# Circut Analysis

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# Contents

# 1 Introduction

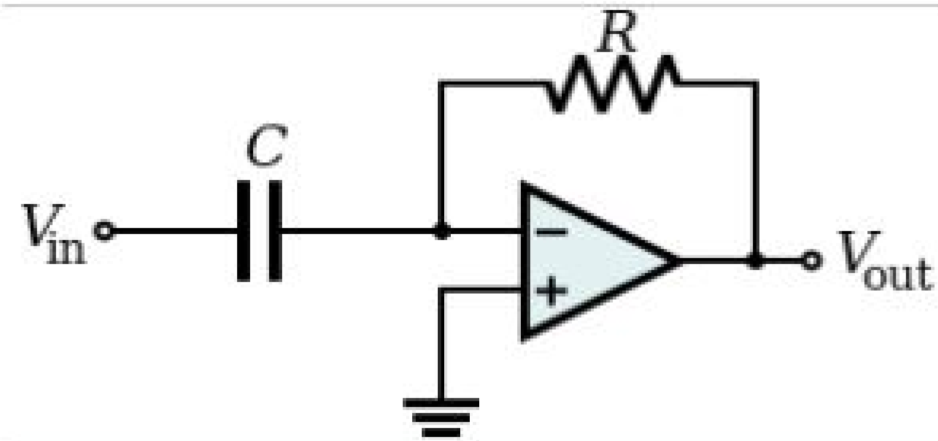
The operational amplifier also known as Op-Amp is one of the most valuable devices in the market now; as for its ability to perform so many different operations when it's combined with other devices like Capacitor, hence it's called an operational amplifier. it's used excessively in analog circuits, especially when it's combined with a capacitor, it can work as Integrator, and so many other mathematical operations like Differentiation, subtraction, and addition.

This report will focus on the analysis of some circuits containing Op-Amp, and show through results, how important this device is.

# 2 Part 1

## 2.1 Circuit definition

One of the very important circuits, The differentiator circuit, will be proven mathematically in the next section, that this circuit can differentiate any wave; as the output voltage is proportional to the rate of change (first derivative) of input voltage.




## 2.2 Circuit analysis

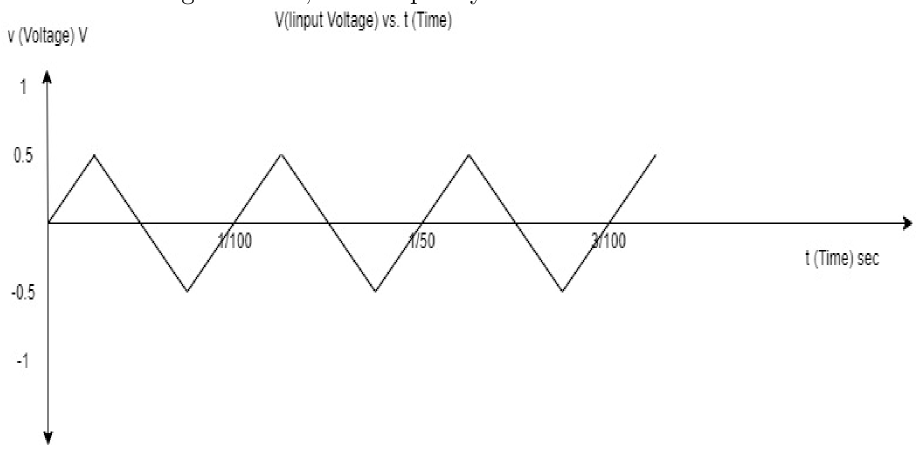
Assuming first that
c: is capacitance of the capacitor
$v_p$: is the voltage at non-inverting terminal of Op-Amp
$v_n$: is the voltage at inverting terminal of Op-Amp
For ideal Op-Amp $v_n = v_p$
$v_{out}$: is the output voltage of Op-Amp

| | | |
|---|---|---|
| $\Rightarrow$ | $v_p = 0$ | Because it's connected to ground |
| $\Rightarrow$ | $v_n = v_p = 0$ | Ideal op-Amp |
| $\Rightarrow$ | $i_n = i_p = 0$ | Ideal op-Amp |
| $\Rightarrow$ | $-c\dfrac{dv_{in}}{dt} + \dfrac{0 - v_{out}}{R} = 0$ | Nodal Analysis at n node |
| $\Rightarrow$ | $v_{out} = -cR\dfrac{dv_{in}}{dt}$ | Simplifying |

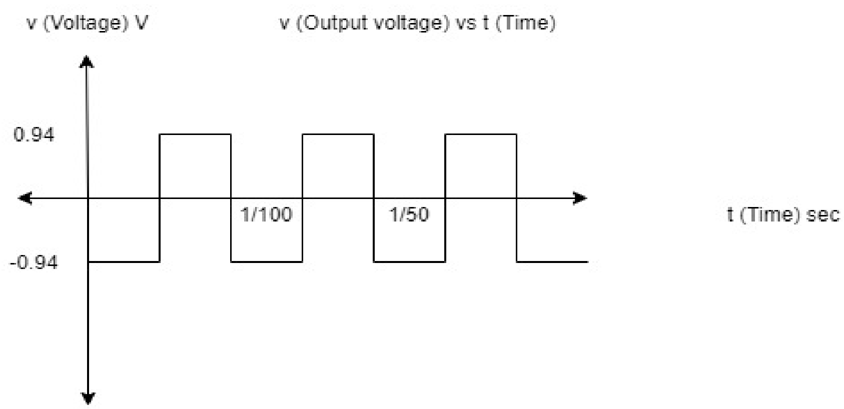
Now it's very apparent that output voltage is equal to the differentiation of any wave multiplied by constant; hence it's called differentiator circuit.

