EE230: Analog Circuits Lab
Lab No. 2

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1 OpAmp based Negative feedback circuits

1.1 Aim of the experiment

Implement a Negative feedback Op-Amp-based circuit and observe the output waveform for different inputs, including the clipping of the output on the supply.

1.2 Design

I applied the input and connected the circuit and the DSO input and output pins as in the circuit diagram given below. The values of the resistances were chosen to be 1 and 10 so that we get an overall gain of -10 for the input signal. The output can be calculated using $\mathrm{V_{out}} = -\frac{R_2}{R_1} \cdot V_{\mathrm{in}}$

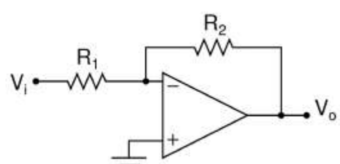


Figure 1: Circuit diagram of an Inverting Amplifier

1.3 Experimental results

R1 = 1kΩ, R2 = 10kΩ.
Sinusoidal input with a peak of 0.1V and frequency of 10KHz.
The experimental results we obtained indicated a negative amplified output of the input for a 0.1V amplitude input. The DSO image for the same is attached here. Also, when we varied the input from 0.1V to 2V, the amplification continued, until we reached the input of 1.5V amplitude, at which the Op Amp output started to get clipped. The reason for the same was that the supply voltage was set to be + and - 15V, so the output of the Op Amp can not exceed the same, hence the mismatch observed between the calculated and the obtained outputs.

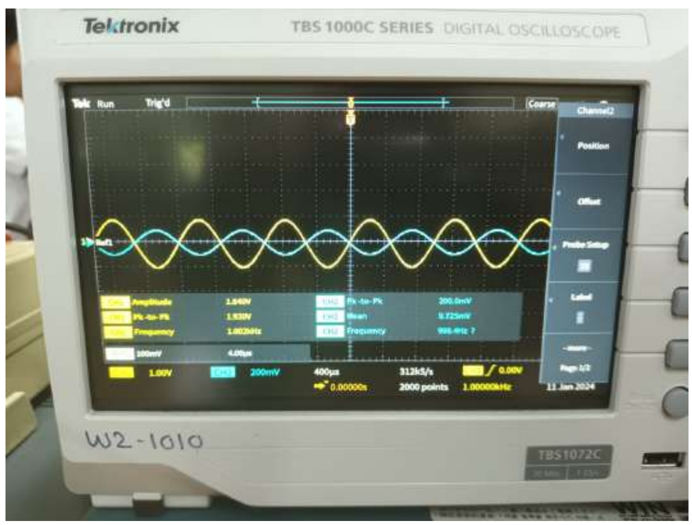


Figure 2: The negative(inverting) amplifier output for an input of 200mV, peak-to-peak

1.4 Conclusion and Inference

The Op Amp acts as an amplifier in the linear region, and in the saturation region, it just gives a straight line output, equal to the positive or negative supply irrespective of the input since it can't amplify any source of voltage. Also, it behaves as a negative amplifier and introduces a phase difference of 180 degrees in the configuration shown in the circuit

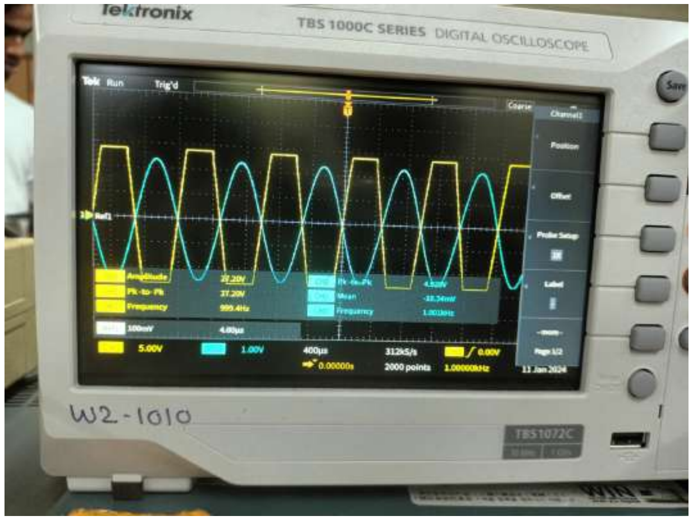


Figure 3: The inverting, clipped output for an input of 4.9V peak-to-peak

1.5 Experiment completion status

Fully Completed.

