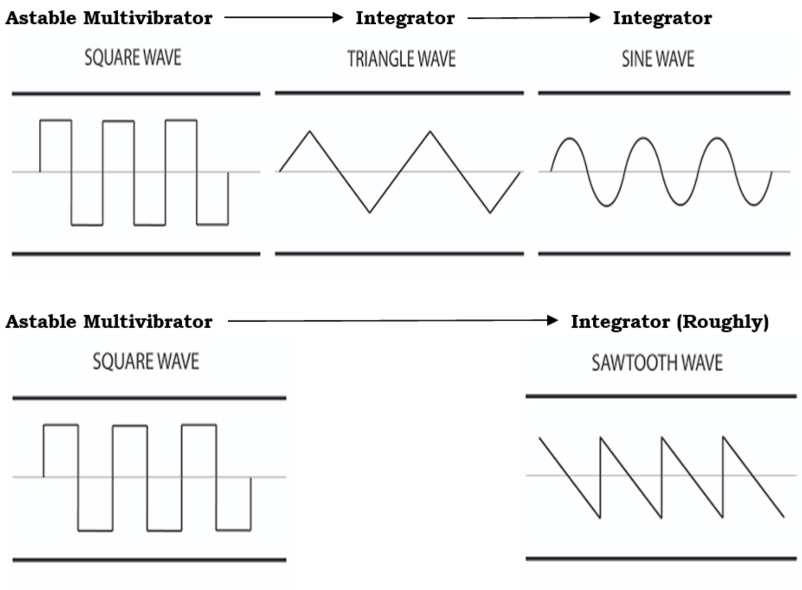

Figure 2.2: Outline of making Function Generator

In the making of Function Generator, the first step I take is the making of the Astable Mutlivibrator.

2.2 Astable Multivibrator

The Astable Multivibrator is additionally referred to as as a free-running Multivibrator. it has 2 quasi-stable states. we do not have to be compelled to given any external signal to provide the changes in its state. The part values determine the time that for which circuit remains in every state, since the Astable Multivibrator oscillates between 2 states, it is also handy to generate Square waves.

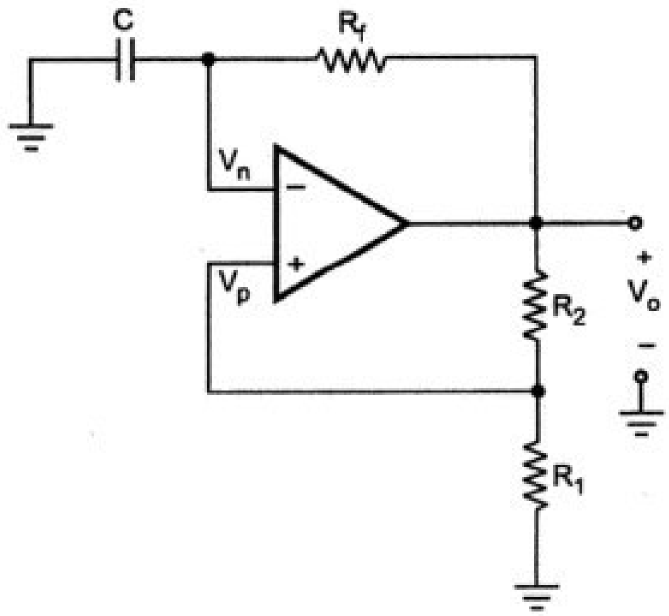

Figure 2.3: Circuit of Astable Multivibrator

The circuit is similar to Schmitt trigger except that the input voltage is replaced by the capacitor. As shown in the Figure 2.3 the comparator and positive feedback resistors R1 and R2 form an inverting Schmitt trigger.

When V_0 is at V_{Sat}, the feedback voltage is called the upper threshold voltage V_{UT} and is given as

$$V_{UT} = R_1 \frac{V_{sat}}{R_1 + R_2}$$

When V_0 is at $-V_{Sat}$, the feedback voltage is called the lower threshold voltage V_{LT} and is given as

$$V_{LT} = -\frac{R_1 V_{sat}}{R_1 + R_2}$$

Circuit operation

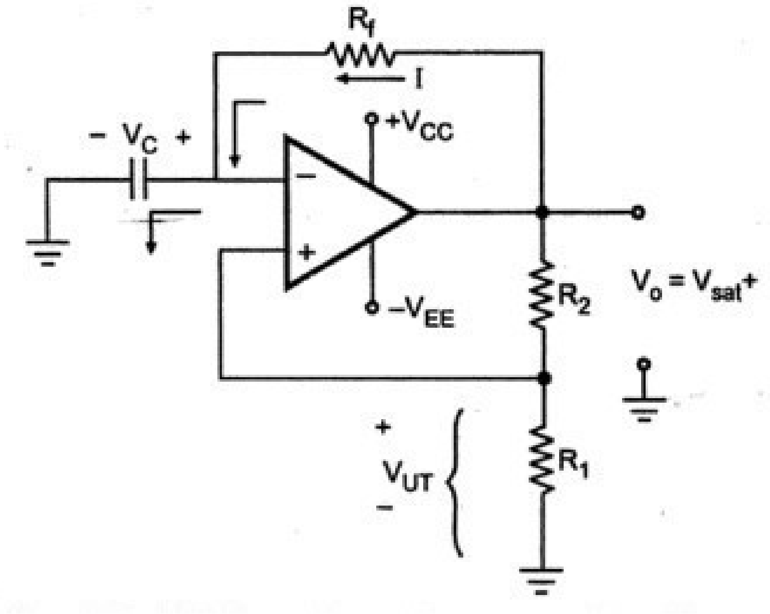

Figure 2.4: Circuit operation 1

1. When power is turned ON, V_0 mechanically swings either V_{Sat} or to $-V_{Sat}$ since these are the only sole stable states allowed by Schmitt trigger. Let us assume it swings to $+V_{Sat}$.
2. Now capacitor starts charging towards $+V_{Sat}$ through the feedback path provided by the resistor Rf to the inverting input. With the provision that the capacitor voltage V_C is less than V_{UT}, the output voltage remains constant at V_{Sat}.

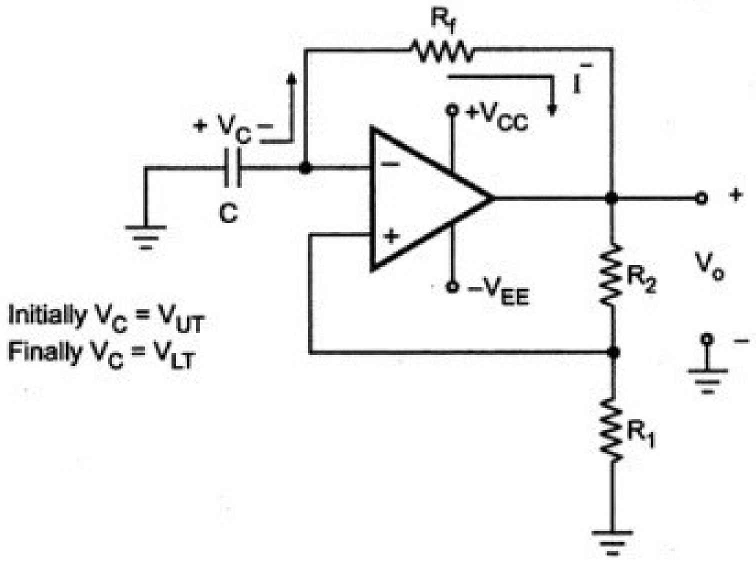

Figure 2.5: Circuit operation 2

3. As soon as V_C gets charged to a value faintly greater than V_{UT}, the input goes positive with respect to the input. This switches the output voltage from $+V_{Sat}$ to $-V_{Sat}$.
4. As V_0 switches to $-V_{Sat}$, capacitor starts discharging through the current I discharge capacitor to 0 V and recharges capacitor to V_{LT}. When V_C becomes slightly more negative than the feedback voltage V_{LT}, output voltage switches back to again $+V_{Sat}$.