## 2.3 Sketching input and output voltage

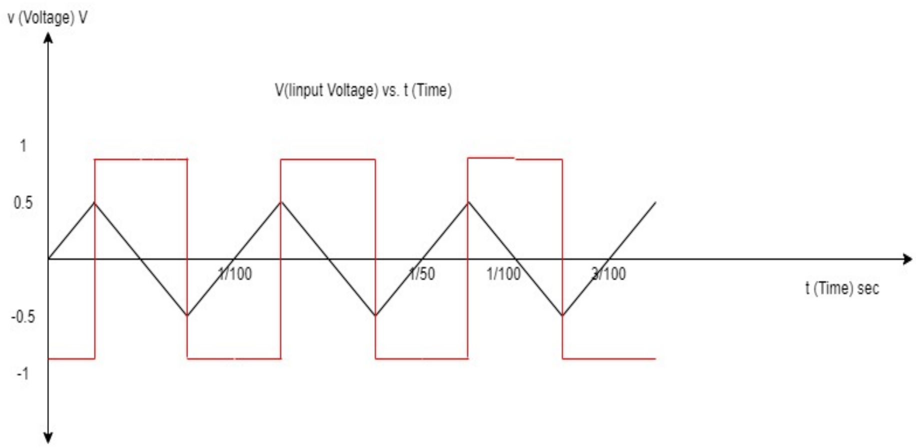
Here is the input voltage as triangular wave versus time. Here it obvious that the maximum voltage is 0.5 V, and frequency is 100 Hz.




And here is the output voltage, for Capacitance 4.7 µF, and Resistance equal to $1k\Omega$. It's obvious that the first derivative for first quadrant of input voltage is constant, and equal to 200 ($\frac{0.5-0}{\frac{1}{400}-0}$), and the output voltage at maximum is equal to 0.94 (($10^3\Omega$)*( 4.7*$10^{-6}$F)$*200$), hence the output voltage will oscillate between +0.94 and -0.94 as the slope increases and decreases.

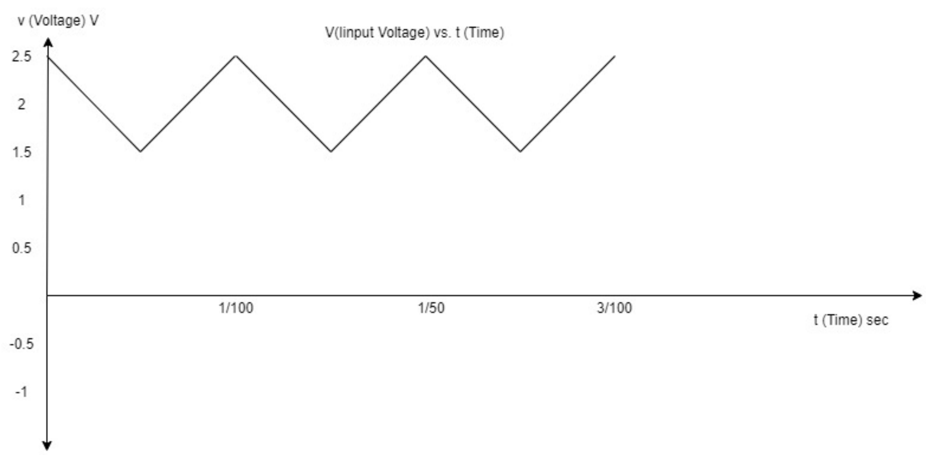



And here is input and output voltages combined togther; Note, the black represents the input voltage, and red represents the output voltage

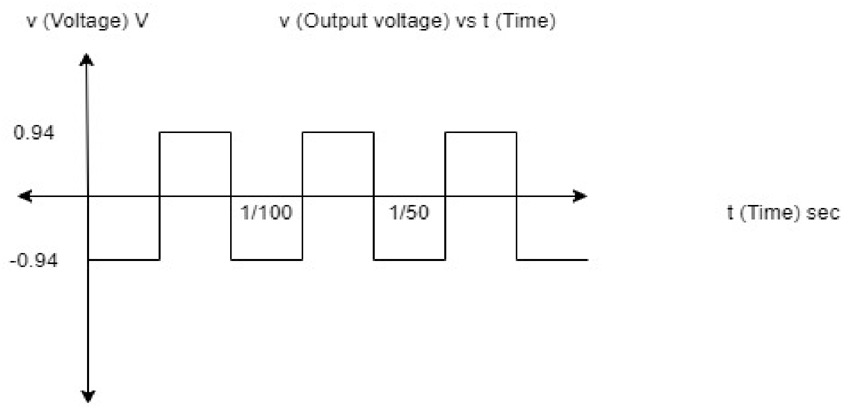



We can see from the equation the the output voltage will be the opposite in sign of rate of change of input voltage, accordingly, when the first derivative is positive, the output voltage is negative.

