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# Lab 1 Report: Introduction to Digital Oscilloscopes

## Purpose

The purpose of the experiment is to get familiar with digital oscilloscope and signal generator by observing basic signal measurements. Moreover, we learn how to set up a basic circuit on a breadboard.

## Methodology

Task 1: In order to make measurements more accurate, we need to compensate the probe by using oscilloscope's compensation signal. The oscilloscope provides built-in reference square wave and it is available at the probe compensation output on the front panel. First, I connected my probe to Channel 1 of the oscilloscope. I attached the ground clip of the probe to the ground and probe tip to signal terminal. At first, the displayed square wave had distorted corners, which means that the probe is not compensated accurately.  After that in the square wave guide, I corrected the distorted corners using the adjustment tool until they became flat. After this adjustment, the probe was properly compensated and ready to used.

Task 2: I used the signal generator to create 5 Volt (peak-to-peak) sinusoidal signal with frequency 1kHz. In order not to have any DC component, I set 0 V DC offset on the signal generator. After that the signal generator signal output was connected to the probe of Channel 1 of the oscilloscope. The ground clip of the probe was attached to the common ground line. The triggering mode controls whether the trigger point is on positive slope or negative slope of the signal. At first, rising edge triggering was used, then it was switched to falling edge triggering.

Task 3: A triangular wave with 1 V (peak-to-peak) amplitude and 2kHz frequency was generated by signal generator. The trigger level sets the voltage point at where oscilloscope starts to capture the signal wave. At this step, I adjust trigger level knob gradually in order to observe how the display changes depending on the trigger point.

Task 4: A digital-to-analog converter (DAC) is a system that converts digital data to analog signals. In contrast, an analog-to-digital converter (ADC) converts an analog signal into digital information. An ADC expresses the continuous input signals as discrete digital values, generally in binary form. By doing so, the data can be processed by digital devices. For instance, microphones and digital cameras use ADCs to convert real-life values to digital ones. A DAC takes digital values, usually in binary form, and converts them into an analog signal such as current or voltage. In this way, information stored digitally can be converted back into signals so that they can be used in real-world systems (like displays or speakers). In oscilloscopes, an analog-to-digital converter (ADC) is used. The oscilloscope samples the incoming electrical signals through the ADC and converts them into binary values. These binary values are then processed and displayed on the screen as a waveform. In order to observe acquisition modes, I generated a 1 V (peak-to-peak) square wave with a 5kHz frequency using the signal generator. First, I used Sample mode, where the oscilloscope takes one sample at each time interval to form the waveform. This is the simplest mode, but very short variations in signal may not appear. Then, I switched to Peak Detect mode. In this mode, the oscilloscope records the minimum and maximum values within each interval. That makes it possible to see sudden changes in waveform that are not visible in Sample mode. Finally, I used Average mode, where the oscilloscope takes averages of multiple acquisitions. This process produced a smoother waveform by reducing random noise.

Task 5: At this stage, I observed the difference between DC coupling and AC coupling on the oscilloscope. DC coupling allows both the DC and AC components of a signal to be displayed. AC coupling blocks the DC component of the signal and shows only alternating part of the waveform. To demonstrate that, I applied a sinusoidal signal with a + 1 V DC offset to the oscilloscope and observed it first in DC coupling mode and then in AC coupling mode.

Task 6: A breadboard is a tool that allows circuits to be built quickly without soldering. It has many holes on the surface where electronic components and jumper wires can be placed, and the rows inside are already connected and on the sides there are + and – columns used for power and ground. First, I set up a basic circuit using jumper wires, breadboard, resistor and capacitor, as shown in Figure 6.1. I connected 1 μF capacitor and 1 kΩ resistor in series on the breadboard. The point between the capacitor and the resistor was defined as point Y, while the input from the function generator was defined as point X. Then I generated a 2 V (peak-to-peak) sinusoidal signal at 1kHz with 0 V DC offset. I borrowed my friend's probe and attached it to Channel 2 of the oscilloscope and connected it to point Y while attaching the first probe to Channel 1 and connecting to point X. The ground connections of the signal generator and the oscilloscope channels were all connected to the same ground line.

