**Experiment 5**

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Course Name: Introduction to Electronic Laboratory Course Number: (EC29003)

**Aim:** Studies on Circuits using Op-Amps

**Procedure:**

**(Taking open loop gain as 100k)**

* DC Gain:

1. Op-Amp in Inverted Configuration:

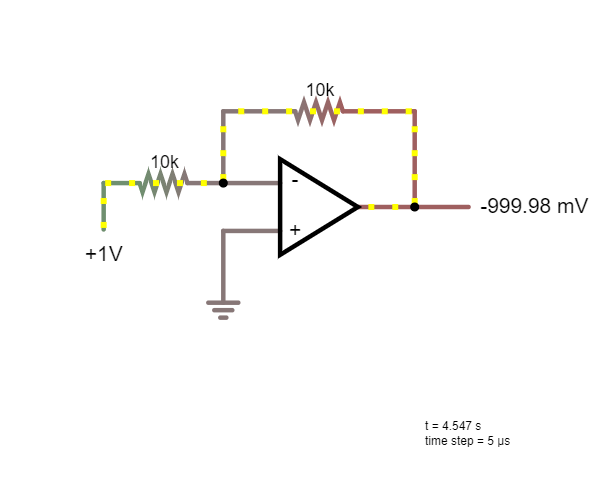
Since and , the gain

Thus, by inputting a voltage of 1 V, we expect a theoretical output voltage of -1 V.

The output voltage via Falstad is -999.98 mV.

This voltage has a smaller magnitude than the expected voltage.

Thus, observed gain =

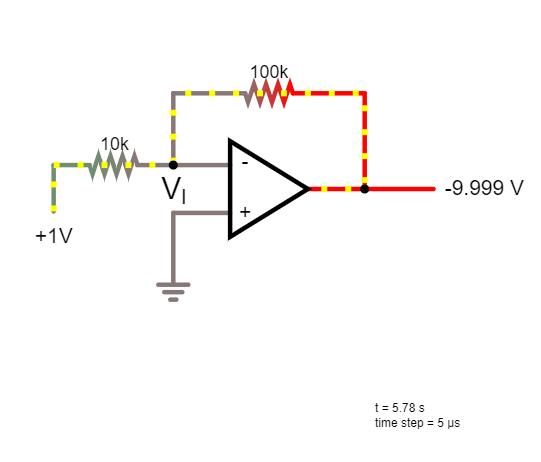


1. and . The gain is

Thus, by inputting a voltage of 1 V, we expect a theoretical output voltage of -10 V.

The output voltage via Falstad is -9.999 V.

Thus, observed gain =



The measured value of , while . Thus, . In fact, we can consider to be 0 V (Since . And by doing this, we can consider to be essentially grounded. This is called as virtual ground with respect to .

1. On measuring in Falstad, , from the circuit used in the point 2 above.

Now for calculating input resistance, we have the formula,

Also, we have

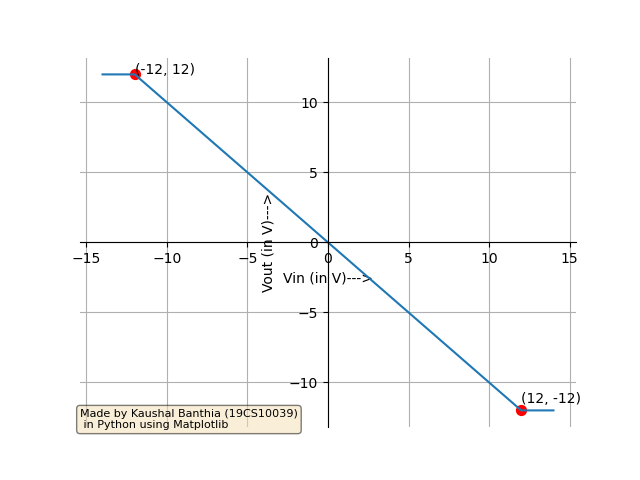
The extra 1 that appears in the observed input resistance can be due to a resistance present in the voltage source, which is labelled as .

1. Now, we calculate the gain produced by the Op-Amp, for various values of and . (for )

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| (in ) | (in) | (in V) | Gain | (in A) | (in V) | (in) |
| 10 | 10 | -0.99998 |  | 99.999 | 10 | 10000 |
| 27 | 10 | -2.7 | -2.7 | 99.997 | 26.999 | 10000.3 |
| 47 | 10 | -4.7 | -4.7 | 99.995 | 46.997 | 10000.5 |
| 100 | 10 | -9.999 | -9.999 | 99.99 | 99.989 | 10001 |

1. Now, we try to make the Voltage Transfer Characteristics () of the Op-Amp, for various values of input voltage. (For )

|  |  |
| --- | --- |
| (in V) | (in V) |
| -14 | 12 |
| -12 | 12 |
| -10 | 10 |
| -5 | 5 |
| -2 | 2 |
| 0 | 0 |
| 2 | -2 |
| 5 | -5 |
| 10 | -10 |
| 12 | -12 |
| 14 | -12 |

From the above graph, we can easily see that the output voltage becomes constant (or saturates) after the magnitude of the input voltage crosses the magnitude of the supplied voltage () (in this case, = 12 V)

Before crossing this point, we had the relation (k = -1 here)

After passing these saturation points,

(if ) and

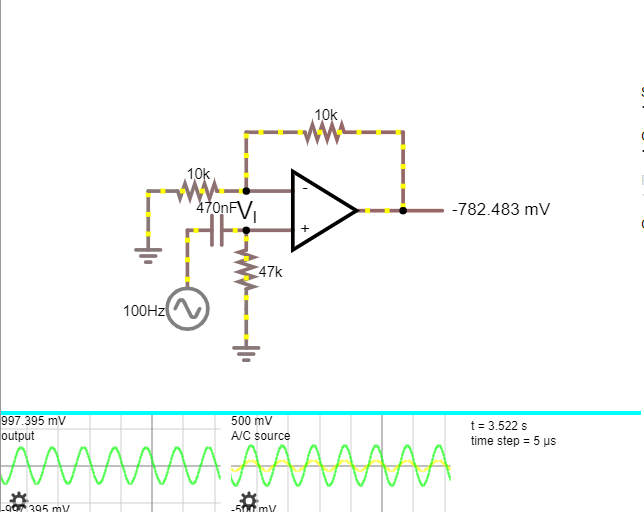
(if )

* NIV Amplifier:

1. (a) and . The theoretical gain is

and sine wave

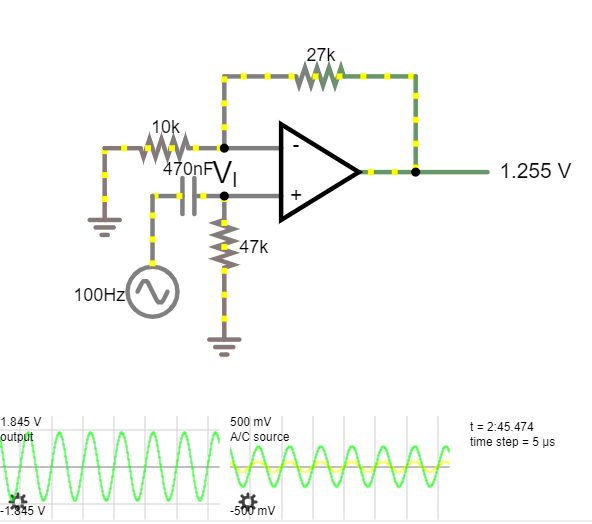
The output voltage in Falstad is 997.395 mV

Thus, the observed gain is

(b) and . The theoretical gain is

and sine wave

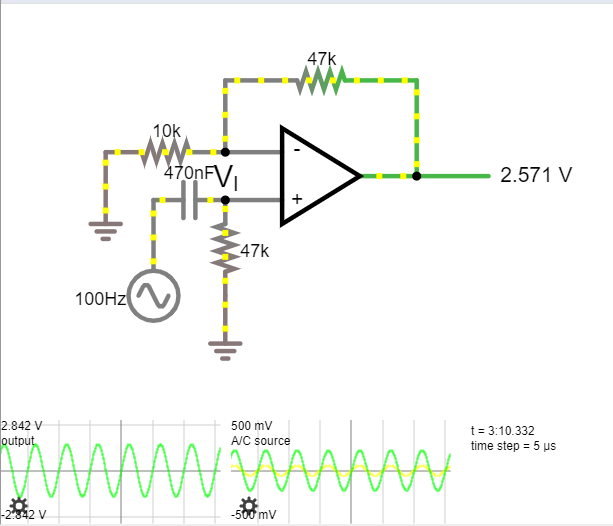
The output voltage in Falstad is 1.845 V

Thus, the observed gain is

(c) and . The theoretical gain is

and sine wave

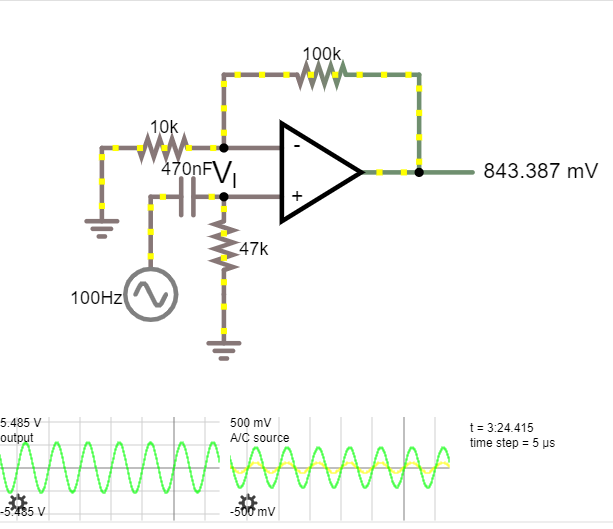
The output voltage in Falstad is 2.842 V