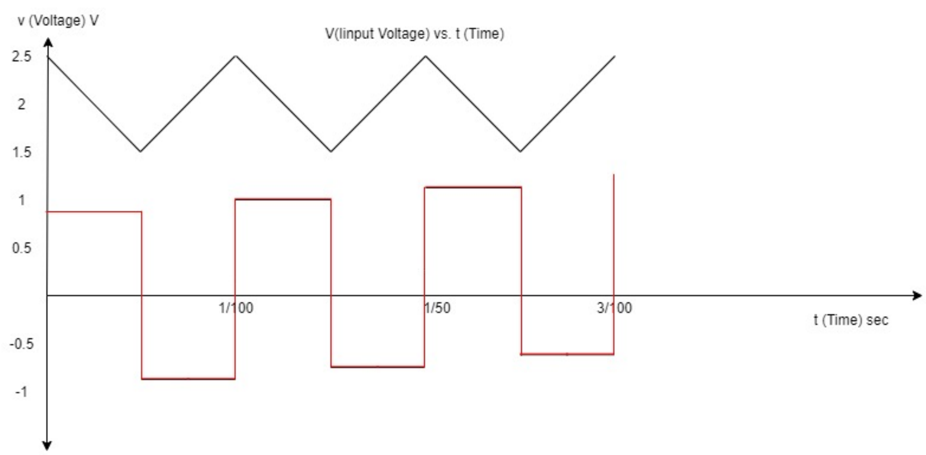
And here an example of wave but with offset equal to 2. we see here that the maximum is 2.5, and frequency is still 100Hz, it's like the last example but only shifted by 2 on y-axix.




and the output voltage doesn't change as the rate of chnage is constant in both cases.

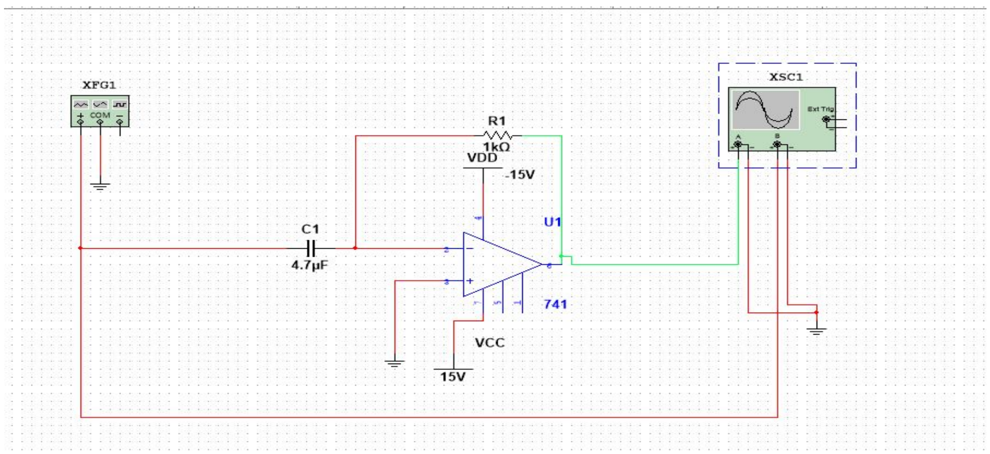



and finally the input and output on the same graph.Note; the input voltage is colored Black, and output is Red.

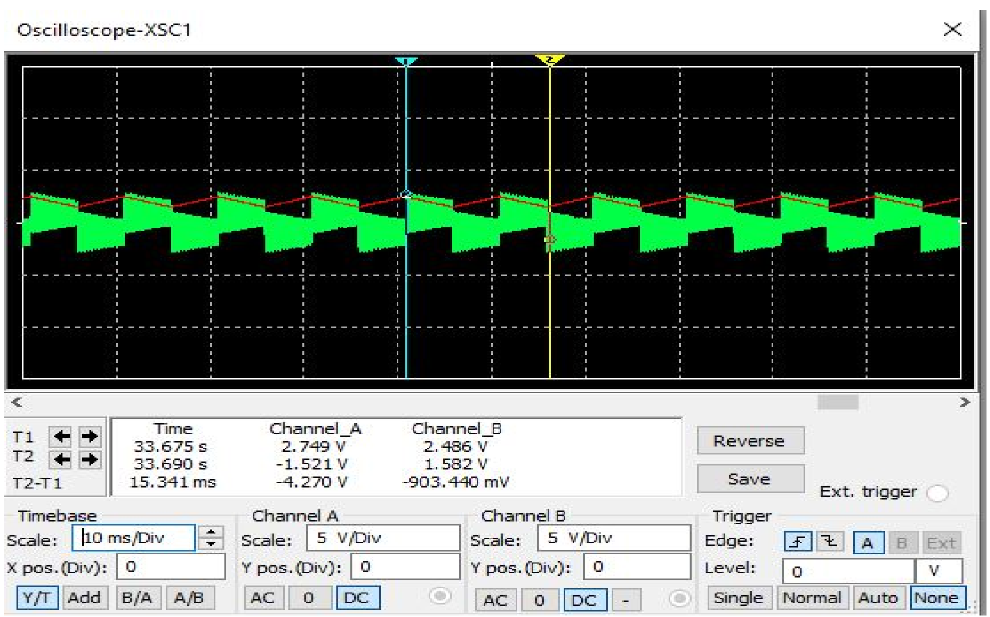


## 2.4 Simulation

A software called Multisim is used here to simulate the circuit, here a function generator is used to generate triangular wave (XFG1), and an Oscilloscope is used to visualize the wave versus time. Resistance and capacitance values are shown in the circuit diagram.

