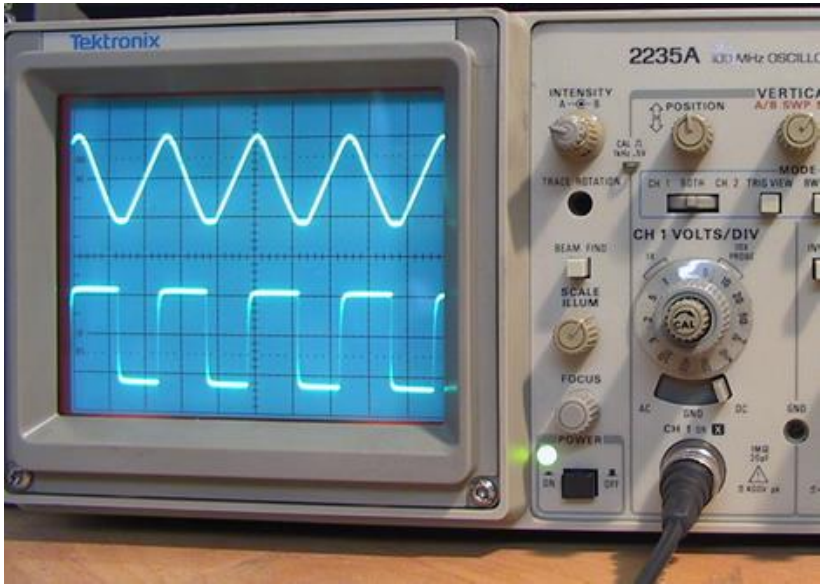
CHAPTER 6

OSCILLOSCOPE



Dr. Wael Salah

OSCILLOSCOPE

Oscilloscope Use cathode ray tube (CRT) to display voltage versus time

The graph Draw by an electronic beam on the inside of a phosphor coated screen

Stand-still because the graph is written repeatedly and the human eye combined with persistence of the phosphor that coat the CRT

Vertical axis ➔ calibrated in volt

Horizontal axis ➔ calibrated in Sec

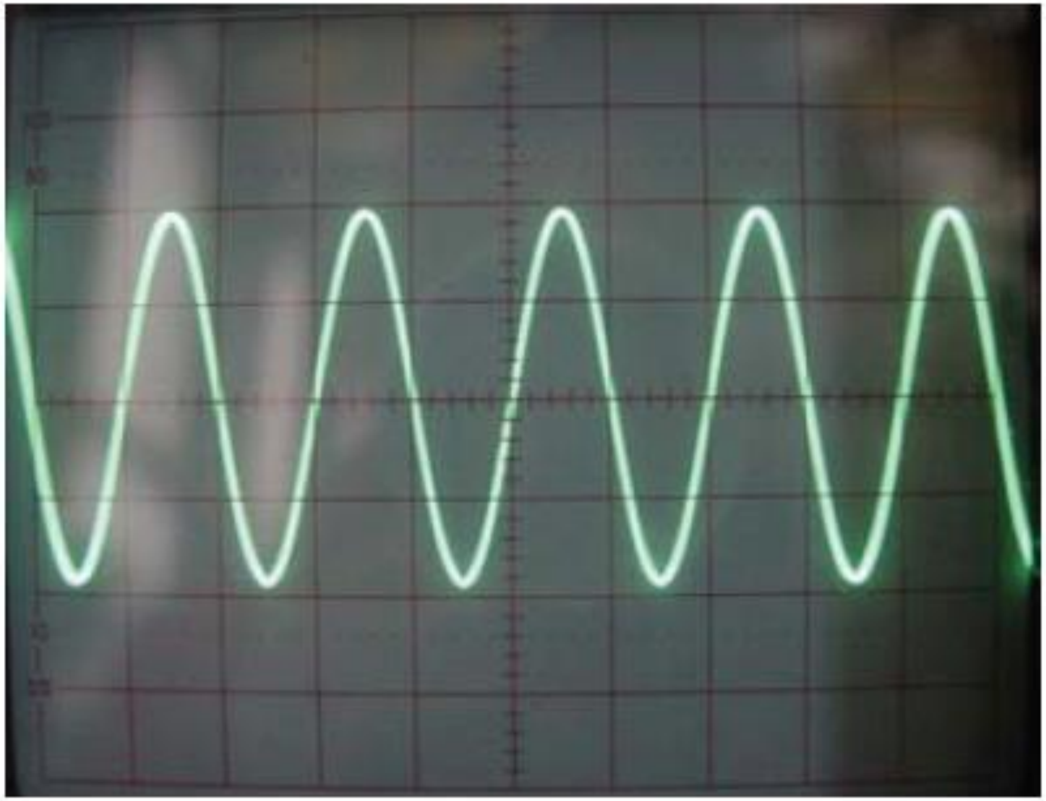


Figure 3.20. The example of the screen of analogue oscilloscope

- Oscilloscope is an important **test instrument** in electrical and electronics field.

- It is used to look at the **'shape'** of electrical signals by displaying a graph of voltage against time on its screen.

- It is like a voltmeter with the extra function showing how the **voltage varies with time**.

- Oscilloscopes are commonly used to observe the **exact wave shape** of an electrical signal.

Information's that given by oscilloscopes are:

1- Time and voltage

2- Frequency and phase

3- Spectral analysis

4- Rise and fall time

Purpose of Use

1- To **examine** analogue and digital circuits

2- Allows the user to **obtain** both time and amplitude information, frequency , phase shift

3- **Measure** signal from low frequency (low amplitude) to high frequency (high amplitude)

4- Show the **difference or summation** of two different signals

The oscilloscope consists of four major subsystem which are:

(a) Vertical section

(b) Trigger section

(c) Horizontal section

(d) Display section

(a) Vertical section

1- where the input signal is applied to it.

2- Used to amplify or attenuate the signal to required level on the screen (volt/div)

