Principles of Physics II (PHY112)

Lab

Experiment no: 3

Submitted by : TASNIM RAHMAN MOUMITA

ID : 22301689

Theory Section : 02

Lab section : 02

Name of the experiment : Determination of the line frequency of Alternating Voltage signal generated by the electric power plant with the help of an alternating voltage signal of known frequency by forming Lissajous curves in an oscilloscope and the determination of the time base of the oscilloscope

Experiment no: 3

Date of Submission : 10.12.2023

Lab

Experiment no: 3

Determination of the line frequency of Alternating Voltage signal generated by the electric power plant with the help of an alternating voltage signal of known frequency by forming Lissajous curves in an oscilloscope and the determination of the time base of the oscilloscope

Resources:

Link for online lab:

- **Lissajous Curves | Academo.org - Free, interactive, education.**
- **Virtual Oscilloscope | Academo.org - Free, interactive, education.**

List and link for the graph-plotting softwares:

- Desmos (Online): Link for the "Desmos" software
- Graph (Offline): Link for the "Graph" software

Tutorials (Graph-plotting):

- Tutorial link for plotting in **Desmos** :
  https://www.youtube.com/watch?v=-lIUNWVKnUY

- Tutorials link for the **Graph** :
  How to install graph software:
  https://youtu.be/e19JqLJMx3A
  How to draw a curve using graph software:
  https://youtu.be/QBkdzU_8vVo
  How to calculate the slope of a line using graph software:
  https://youtu.be/z4cMiUFu5j8

Video-links (Tutorial: Experiment #3):

- CRO (Part I)
- CRO (Part II)

Theory

Alternating current periodically alternates its direction while flowing through a wire. If the alternating current is *sinusoidal* then its magnitude gradually increases from zero to a maximum value towards one direction. This maximum value is the *amplitude* of the alternating current. Then, it decreases down to zero while flowing in this direction. Next, it begins flowing to the opposite direction and its magnitude gradually increases to that direction to reach maximum, i.e. amplitude. After that, its magnitude gets reduced to zero while flowing in the latter mentioned way. Thus a full cycle is completed by the alternating current. Then, again it begins flowing to the first direction and keeps the whole process continuously repeating. The number of complete cycles made by this alternating current per unit time is called its frequency.

Our power plant generates Alternating Current which we use for running our everyday's major electronic devices. In the first part of this experiment we are going to determine the frequency of this Alternating Current, called *power line frequency*. To transmit electrical power efficiently the power plant transmits the power at an alternating voltage of high amplitude and by means of an alternating current of low amplitude[1]. For safer use of this electric power we have to use a step down transformer to transform this alternating voltage of higher amplitude (and current of lower amplitude) to alternating voltage of lower amplitude (and current of higher amplitude). From the electric socket we get the alternating voltage output which is produced by the power plant. A step down transformer receives it as an input and gives an alternating voltage of lower amplitude as an output. However, the frequency of the output alternating voltage remains equal to that of the input alternating voltage. This is the power line frequency which we will determine by using the output alternating voltage.

NOTICE: This part is not necessary to do the simulation but you should read through it to see how the physical oscilloscope works.

Section 1: Cathode Ray Oscilloscope

By using an oscilloscope we can visualize how an alternating voltage signal varies with time. Now, I will briefly discuss the working principle of a Cathode Ray Oscilloscope. In such an oscilloscope there is an electron gun as shown in Figure 1. A coil is connected between two terminals A and B. A potential difference is created between A and B. The terminal A is positive and the terminal B is negative. The current passing through the coil heats up it to emit electrons. Potential difference between A and B heats up the coil. That is why it is called heater voltage.

There is a circular metallic disc, a short distance away from the coil, having a co-centric circular hole in it. This metallic disc is connected with a terminal C. Another voltage difference is created between B and C. B is negative and C is positive. Electrons emitted from the coil get attracted to the positive metallic disc and get accelerated to rush towards the disc. Since, the positive metallic disc attracts negative electrons; the metallic disc is the anode. On the other hand Coil which emits

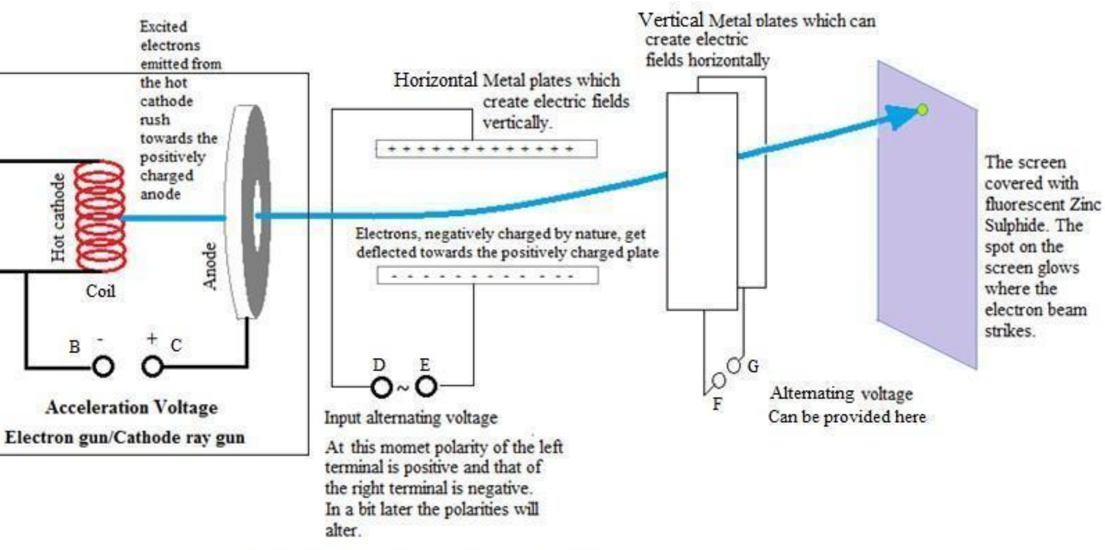
---

1 To know why power is transmitted at alternating voltage of higher amplitude and by means of an alternating current of lower amplitude, you can read this page: https://en.wikipedia.org/wiki/Alternating_current

electrons is the cathode. The accelerated beam of electrons passes through the circular hole of the anode. This flow of electrons is called *Cathode Ray*. The system to produce cathode ray is called *cathode ray gun* or *electron gun*.