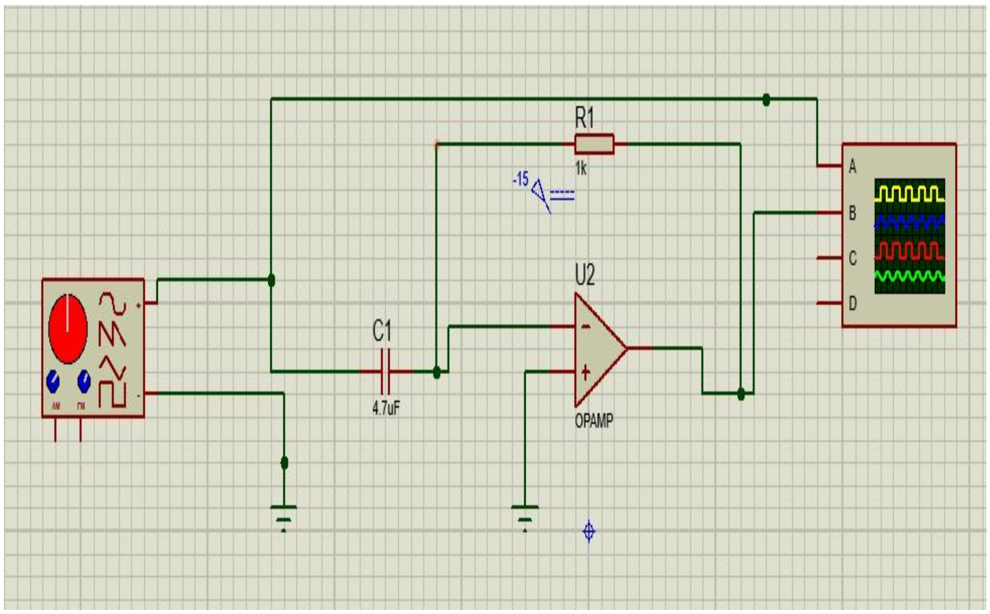



and here is the results from Oscilloscope, Note that the red color represents the input voltage, and Green represents the output voltage.

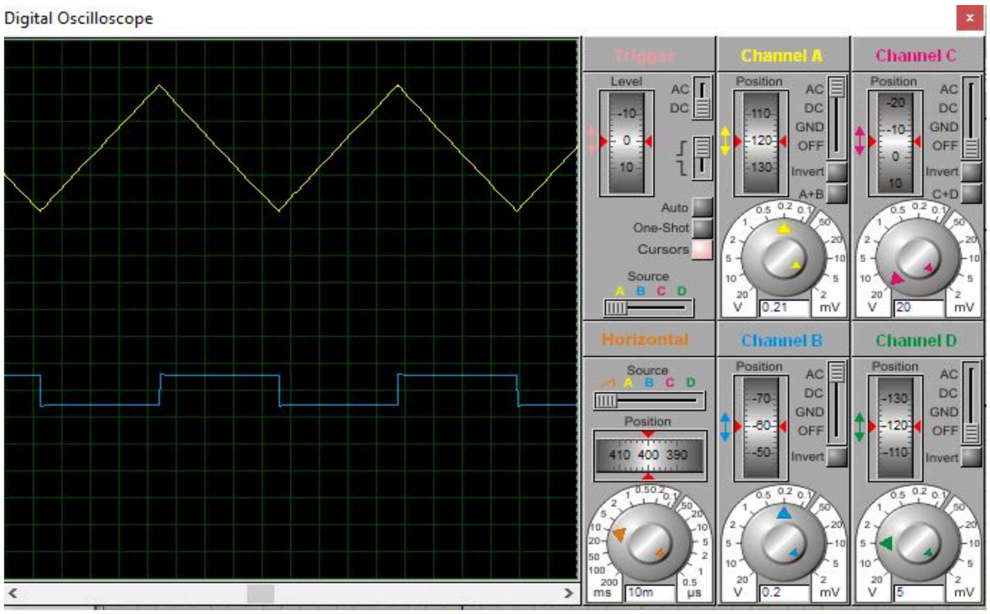


But Actually, the output is not like the expected at all, there is weird oscillation, but at least, when using another software Proteus, and instead of using real Op-amp, an ideal op-amp is used. consequently, the results are perfect and match expectations.

Here is the same circuit in Proteus, but the only difference, is that an ideal op-amp is used.