Thus, the observed gain is

(d) and . The theoretical gain is

and sine wave

The output voltage in Falstad is 5.485 V

Thus, the observed gain is

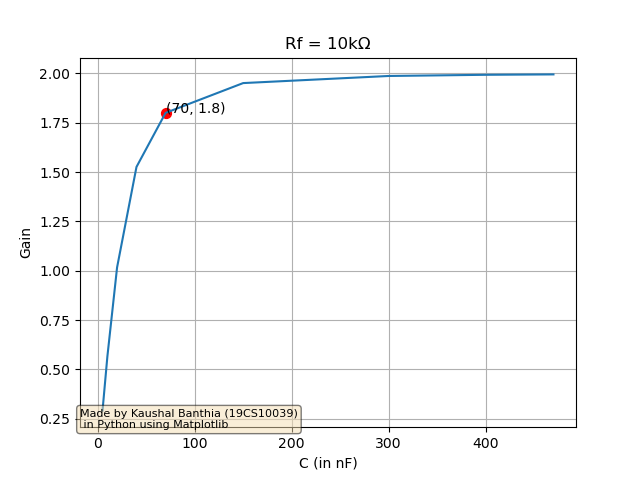
In all the cases (a), (b), (c) and (d), the observed and the theoretical gains were off by a very small margin. This is due to the voltage drop across the capacitor attached to the voltage source in series

1. (a) Gain for Different values of Capacitances:

and . The theoretical gain is

and sine wave

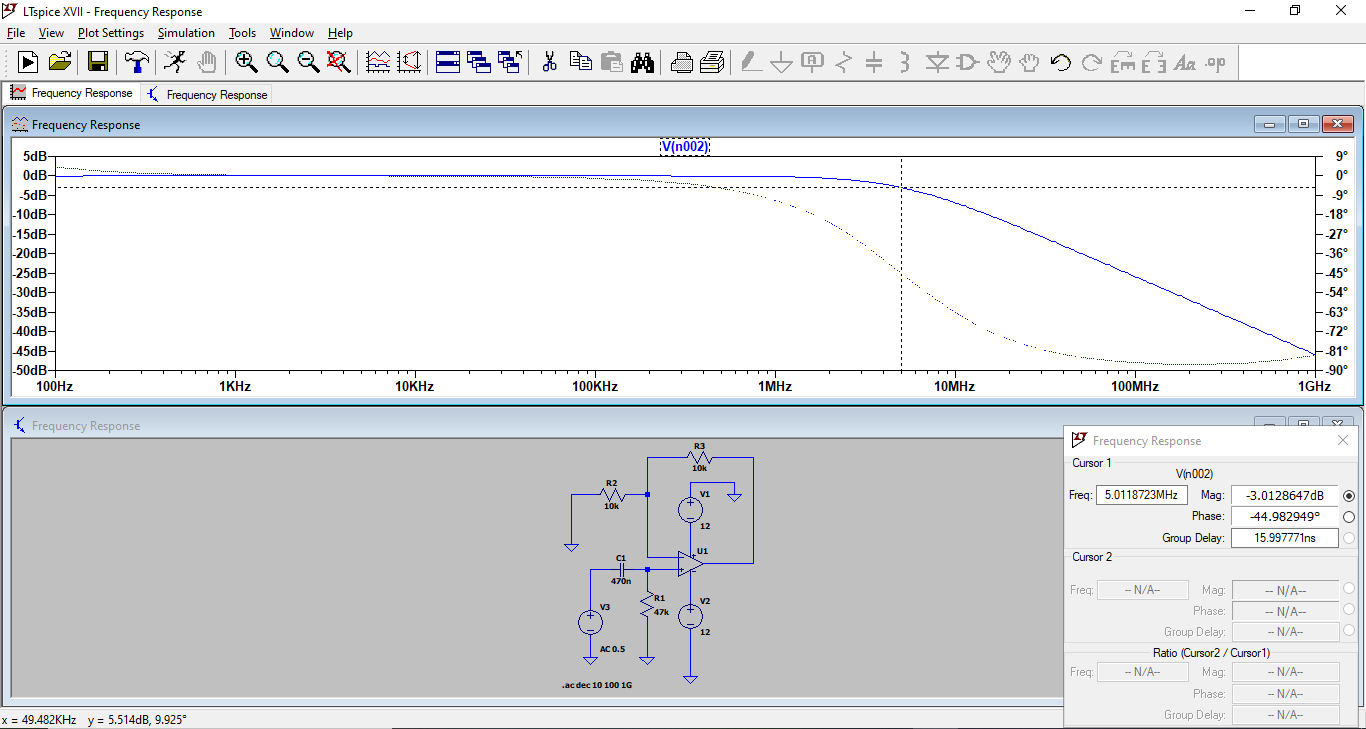
|  |  |  |
| --- | --- | --- |
| C  (in nF) | (in V) | Gain |
| 470 | 997.395 | 1.995 |
| 400 | 996.416 | 1.993 |
| 300 | 993.67 | 1.987 |
| 150 | 975.432 | 1.951 |
| 70 | 900.182 | 1.800 |
| 40 | 763.214 | 1.526 |
| 20 | 508.535 | 1.017 |
| 10 | 283.213 | 0.566 |
| 5 | 146.068 | 0.292 |



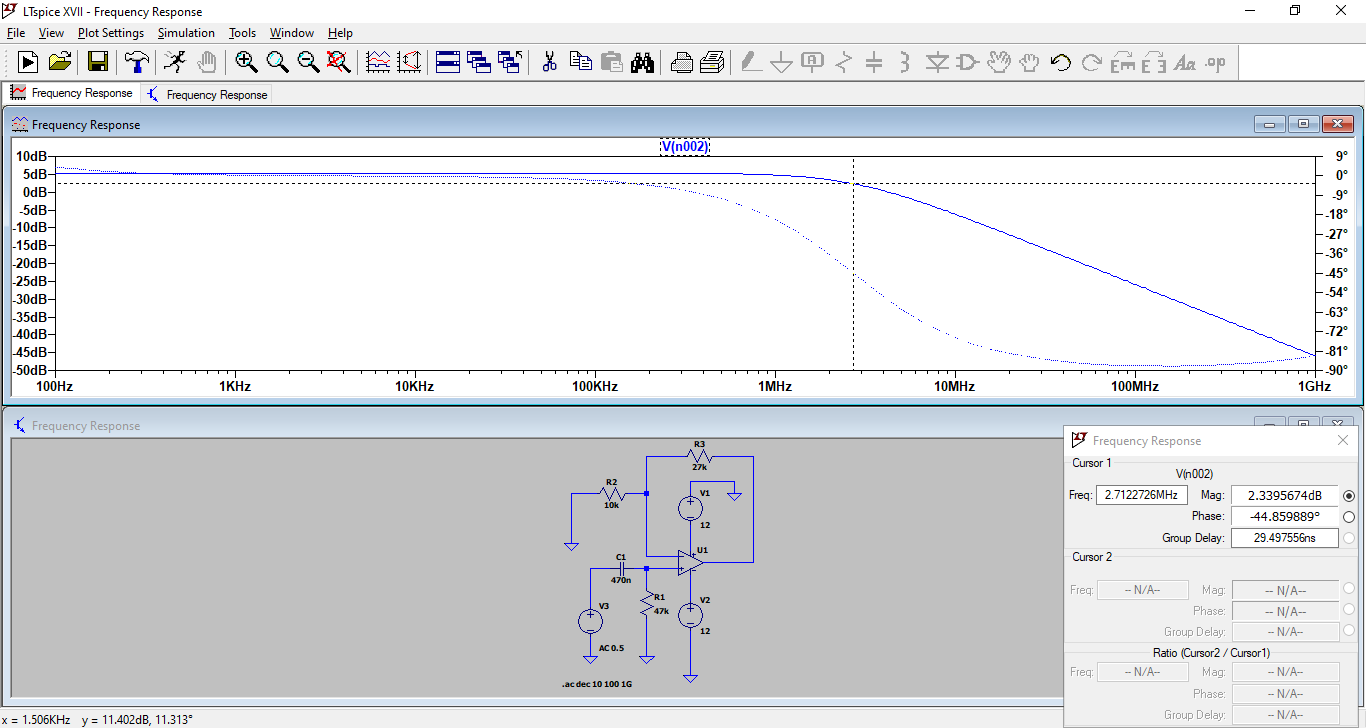
As we can see from the graph and the table above, the gain starts decreasing when C becomes less than 70 nF. This is because, as the value of C decreases the value of the reactance increases, since reactance of a capacitor is inversely proportional to its capacitance. This increase in its reactance causes a higher voltage drop across it, thus leading to a lower output voltage and thus a lower gain. Beyond a certain value of capacitance, the decrease in gain becomes very prominent.