The cathode ray passes through a way between two horizontal plane metal plates as shown in Figure 1. The plates are connected with two electrodes D and E which receive the input voltage signal- subject to our inspection. Voltage signal between D and E oppositely charges the metal plates. Figure 1 shows that at this moment the upper plate is positively charged and the lower one is negatively charged. Electrons, which are by nature negatively charged, will be attracted to the positive plate and will get deflected upward. Suppose, sinusoidal alternating voltage difference is provided between D and E and now the voltage difference is maximum. Next, as time moves on, the positive charge of the upper plate will gradually decrease and the negative charge of the lower plate will also gradually decrease. As a result the amount of upward deflection of the cathode ray will gradually decrease. When the electrodes change their polarity the cathode ray gets deflected downward. The downward deflection increases with time, as positive voltage of E and negative voltage of D increase. After the voltage difference reaches maximum, the process reverses. Electrons begin getting deflected upward again. Hence, the alternating voltage input between the terminals D and E forces the cathode ray to oscillate vertically.

Next, the cathode ray passes through a way between two vertical plane metal plates. They are connected with another couple of terminals F and G which can receive alternating voltage signal. Convince yourself that the alternating electric field created between these two plates by the alternating voltage difference between F & G will force the cathode ray to oscillate horizontally. Finally, the cathode ray strikes a screen of the display box of the oscilloscope. The screen is covered with a fluorescent zinc sulfide layer. The point glows where the ray strikes. The screen is marked with horizontal and vertical gridlines.



ie speed of the electrons
tween the plates. If the
ases, then the amplitude
iaximum deflection of the
i.e. acceleration voltage
flection decreases. In the

oscilloscope there is a knob called 'Volts/Div control'. The pointer of this knob indicates how much voltage difference a single vertical division represents along the Y axis. The oscilloscope is engineered in such a way that by rotating this knob acceleration voltage can be modulated and/or the voltage signal between D and E can be amplified or diminished to see bigger or smaller deflection. However, **by rotating Volts/Div knob the input voltage given between the plates (here, horizontal plates) cannot be changed.** By rotating this knob the amplitude of oscillation of the bright spot (where the cathode ray strikes on the screen) may be varied but the voltage represented by every vertical division changes accordingly to display the actual amplitude of input voltage.

Section 2: Visualization of Voltage versus Time Curve

If only D and E terminals take an input voltage difference between them, and no voltage difference is given between F and G, then the bright spot oscillates vertically. If the period of oscillation is less than 1 ms then oscillation occurs too fast to detect a single bright spot moving with time. Instead of that we see a bright vertical line.

To visualize how the input voltage signal varies with time, the cathode ray should be shifted towards horizontal direction. To do so the oscilloscope itself provides a periodic voltage difference between F and G terminals (which are connected with vertical plates in Figure 1). We call it *Sweeping Voltage.* If the voltage vs. time graph is plotted for this alternating voltage signal, then the shape of this graph seems to be a series of right triangles (Figure 2(c)).

Figure 2(a) implies that the bright spot oscillates vertically when voltage difference between vertical plates, and as well as the horizontal electric field created by it, is not there. Say, at time T the spot is at point 'a'. Then it moves upward to reach the topmost point 'b'. Next, it moves downward and reaches 'a'. After that it keeps moving continuously downward and reaches the bottommost point 'c'. Then again it moves upward. Now, suppose a linearly increasing periodic voltage difference (*sweeping voltage*) is applied between the vertical plates, as shown in Figure 2(c). At time T the spot is at 'a' (Figure 2(b)) but from now on, it will get deflected rightward as it moves upward. Its rightward deflection increases with the linearly increasing sweeping voltage (Figure 2(c)). The bright spot moves along the sinusoidal curve through the points: a-d-e-f-g-h-i. Then at time 2T, the sweeping voltage suddenly drops down to zero and the bright spot almost instantaneously returns to the point 'a'. Then again another cycle starts. During time 2T to 3T the bright spot will again move along the curve shown in Figure 2(b).
The time period of sweeping voltage is T.

We see that, in this example the bright spot completes $1\frac{1}{2}$ cycles during the period of T. Hence, we can find out the period of oscillation of the input voltage given between the horizontal plates, that is $\frac{2}{3}$ T. If this input voltage signal makes *n* cycles during the time period of the sweeping voltage then the time period of the input voltage is T/*n*.

