



Indian Institute of Technology Bombay

**Analog Circuits Lab
EE 230**

**Lab 1
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**Mridul Choudhary
23B3933**

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1 Time response of RC circuit

1.1 Aim of the experiment

The aim of this experiment is to analyze and characterize the time-domain response of an RC low-pass filter circuit under specified input conditions, specifically focusing on the transient response, bandwidth, and signal rise and fall times. The specific objectives include:

1. **Transient Response Analysis:** To study the circuit's response to a square wave input and determine its time constant by measuring the time it takes for the output voltage to rise to 63.2% of its maximum value.
2. **Bandwidth Calculation:** Determine the circuit bandwidth using the reciprocal of the time constant and compare the theoretical and practical values, exploring discrepancies due to real-world factors.
3. **Rise and Fall Time Measurement:** Measure the rise and fall times of the output waveform using both the cursor and measurement functionality of a digital storage oscilloscope (DSO) and to compare the accuracy and consistency of the results.

The purpose of the experiment is to provide insight into the dynamic behavior of RC circuits, their frequency characteristics, and the influence of practical factors on theoretical predictions.

1.2 Design

The design of the circuit requires us to assemble all the required circuit elements on a breadboard and connect them to the Arbitrary Function Generator and probe the circuit using Digital Storage Oscilloscope.

After doing the mesh analysis of the given circuit, we get the following equation, with i being the current in the circuit:

$$V_{in} = iR + \frac{1}{C} \int i dt \quad (1)$$

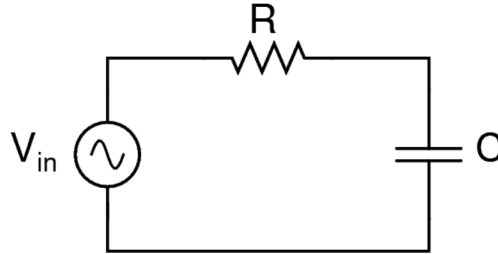


Figure 1: RC Low Pass Filter

1.3 Terminology

1. **Time Constant (τ):** The time taken by output voltage to rise by 63.2% of the maximum output voltage
2. **Bandwidth (rad/s):** The reciprocal of the time constant i.e. $\frac{1}{\tau}$
3. **Bandwidth (Hz):** The reciprocal of the time constant multiplied by 2π i.e. $\frac{1}{2\pi\tau}$
4. **Rise Time (t_r):** Time taken for the signal to go from 10-90% of its peak-to-peak value
5. **Fall Time (t_f):** Time taken for the signal to reach from 90-10% of its peak-to-peak value

1.4 Experimental results

Sr. No.	Quantity	Value
1	Time Constant (measured)	$66\mu s$
2	Time Constant (calculated)	$100\mu s$
3	Bandwidth (measured)	2.4 kHz
4	Bandwidth (calculated)	1.6 kHz
5	Rise Time (cursor)	$98.0\mu s$
6	Rise Time (measure)	$137.9\mu s$
7	Fall Time (cursor)	$170\mu s$
8	Fall Time (measure)	$146.6\mu s$