(b) Frequency Response:

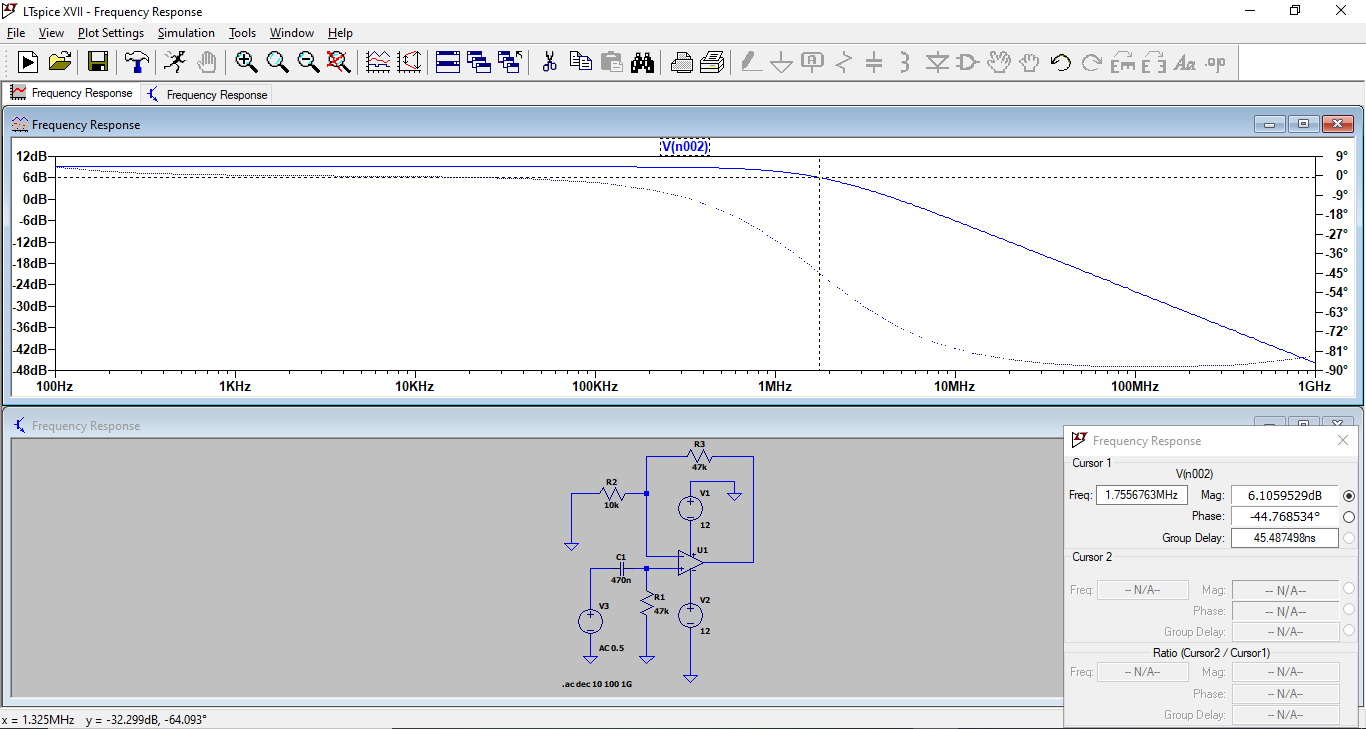
Using LTSpice for this part, because of some fault in Falstad that lead to an almost constant gain for all frequencies.

For

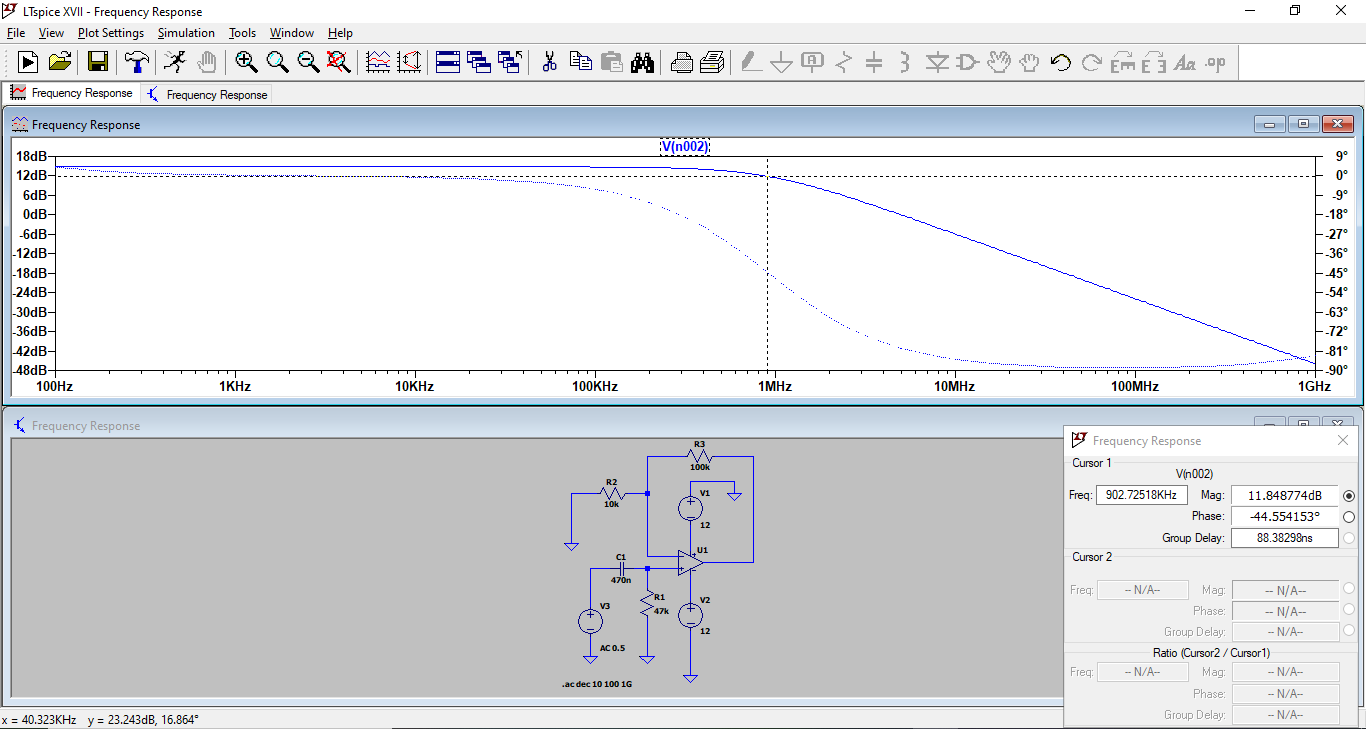
From the above diagram, the -3dB roll off frequency comes out to be 5.012 MHz.

For

From the above diagram, the -3dB roll off frequency comes out to be 2.712 MHz.

For

From the above diagram, the -3dB roll off frequency comes out to be 1.756 MHz.

For

From the above diagram, the -3dB roll off frequency comes out to be 0.903 MHz.

From the above 4 cases, we have observed, that when gain () increases, correspondingly, the roll of frequency decreases. In fact, we can observe a relation in this trend, which is that,

Where, k is the closed loop gain of the Op-Amp, and the is the roll off frequency corresponding to that gain.

|  |  |  |  |
| --- | --- | --- | --- |
| (in | k  () | (in MHz) | Constant  (in MHz) |
| 10 | 2 | 5.012 | 10.024 |
| 27 | 3.7 | 2.712 | 10.034 |
| 47 | 5.7 | 1.756 | 10.009 |
| 100 | 11 | 0.902 | 9.933 |

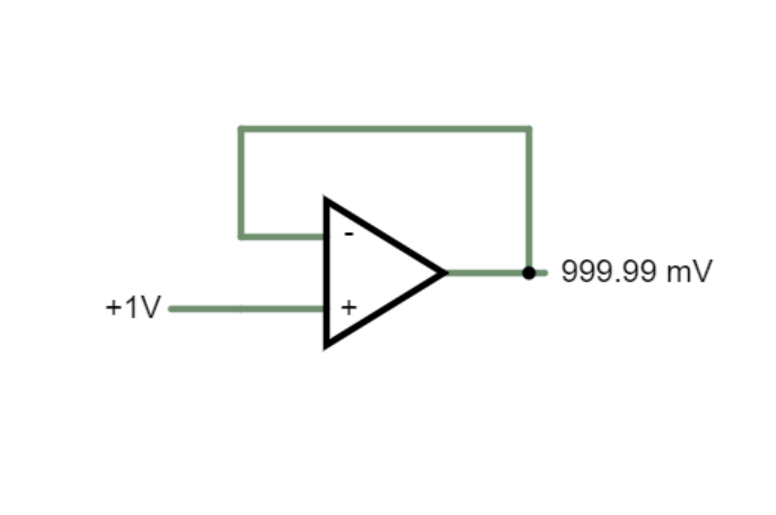
Thus, we can say that the value of the constant is approximately 10 MHz

This constant is also called as the Gain Bandwidth Product (The gain bandwidth product is the product of the Op-Amp’s bandwidth and the gain at which the bandwidth is measured).