2 Differentiator

2.1 Aim of the experiment

Implement a Op-Amp-based differentiator using a R-C-based circuit and observe the output on applying a triangular wave input to the circuit.

2.2 Design

I followed the circuit diagram, and made sure to connect the correct values of R and C to get the desired results. The circuit looked as follows:
The output can be calculated using $\mathrm{V}_{\mathrm{out}}(t) = -R \cdot C \cdot \frac{dV_{\mathrm{in}}(t)}{dt}$

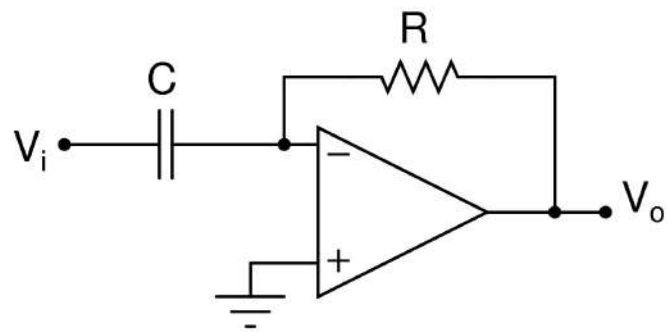


Figure 4: Op-Amp based capacitive differentiator

2.3 Experimental results

R = 10kΩ, C = 0.01µF
Triangle wave input with ±2V, 2.5kHz
The output waveform observed on giving a triangular wave input is a pulsating square wave, that took a positive and a negative value, with the switch occurring at the time of a peak or a valley of the triangular wave. The reason for the same can be attributed to changing the slope of the triangular wave. Here, the output is a differentiated version of the input, and the input is a triangular wave of frequency 2.5KHz, and so the output is a straight line, with its value being 16V/ms. The observed waveform also fluctuated randomly at the ends, or points of transition, which was because of the noise that was coming across the resistor and the capacitor due to external sources

and because the resistor was allowing all the current to pass through it, which was random because of the discharging and charging of the capacitor, which it does not allow to do instantaneously.
C parallel = 0.001µF

Figure 5: Output on applying a triangular wave input

When a capacitor was applied across the R, the output waveform was much finer, with the noise reduced considerably. This is due to the fact that the capacitor now acted as a filter, and so much of the noise was filtered out, since it had to pass through a capacitor, and a capacitor doesn't allow the voltage across it to change instantaneously, and hence the more regular waveform.

2.4 Conclusion and Inference

The Op Amp circuit acts as a differentiator, and the output is a differentiation of the input, with noise, since a very small amount of sudden noise can also get amplified, by a differential type of output. The circuit also gave much finer output by using a capacitive filter across the resistor, that performs the task of smoothening out the output and giving a proper square wave output. The circuit shows how we can use a R-C combination with an Op-Amp to make a differentiation, that can be used as an equation solver.

Figure 6: Output on applying a triangular wave input with an extra capacitor

2.5 Experiment completion status

Fully Completed.

3 Summing Amplifier Circuit

3.1 Aim of the experiment

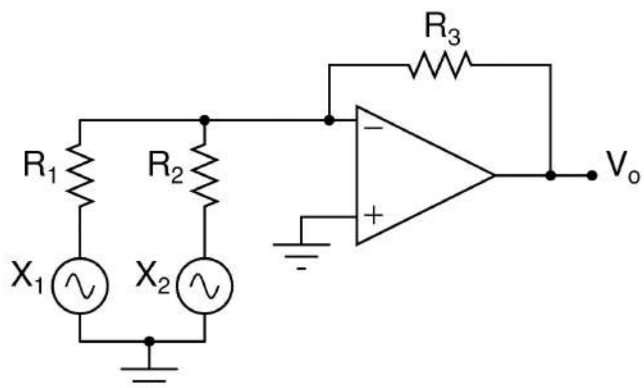
Implement a Op-Amp-based summing amplifier and find the output for different values of the inputs.

