IDC102:Hands-on Electronics

Lecture - 2

Oscilloscope

IISER

Satyajit Jena, 16/05/2022

Satyajit Jena, 16/05/2022

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Acknowledgment:

- *Several contents and materials are collected from google search (mostly picture) and lectures available in internet, the actual one-to-one origins are lost as these are done over several years of my learning and making of slides. Some sentences are kept exactly same as of source as they look beautiful.*

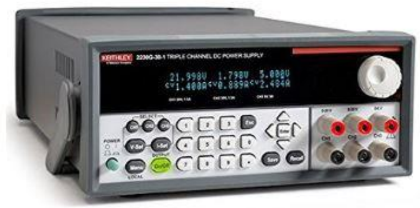
- However, I have taken several materials from following sources:
  - Dr. Samsun M. BAŞARICI,
  - Animated Science,
  - Teachers Lab Group CERN,
  - NTU and KT Oscilloscope Simulation,
  - M. Tonapi, Clemson University
  - J. Schwartz (New York, NY, USA)
  - Google.com
  - *Hawkins Electrical Guide, Volume 6, 1917.*

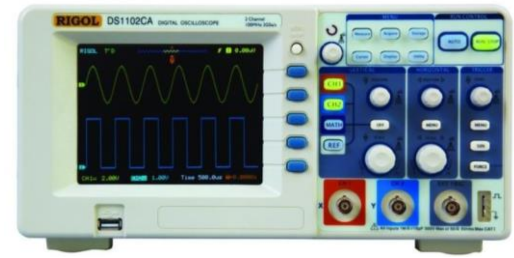
Books:

Hands-On Electronics: A Practical Introduction to Analog and Digital Circuits, by Daniel M. Kaplan and Christophore G. White

Electronics devices and circuit theory, 09th edition, Prentice Hall (2005). By R. L. Boylestad and L. Nashelsky,

Digital Multimeters
Tektronix DMM4020 Datasheet

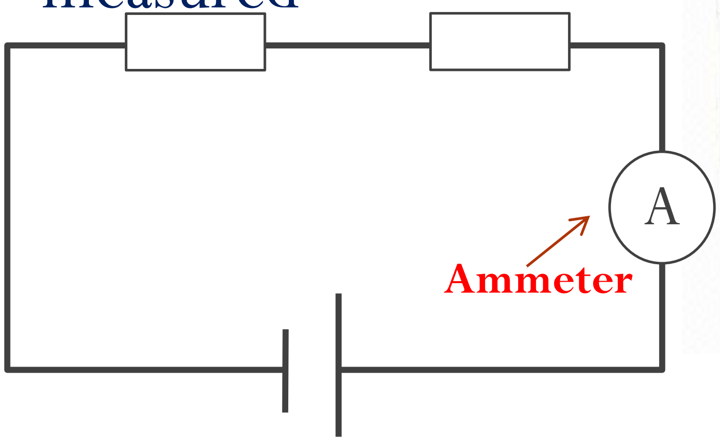


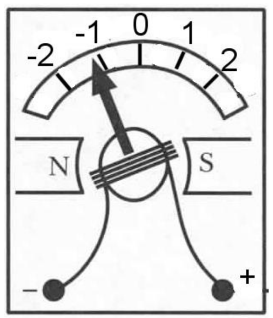


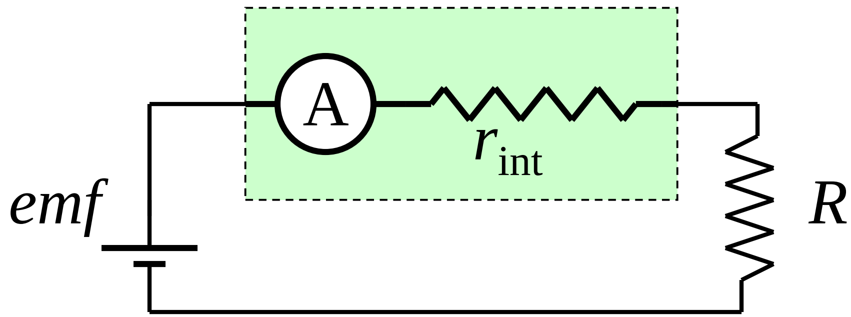
- A measuring instrument is a device for measuring a physical quantity.
- Instruments for measuring electrical quantitates
    - Voltmeter (for measuring Voltage)
    - Ammeter (for measuring current)
    - Ohmmeter (for measuring resistance)
    - Multimeter (for measuring all three quantities)
    - Oscilloscope

Measuring Instruments: Ammeter

- Ammeters, Hooked up in **series** with the component being measured







Ammeters exhibit a very small resistance, and hence are connected in series measured current flows through it.

$$I = \frac{emf}{R}$$

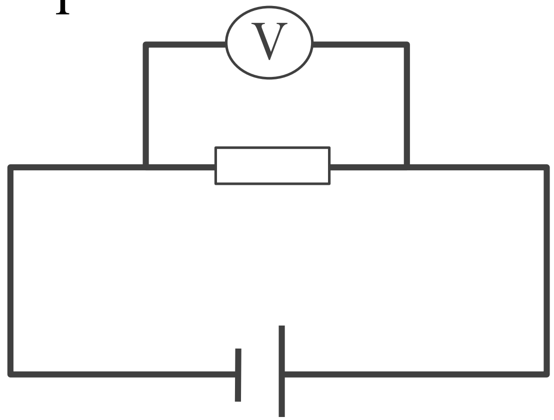
No ammeter

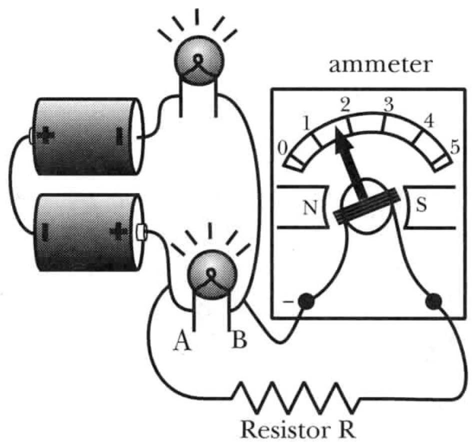
$$I = \frac{emf}{R + r_{int}}$$

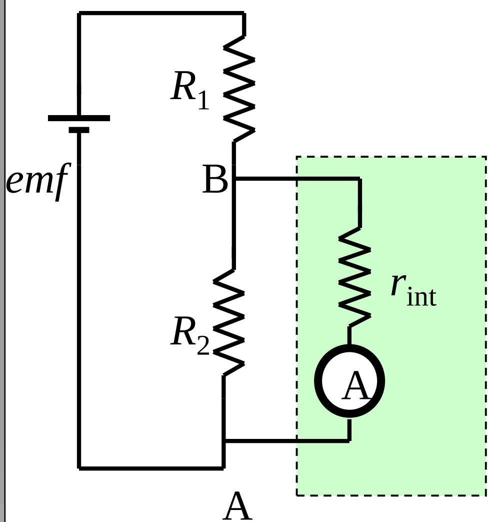
With ammeter

Measuring Instruments: Voltmeter

- Voltmeters are connected in parallel across the points between which potential difference is to be measured.







ΔV_{AB} – add a series resistor to ammeter

$$\boxed{I = \frac{\Delta V}{R}}$$

Measure I and convert to $\Delta V_{AB} = IR$

ΔVAB in absence of a voltmeter

$$\Delta V_{AB} = \frac{R_2}{R_1 + R_2} emf$$

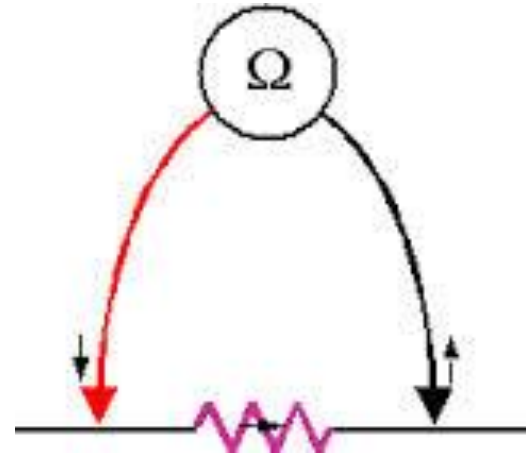
ΔV_{AB} in presence of a voltmeter

$$\Delta V_{AB} = \frac{R_{2\|\text{int}}}{R_1 + R_{2\|\text{int}}} emf \qquad R_{2\|\text{int}} = \frac{R_2 r_{\text{int}}}{R_2 + r_{\text{int}}}$$

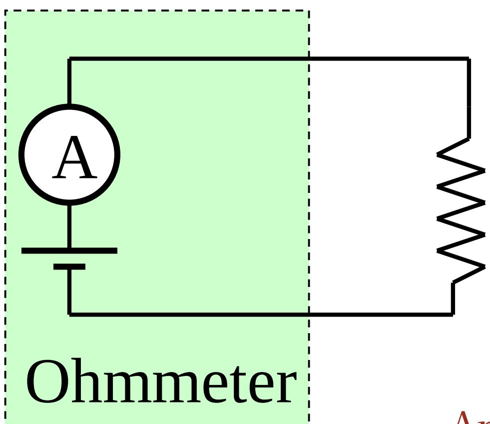
Indirect
- Measure Voltage across Resistor
- Measure Current through Resistor
- Calculate Resistance (Inaccurate)

d'Arsonval Ohmmeter
- Very Simple
- Inaccurate

Wheatstone Bridge (Most Accurate)