* Voltage Follower:

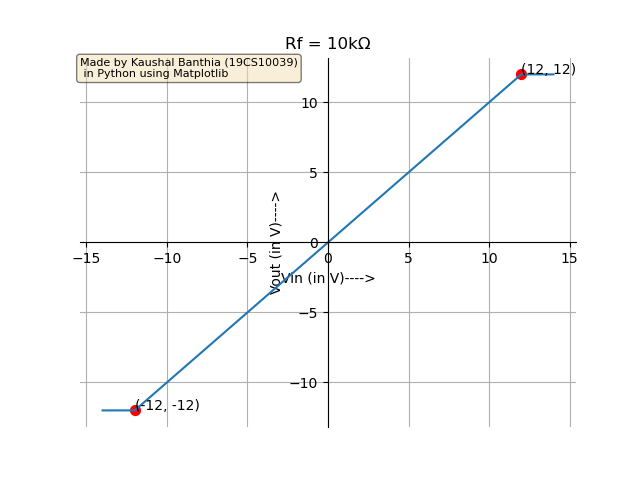
For , the output voltage comes out to be 999.99 mV.

So, we can effectively say that, the output voltage is equal to the input voltage (Characteristic of voltage follower circuit).



Now, we check for different voltages, to find the maximum and the minimum voltages for which the voltage follower circuit works perfectly.

|  |  |
| --- | --- |
| (in V) | (in V) |
| -14 | -12 |
| -12 | -12 |
| -10 | -10 |
| -5 | -5 |
| -2 | -2 |
| 0 | 0 |
| 2 | 2 |
| 5 | 5 |
| 10 | 10 |
| 12 | 12 |
| 14 | 12 |

From the above graph, we can easily see that the output voltage becomes constant (or saturates) after the magnitude of the input voltage crosses the magnitude of the supplied voltage () (in this case, = 12 V)

Before crossing this point, we had the relation (k = 1 here)

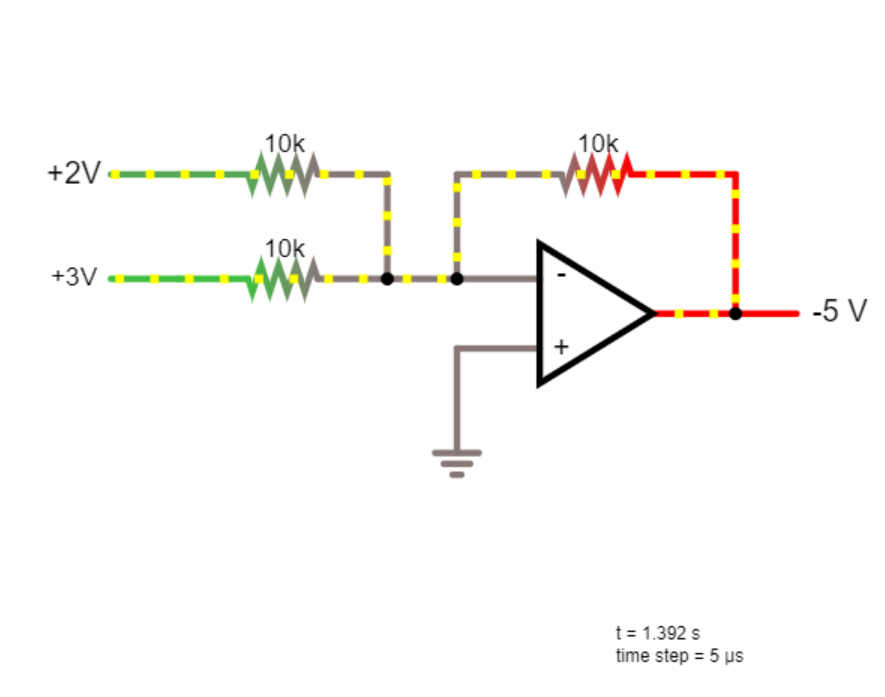
After passing these saturation points,

(if ) and

(if )

* Adder:

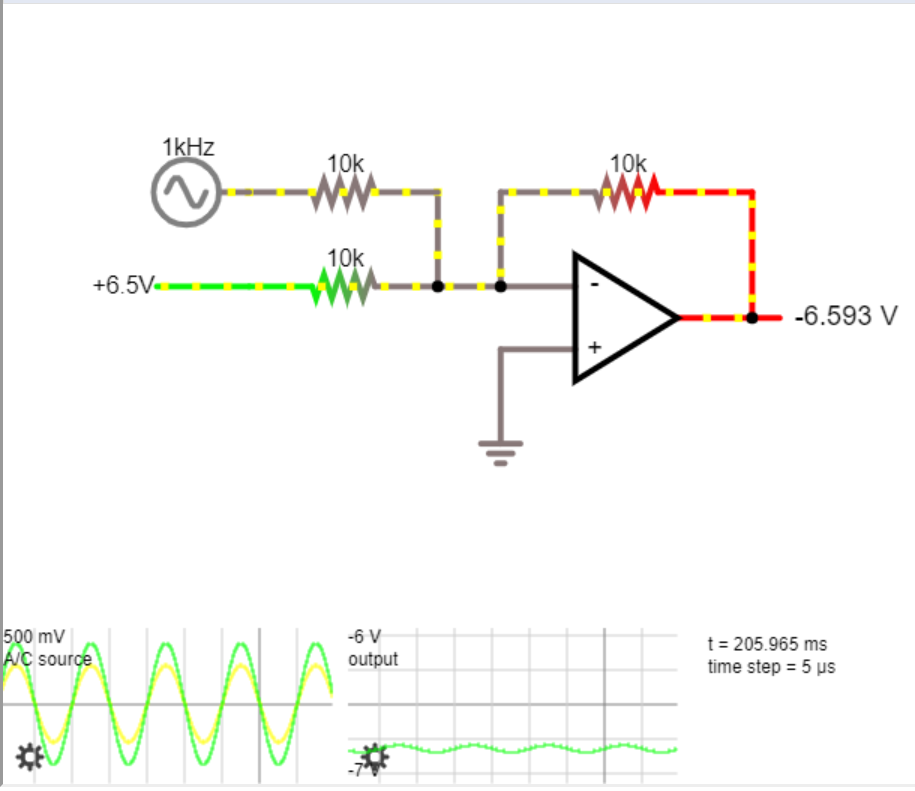
1. For , the output should be -5 V.

We verify this from Falstad.

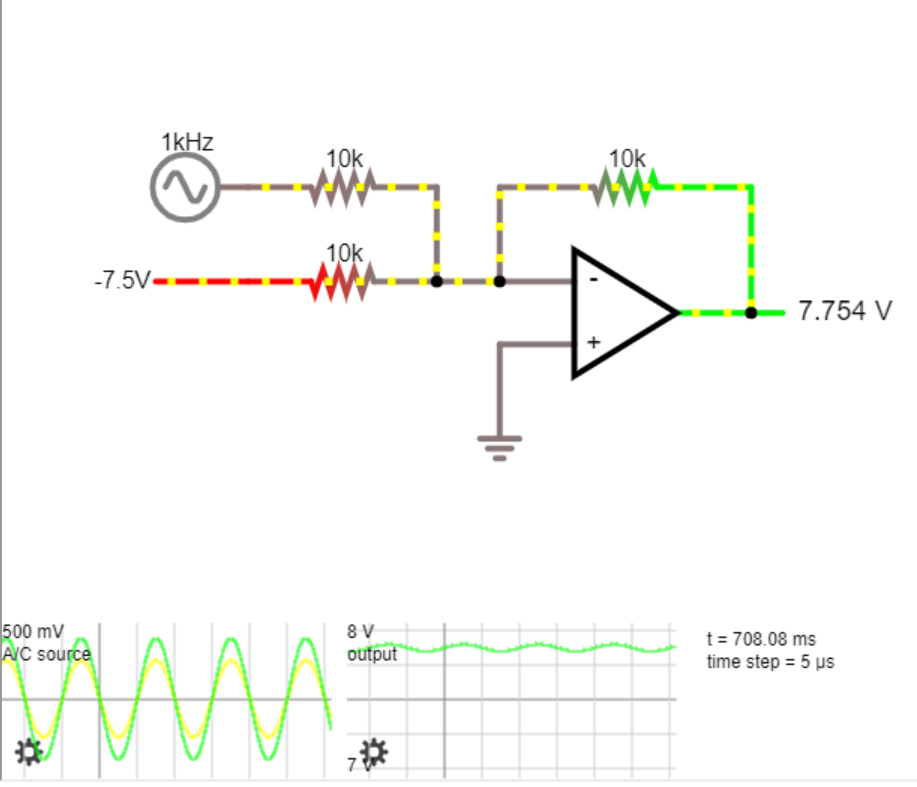
Even in Falstad, we get an output of 5 V.