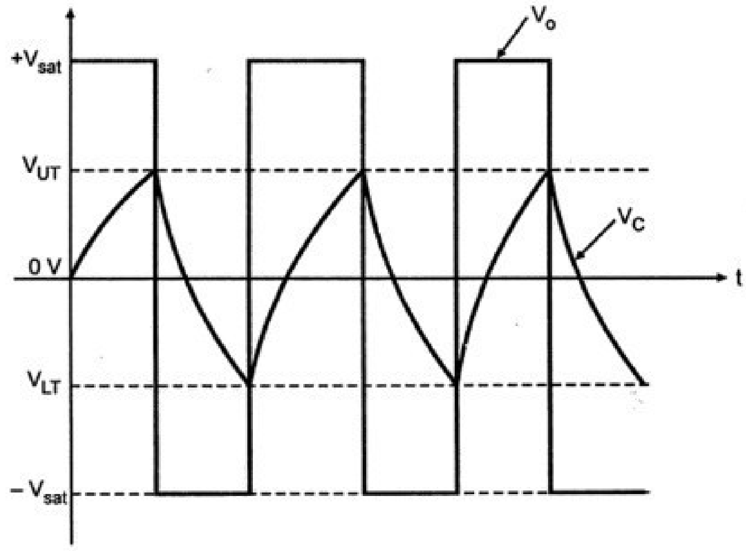

Figure 2.6: Charging and Discharging

Charging and Discharging Equations.

$$T_C = RC\ \ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$\beta = \frac{R_2}{R_1 + R_2}$$

$$T_C = T_d$$

Total Time Period (T)

$$T = T_C + T_d$$

$$\boxed{T = 2RC\ \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

From Astable Multivibrator now we get the Square wave at output and now this Square wave will work as an input for an Integrator to convert it into a Triangular wave or Sawtooth wave.

Therefore, my second step is to feed output of Astable Multivibrator to input of Integrator.

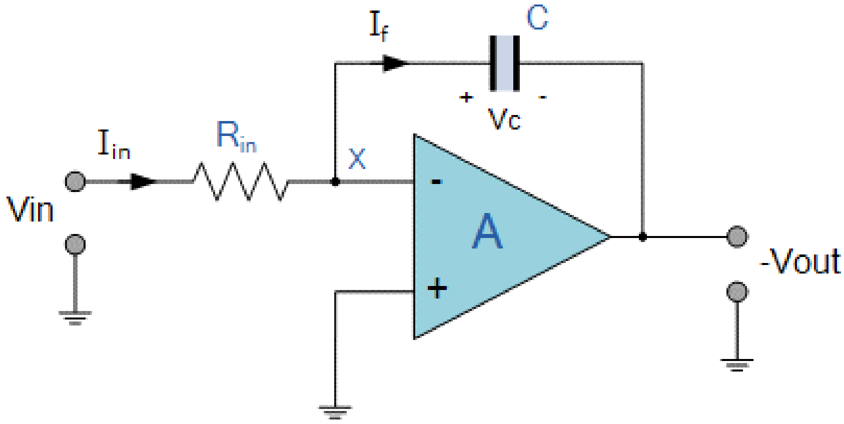

Figure 2.7: Integrator Circuit

The Op-amp Integrator is a type of operational amplifier circuit that performs the mathematical process of Integration, that is we will cause the output to reply to changes within the input voltage over time since the op-amp integrator gives us an output voltage which is directly proportional to the integral of the input voltage. That is, if we tend to feed any arbitrary wave to it, it will give us the Integration of that wave.

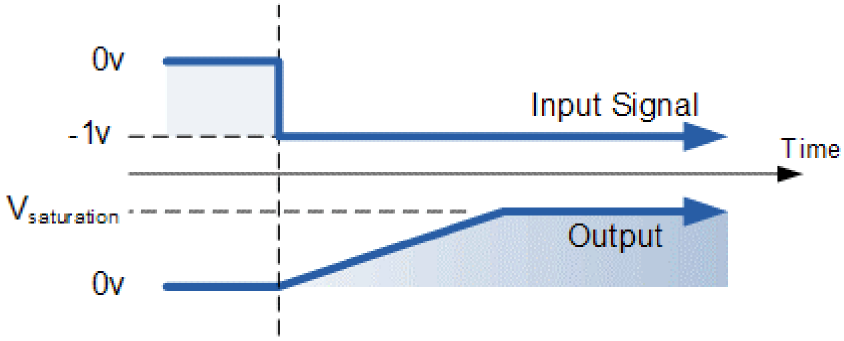

Figure 2.8: Integrator Operation in Graph

$$V_c = \frac{Q}{C}, \qquad V_c = V_x - V_{out} = 0 - V_{out}$$

$$\therefore -\frac{dV_{out}}{dt} = \frac{dQ}{Cdt} = \frac{1}{C}\frac{dQ}{dt}$$

$$I_{in} = \frac{V_{in} - 0}{R_{in}} = \frac{V_{in}}{R_{in}}$$

The current flowing through the feedback capacitor C is given as:

$$I_f = C\frac{dV_{out}}{dt} = C\frac{dQ}{Cdt} = \frac{dQ}{dt} = \frac{dV_{out}.C}{dt}$$

Assuming that the input impedance of the op-amp is never ending that is infinite (ideal conditions in Op-Amp), therefore no current flows into the op-amp terminal. So, by the use of Kirchhoff's Voltage law the nodal equation at the inverting input terminal is given as:

$$I_{in} = I_f = \frac{V_{in}}{R_{in}} = \frac{dV_{out}.C}{dt}$$

$$\therefore \frac{V_{in}}{V_{out}} \times \frac{dt}{R_{in}C} = 1$$

From which we derive an ideal voltage output for the Op-amp Integrator as:

$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}\,dt = -\int_0^t V_{in}\frac{dt}{R_{in}.C}$$

On simplifying it we can also write it as:

$$V_{out} = -\frac{1}{j\omega RC}V_{in}$$

2.4 About LM324 IC

LM324 IC is a Quad op-amp integrated with four operational amplifiers sourced by a ordinary power reservoir. The differential input voltage range can be equivalent to that of power supply voltage. The default input offset voltage is very low which is of magnitude 2 miliVolts. The operating temperature ranges from 0 ^{o}Celsius to 70 ^{o}Celsius at ambient whereas the maximum junction temperature can be up to 150 ^{o}Celsius. Generally, op-amps can perform mathematical operations. It is mainly used as a comparator, also can be used as transducer amplifier, DC gain block etc. It has immense dc voltage gain of about 90-100dB. This IC can be handled over wide range of power supply from 3V to 32V for mono power supply or from ±1.5V to ±16V for dual power supply and it also supports large output (O/P) voltage swing.

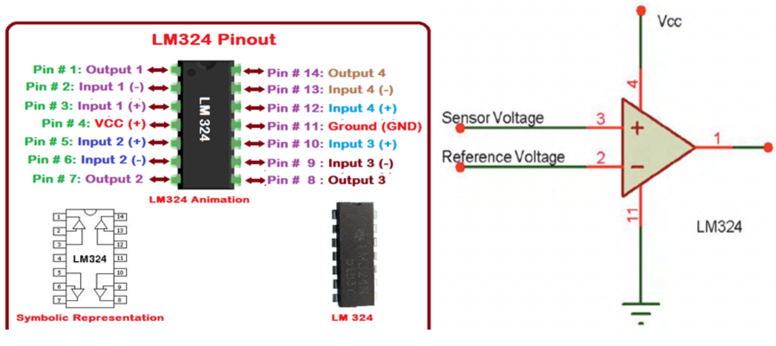

Figure 2.9: LM324 IC Basic Circuit Diagram

Now using all the above logics, we can now understand the working of our Function Generator with single output.

2.5 Components Required

Before starting let me tell you all the components used in making Function Generator with single output: -

1. 11 Resistors (22 k, 100 k, 200 k and 220 kOhm).
2. 2 Variable Resistors (10k and 50kOhm).
3. 4 Electrolytic Capacitors (10nF, 33nF, 33nF and 1uF).
4. 5 LM324's (Astable Multivibrator A, Integrator A, Integrator B, Sawtooth Generator A and Sawtooth generator B).
5. 4-Terminal Switch.
6. Oscilloscope.

