Analog Calculator using OP AMP

Course No: EEE208

Course Title: Electronics Circuit II Laboratory

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Project Overview:

The purpose of our project is to construct an analog calculator with the use of op-amp 741. We have enabled this analog calculator to carry out 7 types of linear and non-linear operation: linear operations: Addition, Subtraction, Differentiation, Integration and non-linear operations: Logarithmic operation, Exponentiation, Multiplication. We have constructed a Proteus circuit in which a user will be able to choose which operation they want the calculator to perform. Then they could select the input as a pulse wave, triangular wave, sinusoidal wave, saw tooth wave, or DC voltage. They also can vary the frequencies and values from the signal generator as required. We can study output without difficulty from the virtual oscilloscope linked to the specific channels.

Circuit diagram:

The circuit shown in Fig 1, includes 8 OP AMPS designed to execute 7 operations in case of both AC and DC signal.

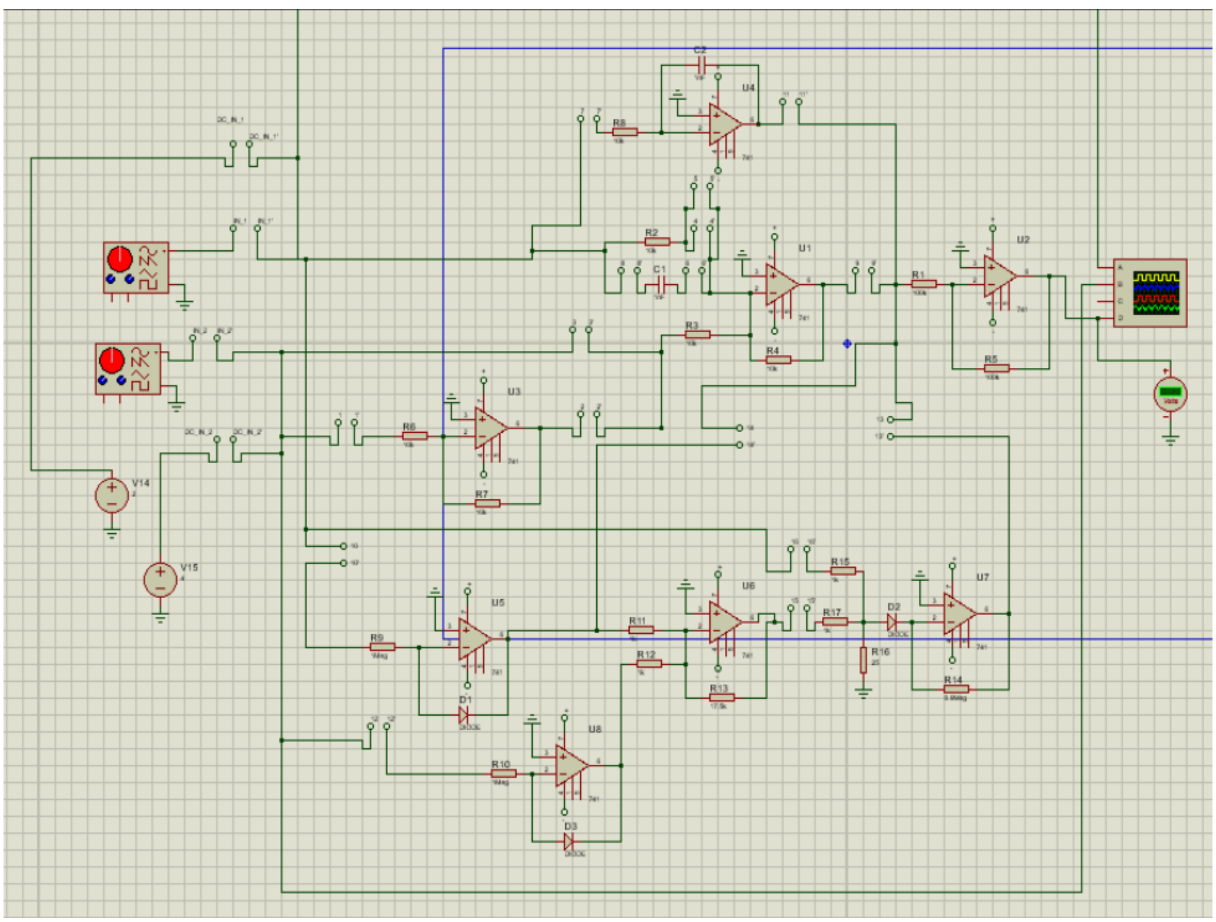

Figure 1: Schematic circuit

Input and operation procedure:

We tried to design a circuit with minimum number of OP AMPs capable of doing the mathematical operations. And so, in the circuit we have used multiple voltage control switches. The part can be found from components searching VSWITCH (part model is shown in Fig 2(a)) in component mode. The default position of the switches is open. Certain number of switches closes to carry out a required operation.

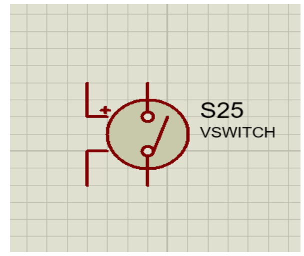

Figure 2(a): VSWITCH part model

As the switches are voltage controlled, they can be closed and opened applying bias voltage. When the bias voltage is more than threshold voltage the switch closes. Here in the circuit, the threshold voltage is set to 5V. Any voltage greater than 5V will close the switch. The OFF resistance of the switch is about 1000MΩ and ON resistance is 0.0001Ω.

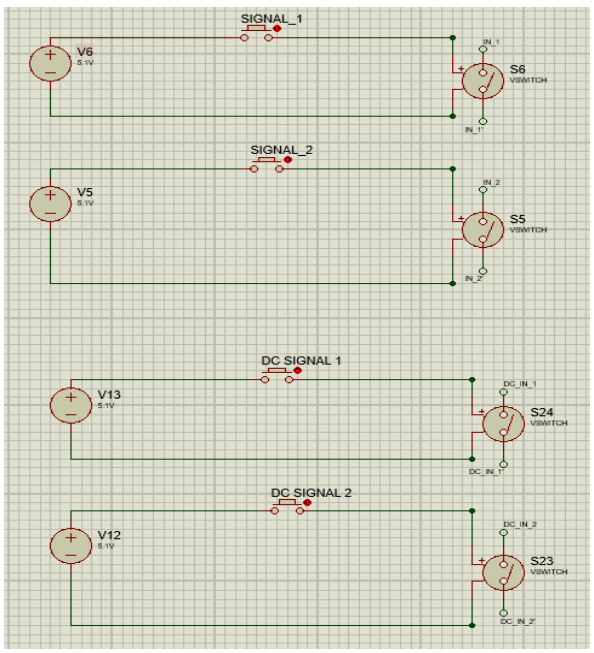

Figure 3(a): Ac signal and dc signal selection

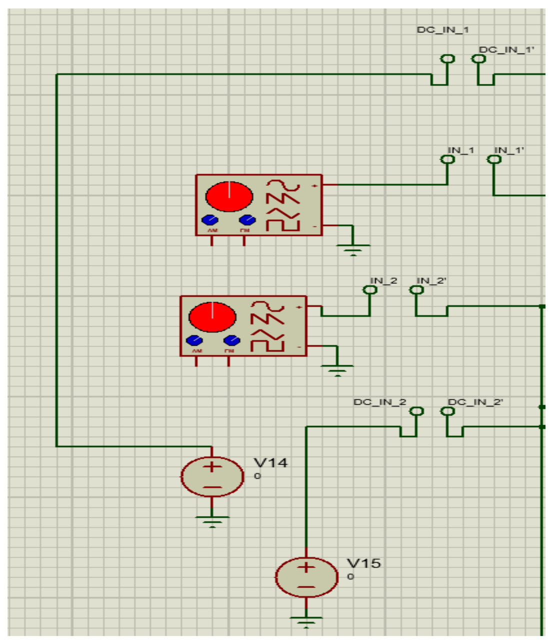

Figure 3(b): Input connection

A voltage of 5.1V is connected to VSWITCH through a push button. When the push button is closed, 5.1V bias is applied to the switches which is more than threshold voltage, hence VSWITCH will close. For example, in Fig 3(a) when 'SIGNAL_1' push button is pressed the VSWTCH S6 will be closed. So, the terminal IN_1 and IN_1' will be shorted. So, the first signal generator will be input of the circuit. We can also choose dc inputs by pressing 'DC_SIGNAL 1' and 'DC_SIGNAL 2' according to our operation.

While choosing operation, same method has been applied. By pressing push button, we can select our desired operation. For instance, if we press 'ADDITION' push button, the terminal 4 – 4', 3 – 3' and 9 – 9' will be shorted (shown in Fig 3(b)). The terminal 4 – 4' will connect input 1 to the inverting terminal through the resistance R2(=10kΩ). And the terminal 3 - 3' will connect input 2 to the inverting terminal through the resistance R3(=10kΩ). So, the OP AMP U1 will serve as an inverting adder. The output of the OP AMP U1 will pass to the OP AMP U2, as the 9 - 9' terminal is shorted. OP AMP U2 will work as an inverter and the final output signal at the output terminal will be the addition of the Input 1 and Input 2.

Now say, we want to differentiate a signal. In this case, terminal 8 - 8', 6 - 6' and 9 - 9' terminal will be shorted. The shorted 8 - 8' and 6 – 6' will connect the capacitor C1(=1nF). So, the inverting terminal of OP AMP U1 will receive signal as input through a capacitor. The OP AMP U1 will act as an inverting differentiator this time. The output of the inverting differentiator will pass to OP AMP U2, an inverter, and the final output will be the differentiator of signal 1. The other operation works similarly. We will discuss them throughout the report.

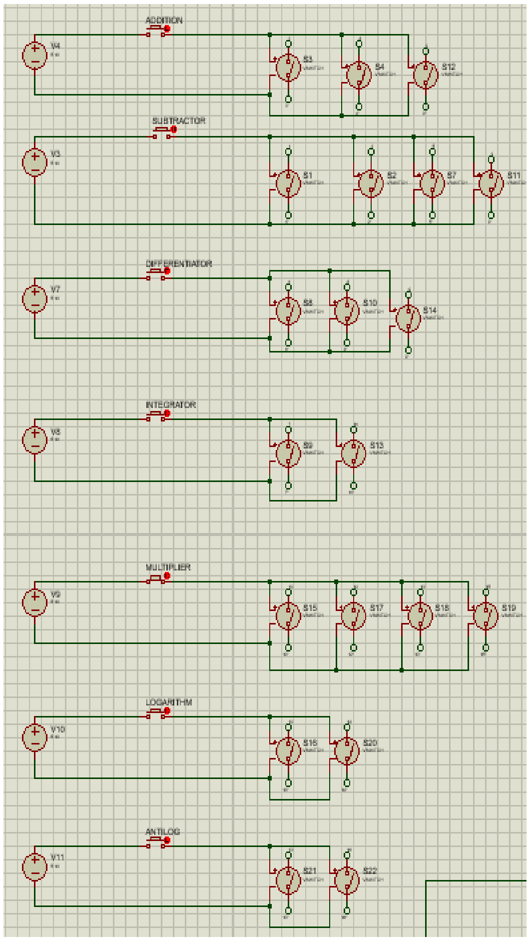

Figure 3(a): Mathematical operation selection

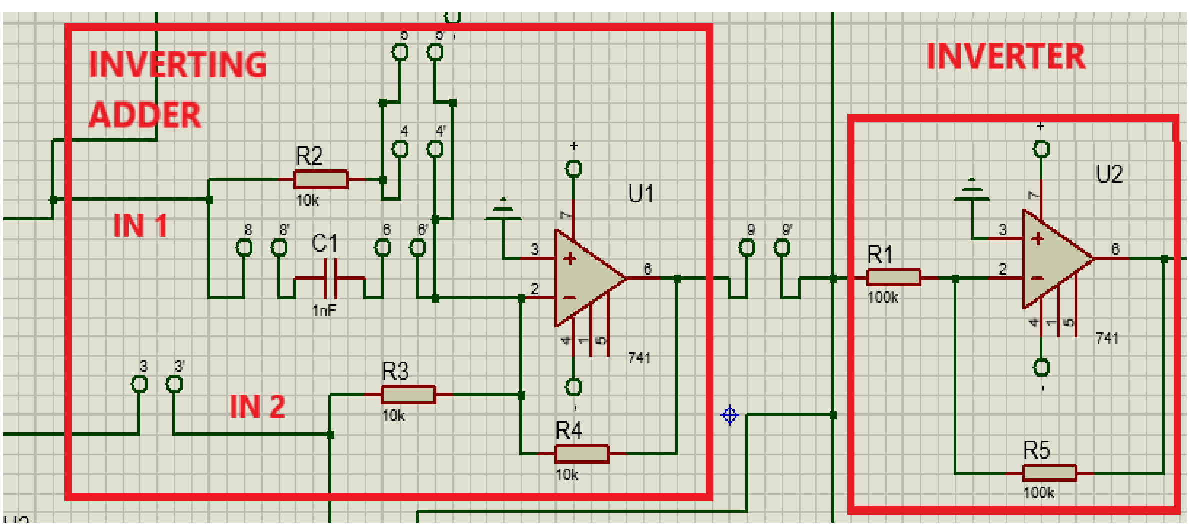

Figure 3(b): Adder circuit connection

Finally, to observe the output, we use a dc digital oscilloscope and a voltmeter, which are connected to the terminal 6 of OP AMP U2. In the oscilloscope, we are able to see the waveform of output, if we take ac signals as input. On the other hand, in dc voltmeter, we can see Dc voltage output if we take DC signals as input. both parts (oscillator & voltmeter) are linked U2 op-amp output terminal.