Oscilloscope Main Components

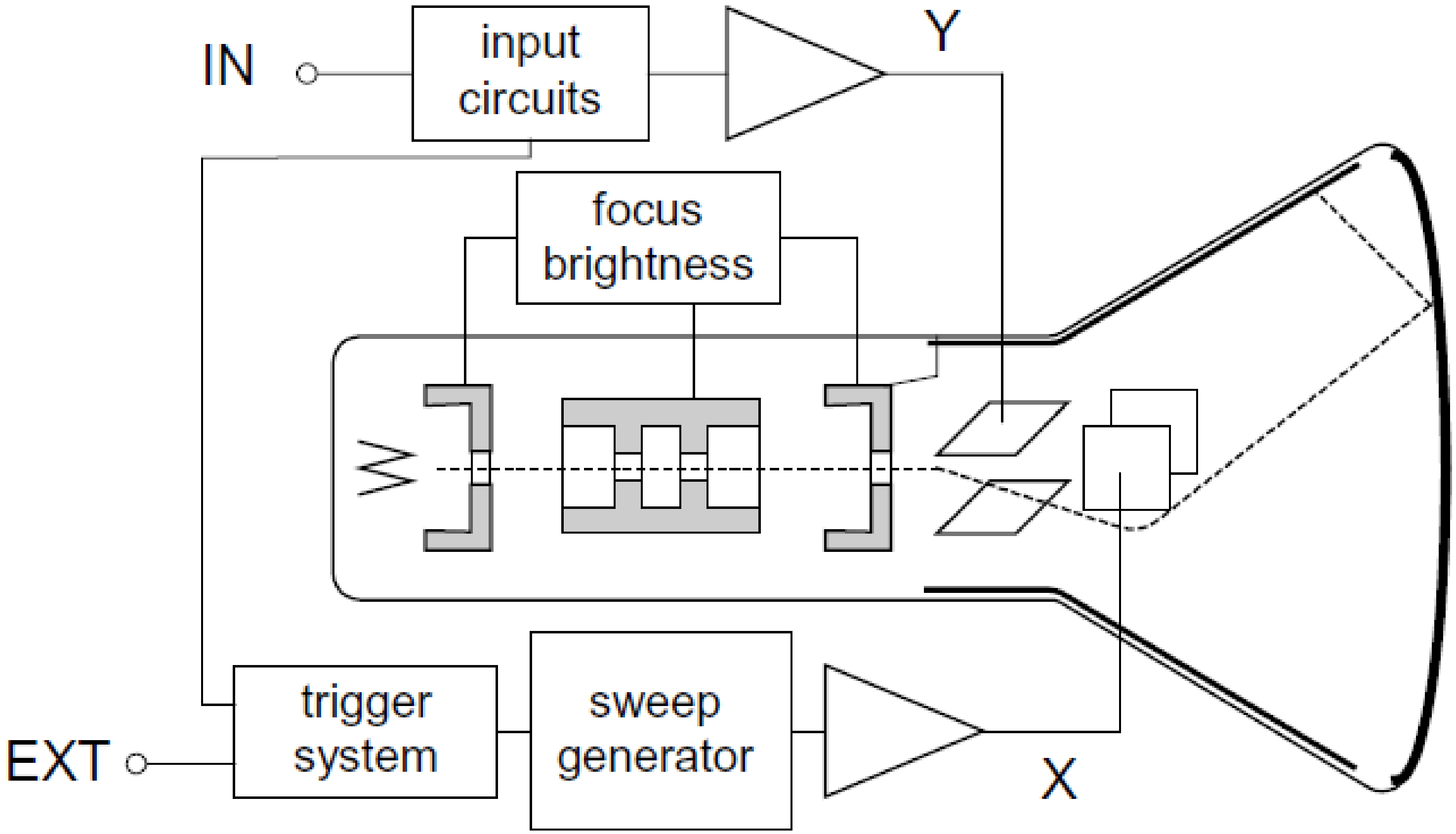


Figure 3.16. The block diagram of a classical oscilloscope

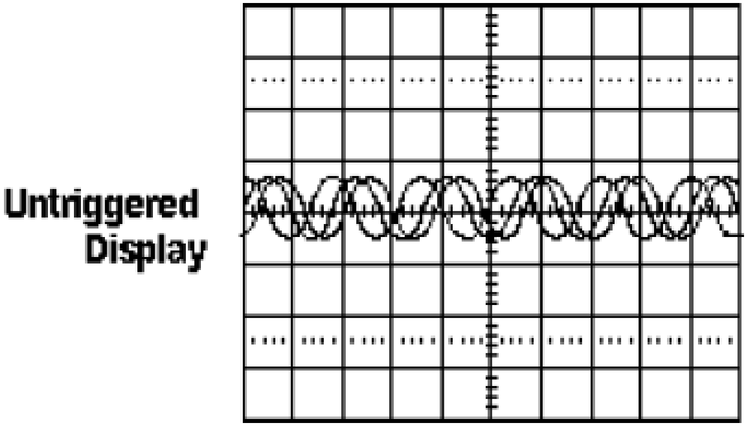
Oscilloscope Main Components

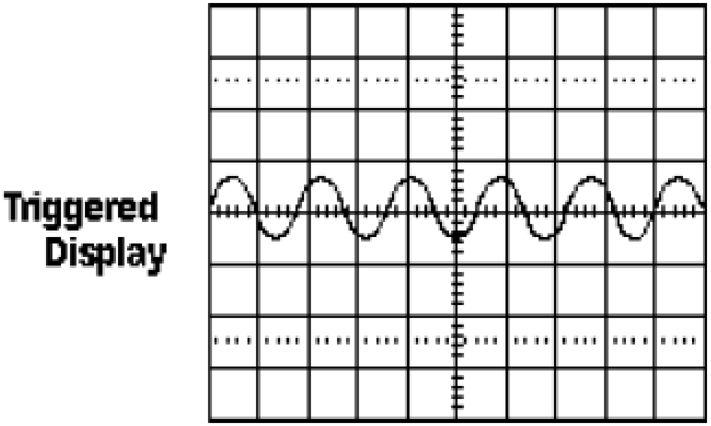
(b) Trigger section

1- Samples the input signal

2- Sends a sync. trigger signal at the proper time to the horizontal sections

3- *Produce succeeding trace on the previous trace., this sections* ***causes the signal to appear to stop****, allowing the viewer to examine the signal*





Oscilloscope Main Components

(c) Horizontal section

1- Contain the time-base (or sweep) generator

2- The horizontal position **of the beam is** proportional to the **time** that passed from start

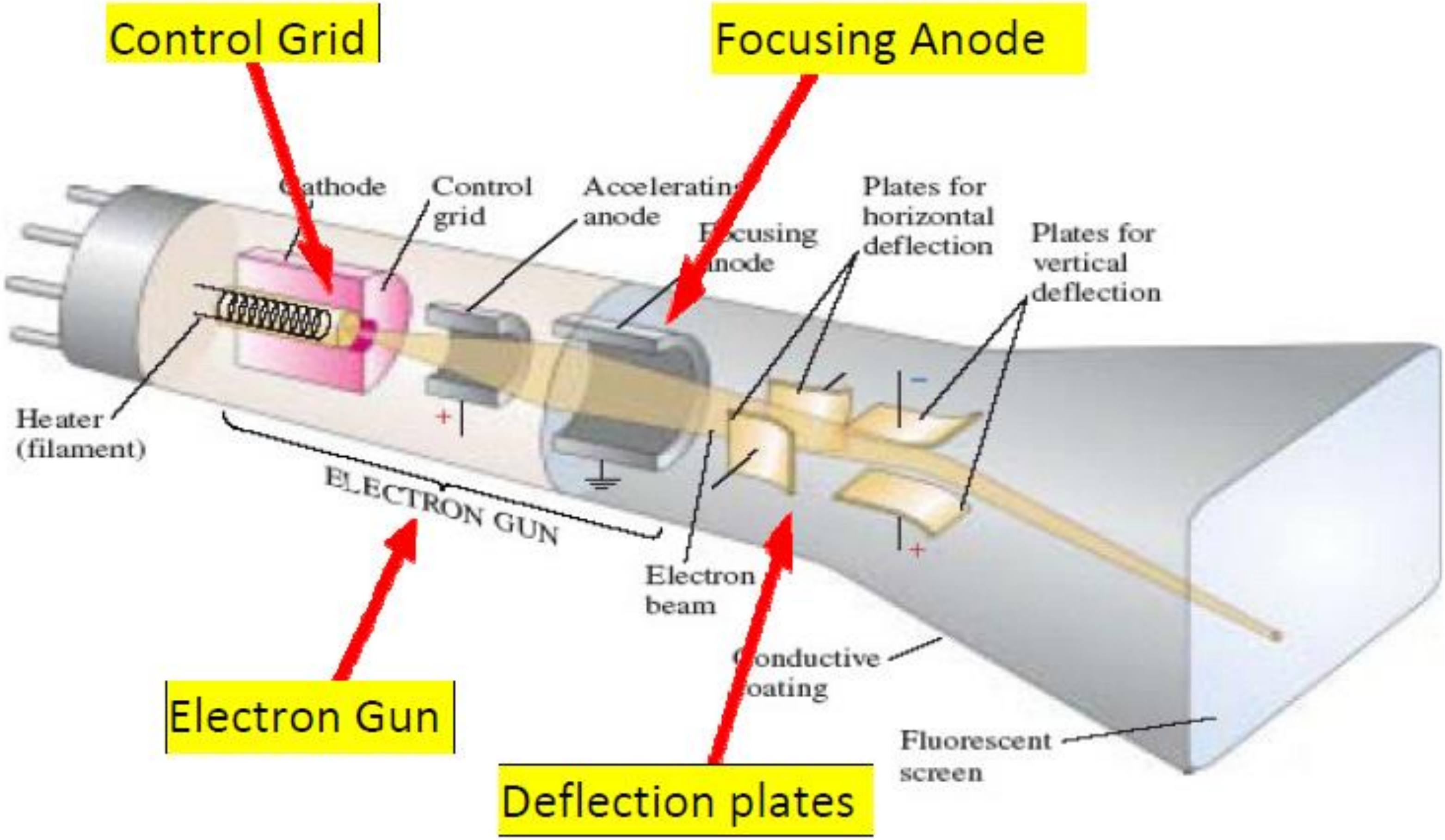
3- The horizontal axis to calibrate in unit of times (sec/div)

4- The output of the horizontal section is applied to the **horizontal deflection plates** of the CRT.

Oscilloscope Main Components

(d) Display section

1- Enables the **user to obtain a sharp** representation with the proper intensity



Oscilloscope Display Section

The Cathode Ray Tube (CRT)

It is a vacuum tube in which a **trace** is made **visible** on a ***Phosphorescent* viewing screen** that **glows** when a narrow beam of electrons strikes the phosphors