3.2 Design

I followed the expression for the output given to us. We had to design a circuit which gave the output,

$$V_0 = -2\left(X_2 + \frac{X_1}{2}\right)$$

The circuit diagram was as follows: Here, the V_{out} using the parameters of



the circuit is $V_{\text{out}} = -\left(\frac{R_3}{R_2}X_2 + \frac{R_3}{R_1}X_1\right)$. Comparing the values, we ended up selecting $V_{\text{out}} = -\left(\frac{1\,\text{k}\Omega}{0.5\,\text{k}\Omega}X_2 + \frac{1\,\text{k}\Omega}{1\,\text{k}\Omega}X_1\right)$, which leads us to:

R3=1kΩ, R2=0.5kΩ R1=1kΩ

3.3 Experimental results

R3=1kΩ, R2=0.5kΩ R1=1kΩ X1 is sinusoidal with 4Vpp and f=500Hz X2 is sinusoidal with 2Vpp and f-500Hz

On applying the inputs as mentioned above and finding the sum using the equation we calculated above, we get the output as -2(2+(4/2)) Vpp which further turns out to be -8Vpp. The theoretical and the calculated values match withing experimental errors, and the output observed on the DSO had a peak-to-peak value of 7.60V. The reason for the same might be the inaccuracies of the Op-Amp, its delay or offsets etc. The plot of the input and the output can be seen clearly in the DSO.

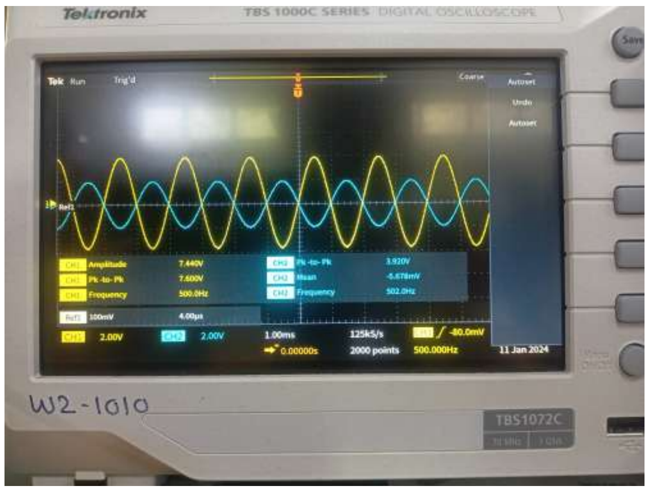


Figure 7: Summed and amplified output

3.4 Conclusion and Inference

The Op Amp circuit acts as a summing amplifier, and the output is a sum of the input. Since two perfectly same frequency sinusoids were applied with different frequencies, the output is also a sinusoid, which is amplified by the necessary condition and the frequency remains the same as earlier. The output and one of the inputs can be clearly seen on the DSO

3.5 Experiment completion status

Fully Completed.

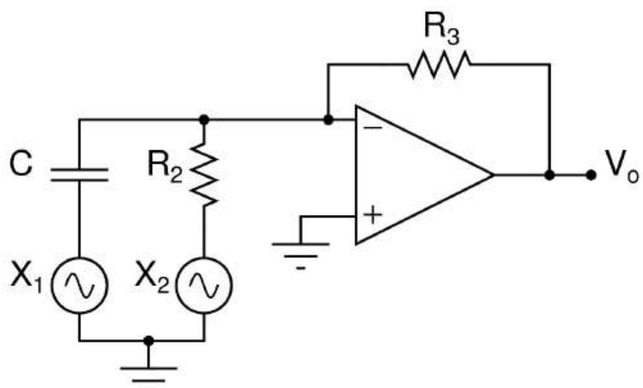
4 Equation Solver

4.1 Aim of the experiment

Implement a Op-Amp-based equation solver, that performs the task of finding the output based on a differential equation of the input(of the first-order)