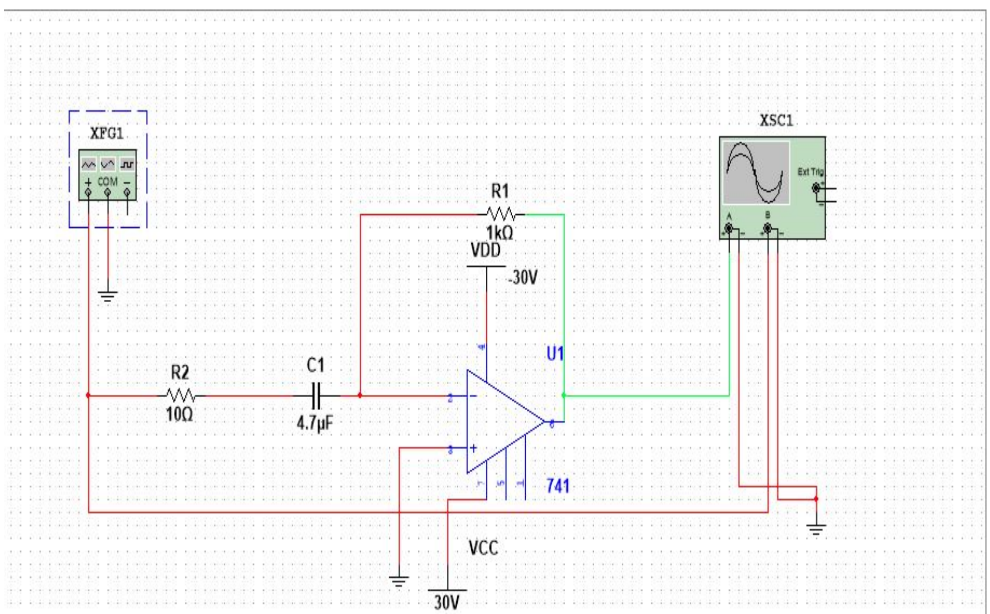



Down here, is input and output voltage as function of time, Note, the input voltage is colored Yellow, and output voltage is colored Blue.



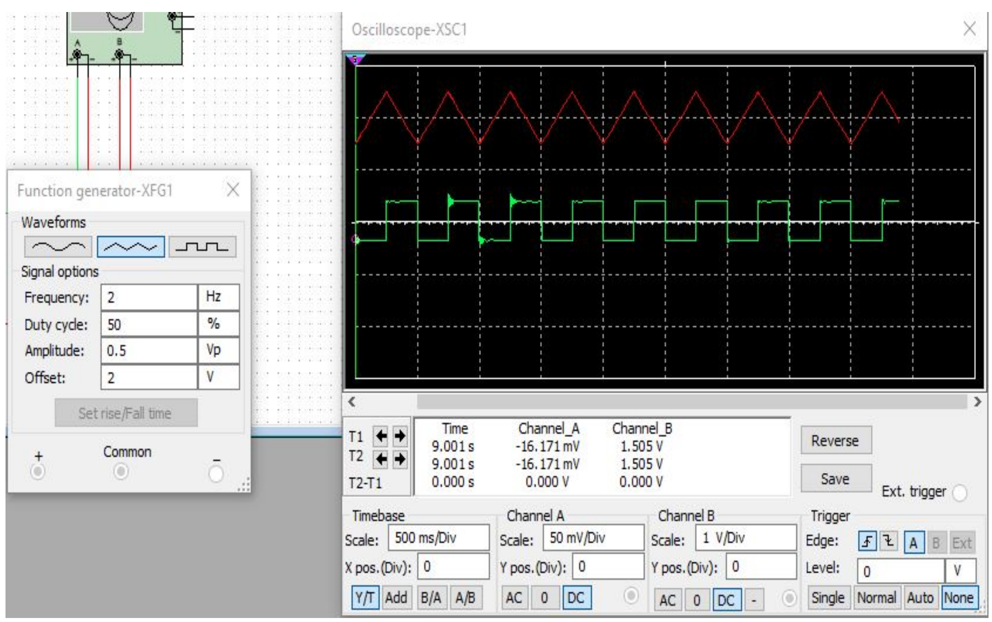

It's very apparent that the output voltage is exactly as same as expectations.

If using an ideal op-amp is not an option, this problem could be solved by inserting a small resistance (10 Ω) in series with capacitor. this will solve the problem. just like that.



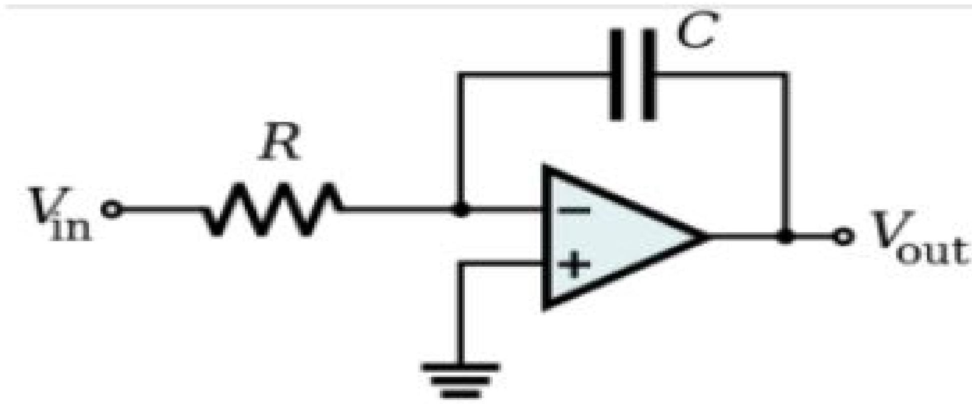

and here is the results.