The Electronic Gun

- **What are the main elements of Electronic Gun?**

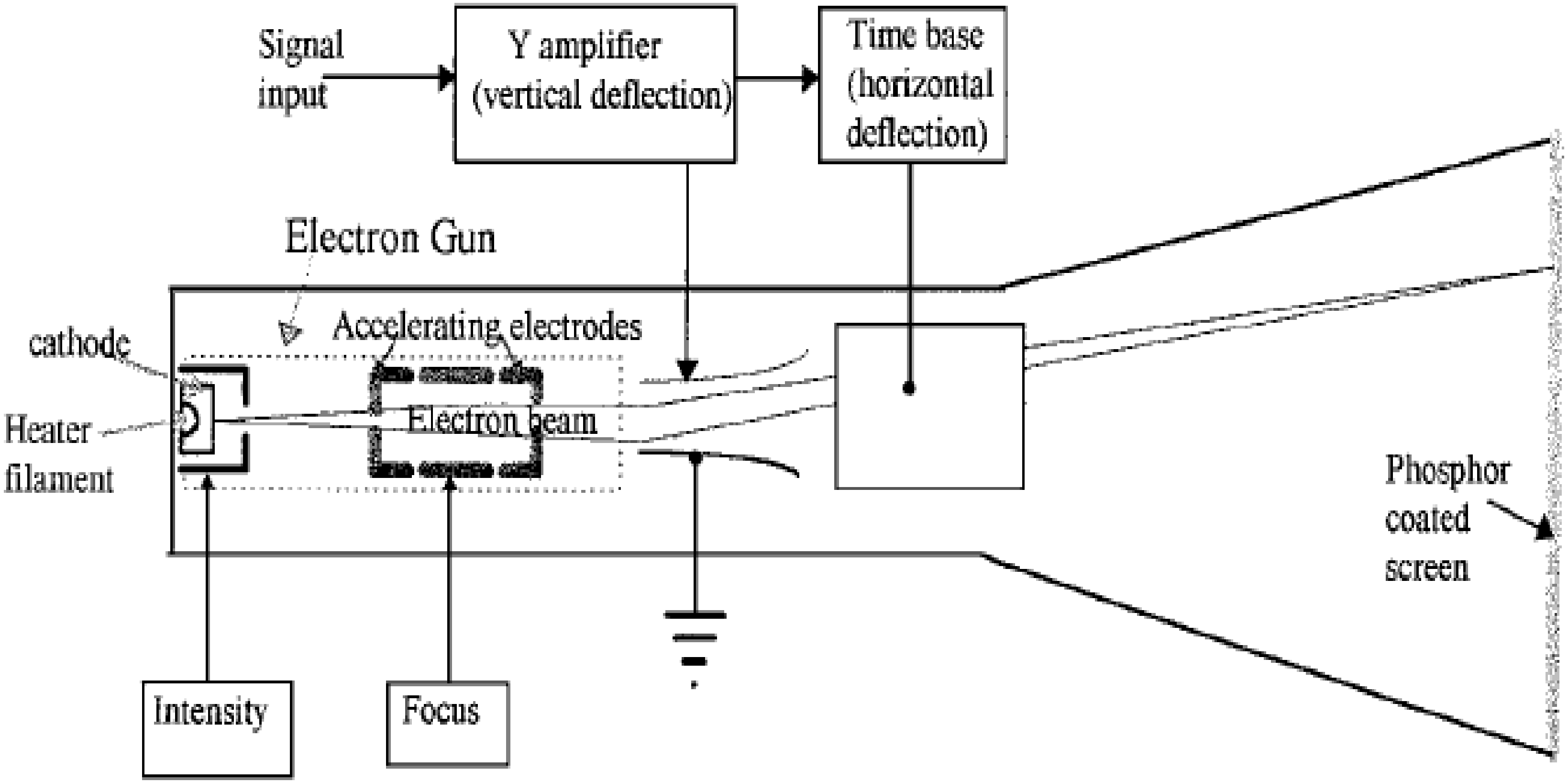
It Consists of

(a) Heater (b)Cathode (c) Control grid

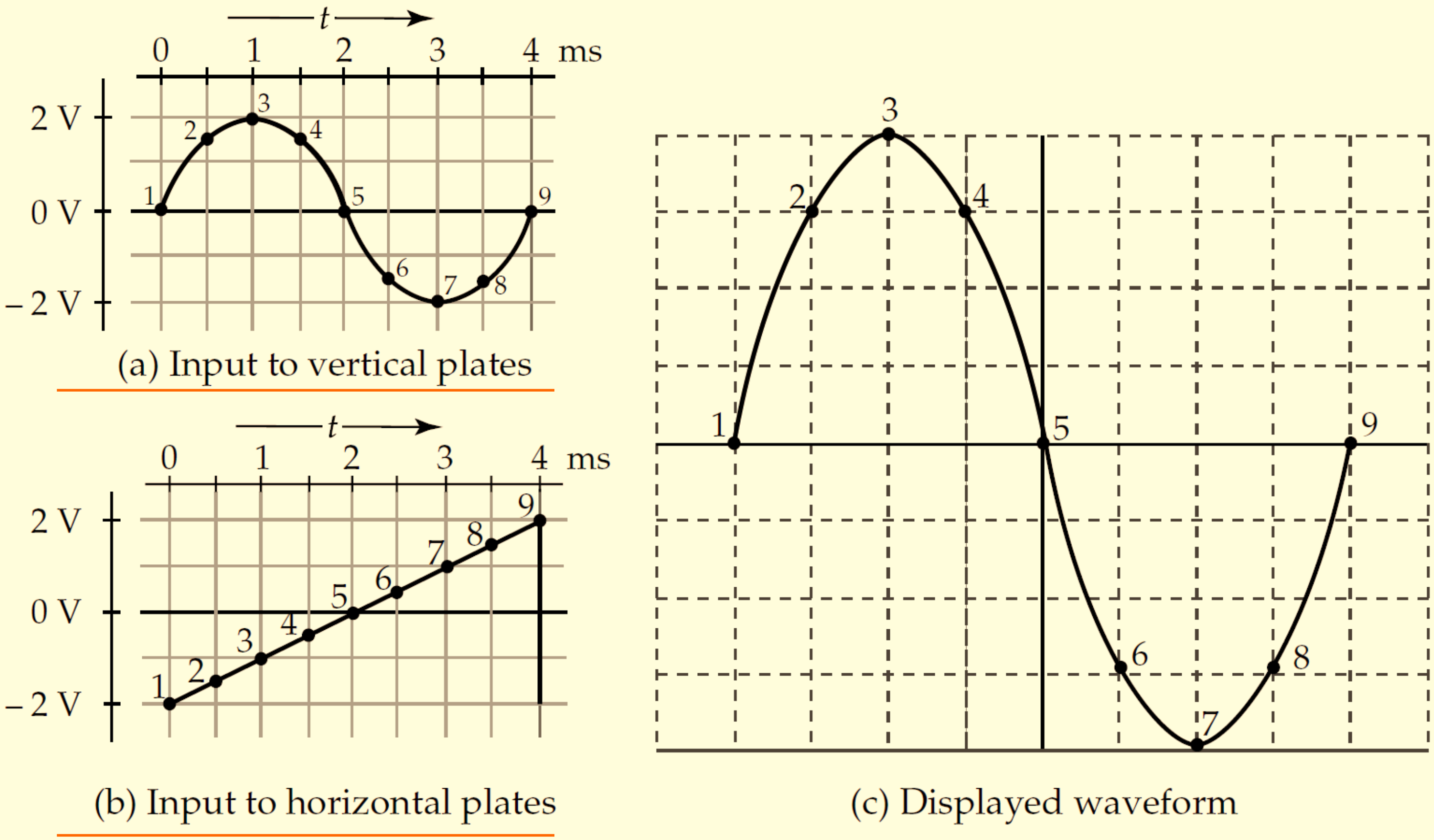
(d) Accelerating anode **accelerate** the electronbeam

(e) Focusing anode to define the electron beam

Oscilloscope CRT Display



Waveform Display



(a) Input to vertical plates

(b) Input to horizontal plates

(c) Displayed waveform

Figure 11-5 A ramp waveform applied to the horizontal deflecting plates of an oscilloscope causes the electron beam to be deflected horizontally across the screen. Another waveform, synchronized with the ramp and applied to the vertical deflecting plates, is displayed on the screen.

Deflection systems

Consists of magnetic or electrostatic deflection systems

1. Magnetic deflection

It is useful for a large deflection angle , which is common in TVs

2. Electrostatic defection

- For general purpose Oscilloscopes Electrostatic deflection used.

- Can be used at **higher frequency** than magnetic deflection

Deflection Section

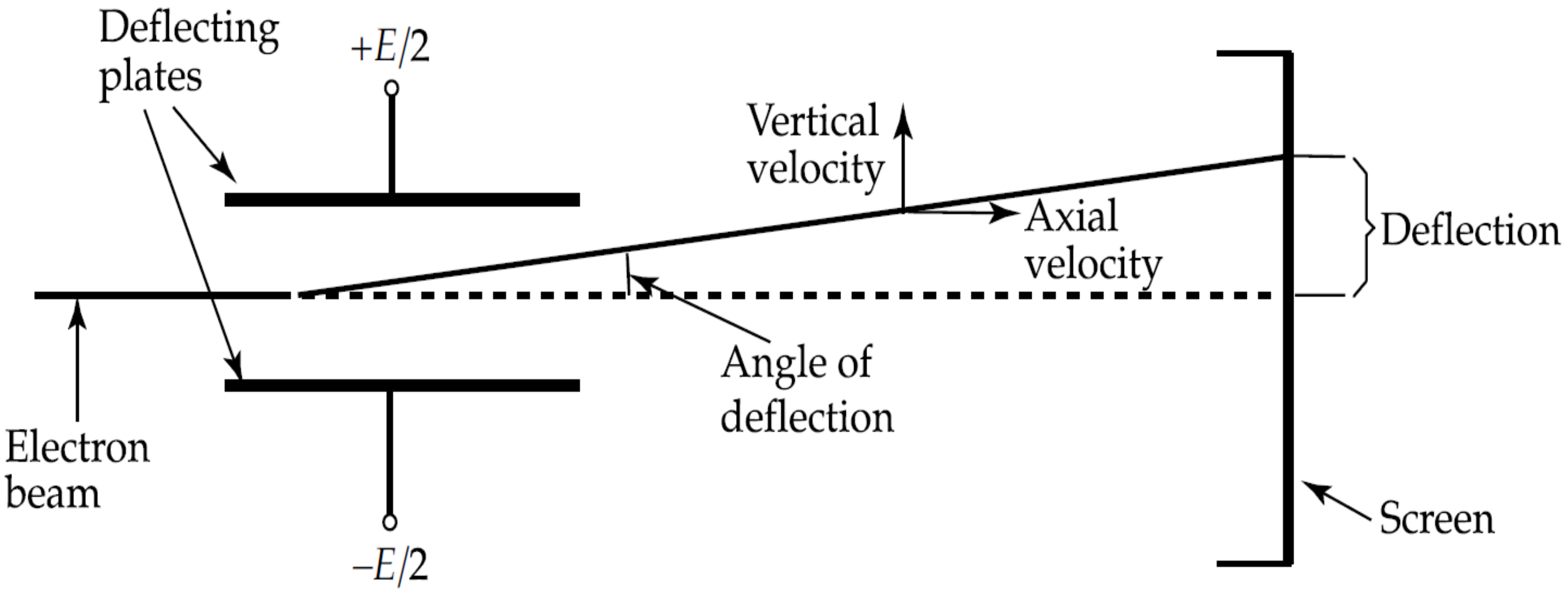
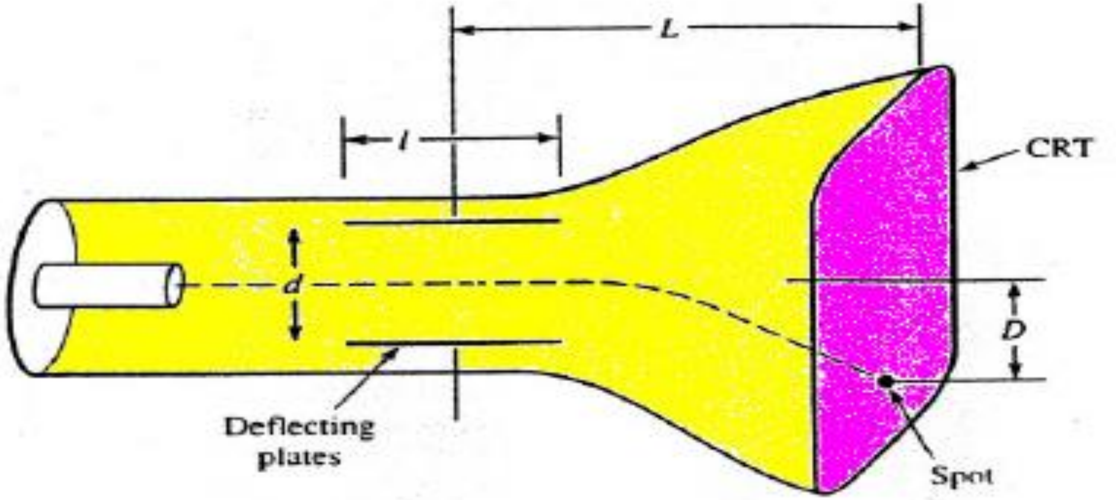


Figure 11-3 Electrostatic deflection. Electrons traveling from the electron gun to the screen of the cathode-ray tube are attracted toward the positive deflecting plate and repelled from the negative plate. The electrons do not strike the plate, but the electron beam is deflected.