2.6 Whole Circuit

Now let's look at the overall circuit first: -

Function Generator Circuit Diagram in PROTEUS

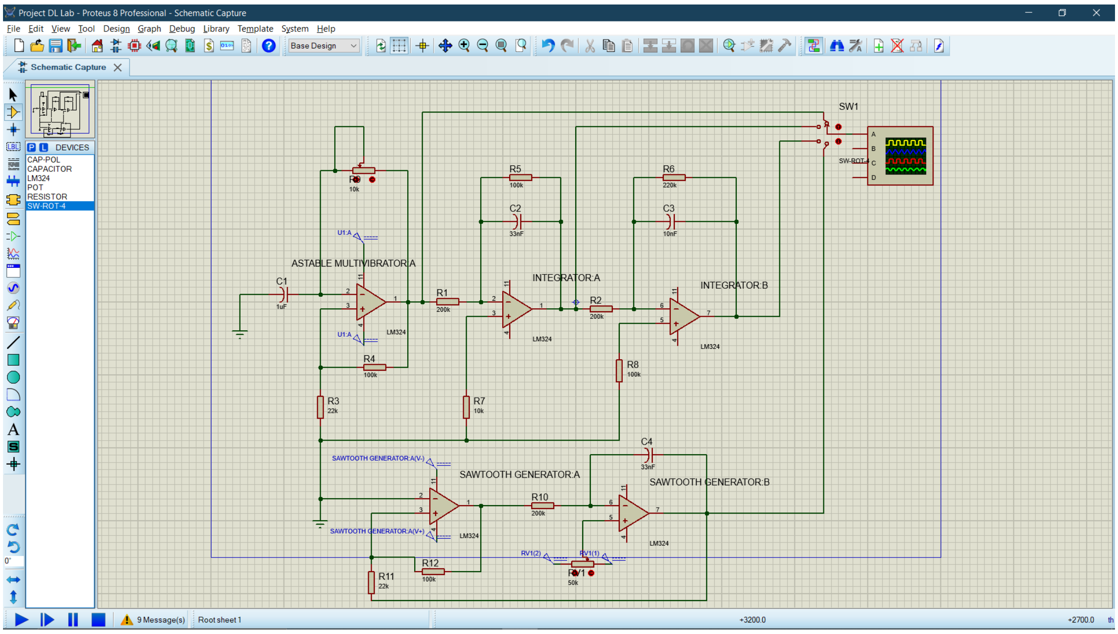

Figure 2.10: Function Generator Circuit

The above circuit looks clumsy but don't worry we will describe all one by one.

2.7 Astable Multivibrator Circuit

First of all, let start with the ASTABLE MULTIVIBRATOR A: -

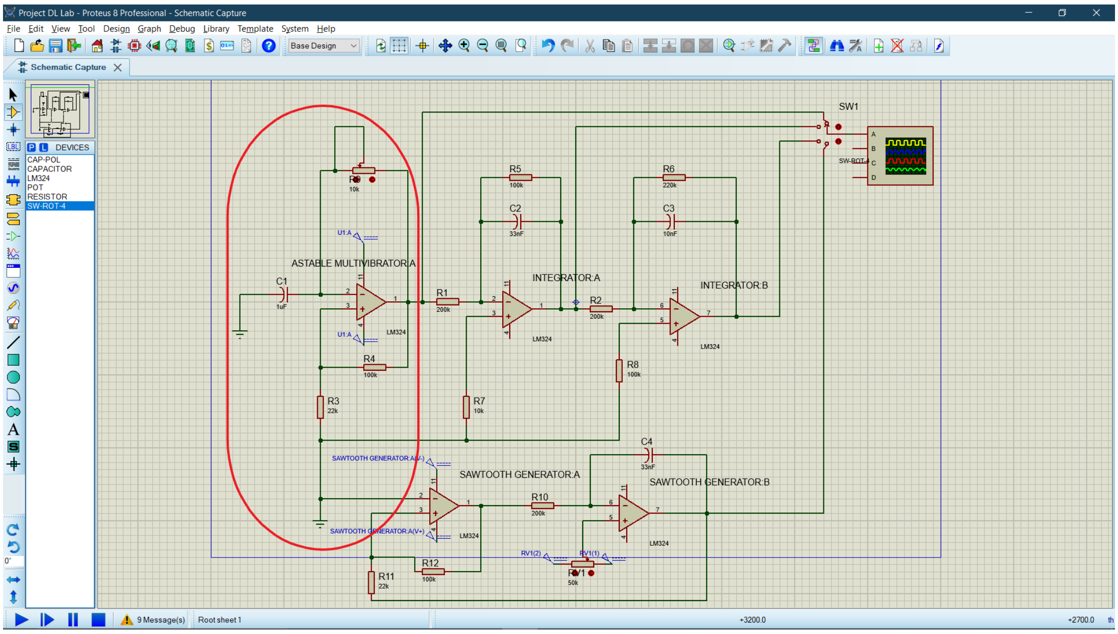

Figure 2.11: Astable Multivibrator Circuit

As you can see in the circuit diagram above in the red capsule region our Astable Multivibrator A (LM324) is there.

Let's take a closer look!

ASTABLE MULTIVIBRATOR

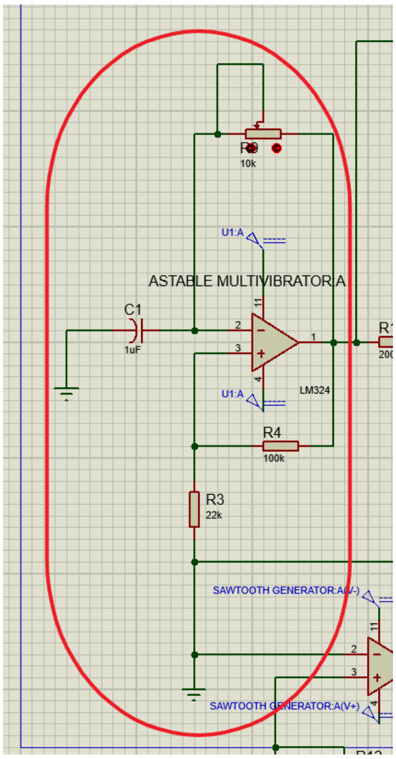

Figure 2.12: Closer look of Circuit

As you can see circuit of Astable Multivibrator A closely we can understand better now how it works because we have already answered its working in the above sections so there will be no problem now, we can clearly see that it will produce the Square wave, only difference is that I used the Potentiometer **R9** of 10 kOhm instead of using the normal resistor so that I can check the perfect formation of Square wave. We also give the +/-5V DC Supply in first LM324 (ASTABLE MULTIVIBRATOR A).
We observe that greater the value of Potentiometer resistor **R9** greater will be the distortion in the output.

Let's see our **output** from ASTABLE MULTIVIBRATOR A.

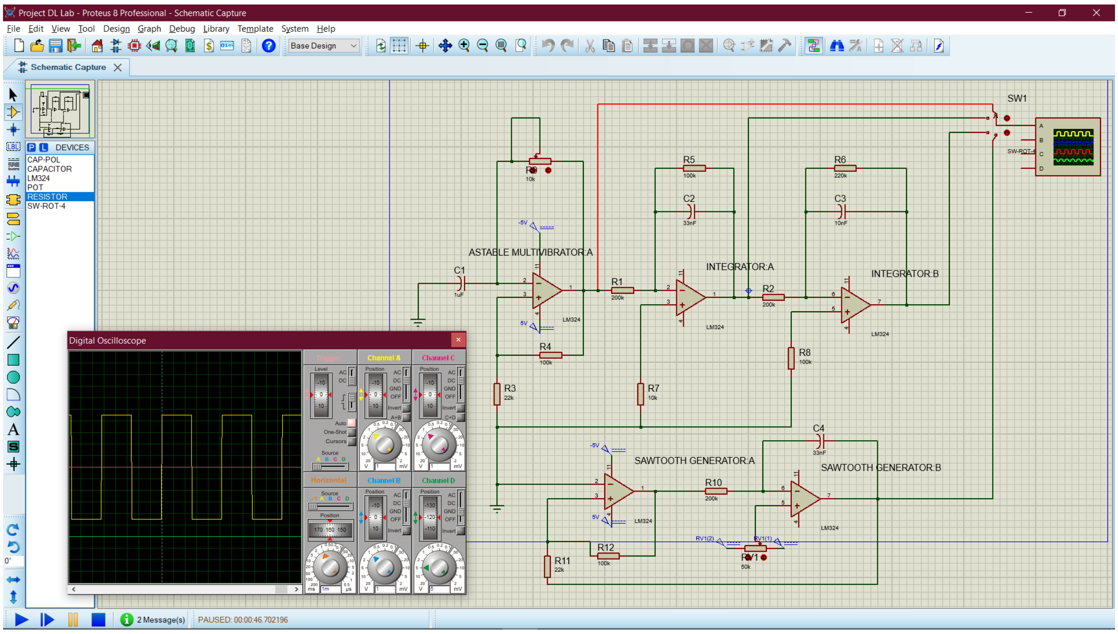

Figure 2.13: Output from Astable Multivibrator

You can clearly see that our output is the Square wave in the Oscilloscope, and near the oscilloscope you will see a 4-Terminal Switch which is set at the 1st terminal which takes the output from ASTABLE MULTIVIBRATOR A. The red wire shows the taken output.
Now I want to generate a Triangular wave and a Sawtooth wave, so I can generate this by cascading INTEGRATOR A (LM324) to ASTABLE MULTIVIBRATOR A (LM324), by which we will get the integration of Square wave which is our required Triangular wave or Sawtooth wave.