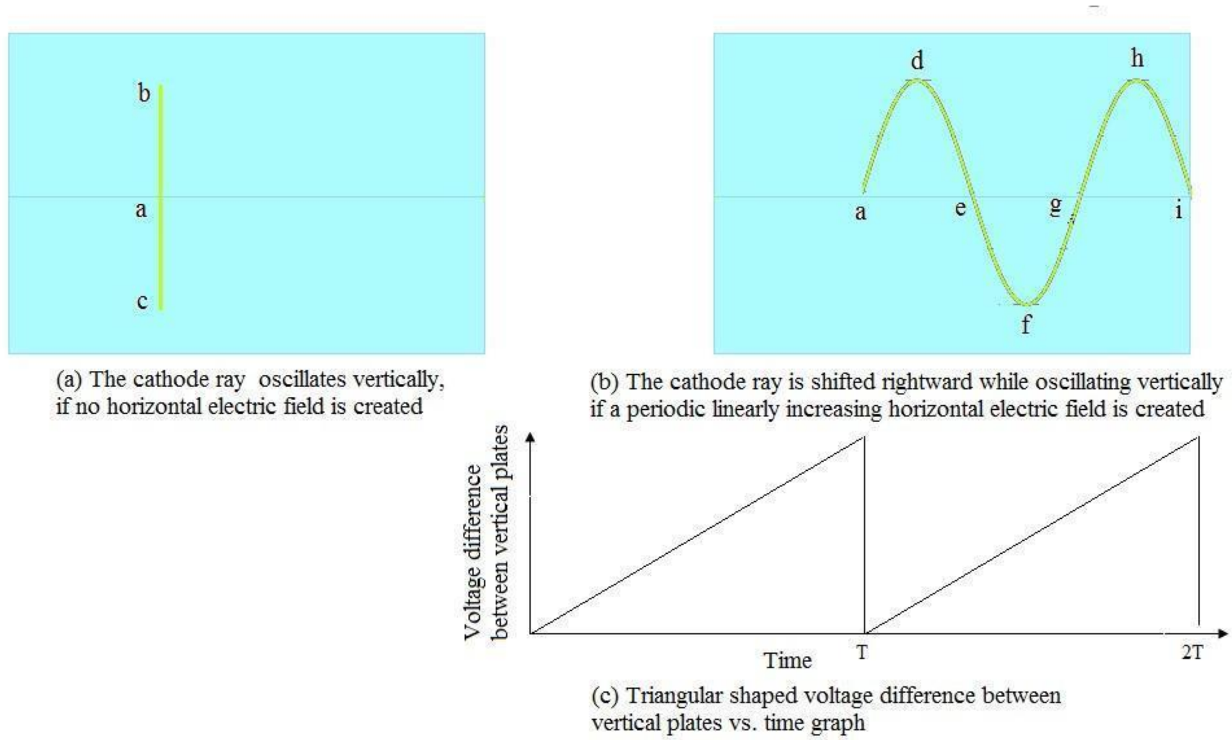


Figure 2: When a periodic linear *sweeping voltage* is applied between the vertical plates, the trajectory of the bright spot (where the cathode ray strikes) represents the input voltage vs. time curve.

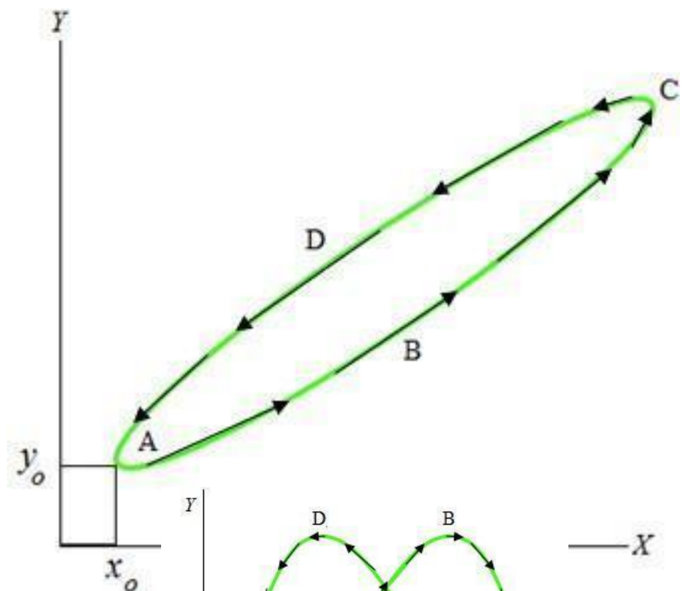
There is a knob called "Time/DIV control" in the oscilloscope. The pointer of this knob indicates the amount of time a single horizontal division (printed on the screen of the oscilloscope) represents. This is the *time base* of the oscilloscope. The time period of the sweeping voltage can be regulated by rotating this knob and the time represented per horizontal division will be varied accordingly. **By rotating the Time/DIV control knob, the time period of the input voltage difference between the horizontal plates cannot be changed.**

To generate a voltage vs. time curve on the screen, the 'x-y' button of the oscilloscope should be turned off. Usually, an oscilloscope has two channels (Channel 1 and Channel 2) to receive input voltage signal(s). By using a special switch, we can select the input voltage signal (s) from either of these two or both channels, to convey to the horizontal metal plates. Then the oscilloscope itself generates the sweeping voltage to produce the voltage vs. time curve for the chosen input voltage signal.

Section 3: Determining the Ratio of the Time Periods of two Alternating Voltage Signals by Observing Lissajous Curves

We can figure out the ratio of the time periods of the alternating voltages which create the Lissajous curves on the display screen of the oscilloscope. Let, T_x is the time period of the voltage signal which creates horizontal electric fields and T_y is the time period of the voltage signal which creates vertical electric fields. In other words T_x and T_y are the periods of oscillation along X and Y axes respectively. See Figures 4, 5 and 6. In every case, let A is the starting point of the bright spot. The projection of point A on the X and Y axes are x_o and y_o respectively. As the bright spot moves around the Lissajous curve, think about the projection of the position of this moving bright spot on the both axes. Count how many number of times the bright spot's projection on x axis completes full cycle along X axis (by returning to x_o) and how many number of times the spot's projection on Y axis completes full cycle along Y axis (by returning to y_o), for making a complete cycle around the curve.

In Figure 3, we see a one loop pattern of the Lissajous curve. The bright spot moves along the curve in the following order:
A-B-C-D-A
It makes a complete cycle along the Y axis when it completes the whole A-B-C-D-A loop.
On the other hand, the spot makes a single cycle along the X axis too, when it completes the whole A-C-D-B-A closed path.



Hence, the time during which the spot completed one cycle along the X axis, it makes one cycle along the Y axis. Therefore,

$$T_x / T_y = 1$$

In Figure 4 we see a Lissajous curve of two loops (horizontal) pattern. The bright spot moves along the curve in the following order: A-B-C-D-A
The bright spot makes a full cycle along Y axis when it completes the portion A-B-C of the trajectory. The bright spot makes another full cycle along the Y axis when it completes the portion C-D-A.
On the other hand, along the X axis the spot makes a single full cycle when it completes the whole A-B-C-D-A loop.