Deflection Relation

$$D = \frac{Ll}{2d} \cdot \frac{V_d}{V_a}$$



D	is the deflection from the screen center , cm
V_d	the deflection plate voltage, V
L	the length form the center of deflection plate to the face of CRT, cm
l	the length of the deflection plates, cm
V_a	the accelerating voltage between the cathode and the final anode, V
d	the separation distance between the deflection plates

Deflection sensitivity(V/Cm) $= \frac{V_d}{D} = \frac{2dV_a}{Ll}$

Example

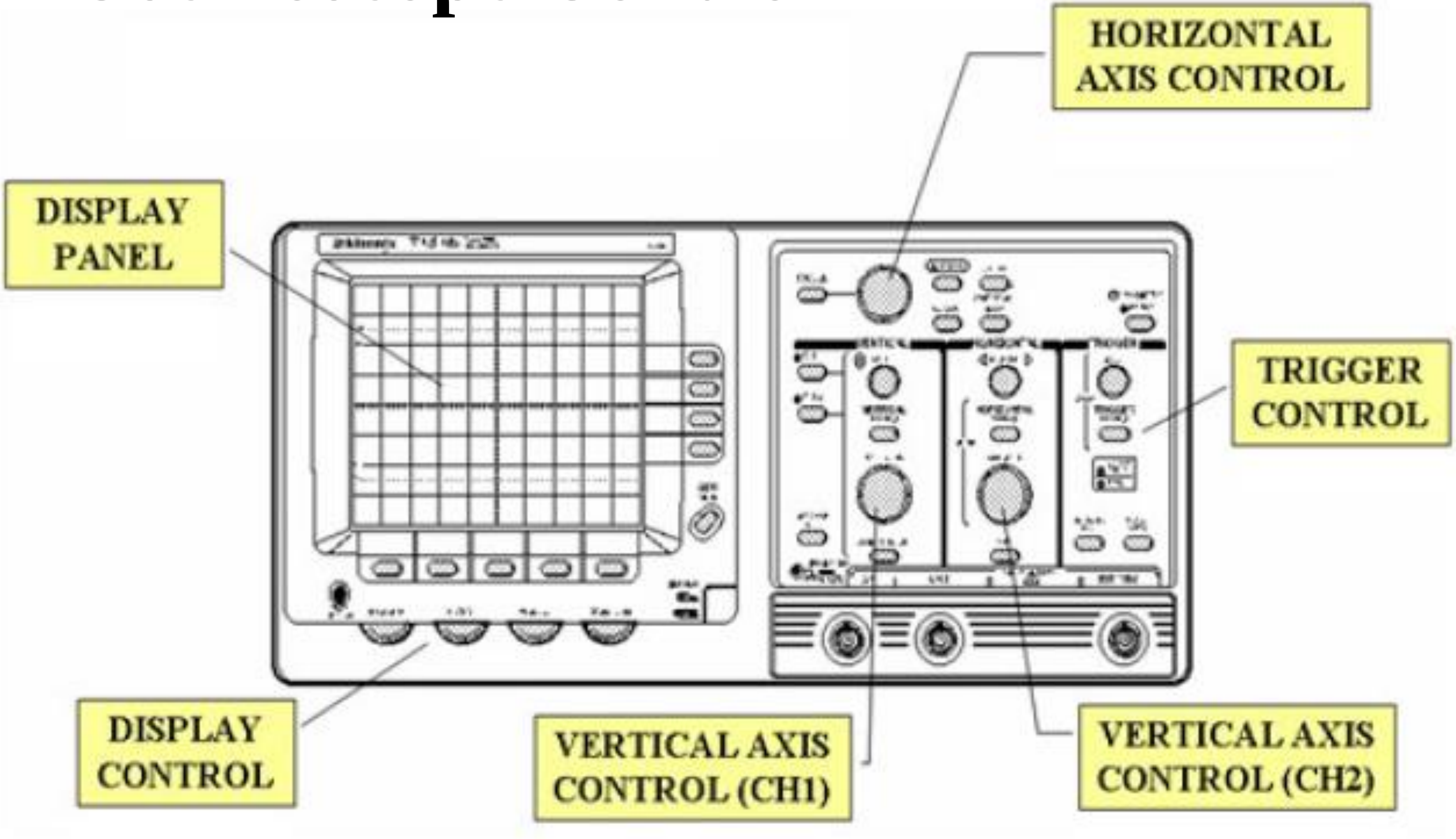
A CRT with 3.0 cm plates separated by distance 1.0 cm operating by accelerating voltage of 1 KV. The length from deflection plates to screen is 22 cm, what is the voltage required between deflection plates to deflect the beam by 4 cm. and calculate also the deflection sensitivity.

$$V_d = \frac{2dV_aD}{Ll} = \frac{2*(1.0)*(1000)*(4.0)}{(22)*(3.0)} = 121.212V$$

$$\text{Deflection sensitivity} = \frac{2dV_a}{Ll} = \frac{2*1.0*1000}{22*3.0} = 30.303V/cm$$

$$\text{Deflection sensitivity} = \frac{V_d}{D} = \frac{121.212}{4.0} = 30.303V/cm$$

Oscilloscope Control



Oscilloscope Control

1- **Display** control, which adjust the focus and intensity (**intensity** switch, **Focus** switch)

2- **Vertical** control, control the (**Volt/div**)

3- **Horizontal** control, control (**Sec/Div**), such as (Time/div)

4- **Trigger** Control , determine the proper time to ***begin*** in order to produce a **stable** display

Probes

- The goal of a probe is to bring the signal from the **circuit to the oscilloscope** with no distortion.
- Probe is the point of **contact** between the instrument and the device or circuit being measured.
- **Its electrical characteristics**, the way it is connected, and its interaction with both the oscilloscope and the circuit **have a significant impact on the measurement.**

Types of the Probes

1- Passive attenuating probes

2- Active probes

3- Current sensing probes

4- High voltage probes

5- Special purpose probes(logic probe, temperature probe, etc.)

1- Passive Probes

- The simplest and least expensive
- Composed of wires and connectors and when attenuation is required, resistors and capacitors as well.
- There are no active components in a passive probe so it can operate without power from the instrument
- Rugged, easy and widely used in general applications.

2- Active Probes

- Advantages of active probes include low loading on the signal source.
- Active probes are available in both single-ended and differential versions.
- Active probes use active components that is maintained over a wide frequency range.
- As active probes have **extremely low loading**, they are essential when **connected to high-impedance** circuits that **passive probes would unacceptably load**.

3- Differential Probes

- Although a separate probe for each signal could be used to probe and measure a differential signal, the best method is by using a **differential probe**.
- A differential probe uses a built in differential amplifier **to subtract the two signals**
- Differential probes can be used for both **single-ended** and **differential** applications.

4- Current Probes

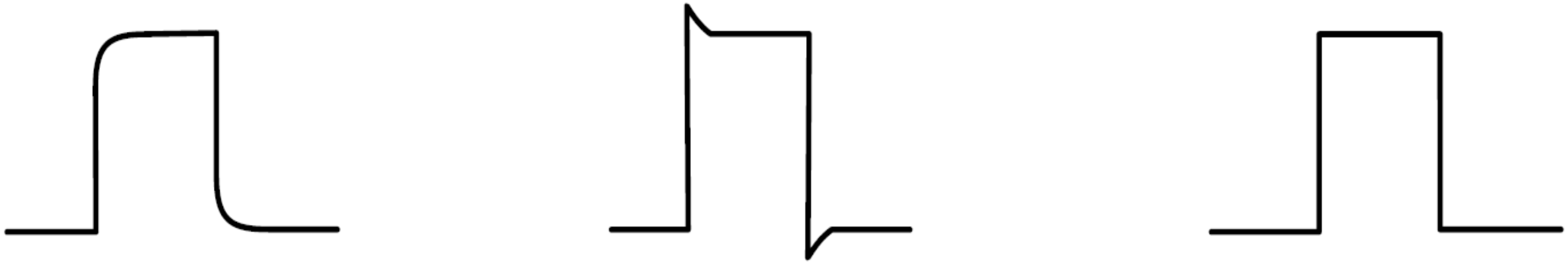
Current probes work by sensing the strength of an electromagnetic flux field when current flows through a conductor.

This field is then converted to a corresponding voltage for measurement and analysis by an oscilloscope.

5- High-Voltage Probes

The maximum voltage for general-purpose passive probes is typically around 400V. When very high voltages are encountered in a circuit ranging as high as 20 kV

Probe Calibration



(a) Under compensated (b) Over compensated (c) Correctly compensated

Figure 11-28 Oscilloscope 10:1 probes are calibrated by connecting a square wave (usually provided at a terminal on the oscilloscope front panel) and adjusting the probe capacitor to obtain an undistorted waveform display.