Another way to solve that problem is to decrease the frequency of triangular wave, a number less than 3Hz will get perfect results, just like that.



# 3 Part 2

## 3.1 Circuit definition




Another common circuit, primarily, it's used as an integrator; It will be proven mathematically that this circuit can integrate any wave

## 3.2 Circuit analysis

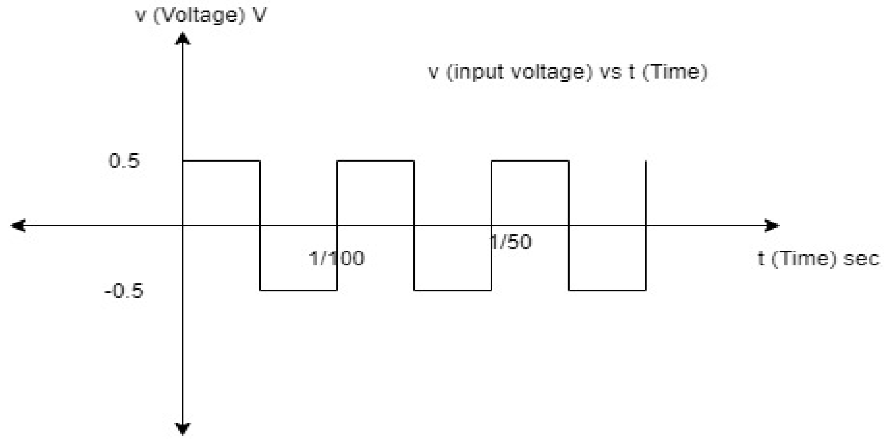
Assuming first that
c: is capacitance of the capacitor
$v_p$: is the voltage at non-inverting terminal of Op-Amp
$v_n$: is the voltage at inverting terminal of Op-Amp
For ideal Op-Amp $v_n = v_p$
$v_{out}$: is the output voltage of Op-Amp

$$\begin{aligned}
\Rightarrow \quad & v_p = 0 && \text{because it's connected to ground} \\
\Rightarrow \quad & v_n = v_p = 0 && \text{Ideal op-Amp} \\
\Rightarrow \quad & i_n = i_p = 0 && \text{Ideal op-Amp} \\
\Rightarrow \quad & \frac{0 - v_{in}}{R} - c\frac{dv_{out}}{dt} = 0 && \text{Nodal Analysis at n node} \\
\Rightarrow \quad & \frac{v_{in}}{R} = -c\frac{dv_{out}}{dt} && \text{Simplifying} \\
\Rightarrow \quad & v_{out}(t) = \frac{-1}{RC}\int_0^t v_{in}dt && \text{Assuming that output voltage intialy equal to 0}
\end{aligned}$$

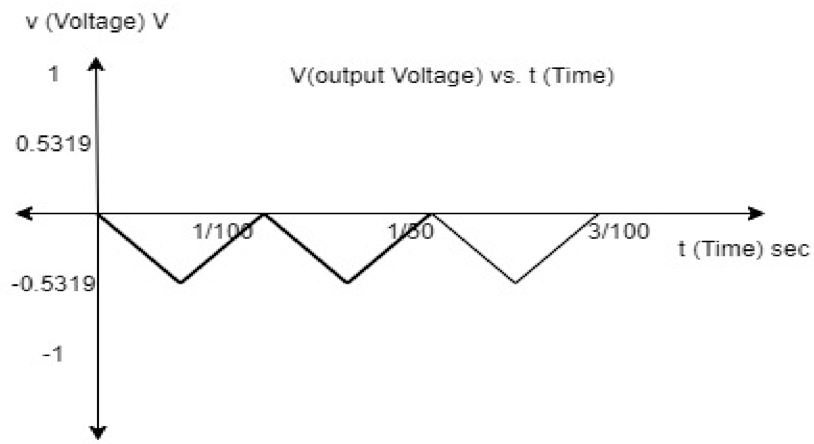
Here it's very apparent that the output voltage is equal to the integration of input voltage wave multiplied by some constant; hence it's called Integrator circuit

## 3.3 Sketching input and output voltage

Here is the input voltage versus time; representing a square wave, with amplitude equal to 0.5v , and frequency = 100

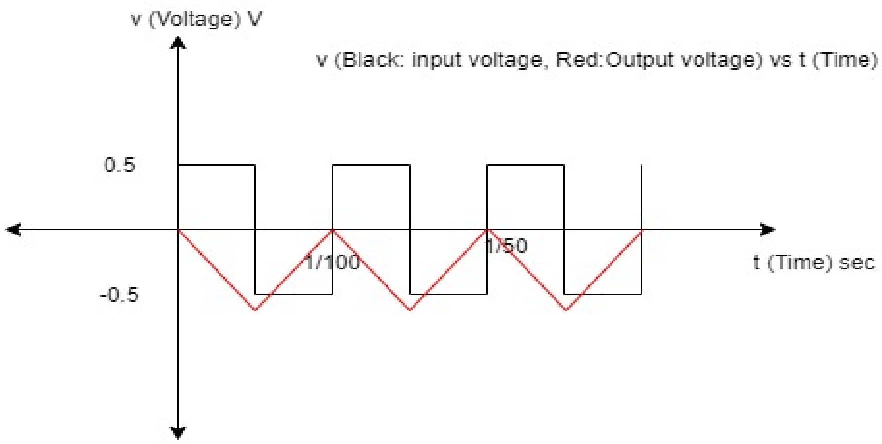



Output voltage versus time. for capacitance equal to 4.7 µF and Resistance equal to 1kΩ



