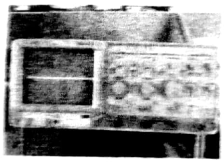
Cathode Ray Oscilloscope (CRO) Controls

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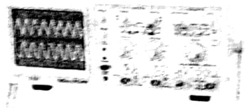
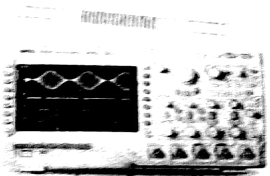
Measuring Instruments

measure a value

Vs

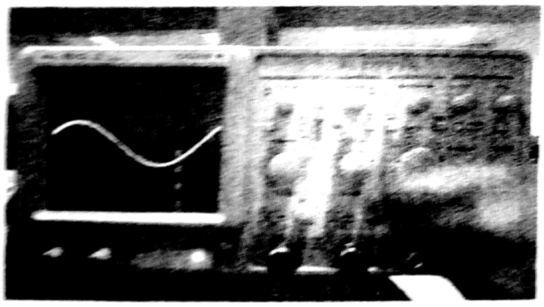



Digital oscilloscope

measure a waveform

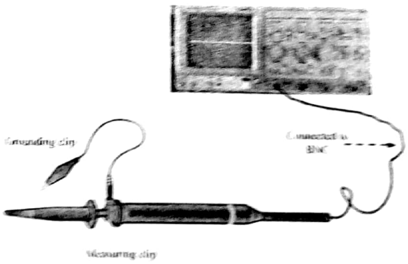
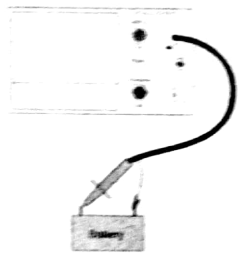
Cathode Ray Oscilloscope (CRO)

- Consists of a cathode ray tube
- display the variation of a voltage in time on the screen

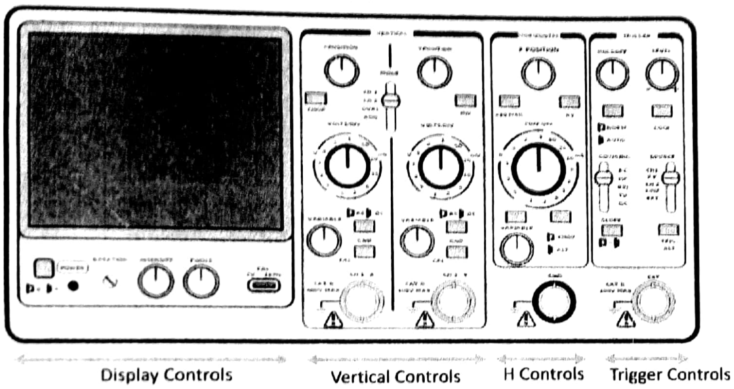


Cathode Ray Oscilloscope (CRO)

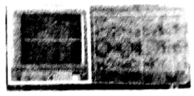
- A probe is used to connect the oscilloscope to the circuit.
- voltage difference between the two terminals of the probe is measured

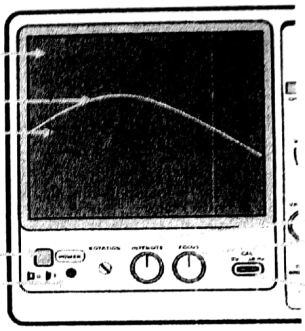



Oscilloscope controls : Front Panel



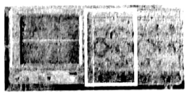
Oscilloscope controls: Display

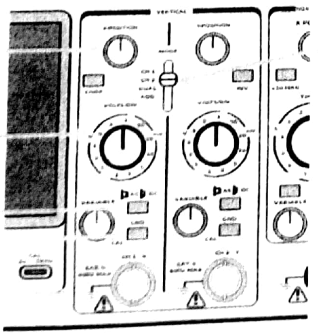




display
trace
grid
power on/off button
power indicator
intensity control
focus control
calibration point

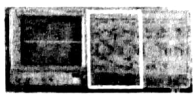
Oscilloscope Controls: Vertical Controls & Coupling





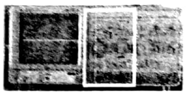
position knob
scale knob
AC/DC coupling GND
input channel
mode

Oscilloscope controls: Vertical Controls



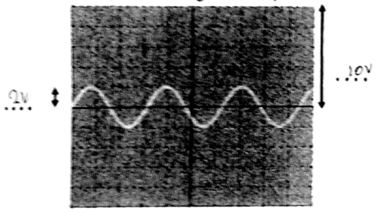
- **Mode**: select the signal to display
- **Position knob:** moves the waveform vertically.
- **Scale knob:** varies volts per division(volts/div), which determines the voltage value corresponding to each vertical division on the oscilloscope's screen.

Oscilloscope controls: Vertical Controls

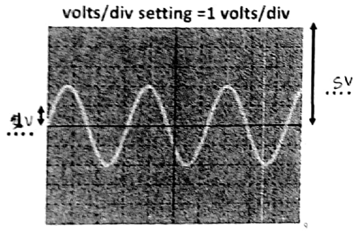


Activity

volts/div setting =2 volts/div



volts/div setting =1 volts/div

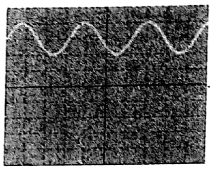


Oscilloscope controls: Input Coupling

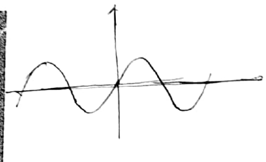
Activity

$y(t) = 3 + \sin(wt)$, given that volts/div setting =1 volts/div

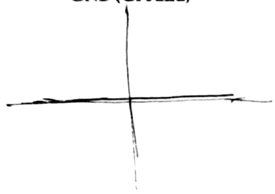
DC coupling



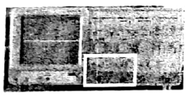
AC coupling



GND (Ground)

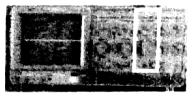


Oscilloscope controls: Input Coupling

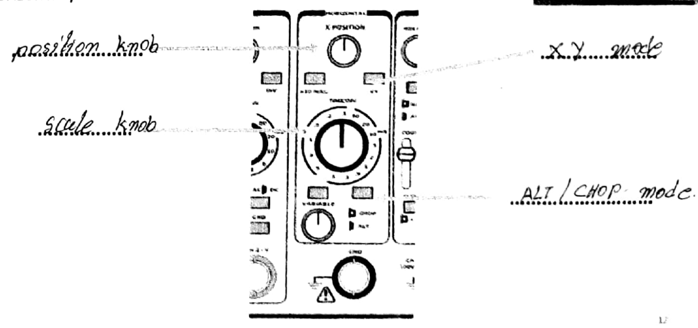


- **DC coupling**: both AC and DC components of the input waveform are passed to the oscilloscope
- **AC coupling**: the DC offset voltage is removed from the input waveform, so that the waveform is zero centered
- **GND (Ground)**: The ground setting disconnects the input signal from the vertical system, which lets you see where zero volts is on the screen.