Measurements with Oscilloscope

Peak-to-Peak Voltage Measurement

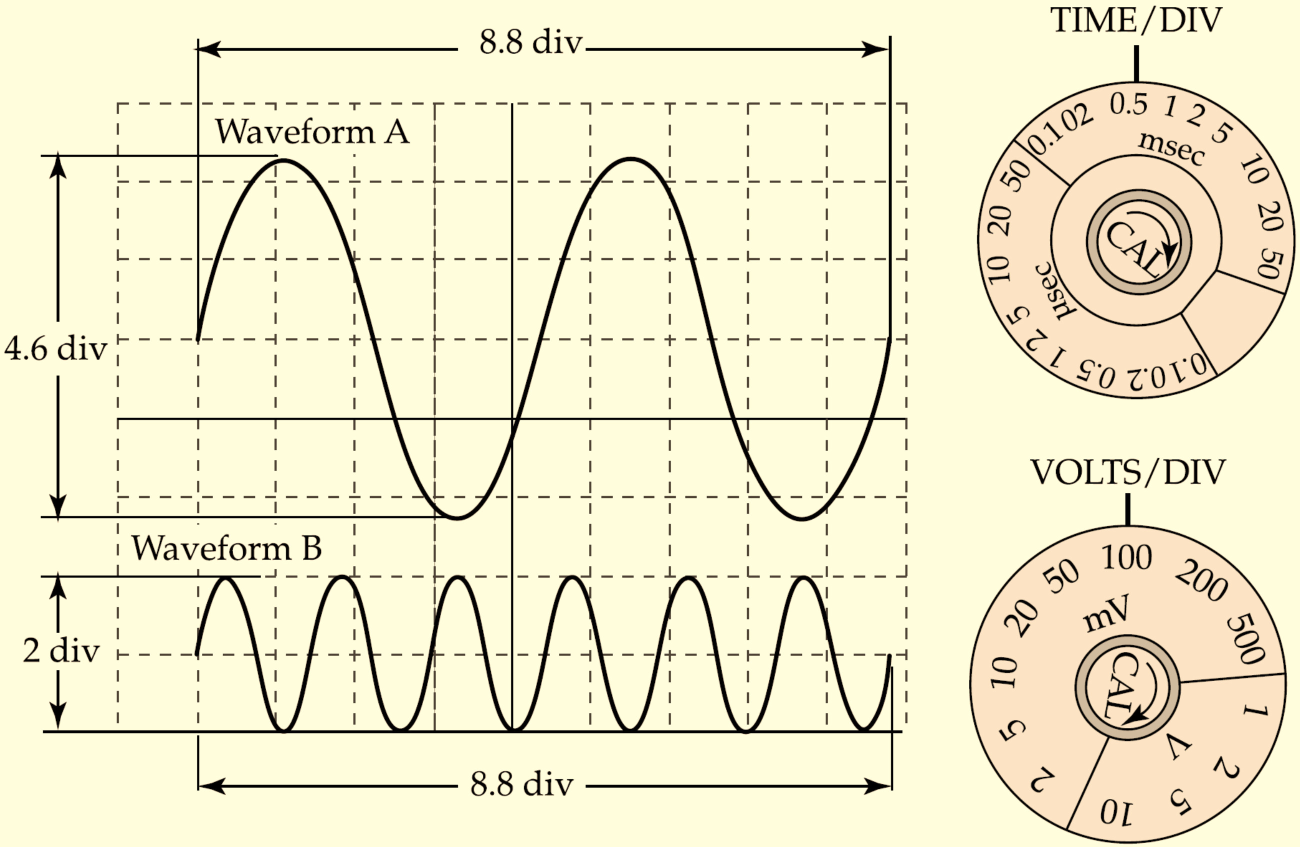


Figure 11-18 The peak-to-peak voltage of a waveform is measured by multiplying the VOLTS/DIV setting by the peak-to-peak vertical divisions occupied by the waveform. The time period is determined by multiplying the horizontal divisions for one cycle by the TIME/DIV setting.

Phase Measurement

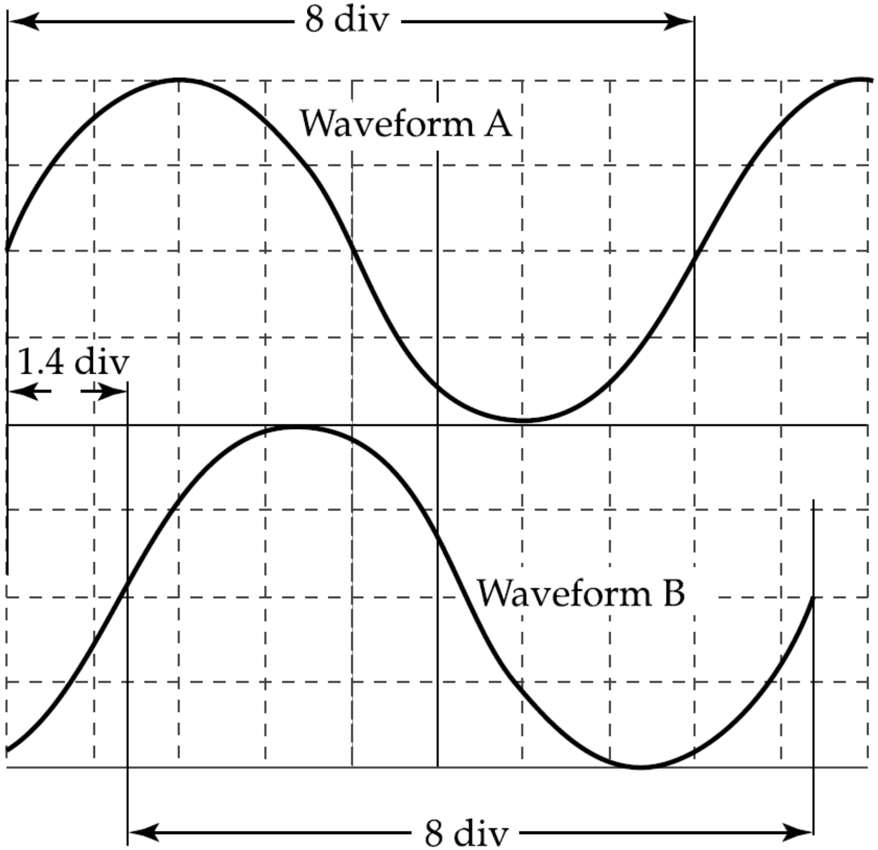


Figure 11-19 The phase difference between two sine waves may be determined by first calculating the horizontal degrees/division for one cycle. This factor is then multiplied by the horizontal divisions between commencement of the two waveform cycles.

Pulse Measurement

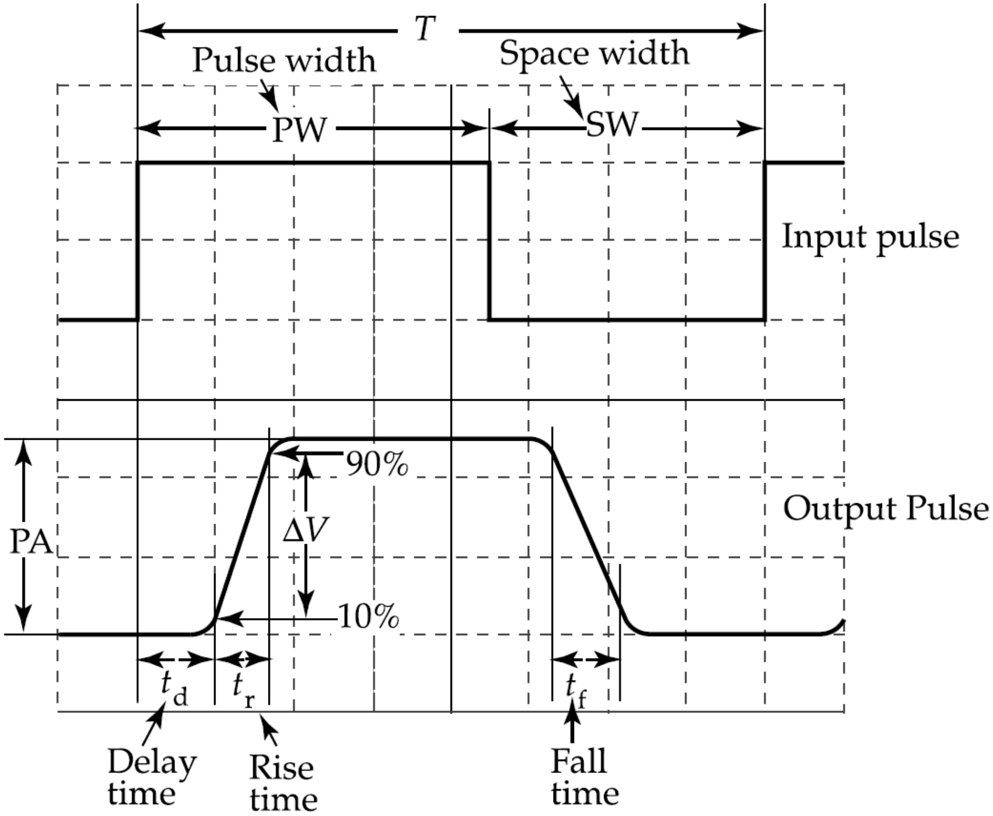
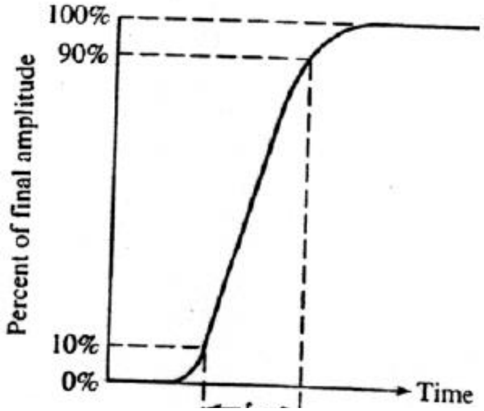


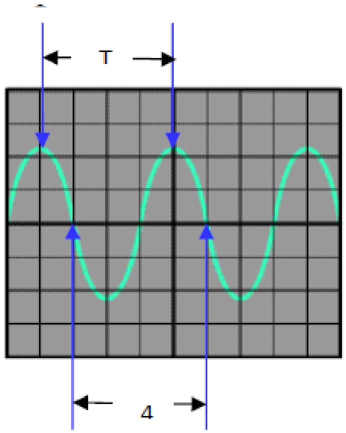
Figure 11-21 Pulse width is determined by multiplying the TIME/DIV setting by the horizontal divisions occupied by the pulse. Pulse amplitude is VOLTS/DIV × (waveform vertical divisions). Rise time is TIME/DIV × (horizontal divisions from 10% to 90% of pulse amplitude). Fall time equals TIME/DIV × (horizontal divisions from 90% to 10% of pulse amplitude).