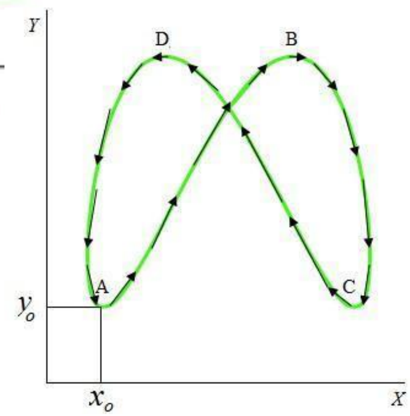


Figure 4: 2-loops (horizontal) pattern

Hence, the time during which the spot completed one cycle along the X axis, it makes two cycles along Y axis. Therefore,

$$T_x / T_y = 2$$

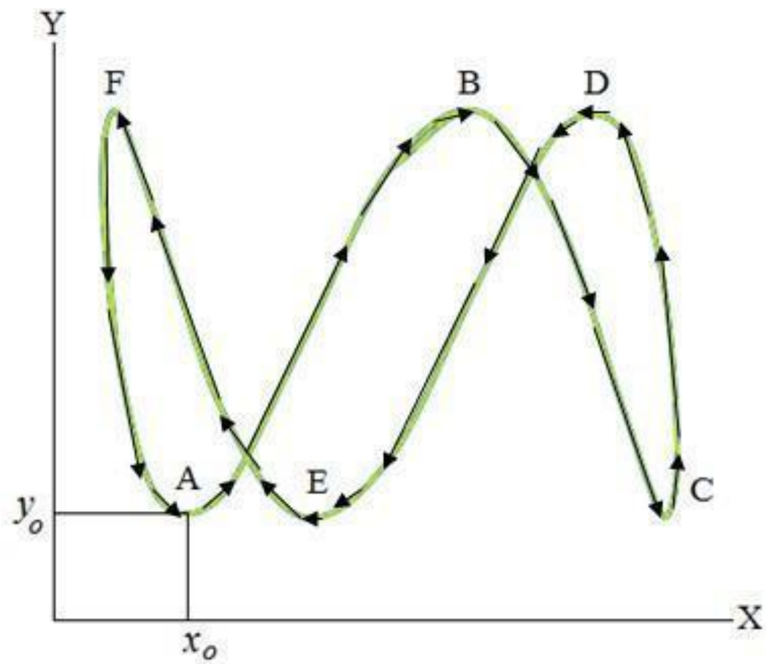


Figure 5: 3 loop (horizontal) pattern

In Figure 5 we see a Lissajous curve of three loops (horizontal) pattern. The bright spot moves along the curve in the following order:
A-B-C-D-E-F-A

The bright spot makes a full cycle along the Y axis when it completes the portion A-B-C of the trajectory. Then the bright spot makes another full cycle along the Y axis when it completes the portion C-D-E. Next, it makes the third full cycle along the same axis when it completes the portion E-F-A.

On the other hand along the X axis the spot makes a single full cycle when it completes the whole A-B-C-D-E-F-A closed path.

Hence, the time during which the spot completed one full cycle along the X axis, it makes three full cycles along Y axis. Therefore,

$$\boldsymbol{T_x / T_y = 3}$$

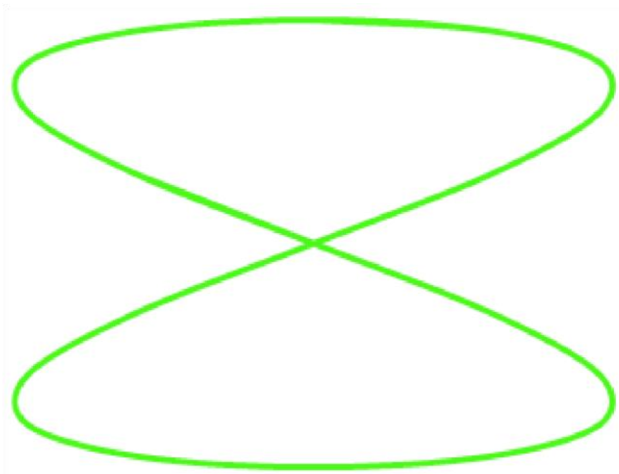


Figure 6: 2 loops (vertical) pattern

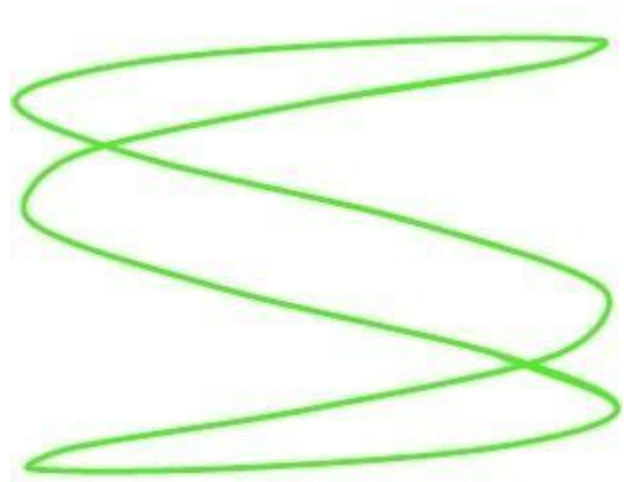


Figure 7: 3 loops (vertical) pattern

In the same way we can argue that in the case of a Lissajous curve of 2 loops (vertical) pattern as shown in Figure 6,

$$T_x \,/\, T_y = 1 \,/\, 2$$

In the case of a Lissajous curve of 3 loops (vertical) pattern as shown in Figure 7,

$$T_x \,/\, T_y = 1 \,/\, 3$$

By analyzing all the exemplar curves we can formulate the following rule:

$$\boxed{T_x \,/\, T_y = n_x \,/\, n_y} \qquad (1)$$

Here, n_x = number of full cycles completed along x axis for a complete cycle around the Lissajous curve

n_y = number of full cycles completed along y axis for a complete cycle around the Lissajous curve

We know that the frequency of a body in simple harmonic motion is inversely proportional to the time period. Suppose, f_x and f_y are the frequencies of the voltage signals given in Channel 1 (X) and Channel 2 (Y) respectively. Therefore,

$$\boxed{f_x \,/\, f_y = n_y \,/\, n_x} \qquad (2)$$

Section 4: Determination of the Time Base

Now, the ‘x-y’ button of the oscilloscope is turned off. An input alternating voltage signal is given through either Channel 1 or Channel 2. This voltage signal produced an alternating potential difference between the horizontal plates. The oscilloscope itself will generate the sweeping voltage difference between the vertical plates. A voltage vs. time curve (Figure 8) is generated on the display screen. We want to determine the ‘Time Base’ of the oscilloscope, which is the amount of time represented by a single division of the horizontal side of a square drawn on the display box of the oscilloscope. We know the frequency, f of the applied alternating voltage signal. By using it we can find out the time period, T (= $1/f$).