Oscilloscope controls: Horizontal Controls

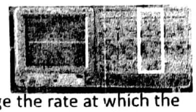


Horizontal controls are used to position and scale the waveform horizontally.



Scanned by CamScanner

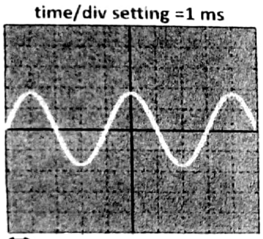
Oscilloscope controls: Horizontal Controls



- **Position knob:** moves the waveform horizontally.
- **Scale knob:** varies time per division (time/div) setting which change the rate at which the waveform is drawn across the screen (also known as the time base setting or sweep speed)

Activity

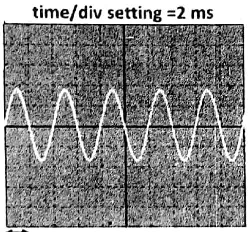
time/div setting =1 ms



.1ms.

10 ms

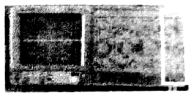
time/div setting =2 ms



.2ms

20 ms

Oscilloscope controls: Trigger Controls



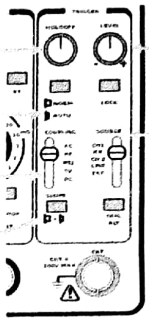
Use to achieve a steady plot on the screen. how? later..

Hold off

Auto or manual trigger selection

coupling selation of trigger signal.

slope (+/-)



level

Trigger source selection.

Oscilloscope Measurement Techniques

- Typical quantities, which are of primer interest when observing a signal with the scope are shown in the figure x.

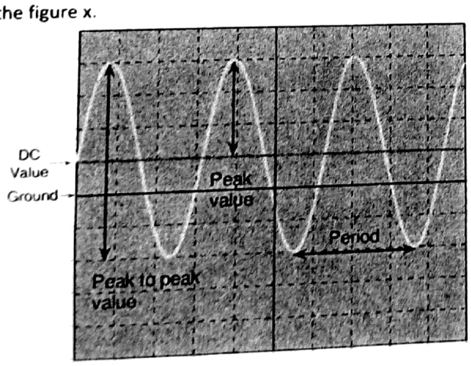


Figure x

Home Work

suppose that the variables **volt/div** and **time/div** are set to:
volt/div = 2Volts/div.
time/div = 1millisecond/div

Then the corresponding values shown on the figure x are calculated to be;
Peak Value = 6volts
Peak to peak value = 12 Volts
DC Value (Average Value) = 2 Volts
Period = 3 milliseconds

Calculate the frequency and write down the expression explaining the signal s(t) shown in figure x..

frequency =..

s(t) =..

EE251: Principles of Electrical Measurements

Cathode Ray Oscilloscope (CRO)

By

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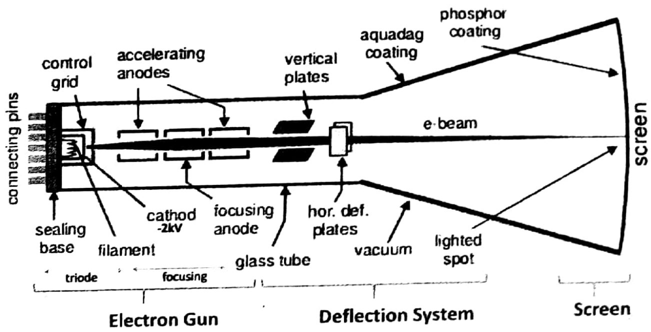
Cathode Ray Tube



Electron Gun : Triode Section

Filament:
- heat the Cathode

Cathode:
- nickel cylinder with a flat, oxide coated, electron emitting surface
- typically held at -2000 V
- emit electrons

Control Grid:
- nickel cup with a hole in it, almost enclosing the cathode
- grid potential is adjustable from approx. -2000V to -2050V
- Grid-Cathode potential controls the electron flowrate from the cathode
- Controls the intensity of trace

controls the electron flowrate.

Electron Gun : Focusing Section

Accelerating anode 1 (A1):
- first anode after the triode, cylinder shaped
- A1 is grounded .i.e. A1 is highly positive w.r.t. cathode
- Causes electrons to be accelerated

Focusing anode (A2):
- A2 potential is adjustable around -2000V
- sometimes refer to as focus ring
- adjust the focusing of the electron beam

Accelerating anode 2 (A3):
- A3 is grounded. i.e. A3 is highly positive w.r.t. A2
- accelerate the electrons towards the deflection system.

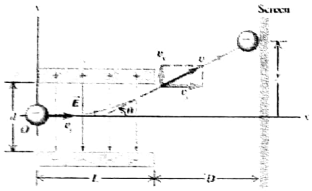
Deflection System

Horizontal deflection plate:

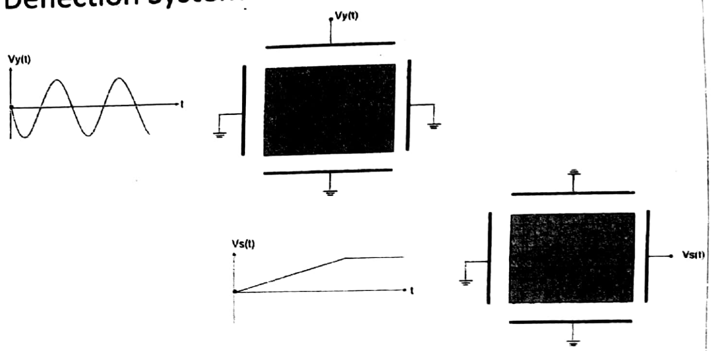
- deflect the electron beam horizontally according to the applied voltage to the plates

Vertical deflection plate:

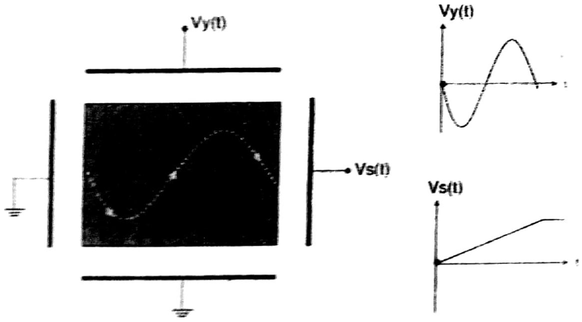
- deflect the electron beam vertically according to the applied voltage to the plates