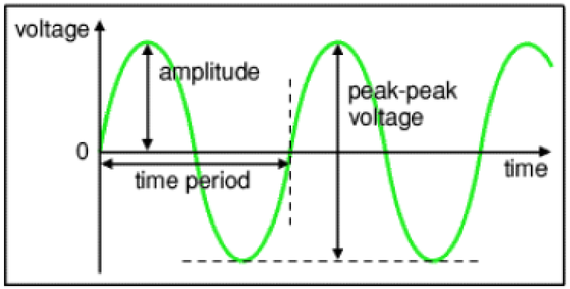
Measurements with Oscilloscope



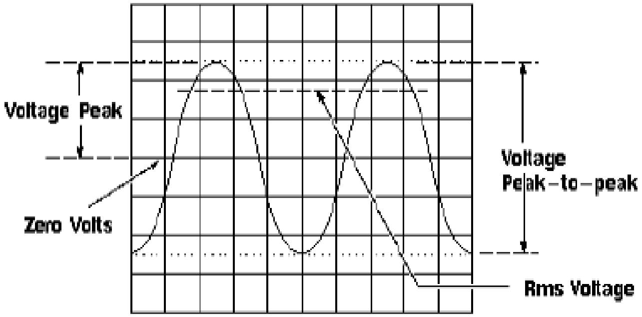
Rise time

Time measurement





Amplitude measurement



X-Y measurements

Phase Angle Measurement

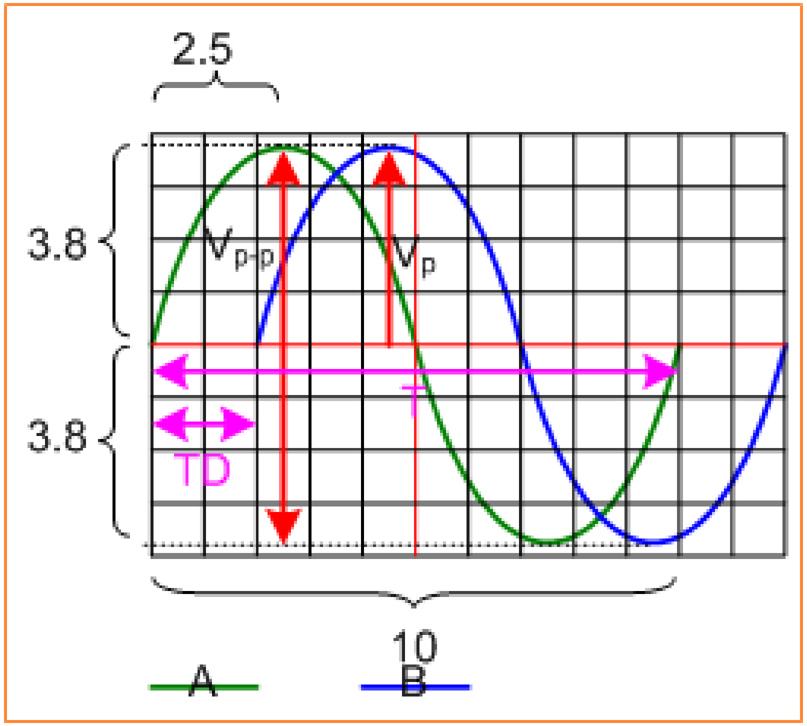
1- Normal method

2- The Lissajous figure

Measurements with Oscilloscope

Phase Angle Measurement 1- Normal method

The phase angle measurement always involve the comparison of two signals *of **the same frequency***



(Time/Div : 0.5ms/Div)

1 cycle = 10 div

TD = 2 div

Therefore,

1 cycle : 10 div = 360°

1 div = 360° / 10 = 36°

2 div = 2 x 36° = 72°

Phase Angle Measurement

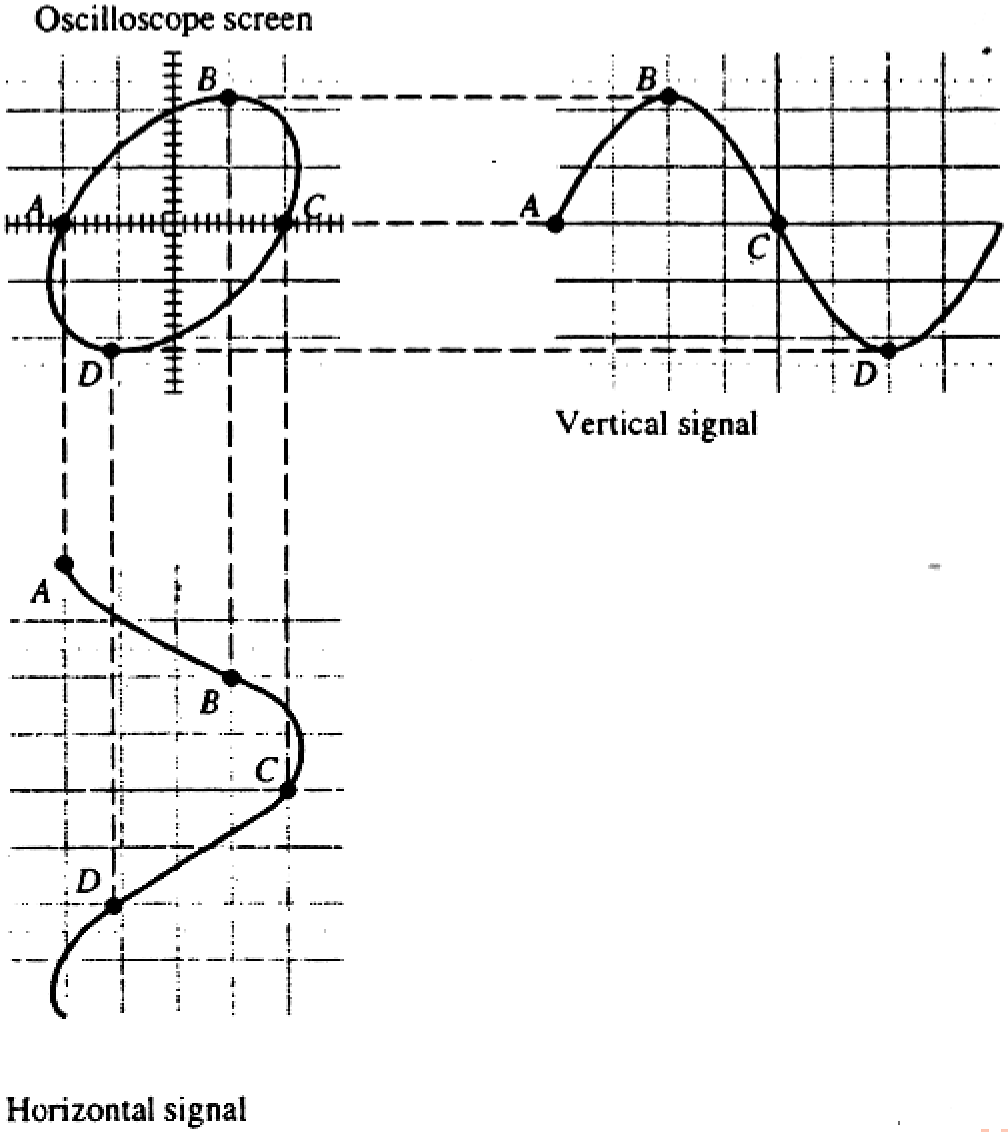
2- The Lissajous figure

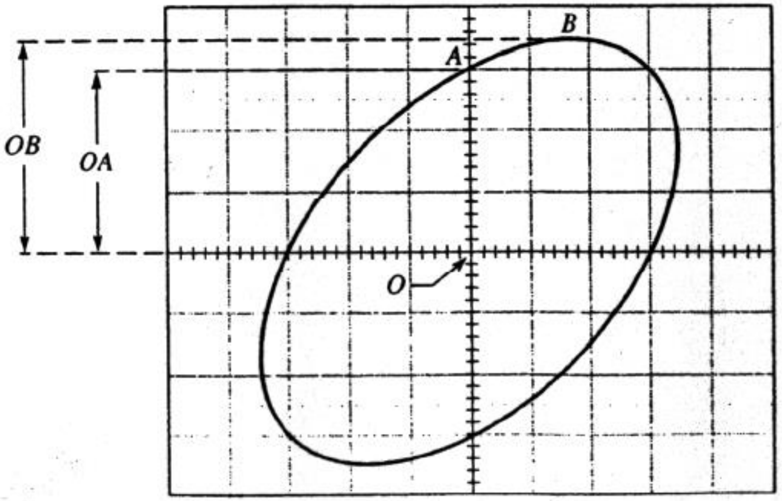
The plots presented here represent the case of the same frequency is