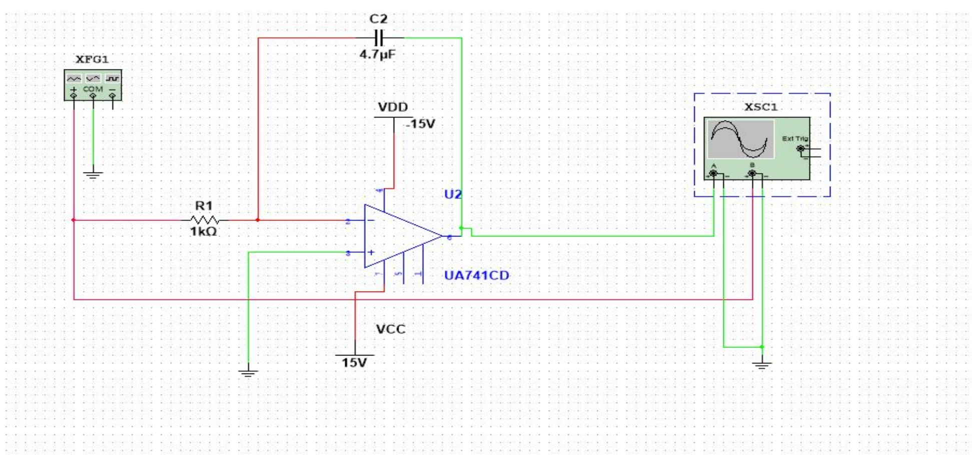

We see that this circuit is integrating the square wave, hence the maximum value will at the down edge of square wave but in negative. hence the minimum value is equal to $\frac{-1}{10^3 * 4.7 * 10^{-6}} * 0.5 * \frac{1}{200}$ which is equal to 0.531

And Finally the two graphs combined together, Note, The black represents the input voltage, and red represents the output voltage

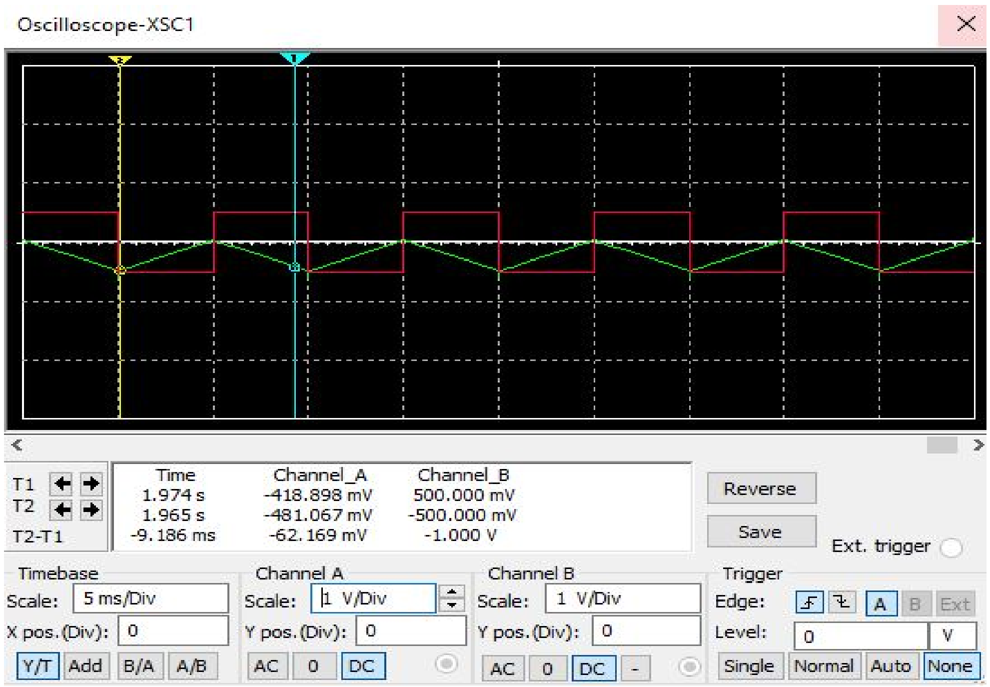



## 3.4 Simulation

Again Software Multisim is used to see the behavior of that circuit. here a function generator is used to generate square waves(XFG1), and Oscilloscope to visualize the wave exactly, and also all other components that were used in the theoretical derivation, the values for Resistance and capacitance are shown on in the circuit.