4.2 Design

To design the circuit, I realized that the output was a sum of the input multiplied by a constant and differentiation of the input, meaning that a summing amplifier had to be made, with the inputs coming one from the capacitor and the other from a resistor itself and the values selected so as to get the required parameters. The output is supposed to be $V_0 = -(0.0001\frac{d}{dt}X_1 + 2X_2)$.
The circuit diagram was as follows:



We needed $R_3C = 10^-4, and R_3/R_2 = 2$, so we chose:
R3=1kΩ, R2=0.5kΩ and C=0.1µF

4.3 Experimental results

We can clearly see that the output is the solution of the differential equation that we obtain when we put in the required values(given in the inputs) as X1 = 10 sin(2 500 t) X2 = 2.5 sin(2 500 t). The calculations for the same are as follows:

$$V_0 = -(0.0001\frac{d}{dt}X_1 + 2X_2)$$

$$
\begin{aligned}
V_0 &= -(0.0001a\omega\cos(\omega t) + 2b\sin(\omega t)) \\
&= -\sqrt{(0.0001a\omega)^2 + (2b)^2}\sin\left(\omega t + \tan^{-1}\left(\frac{0.0001a\omega}{2b}\right)\right)
\end{aligned}
$$

$$V_0 = -\sqrt{\pi^2 + 25}\sin\left(1000\pi t + \tan^{-1}\left(\frac{\pi}{2.5}\right)\right)$$

$$V_0 = -\sqrt{\pi^2 + 25}\sin\left(1000\pi t + \tan^{-1}\left(\frac{\pi}{2.5}\right)\right)$$

$$V_0 \approx -5.91\sin\left(1000\pi t + 32^\circ\right)$$

Hence, the output must have a peak to peak value of 11.8V and a phase difference(i.e. a lead) of 32 degrees, which was what we observed in the DSO waveform, as can be clearly seen in the photo below.

Vpp=11.2V(expected value=5.91*2=11.8)
Frequency=500Hz(doesn't change)

4.4 Conclusion and Inference

The Op Amp circuit acts as an equation solver, by using a capacitor and resistor-based negative amplifier, and solves the differential equation to find the output. Note that the frequency does not change, since on differentiating the frequency of the output doesn't change and only the amplitude and the phase of the sine waves change. With it, we also infer that an Op-Amp can be used as a equation solver, of any order differential equation, and the output can be observed on the DSO.

4.5 Experiment completion status

Fully Completed.

5 OP-AMP BASED POSITIVE FEEDBACK CIRCUITS-Schmitt Trigger Circuit

5.1 Aim of the experiment

Designing a Schmitt Trigger circuit, for an upper threshold value (VTH) of 2.5V and lower threshold value (VTL) of -2.5V, assuming Va = 0V (GND), and using a dual supply for the Op-amp 741. Later, we change Va, and find the new thresholds for the Schmitt trigger and analyze the design.

5.2 Design

To design the circuit, the first step was to create a voltage of 2.5V at the input when the voltage was 15V at the output, and -2.5V when it was -15V at the output. Since it is made by a simple resistive divider, we used the values of resistances in the ratio 1:5. The circuit diagram was as follows:

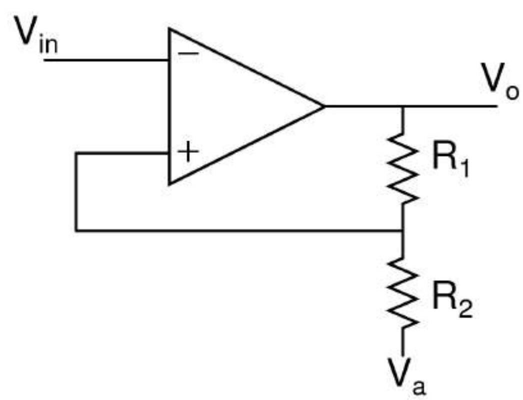


Figure 8: Schmitt Trigger circuit Diagram

The values chosen were R1=10kΩ and R2=2kΩ, which gave us the final value at the non-inverting input of the trigger to be 2.5V(a simple voltage divider) and -2.5V. Both of these values act as the thresholds, since when the input tries to cross 2.5V, starting from the positive direction, the output toggles at +2.5V and similarly, when the input tries to cross starting from the negative direction, the output toggles at -2.5V. For the second part, Va is made 2V while the resistances are kept the same.

