Cathode ray Oscilloscope
(ModernPhysics)

e-content for B.Sc Physics (Honours)
B.Sc Part-II
Paper-IV

Dr. Ayan Mukherjee,
Assistant Professor,
Department of Physics,
Ram Ratan Singh College, Mokama.
Patliputra University, Patna

OSCILLOSCOPES AND SIGNAL GENERATOR

OSCILLOSCOPE

Introduction

The cathode ray oscilloscope (CRO) provides a visual presentation of any waveform applied to the input terminal. The oscilloscope consists of the following major subsystems.

- Cathode-ray tube(CRT)
- Vertical amplifier
- Horizontal amplifier
- Sweep Generator
- Trigger circuit
- Associated power supply

It can be employed to measure such quantities as peak voltage, frequency, phase difference, pulse width, delay time, rise time and fall time.

Basic Operation of Oscilloscope

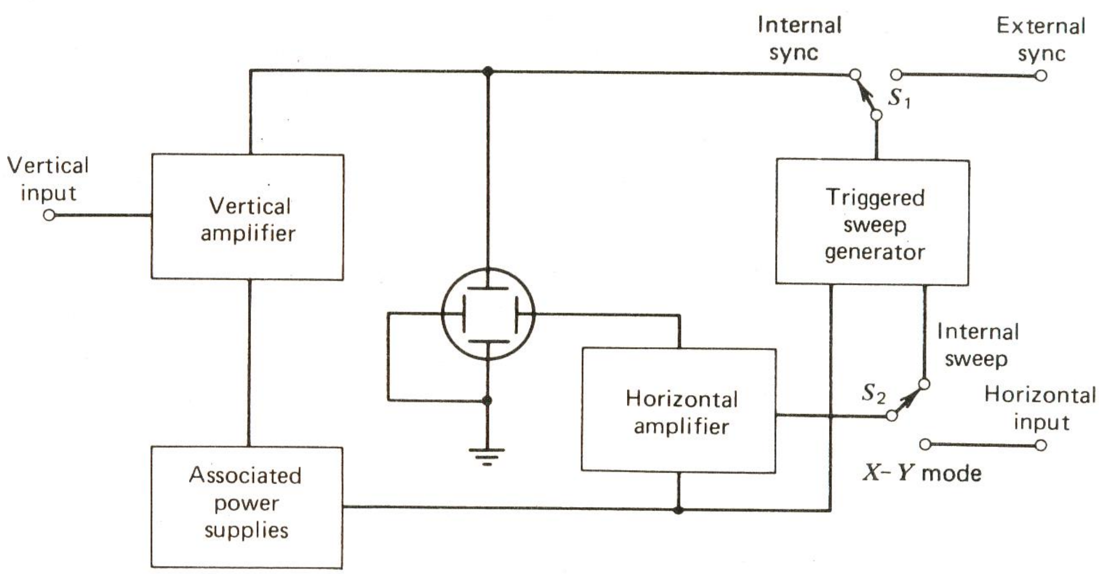

Figure 1: Block diagram of a basic cathode-ray oscilloscope

The basic parts of CRO are shown in Figure 1. In inexpensive, general-purpose oscilloscopes, the left horizontal deflection plate (looking toward the screen) and the lower vertical deflection plate are sometimes connected to ground. The beam is deflected upward and to the right by signals applied to the upper vertical deflection plate or to the right horizontal deflection plate. A signal to be displayed on the CRT screen is applied to the vertical input terminal where it is fed into the vertical amplifier.

The signal is amplified and applied to the vertical deflection plate, which cause the beam to be deflected in the vertical plane. As can be seen in Figure 1, the output of the vertical amplifier is connected to the internal sync position of switch S_1. With the switch set to internal sync, as it is for normal operation of the oscilloscope, the output of the vertical amplifier is applied to the sweep generator. This signal triggers the sweep generator, except in low-cost oscilloscopes with a free-running sweep generator. The purpose of the sweep generator is to develop a voltage at the horizontal deflection plate that increase linearly with time. This linearly increasing voltage, called ramp voltage or a saw tooth waveform, causes the beam to be deflected equal distance horizontally per unit of time.