How would you measure R?



$$R = \frac{emf}{I}$$

$$\boxed{I = \frac{emf}{R}}$$

Ammeter with a small voltage source

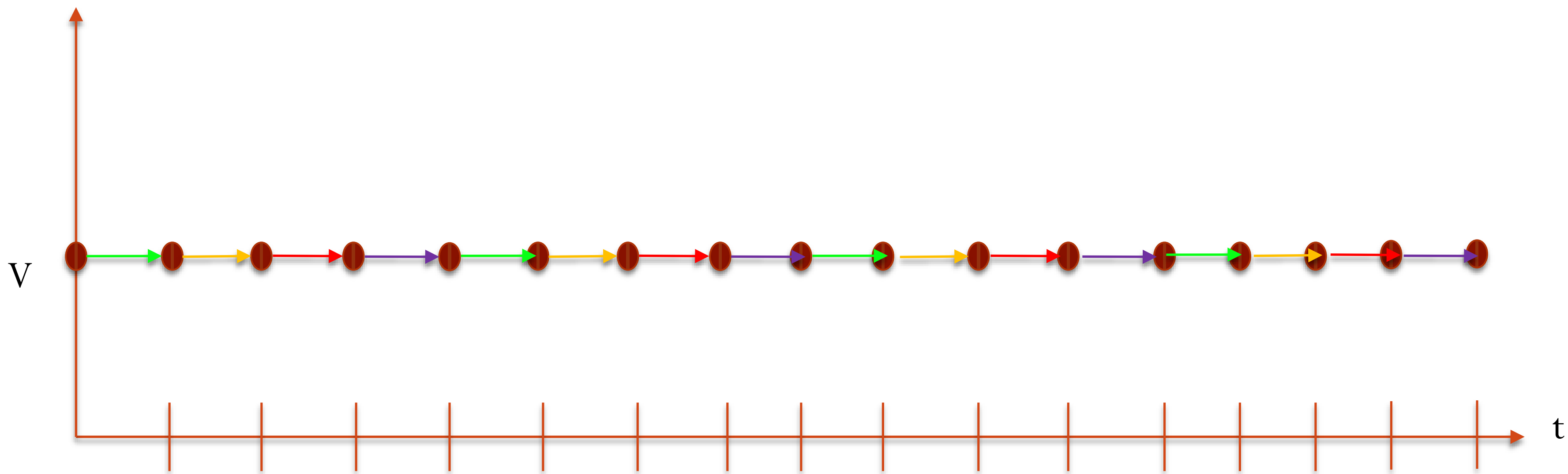
Measuring Instruments: Multimeter

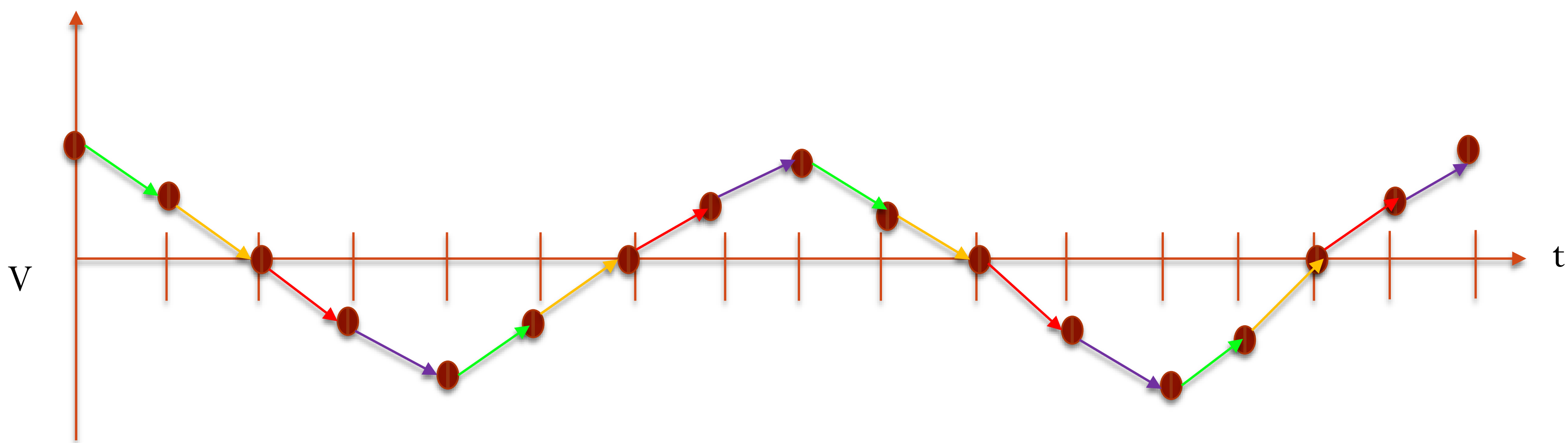
Measuring Instruments: Multimeter

- Digital Multimeter (DMM) facilities
  - While the facilities that a digital multi-meter can offer are much greater than their analogue predecessors, the cost of DMMs is relatively low. DMMs are able to offer as standard the basic measurements that would typically include:
  - Current (DC)
  - Current (AC)
  - Voltage (DC)
  - Voltage (AC)
  - Resistance

- However, using integrated circuit technology, most DMMs are able to offer additional test capabilities. These may include some of the following:
  - Capacitance
  - Temperature
  - Frequency
  - Transistor test - hfe, etc
  - Continuity (buzzer)

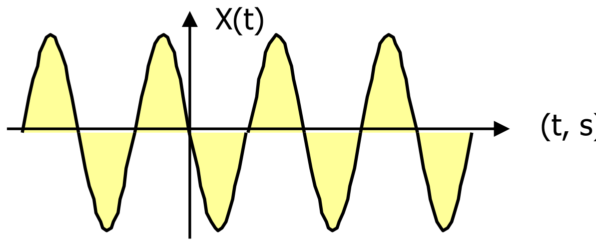
Time Series Measurements

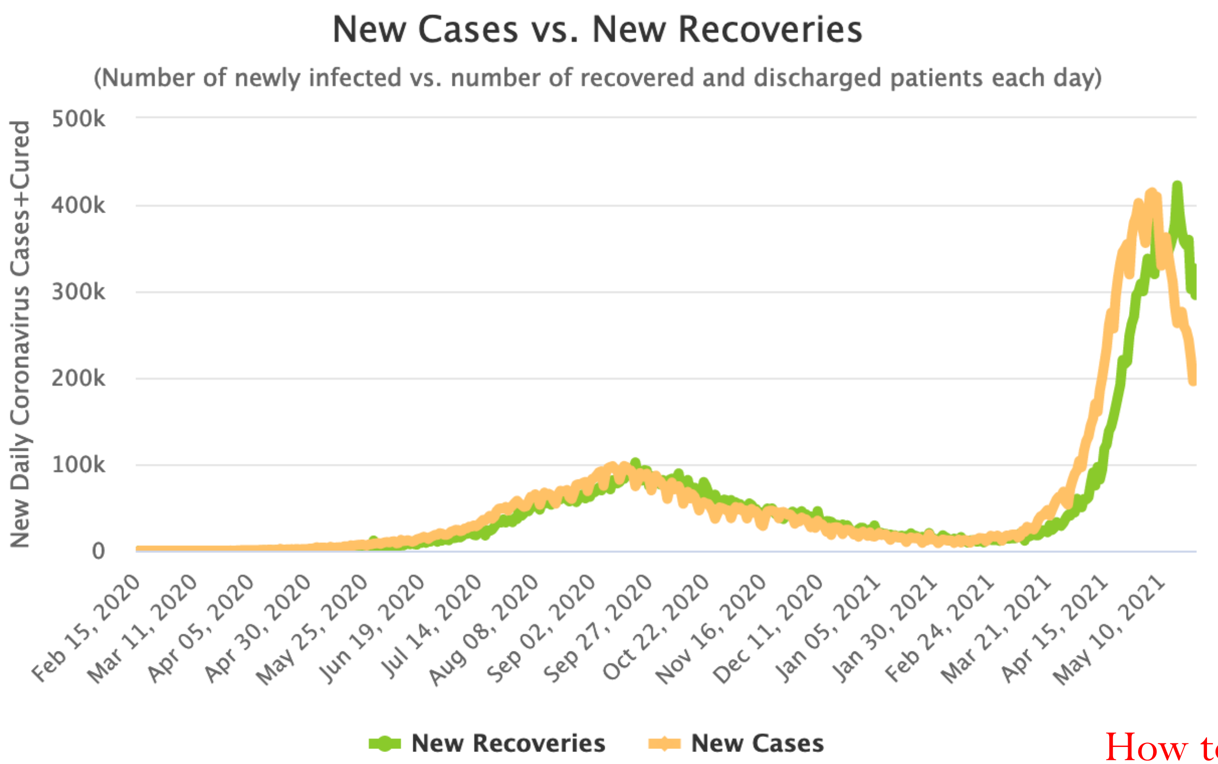




Time Series Measurement: Example

- A physical variable associated with a system, and it is almost always a function of time. Force, velocity, and of course voltage, current over time etc