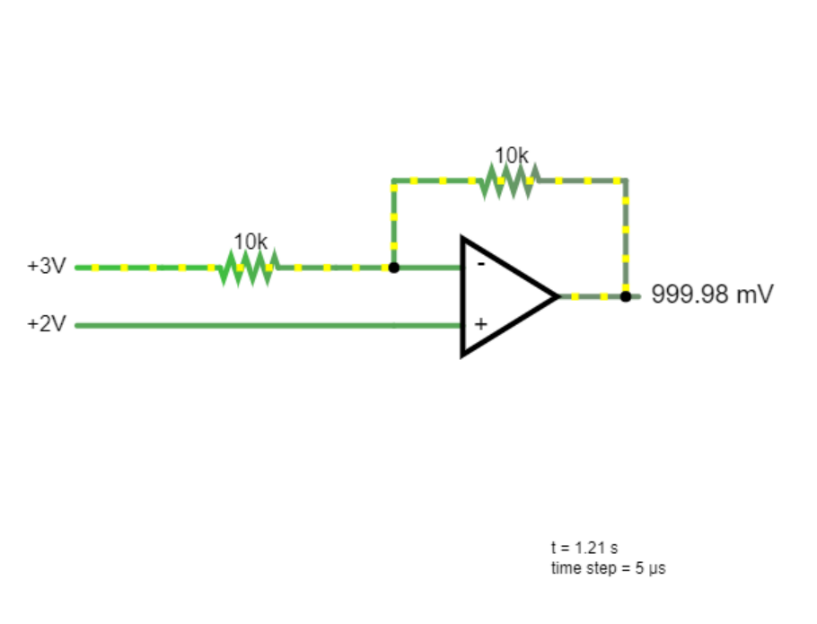
1. (a) Summing Amplifier:

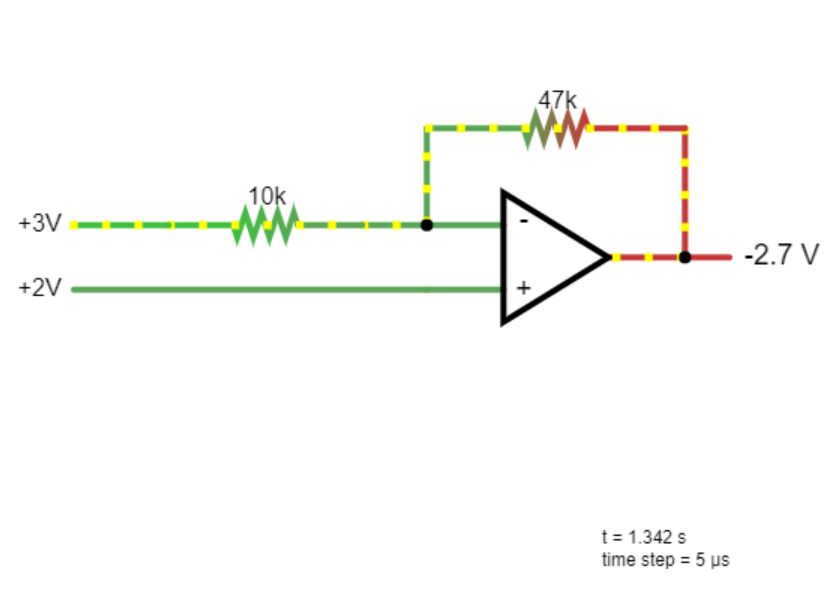
For , and sine wave, the output is a sine wave with maximum voltage of -6 V and minimum voltage of -7 V, with same frequency.

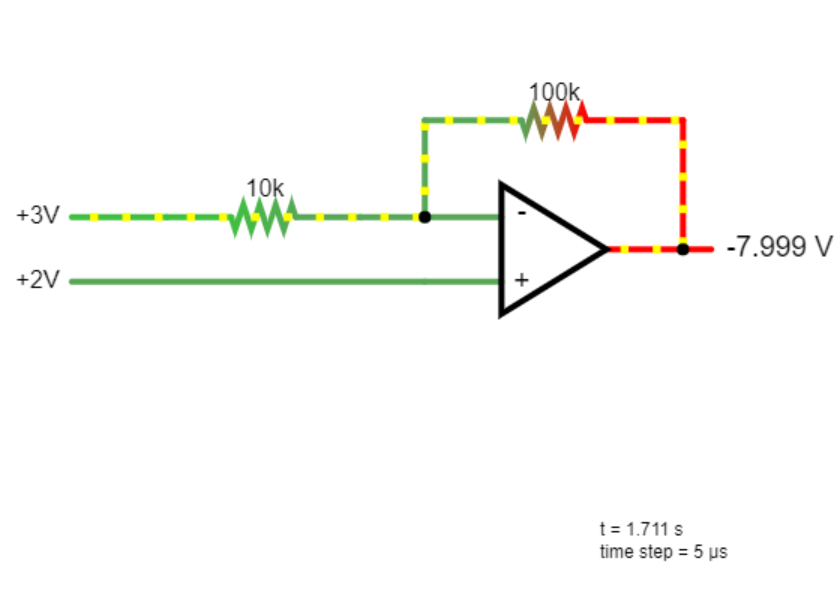
Basically,

1. For , and sine wave, the output is a sine wave with maximum voltage of 8 V and minimum voltage of 7 V, with same frequency.

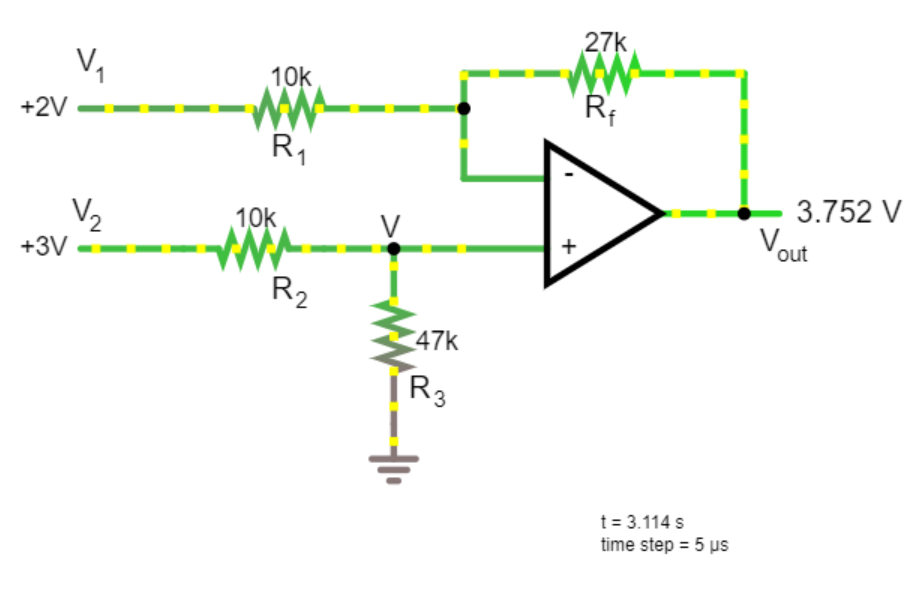
Basically,

* 1. (a) For , , and

 (b) For , , and

 (c) For , , and

2. Differential Amplifier:

(a) For , , , , and

Let Current through be (since an Op-Amp doesn’t take any input current) and through be (since an Op-Amp doesn’t take any input current).

Then we get,

(By voltage divider formula) => (1)

(By using the concept of Virtual Shorting for Op-Amps and KVL)

(From (1)) => (2)

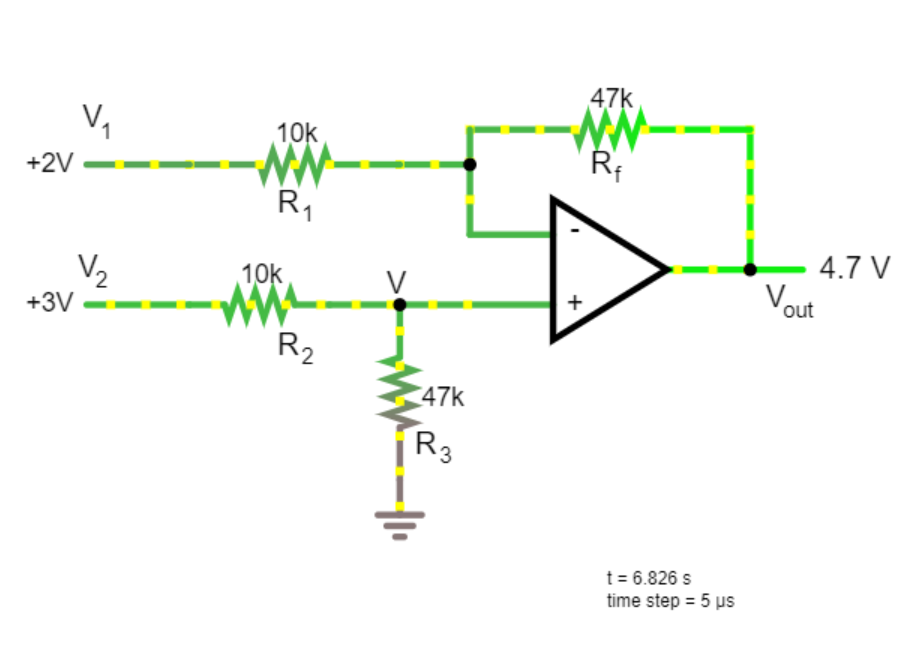
(By using KVL)

(From (1) and (2))

(Rearranging Terms)