To evaluate phase shift in the circuit, I used the oscilloscope's cursors to measure the time delay ($\Delta t$) between the input signal at point X and the output signal at point Y. The phase difference ($\varphi$) can be calculated with the given formula:

$$\varphi = 360° \times f \times \Delta t$$

Where $\varphi$ is the phase difference in degrees, $f$ is the frequency of the applied signal, and $\Delta t$ is the measured delay. As the signal frequency increases, the impedance of the capacitor decreases. This leads to a reduction in the phase difference between the input and output. As a result, the phase shift is noticeable at low frequencies but becomes very small at higher frequencies. After completing the calculation at 1 kHz, I repeated the same procedure with a 100 kHz sinusoidal signal and observed the difference.

## Result

Task 1: I first attached my probe to oscilloscope as I have mentioned before. Then I observe that the probe was overcompensated due to the fact that square wave corners are distorted upwards. Before compensation, the signal was as shown in Figure 1.1. After adjusting the probe with compensation tool, the expected square wave form was observed, which means that the compensation properly done, as shown in Figure 1.2.

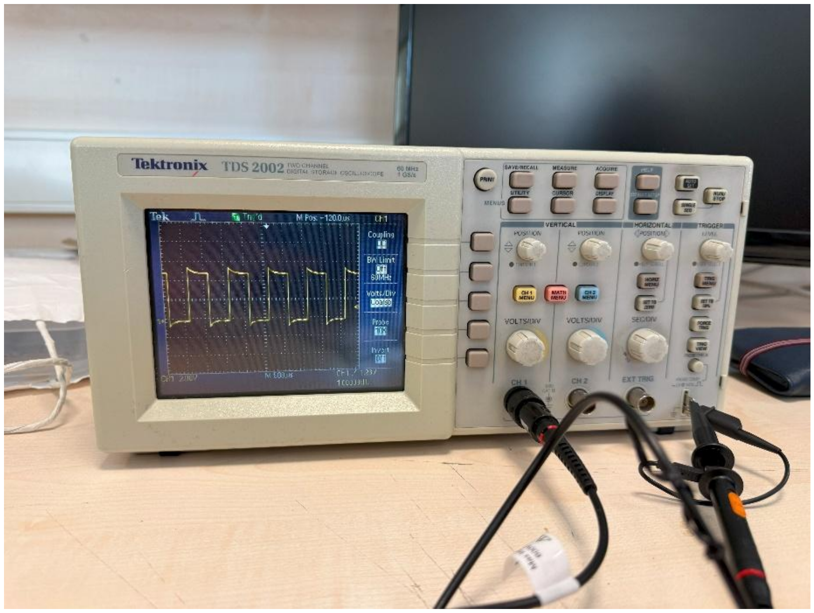