Amplifier circuits are needed to increase the input signal to the voltage levels required to operate the tube because the signals measured using CRO are typically small. There are amplifier sections for both vertical and horizontal deflection of the beam.

The horizontal amplifier serves to amplify the signal at its input prior to the signal being applied to the horizontal deflection plates. The input signal to the horizontal amplifier depends on the position to which S_2 is set. In normal operation of the oscilloscope, the switch is set to internal sweep. When the instrument is used in the X-Y mode, for phase-shift measurements or to determine the frequency of a signal, the signal that is applied to the horizontal input terminal is amplified by the horizontal amplifier.

Vertical Amplifier – amplify the signal at its input prior to the signal being applied to the vertical deflection plates

Horizontal Amplifier – amplify the signal at its input prior to the signal being applied to the horizontal deflection plates.

Sweep Generator – develop a voltage at the horizontal deflection plate that increase linearly with time

Cathode Ray Tube (CRT)

A cathode ray tube (CRT) much like a television tube provides the visual display showing the form of signal applied as a waveform on the front screen. The CRT is the heart of the CRO providing visual display of an input signal waveform. A CRT contains four basic parts:

1. An electron gun to provide a stream of electrons.
2. Focusing and accelerating elements to produce a well define beam of electrons.
3. Horizontal and vertical deflecting plates to control the path of the electron beam.
4. An evacuated glass envelope with a phosphorescent screen which glows visibly when struck by electron beam.

Basic Operation of CRT

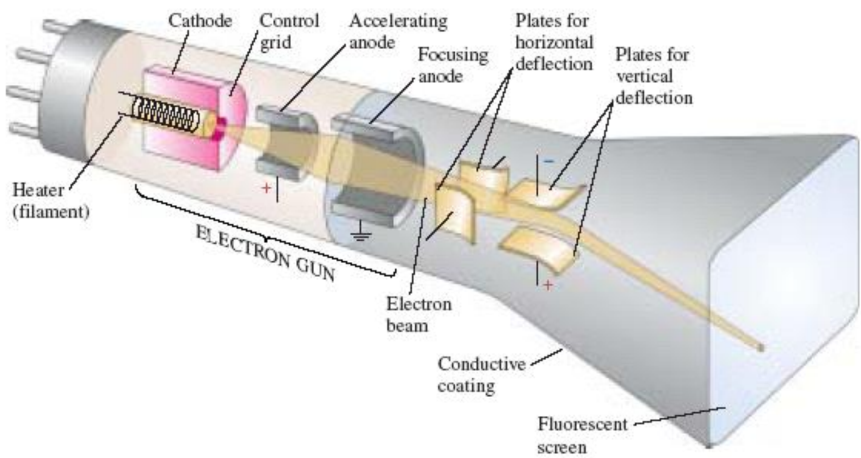

Figure 2: Basic construction of CRT

Figure 2 shows the basic construction of CRT. A cathode containing an oxide coating is heated indirectly by a filament resulting in the release of electrons from the cathode surface.

The control grid, which has a negative potential, controls the electron flows from the cathode and thus controls the number of electron directed to the screen. Once the electron passed the control grid, they are focused into a tight beam and accelerated to a higher velocity by focusing and accelerating anodes. The high velocity and well-defined electron beam then passed through two sets of deflection plates.

The first set of plates is oriented to deflect the electron beam vertically. The angle of the vertical deflection is determined by the voltage polarity applied to the deflection plates. The electron beam is also being deflected horizontally a voltage applied to the horizontal deflection plates. The tube sensitivity to deflecting voltages can be expressed in two ways that are deflection factor and deflection sensitivity.

The deflected beam is then further accelerated by very high voltages applied to the tube with the beam finally striking a phosphorescent material on the inside face of the tube. The phosphor glows when struck by the energetic electrons – the visible glow will be seen continue to emit light for a period of time after the source of excitation is removed.