Deflection System

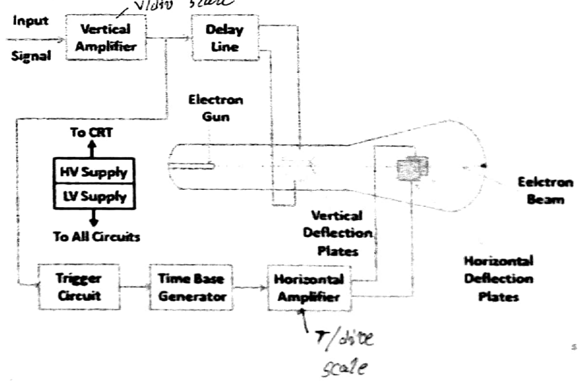


Deflection System



Block Diagram of CRO

V/div scale



EE251: Principles of Electrical Measurements

Cathode Ray Oscilloscope (CRO)-III

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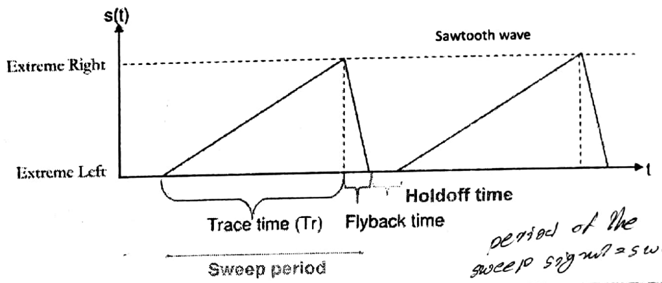
Displaying a Voltage Waveform

- If the signal to be observed is periodic, then a periodic voltage waveform that varies linearly with time, as shown in figure below, is applied to the horizontal deflection plates.



period of the sweep signal = sweep per[iod] + Hol[doff] tim[e]

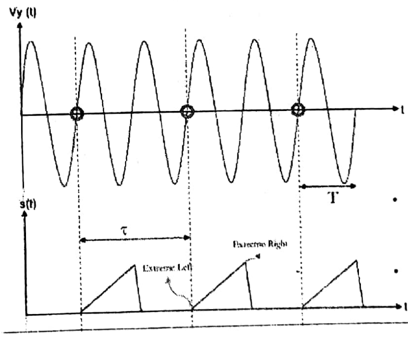
Sweeping

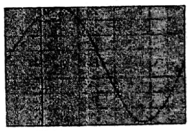
- trace time : time taken for the electron beam/spot to travel from extreme left to extreme right of the screen
- flyback time: time taken for the electron beam/spot to travel back to extreme left of the screen from extreme right
- Blanking: prevents any reverse retrace (or shadow) as the beam is going back to the extreme left-hand position. a high negative voltage pulse is applied to the control grid of the electron gun to prevent electron beams reaching the CRO screen (intensity control).
- sweep period: the time period including the trace time and the flyback time is called the sweep period.

How to adjust sweep period to obtain a steady plot????

Triggering

- Lets apply following voltage signals to the vertical and horizontal deflection plates

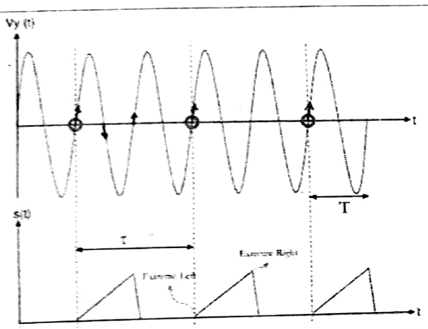




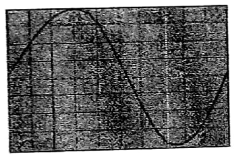
Steady Waveform is obtained

- Note that, at the beginning of each sweep cycle,(i.e when the bright spot is at extreme left) $V_y(t)$ gets exactly the same value (The points indicated by red circles)
- therefore the bright spot is following exactly the same path in each sweep cycle.

Triggering



CRO SCREEN



Steady Waveform is obtained

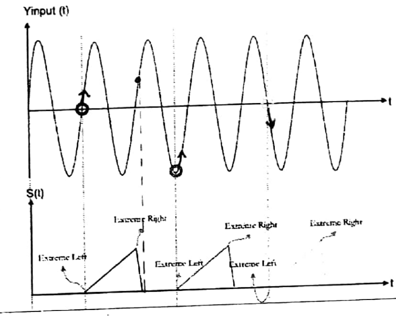
- time between the beginning of two consecutive sweep cycles

$\boxed{\tau = nT}$ ⟵ sweep cycles is a multiple of input signal period

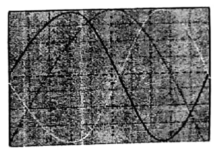
$n \in \mathbb{Z}$

Triggering

- Lets apply following voltage signals to the vertical and horizontal deflection plates



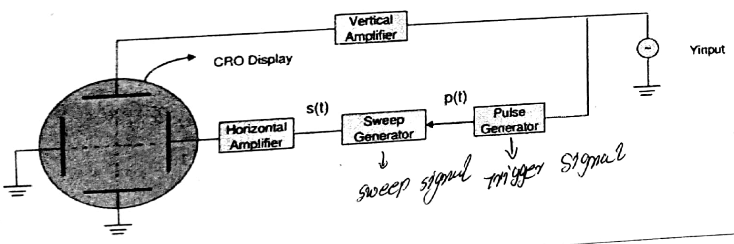
CRO SCREEN



Waveform is not steady!

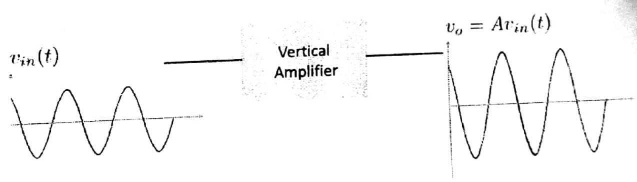
Triggering

- to obtain stable and stationary waveform displays, the sawtooth signal should be applied to the horizontal deflection plates, in synchronism with the waveform being displayed.
- CRO handles this synchronization problem by using the following structure.