**Figure 1.1: Before Compensation (Overcompensated)**

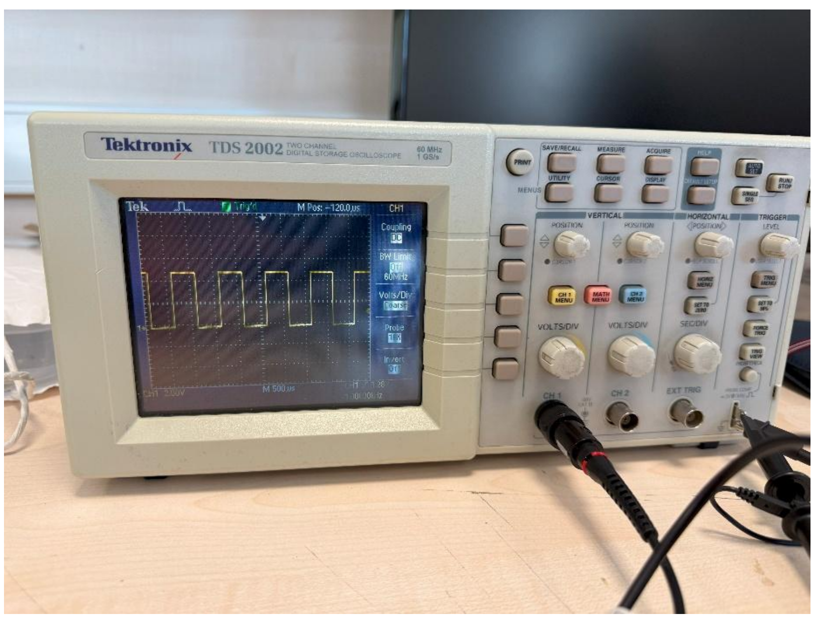


**Figure 1.2: After Compensation**

Task 2: I generated a 5 V (peak-to-peak) sinusoidal signal with 1kHz frequency and there is no DC component. Then I used positive and negative edge triggering. First, in Figure 2.1, I used positive edge triggering, where the trigger point stayed on the rising edge of the signal. After that, I applied negative edge triggering and the oscilloscope used the falling edge of the waveform as the trigger point, as shown in Figure 2.2. I found that the positive edge triggering and the negative edge triggering waveforms are symmetric with respect to the y-axis.

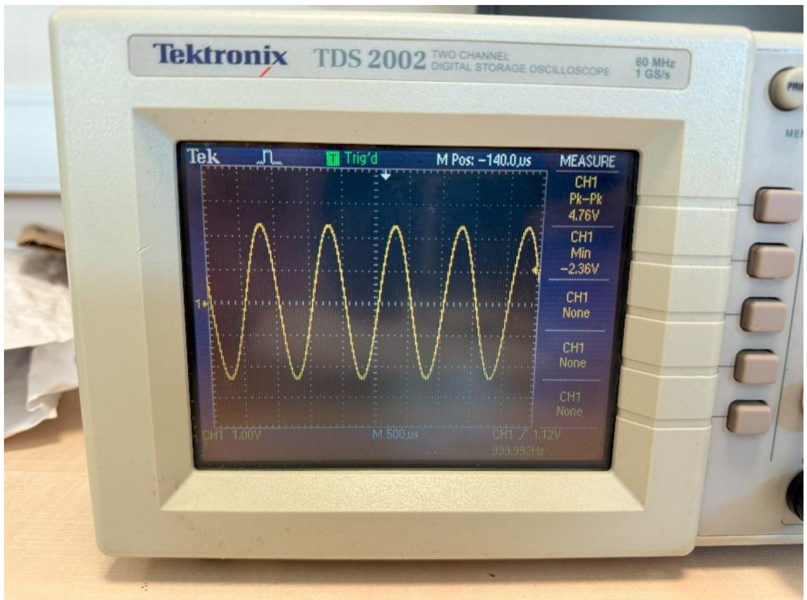


**Figure 2.1: Sinusoidal wave with Positive Edge Triggering**

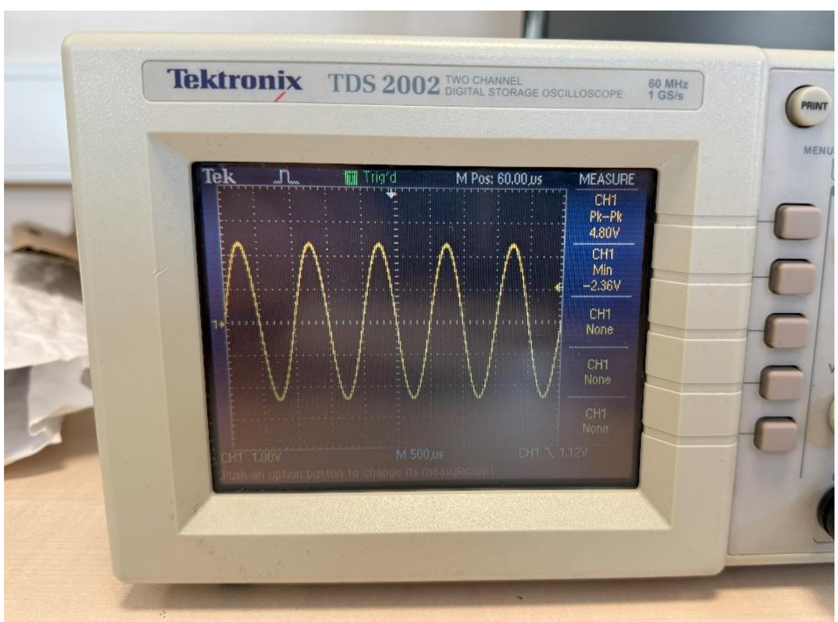


**Figure 2.2: Sinusoidal wave with Negative Edge Triggering**

Task 3: I applied 1 V (peak-to-peak) triangular wave with 2kHz frequency to the oscilloscope. Then I gradually adjusted the trigger level knob, making the waveform shift horizontally on the screen. While the trigger level was within the amplitude range of the signal, waveform appeared stable on screen, as shown in Figure 3.1. However, when I moved the trigger level outside of this range, the waveform became unstable and started shifting on the display, as shown in Figure 3.2.