Control Grid	Regulates the number of electrons that reach the anode and hence the brightness of the spot on the screen.
Focusing anode	ensures that electrons leaving the cathode in slightly different directions are focused down to a narrow beam and all arrive at the same spot on the screen
Electron gun	cathode, control grid, focusing anode, and accelerating anode
Deflecting plates	An electric field between the first pair of plates deflects the electrons horizontally, and an electric field between the second pair deflects them vertically. If no deflecting fields are present, the electrons travel in a straight line from the hole in the accelerating anode to the center of the screen, where they produce a bright spot.

Oscilloscope Application

(a) Voltage Measurement

The most direct voltage measurement made with an oscilloscope is the peak-peak value. The rms value of the voltage can easily be calculated from the peak to peak measurement if desired. The peak to peak value of voltage is compute as

$$V_{p\text{-}p} = (\text{vertical p-p division}) \times \text{volts/div}$$

Example 1

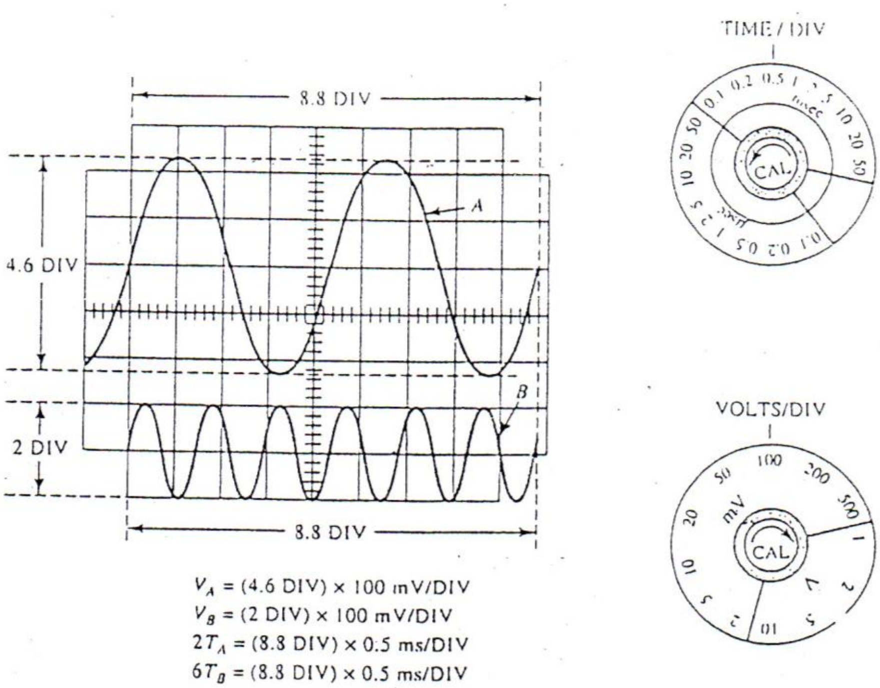

Figure 3: The peak-peak voltage of a waveform is measured by multiplying the VOLTS/DIV setting by the peak-peak vertical divisions occupied by the waveform. The time period is determined by multiplying the horizontal divisions for one cycle by the TIME/DIV setting.

Refer to figure 3, find the peak-peak voltages for each wave.

Wave A : $V_{p\text{-}p}$ =(4.6 divisions) x 100 mV = 460 mV
Wave B : $V_{p\text{-}p}$ = (2 divisions) x 100mV = 200mV

(b) Period and frequency measurement

The time period of a sine wave is determined by measuring the time for one cycle in horizontal divisions and multiplying by setting of the time/div control

Period, T = (horizontal divisions / cycle) (time / div)
Frequency, f = 1 / T

(c) Phase difference measurement

Phase difference, θ = (phase difference in divisions) x (degree/div)

Example 2
The phase difference between two waveforms is measured by the method illustrated in figure 4.