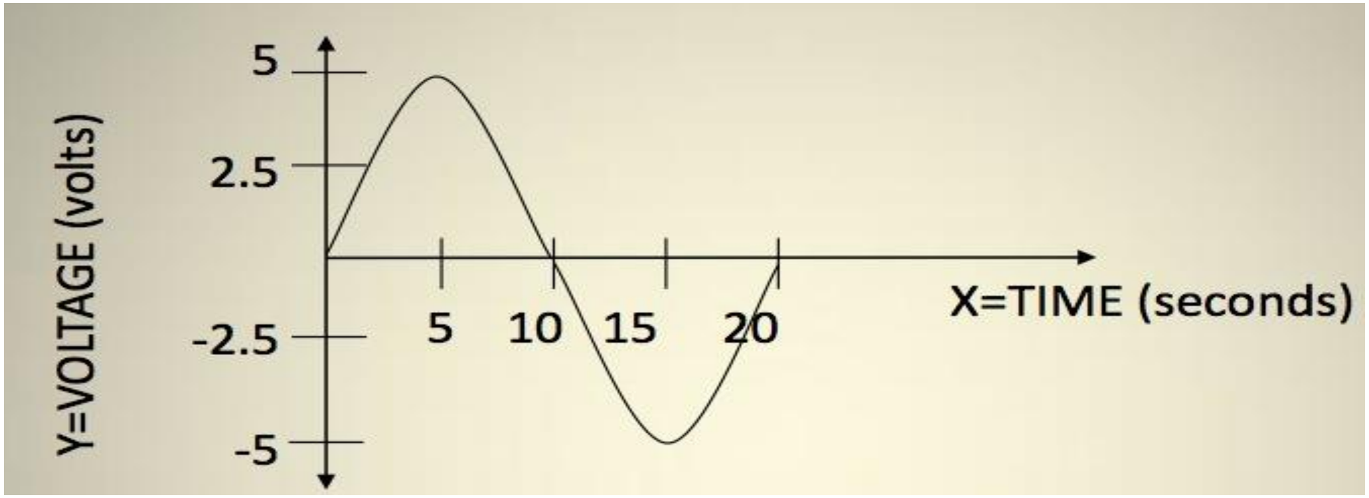
How to measure?

Time Series Measurement

- You measure Voltage or Current at a particular instant of time
- What if I ask to measure these quantities with respect to time??

Time	T0	T1	T2	T3	T4	T5	T6	T7	…
Voltage	V1	V2	V3	V4	V5	V6	V7	V8	…
Current	I1	I2	I3	I4	I5	I6	I7	I8	…

- Plot Time vs Voltage and Time vs Current => **Waveforms**



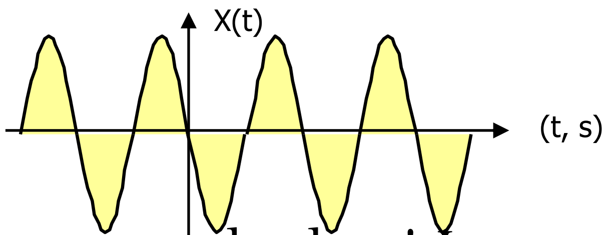
What else can be a time series measurements?

How to Measure?

- How to we do in multimeter?
- We measure a voltage or current in particular instant
- We can measure with a time tagging and note it down
- So that we can get this table

Time	T0	T1	T2	T3	T4	T5	T6	T7	…
Voltage	V1	V2	V3	V4	V5	V6	V7	V8	…
Current	I1	I2	I3	I4	I5	I6	I7	I8	…

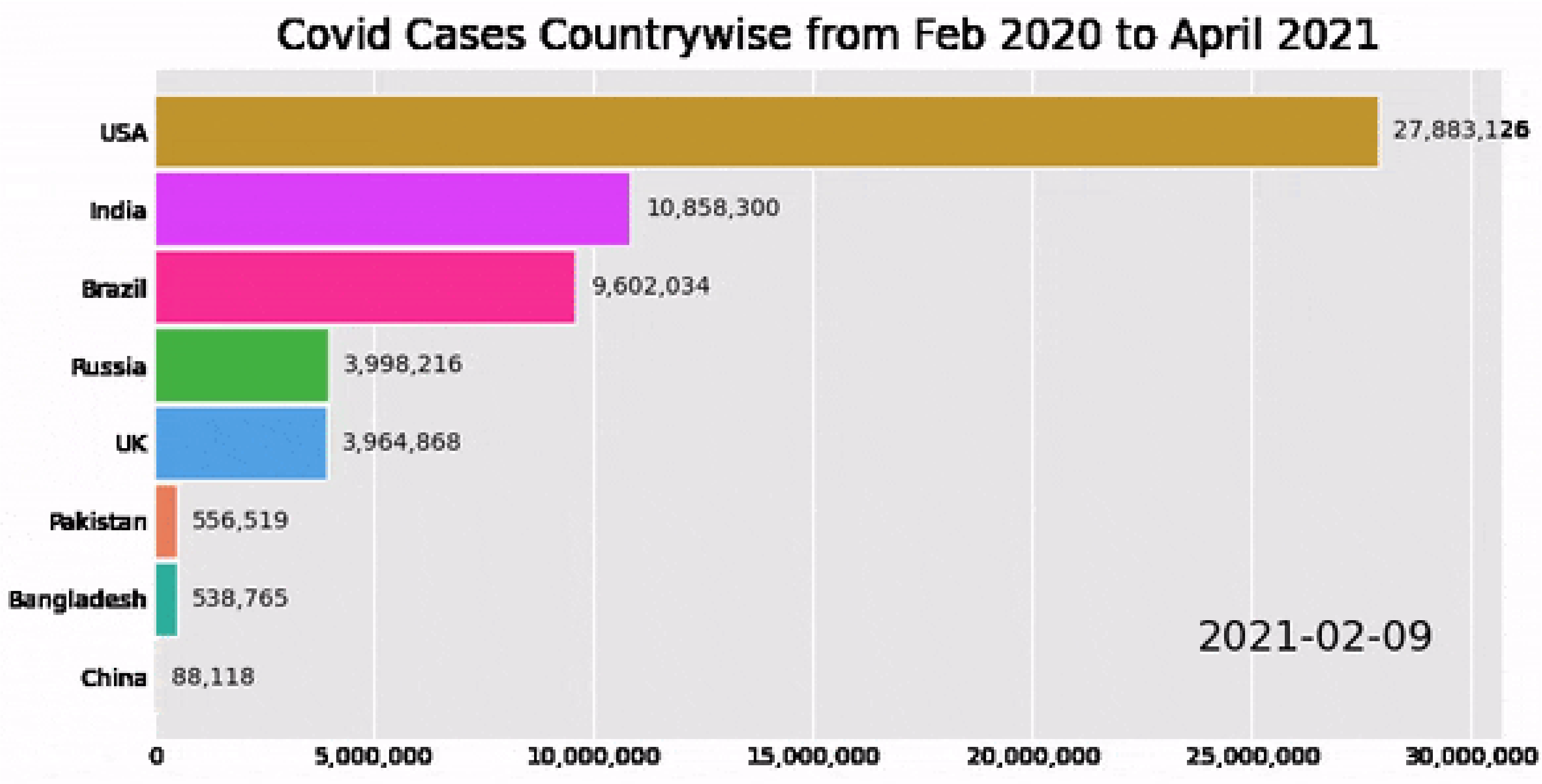
- We can then plot it



- This measurement by hand will be extremely slow! I am afraid if we can ever measure even a complete cycle of AC supply at home (60Hz)

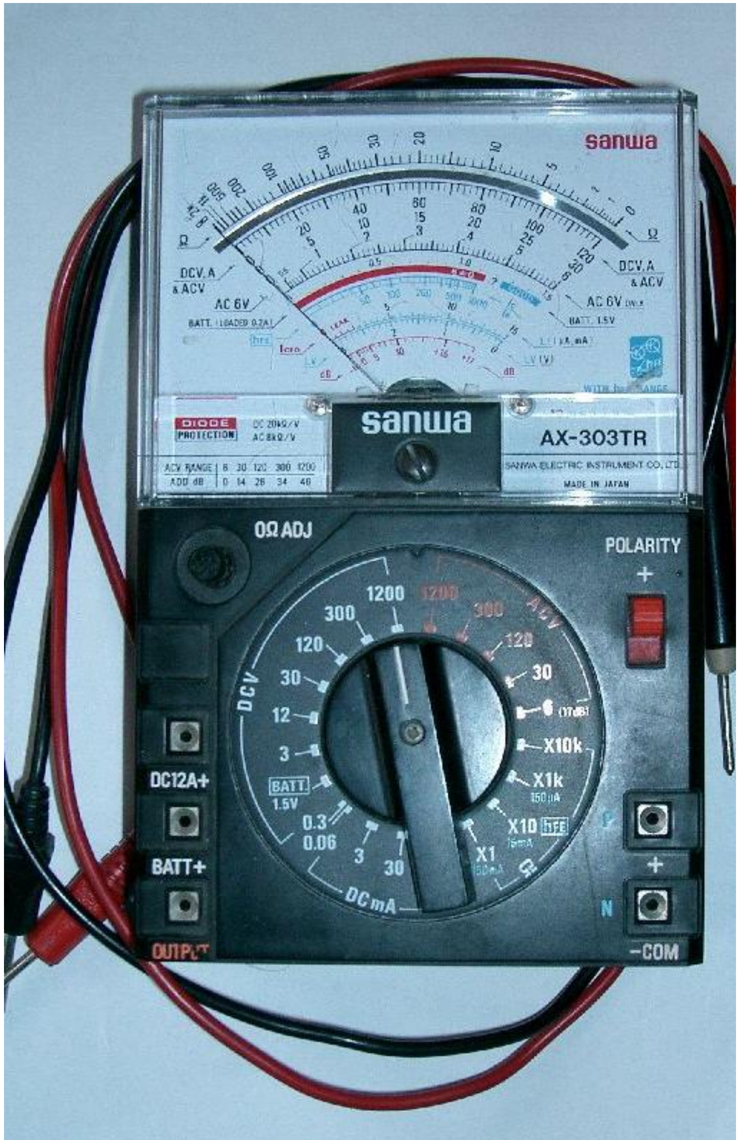
What to do?