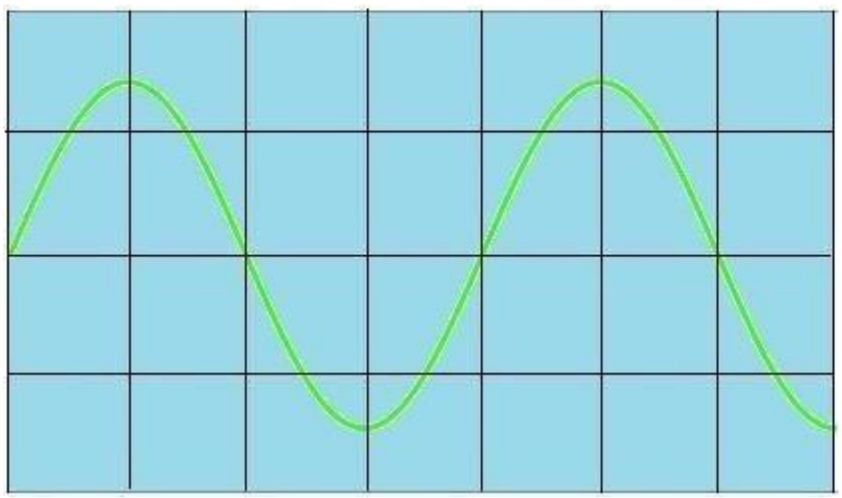


Figure 8: Voltage vs. time curve on the display screen

If there are a D number of divisions between two consecutive peaks, D divisions represent an amount of time which is equal to the time period, $T = 1/f$ of the alternating input voltage signal. Therefore, a single division represents $T/D = 1/(D f)$ amount of time.

Time base of the oscilloscope,

$$\boxed{T_B = 1/(Df)} \qquad (3)$$

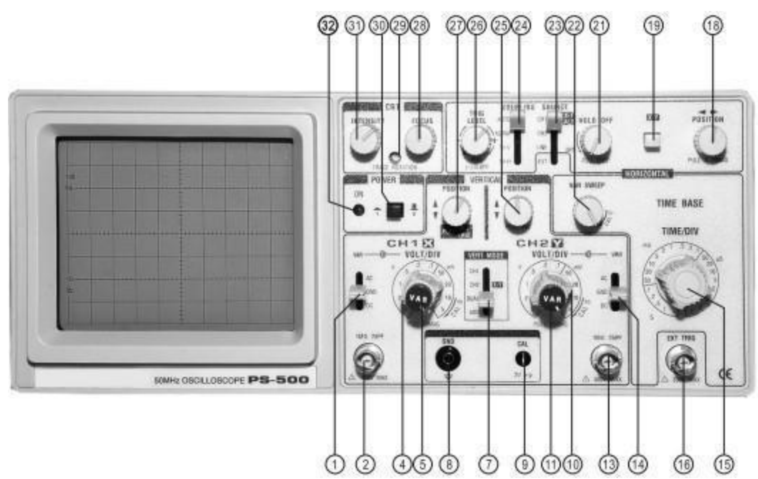
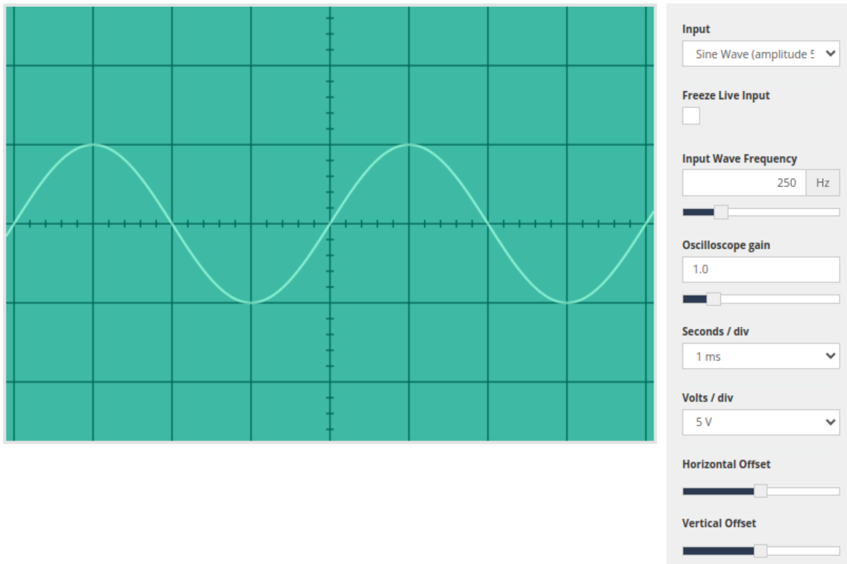


Figure 9: An oscilloscope (courtesy: pintek.com)

Section 5: Description of the Oscilloscope Simulator

To use the simulator, open your web browser and navigate to the following: [Virtual Oscilloscope | Academo.org - Free, interactive, education.].

The following are a few terms you should familiarize yourself with.



1) Right bar contains input fields for the signal which is shown within the green screen. Below are the description about each parameter of the input fields:

   A) Input : Make sure it is set to “Sine Wave”.

   B) Freeze Live Input : Make sure that it is deselected.

   C) Set the "input wave frequency" to 250 Hz. (See the procedure)

   D) Oscilloscope gain: This is a number that the incoming signal is multiplied by. A gain of 1 will have no effect, a gain of less than 1 will make the signal smaller and a gain of more than 1 will make it larger.

   E) Seconds / div: This control allows you to adjust the length of time that each square of the grid represents. Different values will stretch the wave proportionately in the x-axis.

   F) Volts / div: This setting stretches the wave along the y-axis. If the sine wave has an amplitude of 5V, when volts/div is set to 5, the waveform just reaches the top of the first square. If you were to change the setting to 10 volts/div, the waveform now only reaches up half of a square.

   G) Horizontal and Vertical Offsets: These two sliders allow you to adjust the position of the oscilloscope's trace on the grid. They are particularly useful for lining up parts of the waveform with the grid-lines (this can make it easier for you to count the squares when determining wavelength, for example).