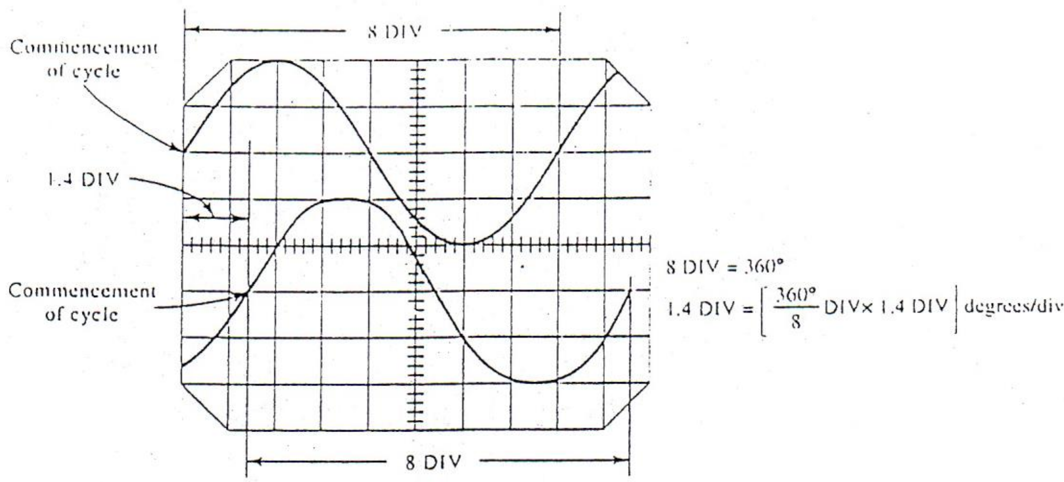

Figure 4

Each wave has a time period of 8 horizontal divisions, and the time between commencements of each cycle is 1.4 div

one cycle = 8 div = 360^o
$\therefore$ 1 div= 45^o

Thus, the phase different is

θ = $(1.4)(45^o/\text{div})$
= 63^o

Example 3
Determine the amplitude, frequency and phase difference between two waveform illustrated in figure 5.

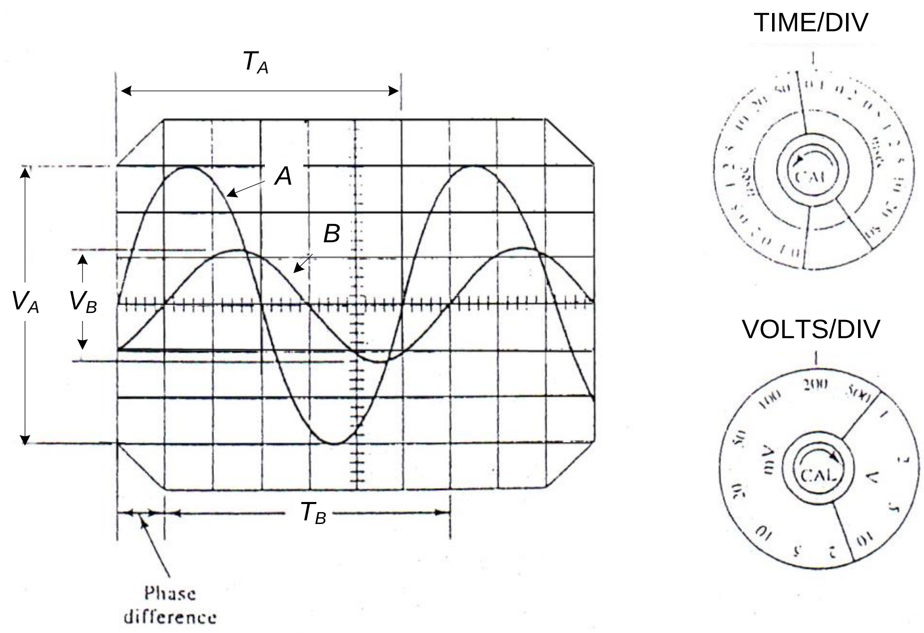

Figure 5

Solution

V_A peak-peak = (6 vertical div) x (200mV/div) = 1.2 V
T_A = (6 horizontal) x (0.1 ms/div) = 0.6 ms
f_A = 1/T = 1667 Hz