**Formula:**

Now, we input the values in this formula

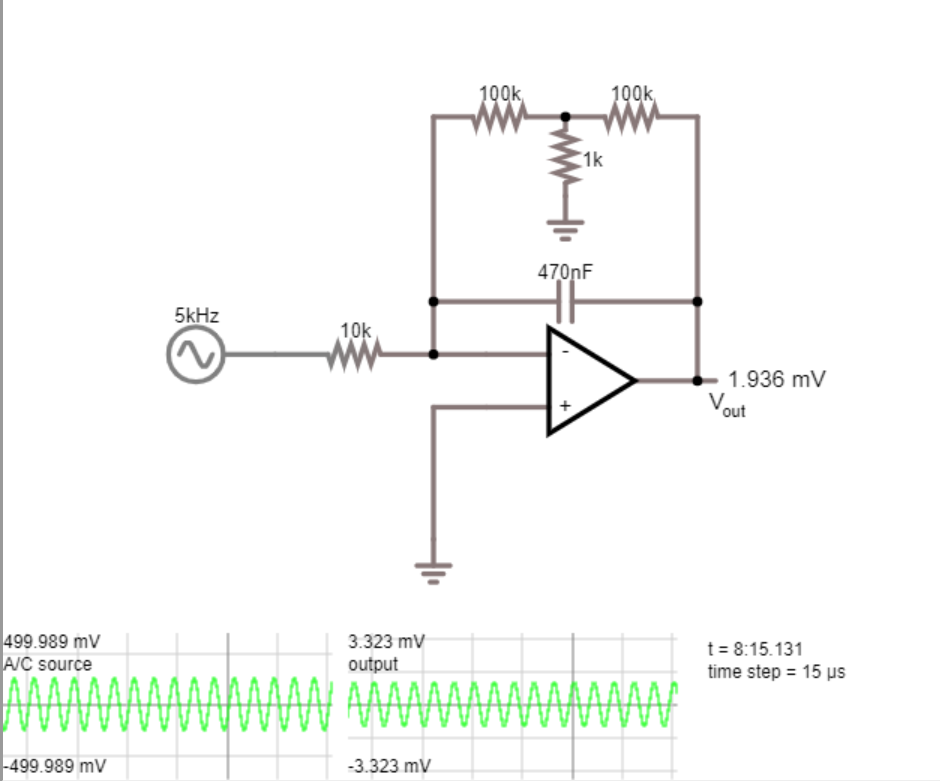
(b) For , , , , and

Using the Formula, that we derived earlier,

1. For and , the formula simplifies as follows

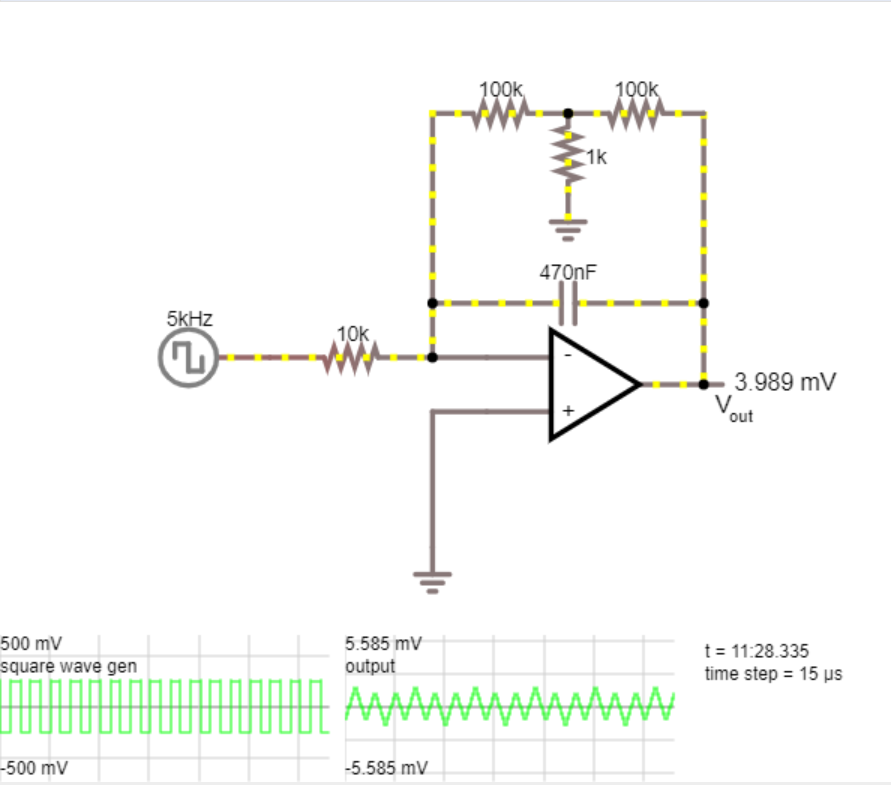
**Simplified Formula for this case:**

* Integrator:

1. The given circuit has a sine wave

cosine wave

We can ascertain that the output wave is a cosine, because when we look at the dark line in both the graph just above, we can see that while the first wave is almost 0 (sine), the other one has its maximum value (cosine) at that point.

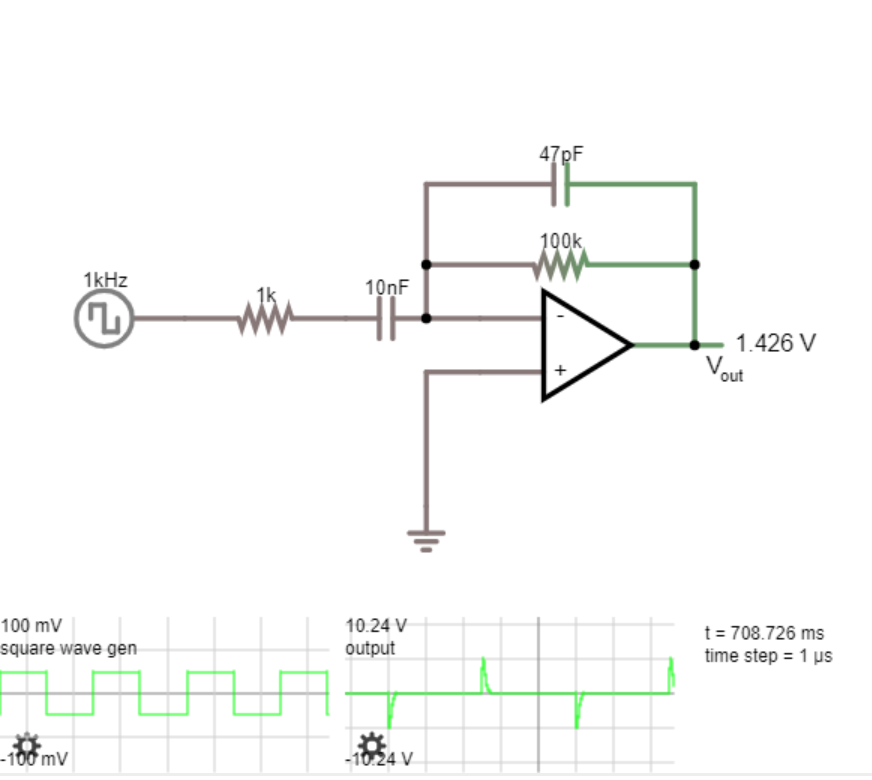
1. The given circuit has a square wave

The output voltage is a triangle wave that has a maximum voltage of 5.585 mV and minimum voltage of -5.585 mV and the same frequency as the input voltage.

1. Performing a frequency response for square wave with , for the above circuit

|  |  |
| --- | --- |
| Frequency  (in kHz) | (in mV) |
| 1 | 26.543 |
| 2 | 13.246 |
| 3 | 8.884 |
| 4 | 6.599 |
| 5 | 5.585 |
| 6 | 4.418 |
| 7 | 3.884 |
| 8 | 3.985 |
| 9 | 3.140 |
| 10 | 2.613 |

* Differentiator:

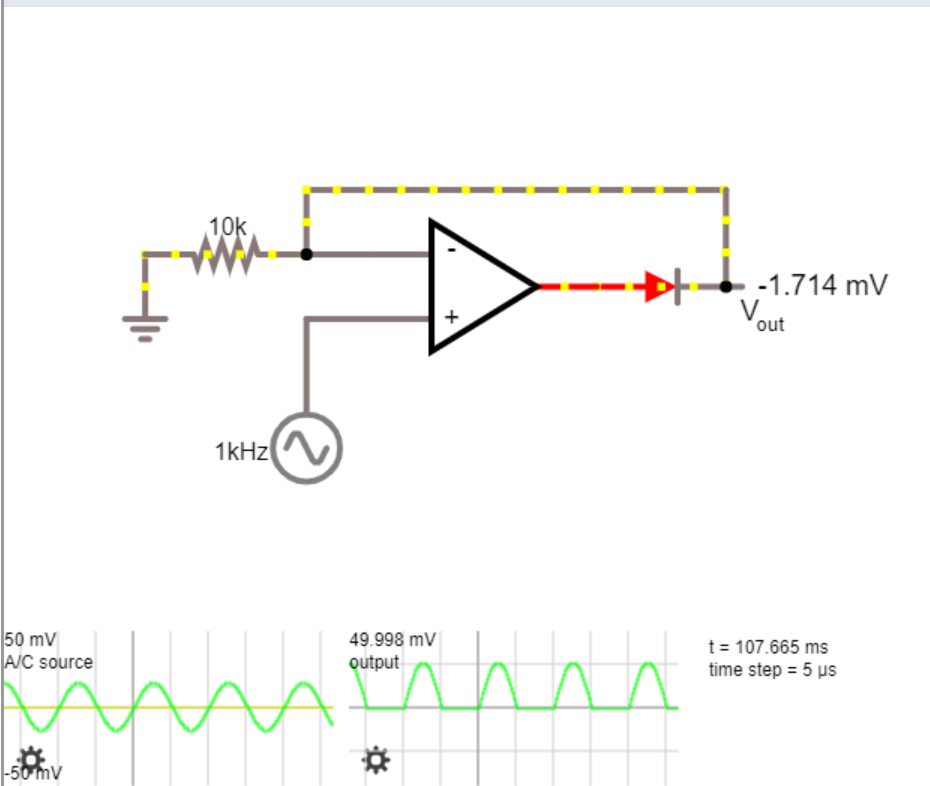
1. The given circuit has a square wave

The output wave is an impulse function repeating with a frequency which is the same as that of the input wave (= 1 kHz)