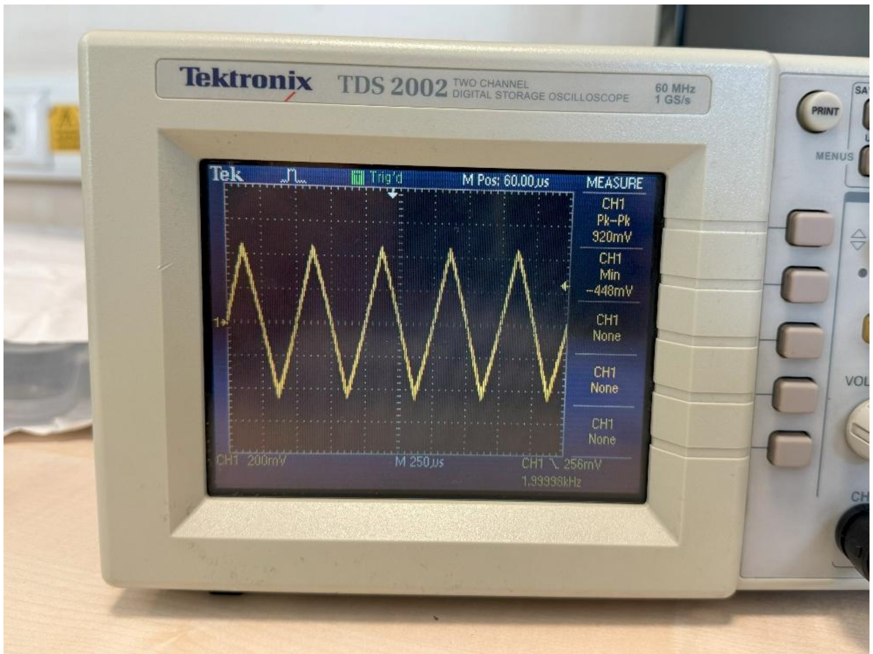


**Figure 3.1: Stable Waveform**

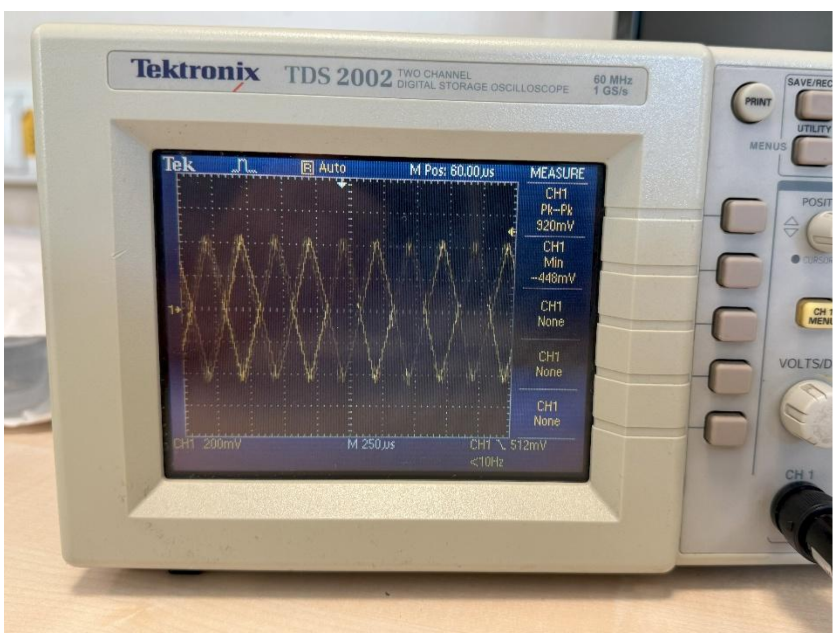


**Figure 3.2: Unstable Waveform**

Task 4: I generated a 1 V (peak-to-peak) square wave with 5kHz frequency to test acquisition modes. First, the oscilloscope displayed the waveform on Sample Mode by taking one sample per interval, as shown in Figure 4.1. Then I switched to Peak Detect Mode in Figure 4.2, where the maximum and minimum points were recorded for each time interval. Finally, I used Average mode, where the random noise was reduced, demonstrated in Figure 4.3.