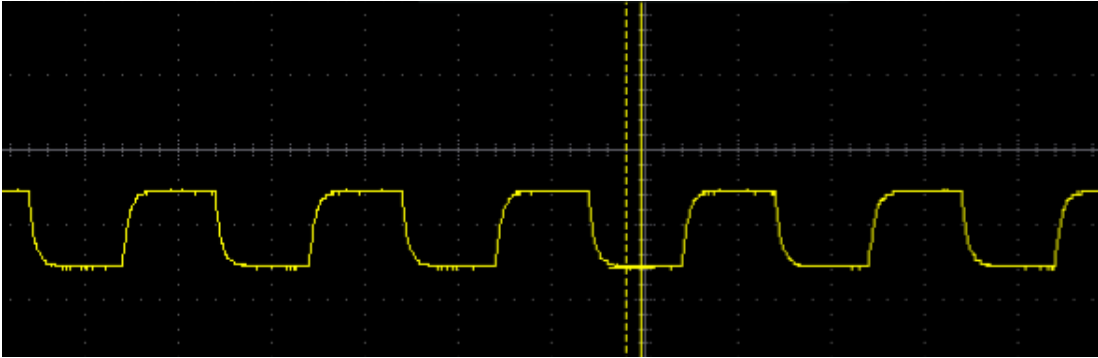


Figure 2: Output Waveform

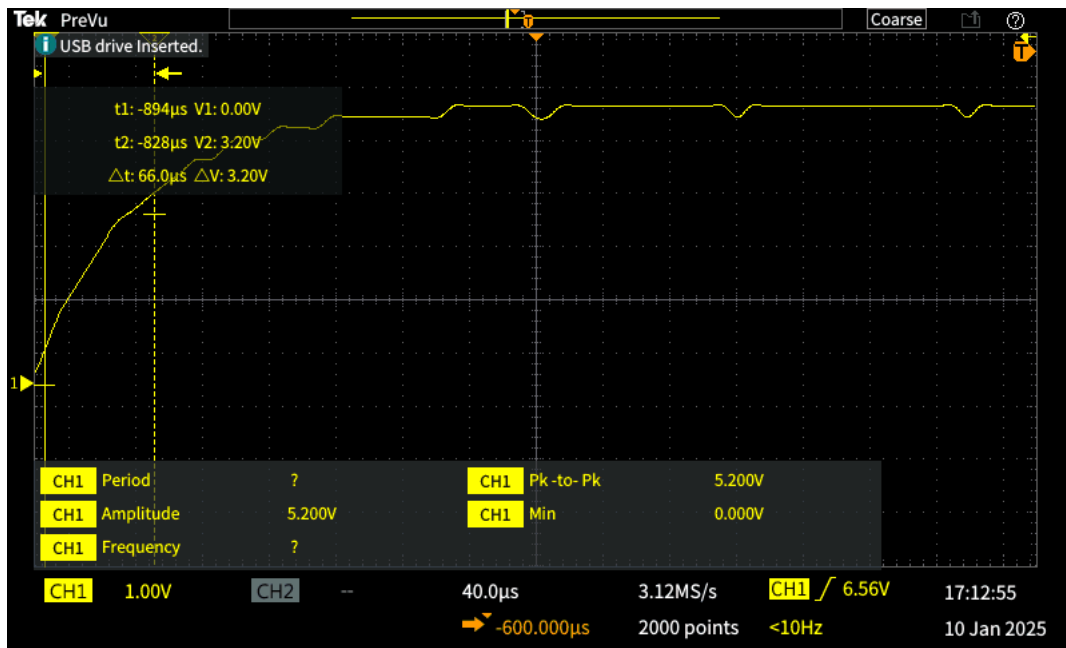


Figure 3: Calculation of the Time Constant

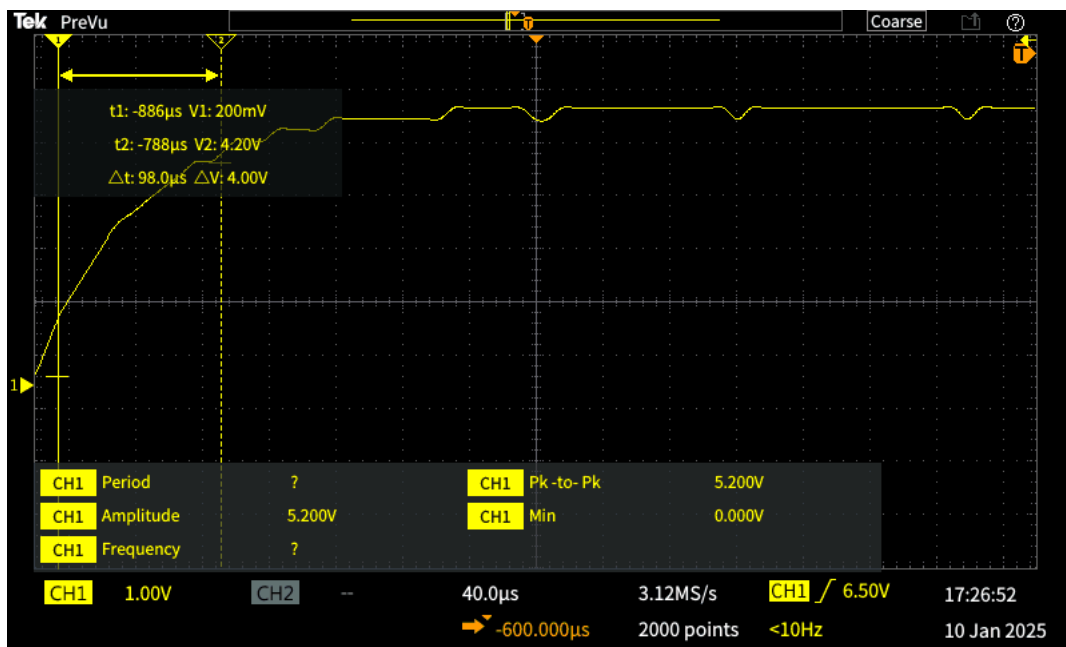


Figure 4: Calculation of the Rise Time (Cursor)

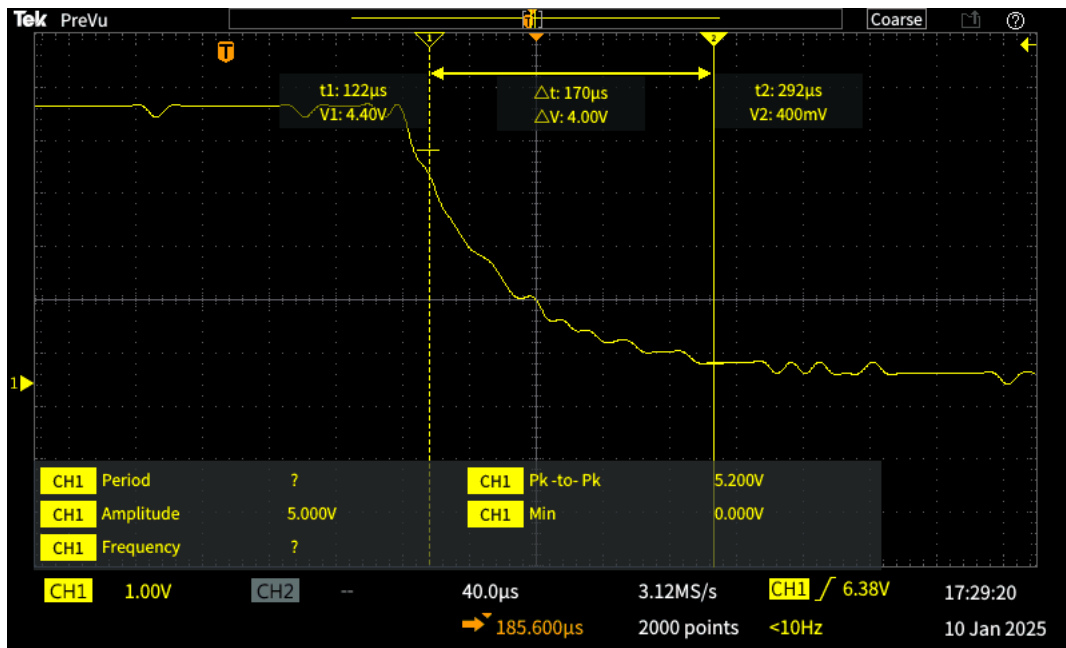


Figure 5: Calculation of the Fall Time (Cursor)