For example:



What is A Waveform Display Device

How to Measure?



We always single point in these multimeters

Time	Voltage
1	3.0
2	4.3
3	4.7
4	5
5	5.1
6	5.2
7	5.2
8	5.1
9	5.3

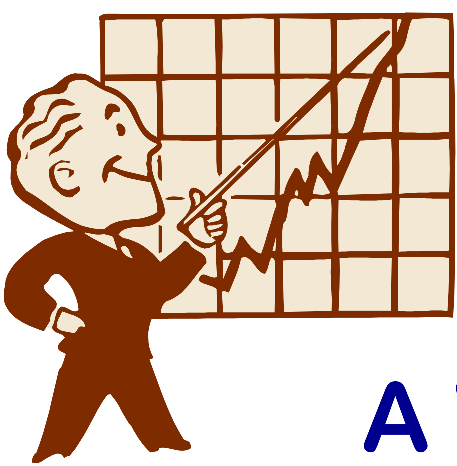
We need something which can display all these at once

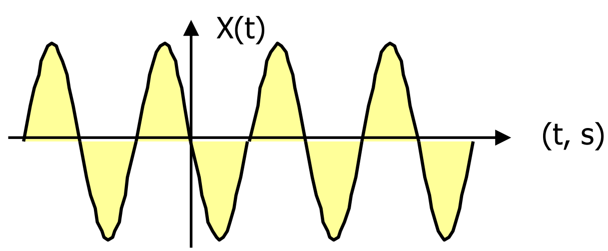
What we need?

- We need a device which can show a series of data (measurements) with respect to time =>
- Like displaying this table!!!
- Well, this will not be great as the values will be changing very fast a time passes! Isn’t it?

Time	Voltage
1	3.0
2	4.3
3	4.7
4	5
5	5.1
6	5.2
7	5.2
8	5.1
9	5.3

But, if we draw these data over time, it is more intuitive



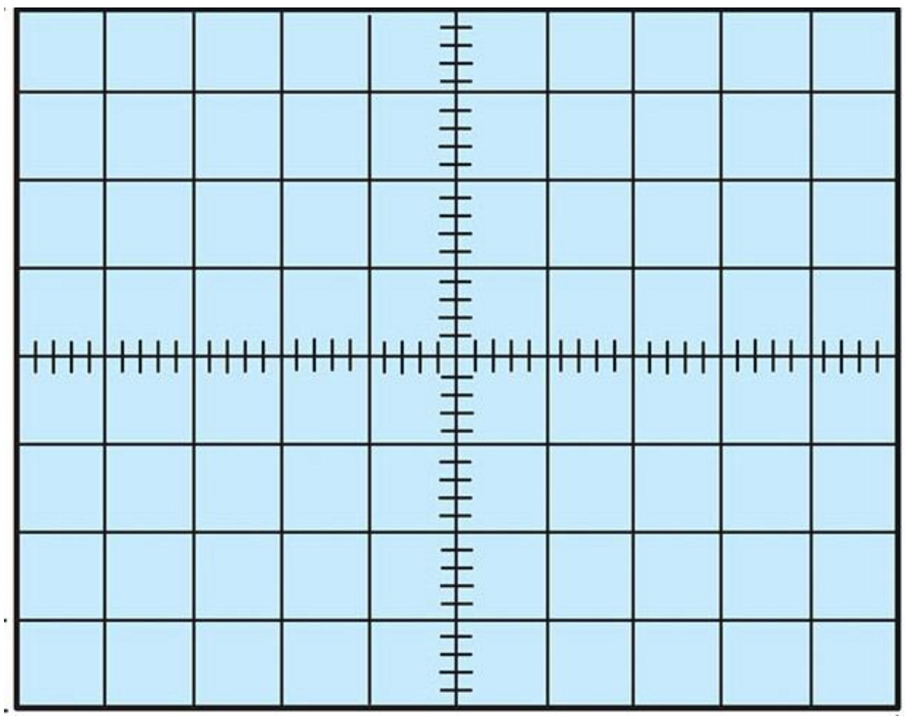


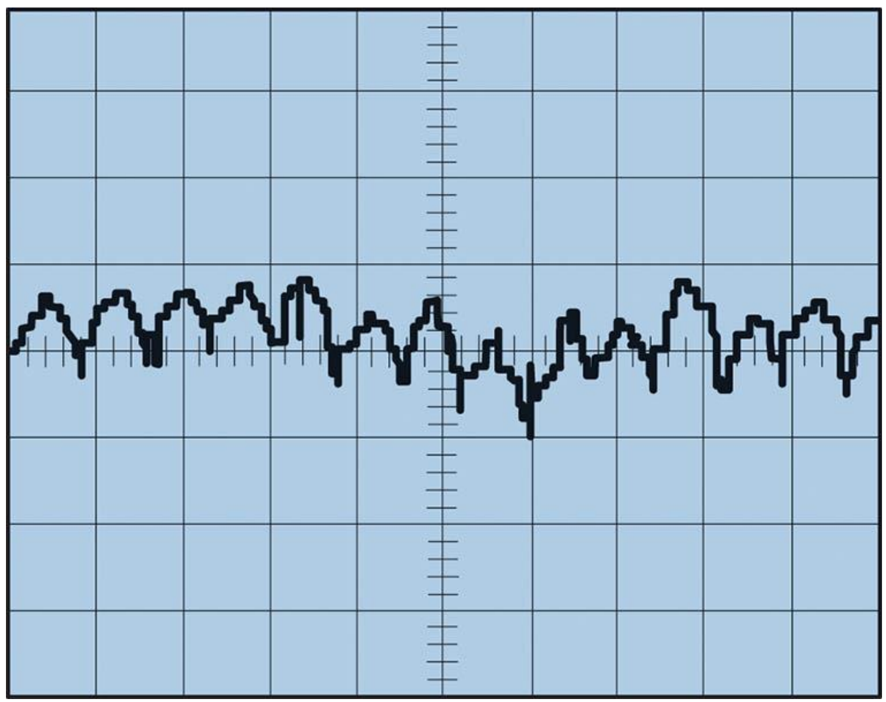
A Waveform Display Device

What we need?

- Everything perhaps possible if we measure in days, or hours, or minutes or even seconds using the techniques as in earlier slides! But we need something which is really fast

1 ms
10 ms
50 ms
100 ms





A Waveform Display Device

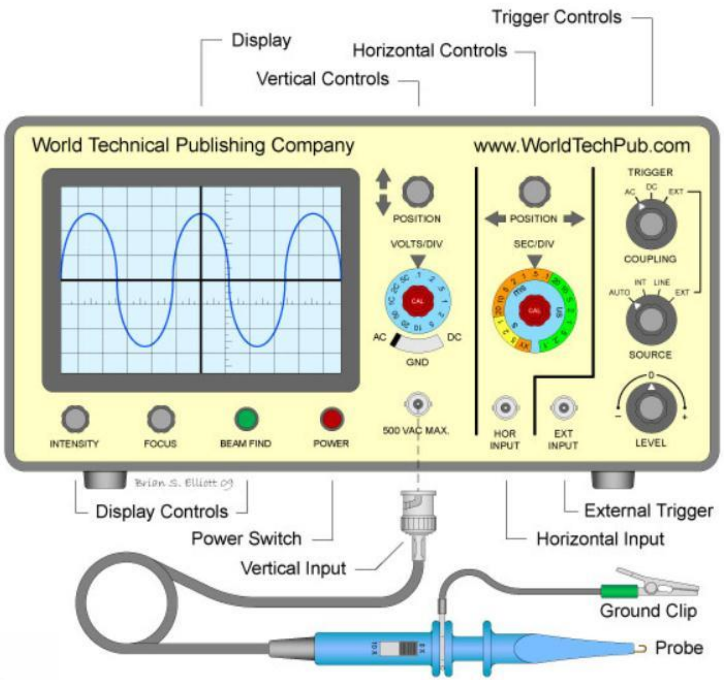
- In modern days such devices are widely available anyone designing, manufacturing or repairing electronic equipment and it is called Oscilloscope.

- An advanced oscilloscope allows the engineer to examine time varying waveforms to determine the magnitude, frequency, phase angle, and other waveform characteristics which depend upon the interaction of circuit elements with the sources driving them.

- The usefulness of an oscilloscope is not limited to the world of electronics. With the proper sensor, an oscilloscope can measure all kinds of phenomena.

An Oscilloscope

An oscilloscope is an instrument that allows observation of constantly varying signal voltages, usually as a two-dimensional graph of one or more electrical potential differences using the vertical or 'Y' axis, plotted as a function of time, (horizontal or 'x' axis).



Type of oscilloscope? And how does oscilloscope work?