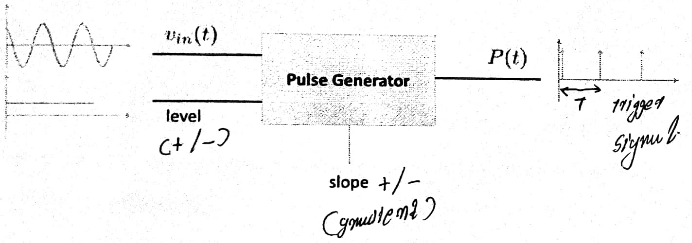
Triggering: Vertical Amplifier

- the amplitude of the input waveform is amplified



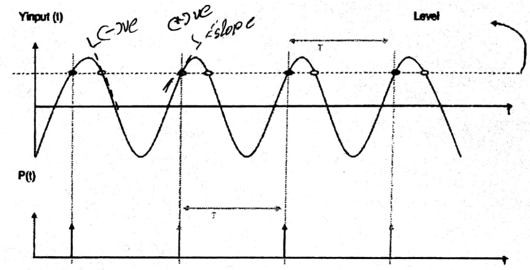
Triggering: Pulse Generator

- produce periodical pulses with a period of T, which is equal to the period of the input signal
- the input signal is compared to a certain voltage level, producing pulses each time the input voltage is equal to that certain voltage level



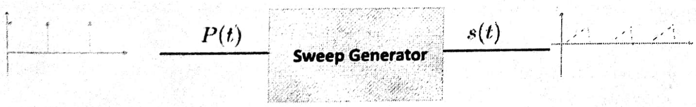
Triggering: Pulse Generator

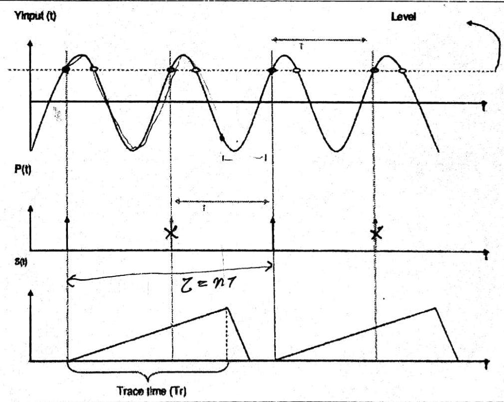
- the 'Level' intersects the input signal more than once in one period. Therefore, one of the intersection points is neglected in each period by checking the slope



Triggering: Sweep Generator

- produce one cycle of a sawtooth waveform, when it receives a pulse at its input.
- If the sweep generator receives a trigger pulse during its sweep cycle (i.e., during the trace period Tr), it will simply ignore the pulse and continue with the completion of its sweep cycle

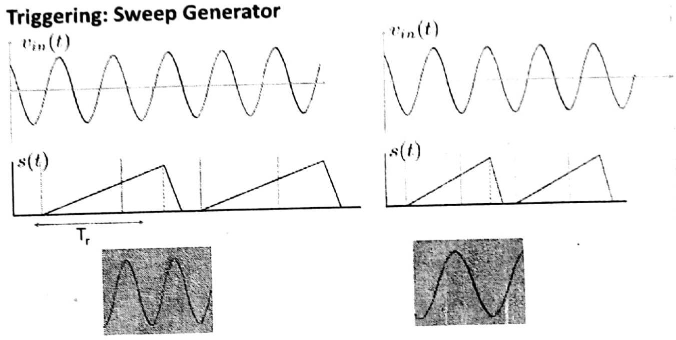




Triggering: Sweep Generator

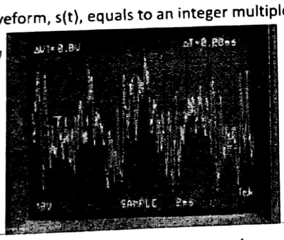
- at the end of each sweep cycle, the sweep generator stops its output and awaits the arrival of the next trigger pulse before producing a new sweep cycle.
- trigger pulse received after the completion of the trace period will initiate the new sweep cycle.
- This allows the scope to display more than one cycle, of period T, of the signal connected to its vertical deflection plates.
- trace time of the sweep generator is adjusted by the time/div button

Triggering: Sweep Generator

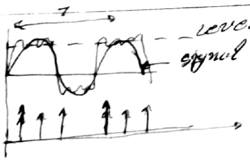


External Triggering

- Rather than the input signal itself, an external signal can also be used for triggering
- The external signal should satisfy certain conditions in order to obtain a steady waveform on the CRO screen.
- i.e. To keep the period of the sawtooth waveform, s(t), equals to an integer multiple of the period of the input signal

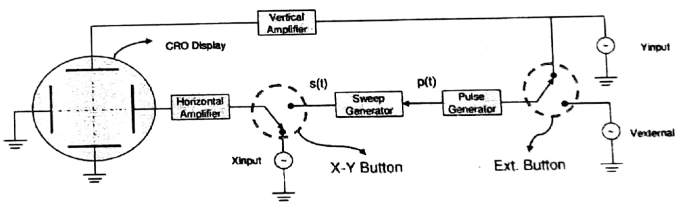


External signal period should be an integer multiple of input.



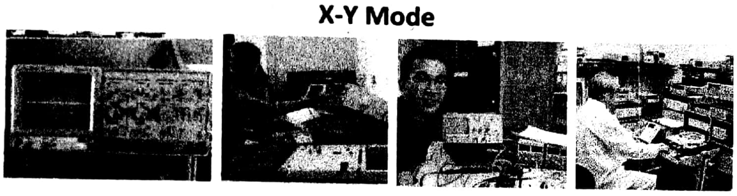
level
signal with same period.

External Triggering



EE251: Principles of Electrical Measurements

Cathode Ray Oscilloscope (CRO): X-Y Mode



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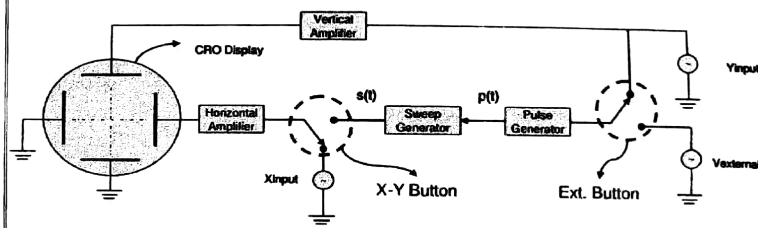
X-Y Mode

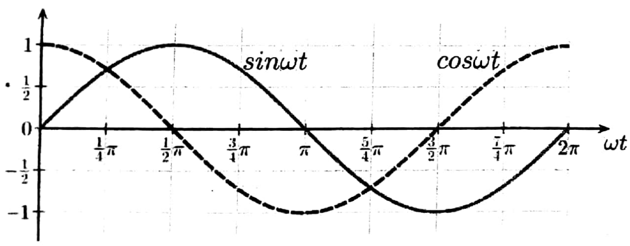
- one i/p channel signal is **applied to the** vertical deflection plates
- other i/p channel signal is **applied to the** horizontal deflection plates.