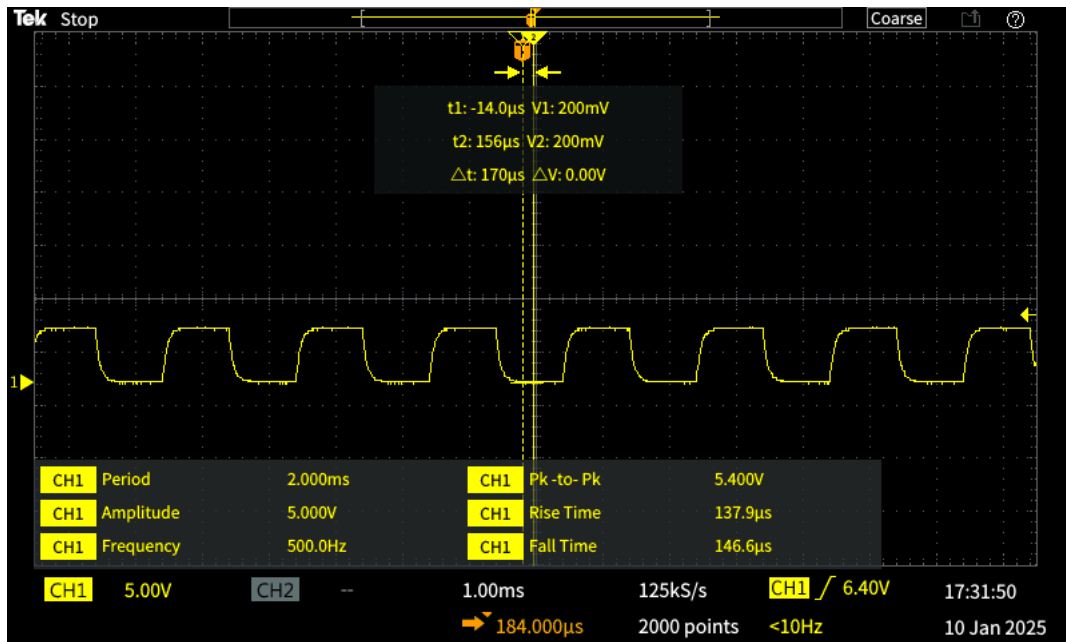


Figure 6: Calculation of the Rise and Fall Time (Measure)

1.5 Conclusion and Inference

1. The waveform corresponds to the charging and discharging of the capacitor across the resistor. During the charging phase, the slope of the graph is high and as the capacitor gets charged, the graph's slope becomes almost 0 and the same goes for discharging of the capacitor.
2. The huge difference between the measured and calculated values of bandwidth is because of the non-ideal nature of the capacitor in real life due to which its working capacitance varies significantly and causes such ginormous error in the bandwidth.
3. The results for Rise Time and Fall Time from Cursor and Measure are different but are also in each other's vicinity which is due to the fact that Cursor uses points in vicinity of the actual value points to get the values and at these small scales, even small perturbations lead to significant deviation from the actual value.
4. This experiment showcases the importance of accurate and precise measurements, error-less instruments and the use of ingenuity while experimenting to figure out where its going wrong. Other than that, it covered the part which was already taught in earlier courses with extra info about Rise Time and Fall Time. We also learnt how to use the DSO, the AFG and how to work around errors and difficulties which arise during experimentation.

1.6 Experiment completion status

The complete experiment was performed in front of the TA in the lab itself.

2 Frequency response of RC circuit

2.1 Aim of the experiment

To study the frequency response of an RC low-pass filter circuit and determine its amplitude-frequency characteristics. Specifically:

1. **Amplitude-Frequency Response:** Measure and analyze the output amplitude (V_{outpp}) at various input frequencies, starting from 5 Hz and increasing up to 1 MHz in decade steps, using a sinusoidal input signal of $1 V_{pp}$ and then record the results and plot the Bode plot.
2. **Bandwidth Determination:** Identify the bandwidth of the RC circuit by locating the frequency range where the output amplitude decreases to $\frac{1}{\sqrt{2}}$ (approximately -3 dB) of the input amplitude.
3. **Comparison and Analysis:** Compare the experimentally measured bandwidth with the theoretical bandwidth calculated using the circuit's time-domain response and provide explanations for any discrepancies or observations.

2.2 Design

The design of the circuit requires us to assemble all the required circuit elements on a breadboard and connect them to the Arbitrary Function Generator and probe the circuit using Digital Storage Oscilloscope.

After doing the mesh analysis of the given circuit, we get the following equation, with i being the current in the circuit:

$$V_{in} = iR + \frac{1}{C} \int i dt \quad (2)$$

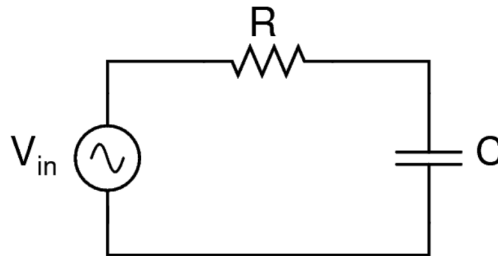


Figure 7: RC Low Pass Filter

2.3 Terminology

1. **Amplitude-Frequency response (Bode Plot):** A graphical representation of the system's frequency response, showing how the magnitude (gain) and phase shift of the current change with respect to the voltage at different frequencies

2. **Bandwidth (Hz):** The frequency range in which the output of a circuit reaches $\frac{1}{\sqrt{2}}$ times the amplitude of the input signal, often corresponding to a -3 dB reduction in output amplitude

2.4 Experimental results

Sr. No.	Frequency	V_{PP} (mV)
1	5 Hz	1000
2	50 Hz	1000
3	200 Hz	1000
4	1 kHz	900
5	2 kHz	652
6	3 kHz	500
7	5 kHz	364
8	10 kHz	208
9	20 kHz	108
10	30 kHz	76
11	40 kHz	58
12	50 kHz	45.6
13	60 kHz	36
14	70 kHz	33.6
15	80 kHz	28.8
16	90 kHz	21.6
17	100 kHz	18.4
18	200 kHz	12
19	300 kHz	8.8
20	400 kHz	7.8
21	500 kHz	5
22	600 kHz	4
23	700 kHz	3.2
24	800 kHz	2.4
25	900 kHz	2
26	1 Mhz	1.4

Sr. No.	Quantity	Value
1	Bandwidth (measured)	1.8 kHz
2	Bandwidth (calculated)	1.6 kHz