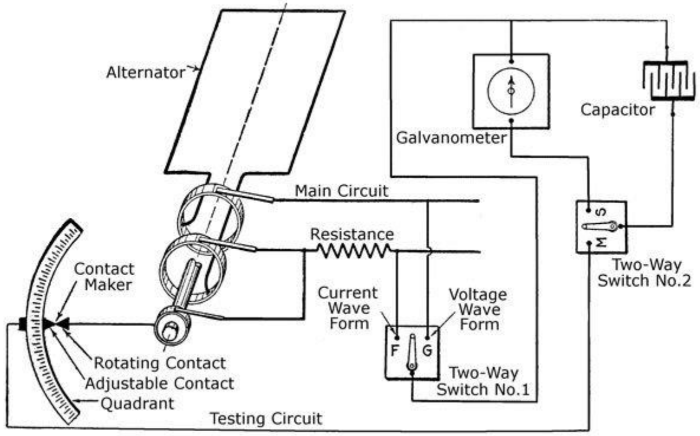
Before we understand the oscilloscope let's see what exactly we need to measure

Waveform Measurements: 1893

- In earliest methods of creating a waveform image used to be extremely difficult and tedious tasks!
- it was kind of hand drawn electrical waveforms and done by taking measurements of current around a rotor using a contact, the angle relative to the rotor's axis, and plotting the current or voltage measurement. Thus, doing such rotation of the contact and the plotting of the values were not only time-consuming and painstaking but fairly imprecise.
- French scientist, *Jules François Joubert* invented a semi-automated waveform drawing machine:

- This consisted of a special single-contact commutator attached to the shaft of a spinning rotor. The contact point could be moved around the rotor following a precise degree indicator scale and the output appearing on a galvanometer, to be hand-graphed by the technician.

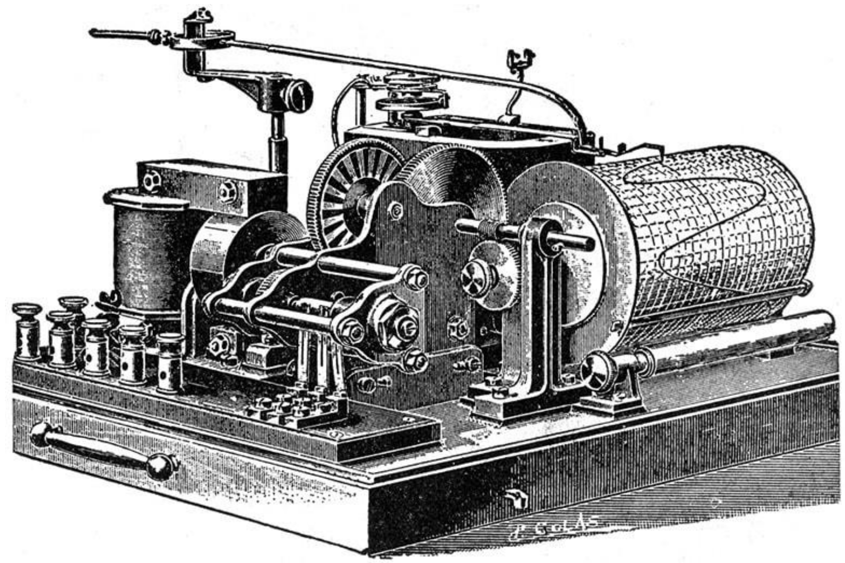
:Hand-drawn oscillograms



Hawkins Electrical Guide,Volume 6, 1917.

Waveform Measurements: 1900

- The first automatic oscillographs used a galvanometer to move a pen across a scroll or a paper drum.
- The first fully automated waveform generator was invented by Édouard Hospitalier, French engineer, in 1902. Known as the Hospitalier Ondograph,

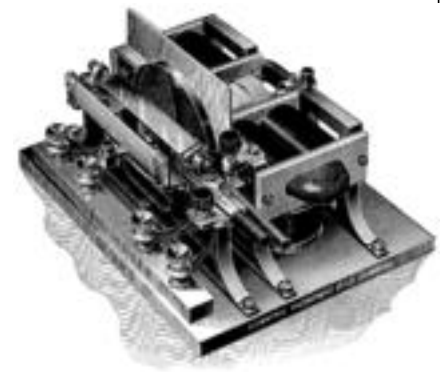


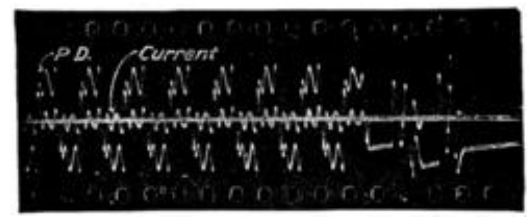
- The charge being recorded would be fed to a capacitor, which would discharge to the galvanometer. Over many successive measurements, an average would be taken to create the overall waveform.

This was still far from being anywhere close to a real-time measurement of a waveform, but improved the ability to gather this data significantly.

Waveform Measurements: 1900-1930

- The direct measurement of waveforms was possible by the development of the *moving-coil oscillograph* by William Duddell which in modern times is also referred to as a mirror galvanometer.
- Duddell moving-coil oscillograph with mirror and two supporting moving coils on each side of it, suspended in an oil bath. The large coils on either side are fixed in place, and provide the magnetic field for the moving coil. (Permanent magnets were rather feeble at that time.)

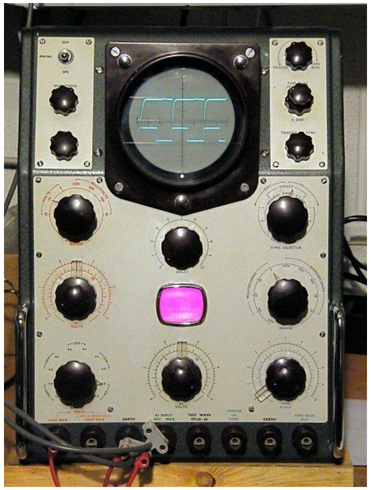


In the meantime, there was invention of ***cathode ray tube*** in the year 1897 by *physicist Karl Ferdinand Braun*.

Waveform Measurements: 1930 onwards

- The first dual-beam oscilloscope was developed in the late 1930s by the British company A.C.Cossor
- General Radio developed The Electron Oscillograph Type 535-A in 1931, that was made in two parts. The CRT was mounted separately on a stand, and the power supply in a separate cabinet, and was connected to it by a cable.
- DuMont began selling the DuMont 164 oscilloscope in 1939, and invented the first frequency trigger and sweep oscilloscope, the Model 224-A.
- In 1946, two men by the name of Howard Vollum and Melvin Jack Murdock founded Tektronix, which today is one of the world's leaders in producing oscilloscopes. In that same year, they invented their first oscilloscope, the model 511, with triggered sweep and 10 MHz bandwidth.

The A.C. Cossor 1035 MKIII CRT display oscilloscope



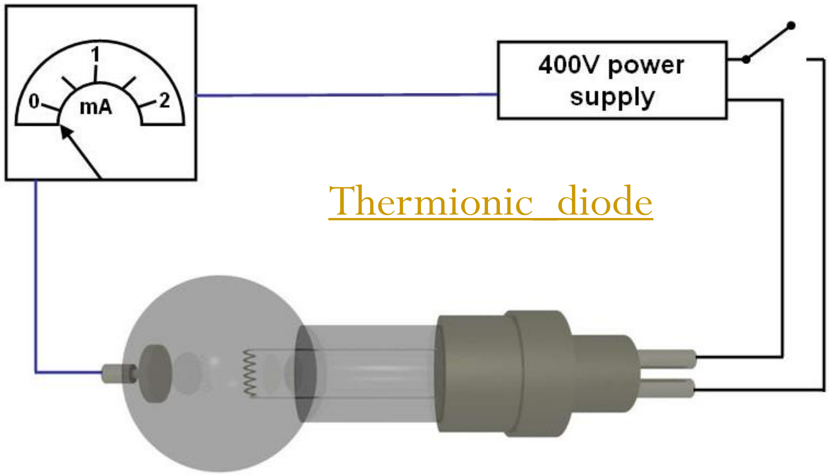
Tektronix Type 511 oscilloscope

The Turning point of Oscilloscope Development Was the development of Cathode Ray Tube by Karl Ferdinand Braun in the year 1897

Let's see about Cathode Ray Tube

CRT: Thermionic emission

- In the vacuum tube there are two electrodes
- Cathode -ve Anode +ve
- When the filament is switched on electrons start to flow from the cathode the tungsten filament and are attracted to the anode