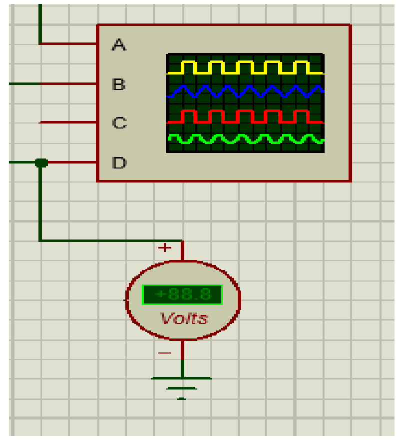

Figure 3(c): Oscilloscope and DC voltmeter

Adder circuit:

Working principle:

Op-amp is used to design a circuit whose output is the sum of several input signals. Such a circuit is called a summing amplifier or a summer or adder.

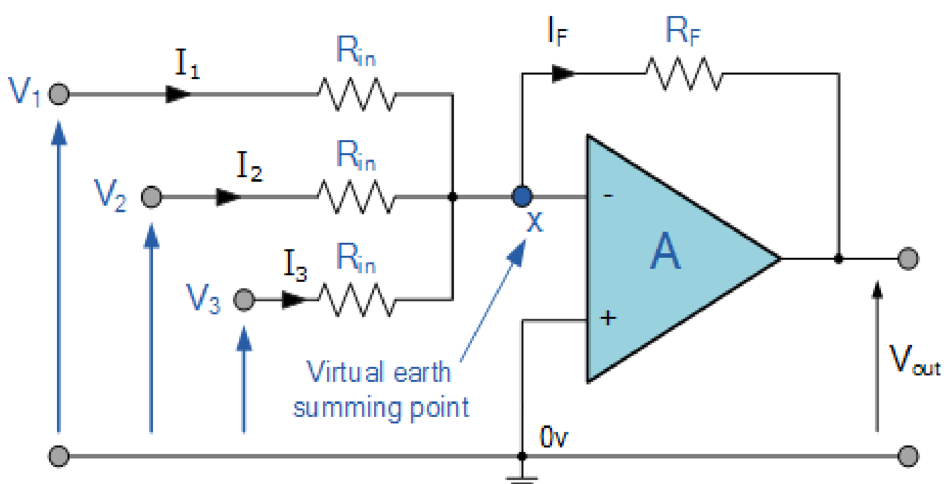

Figure 4: Inverting Adder circuit

Here,

$I_1 = \frac{V1}{Rin}$; $I_2 = \frac{V2}{Rin}$; $I_3 = \frac{V3}{Rin}$

$I_f = I_1 + I_2 + I_3$;

Vo = - $I_f R_f$

=- $R_f (I_1 + I_2 + I_3)$

=- $R_f \left(\frac{V1}{Rin} + \frac{V2}{Rin} + \frac{V3}{Rin}\right)$

If $R_f = R_{in}$

Vo = $-(V_1 + V_2 + V_3)$

Here, in this circuit the first op amp takes two inputs and gives output with gain -1. Since this is an inverting amplifier, we have put the output through another op amp with -1 gain so that the output again inverts and we get our desired value.

Schematic:

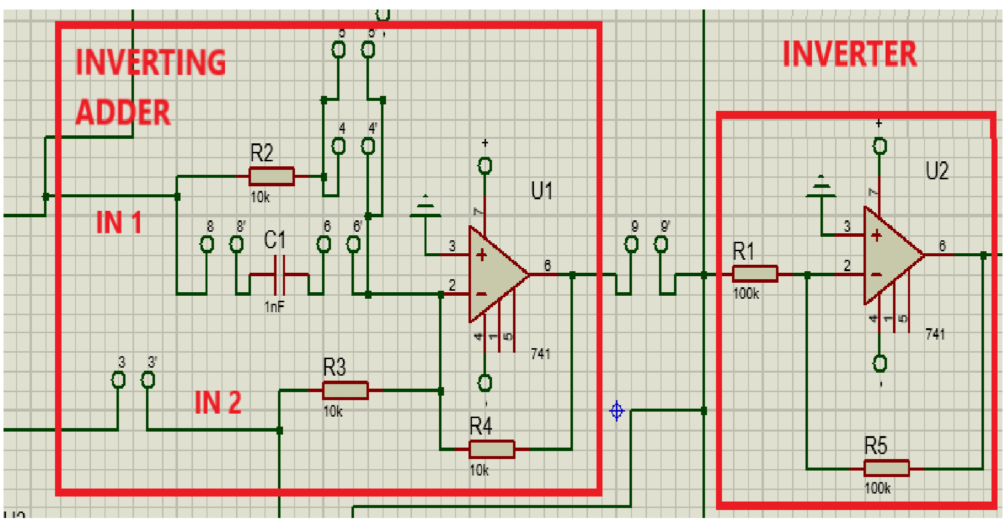

Figure 5: Adder circuit connection

After pressing 'ADDITION' push button, the terminal 4 – 4', 3 – 3' and 9 – 9' will be shorted. The terminal 4 – 4' will connect input 1 to the inverting terminal through the resistance R2(=10kΩ). And the terminal 3 - 3' will connect input 2 to the inverting terminal through the resistance R3(=10kΩ). So, the OP AMP U1 will serve as an inverting adder. The output of the OP AMP U1 will pass to the OP AMP U2, as the 9 - 9' terminal is shorted. OP AMP U2 will work as an inverter and the final output at the output terminal will be the addition of the Input 1 and Input 2.

Input output waveform:

1. The first input waveform is a square wave with peak value 1V and a frequency of 2kHz which is denoted by yellow waveform. The second input waveform is a sine wave with peak value 0.5Vand a frequency of 2kHz which is denoted by blue waveform. The output is denoted by green waveform. Its peak value is 1.5V and frequency is 2kHz.

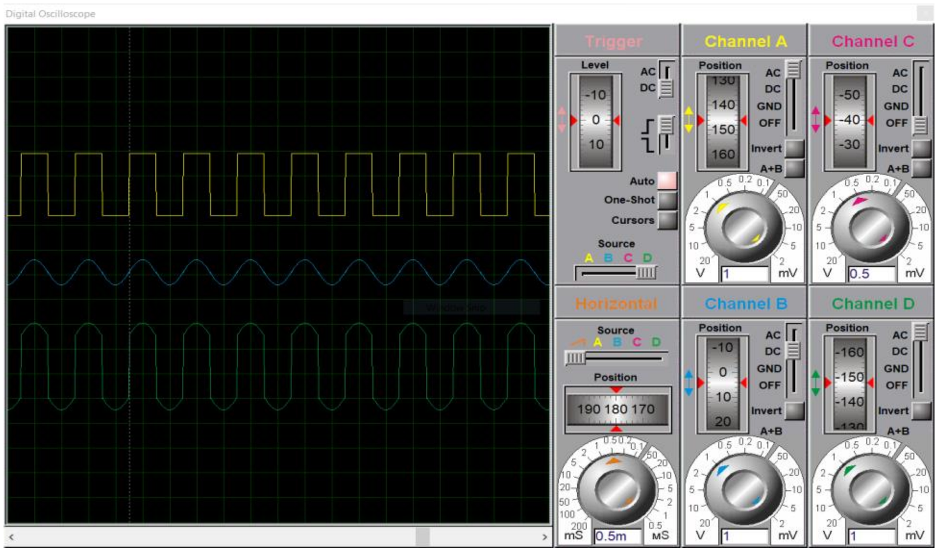

Figure 6: Oscilloscope window

2. The first input waveform is a sine wave with peak value 1V and a frequency of 2kHz which is denoted by yellow waveform. The second input waveform is a sine wave with peak value 0.5Vand a frequency of 2kHz which is denoted by blue waveform. The output is denoted by green waveform. Its peak value is 1.5V and frequency is 2kHz.

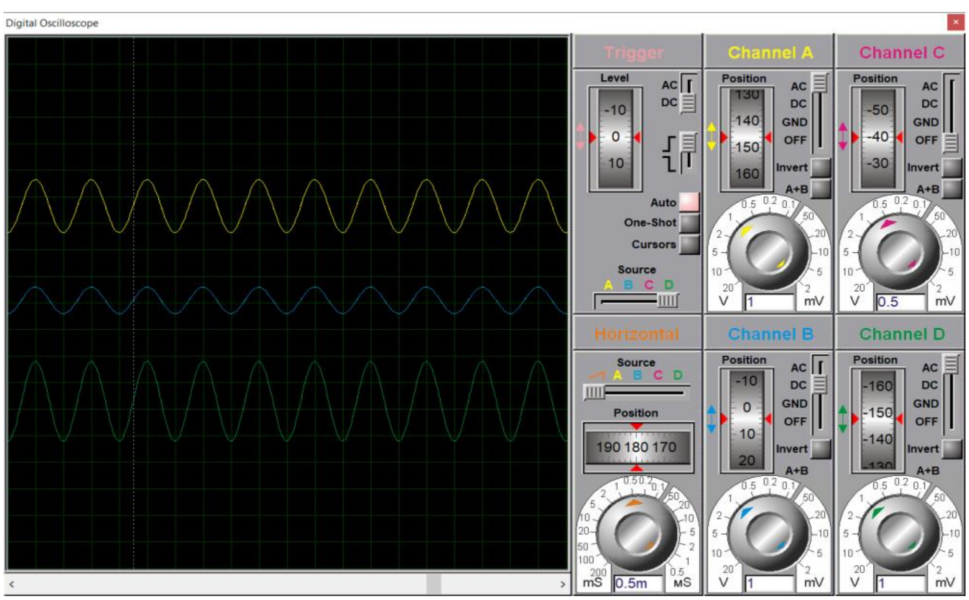

Figure 7: Oscilloscope window

Output for DC input:

For,

DC input signal 1 = 2V

DC input signal 2 = 4V

The output is 6.01V.

But the output of the adder should be 6V.

The error in the output may be the cause of offset voltage and offset current.