Let's make it easy by looking into circuit of INTEGRATOR A and SAWTOOTH GENERATOR A and B: -

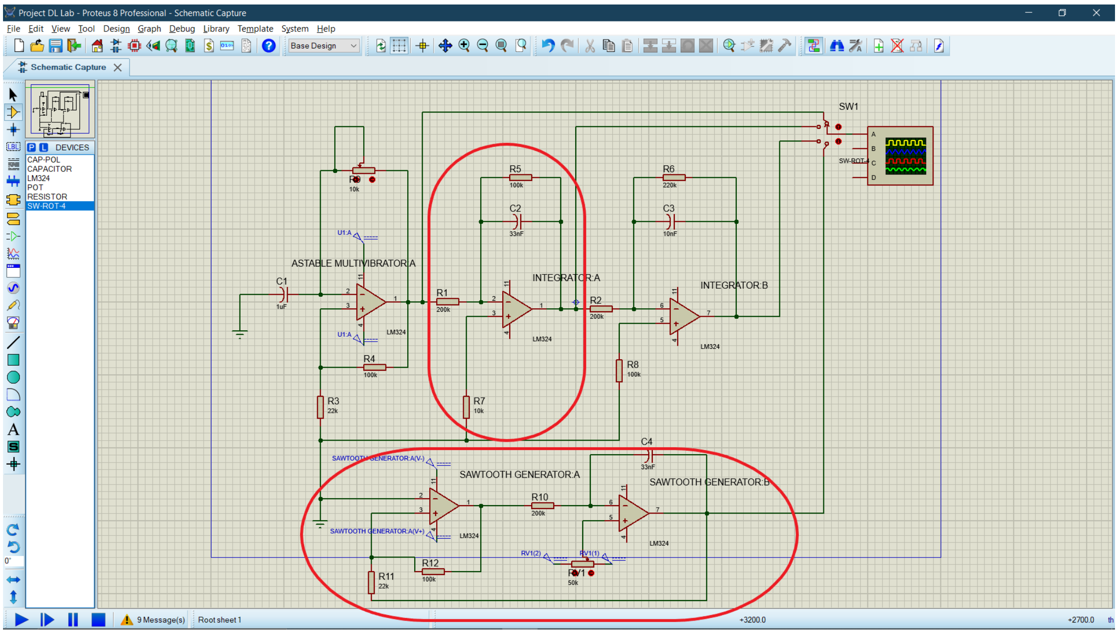

Figure 2.14: Integrator A and Sawtooth Generator Circuit

As you can see in the circuit diagram above in the red capsule region our Integrator A (LM324) and Sawtooth Generator A and B are there.

Let’s take a closer look!

INTEGRATOR A **SAWTOOTH GENERATOR A and B**

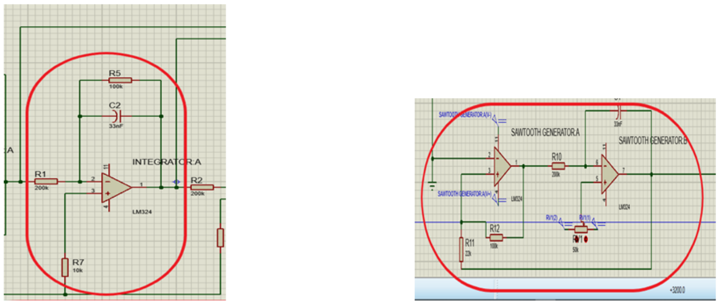

Figure 2.15: Closer look of Circuit

In the **Integrator A** we can see that we use the combination of R and C such that we can get the best Triangular wave from its output at 2nd terminal of 4-Terminal Switch.
We observe that when we decrease R5 and C2 any one of that or both then our generated Triangular wave at output gets distorted, and the same thing happens when we decrease R1 also.

Let's see our **output** from INTEGRATOR A.

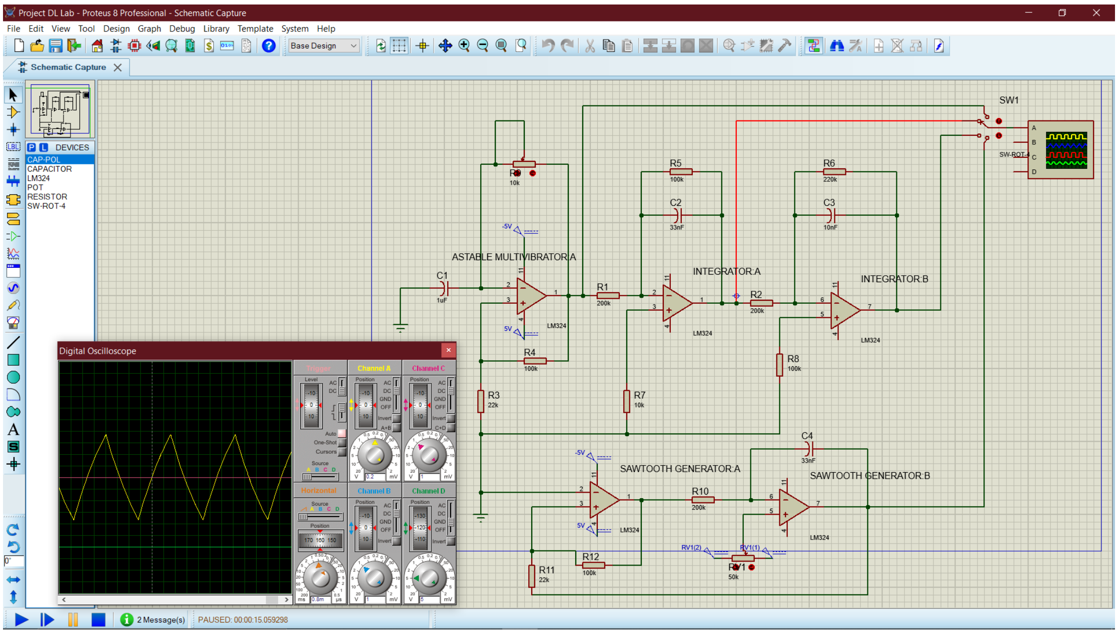

Figure 2.16: Output from Integrator A

We are clearly getting a Triangular wave at the output; near the oscilloscope you will see a 4-Terminal Switch which is set at the 2nd position which takes the output from INTEGRATOR A. The red wire shows the taken output. As we increase the value of R5 or C2 we will get a more perfect Triangular wave.

Let me show you what happens when we increase the R5 from 100 kOhm to 1000 kOhm.

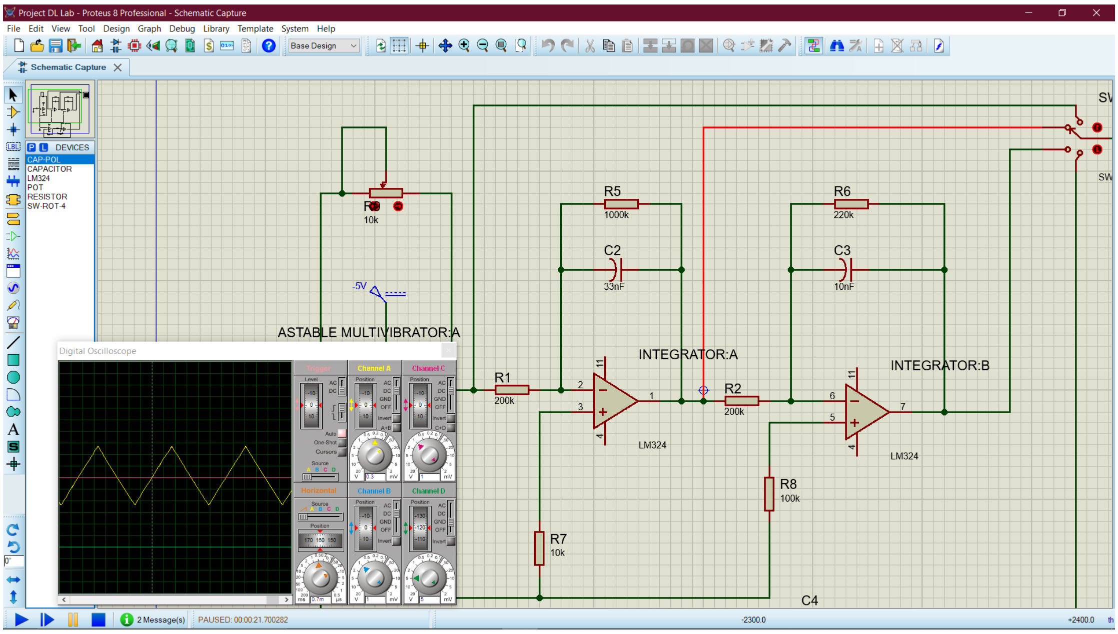

Figure 2.17: Updated Circuit with change in resistance

You can clearly see that the triangular waves are now more perfect than before. The red wire shows the taken output.