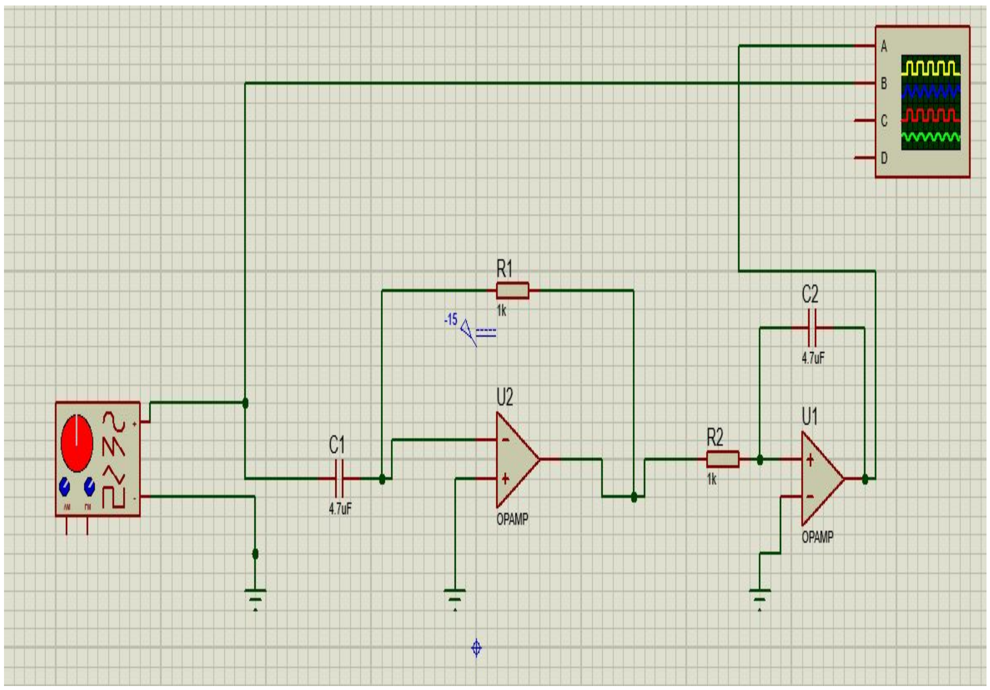



And here is the $v_{out}$ and $v_{in}$ as function of time; Note, The $v_{out}$ is colored Green, and $v_{in}$ is colored Red

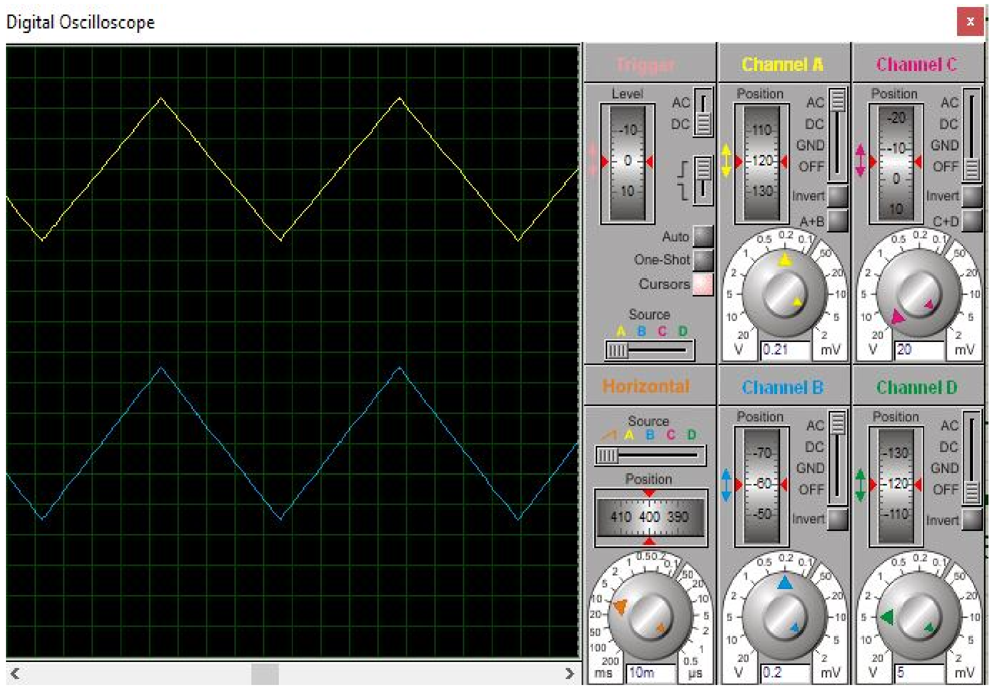

Oscilloscope-XSC1
T1
T2
T2-T1
Time
1.974 s
1.965 s
-9.186 ms
Channel_A
-418.898 mV
-481.067 mV
-62.169 mV
Channel_B
500.000 mV
-500.000 mV
-1.000 V
Reverse
Save
Ext. trigger
Timebase
Scale: 5 ms/Div
X pos.(Div): 0
Y/T Add B/A A/B
Channel A
Scale: 1 V/Div
Y pos.(Div): 0
AC 0 DC
Channel B
Scale: 1 V/Div
Y pos.(Div): 0
AC 0 DC -
Trigger
Edge: A B Ext
Level: 0 V
Single Normal Auto None

# 4 Conclusion

The last two circuits could be thought of as inverse of each other, one integrating and the other is differentiating. When combining the two cir cuts together, the output voltage will be exactly like the input voltage just like that.




Result of simulations, Note the input is colored Yellow, and Output is colored Blue.


Digital Oscilloscope
Trigger
Channel A
Channel C
Horizontal
Channel B
Channel D
Level
Auto
One-Shot
Cursors
Source
Position
AC
DC
GND
OFF
Invert
A+B
C+D
410 400 390
10m
0.21
20
0.2
5