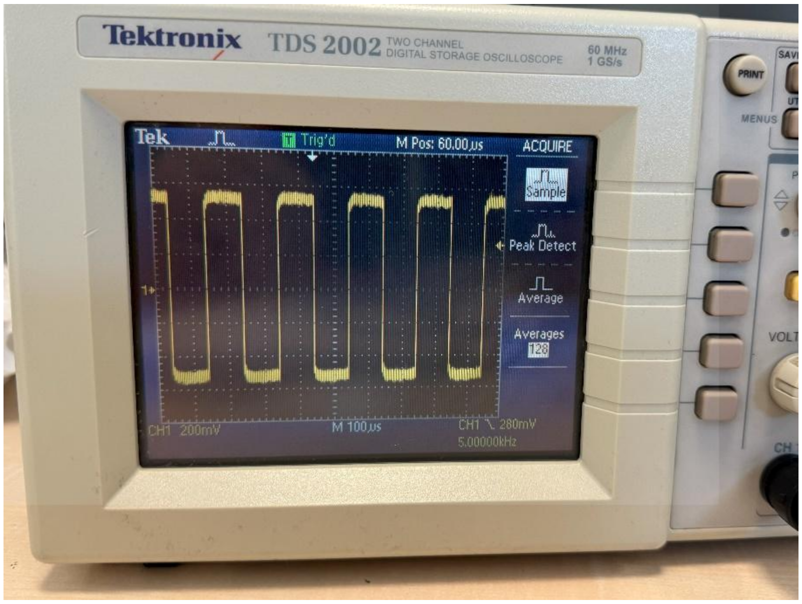


**Figure 4.1: Square Wave in Sample Mode**

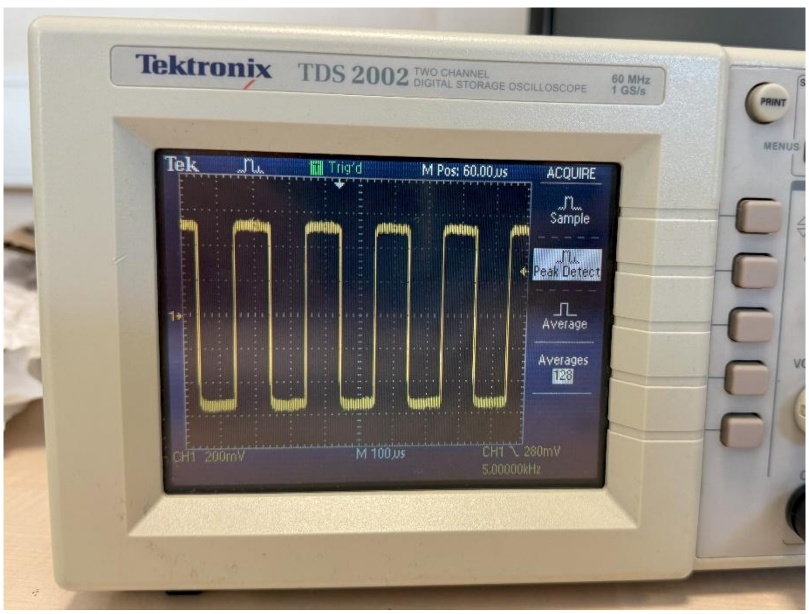


**Figure 4.2: Square Wave in Peak Detect Mode**

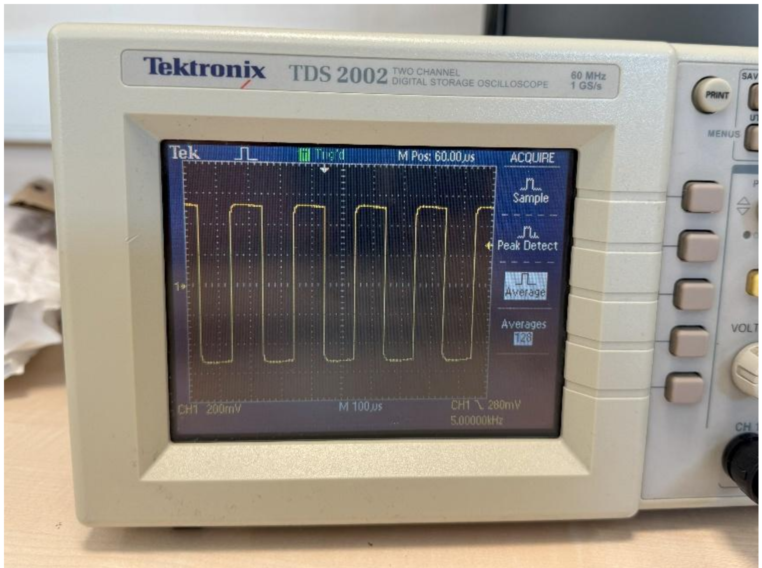


**Figure 4.3: Square Wave in Average Mode**

Task 5: By generating a sinusoidal signal with 2 V (peak-to-peak) amplitude and 1kHz frequency. I also applied a 1 V DC offset. In Figure 5.1, I used DC coupling, which made the offset visible and the waveform shifted upward due to the DC component of the signal. Then I applied AC coupling, which blocked the DC component and made the sinusoidal waveform centered around zero volts, illustrated in Figure 5.2. In DC coupling mode the minimum value of the waveform was about 0 V, whereas in AC coupling mode the minimum value dropped to – 1. This happens because AC coupling mode blocks the DC offset and shift the entire waveform so that it is centered around 0 V.