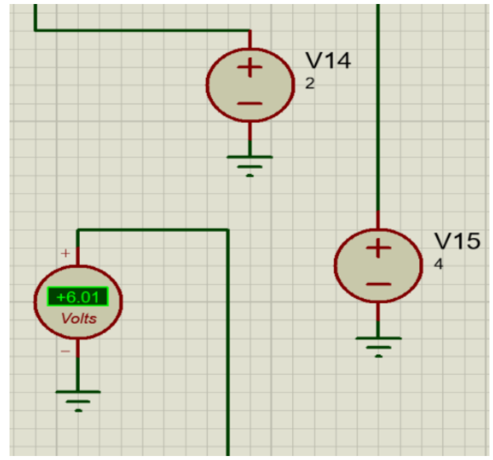

Figure 8: Adder circuit input for two DC voltage

Subtractor:

Working principle:

A subtractor is an electronic circuit that produces an output, which is equal to the difference of the applied inputs. This section discusses about the op-amp based subtractor circuit. An op-amp based subtractor produces an output equal to the difference of the input voltages applied at its inverting and non-inverting terminals.

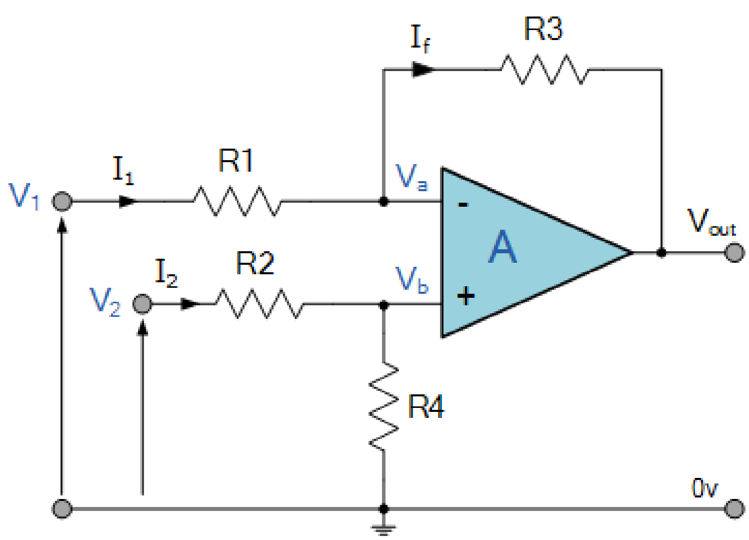

Figure 9: subtractor circuit

Here,

Output for first Amplifier,

$V_{o1} = -\frac{Rf1}{R1}V_1$

If, $Rf_1 = R_1$

$V_{o1} = -V_1$

Output for second amplifier,

$V_{o2} = -\frac{Rf2}{R2}V_{o1} - \frac{Rf2}{R3}V_2$

If, $R_{f2} = R_2 = R_3$

$V_{o2} = -V_{o1} - V_2$

$= -(-V_1) - V_2$

$= V_1 - V_2$

$= \mathbf{V_{out}}$

Here, output is the subtraction of two signal. We used here two op-amp for subtraction.

Schematic:

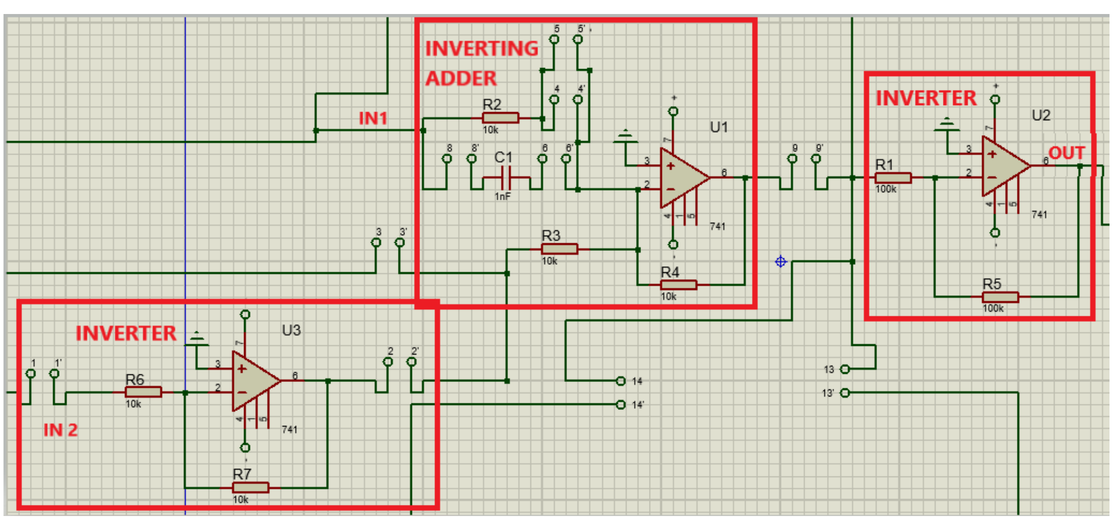

Figure 10: subtractor circuit connection

After pressing 'SUBTRACTOR' push button, the terminal 1 – 1', 2 – 2', 5 – 5' and 9 – 9' will be shorted. The terminal 5 – 5' will connect input 1 to the inverting terminal through the resistance R2(=10kΩ). And the terminal 1 - 1' will connect input 2 to the inverting terminal of OP AMP U3 through the resistance R6(=10kΩ). The output of OP AMP U3 will be inversion of input 2 and pass on to OP AMP U1, as terminal 2 – 2' is shorted.

So, the OP AMP U1 will serve as an inverting adder. It will add input 1 and inversion of input. The output of the OP AMP U1 will pass to the OP AMP U2, as the 9 - 9' terminal is shorted. OP AMP U2 will work as an inverter and the final output at the output terminal will be the addition of the Input 1 and inversion of Input 2, which is basically a subtraction of input 1 and input 2.

Input output waveform:

1. The first input waveform is a sine wave with peak value 1V and a frequency of 2kHz which is denoted by yellow waveform. The second input waveform is a sine wave with peak value 0.5V and a frequency of 2kHz which is denoted by blue waveform. The output is denoted by green waveform. Its peak value is 0.5V and frequency is 2kHz.

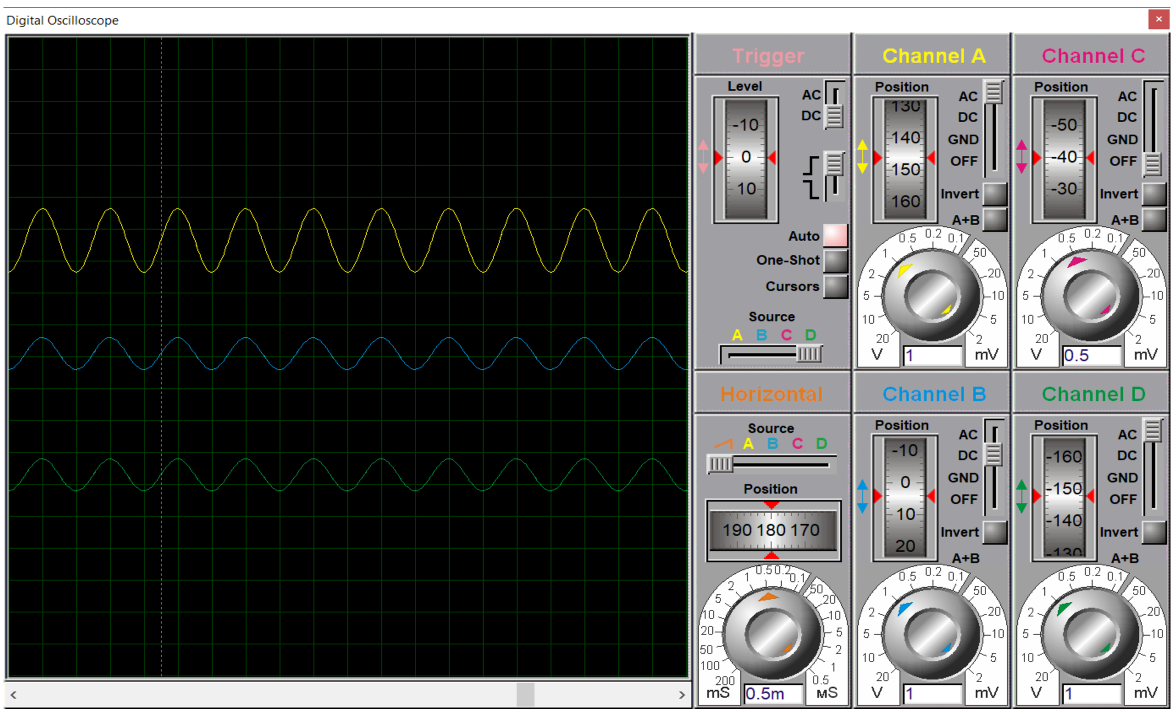

Figure 11: Oscilloscope window

2. The first input waveform is a square wave with peak value 1V and a frequency of 2kHz which is denoted by yellow waveform. The second input waveform is a sine wave with peak value

0.5Vand a frequency of 2kHz which is denoted by blue waveform. The output is denoted by green waveform. Its frequency is 2kHz.

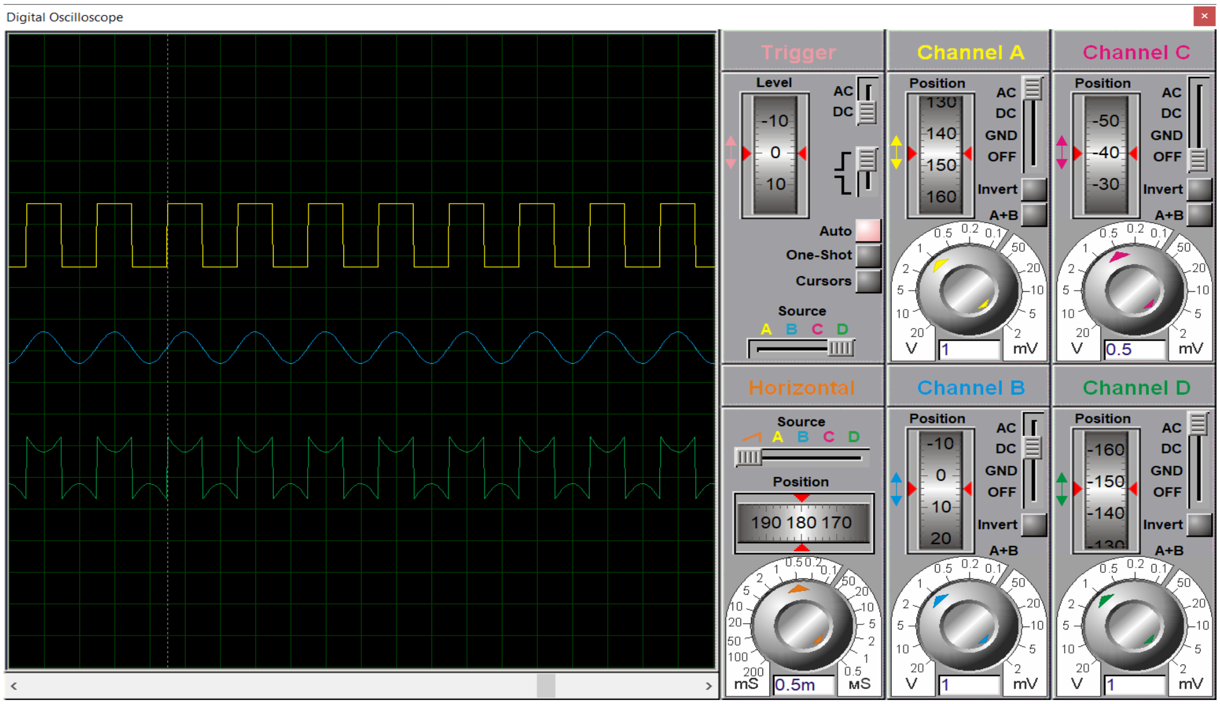

Figure 12: Oscilloscope window

Circuit output for DC input:

For,

DC input signal 1 = 2V

DC input signal 2 = 4V

The output is -1.99.

But the output result of the subtractor should be -2V.

The error in the output may be the cause of offset voltage and offset current.