X-Y Mode

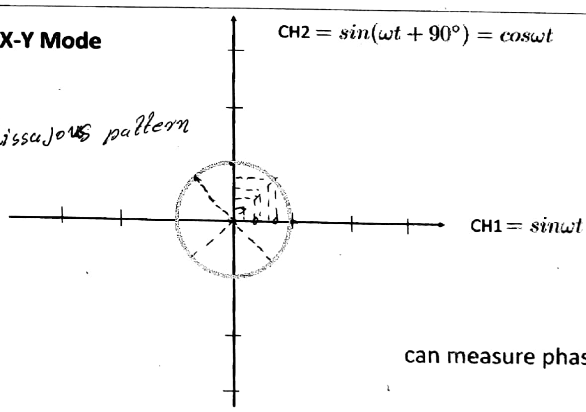
CH1 $\quad x(t) = Asin(\omega t)$

CH2 $\quad y(t) = Asin(\omega t + 90°)$



X-Y Mode

Lissajous pattern



can measure phase difference

Phase difference

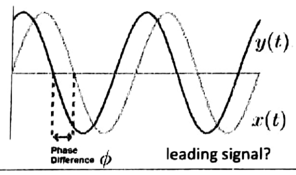
- Phase difference or phase shift is the angle difference (or time difference) between two signals with [redacted]

$$x(t) = Asin(\omega t)$$
$$y(t) = Bsin(\omega t \pm \phi)$$

phase angle between x and y

Ex:

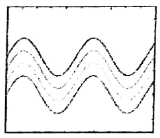
$x(t)$ $y(t)$



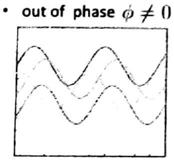
leading signal?

Phase difference

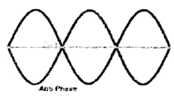
- in phase $\phi = 0$



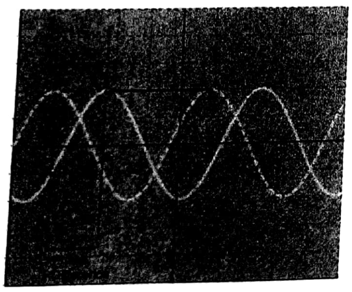
- out of phase $\phi \neq 0$



- anti phase $\phi = 180°$



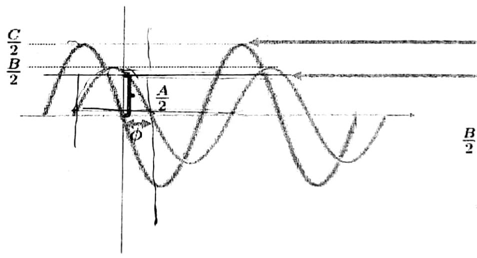
Phase difference Using Dual Mode



leading –dash curve

$$\phi = \frac{\Delta T}{T} \times 360° \quad \textit{in degrees}$$
$$\phi = \frac{\Delta T}{T} \times 2\pi \quad \textit{in radians}$$

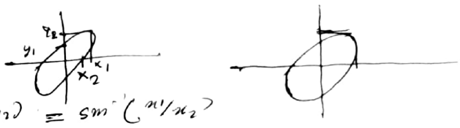
Phase difference of Sinusoidal Signals Using XY Mode



$x(t) = \frac{C}{2}sin(\omega t)$ CH1

$y(t) = \frac{B}{2}sin(\omega t - \phi)$ CH2

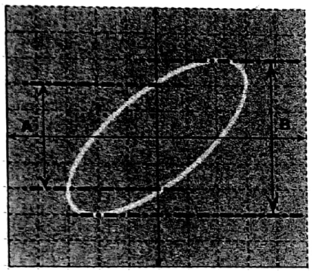
$$\frac{B}{2}sin(180 - \phi) = \frac{B}{2}sin\phi$$
$$\frac{B}{2}sin\phi = \frac{A}{2}$$
$$\boxed{\phi = sin^{-1}(\frac{A}{B})}$$



$\sin^{-1}(y_1/y_2) = \sin^{-1}(x_1/x_2)$

Phase difference of Sinusoidal Signals Using XY Mode

Lissajous pattern

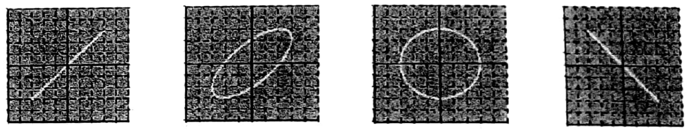


$$x(t) = \frac{C}{2}sin(\omega t)$$
$$y(t) = \frac{B}{2}sin(\omega t - \phi)$$

$$\boxed{\phi = sin^{-1}(\frac{A}{B})}$$

Lissajous patterns

- when frequency is equal, but phase angle is different



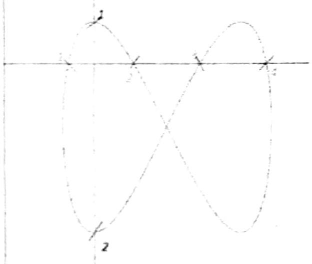
0° 45° 90° 180°

$\sin^{-1}(0/a)$ $\sin^{-1}(3/3)$

- to check leading or lagging phase angle, you have to go back to dual mode.

Lissajous patterns

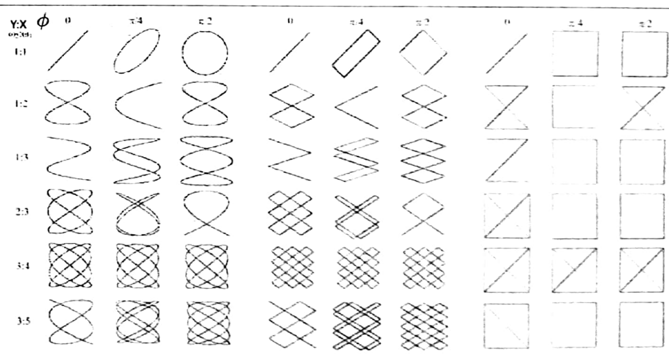
- when frequency is different, but phase angle is equal



$$\frac{\omega_y}{\omega_x} = \frac{4}{2}$$

$$\frac{\omega_y}{\omega_x} = \frac{f_y}{f_x} = \frac{Number\ of\ horizontal\ tangencies}{Number\ of\ vertical\ tangencies}$$

minimum number for horizontal
dir

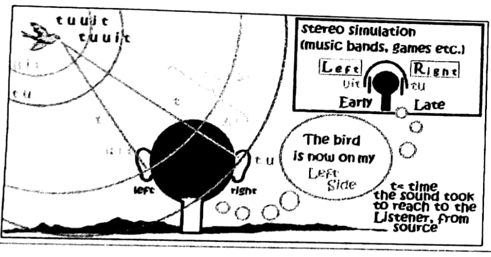


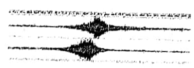
for sinusoidal signals for triangular signals for square signals

Lissajous Patterns for Stereophonics

Stereophonic sound or, more commonly, stereo, is a method of sound reproduction that creates an illusion of multi-directional audible perspective. This is usually achieved by using two or more independent audio channels through a configuration of two or more loudspeakers (or stereo headphones)

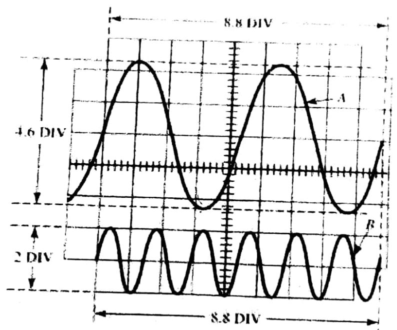
-wikipedia





Time difference in a stereophonic recording of a car going past.