5.3 Experimental results

On applying a sinusoidal input of 10Vpp and 1KHz frequency, we see that the circuit works correctly as a schmitt triggering, and the output fluctuates between +15V and -15V, as and when the output crosses 2.5 from the negative side or -2.5 from the positive side. When we have Va to be 2V,

Figure 9: The output when Va=0V

the circuit still acts as a voltage divider, but now the thresholds change. When Vout=15V, the voltage at the non-inverting input is 4.6V, and when Vout=-15V, the voltage at the non-inverting input is -1.2V, which become the new high and low thresholds of the Schmitt Trigger circuits. We can clearly observe these in the DSO image attached.
It is a very good design, but not entirely robust, since a little resistance mismatch can change the thresholds of the Schmitt Trigger. With it, output and input bias currents may also affect. But, the feedback is accounted for here, and so any change in the output, will again be countered due to the closed-loop design making it a fairly good design.

5.4 Conclusion and Inference

The Op Amp circuit acts as a Schmitt Trigger, and the Trigger switches its values at the calculated thresholds by using the normal Op-Amp equations. The circuit also acts as a square pulse generator, and can be used as a latch

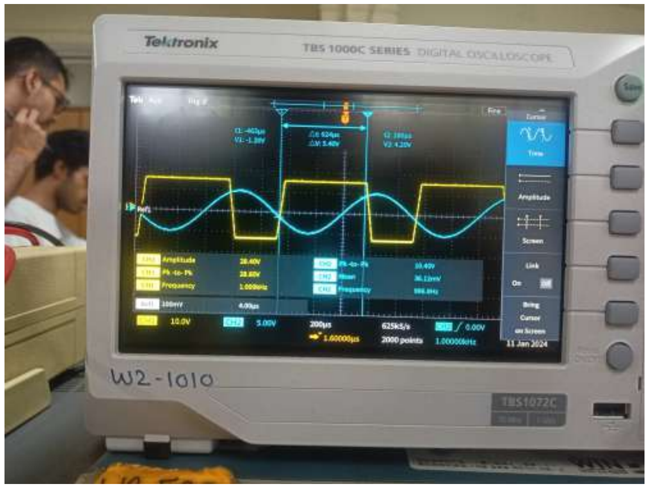


Figure 10: The output when Va=2V

also. The overall circuit thresholds depend on Va, which is the voltage at the point where the two resistors are connected. Overall, the circuit implements a Schmitt Trigger, using a resistive-divider circuit.

5.5 Experiment completion status

Fully Completed.

6 Modified Schmitt Trigger

6.1 Aim of the experiment

Designing a different and modified Schmitt Trigger circuit, using Zener diodes, connected at the output voltages which restrict the output to a value lower than their supply and use a resistive voltage divider to find the thresholds of the circuit.

6.2 Design

To design the circuit, I connected the resistors and the diodes in the direction specified in the manual The circuit diagram was as follows:

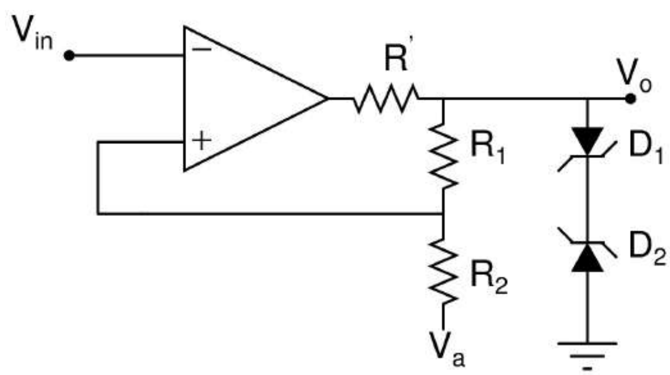


Figure 11: Modified Schmitt Trigger circuit Diagram

The values chosen for the resistors were both R1=R2=10kΩ, and the zener diodes had a breakdown voltage of 4.7V and a forward bias voltage of 0.7V(since it acts almost like a normal diode in the forward bias)

