Introduction to Oscilloscopes

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1 Introduction

In this exercise we aim to learn how to operate the oscilloscope by performing various exercises based on its functions. The controls are broken down into three overarching categories:

i) Vertical System Controls: These controls include the y-motion, vertical position, vertical sensitivity (volts-per-division), input channel selection (CH1/CH2) and DC-AC group input coupling switches.
ii) Horizontal System Controls: These controls include x-motion, horizontal position, horizontal sensitivity (time-per-division) and acquisition sweep speed.
iii) Trigger System: This system synchronizes the horizontal sweep with the correct point from the signal to stabilize the waveform. These controls include: trigger level, slope, modes and coupling.

The Oscilloscope used in this experiment is the Tektronix TDS210 or TDS1002 which has knobs and buttons organized based on the above systems. Learning these systems and functionalities helps improve our understanding of the instrument and will prove to be important for future experiments which utilize the oscilloscope.

2 Methods and Materials

The materials utilized for this experiment were: an oscilloscope, a Wavetek wave generator, an instrument which supplies various variations of AC and DC current (60 Hz). The voltages provided by this instrument are:

i) VDC (11V in DC)
ii) VACDC (1V AC superimposed on 11V DC)
iii) VREF (8V RMS – 11V in AC)
iv) VPH (8V RMS AC with adjustable phase with respect to the VREF)
v) VREF-VDC (8V RMS AC superimposed on 11V DC).

Various cables are also used to connect the instruments according to the exercises.

3 Experimental Procedure

Exercise A: For this exercise the oscilloscope is used in the time-base mode with only one beam turned on. We begin by applying autoset to the instrument and selecting the edge function in the trigger menu. The mode is then set to auto with the source set as CH1. The CH1 input is connected to the Function Generator Main Out for a sine waveform with 10 kHz frequency. The beam is adjusted to be at vertical centre by using the vertical system controls. Throughout the experiment the coupling is switched between AC and DC to observe and correct for the offset in the waveform.

Exercise B: Again, the Oscilloscope is set to time-base mode. The CH1 input is connected to the Function Generator Main Out the same way as the previous exercise and the source is selected to be EXT with mode set to auto still. The trace is positioned horizontally to allow the trigger to be near the horizontal. Then the SEC/DIV sweep controls are set such that only one or two periods of the waveform appear on the screen. The functionality of auto trigger mode is explored by changing the trigger source between channels. Additionally, the normal trigger mode is applied with different trigger levels and slope.

Exercise C: The following trigger settings were used for this exercise: type – edge, source – CH1, slope – rising, mode – auto and coupling – DC. A MHz sawtooth wave signal's period and frequency is measured both manually and using the measure functionally on the Oscilloscope. The cursor tool is also applied to check if these values agree with our observations. Using the probe comp terminal for a standard 1kHz and 5V voltage, we are able to check the calibrations and response to a square wave.

Exercise D: For this exercise the oscilloscope is used in the XY mode to plot the vector sum of displacements in two perpendicular directions for two applied voltages. The coupling of both CH1 and CH2 are set to DC; VREF is applied to CH1 and VPH is applied to CH2 for three separate phases (45^o, 60^o and 90^o).

Exercise E: Using a BNC-banana cable on CH1 with the other end exposed the noise is filtered with the average functionality in the acquire menu on the Oscilloscope. The average is also applied for various numbers (4, 16, 64 and 128).

4 Observations and Comments

4.1 Exercise A – Plotting one voltage on a Y input as a function of time:

First the coupling is set to ground and we observe a flat signal, thus implying that there is no signal. This is because the coupling of the signal is set to ground which itself does not supply any voltage to the system. Setting the coupling to DC we observe a sinusoidal waveform. When the offset is changed using the "+" division, the waveform moves up and the "-" division results to the waveform moving down.

However when the offset is changed, the frequency and amplitude of the waveform remain constant; this suggests that the offset corresponds to shifting the voltage of the entire signal. Then the coupling is switched to AC and the sinusoidal waveform shifts back to vertical centre because it is only measuring the AC signal in the system. Cancelling the DC offset with DC coupling causes the waveform to move back to vertical centre but the signal is slightly lower than the AC coupling. To get them to be identical, we must couple with AC and cancel the DC offset.

Normally, the oscilloscope should be used with DC coupling because it shows you the whole signal and thus the actual voltage. On the other hand AC coupling only shows the AC component of the signal (hence the initial offset between the two waveforms). Using AC coupling is useful for certain conditions, for example to remove the average DC bias. Specifically this would be useful if you wanted to look at any voltage deviations in the system from that average.

4.2 Exercise B – Using the oscilloscope to plot voltages as a function of time with varying trigger methods:

Setting the source to CH1 in the trigger menu displayed a normal sinusoidal waveform that is still. When this is switched to CH2 the trace becomes very chaotic and unstable; it appears as if the waveform is moving around a lot. Setting the source of EXT has a similar outcome to CH2 where the trace becomes chaotic. For AC LINE the trace becomes increasingly unstable; more than CH2 and EXT even. For this setting it appears that the waveform is rapidly sweeping across the screen. Although, if the oscilloscope is connected to the external trigger input using a T-connector while on EXT source, a normal sinusoidal waveform is produced similar to the first observation for this sub-section.