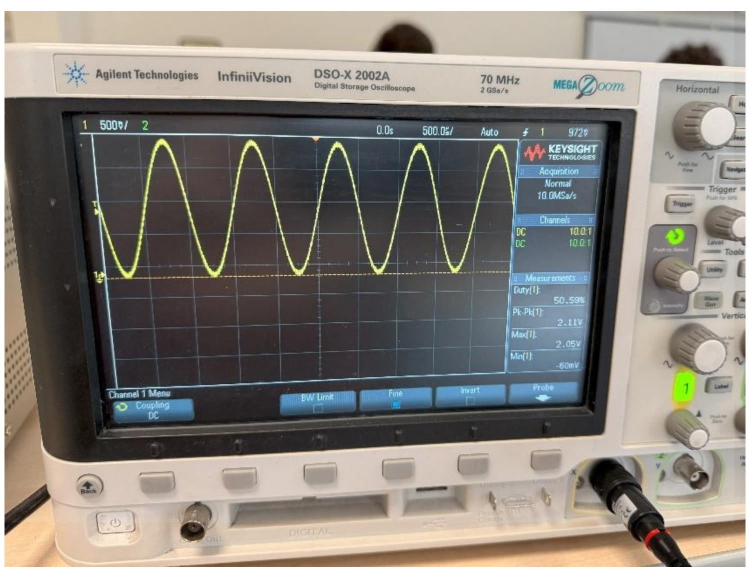


**Figure 5.1: Signal with DC Coupling**

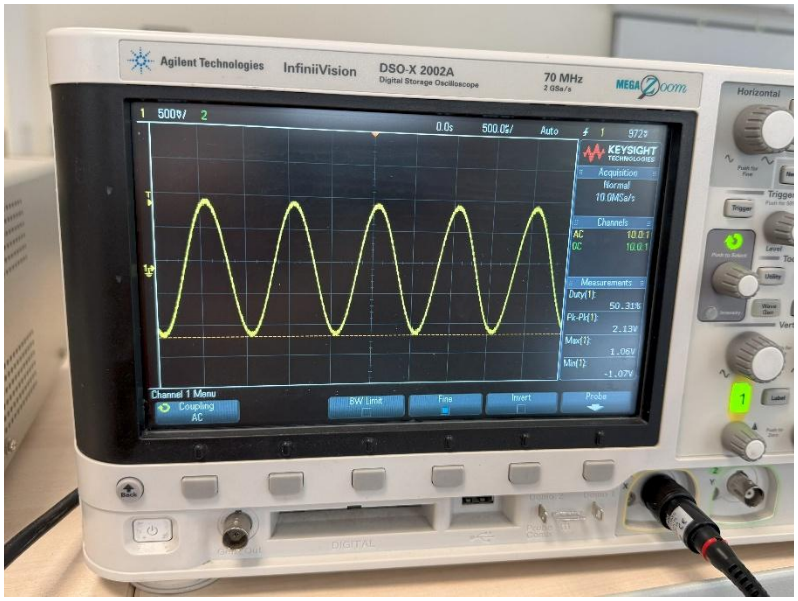


**Figure 5.2: Signal with AC Coupling**

Task 6: I set up the circuit on the breadboard and applied a 2 V (peak-to-peak) sinusoidal signal with 1 kHz frequency (with 0 DC offset). The set up of the circuit can be seen on Figure 6.1 and by generating X and Y signals I measured the time delay ($\Delta t$) and the voltage difference. There was nearly 0.1 V voltage difference and the time delay was – 14 microseconds ($\mu s$), which can be seen on Figure 6.1. After that I increased the frequency from 1 kHz to 100 kHz. Then I calculated the voltage difference as nearly 0.3 V and the delay was 45 nanoseconds ($ns$). Using the formula that I have mentioned above, the phase difference angle was 5.0° for the 1kHz signal and 1.6° for the 100 kHz signal. Furthermore, the small voltage variations can be explained by device limitations and measurement uncertainty.”. As a result, consistent with theoretical expectation, the phase angle decreased as the frequency increased. The phase difference for the signals with 1 kHz is shown in Figure 6.2, whereas the result for 100 kHz is presented in Figure 6.3.