1. Performing a frequency response for square wave with , for the above circuit

|  |  |
| --- | --- |
| Frequency  (in kHz) |  |
| 1 | Impulse Function with Frequency 1 kHz |
| 2 | Impulse Function with Frequency 2 kHz |
| 3 | Impulse Function with Frequency 3 kHz |
| 4 | Impulse Function with Frequency 4 kHz |
| 5 | Impulse Function with Frequency 5 kHz |
| 6 | Impulse Function with Frequency 6 kHz |
| 7 | Impulse Function with Frequency 7 kHz |
| 8 | Impulse Function with Frequency 8 kHz |
| 9 | Impulse Function with Frequency 9 kHz |
| 10 | Impulse Function with Frequency 10 kHz |

1. Active Rectifier:

Using a diode along with an Op-Amp we can rectify a signal using the following circuit. We use an Op-Amp along with the diode, so that we have the circuit behave as if it contains an ideal diode (thus, no voltage drop across it).

Here the output wave is a half wave rectified version of the input wave.

In this circuit with input voltage , sine wave, although the voltage drop across the diode is not exactly 0, it is very close to 0 (= ). Here the diode used has a threshold voltage of 526.074 mV.

Had we used just the diode for rectification, nothing would have happened, since the input voltage (=50 mV) is less than the threshold voltage of the diode.

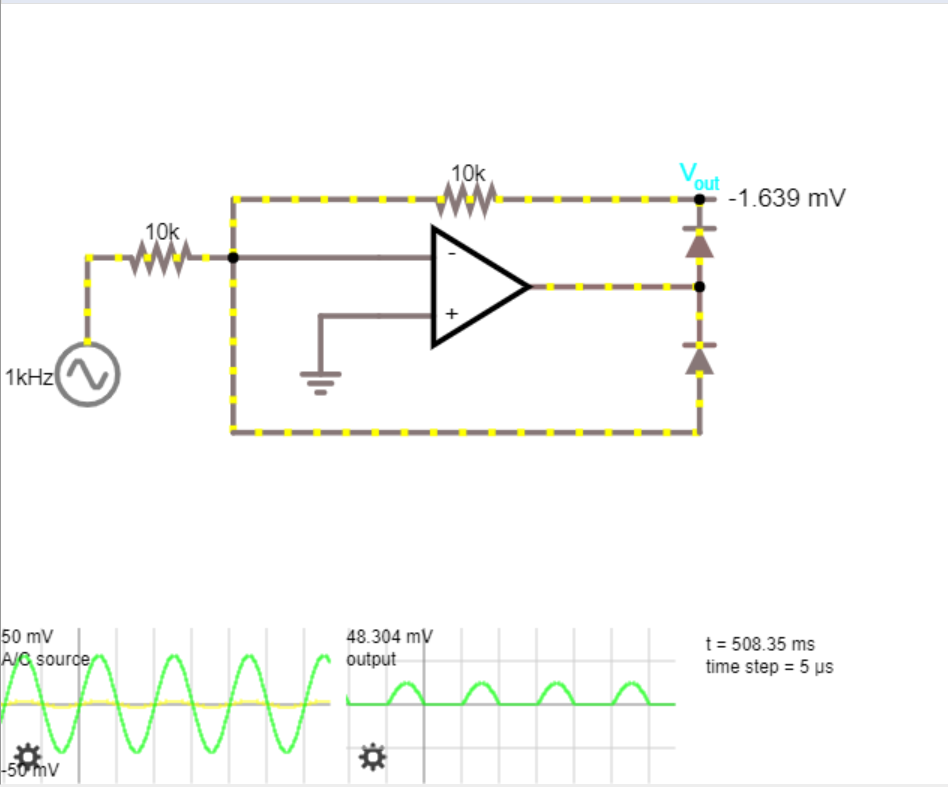
But now the new threshold voltage is = (which is much lesser than the input voltage).

Thus, this way of using an active rectifier (also called as precision rectifier or a super diode) is very useful for getting ideal diodes.

Even though very useful, this configuration has an issue. When the input voltage becomes negative, the diode acts as an open circuit, and thus, the Op-Amp becomes an Open-loop. Now, if the open loop gain is very high in the Op-Amp, then the output will saturate.

When the input gets positive again, the Op-Amp takes some time to get out of the saturated phase and thus skips many cycles of input voltage with high frequency. This limits the frequency response (The Bandwidth) of the circuit by a lot.

To overcome this problem, we look at the following circuit that is designed so that it never goes into the saturation phase.

1. 

Here we use 2 diodes in place of 1, to ensure that the Op-Amp doesn’t go into saturation.

When the input voltage is negative, the lower diode is off, while the upper diode is on.

When the input voltage is positive, the upper diode is off, while the lower diode is on.

This ensures that, at any time, at least one diode is on, so that the Op-Amp never goes into the open-circuit mode.

If the Op-Amp never goes into open-circuit mode, we don’t need to worry about saturation.

Thus, we obtain a much higher frequency response (bandwidth) for the active rectifiers, using this configuration.

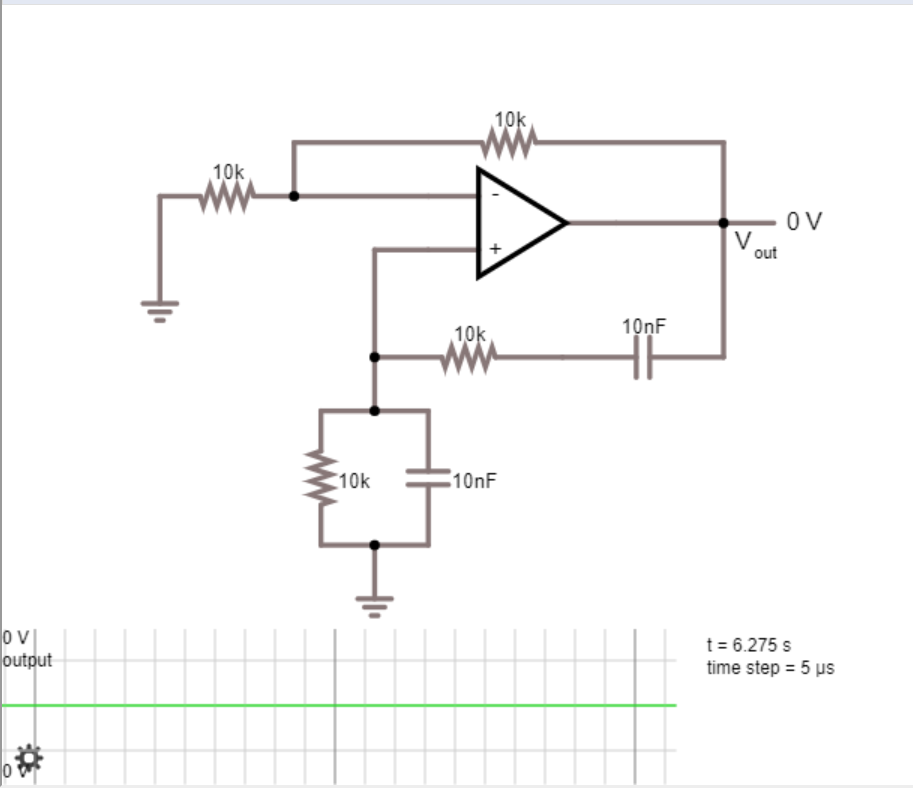
But in this case, we need to take 2 diodes and thus the output voltage would be lesser than the previous case, because of more drop across the diodes now, each time the input crosses zero.