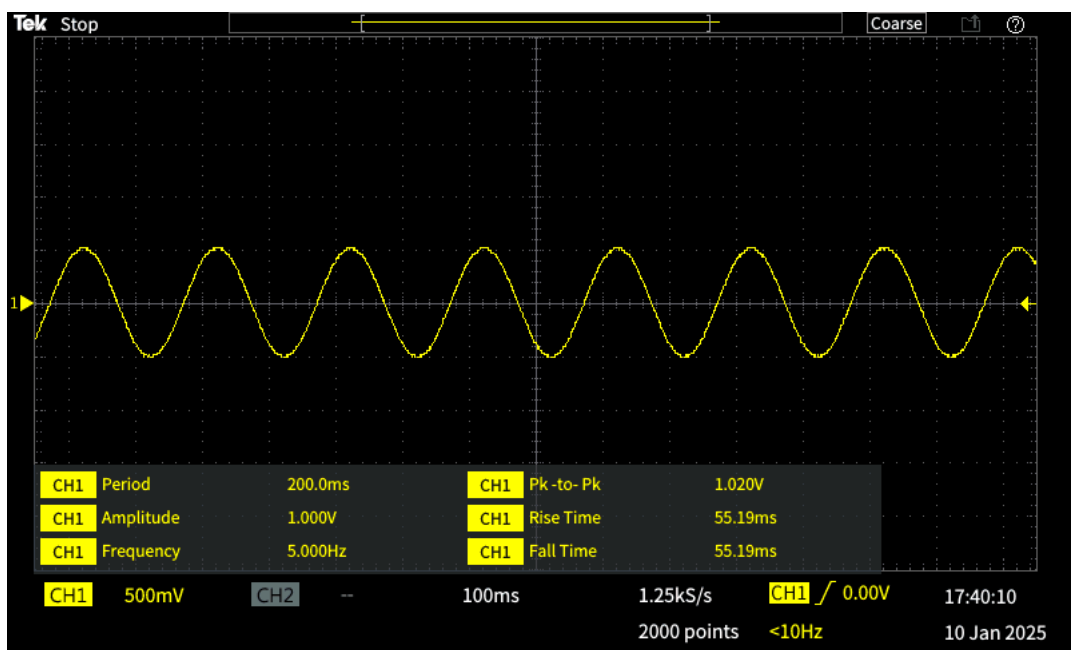


Figure 8: Output Waveform at 5 Hz

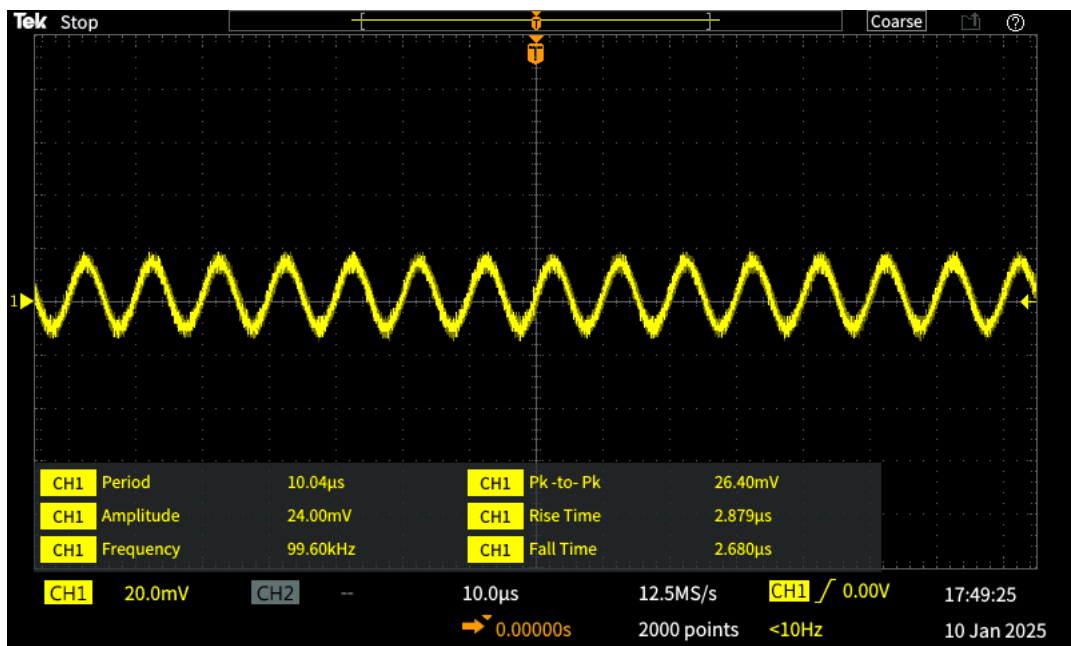


Figure 9: Output Waveform at 100 kHz

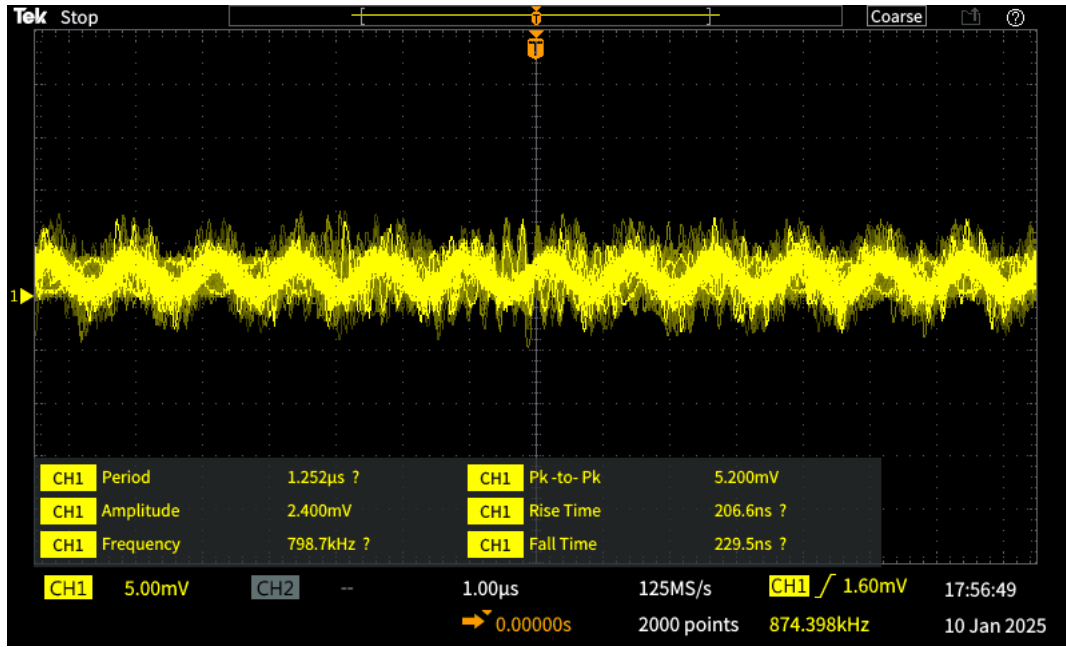


Figure 10: Output Waveform at 800 kHz

2.5 Conclusion and Inference

1. The deviation of the measured Bandwidth from the calculated Bandwidth is because of the non-ideal behavior of the various components of the circuit especially the capacitor which just disturbs the mean Bandwidth of the circuit.
2. The experiment also shows how small errors add up over time to change the output so much that it becomes irrerecognizable like in the case of measured and calculated Bandwidths. It also gives insights into the Bode plot method of the evaluation of various parameters of a system.