6.3 Experimental results

On applying a sinusoidal input of 10Vpp and 1KHz frequency, we see that the circuit works correctly as a Modified Schmitt Triger, and the output fluctuates between +5.4V and -5.4V, as and when the output crosses 2.7 from the negative side or -2.7 from the positive side. The outputs observed here can be compared to the calculated values as following: One of the diodes

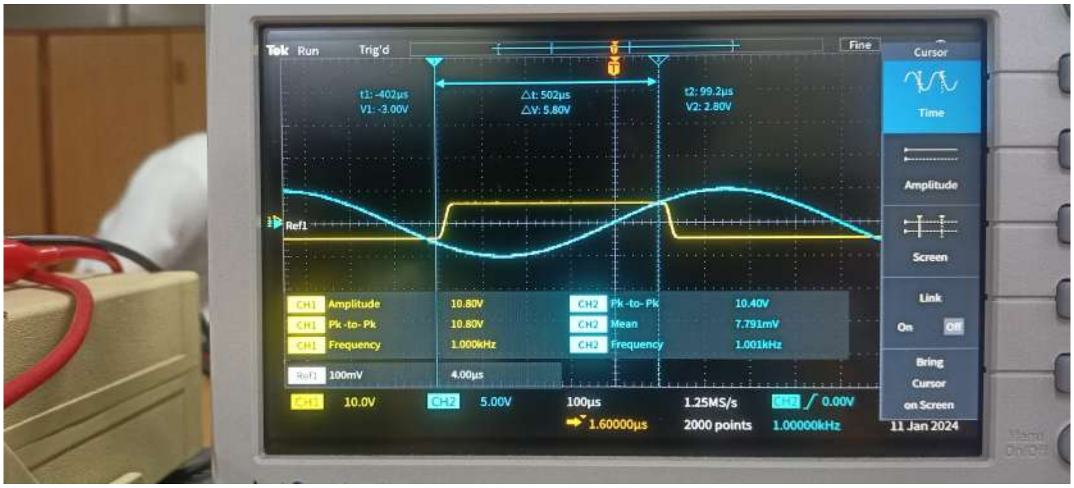


Figure 12: The output with the Zener diodes

will be in reverse bias while the other in forward bias, whenever the output voltage is either +Vcc or -Vcc. In case of the output being +15V, we have the upper diode being forward bias and the lower one being reversed bias, and so V0=4.7+0.7=5.4V. Thus the non-inverting terminal had an input of 5.4/2=2.7V and so the upper threshold being the same. Similarly, the upper diode is reverse and the lower diode is forward biased in the situation with V0=-15V, and so the threshold for the other transition being -2.7V. The obtained thresholds of +3V and -2.8V, agree to the outputs calculated, within experimental errors. We need to have a R'=1kΩ over here, so that excess current does not flow through the Zener diodes and also so that the diodes do not get damaged because the voltage of the output of the Op Amp is not equal to that across the diode and the ground.

6.4 Conclusion and Inference

The Op Amp circuit acts as a modified Schmitt Trigger, and the Trigger switches its values at the calculated thresholds by using the normal Op-Amp equations. The circuit can also act as a square pulse generator, and can be used as a latch also. The overall circuit thresholds depend on the diodes used, specifically the reverse breakdown voltages of the same. The output calculated and the actual values match within experimental errors.

6.5 Experiment completion status

Fully Completed.

7 Op-Amp based Feedback Circuit

7.1 Aim of the experiment

To observe both positive and negative feedbacks of an Op-Amp based circuit, depending on the values selected for a set of resistors.