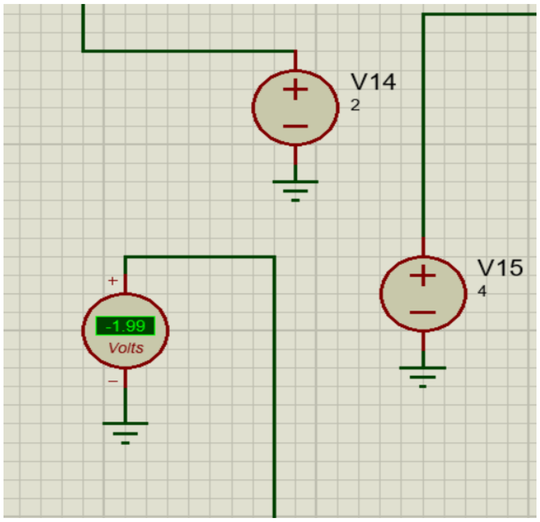

Figure 13: Subtractor circuit input for two DC voltage

Integrator circuit:

Working principle:

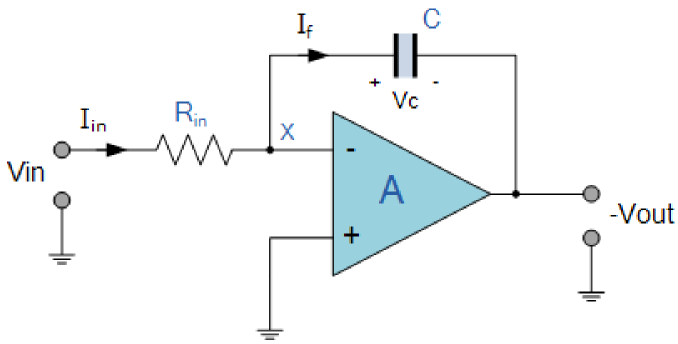

Figure 14: Inverting integrator circuit

As its name implies, the Op-amp Integrator is an operational amplifier circuit that performs the mathematical operation of Integration, that is we can cause the output to respond to changes in the input voltage over time as the op-amp integrator produces an output voltage which is proportional to the integral of the input voltage.

Here, V_x=0;

$I_{in}=I_f$;

$I_{in} = \frac{\text{Vin}}{R}$ =If;

Again,

$I_c=I_f=C\frac{dVc}{dt}$;

$V_c= \int_0^t \frac{Ic\ dt}{C}$

$=\frac{1}{RC}\int_0^t \text{Vin}\ dt$

Again, $V_o = -V_c$

$V_o = \frac{-1}{RC}\int_0^t Vin\ dt$

Schematic:

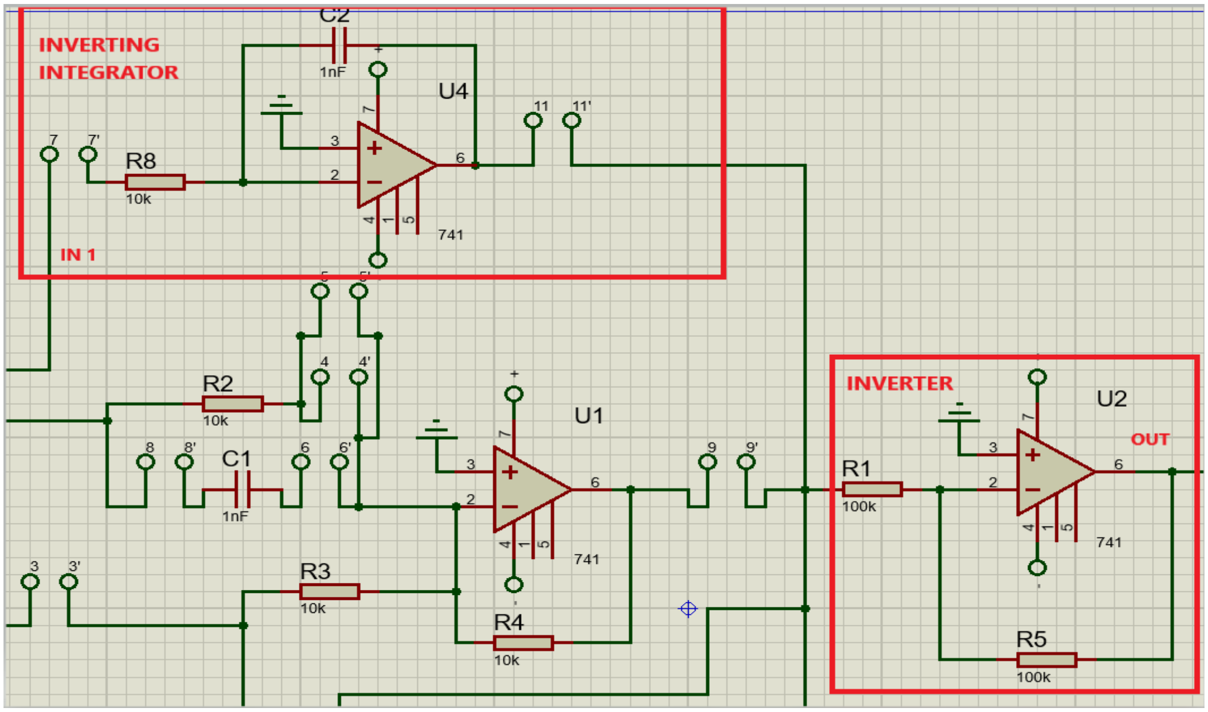

Figure 15: Integrator circuit connection

After pressing 'INTEGRATOR' push button, the terminal 7 – 7'and 11 – 11' will be shorted. The terminal 7 – 7' will connect input 1 to the inverting terminal of the OP AMP U4 through the resistance R8(=10kΩ). The output of the OP AMP U4 will pass to the OP AMP U2, as the 11 - 11' terminal is shorted. OP AMP U4 will serve as an inverting integrator and OP AMP U2 will work as an inverter. The final output at the output terminal will be the integration of input 1.

Input Output waveform:

1. Here by integrating input sine wave (yellow) we get green cosine wave as output.

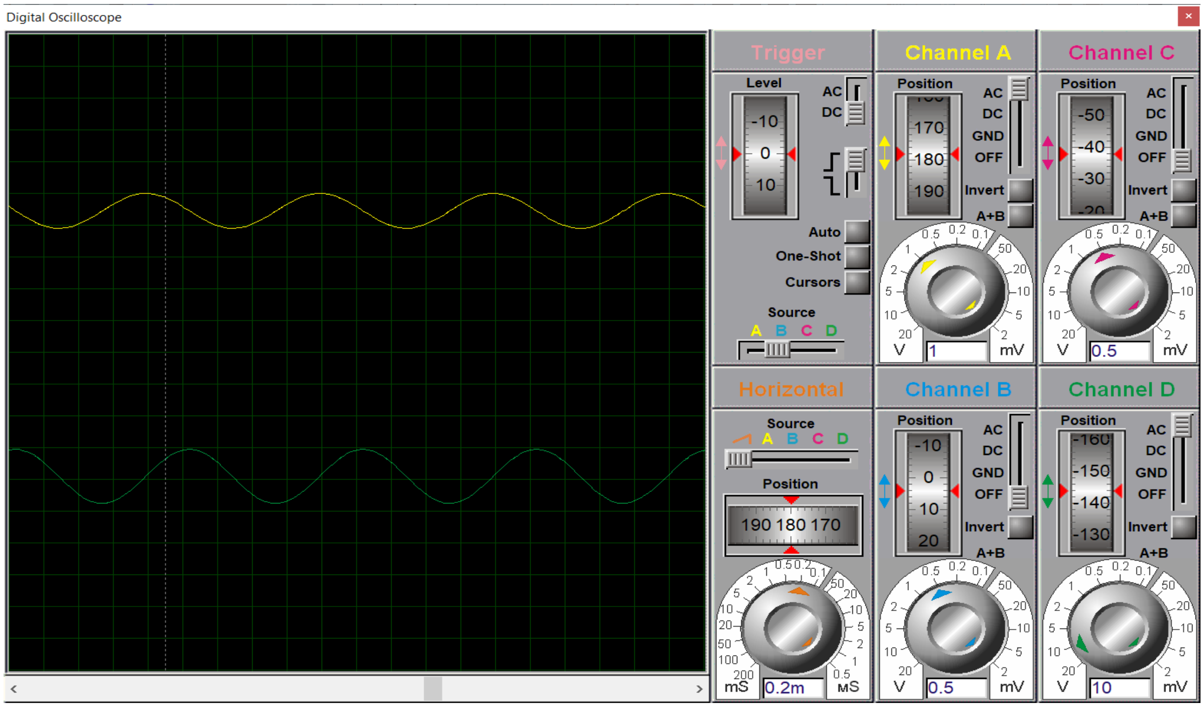

Figure 16: Oscilloscope window

2. We get triangle wave when our circuit input is a square wave.

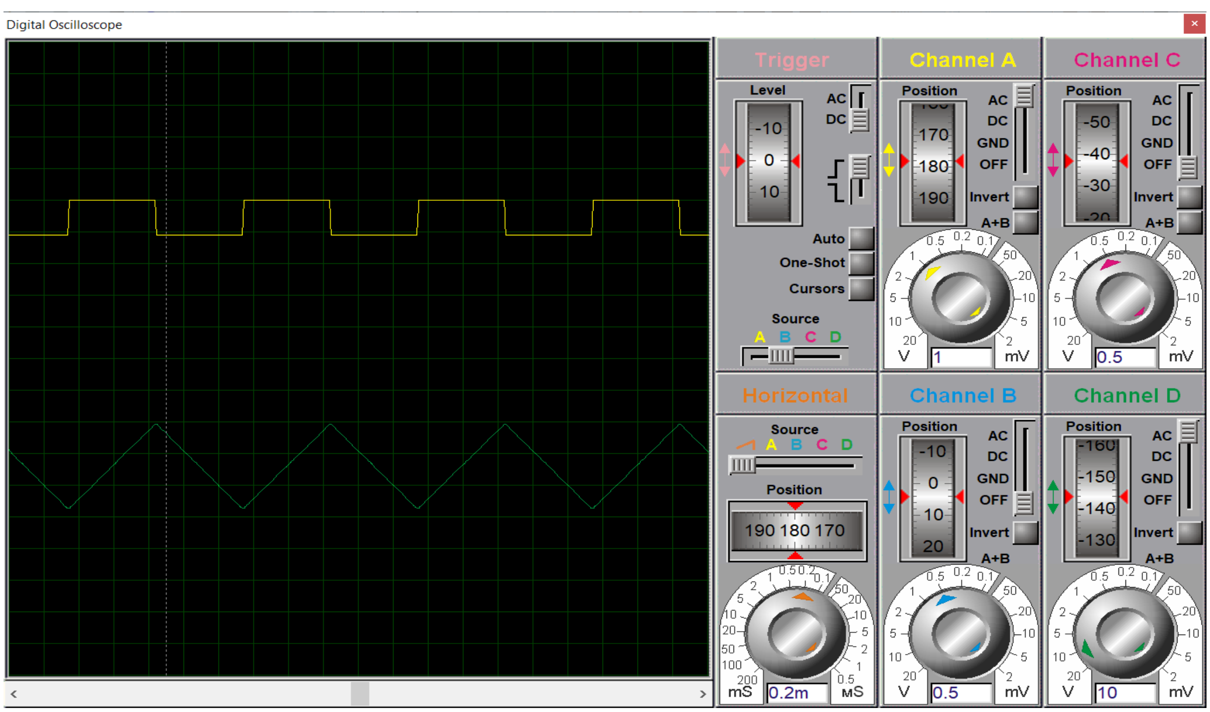

Figure 17: Oscilloscope window

3. Also, we get a parabolic wave by passing triangular wave through our integrating circuit.

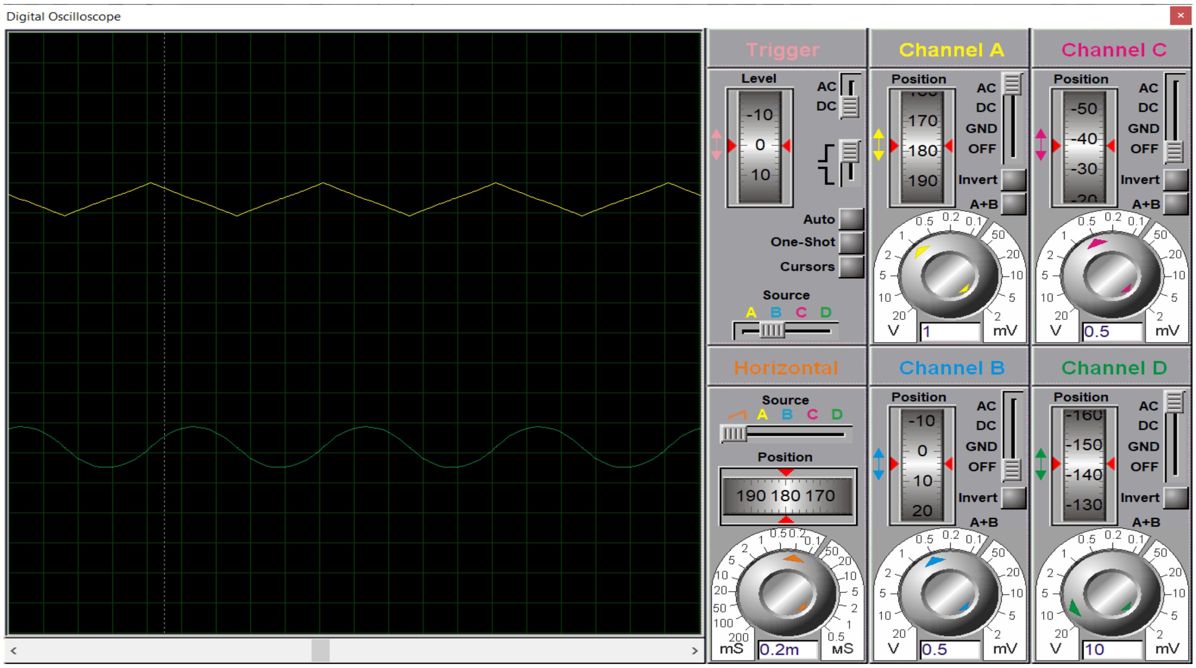

Figure 18: Oscilloscope window

Differentiator circuit:

Working principle:

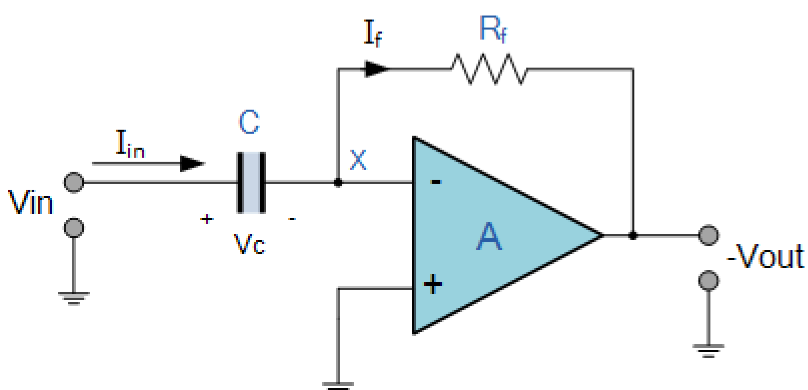

Figure 19: Inverting differentiator circuit

The basic operational amplifier differentiator circuit produces an output signal which is the first derivative of the input signal.

Here,

$V_x=0$

$I_{in}=I_f$

$V_{in}= V_c$

$I_{in} = C\frac{dVc}{dt}$

Again,

$V_o = -I_fR_f$

$= -I_{in}R_f$

$= -R_fC\frac{dVc}{dt}$

Schematic:

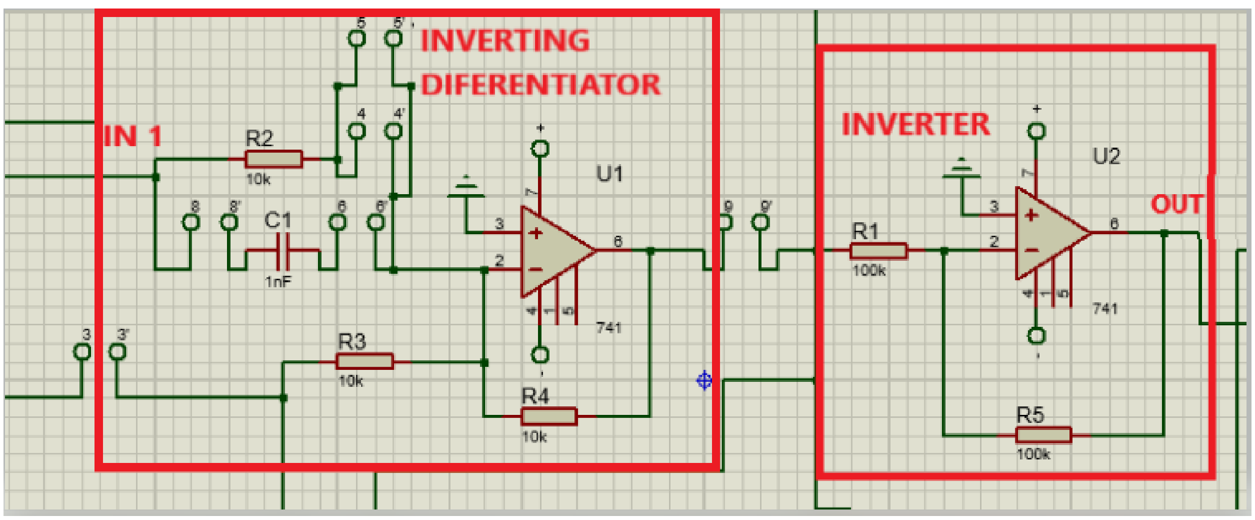

Figure 20: Differentiator circuit connection

After pressing 'DIFFERENTIATOR' push button, the terminal 6 – 6', 8 – 8' and 9 – 9' will be shorted. The terminal 6 – 6' and 8 – 8' will connect input 1 to the inverting terminal of the OP AMP U1 through the capacitor C1(=10nF). The output of the OP AMP U1 will pass to the OP AMP U2, as the 9 - 9' terminal is shorted. OP AMP U1 will serve as an inverting differentiator and OP AMP U2 will work as an inverter. The final output at the output terminal will be the differentiation of input 1.

Input output waveform:

1. By differentiating sine wave we get cosine wave with as output from the circuit.

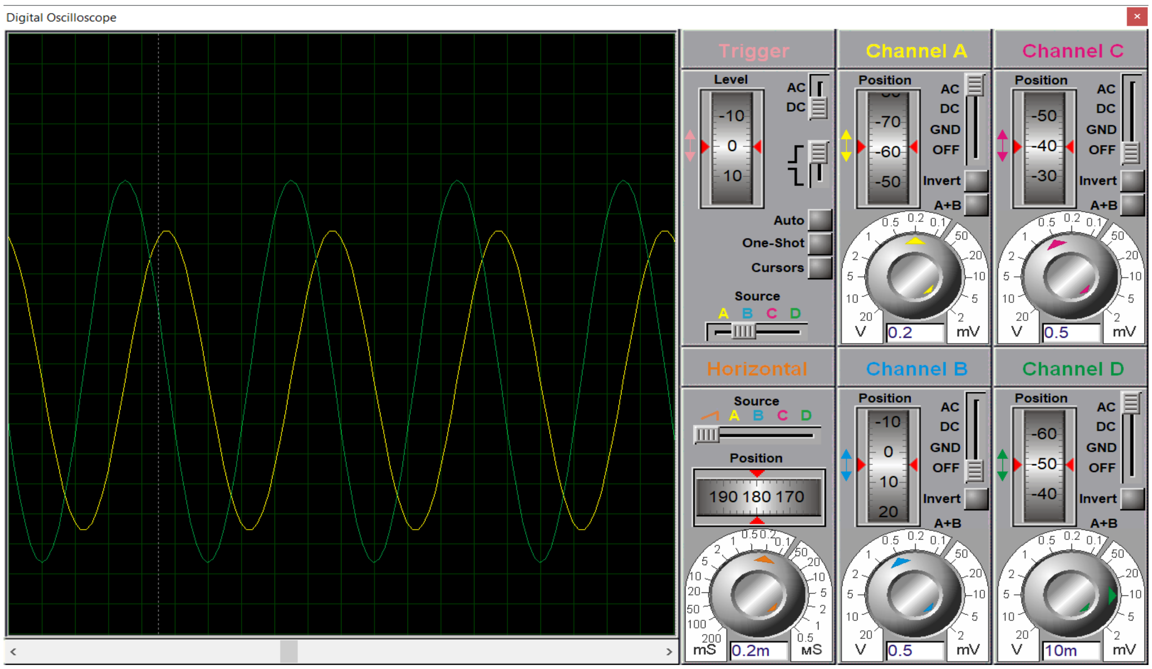

Figure: Oscilloscope window

2. When circuit input is triangle wave output should be pulse wave. We get pulse wave with some distortion where the slope of the triangle changes abruptly.