Procedure

Lissajous Curves

Tutorial: CRO (Part I)

1. Open an internet browser, preferably Google Chrome, and navigate to the following link: **Lissajous Curves | Academo.org - Free, interactive, education.**

2. On the right-hand side, locate two sliders labeled *'a'* (i.e. f_x) and *'b'* (i.e. f_y). These two inputs represent the frequency of signals. You can adjust these sliders to modify the input frequencies (x and y respectfully). You can either use the sliders or manually input values. Note that the frequency will not exceed 20Hz.

3. Using different value units of '*a*', fill out table 1 and check whether the data matches up as it should. **In this case, you should set the *'a'* value at 4Hz, 5Hz and 10Hz, and *'b'* value should remain fixed at 20Hz.**

4. Use the ϕ slider to control the phase difference between the two input signals. The slider's scale ranges from 0 to 2π radians. Toggle animation on or off by checking the box under the 'Animate ϕ' button. **In this case, you should set the ϕ at 0.51 radians.**

5. You can adjust sliders A and B to change the amplitudes' scale for the input frequencies. Slider A affects the horizontal component, while B influences the vertical component of the Lissajous Curve. Observe the Lissajous curves for the given set of frequencies and count the number of peaks visible in the graph. Note that, in some cases, adjusting the phase difference may be necessary to observe all curves.

Virtual Oscilloscope

Tutorial: CRO (Part II)

1. We want to find out whether the time base of our simulator oscilloscope matches with our expected value for a certain frequency. Open an internet browser, preferably Google Chrome, and navigate to the following link: **Virtual Oscilloscope | Academo.org - Free, interactive, education.**

2. Set the "input wave frequency" to 250 Hz. The other settings should have values: gain = 1.0, sec/div = 1 ms, volts/div = 5V.

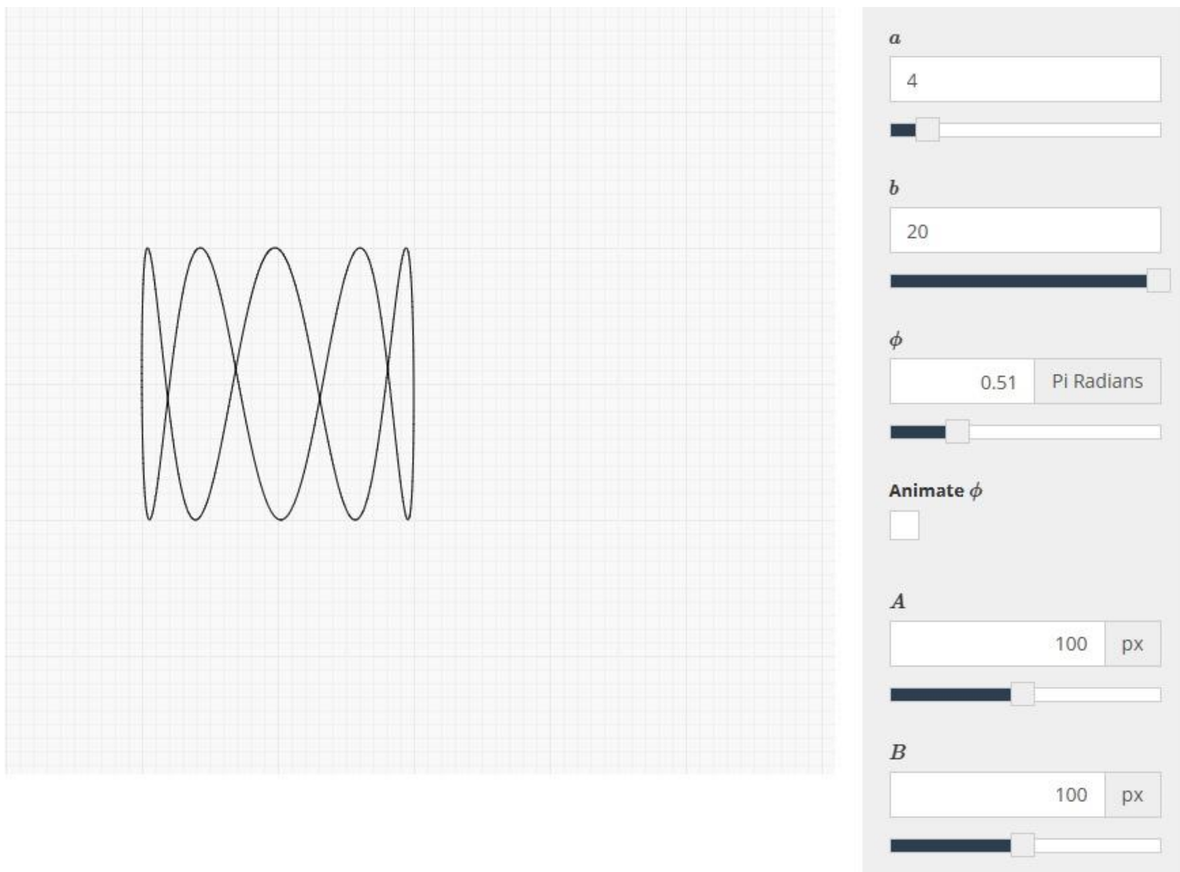
3. Count the time period of your wave. Using eqn.(3), calculate the time base. Does it match with our expectations?

4. In table 2, measure and write down the values for 5 different input frequencies increasing by 50 Hz each time (starting with the initial 250 Hz). Calculate the time base for each individual frequency.

Name: TASNIM RAHMAN MOUMITA ID:22301689 Sec:02 Group:05 Date: 10.12.2023

TASK:

- Set *‘a’* = 4 Hz and *‘b’* = 20 Hz and ϕ = 0.51 radian(pause the animation) and take your reading.



- Proceed to count the loops by following the instructions on Theory (Section 3) and Tutorial.
- Likewise, set *‘a’* at 5 Hz and 10 Hz ; *‘b’* = 20 Hz and ϕ = 0.51 radian(Pause the animation) and take the readings.
- Determine the line frequency.
- Proceed to familiarize yourself with the Oscilloscope simulator. Then determine its time-base after setting "input wave frequency" to 250 Hz. The other settings should have values: gain = 1.0, sec/div = 1 ms, volts/div = 5V. Follow the instructions on Theory (Section 4) and Tutorial.