2.6 Experiment completion status

All the activities of the experiment were completed in the lab itself with utmost care and diligence.

3 Basics of probing the circuit

3.1 Aim of the experiment

To understand the basics of circuit probing using a potential divider circuit and demonstrate correct methods of measuring electrical signals. Specifically:

1. Measure the voltage across R_3 and compare it with the expected value.
2. Measure the voltage across R_2 without removing the connection across R_3 , compare results, and explain the cause of error.
3. Identify the appropriate instrument to avoid this error.
4. Apply a sinusoidal input across the potential divider, measure the voltage waveform across R_2 , and compare it with the expected waveform.

3.2 Design

The experiment requires us to arrange the resistors in the given manner on the breadboard and then applying voltages of $V_{DD} = +15V$ and $V_{SS} = -15V$ in the first part followed by a sinusoidal input of $5 V_{PP}$ at $4.7 KHz$ from the AFG. The equations describing the workings of the circuit is:

$$V_{DD} - V_{SS} = i(R_1 + R_2 + R_3) \quad (3)$$

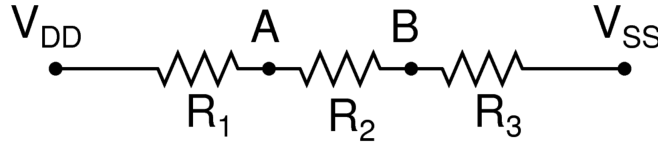


Figure 11: Potential Divider Circuit

3.3 Experimental results

Sr. No.	Quantity	Value
1	V_{R_3} (measured)	10.11 V (DC)
2	V_{R_3} (calculated)	10 V (DC)
3	V_{R_2} (measured)	19.77 V (DC)
4	V_{R_2} (calculated)	10 V (DC)
5	V_{R_2} (measured)	2.8 V (AC)
6	V_{R_2} (calculated)	1.66 V (AC)