Now let's talk about the **Sawtooth Generator A and B.**

In Sawtooth Generator we use again LM324 Square wave circuit and cascade with other LM324, the only difference from changing Triangular wave to Sawtooth wave is to connect a +/- DC source Supply at the positive terminal of other LM324 (SAWTOOTH GENERATOR B) that is 5th pin of it with a variable resistor of 50kOhm, by varying the this resistor we can get our required Sawtooth wave according to it.
And this Sawtooth wave we will get at the 4th position of our 4-Terminal Switch near the oscilloscope.

Let ‘s see the Sawtooth wave from our **output** now.

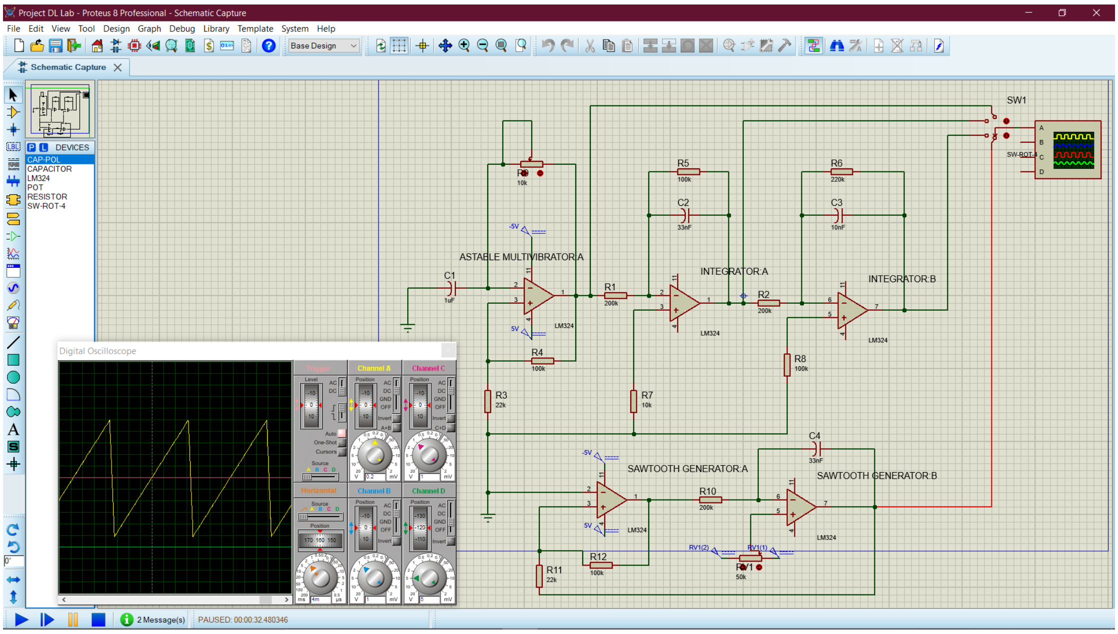

Figure 2.18: Output from Sawtooth Generator

You can clearly see our result!!! means that the circuit is working fine. The red wire shows the taken output.

Now since we get the Triangular wave and Sawtooth wave as our output so our last task is to again integrate the Triangular wave and make it finally a Sinusoidal wave, therefore we need an integrator again that’s why we cascade INTEGRATOR A to INTEGRATOR B so that we can now get Sinusoidal wave at last.

Let's see it through looking into the circuit of INTEGRATOR B.

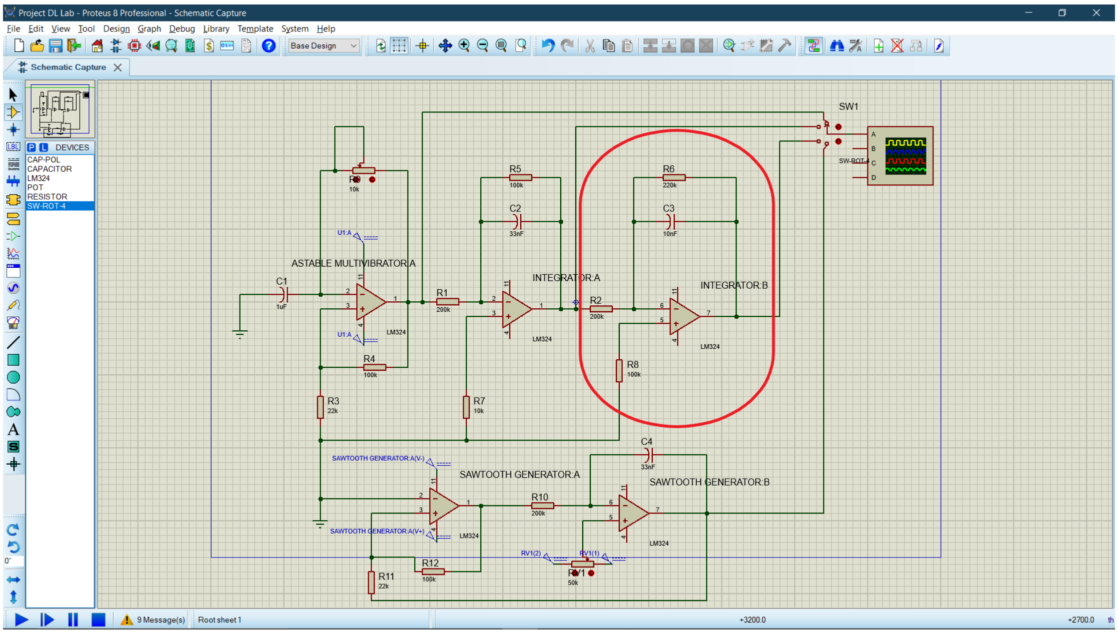

Figure 2.19: Integrator B Circuit

As you can see in the circuit diagram above in the red capsule region our Integrator B (LM324) is there.

Let's take a closer look!

INTEGRATOR B

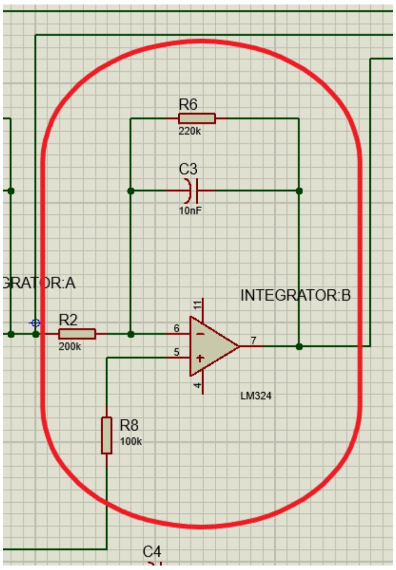

Figure 2.20: Closer look of Circuit

As you can see in our final circuit of other integrator that is INTEGRATOR B, all things and theories remain same, the only difference this time is that we want a Sinusoidal wave so our output from INTEGRATOR A which is a Triangular wave will act as a input for the INTEGRATOR B so we will now do the integration of Triangular wave and we know that the integration of Triangular wave is Sinusoidal wave.

Hence our output will be Sinusoidal wave.

Let's see our final **output** (Sinusoidal wave) of the whole circuit.