V_B peak-peak = (2.4 vertical div) x (200mV/div) = 480 mV
T_B = 0.6 ms
f_B = 1667 Hz

one cycle = 6 horizontal div = 360°
$\therefore$ 1 div= 60°

Phase difference, θ = 1 div = 60°

Lissajou Patterns

(a) Frequency measurement

If we apply input signal to both horizontal and vertical deflection plates of x-y oscilloscope and time base generator is disconnected, it forms a vector pattern that allows us to discern the relationship between the two signals. Such diagram are called Lissajous pattern.

$$\frac{F_Y}{F_x} = \frac{\text{number of times tangent touch top or bottom}}{\text{number of times tangent touch other side}}$$

$$= \frac{\text{number of horizontal tangencies}}{\text{number of vertical tangencies}}$$

$$\text{or} \quad = \frac{\text{number of positive peaks}}{\text{number of right hand side peaks}}$$

where F_Y = frequency of signal applied to Y-plates (vertical)
F_X = frequency of signal applied to X-plates (horizontal)

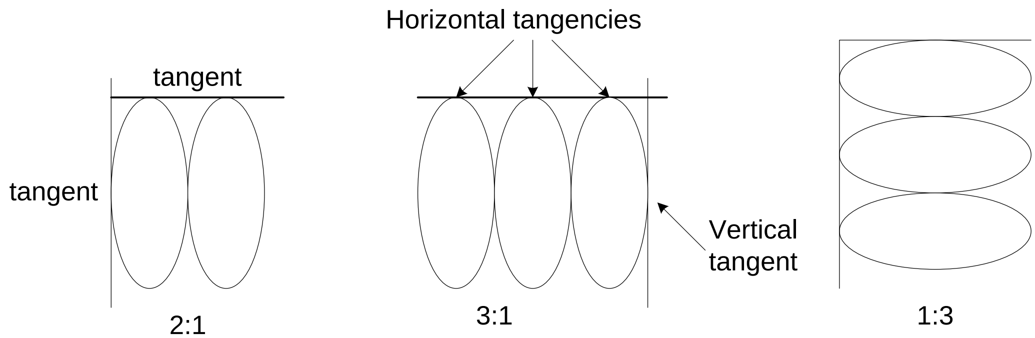

Figure 6 Lissajou patterns with different frequency ratios

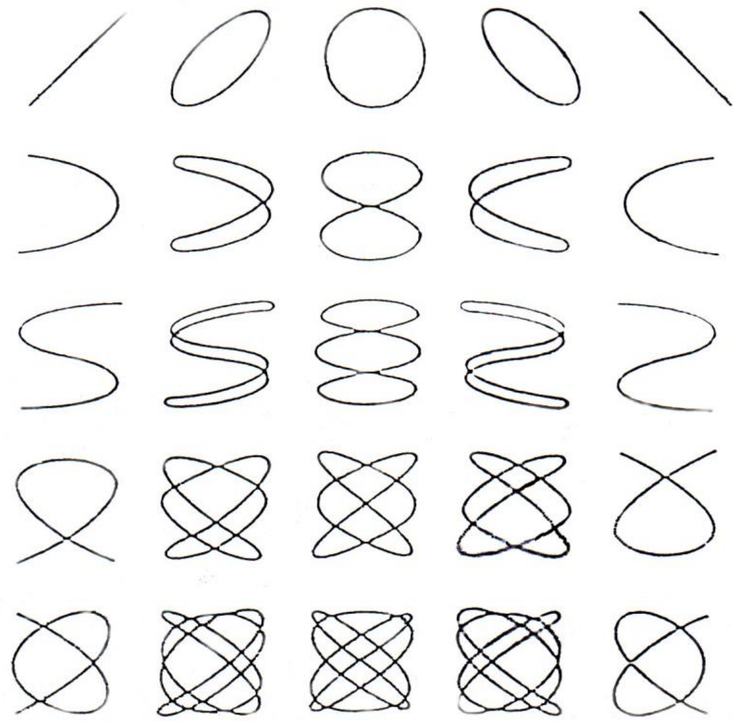

Figure 8: Lissajou Pattern

(b) Phase Angle computation

Oscilloscope can also be used in the X-Y mode to determine the phase angle between two signals of the same frequency.