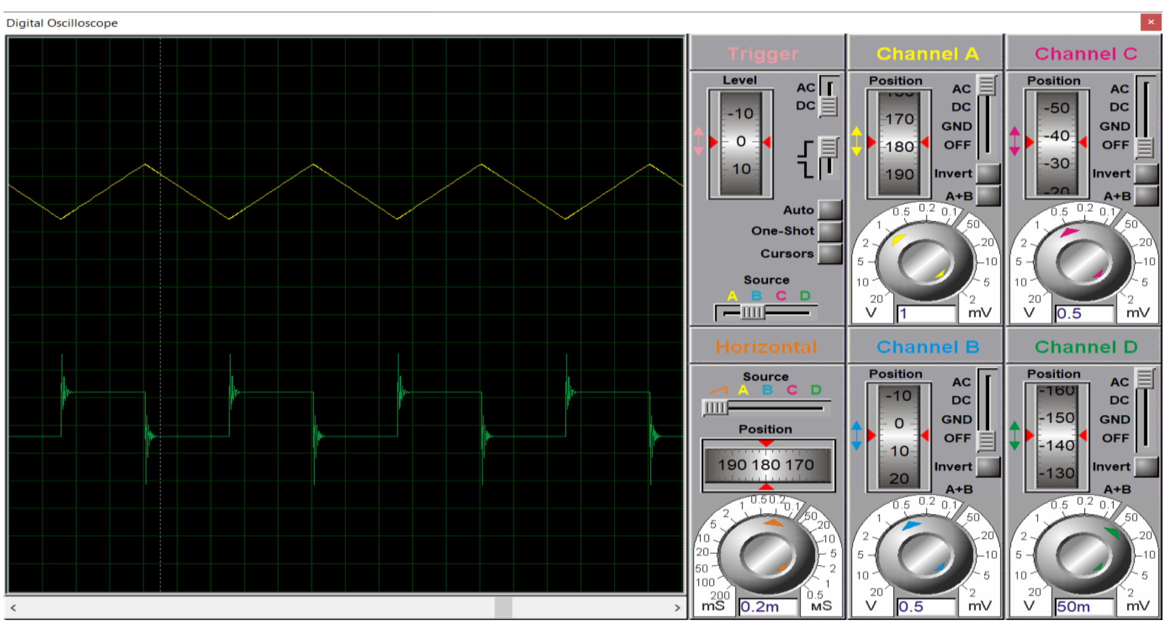

Figure 20: Oscilloscope window

3. Here, circuit input is a pulse wave and output wave is an impulse wave.

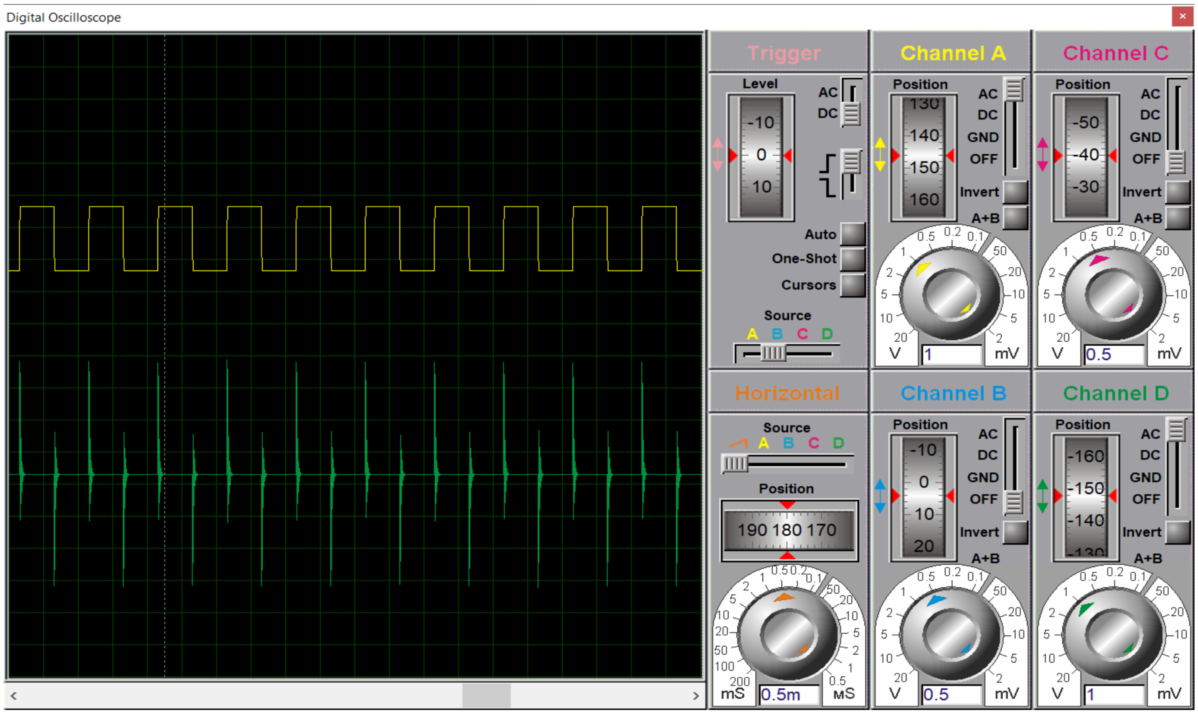

Figure 21: Oscilloscope window

Logarithmic circuit:

Working Principle:

A logarithmic amplifier, or a log amplifier, is an electronic circuit that produces an output that is proportional to the logarithm of the applied input to the resistor connected to its inverting terminal. This section discusses the op-amp based logarithmic amplifier in detail.

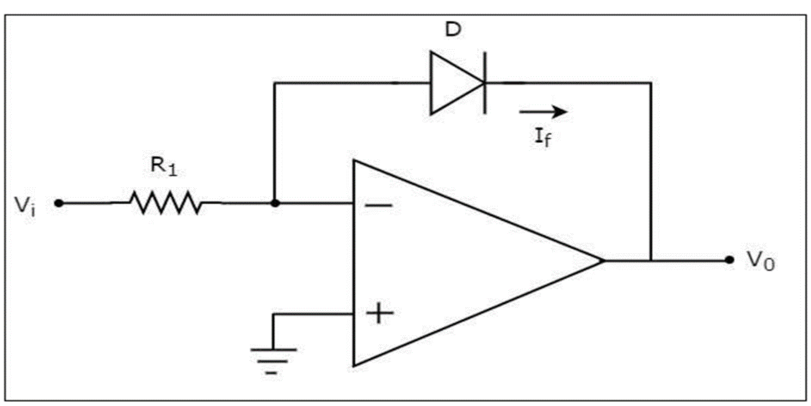

Figure 22: Inverting logarithmic circuit

The diode is connected in forward biasing. So, the diode current can be represented as:

$$i_D = I_s\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

Where I_s is the saturation current, V_D is the voltage drop for the diode. The V_T is the thermal voltage. The diode current can be rewritten with high biasing conditions,

$$e^{\frac{V_D}{\eta V_T}} >> 1$$

The i_1 expressed by,

$$i_1 = \frac{V_i}{R_1}$$

Since the voltage at inverting terminal of the op-amp is at virtual ground, hence, the output voltage is given by $V_0 = -V_D$

Noting that $i_1 = i_D$, we can write

$$i_1 = \frac{V_i}{R_1} = i_D = I_s e^{\frac{V_D}{\eta V_T}}$$

But, as noted earlier, $V_D = -V_0$ and so,

$$\frac{V_i}{R_1} = I_s e^{-\frac{V_0}{\eta V_T}}$$

Taking natural logarithm on both sides of this equation, we found

$$\ln\left(\frac{V_i}{I_s R_1}\right) = -\frac{V_0}{\eta V_T}$$

Or,

$$V_o = -\eta V_T \ln\left(\frac{V_i}{I_s R_1}\right)$$

The equation of the output voltage (V_0) of the logarithm amplifier contains a negative sign, which indicates that there is a phase difference of 180 ^{o}. Or,

$$V_o = \eta V_T \ln\left(\frac{I_s R_1}{R_1}\right)$$

Schematic:

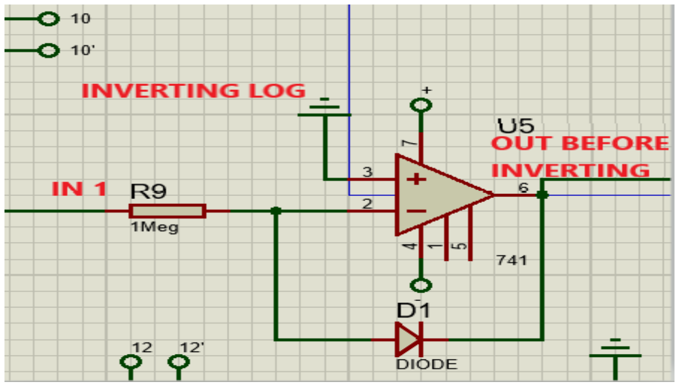

Figure 23: Log circuit connection

After pressing 'LOGARITM' push button, the terminal 10 – 10' and 14 – 14' will be shorted. The terminal 10 – 10' connect input 1 to the inverting terminal of the OP AMP U5 through the resistor R9(=1MΩ). The output of the OP AMP U5 will pass to the OP AMP U2, as the 14 – 14' terminal is shorted. OP AMP U5 will serve as an inverting logarithmic amplifier and OP AMP U2 will work as an inverter. The final output at the output terminal will be the log operation of input 1.

Input output waveform:

As we can see, the input is a sinusoid with amplitude of 3mV denoted by yellow, and the output is denoted by green.

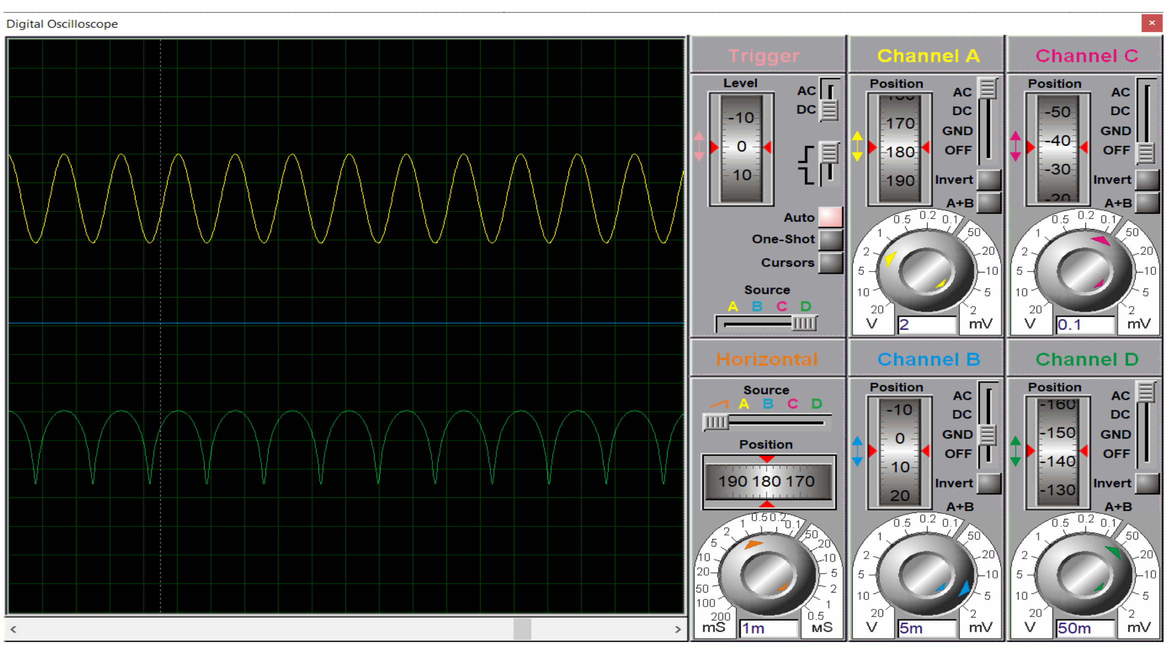

Figure 24: Oscilloscope window

Circuit output for DC input:

The output from the OP AMP is about 17.5 times less than actual output. So, we have changed the inverter resistance such a way that the gain is 17.5.

This has to be done by this method instead of multiplying the output with the gain factor because the voltmeter can be accurate till two digits after a decimal point. As the output is very low, we get a large deviation from the actual result.

The table given below shows output of logarithmic circuit for various input.

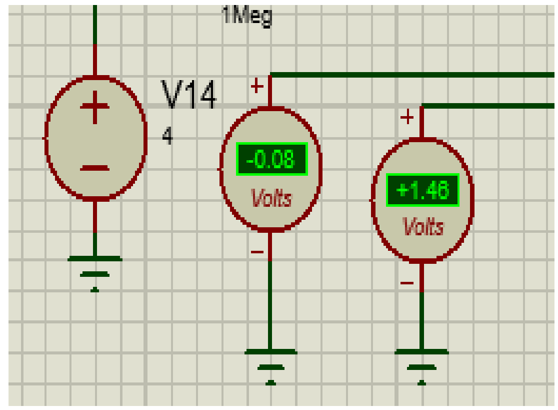

Figure 25: Log circuit input for DC voltage input

Table 1: Comparison between actual and experiment value of ln CKT

DC INPUT 1	Voltmeter output	Output with gain	Actual value	Error (in %)
4	0.08	1.46	1.386	5.31
5	0.09	1.62	1.609	0.66
6	0.09	1.77	1.792	-1.21
7	0.11	1.89	1.946	-2.87
8	0.11	2.00	2.079	-3.82
9	0.12	2.09	2.197	-4.9
10	0.12	2.18	2.302	-5.32

Anti-Logarithmic circuit:

Working Principle:

An anti-logarithmic amplifier, or an anti-log amplifier, is an electronic circuit that produces an output that is proportional to the anti-logarithm of the applied input. This section discusses the op-amp based anti-logarithmic amplifier in detail.

An op-amp based anti-logarithmic amplifier produces a voltage at the output, which is proportional to the anti-logarithm of the voltage that is applied to the diode connected to its inverting terminal.

The circuit diagram of an op-amp based anti-logarithmic amplifier is shown in the following figure:

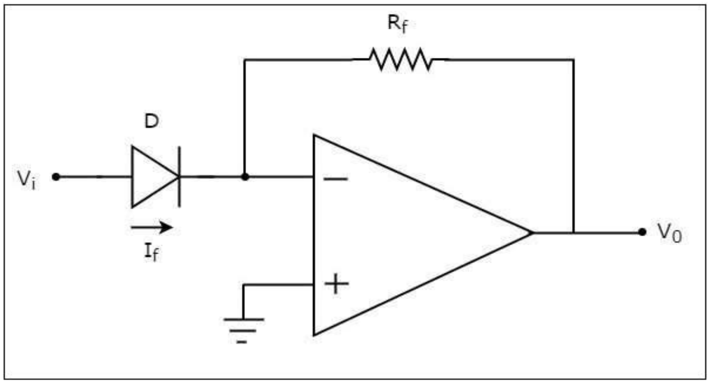

Figure 26: Inverting anti-logarithmic circuit

The compliment or inverse function of the logarithmic amplifier is ‘exponential’, anti-logarithmic or simply known as ‘antilog’. Consider the circuit given in the figure. The diode current is

$$i_D = I_s\left(e^{\frac{V_D}{\eta V_T}}\right)$$

Where, V_D is the diode voltage. According to the concept of virtual ground, V_1=0 as the non-inverting terminal is grounded as shown in the figure. Therefore, the voltage across the diode can be expressed as $V_D = V_i - V_1$ or $V_D = V_i$ Hence, the current through the diode is

$$i_D = I_s\left(e^{\frac{V_i}{\eta V_T}}\right)$$

Due to the ideal characteristics of an op-amp (infinite input impedance), the current flowing through the diode (i_D) flows along the feedback path through the resistor R, as we can observe in the figure.