* Wein-Bridge Oscillator:

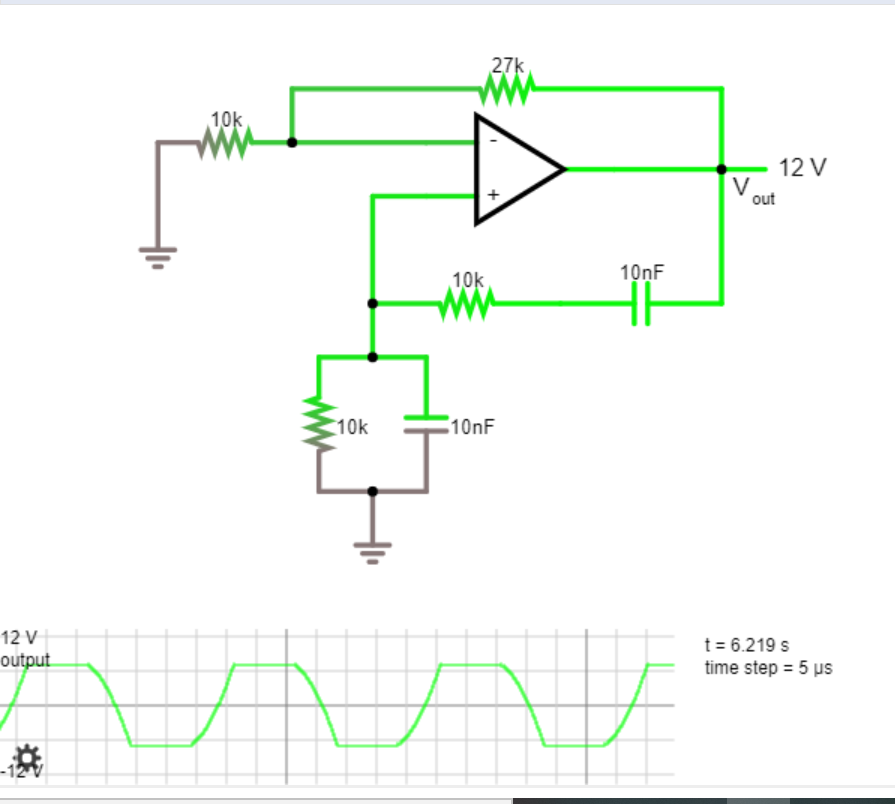
In this oscillator, no input is needed in real life. It just starts with a small disturbance from the surroundings and then gives a periodic signal as an output.

But in Falstad, to model the same, we attach a DC source to the leftmost , between and the ground. After attaching we pause the circuit and then remove the source and then connect to the ground. This way, we start the Wein-Bridge Oscillator.

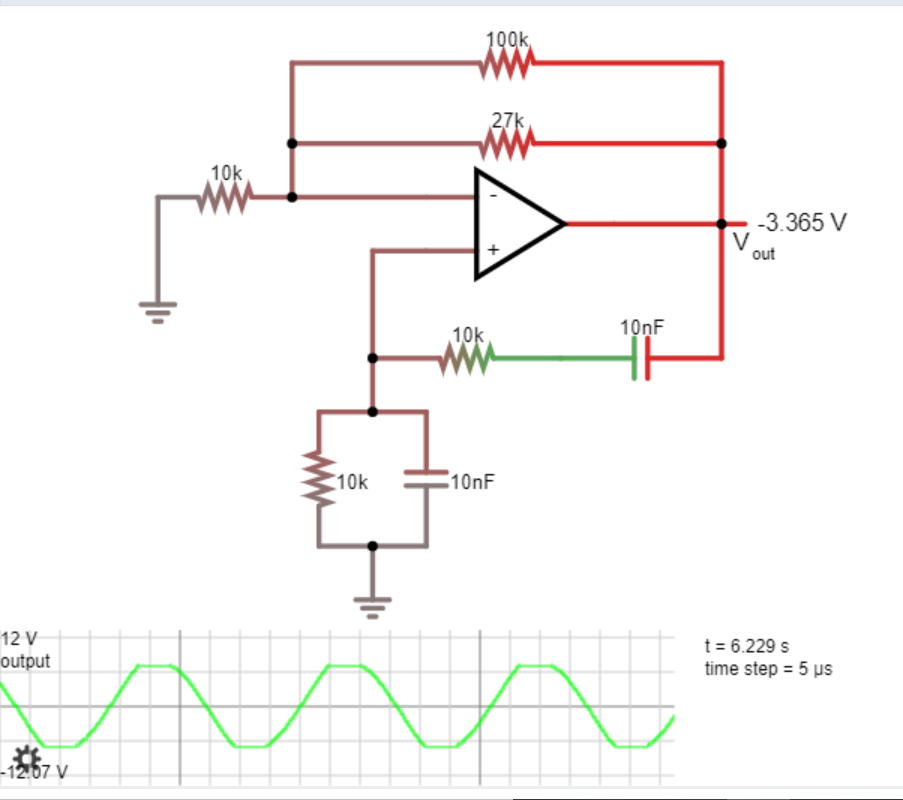
-0o

1. For and

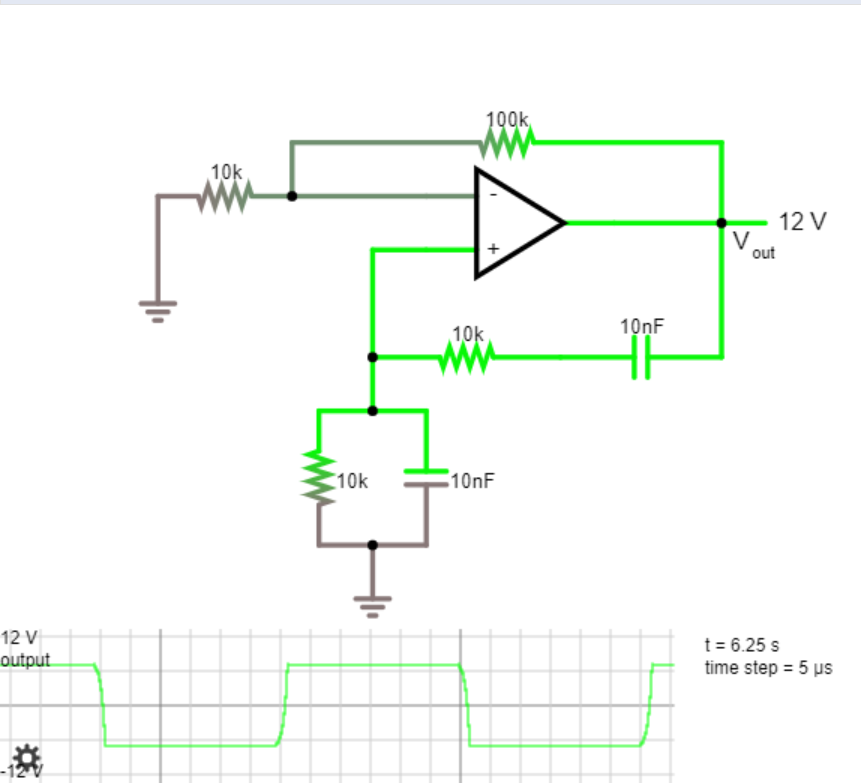
After applying an initial excitation, it soon dies down in this configuration. Thus, no oscillation happens for

1. For and

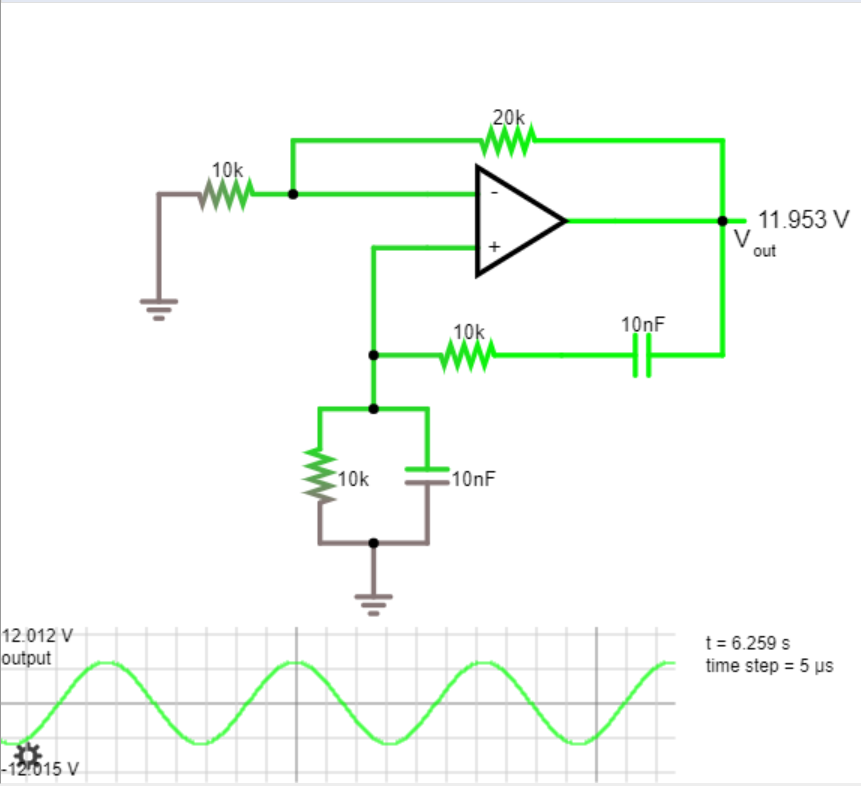
After applying an initial excitation, it soon grows into a clipped signal with maximum and minimum voltage of 12 V and -12 V respectively. Thus, an oscillation happens for , but it is not sinusoidal.

1. For and

After applying an initial excitation, it soon grows into a clipped signal with maximum and minimum voltage of 12 V and -12 V respectively. Thus, an oscillation happens for , but it is not sinusoidal. (Though the clipped part is significantly lesser than before)

1. For and

After applying an initial excitation, it soon grows into a clipped signal with maximum and minimum voltage of 12 V and -12 V respectively. Thus, an oscillation happens for , but it is not sinusoidal. (The clipped part is very large as compared to the previous two cases).

From the 4 cases we have considered, we can observe that when the value of ranges between 2 to 10, oscillations happen, but with clipping. As the value of comes down from 10 to 2, the clipping gets reduced significantly, with no clipping at . At this value, the output wave is completely sinusoidal, as given below.

As the value of further decreases from 2, the oscillations stop and the output wave dies down.