Then the trigger mode is set to normal with CH1 as the source and trigger level is changed. It is observed that the trigger level shift the waveform horizontally (raising trigger level moves the wave left and lowering moves it right). After a certain point at either extreme the waveform stops shifting horizontally and it appears that it beings to fade out. If instead the trigger slope is changed, the point where the waveform starts is altered. A rising slope makes it such that the wave starts at its minimum point and alternatively a falling slope causes it to start at a maximum point.

Changing the horizontal position knob for the CH1 trace we find that this causes the trace to shift horizontally.

4.3 Exercise C – Frequency measurement and the calibration signal:

The calibration for this exercise is discussed in the experimental procedure section. In the measure functionality there are a plethora of tools that can be used to analyze the waveform, these include:

i) FREQ: Measures the frequency of the wave, i.e. the number of waves the passes a given point per second.

ii) PERIOD: Measures the period of the wave, i.e. the time needed to complete one cycle.

iii) MEAN: Measures the mean voltage (y-axis) of the wave.

iv) PK-PK: Measure the difference between the highest and lowest peaks for the voltage.

v) CYC RMS: Measures the room mean square which is defined to be $\sqrt{< v^2 >}$, for voltage v. For a sawtooth waveform this value is defined to be $A/\sqrt{3}$, for amplitude A.

The measurements using the measure functionality were as follows: FREQ = 1.025 MHz, PERIOD = 972 ns, MEAN = -159 mV, PK-PK = 15.7 V and CYC RMS = 4.56 V.

Using the cursor functionality the previous measurements were verified manually. The following values were obtained: PERIOD = 980 ns, FREQ = 1/PERIOD = 1.020 MHz, PK-PK = 15.6 V (7.68 to -7.92V), MEAN = (7.68 - 7.92)/2 = 120 mV, CYC RMS = $A/\sqrt{3}$ = 4.50 V. These values agree with the measurements directly from the oscilloscope within a reasonable margin.

The probe comp terminal has a standard 1 kHz and 5V voltage which creates a very square wave shape. This was used to check the calibrations of the system by checking the height, frequency and shape of the signal. The results were: PK-PK = 5.12 V, FREQ = 1.00 kHz and the shape was a square waveform. Thus it was concluded that the signal matches with the expected outcome for the probe comp terminal.

4.4 Exercise D – Using the oscilloscope as a two dimensional voltmeter:

For the calibrations of this exercise please refer to the experimental procedure section. For the 45^o phase we find that the x-component (CH1) and y-component of the system are described by:

$$x(t) = Acos(\omega t)$$

$$y(t) = Acos\left(\omega t - \frac{\pi}{4}\right)$$

Where $x(t)$ and $y(t)$ are the two perpendicular components of the system as a function of time, A is the amplitude of the wave, ω is the frequency, t is time and $\pi/4$ is the phase difference. Thus we can combine these two components to show that the voltage is:

$$V(t) = Acos(\omega t)\hat{x} + Acos\left(\omega t - \frac{\pi}{4}\right)\hat{y}$$

Due to the phase shift between the two components, the Lissajous figure becomes a slanted ellipse.

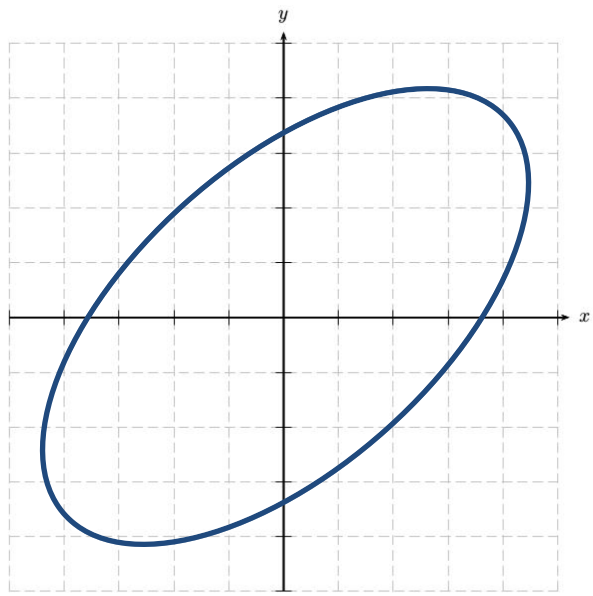

Figure 1: *Lissajous figure for a phase shift of 45°($\pi/4$) between the x and y voltage components.*

Similarly for the 60° phase shift, we find the voltage in the system over time is described by:

$$V(t) = Acos(\omega t)\hat{x} \; + \; Acos\left(\omega t - \frac{\pi}{3}\right)\hat{y}$$

Where all that has changed from the previous case is that the phase shift is now $\pi/3$. Again, this describes an ellipse, however it is slightly more round and approaching a circular shape than Figure 1.