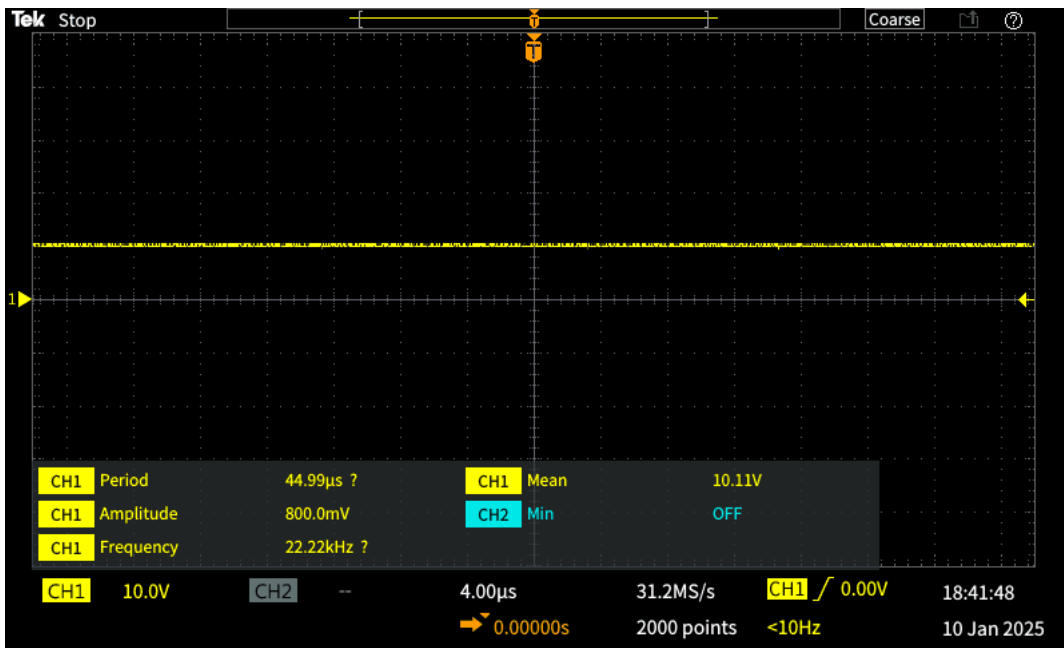


Figure 12: DC Voltage across R_3 at CH1

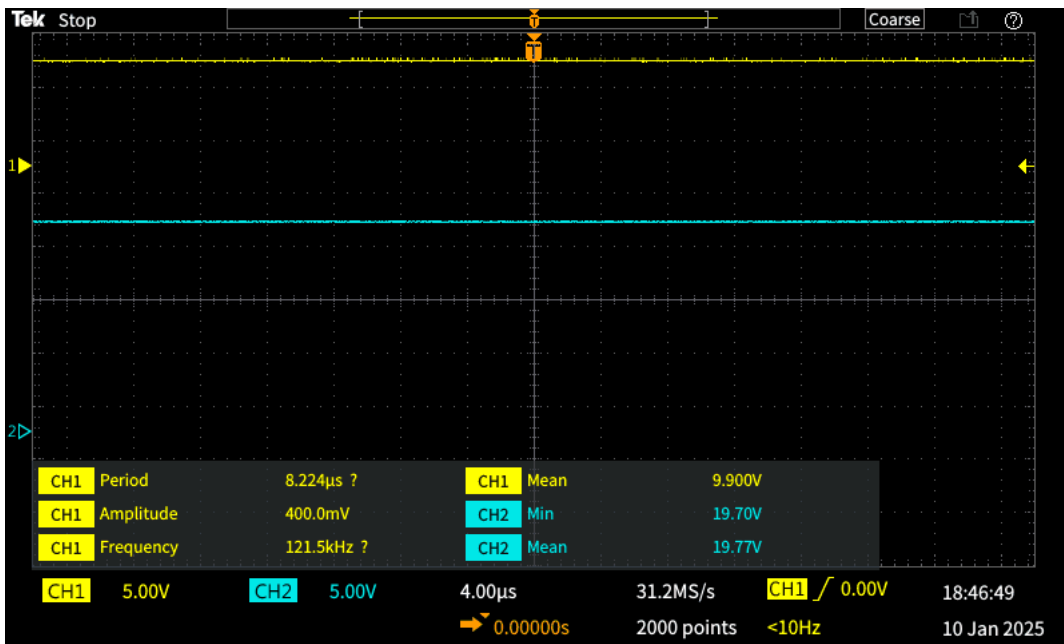


Figure 13: DC Voltage across R_2 at CH2

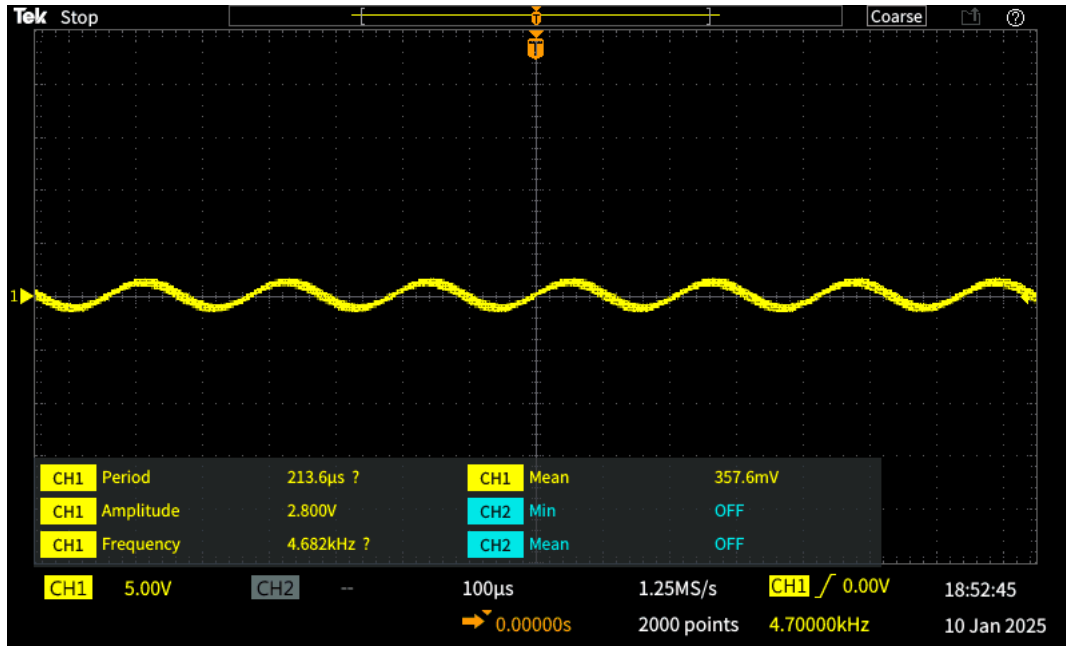


Figure 14: AC Voltage across R_2 at CH1

3.4 Conclusion and Inference

1. The expected value and calculated values of voltage across R_3 are similar with a small discrepancy arising due to inaccurate instruments, the resistance of wires and the voltage fluctuation by the source. The non-ideal behavior of resistors also contributes to the above cause.
2. The voltage gap between the measured value and the calculated value of R_2 arises due to the internal connections of the DSO. To measure the voltage across the second resistor, we end up shorting the third one and thus the effective resistance of the circuit becomes $20\ \Omega$, leading to the significant rise in the voltage at R_2 .
3. We can avoid the above error by using a high-impedance probe such as 10x or 100x attenuation probe with DSO which reduces the loading effect and thereby reduces the error.
4. Again the measured and calculated values differ because of the loading effect and internal flaws of the circuit.

3.5 Experiment completion status

All the parts of the experiment were done in the lab itself and nothing was left for later.

4 Half wave Rectifier

4.1 Aim of the experiment

To analyze the operation of a half-wave rectifier circuit using a sinusoidal input signal. Specifically:

1. Observe and plot the input and output waveforms using a DSO.
2. Explain the reduction in peak amplitude between the input and output voltages.
3. Reverse the diode polarity, observe the changes, and explain the resulting waveforms.

4.2 Design

The experiment uses key components including a 1N4007 diode, a 22 k Ω resistor, a signal generator to apply a sinusoidal input of 4 V_{PP} at 1 kHz, and a digital storage oscilloscope (DSO) to observe and plot the input (V_i) and output (V_o) waveforms. The circuit is arranged with the diode in series with the resistor, forming a simple half-wave rectifier. The anode of the diode is connected to the input source, while the cathode is connected to one end of the resistor. The output is measured across the resistor using the DSO.

The following equations describe the circuit:

$$V_{out} = V_{in} \quad (\text{Diode On}) \quad (4)$$

$$V_{out} = 0 \quad (\text{Diode Off}) \quad (5)$$

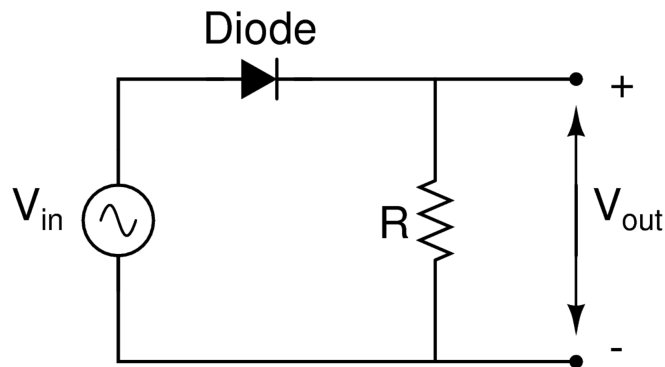


Figure 15: Half Wave Rectifier

4.3 Experimental results

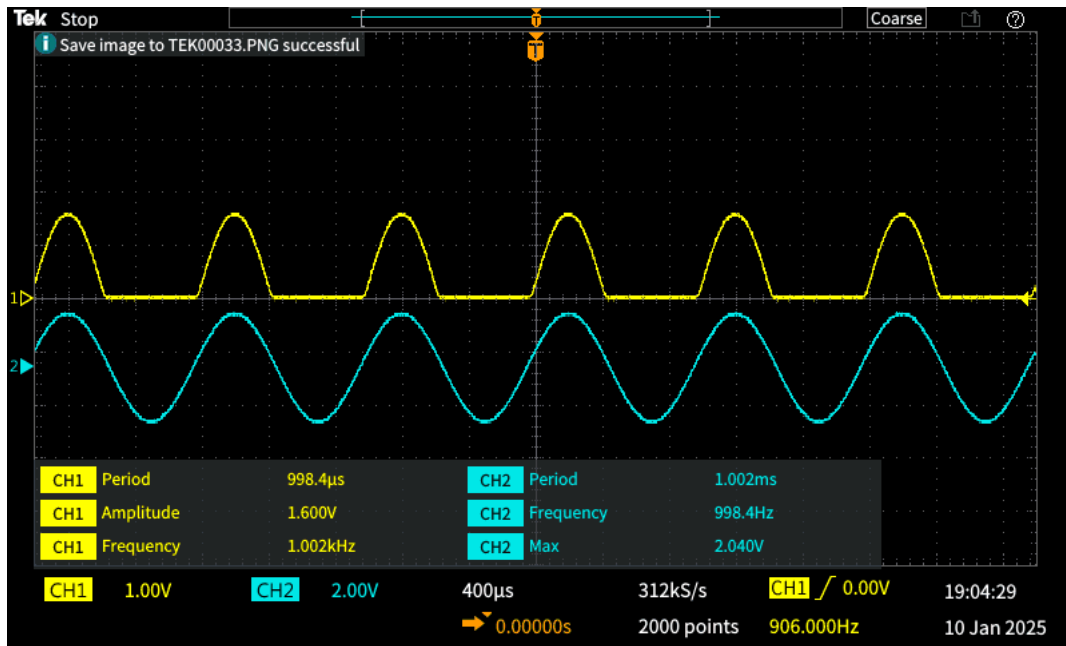


Figure 16: V_o and V_i against t

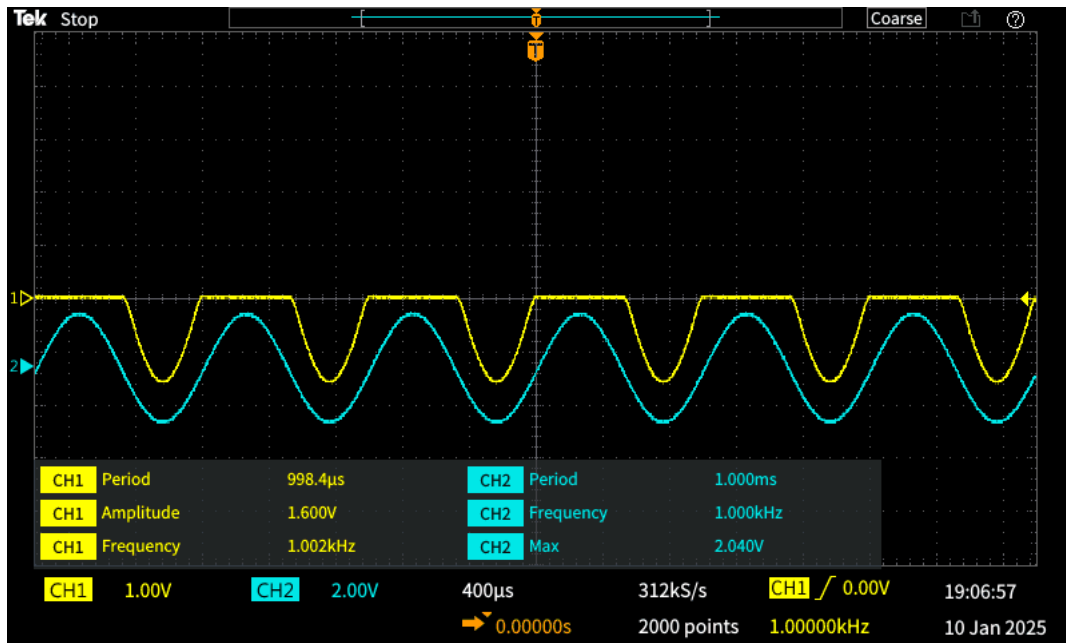


Figure 17: V_o and V_i against t after change of polarity of diode

4.4 Conclusion and Inference

1. The reduction in the peak amplitude between the input and the output voltage is attributed to the diode drop which is the voltage required to overcome the internal voltage barrier of the diode.
2. Now, by changing the polarity of the diode, the direction in which the current flows gets reversed and the graph of V_{out} gets flipped across the x-axis leading to only negative voltages at the output terminal.

4.5 Experiment completion status

The experiment, in its entirety was completed in the lab itself with some help from the intelligent and very kind TA.

5 OpAmp based negative feedback circuits - Non Inverting Amplifier

5.1 Aim of the experiment

To study the operation of an inverting amplifier circuit by analyzing its input and output waveforms. Specifically:

1. Plot the input and output waveforms for a sinusoidal input of 0.1 V peak at 1 kHz and observe the circuit's behavior.
2. Vary the input amplitude from 0.1 V to 2 V, observe changes in the output waveform, and explain the behavior of the output voltage beyond a certain input threshold.