Measurements of Voltages, Frequency and Phase



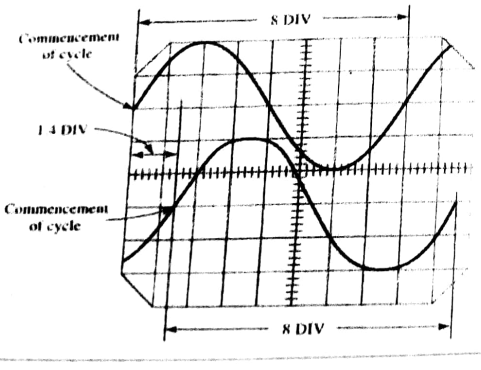
TIME/DIV=0.5ms

VOLTS/DIV=100mV

Vp-p?

Frequency?

Measurements of Voltages, Frequency and Phase



Phase difference?

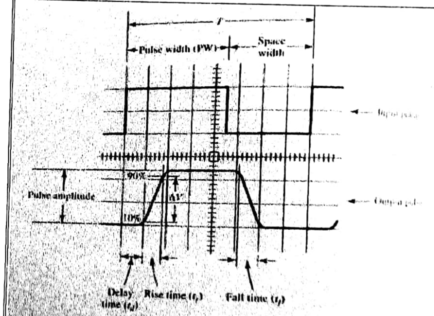


Figure 9-21 Pulse width is determined by multiplying the TIME/DIV setting by the horizontal divisions occupied by the pulse. Pulse amplitude is VOLTS/DIV × (vertical divisions). Rise time is TIME/DIV × (horizontal divisions from 10% to 90% of pulse amplitude). Fall time equals TIME/DIV × (horizontal divisions from 90% to 10% of pulse amplitude).

TIME/DIV=1us

Rise time?

Fall time?

Delay time?

EE251: Principles of Electrical Measurements

Cathode Ray Oscilloscope (CRO): Oscilloscope Probe

By

Dr. Chathurika Dharmagunawardhana

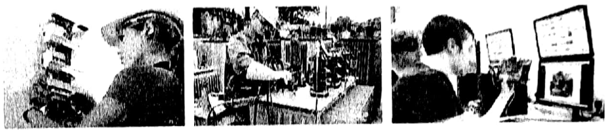
Department of Electrical and Electronic Engineering

Introduction

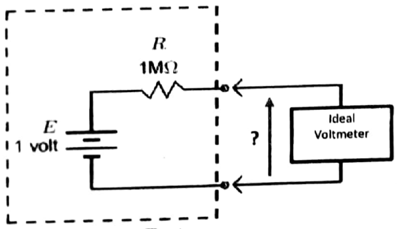
- Process of measuring affects the input measuring signal

TRUE/FALSE

- cannot be totally eliminated but it can be minimized sufficiently



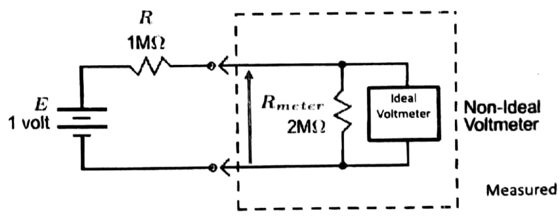
Ex: Ideal Measuring Process



Circuit Under Test

Measured Voltage = ...1V.....

Ex: Real Measuring Process

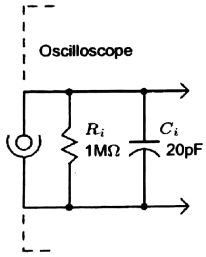


Measured Voltage = 2/3 V

this called loading effect

Scanned by CamScanner

The Oscilloscope : equivalent input circuit

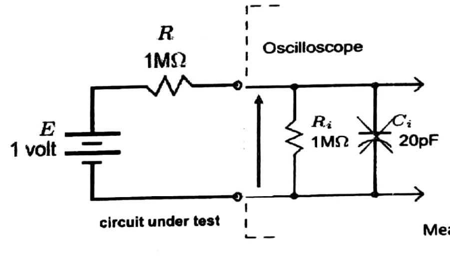


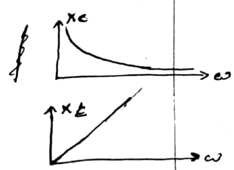
Loading Effect and The Oscilloscope

$Z_c = \frac{1}{j\omega C} = -jX_c$ Reactance

$Z_L = j\omega L = jX_L$

At low frequencies,





$X_L = \omega L$

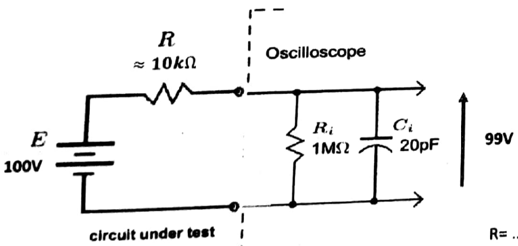
$\omega\downarrow \rightarrow Z_c\uparrow$

$\omega\uparrow \rightarrow Z_c\downarrow$

Measured Voltage = 0.5V

Loading Effect and The Oscilloscope

At low frequencies, if reading is accurate to ±1%



R= 10kΩ

$\frac{100}{99} = \frac{R+1}{1}$

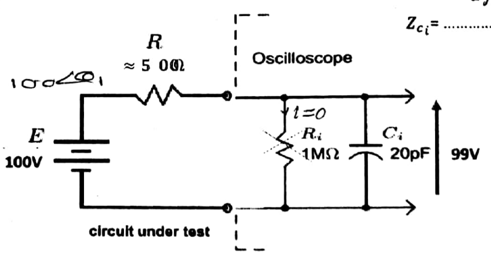
Loading Effect and The Oscilloscope

At high frequencies, ex: 2MHz

X_{c_i}= ....

$-j$

Z_{c_i}= ....