Data

Table 1: Data for working out the unknown frequency of an alternating voltage signal

Known frequency (frequency of the alternating voltage signal generated by function generator) *'a'* (Hz)	Number of complete cycles along the x axis for one complete cycle around the Lissajous curve n_x	Number of complete cycles along the y axis for one complete cycle around the Lissajous curve n_y	$b = a \cdot n_x / n_y$ (line frequency) *'b'* (Hz)	Mean value of *'b'* (Hz)
4	5	1	20	(20+20+20)/3 = 20
5	4	1	20	
10	2	1	20	

Here, we plot the graph below :

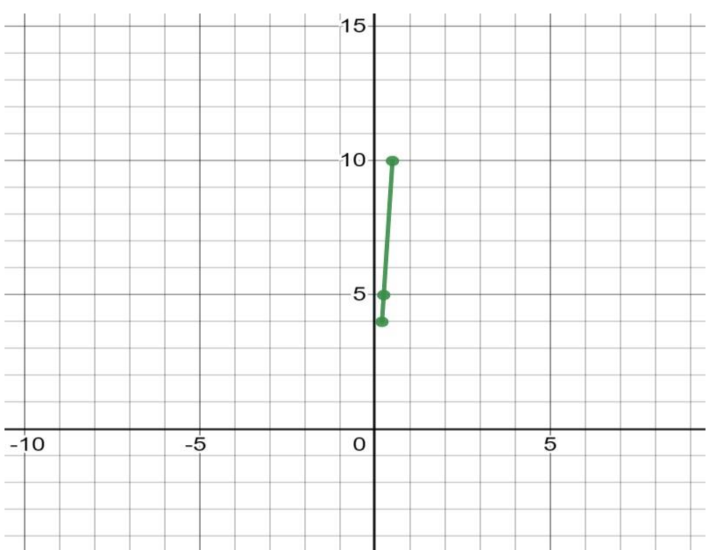


Figure : plot of 'a'(fx) vs '1/nx' from data table-1('a' in the Y- axis and '1/nx' in the X-axis)

- Find the slope from '*a*' vs. *1/n*$_x$ graph (Calculate *m* from best-fit line. It should be a straight line passing through the origin):

Answer:

The slope from 'a' vs. graph : 20

Frequency to be determined (line frequency), '*b*' (Hz) = 20 Hz (Ans.)

Table 2: Data for determining *time base* of the oscilloscope

Frequency of the alternating voltage signal generated by function generator *f* (Hz)	Number of horizontal divisions between two consecutive peaks *D*	Time base (time/division) T_B (s/*Div*)	Average value of the Time base (time/division) T_B (s/*Div*)
250	20	2×10^{-4}	2×044^{-4}
300	16	2.08×10^{-4}	2×044^{-4}
350	14	2.04×10^{-4}	2×044^{-4}
400	12	2.08×10^{-4}	2×044^{-4}
450	11	2.02×10^{-4}	2×044^{-4}

plotting the values in the graph,

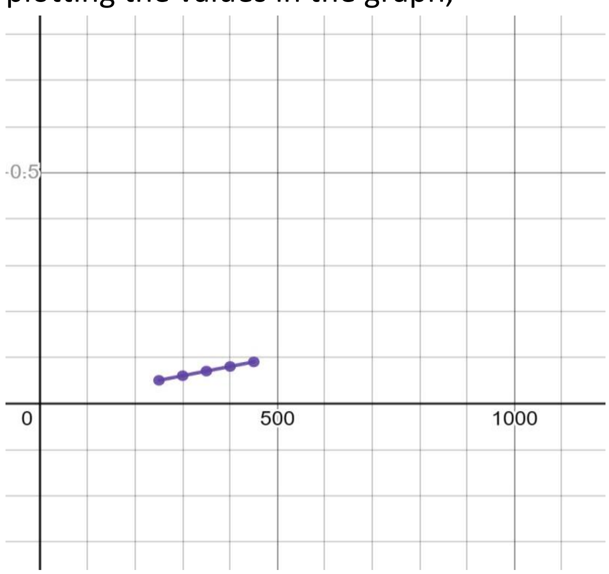


Figure : plot of '1/D' vs 'f' from data table-1('f ' in the X- axis and '1/D' in the Y-axis)

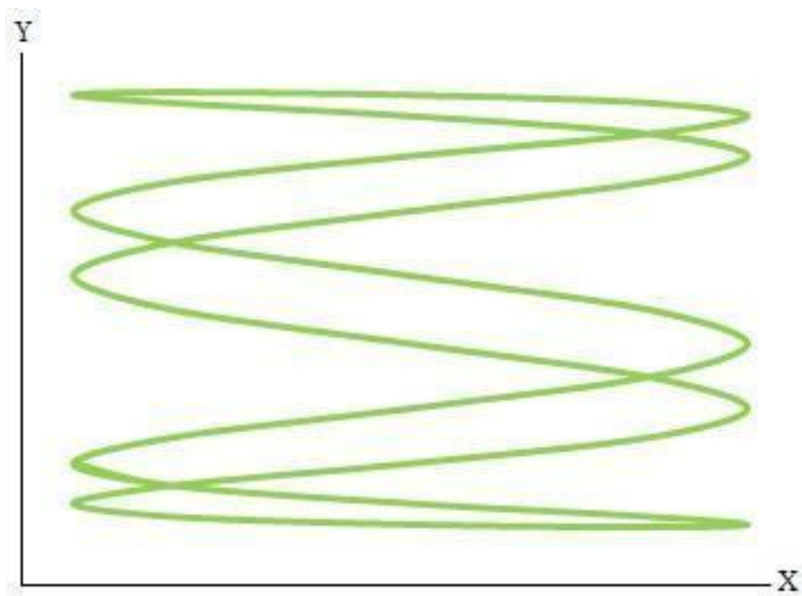
- Find the slope from *1/D* vs. *f* graph (Calculate *m* from best-fit line. It should be a straight line passing through the origin):

Answer: **Slope of 1/D vs. f graph:** 2×10^{-4}

Time base of the oscilloscope, T_B = 2×10^{-4}

Answer the following questions:

1) See the Figure:



For this Lissajous curve what is T_x / T_y ?