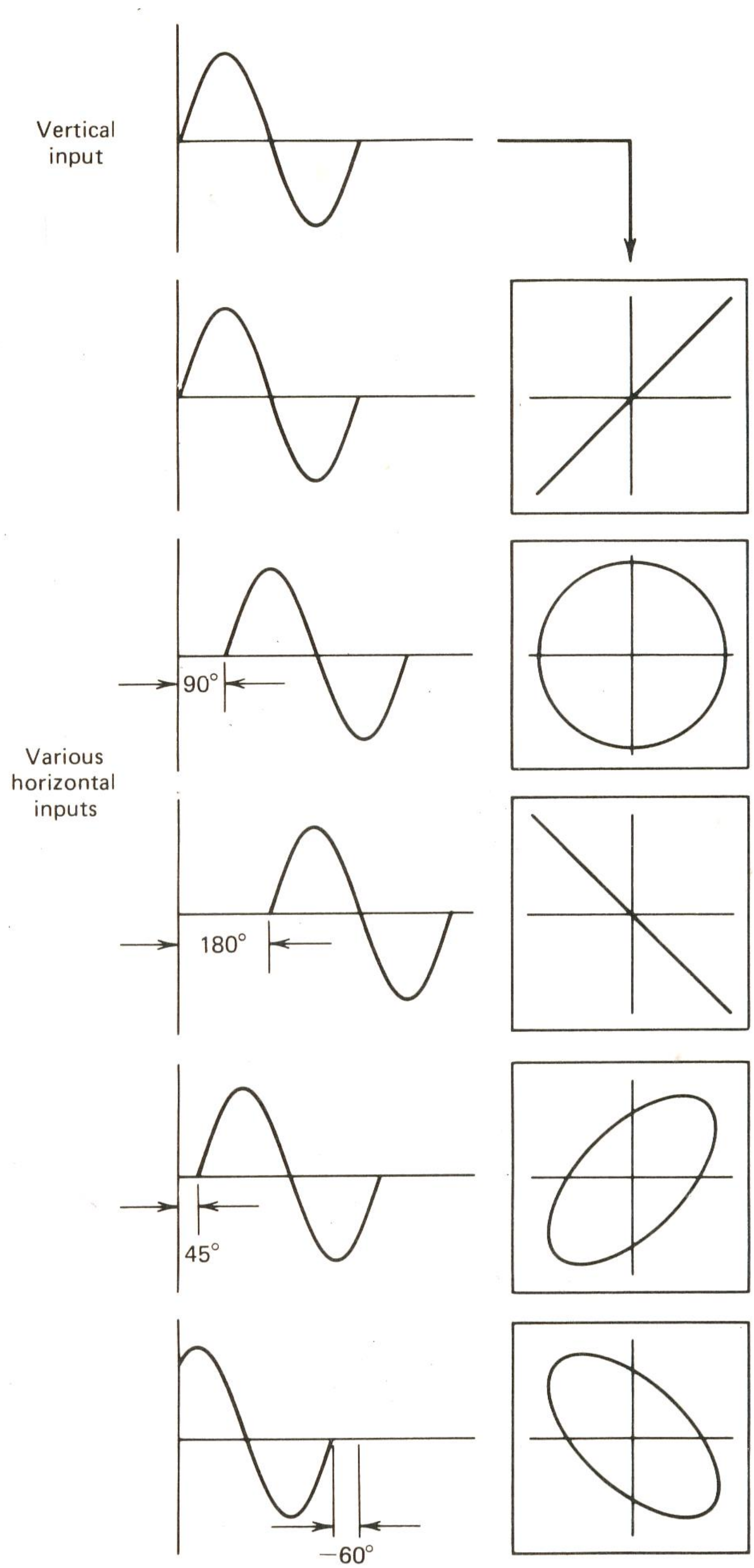

Figure 7: Lissajous patterns for selected phase angle

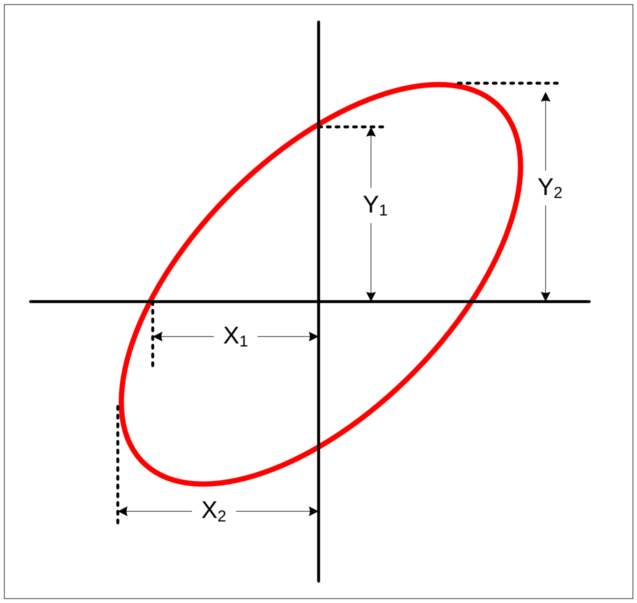

Figure 8: Determination of angle of phase shift

The phase angle:

$$\sin\theta = \frac{Y_1}{Y_2} = \frac{X_1}{X_2}$$

where:

θ	= phase angle in degrees