5.2 Design

The experiment involves an inverting amplifier circuit using an operational amplifier (OpAmp) powered by a ± 15 V dual supply. Key components include resistors $R_1=1$ k Ω and $R_2=10$ k Ω , a signal generator to provide a sinusoidal input with an initial peak amplitude of 0.1 V at 1 kHz, and a digital storage oscilloscope (DSO) for plotting input (V_i) and output (V_o) waveforms. The circuit is arranged with R_1 connected between the input signal and the inverting terminal of the op-amp, and R_2 providing feedback between the output and the inverting terminal. The non-inverting terminal is grounded. The output is measured directly on the DSO, which serves as the load. Changes in input amplitude from 0.1 V to 2 V are applied, and the corresponding output waveforms are observed and analyzed.

$$V_o = V_i \left(1 + \frac{R_2}{R_1}\right) \quad (\text{Operating Mode}) \quad (6)$$

$$V_o = 15V \quad (\text{Saturation Mode}) \quad (7)$$

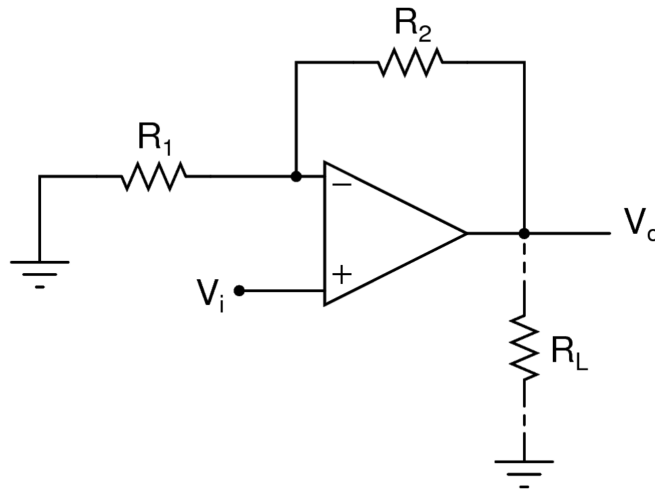


Figure 18: Non-Inverting Amplifier

5.3 Experimental results

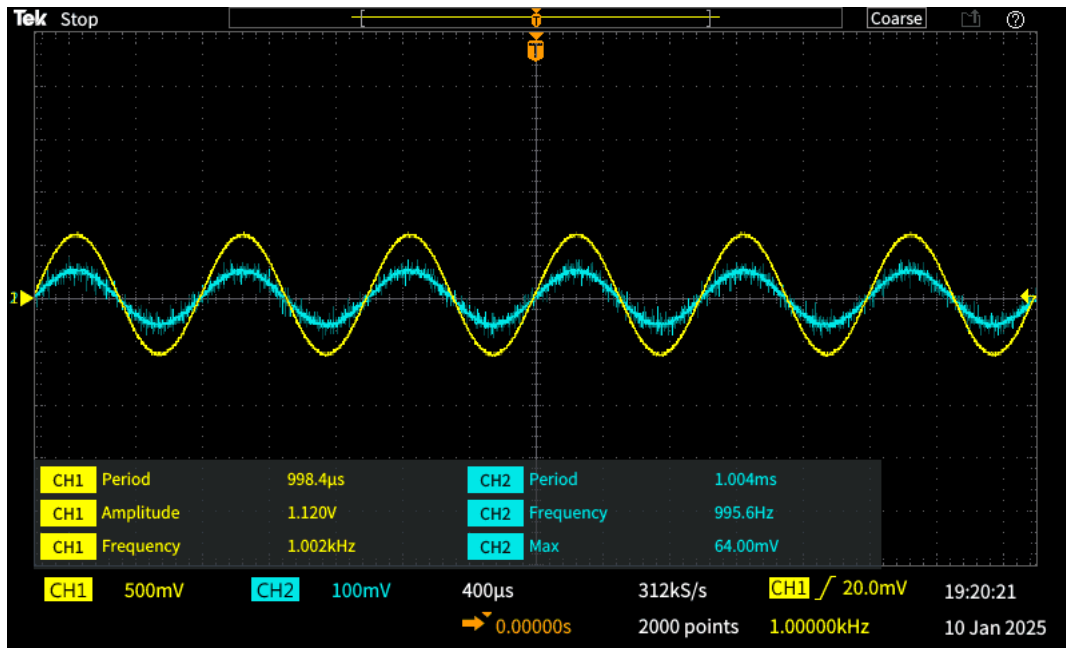


Figure 19: V_o and V_i against t

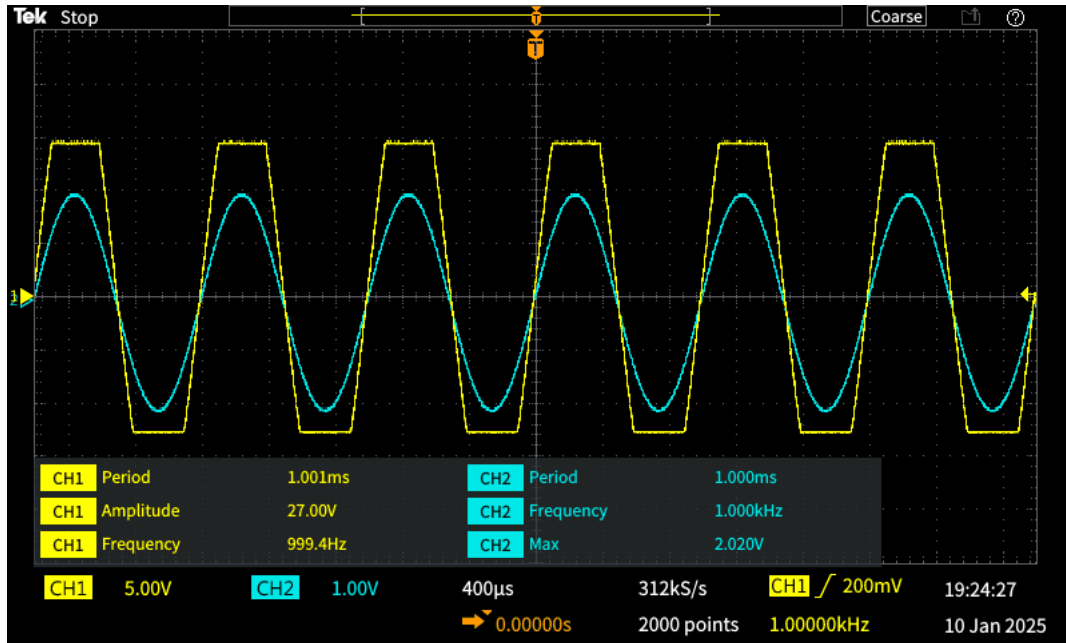


Figure 20: V_o and V_i against t at $|V_i| = 2$ V

5.4 Conclusion and Inference

1. By changing the input amplitude from 0.1 V to 2 V, we exceed the voltage threshold for the amplifier and it goes into the saturation mode, outputting a voltage of 15 V regardless of the input voltage.

5.5 Experiment completion status

Each and every part of this very long experiment was performed by me at the lab and nothing was left for later.