7.2 Design

We followed the circuit diagram, and made the circuit as follows: The values

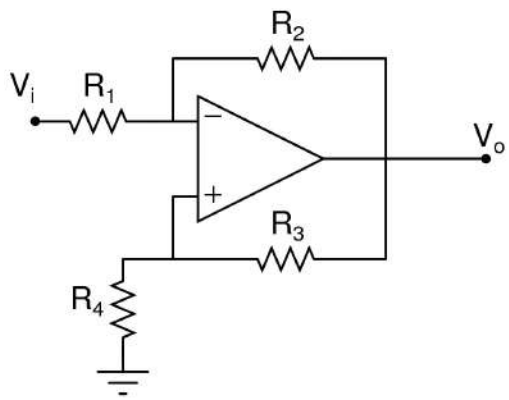


Figure 13: The Circuit diagram

of the resistances were changed twice and depends on the type of experiment we were performing. The circuit can act as both positive and negative feedback, and both of them can be observed by changing the values of the resistances.

7.3 Experimental results

We first took the values as R1 = 1kΩ, R2 = 10kΩ, R3 = 100kΩ, R4 = 1kΩ. In this case, the type of feedback is negative, that is the circuit is working in the linear region, and so the output is not saturated, but an amplified version of the sinusoidal input applied, with a a peak of 0.1V and frequency 1kHz. The output has negative feedback, and so it acts like an inverting amplifier thus giving us an output as can be seen in the DSO.

In the case with the values of resistances being R1 = 1kΩ, R2 = 100kΩ, R3 = 10kΩ, R4 = 1kΩ, the output has positive feedback, and so it saturated

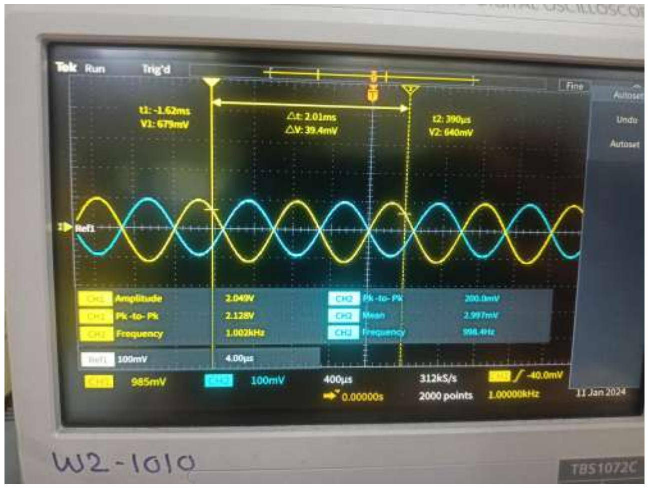


Figure 14: Negative Feedback

to the positive supply rail of the Op Amp, which can be clearly seen in the DSO output.

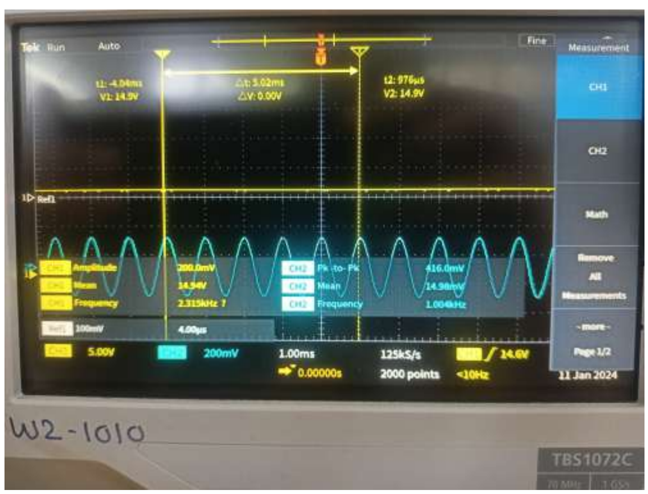


Figure 15: Positive Feedback

7.4 Conclusion and Inference

We can clearly see the Op-Amp acting as both a positive feedback circuit and a negative feedback circuit, depending on the ratios of R2/R1 and R3/R4. When the former is greater, the negative feedback prevails, and it acts like an inverting amplifier, and while the latter is greater, the positive feedback prevails and it gives a saturated output. This shows that the Op Amp can act as both a positive and a negative feedback circuit.

7.5 Experiment completion status

Fully Completed