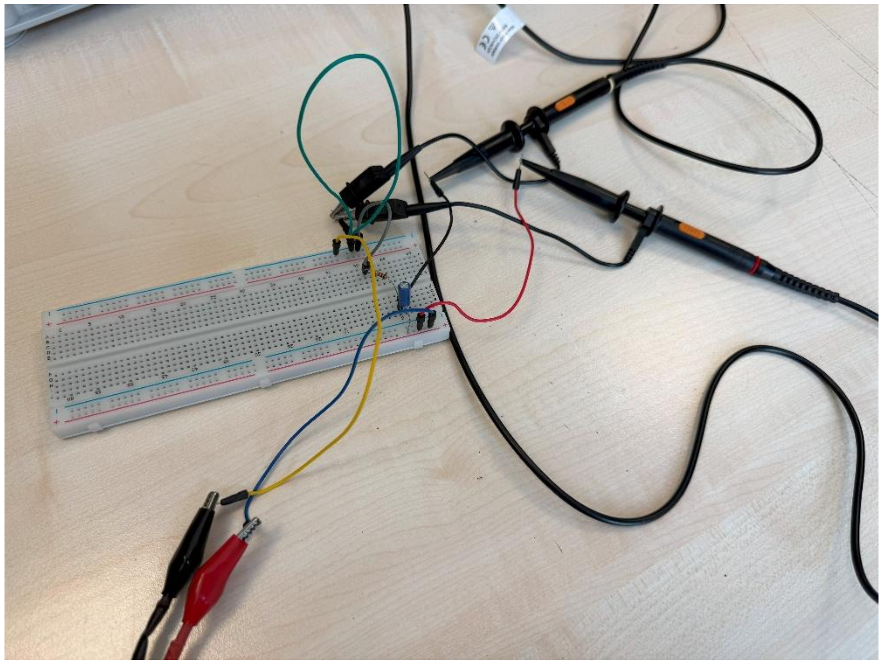

**Figure 6.1: Circuit Setup on Breadboard**

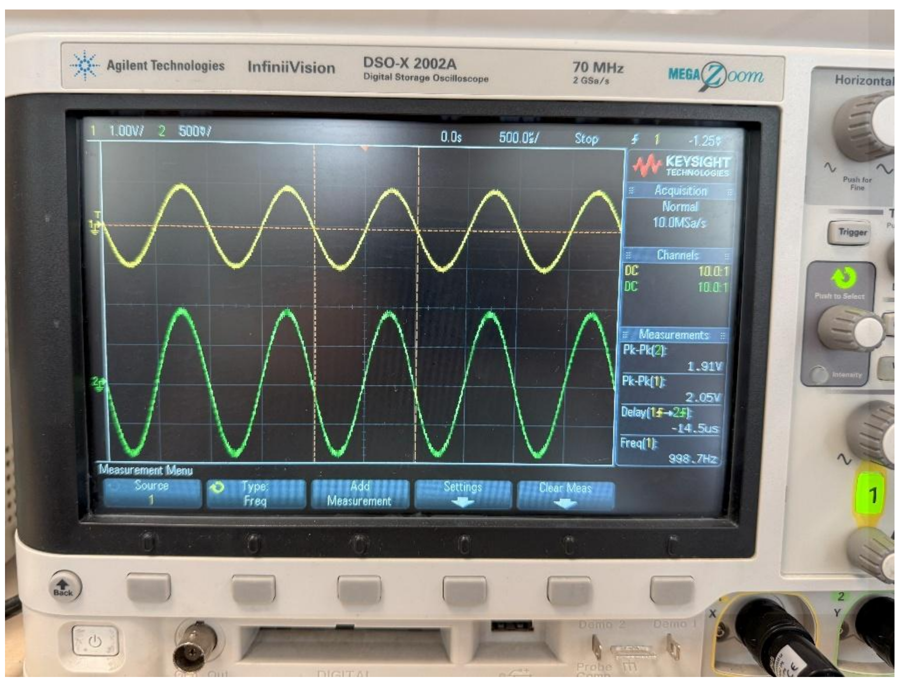


**Figure 6.2: Measured Signals at 1 kHz**

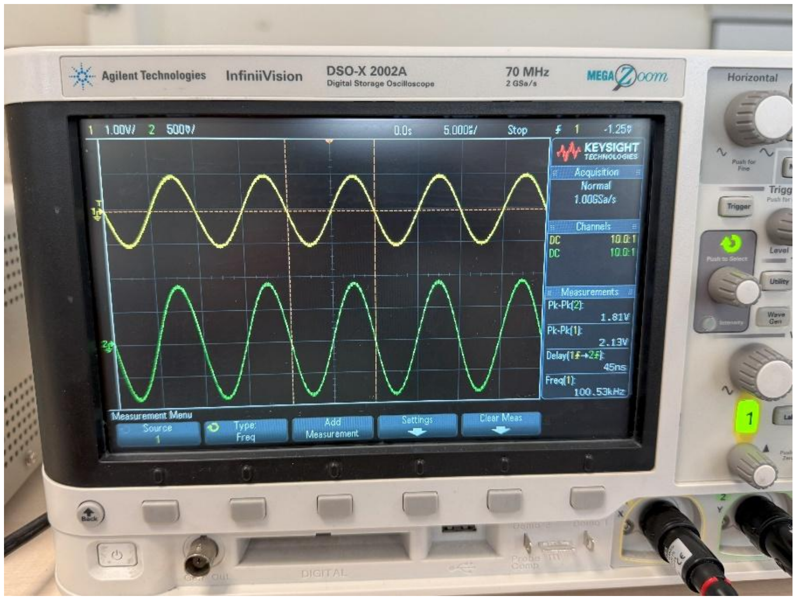


**Figure 6.3: Measured Signals at 100 kHz**

## Conclusion

In this lab, I learned the basic principles and the practical use of the oscilloscope and signal generator. I first learned how to compensate a probe and understood its importance for accurate measurements. I also practiced using different coupling and edge triggering, as well as acquisition modes. Finally, I measured the time delay and phase shift between two signals and observed that the phase difference decreases as the frequency increases which matches with theoretical formula. Overall, this lab provided a clear understanding of how to properly use oscilloscope and signal generator. Furthermore, I have learned how to set up a basic circuit on breadboard and working principle of the breadboard.

## References

https://www.totalphase.com/blog/2022/06/analog-vs-digital-signals-adc-vs-dac/?srsltid=AfmBOophwrD1dtO-DGJ-TN2QJ25EFYqhi4X5gdk6fXvDnss1L8mFczVz

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