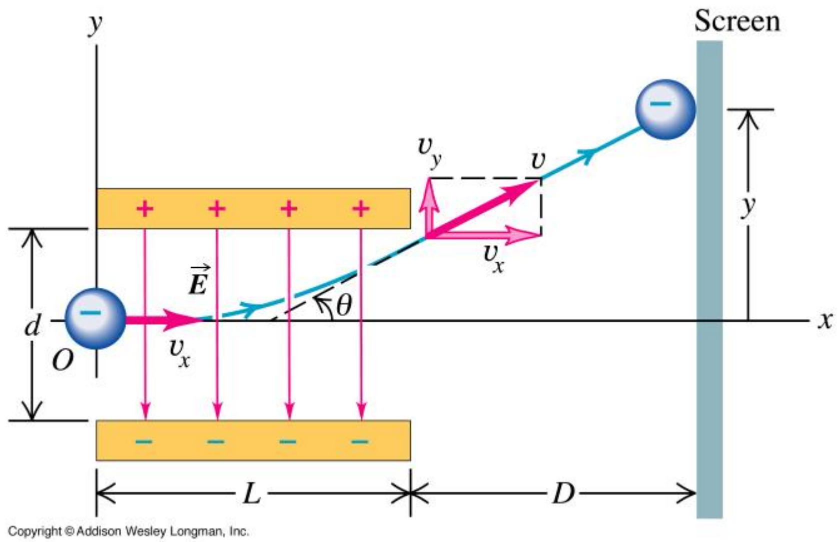
Thermionic diode

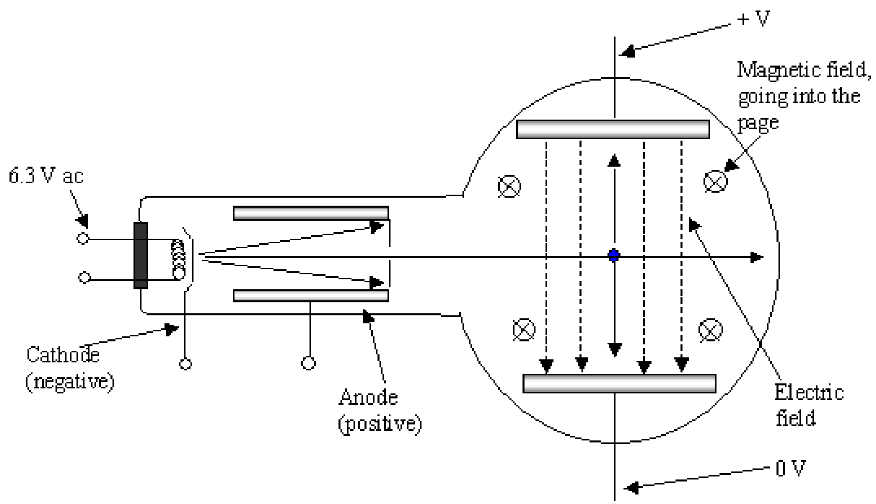
You need a vacuum as the electrons would collide with the gas particles. Also the filament would burn up => a thermionic diode

- If a tungsten filament is heated to about 2000 ° C, some of the electrons have sufficient kinetic energy to escape from the surface of the wire.
- This effect is called **thermionic emission**.
- It is quite easy to imagine this if we think about a metal wire as a lattice of ions in a sea of free electrons. In effect we are boiling the electrons off.

Defection by an electric field

- The negatively charged electrons are attracted towards the positive plate.

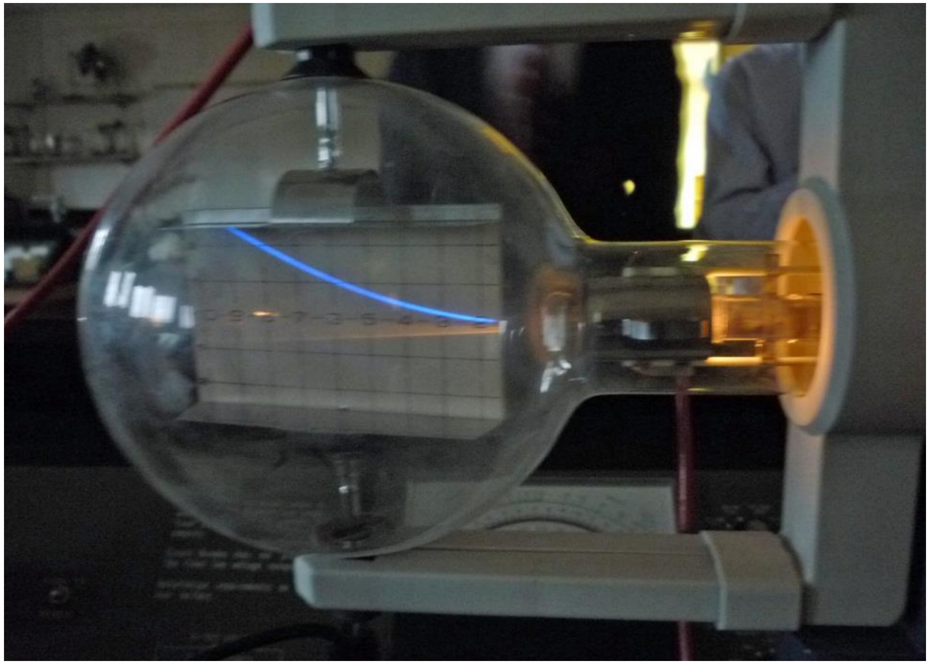


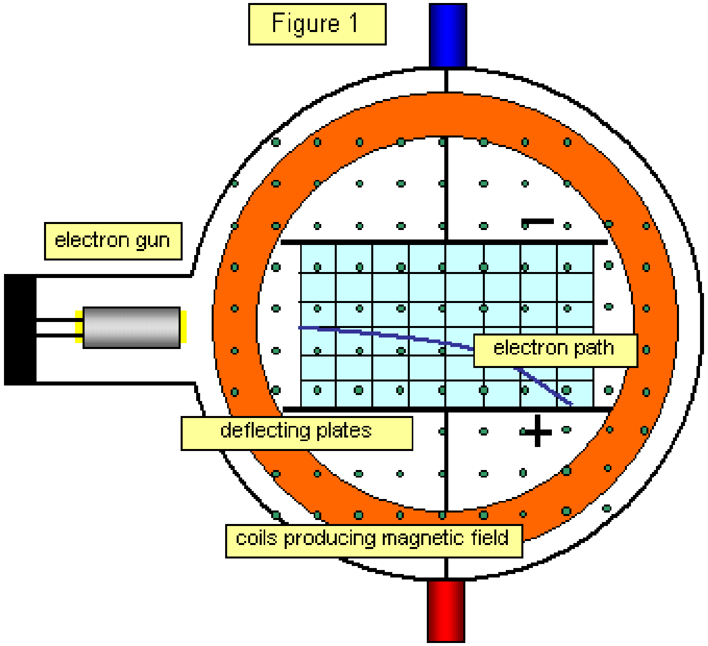


- In a magnetic field the electron is deflected depending on the direction of the magnetic field - Use Lenz's left-hand rule.

Deflection tube

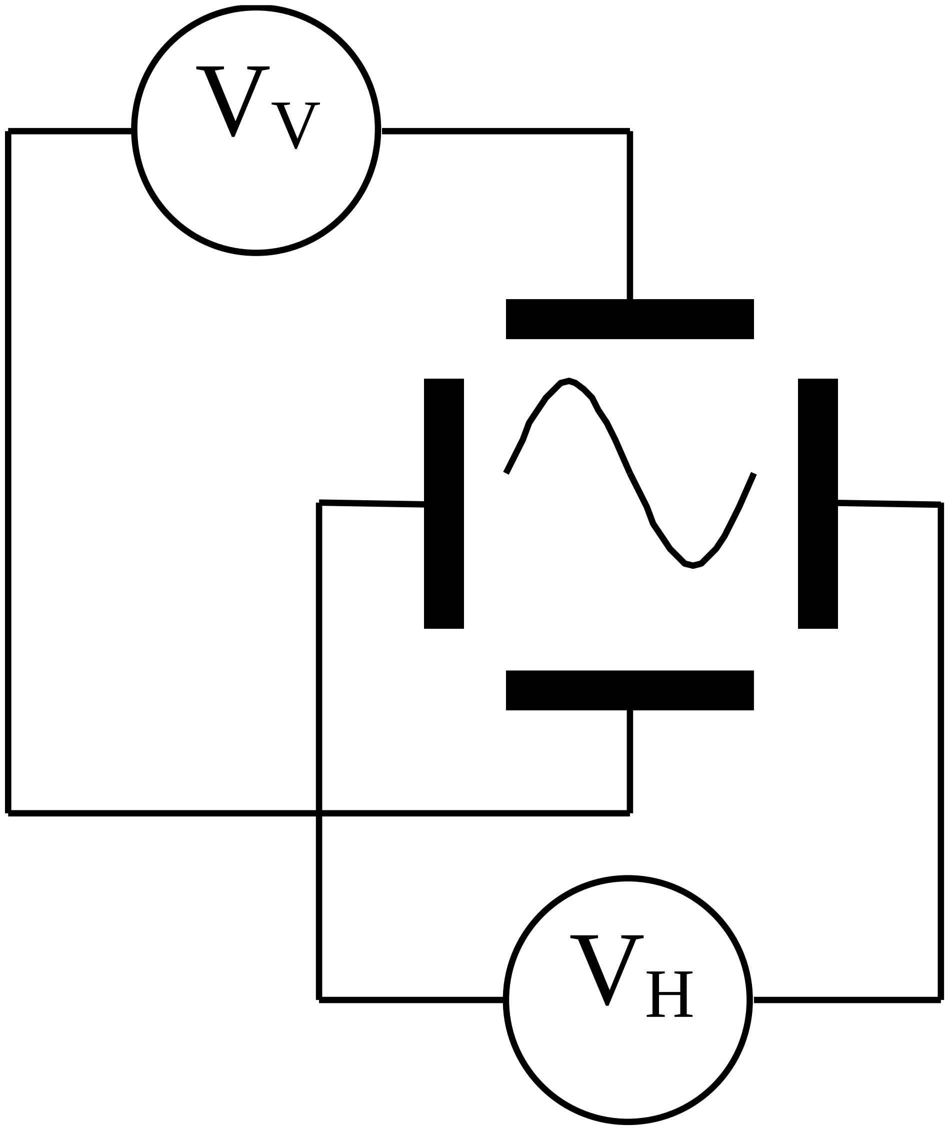
- The electron gun consists of a heated filament/cathode and an anode with a hole in it.
- This produces a narrow beam of electrons
- The screen is coated with a fluorescent material which glow when electrons strike it.