99∠θ₂

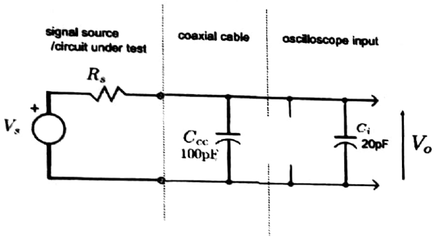
R= ....

$\left|\frac{1}{1+j\omega RC}\right| = \frac{99}{100}$

$\frac{1}{99} = j\omega C R$

$R = \frac{-j}{99 \times 2\pi \times 2 \times 10^6 \times 20 \times 10^{-12}}$ 2

Equivalent Circuit with 1:1 Probe



<u>for high frequencies,</u>
Capacitive reactance is low.

$C_1 = C_{cc} + C_i$

$$\boxed{V_o = V_s \frac{Z_{C_1}}{Z_{C_1}+Z_{R_s}}}$$

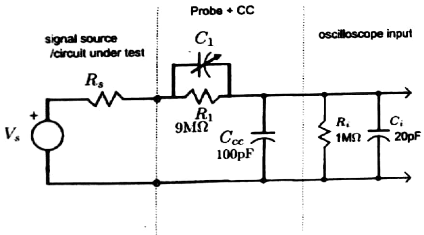
$X_{C_1} >> R_s$
for minimize loading effect/ signal attenuation

Since in high frequencies X_{C_1} is small, if R_s is not sufficiently small, signal will start to attenuate due to loading

10:1 Probe/ Attenuator Probe

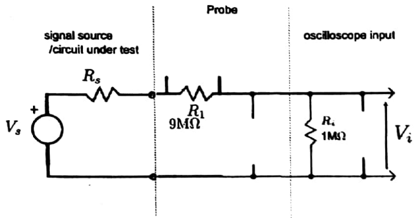
- attenuate input signal by a factor 10
- offer much larger input impedance than 1:1 probe
- compensation is included for coaxial cable capacitance
- probes are available with different attenuation factors
- use x10 button in the CRO panel to view correct values on the screen

Equivalent Circuit with 10:1 Probe



Equivalent Circuit with 10:1 Probe

<u>for low frequencies,</u>
Capacitive reactance is high.



$$\boxed{V_i = V_s \frac{R_i}{R_i+R_s+R_1}}$$

$R_1 >> R_s$

$V_i = V_s \frac{R_i}{R_i+R_1}$

if $R_1 = 9M\Omega, R_i = 1M\Omega$

$$\boxed{V_i = \frac{V_s}{10}}$$

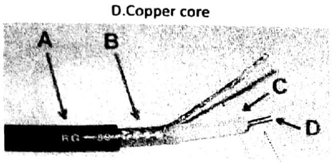
- R_1 increase the input impedance. reduce loading effect

4

Coaxial Test Lead

- signal is usually connected to CRO via coaxial cables with probes on one end

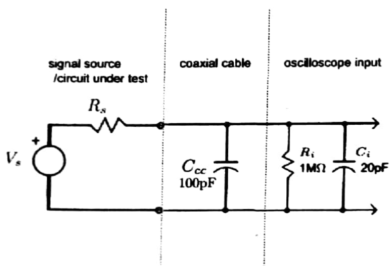
A.Outer plastic sheath
B.Woven/braided copper shield
C.Inner dielectric insulator
D.Copper core



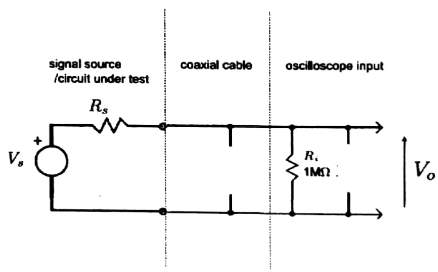
Oscilloscope with Coaxial Test Lead

- There are three basic types of oscilloscope probes
  - 1:1 Probe
    limited to low frequency measurements.
  - 10:1 Probe/ Attenuator Probe
    can measure signals over a large range of frequencies
    attenuate the signal by a factor 10
    can measure high voltage levels
  - Active Probe
    has a voltage follower circuit inside probe to increase input impedance

Equivalent Circuit with 1:1 Probe



Equivalent Circuit with 1:1 Probe



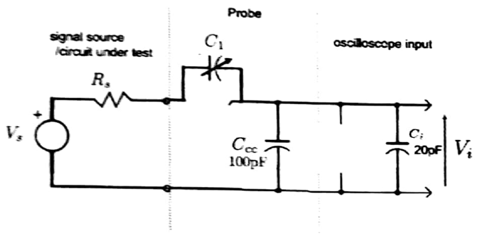
<u>for low frequencies,</u>
Capacitive reactance is high.

$$\boxed{V_o = V_s \frac{R_i}{R_i + R_s}}$$

$R_i >> R_s$

for minimize loading effect/ signal attenuation

Equivalent Circuit with 10:1 Probe



for high frequencies,
Capacitive reactance is low.

$$C_2 = C_{cc} + C_i$$

$$\boxed{V_i = V_s \frac{Z_{C_2}}{R_s + Z_{C_1} + Z_{C_2}}}$$

it can be shown that,

$$\boxed{V_i = V_s \frac{C_1}{C_{cc} + C_i + C_1}}$$

therefore, by adjusting C1 you can remove the loading effect

Probe Compensation with 10:1 Probe

for high frequencies,
the value of C1 required to compensate for C2 is given by,

$$\boxed{C_1 = C_2 \frac{R_i}{R_1}}$$

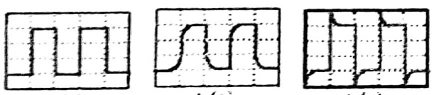
then since, $V_i = V_s \frac{C_1}{C_2 + C_1}$

by substituting C1 and using $R_1 = 9M\Omega$, $R_i = 1M\Omega$

$$\boxed{V_i = \frac{V_s}{10}}$$

therefore, high frequencies are not attenuated at the correct value of C1.

Probe Compensation with 10:1 Probe



t (s) correctly compensated	t (s) under-compensated	t (s) over-compensated
	C_1 too small	C_1 too large
	high frequencies are attenuated	low frequencies are attenuated

When to Use a 10:1 Scope Probe

You should use a 10:1 scope probe for measurements when:

- The circuit impedance is approaching the input impedance of the scope, or
- The measurement includes high frequencies
- The input capacitance of the scope causes the test circuit to malfunction
- The measurement voltage exceeds the range of the scope.

You do not need a 10:1 scope probe

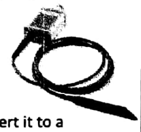
- The circuit impedance is much less than the input impedance of the scope
- The frequencies being measured are low
- The signal magnitude is not too large to display on the scope.