y_1	= Y-axis intercept
y_2	= maximum vertical deflection

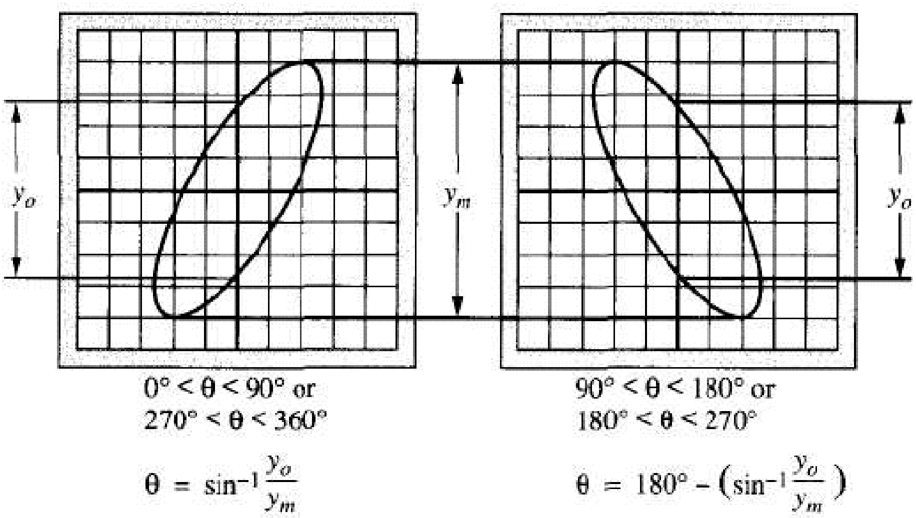

Figure 9

Example 4

If the distance y_1 is 1.8 cm and y_2 is 2.3 cm, what is the phase angle?

Solution

$$\sin\theta = \frac{y_1}{y_2}$$

$$= \frac{1.8}{2.3}$$

$$= 0.783$$

$$\therefore \theta = 51.5^o$$