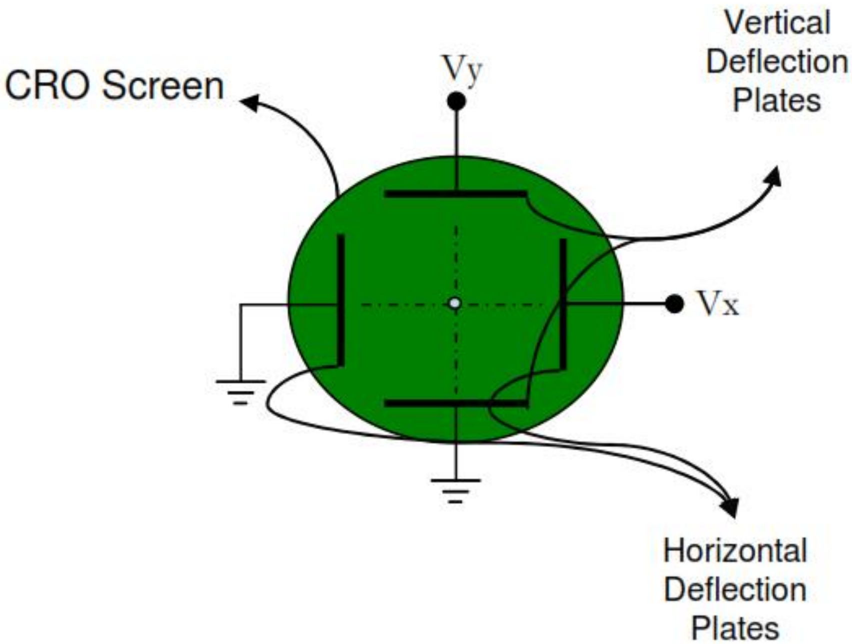


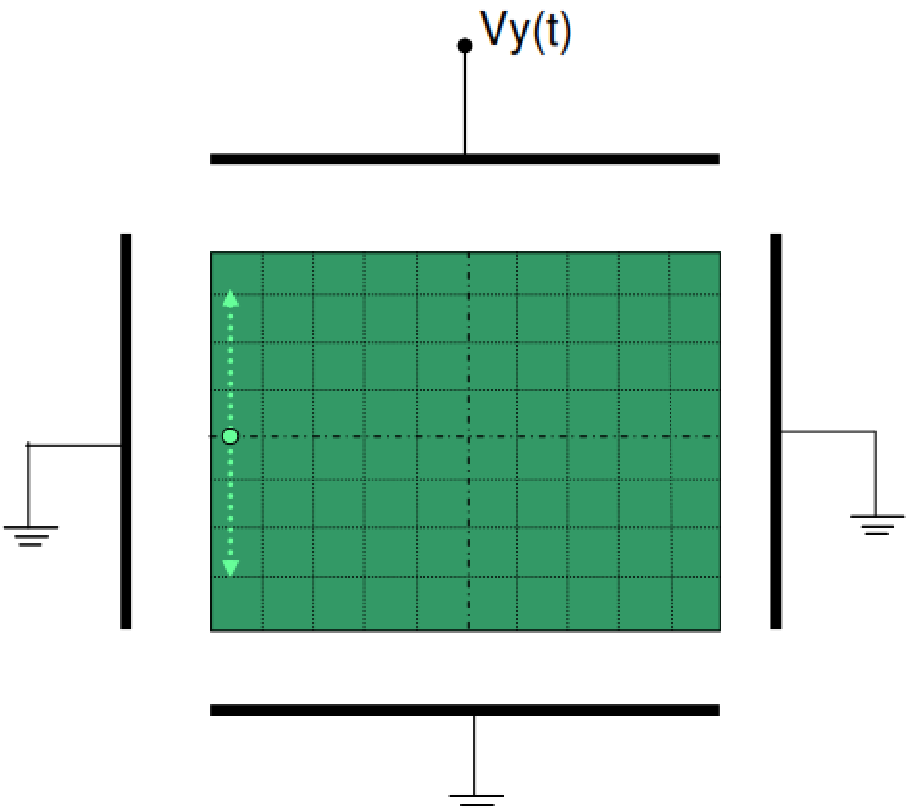
This is how oscilloscope works

Basic Oscilloscope Operations

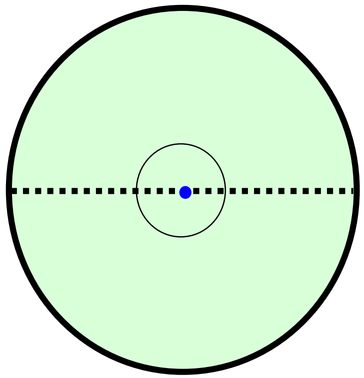


- A +V is applied to Y I/p e-beam deflect vertically upward
- A –V is applied to Y I/p e-beam deflect vertically downward.
- The same is for X I/p.