5

Extra: Active Probe

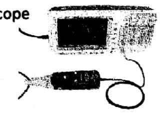
- Contain electronic amplifiers that increase the probe input resistance and minimize its input capacitance

- power must be supplied to the operate the amplifier which may derived from the oscilloscope, or probe may contain its own regulated power supply

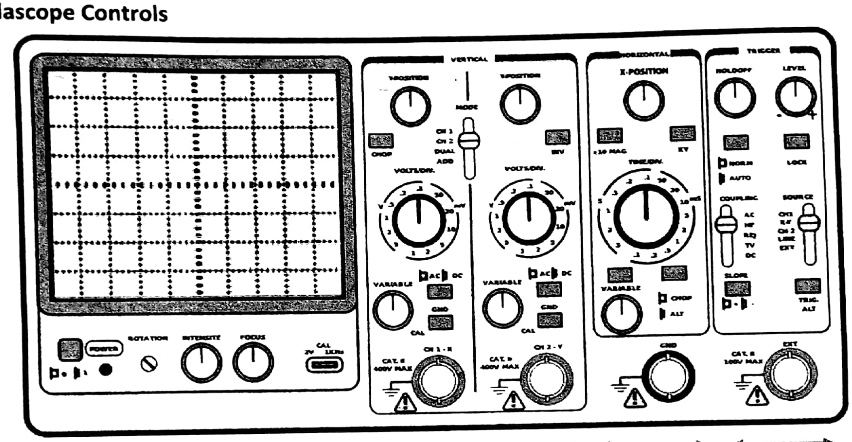


Extra: Current Probe

- Current probes sense the current flowing through a conductor and convert it to a voltage that can be viewed and measured on an oscilloscope



1.0 Oscillascope Controls



1.1 Display Controls

This group is used to display and adjust the signal for optimal viewing.

• **display screen:** a 8 by 10 cm phosphor coated screen with grid lines. The oscilloscope draws a 'trace' or graph by moving an electron beam across the phosphor coating on the inside of the cathode-ray tube (CRT). The excited phosphorous glows for a short period of time, thereby tracing the path of the beam.

• **intensity-control knob**: adjust the brightness of the trace.

• **focus-control knob**: adjusts the electron beam for optimal trace resolution.

• **calibration point:** labeled CAL. Provide a sample square wave of specific amplitude and frequency to aid calibration of the oscilloscope screen.

1.2 Vertical Controls:

This group is used to adjust the vertical components (Y-axis) and the vertical position of the signal. There is one set of switches for each channel.

• **vertical-position control:** vertically move the trace of one channel or the other.
• **channel-selector switch:** labeled 'CH1 /CH2/DUAL/ADD', selects which channels are displayed on the screen, channel 1 signal (CH1), channel 2 signal (CH2), both (DUAL) or sum of channel 1 and channel 2 signals (ADD).

• **volts-per-division knob:** sets the vertical scale. A division is one "block" on the screen. Change the voltage per division.

• **input-coupling switch**: labeled 'AC/GND/DC', selects the coupling mode of that channel's display. AC means that only the alternating portion of the signal is displayed. DC will display both the alternating portion of the signal, plus any DC component. GND shows the 0 V reference level.

• **channel-mode-selector switch**: labeled 'ALT/CHOP', is activated only when DUAL is selected on the channel-selector switch. ALT traces one channel, then the next. CHOP works like ALT, but jumps back and forth between the two channels during a single trace.

1.3 Horizontal Controls

This group is used to adjust the horizontal components (X-axis) and the horizontal position of the signal.

• **horizontal-position-control:** horizontally move the trace

• **horizontal-magnification switch**: ('x10 MAG') magnify the horizontal axis scale by ten times.

• **time-per-division knob:** sets the time (horizontal) scale. Change the time per division. There is only one horizontal scale for both channels.

1.4 Trigger Controls

This group is used to achieve a steady signal waveform trace on the screen.

• **trigger-level knob:** sets the voltage level at which the oscilloscope will 'trigger'.

• **rising/falling-edge (+/-) switch**: selects whether the oscilloscope will trigger on the positive(rising) or negative (falling) slope of the signal.

• **trigger-mode switch**: labelled (AUTO/NORM) normally set to AUTO, but sometimes it is necessary to use NORM.

• **holdoff knob:** affects the delay associated with triggering.

• **trigger-source switches**: select which signal the oscilloscope will use to generate trigger pulse. Possible choices include CH1, CH2, VERT MODE, or EXTERNAL. Selecting CH1 or CH2 will make the oscilloscope attempt to trigger on those channels. it is recommended that this switch be left on VERT MODE which provides an automatic trigger based on either CH1 or CH2. EXTERNAL provide an external signal connected to EXT for trigger pulse generator.

• **trigger-coupling switch**: determine AC/DC coupling and other features of trigger source signal. This switch should [redacted]. may also have high frequency rejection, low frequency rejection, and noise rejection trigger coupling. These special settings are useful for eliminating noise from the trigger signal to prevent false triggering

1.5 Setting Up Your Oscilloscope

1. **Examine all the controls on your scope and set them to normal positions.** For most scopes, all rotating dials should be centered, all pushbuttons should be out, and all slide switches and paddle switches should be up.
2. **Turn your oscilloscope on.**
3. **Set the VOLTS/DIV control to 1V**. This sets the scope to display one volt per vertical division. Depending on the signal you're displaying, you may need to increase or decrease this setting, but one volt is a good starting point.
4. **Set the TIME/DIV control to 1 ms.** This control determines the time interval represented by each horizontal division on the display. Try turning this dial to its slowest setting. Then, turn the dial one notch at a time and watch the dot speed up until it becomes a solid line.
5. **Set the Trigger switch to Auto**. The Auto position enables the oscilloscope to stabilize the trace on a common trigger point in the waveform. If the trigger mode isn't set to Auto, the waveform may drift across the screen, making it difficult to watch.
6. **Connect a probe to the input channel.**
7. **Touch the end of the probe to the scope's calibration terminal.** This terminal provides a sample square wave that you can use to calibrate the scope's display. Some scopes have two calibration terminals, labeled 0.2 V and 2 V. If your scope has two terminals, touch the probe to the 2 V terminal. It isn't necessary to connect the ground lead of your test probe for calibration. If necessary, adjust the TIME/DIV and VOLTS/DIV controls until the square wave fits nicely within the display.
8. **If necessary, adjust the Y-POS control to center the trace vertically.**
9. **If necessary, adjust the X-POS control to center the trace horizontally.**
10. **If necessary, adjust the Intensity and Focus settings to get a clear trace.**

Congratulation!

You're now ready to begin viewing the waveforms of actual electronic signals using the oscilloscope.