$X = \mathrm{Cos}(\mathrm{w}t)$

$Y = \mathrm{Cos}\,(\mathrm{w}t + \varphi)$

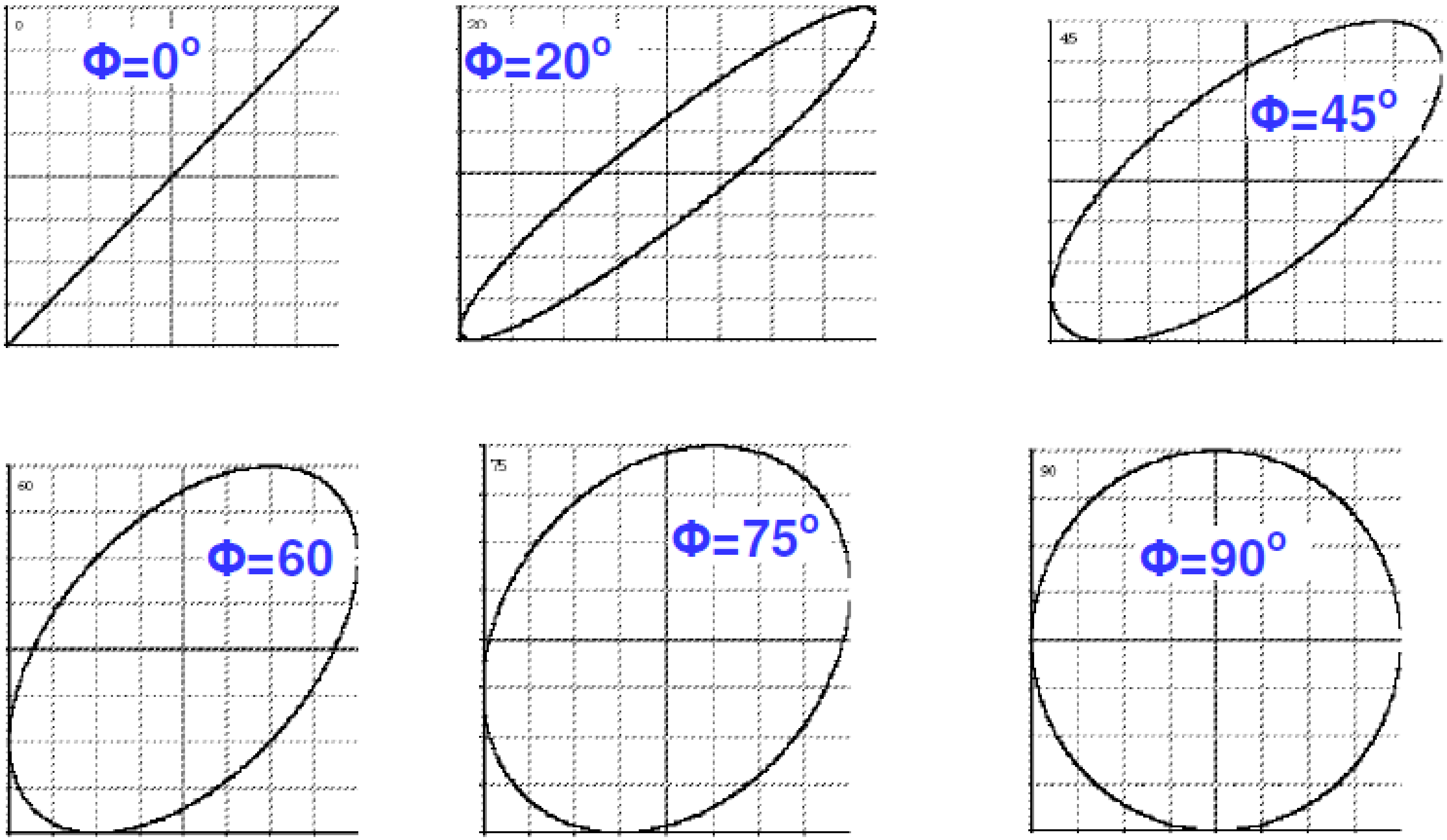
Where φ is the phase shift between the two signals





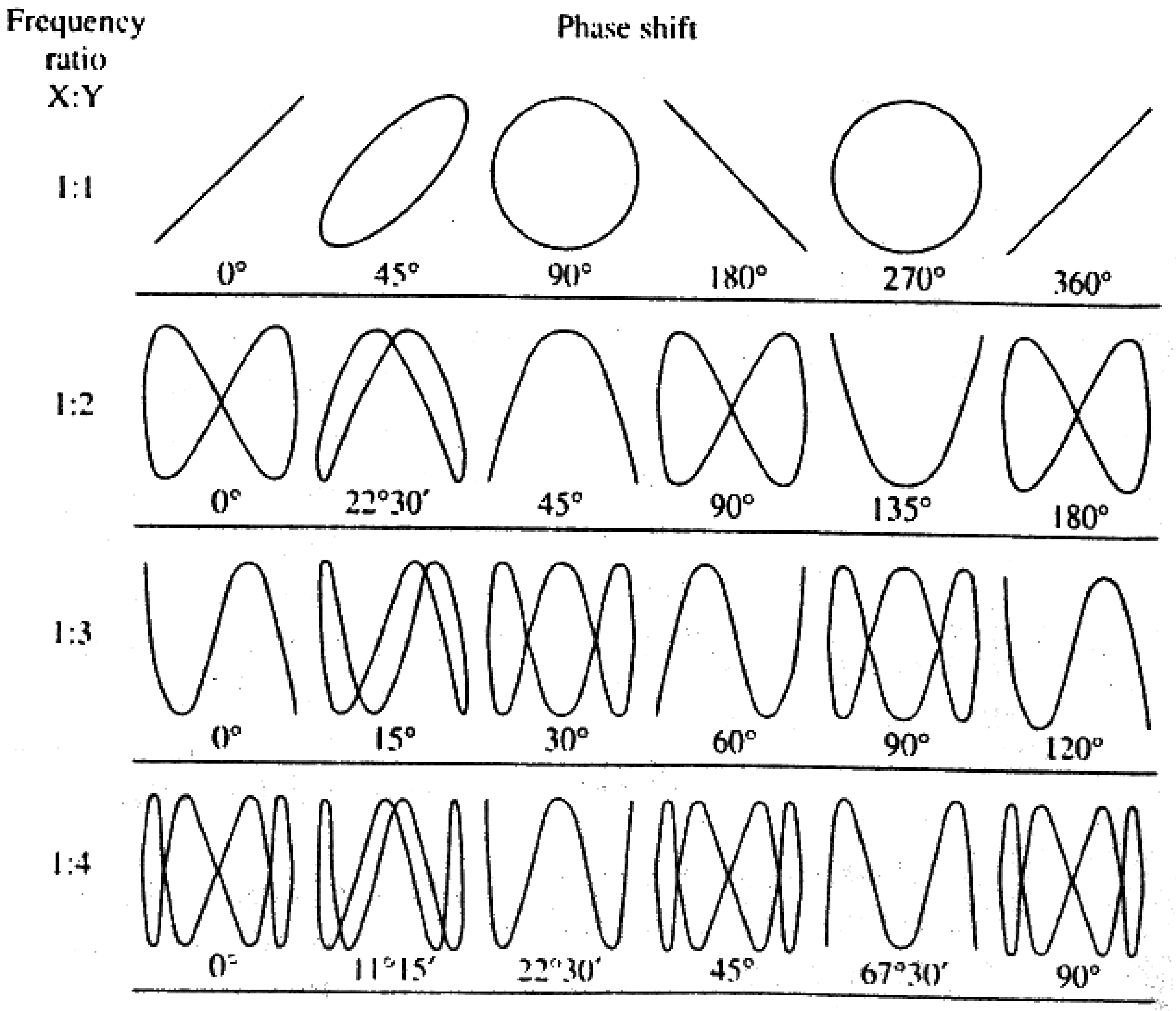
$$\theta = \arcsin \frac{OA}{OB}$$

Lissajous Figure

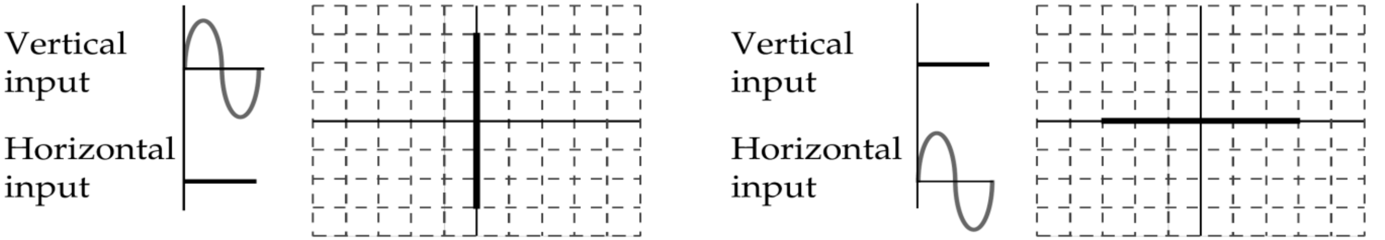


X-Y Mode Measurements

- This method is done also by Lissajous figures
- This method can be used to **compare two frequencies** and **phases**

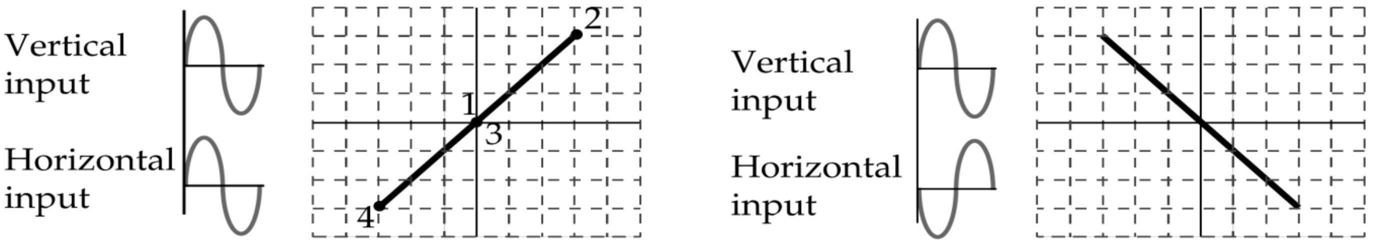


X-Y Displays



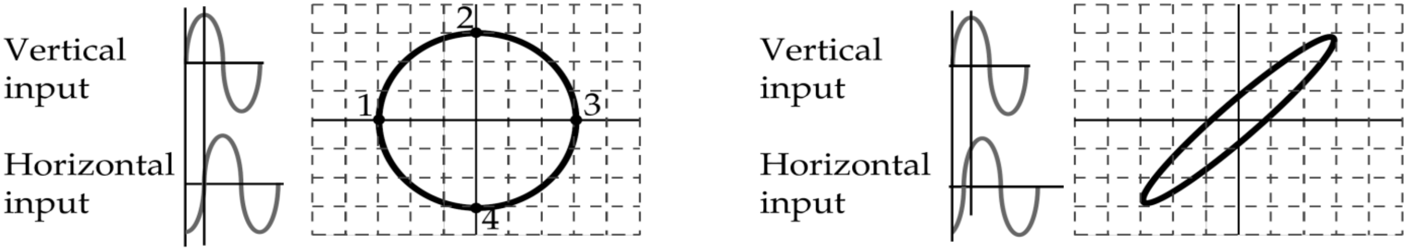
(a) Sine wave vertical input, zero horizontal input