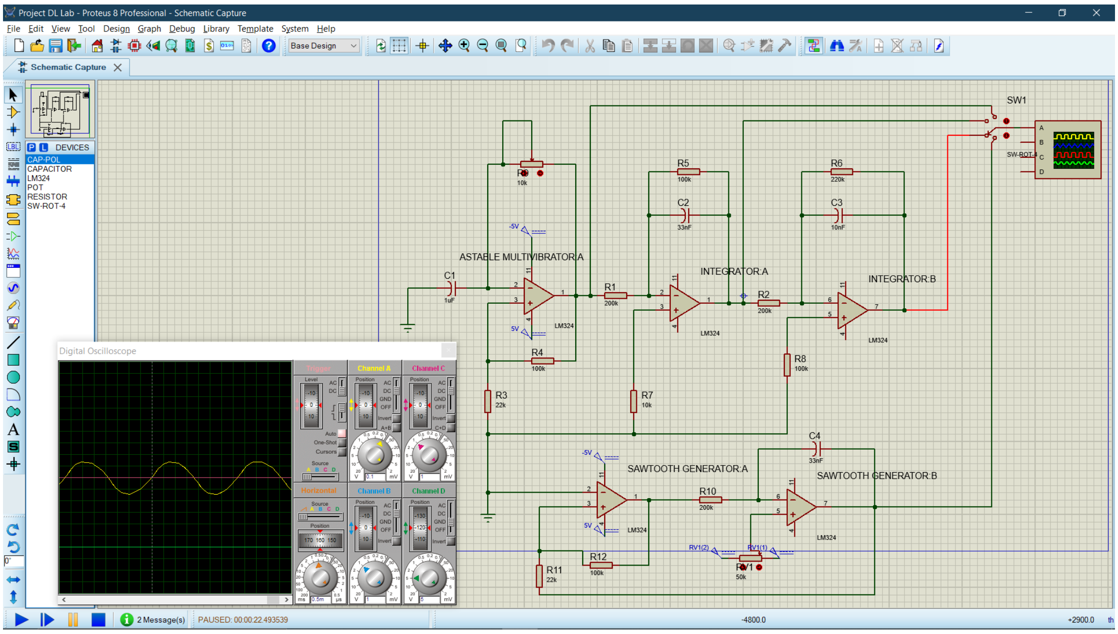

Figure 2.21: Output from Integrator B

Finally, we can clearly see that our output is the Sinusoidal wave in the Oscilloscope, and near the oscilloscope you will see a 4-Terminal Switch which is set at the 3rd terminal which takes the output from INTEGRATOR B. and as always, the red wire shows the taken output.
Hence now our final work is to collect all these theories and observations into one sentence, which we will do in Results Section.

3 RESULTS

Now our Function Generator circuit is completed so let's see its single output in oscilloscope. I mainly use the 4-Terminal Switch to get different outputs at different terminals. In this circuit we have generated 4 different kinds of waves: -

1. Square wave.
2. Triangular wave.
3. Sinusoidal wave.
4. Sawtooth wave.

Let's see the all outputs one by one.

3.1 ONE BY ONE OUTPUT

Output 1: - Square wave. (The red wire)

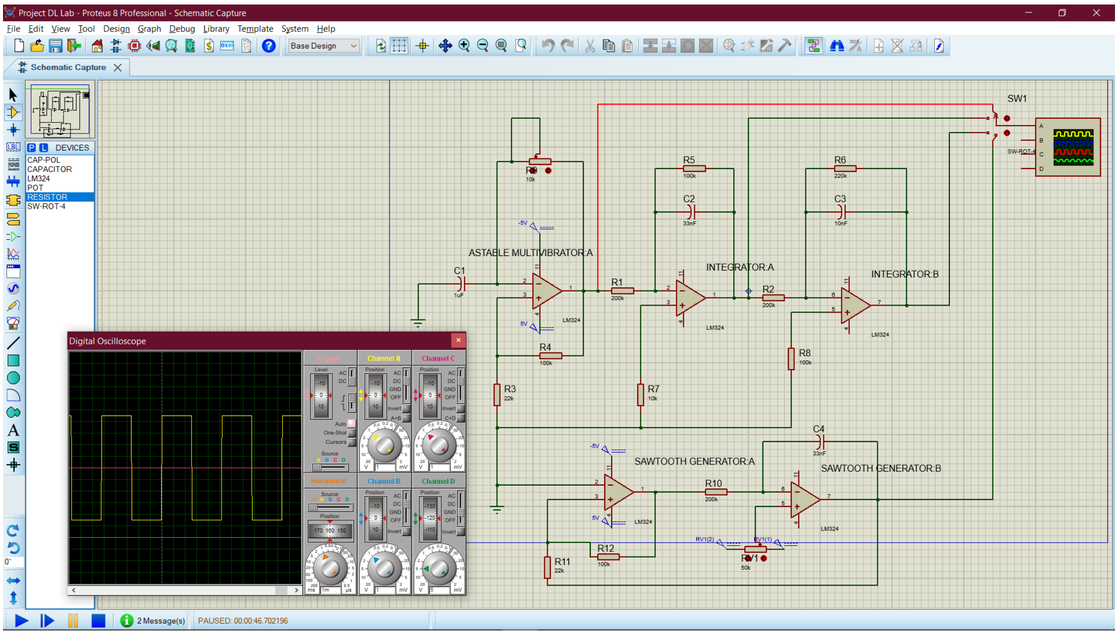

Figure 3.1: Square wave Output

Output 2: - Triangular wave. (The red wire)

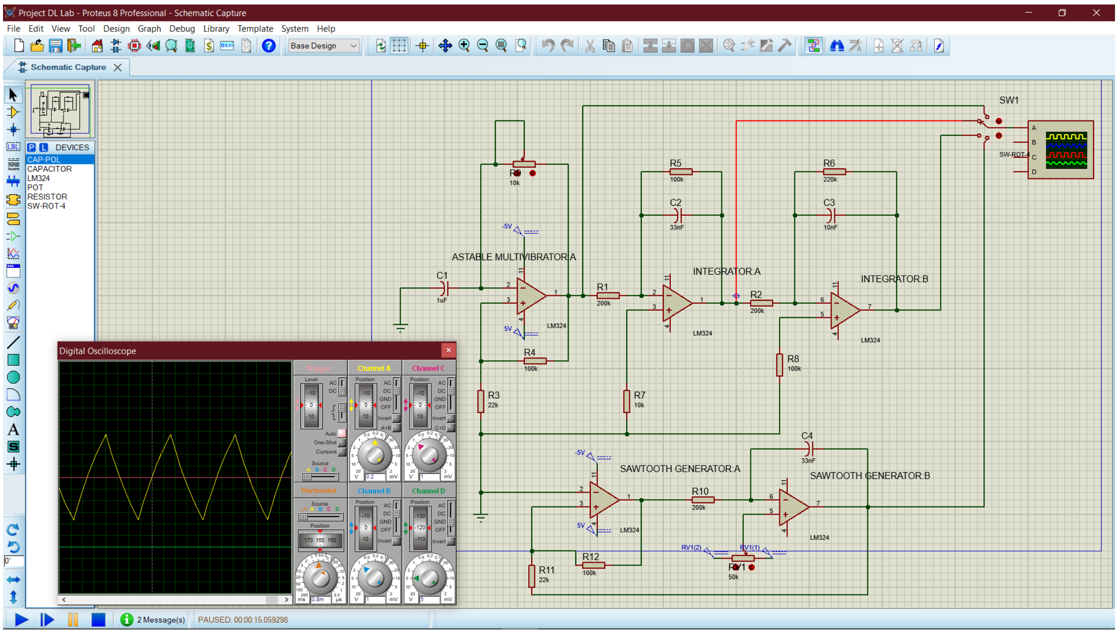

Figure 3.2: Triangular wave Output

Output 3: - Sinusoidal wave. (The red wire)

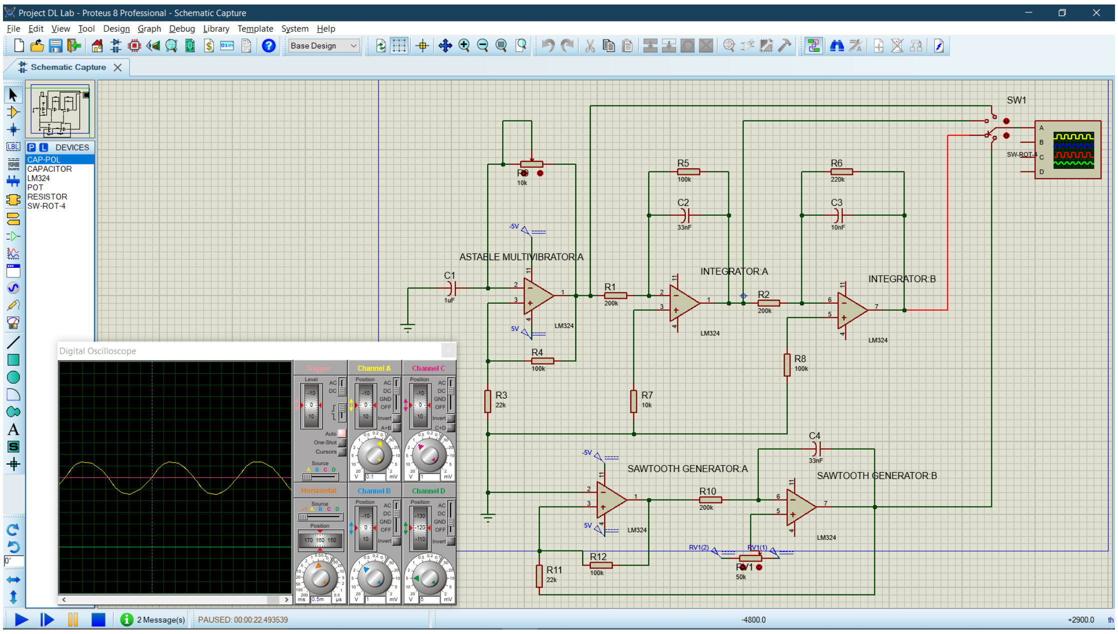

Figure 3.3: Sinusoidal wave Output

Output 4: - Sawtooth wave. (The red wire)