Therefore, $i_D = i_2$

And, $V_0 = -i_2R = -i_DR$

Replacing i_D in the above equation we get

$$V_0 = -I_sR\left(e^{\frac{V_i}{\eta V_T}}\right)$$

The parameters n, V_T and I_S are constants (they are only dependent on the diode characteristics which are always constant for a particular diode). Therefore, if the value of the feedback resistor R is fixed, then the output voltage V_0 is directly proportional to the natural anti-logarithm (exponential) of the applied input voltage V_i. The above equation then can be simply represented as

$$V_0 = Ke^{a*V_i}$$

Where K = – I_SR and

$$a = \frac{1}{\eta V_T}$$

Therefore, we can notice that the anti-logarithmic op-amp produces its output signal as the exponential value of the input voltage signal applied.

The gain of the anti-log amplifier is given by the value of K that is equal to -I_SR.

The –Ve sign point out that there is a phase difference of 180degrees between the applied input s and the output of the anti-log amplifier.

Schematic:

After pressing ‘ANTILOG’ push button, the terminal 13 – 13’ and 16 – 16’ will be shorted. The terminal 16 – 16’ connects input 1 to the series resistors R15(=1kΩ) and R16(=25Ω). The voltage across the resistor R16 is taken as the input to the inverting terminal of the OP AMP U7 through a diode. It is done as an amplification factor ‘a’ is multiplied in exponential term. So, the output voltage is a function of ‘ax’.

$V_{out} = k*e^{ax}$

So, to cancel out the effect, we are using voltage amplifier which makes the input 1/a times smaller. The amplification factor ‘a’ can be expressed as,

$$a = \frac{1}{\eta V_T}$$

The output of the OP AMP U7 will pass to the OP AMP U2, as the 13-13’ terminal is shorted. OP AMP U7 will serve as an inverting anti-logarithmic amplifier and OP AMP U2 will work as an inverter. The final output at the output terminal will be the anti-log operation of input 1.

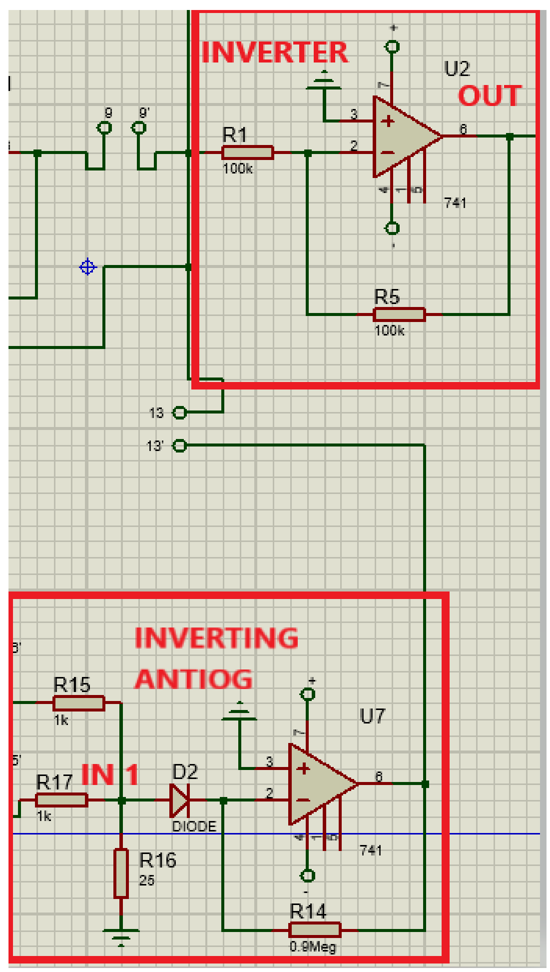

Figure 27: Anti-log circuit connection

Input output waveform:

As we can see, the input is a sinusoid with amplitude of 20 mV, denoted by yellow, and the output is denoted by green.

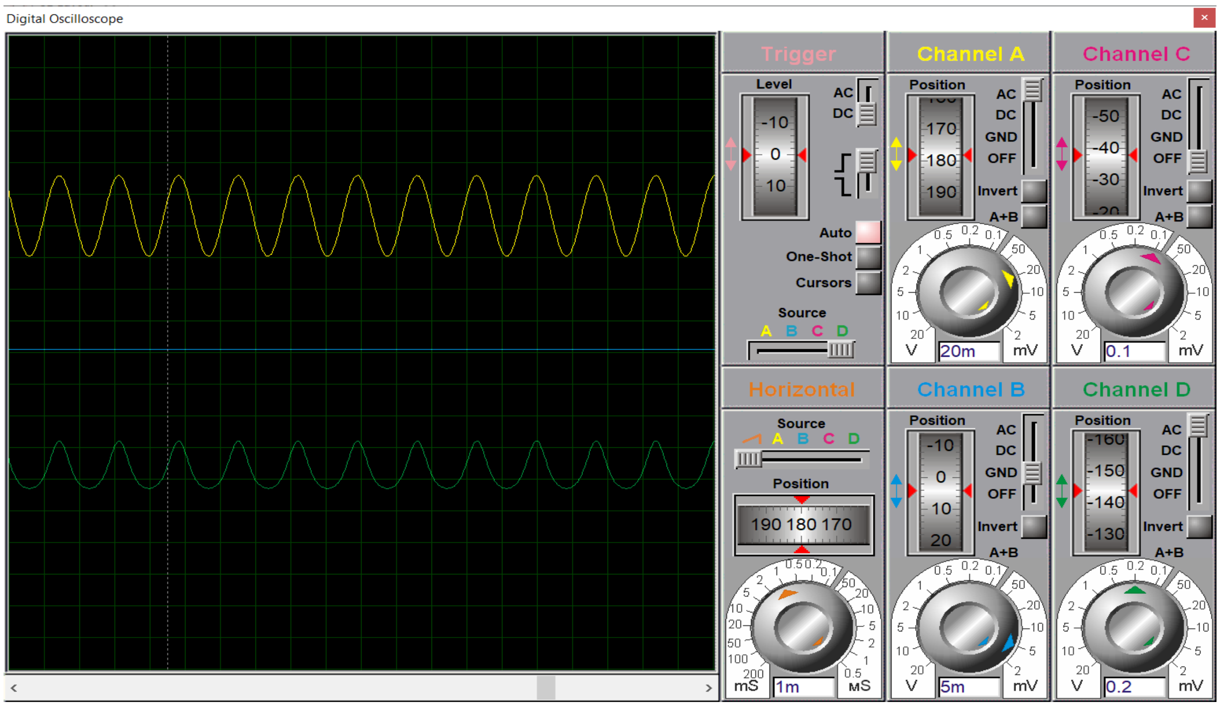

Figure 28: Oscilloscope window

Circuit output for DC input:

The output from the OP AMP is about 6 times less than actual output. So, we have changed the inverter resistance such a way that the gain is 6.

This can to be done by this method instead of multiplying the output with the gain factor. Here we manually calculated the output voltage with a factor of 6.

The table given below shows output of anti-logarithmic circuit for various input.

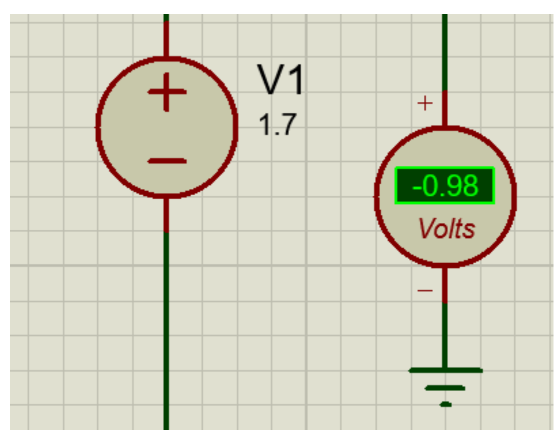

Figure 29: Anti-log circuit input for DC voltage input

Table 2: Comparison between actual and experiment value of anti-ln CKT

DC INPUT 1	Voltmeter output	Output with gain	Actual value	Error (in %)
1.0	0.43	2.59	2.718	-4.71
1.1	0.5	3.00	3.004	-0.2
1.2	0.57	3.43	3.320	3.31
1.3	0.65	3.88	3.669	5.74
1.4	0.72	4.35	4.055	7.3
1.5	0.81	4.84	4.482	7.99
1.6	0.89	5.36	4.953	8.21
1.7	0.98	5.90	5.474	7.78
1.8	1.08	6.47	6.049	6.95
1.9	1.18	7.07	6.686	5.75
2.0	1.28	7.69	7.389	4.07

Multiplier:

Working Principle:

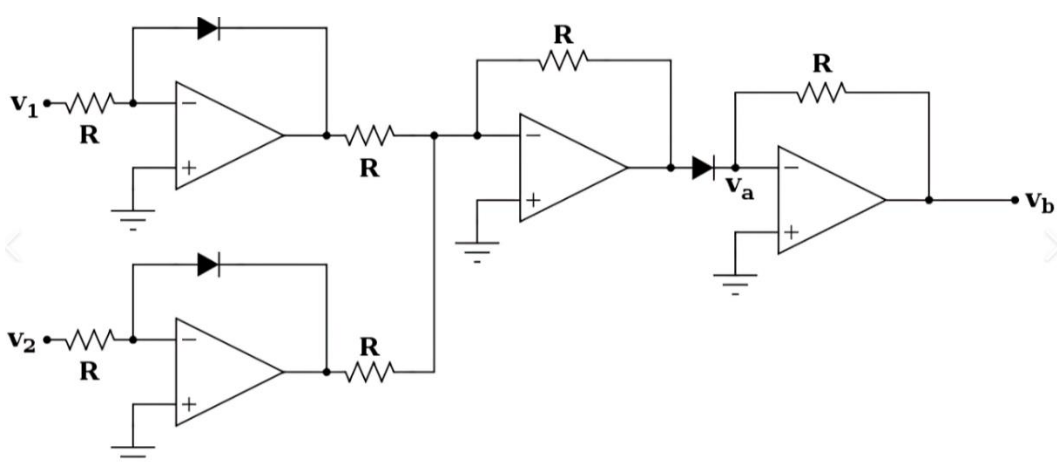

Figure 30: Multiplier circuit

Here, for the first input, the input goes to a logarithmic circuit. So, output of the first OP-AMP is lnV1.

For the second input, the input goes to a logarithmic circuit like the first input. So, output of the second OP-AMP is lnV2.

Then these two outputs go to an inverting summer circuit and the output of the inverting summer is = lnV1 + lnV2 = ln (V1 × V2)

Then this output goes through an exponential circuit. The output of the exponential amplifier is = $e^{\ln(V1 \times V2)}$ = (V1 × V2).