(b) Zero vertical input, sine wave horizontal input



(c) Two in-phase sine waves

(d) Two anitphase sine waves

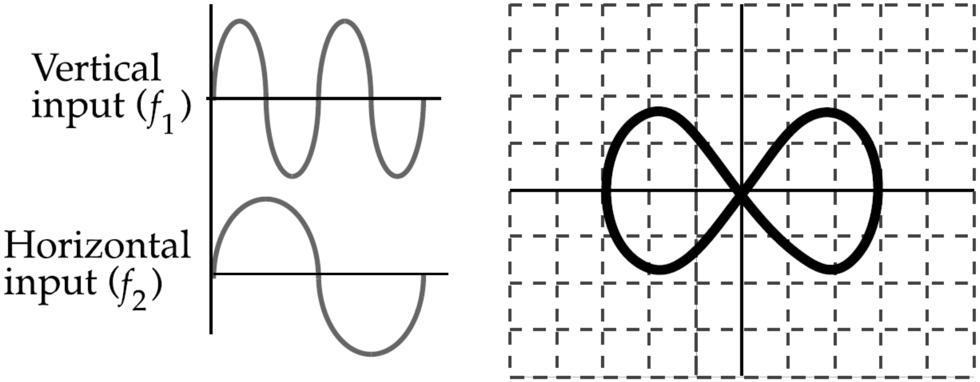


(e) Sine waves with 90° phase difference

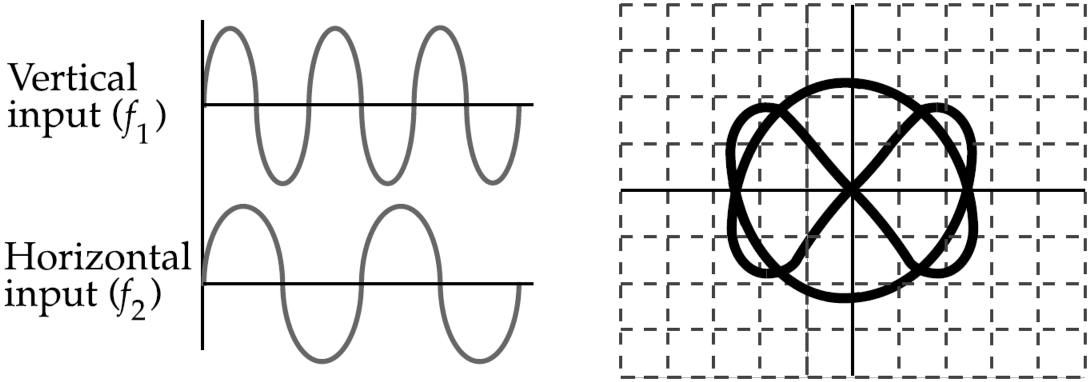
(f) Sine waves with phase difference greater than zero but less than 90°

Figure 11-30 The display produced when equal-frequency sine waves are applied to the horizontal and vertical inputs of an oscilloscope depends on the phase relationship between the waveforms.

X-Y Displays



(a) Vertical input frequency twice the horizontal frequency



(b) $f_1/f_2 = 3/2$

Figure 11-31 Lissajou figures are generated when sine waves having different frequencies are applied to the vertical and horizontal inputs of an oscilloscope.

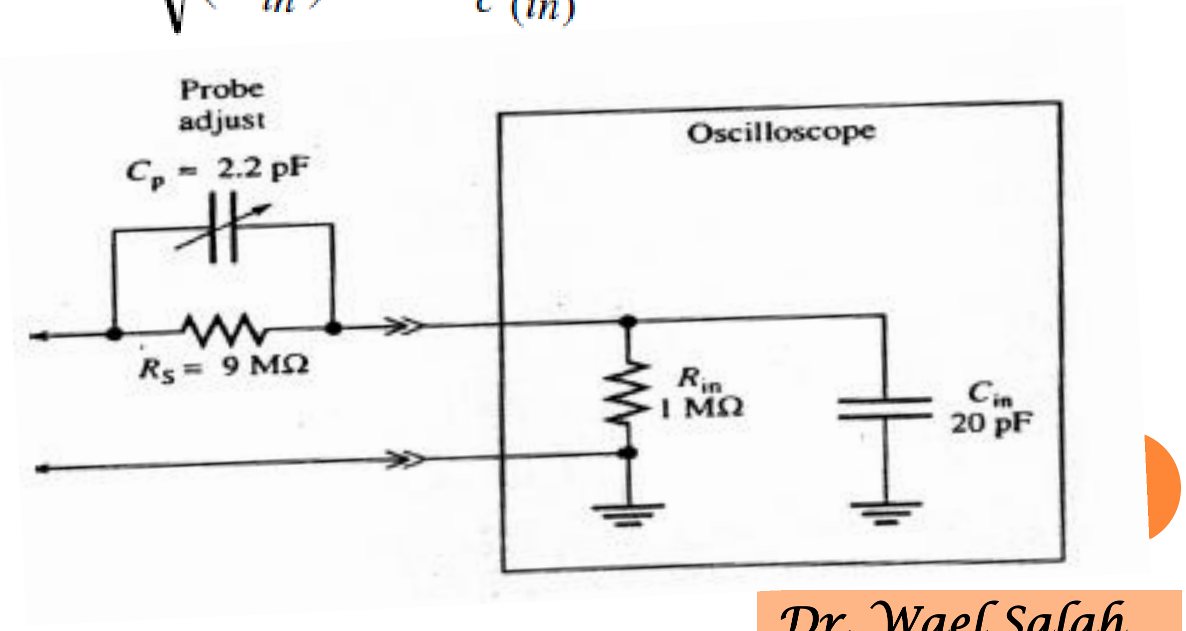
Probe Bandwidth

Bandwidth is the frequency between **low** and **high** frequency range

The input resistance of the **probe** appears to be in ***parallel*** with the input capacitance of the probe.

$$Z_{in} = \frac{(R_{in})*(-jX_{c(in)})}{R_{in} - jX_{c(in)}} = \frac{(R_{in})*(-jX_{c(in)})}{\sqrt{(R_{in})^2 + X_{c\,(in)}^2}}$$

$$X_{c\,(in)} = \frac{1}{2\pi f C_{in}}$$



Example

A 10X-probe has 20 pF of capacitance to ground and an input resistance of 10 M. what is the input impedance of the probe at a frequency of 100KHz

$$X_{c(in)} = \frac{1}{2\pi f C_{in}} = \frac{1}{2\pi * 100 * 10^{3} * 20 * 10^{-12}} = 79.58\ K\Omega$$

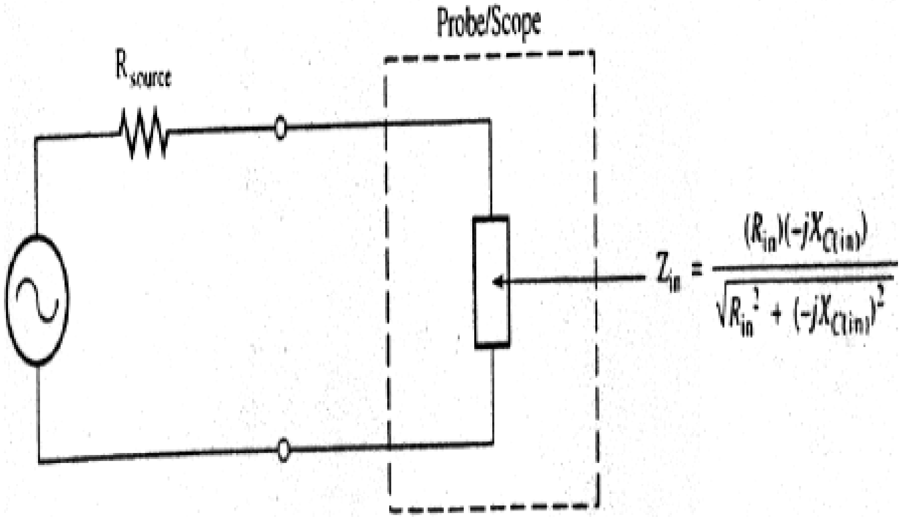
$$Z_{in} = \frac{(R_{in}) * (-jX_{c(in)})}{\sqrt{(R_{in})^2 + X_{c(in)}^2}} = \frac{10 * 10^6 * (-j79.58 * 10^3)}{\sqrt{(10^7)^2 + (79.58 * 10^3)^2}} = -j79.577\, K\Omega$$

it is clear above the cut-off frequency the input impedance of the probe can be determined by the capacitive reactance. [Zin ≅ Xc(in)]

A way to minimize ***the capacitive loading*** is the increasing of the **resistive loading** by using low resistance probe

The resistive loading effect is computed by the voltage divider

$$V_{obs} = V_{test}\left(\frac{Z_{in}}{Z_{in}+Z_s}\right)$$



V_{obs} = the signal observed by the oscilloscope

V_{test} = the unloaded test voltage of the point being probed

Zs = the source impedance , Ω

Z_{in} = the probe input impedance, Ω

When $Z_{in} > Z_s$ ➔ $V_{obs} = V_{test}$ (ideal case)

When $Z_s > Z_{in}$ ➔ V_{obs} will be very small , which means it faces a lot of attenuation (problem)

Restriction at Measurements

- When probing an unknown impedance, a high input impedance is necessary to avoid attenuation
- If the source impedance is known, a low impedance probe virtually eliminates the capacitive loading

Example

Compute the cutoff frequency for 1K, 0.7pF Probe.

Cutoff frequency calculated when Xc=R

$$X_c = R = \frac{1}{2\pi F_{co} C}$$

$$F_{co} = \frac{1}{2\pi RC} = \frac{1}{2\pi * 1 * 10^3 * 0.7 * 10^{-12}} = 227.3642 MHz$$

Which means that, the probe can be used up to this frequency