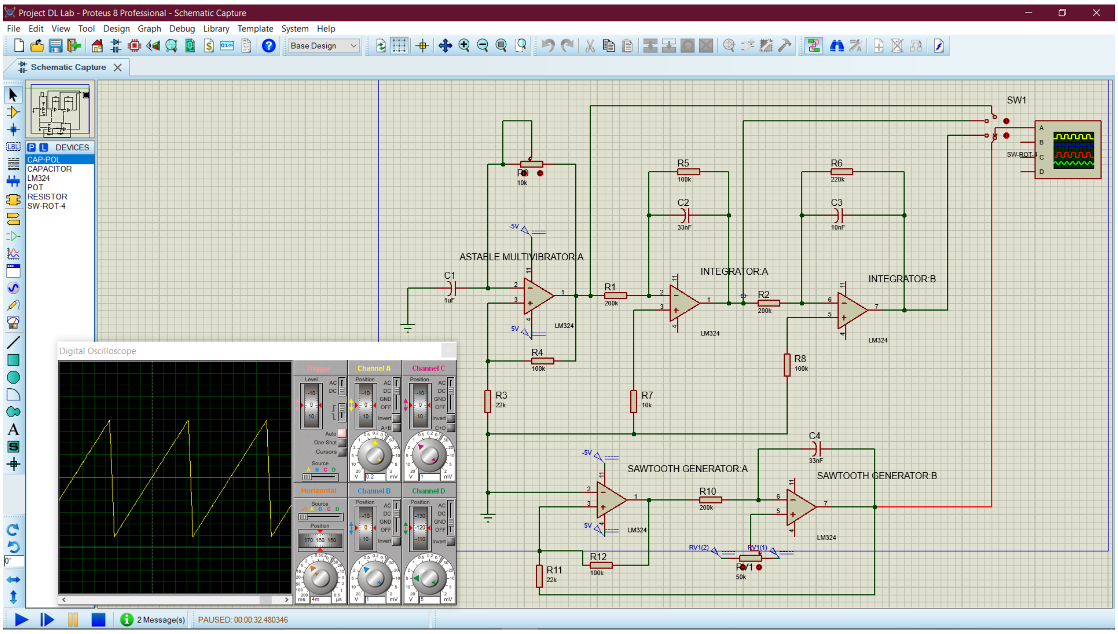

Figure 3.4: Sawtooth wave Output

Now let's see all the outputs together.

3.2 ALL OUTPUTS TOGETHER

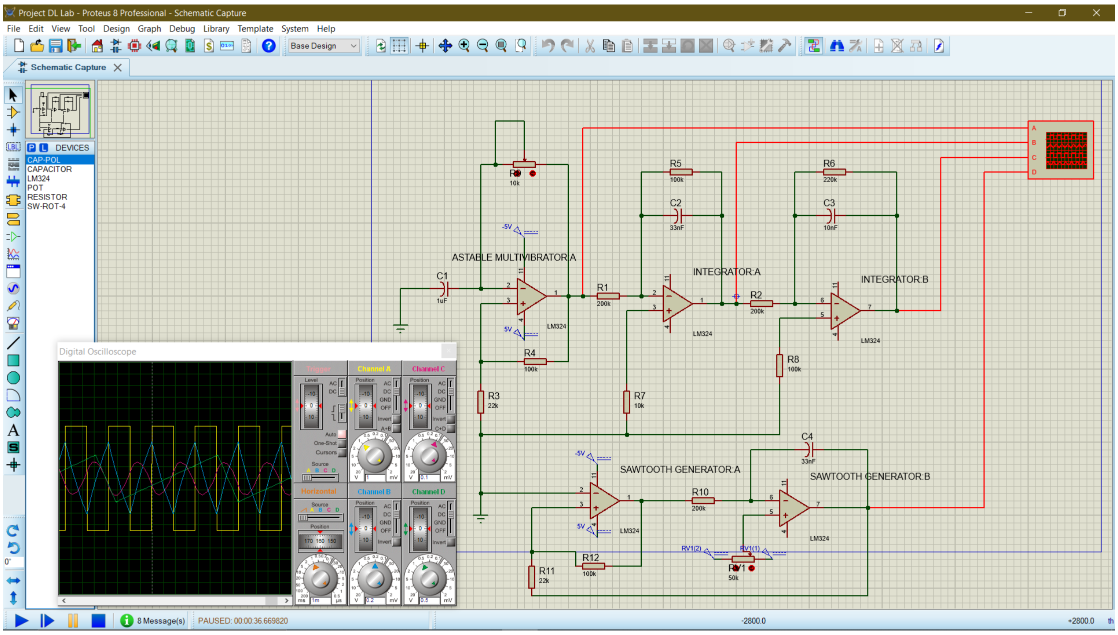

Figure 3.5: All Outputs Together

Let's take a closer look!

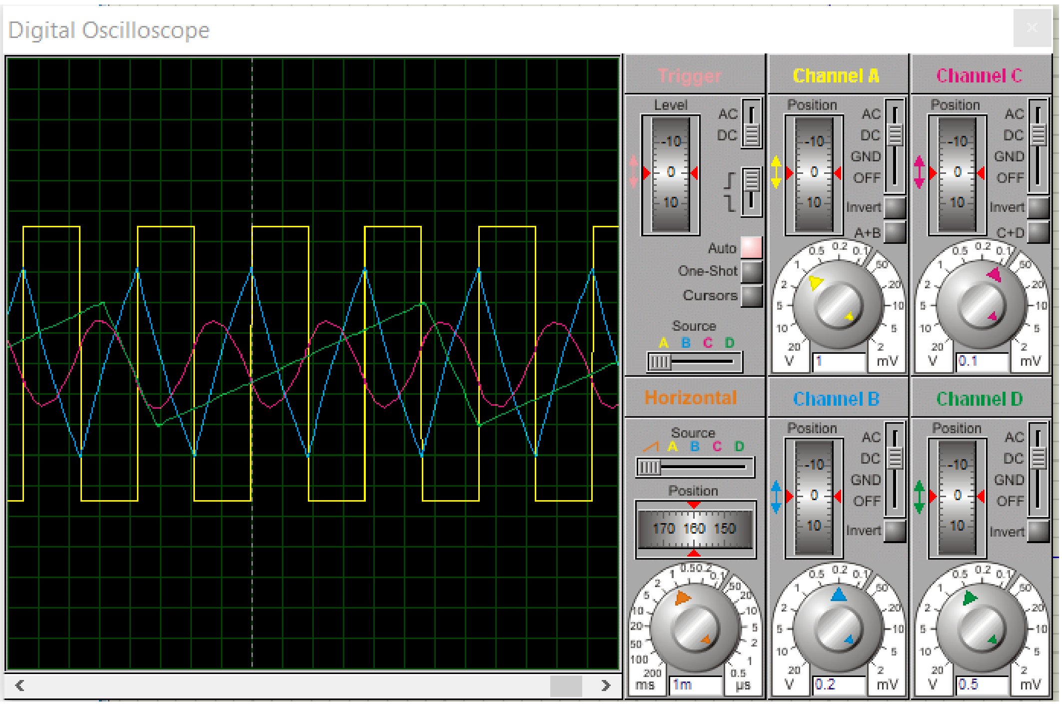

Figure 3.6: Closure look of all Outputs

These are all 4 waves which we produced above. All the diagrams which you see above starting from making of Function Generator circuit was made in the software used for Simulation of electronic circuits called ***Proteus 8 Professional.***

As we have already discussed that if we want more perfect results of any wave which we are getting, just make the time constant of the respective capacitors greater so that there will be less distortion and more perfection, or we can also vary the potentiometer in first LM324 (Astable Multivibrator).

We have also observed that if we increase resistances which are between cascaded LM324's, amount of distortion gets reduced.

3.3 DISTORTION CASE

Now we will show you what happens when we make the time constant smaller of respective LM324's or the increasing resistance of potentiometer in Astable Multivibrator or decreasing the resistances which are between cascaded LM324's.