Schematic:

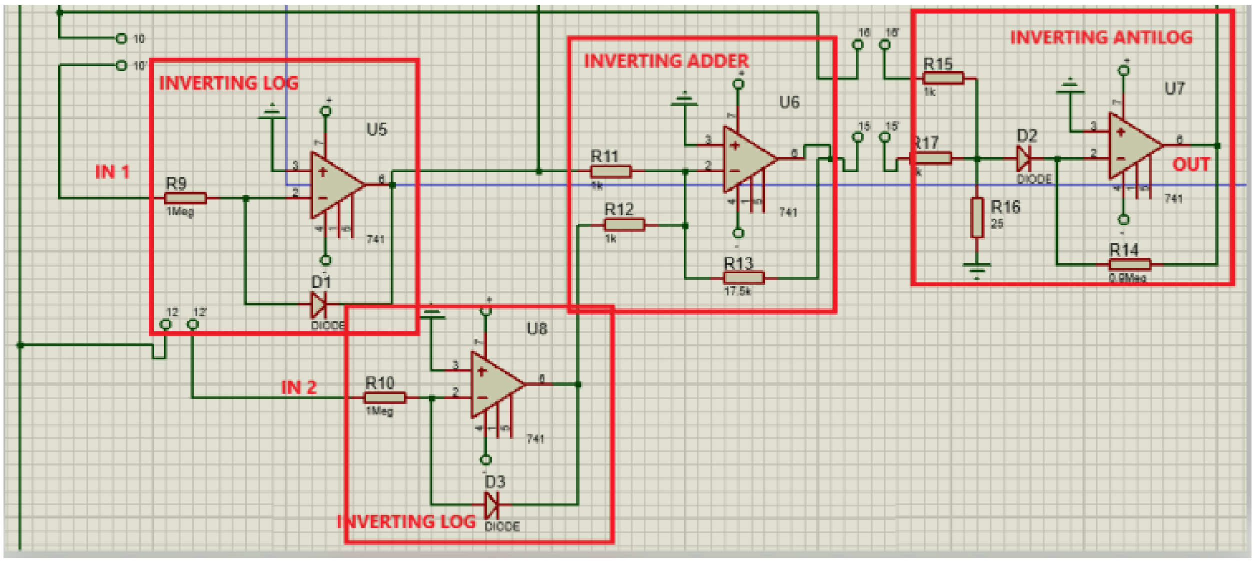

Figure 31: Multiplier circuit connection

After pressing 'MULTIPLIER' push button, the terminal 10 – 10', 12 – 12', 13 – 13' and 15 – 15' will be shorted. 10 – 10' and 12 – 12' passes input signal 1 and input signal 2 to OP AMP U5 and OP AMP U8 accordingly, both op amps operate as inverting logarithmic circuit. The outputs of the both op amps are passed to OP AMP U6, which then acts as an inverting adder.

The terminal 15 – 15' connects the output of the adder to the series resistors R15(=1kΩ) and R16(=25Ω). The voltage across the resistor R16 is taken as the input to the inverting terminal of the OP AMP U7 through a diode. It is done as an amplification factor 'a' is multiplied in exponential term. So, the output voltage is a function of 'ax'. Here x = c*ln(V1*V2)

$V_{out} = k*e^{ax}$

So, to cancel out the effect, we are using voltage amplifier which makes the input 1/a times smaller. The amplification factor 'a' can be expressed as,

$$a = \frac{1}{\eta V_T}$$

The output of the OP AMP U7 will pass to the OP AMP U2, as the 13-13' terminal is shorted. OP AMP U7 will serve as an inverting anti-logarithmic amplifier and OP AMP U2 will work as an inverter. The final output at the output terminal will be the multiplication of input signal 1 with input signal 2.

Input output waveform:

1. As we can see, both input is a sinusoid with amplitude of 5mV & 20mv respectively, denoted by yellow, and we get the output wave as displayed in oscilloscope is a denoted by green.

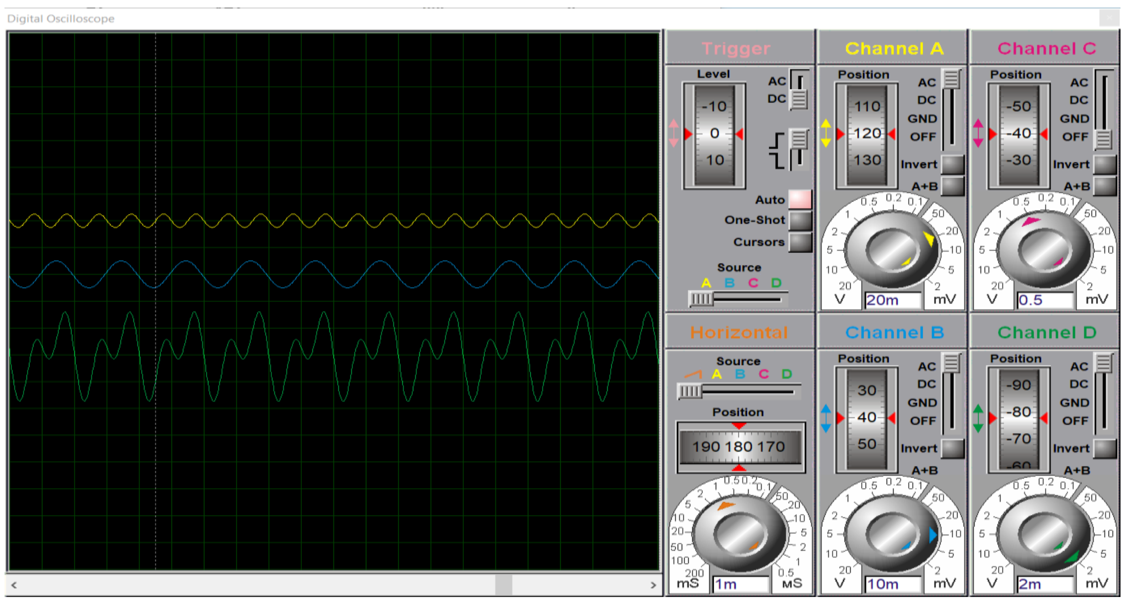

Figure 32: Oscilloscope window

2. Here, the first input is a sinusoid with amplitude of 5 mV, denoted by yellow, 2nd input is pulse train with amplitude of 5mV and the output denoted by green.

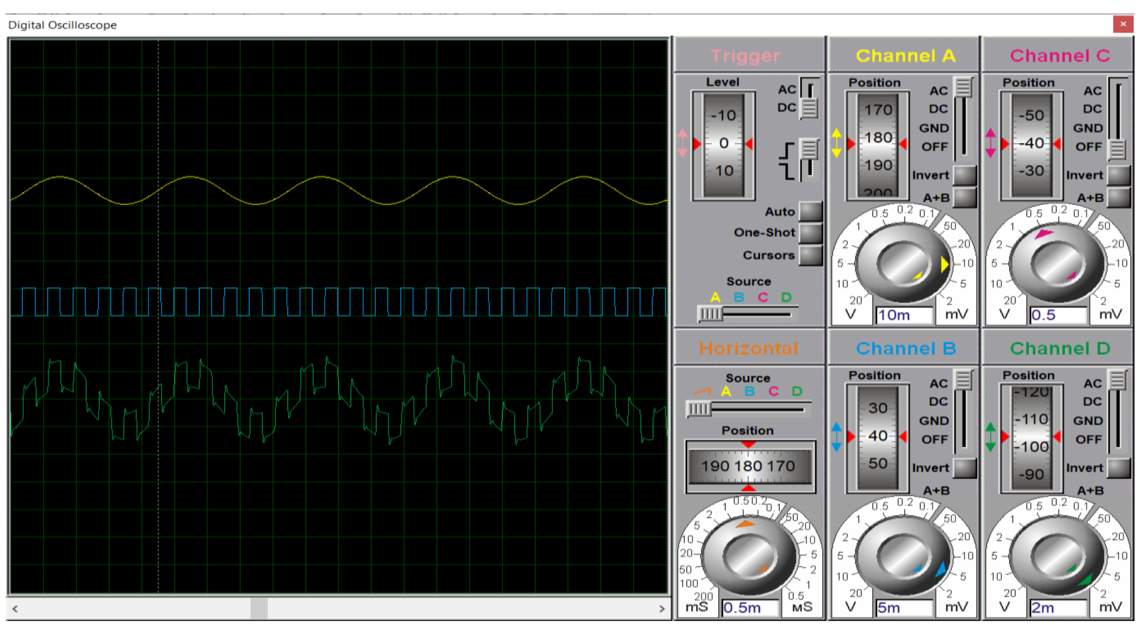

Figure 33: Oscilloscope window

Circuit output for DC input:

At first sight, the output may seem to be mismatching the actual result. But after close observation, it can be stated that the output voltage is increasing almost linearly with respect to our expected multiplication. If we plot the points in the MATLAB and find the best fit curve. The code is written:

```
>> x = [2 3 4 5 6 7 8 9];
>> y = [0.87 1.11 1.22 1.38 1.52 1.65 1.77 1.85];
>> polyfit(x,y,1)

ans =

    0.1380    0.6624
```

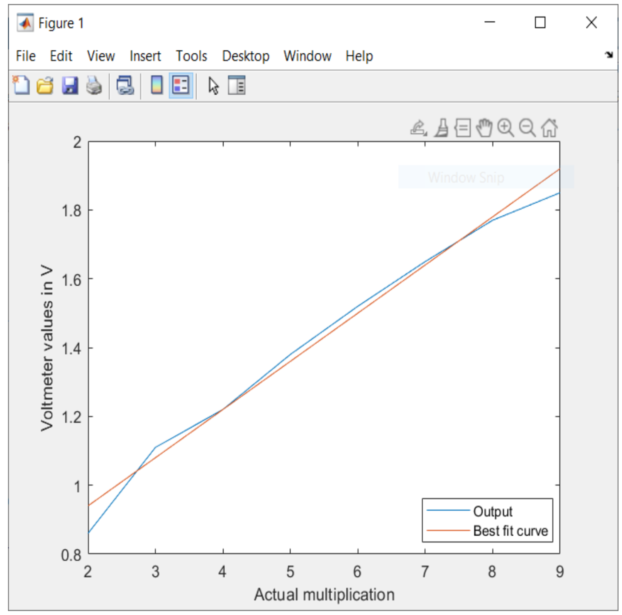

Figure 34: Matlab plot

We get the equation mentioned below.

y = 0.14 x + 0.66 …………(1)

or, x = (y-0.66)/0.14

Here, y is the output voltage and x is the actual result.

The constant of 0.66 in the equation (1) can be interpreted as the effect of input bias current. Since the resistance in feedback is high, the bias current through the inverting terminal has significant effect in the output voltage. And the slope of equation (1) is the gaining factor which is being multiplied throughout the operation.

Table 3: Comparison between actual and experiment value of multiplier CKT

V1	V2	Voltmeter output	Output without gain	Actual value	Error (in %)
1	3	1.11	3.21	3	7.0
2	2	1.22	4	4	0.0
2	2.5	1.38	5.14	5	2.8
2	3	1.52	6.14	6	2.33
2	3.5	1.65	7.07	7	1
2	4	1.77	7.93	8	-0.88
3	3	1.85	8.5	9	-5.55

Discussion:

In this experiment of circuit simulation, we mainly focused on some linear and nonlinear operations of an operational amplifier. During the simulation, linear operations such as addition, subtraction, integration, differentiation circuits work correctly under DC and AC signals. Though, there is some minor distortion because of the deviation of an ideal op-amp to a practical op-amp.

But, in the case of nonlinear operations like log and anti-log circuits, distortion was greater and error was diverging. Some possible reasons for this distortion are the saturation current of diode, offset voltage of non-ideal op-amp, and also finite slew rate. Though multiplication is a linear operation, but we implement multiplication circuit based on log and anti-log circuits. So, errors occurred during these operations.

As the project name 'analog calculator' suggests, users can do calculations using it. Our project is handy for both AC and DC inputs and additionally, users can easily vary input signal (sine wave, pulse train, triangle wave, saw tooth and also DC signal with desired frequencies). So, users can visualize the effect of input after doing an operation on these signals.

We tried to build this circuit by using fewer components to make it cheaper in implementation. To do this we had to use more switches by which there was some leakage current that distort our output signals. Also, we deal with AC signal very carefully and our output results for DC and AC signals were satisfied. So, we see that there were a few limitations of our project due to the software restrictions and op-amp non ideal characteristics. Overall, the result of our project was satisfactory.