Ans: Here,

$n_x=5$

and $n_y=1$

we know, $Tx/ Ty = nx /ny$

Therefore, $Tx /Ty = 5 / 1$

2) What is the specific phase condition required to achieve a perfect circular Lissajous curve when both input signals 'a' and 'b' share identical frequencies?

Ans: The specific phase condition required to achieve a perfect circular Lissajous curve when both input signals 'a' and 'b' share identical frequencies is that the phase difference between the two signals must be $\pi/2$ radians or 90 degrees.

In other words,

at 0.50 pi radian and 1.50 pi radian .

3) Provide an explanation for the similarity in the Lissajous figures when inputting values a = 1 and b = 3 compared to a = 5 and b = 15.

Ans:

For a =1 and b = 3 ,

we get n_x =1and n_y = 3

and for a = 5 and b = 15,

we also get n_x =1and n_y = 3.

Both are similar because the Time base for both cases will be same as the ratio is same.

4) Define the "Time Base" of an Oscilloscope.

Ans:

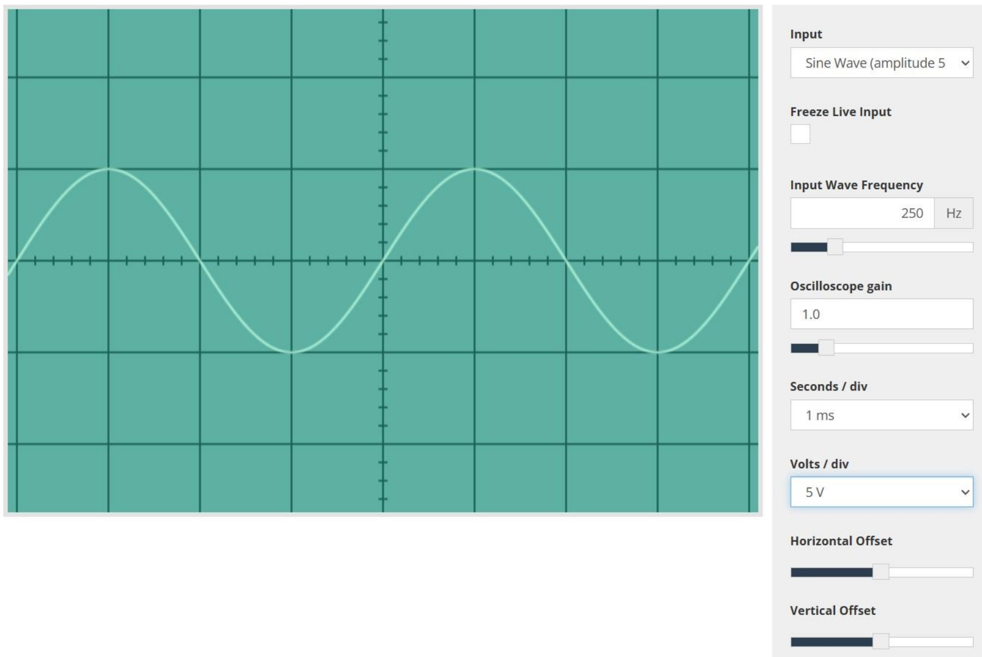
Time Base of an oscillation is the amount of time represented by a single division of the horizontal side of a square drawn on the display box of the oscilloscope. If there are D number of divisions between the two consecutive peaks and f is the frequency applied then,

$$T_B = \overline{Df1}$$

5) Go to [Virtual Oscilloscope | Academo.org - Free, interactive, education.]() If we were to keep the input frequency in our virtual oscilloscope fixed and change other parameters in the following

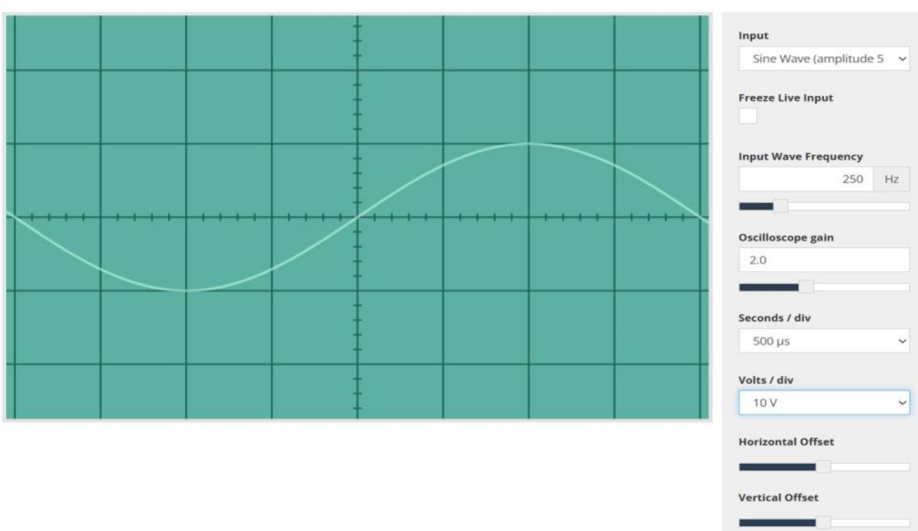
ways, what would happen in each case? (i) doubling gain (ii) **halving** the time base & (iii) doubling the volts/div. Discuss any change in values as well as in the output in our oscilloscope screen.

Ans:



Now, changing the parameters,

We can see from the picture below :



i) The output waveform's amplitude **doubles** but its frequency stays constant when we double the gain while maintaining the same input frequency.

ii) The output waveform will be compacted along the horizontal axis by a factor of two if the time base is cut **in half**. Consequently, even though the frequency has not changed, it will appear to be twice as high.

iii) If we **double the volts/div setting**, the output waveform will be compressed by a factor of two along the vertical axis. Its amplitude will appear half as large as before even though it has not changed.

So, in a short way, it can be said that,
Looking at the two figures above, it's clear that keeping the frequency constant while changing other parameters results in a higher division count between the two peaks. This suggests that the wave is spreading out over time.