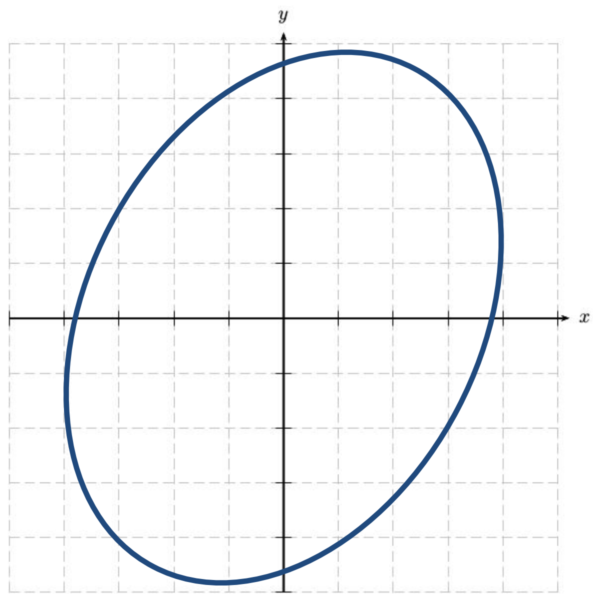

Figure 2: *Lissajous figure for a phase shift of 60° ($\pi/3$) between the x and y voltage components.*

Finally for the case that the phase shift is 90° the voltage is described by:

$$V(t) = Acos(\omega t)\hat{x} + Acos\left(\omega t - \frac{\pi}{2}\right)\hat{y} = Acos(\omega t)\hat{x} + Asin(\omega t)\hat{y}$$

$$\Longrightarrow |V(t)| = \sqrt{A^2 \cos^2(\omega t)\,\hat{x} + A^2 \sin^2(\omega t)\,\hat{y}} = \sqrt{A^2(1)} = A$$

However, this implies that $|V(t)|$ is constant and therefore the Lissajous figure for the case that the phase shift is 90° is given by a circle.

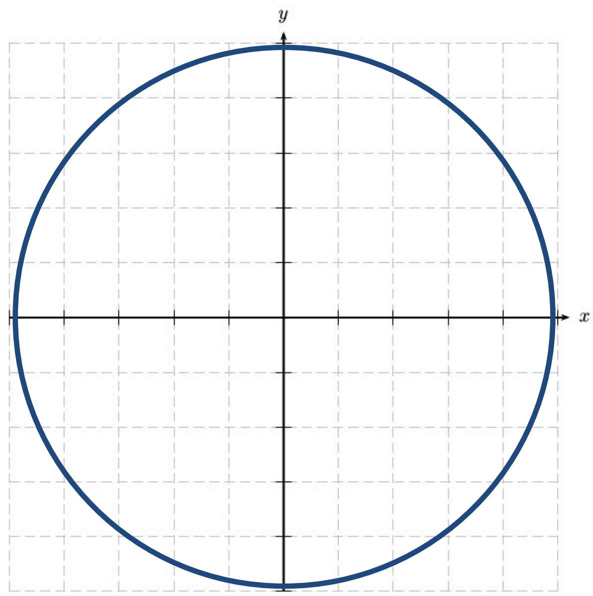

Figure 3: *Lissajous figure for a phase shift of 90° ($\pi/2$) between the x and y voltage components.*

Overall this exercise shows a trend that as the phase difference approaches 90° from 0°, the shape of its Lissajous figure becomes more circular. Ideally this would reverse between 90° and 180° and the shape would progressively become more elliptical again.

4.5 Exercise E – Noise cleaning:

Bringing the open cable closer to an instrument or cables we find that the noise on the oscilloscope increases. This is due to there being a stronger voltage near instruments and cables than in the rest of the room. Using the average functionality in the acquire menu this noise is cleaned for various average numbers (4, 16, 64 and 128). As you increase these numbers, more noise is cleared and the waveform becomes increasingly flat.

5 Conclusion

Through these exercises we were able to understand the functionalities of an oscilloscope and how to operate one for future experiments. In the first exercise we plotted one voltage source as a function of time and dealt with the offset between AC and DC coupling. Additionally noting that most times it is beneficial to use DC coupling but there are specific cases where AC coupling is preferred such as when we want to remove the average DC bias. For the second exercise we varied trigger methods and found that when the oscilloscope input matches the source we are using, a stable waveform is produced, otherwise it becomes very chaotic and unstable. Additionally, changing the trigger level shifts the waveform horizontally and the trigger slope can be set to rising (wave starts at min) or falling (wave starts at max). From the third exercise we learned about the measure and cursor functionalities which can be used to a wide range of measurements regarding the waveform. In the fourth exercise we plot two voltages on perpendicular axes to generate Lissajous figures for the voltage at different phase shifts. It is found that as the phase difference approaches 90^o from 0^o, the shape of its Lissajous figure becomes more circular. Finally, in the fifth exercise we learn how to remove noise using acquire menu on the oscilloscope; more noise can be removed by increasing the average numbers (4, 16, 64 and 128).

6 References

[1] Pandhi, A. and Chen, X., University of Toronto, Toronto, ON. "PHY224 Laboratory Notes: Introduction to Oscilloscopes", October 2018.