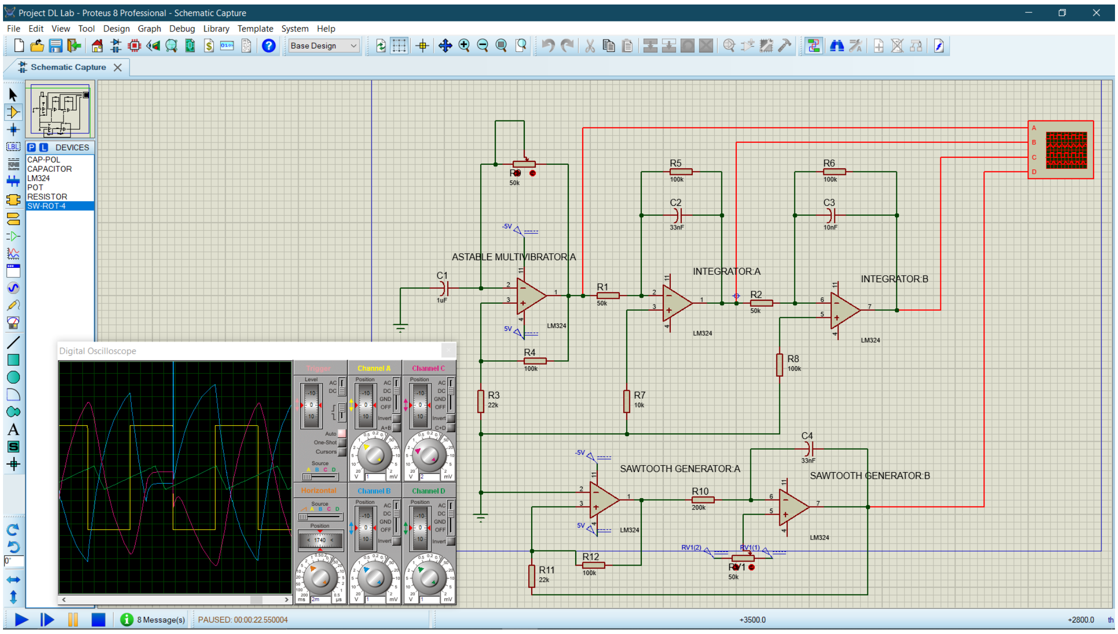

Figure 3.7: Distorted Outputs

Let's take the closer look of this also!

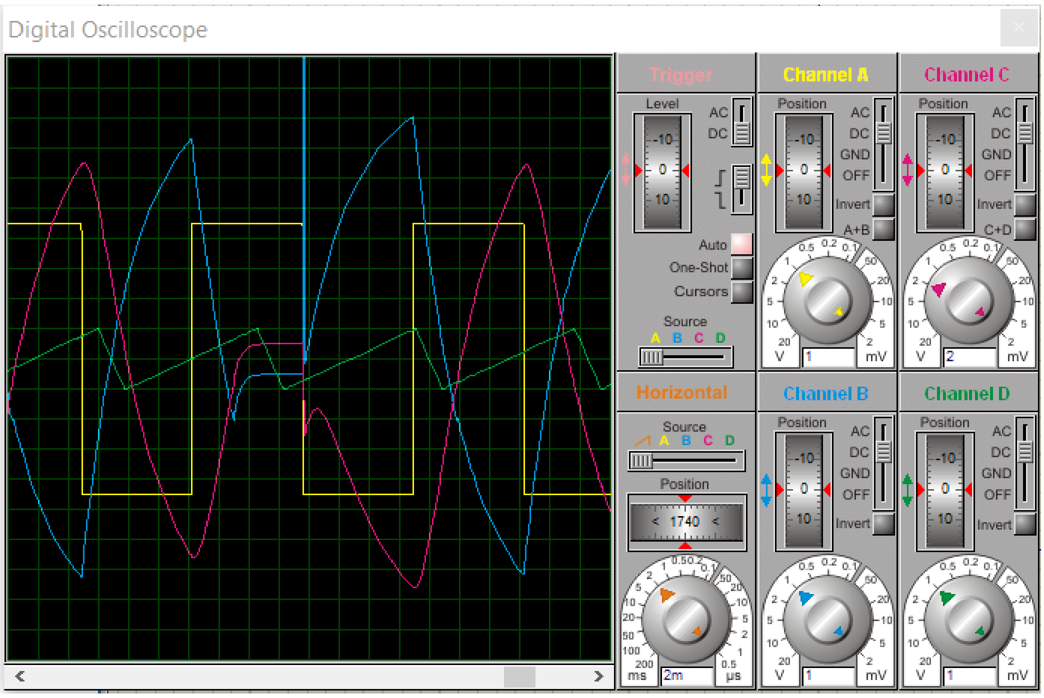

Figure 3.8: Closer look of Distorted Outputs

I also faced many significant problems during this project.

1. I started running into significant issues. Getting the design of the integrator block was very tricky and even when I finally saw a sine wave output, getting this amplitude to remain relatively constant without sacrificing too much of the sine wave quality was the most significant design challenge I faced.
2. The packaging facet of the project was also very difficult. I had trouble in finding ways to attach my potentiometers to the LM324's.

4 Conclusion and future work

During the course of this project, I learned several things. Like I learned about the basics of the Function Generator, about LM324, revised the Integrator and Astable Multivibrator Circuits, I learned about how to design various analog circuit blocks to produce specific waveforms. I found the theory of how it all works beautiful - my circuit analysis classes finally came to life and helped me produce something meaningful. This project also helped me gain experience in making my work look nice and polished - it is a very useful skill to have and it is often neglected in engineering classes. Within the globe, it isn't enough for a product to figure. It needs to have aesthetic attractiveness - This is often why Apple is triple-crown. Other than learning about the importance of packaging, I learned many other things in this project.

1. Op-amps are incredibly powerful and it is very easy to chain them together without worrying about loading effects due to high input impedance.
2. Theory is nice, however in follow, you frequently ought to attempt things rather than thinking too arduous i.e, you often need to try things instead of thinking too hard. Experimenting with different values for different components was very useful, especially when it came to the design of the integrator and compensating for its gain.
3. It is always a pleasant plan to keep a notebook. It helped me remember what I did and when, what values I used, and what I need to do next time. It also helped me write this report!

There are also many improvements that could be made to this project.

1. By changing the potentiometer set up on the LM324's or the value of capacitor, we can easily get more perfect waves.
2. By varying the resistor on first LM324 IC or the by varying the resistances between the cascaded LM324's or by changing the time constants of respective LM324's capacitors, again we can get more perfect waves.
3. The quality of the sine wave may be improved by some additional through some careful experimentation.
4. It also would be nice to form a far better interface for connecting to the our Function generator than exposing 2 pins.

Reference from our honourable teachers [1]

Diagram of Function Generator was taken from [2]

Waves use in my outline were taken from [3]

For understanding the working of Astable Multivibrator I read it from [4]

Similarly for understanding the working of Op-Amp Integrator I read it from [5]

For getting basic idea about LM324 I read it from [6]

For more detailed knowledge of LM324 go to [7]

References

[1] Sandeep Saini, Umang Sehgal, and Vineet Sahula. Relative clause based text simplification for improved english to hindi translation. In *Advances in Computing, Communications and Informatics (ICACCI), 2015 International Conference on*, pages 1479–1484. IEEE, 2015.

[2] Tgf4042 arbitrary function generator, 2x 40mhz aim-tti. `https://www.distrelec.biz/en/arbitrary-function-generator-2x-40mhz-aim-tti-tgf4042/p/30143711`. (Accessed on 09/14/2020).

[3] Types of sound waves | thedawstudio.com. `https://www.thedawstudio.com/types-of-sound-waves/`. (Accessed on 09/14/2020).

[4] Astable multivibrator using op-amp | circuit, operation and analysis – eeebooks4u. `https://eeebooks4u.wordpress.com/2017/03/25/astable-multivibrator-using-op-amp/`. (Accessed on 09/15/2020).

[5] Op-amp integrator, operational amplifier integrator. `https://www.electronics-tutorials.ws/opamp/opamp_6.html`. (Accessed on 09/15/2020).

[6] Introduction to lm324 - the engineering projects. `https://www.theengineeringprojects.com/2017/06/introduction-to-lm324.html`. (Accessed on 09/15/2020).

[7] Lm324 comparator ic circuit working and its applications. `https://www.watelectronics.com/lm324-comparator-ic-working-applications/`. (Accessed on 09/15/2020).