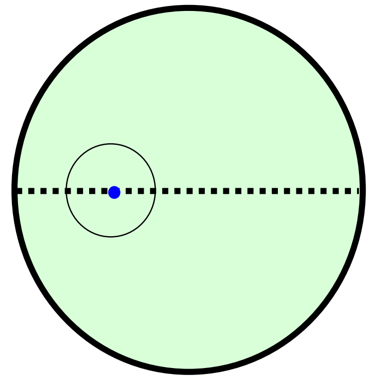




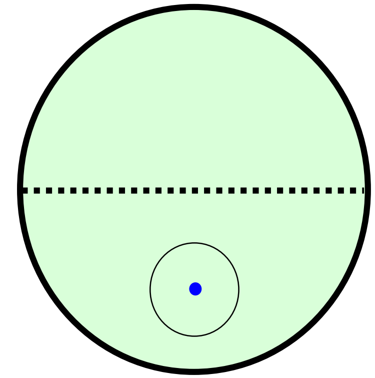
The traces we get with time base off



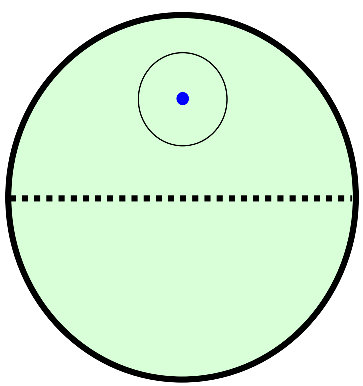
no input



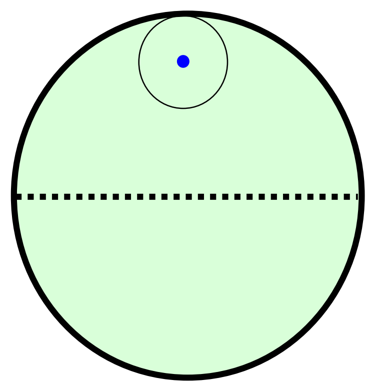
no input – spot adjusted left



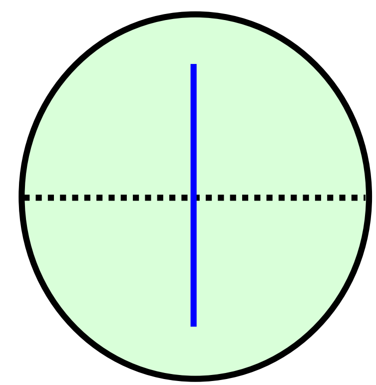
d.c input lower plate positive



d.c input upper plate positive

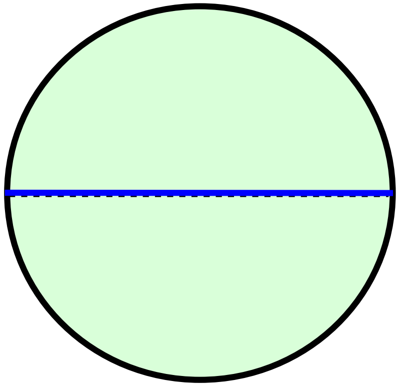


d.c input upper plate more positive

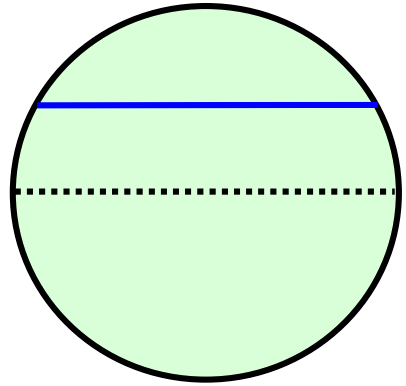


a.c input

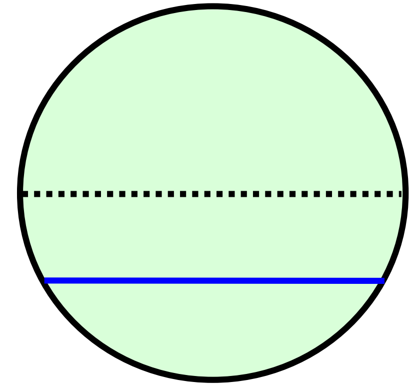
The traces we get with time base on



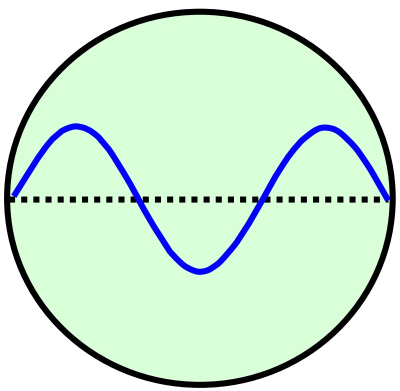
no input



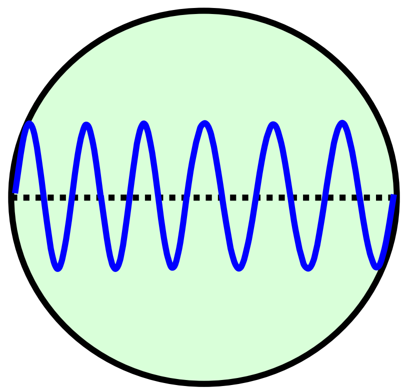
d.c input – upper plate positive



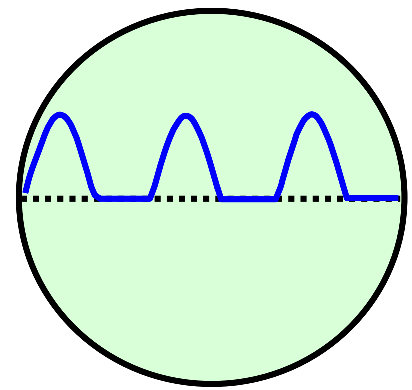
d.c input – lower plate positive



low frequency a.c input



high frequency a.c. input



a.c input with a diode

CATHODE RAY TUBE

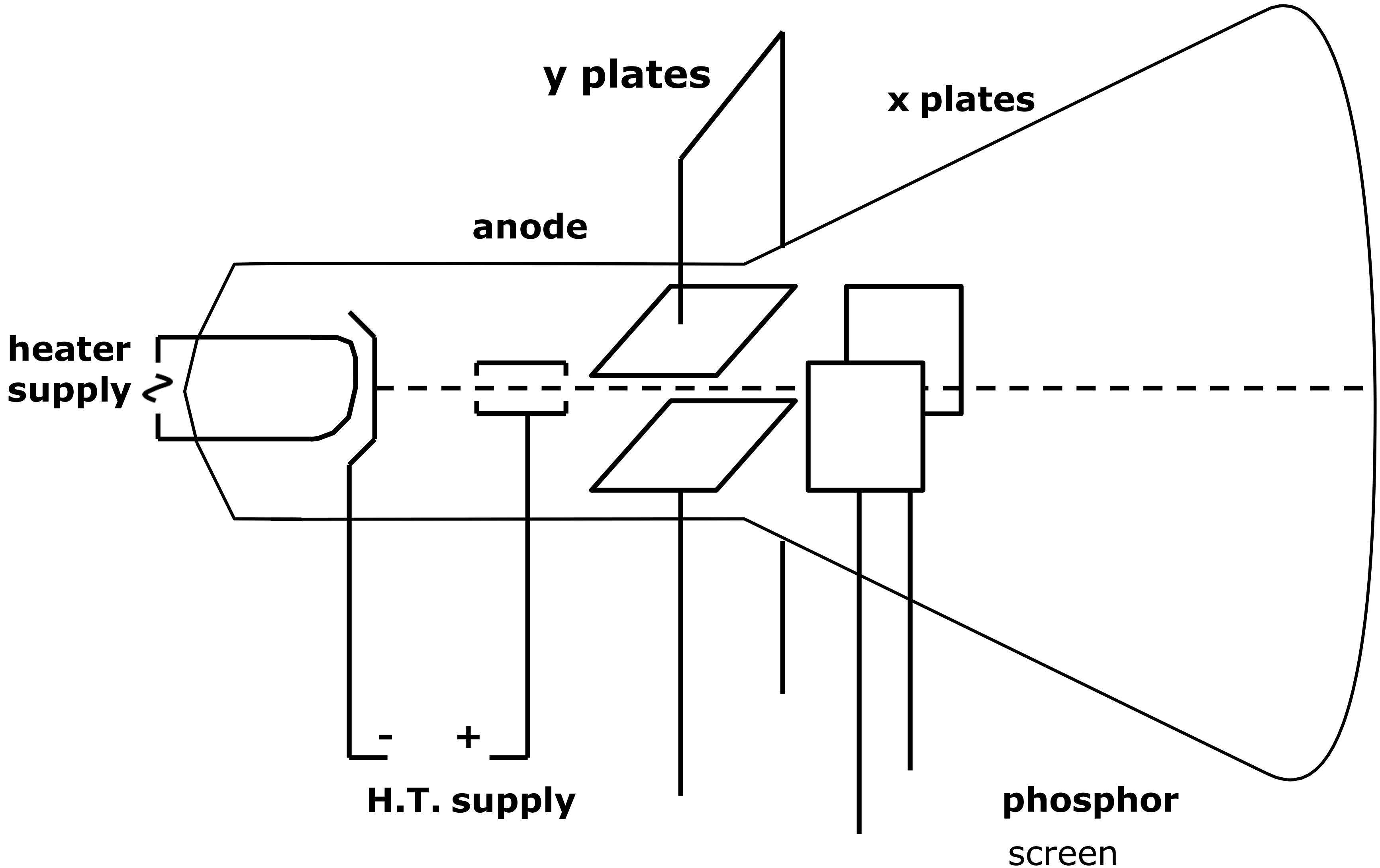
- The experimentation of cathode rays is largely accredited to J.J. Thomson, an English physicist who, in his three famous experiments, was able to deflect cathode rays, a fundamental function of the modern CRT in 1897.
- In 1907, Russian scientist Boris Rosing used a CRT in the receiving end of an experimental video signal to form a picture. He managed to display simple geometric shapes onto the screen, which marked the first time that CRT technology was used for what is now known as television.
- The first commercially made electronic television sets with cathode ray tubes were manufactured by Telefunken in Germany in 1934.

A Braun tube, this small early 1900 tube is in fact a cold Cathode Crookes tube

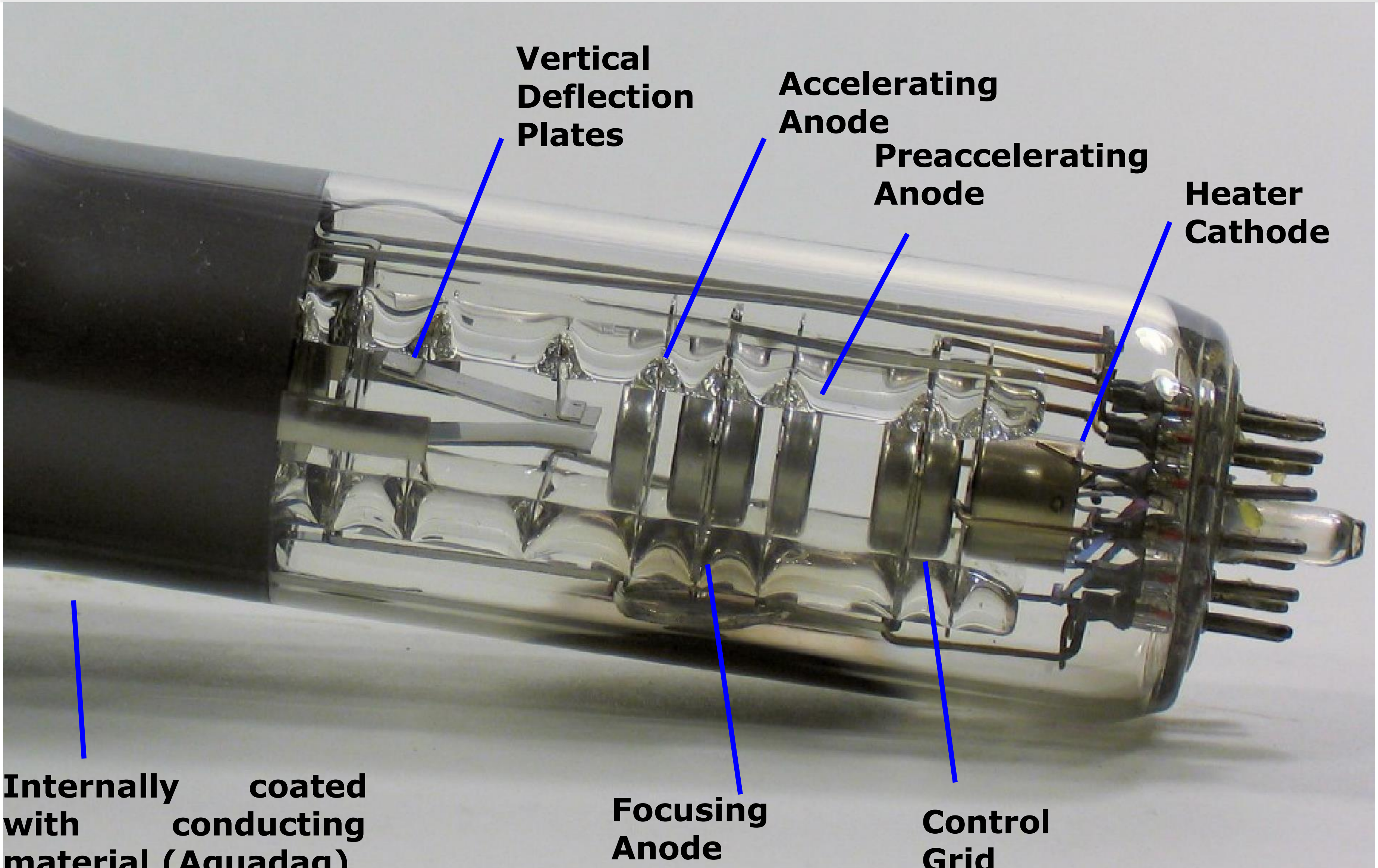
Cathode Ray Tube (CRT)

The cathode ray tube (CRT) is a vacuum tube containing an electron gun (a source of electrons) and a fluorescent screen, with internal or external means to accelerate and deflect the electron beam, used to create images in the form of light emitted from the fluorescent screen.

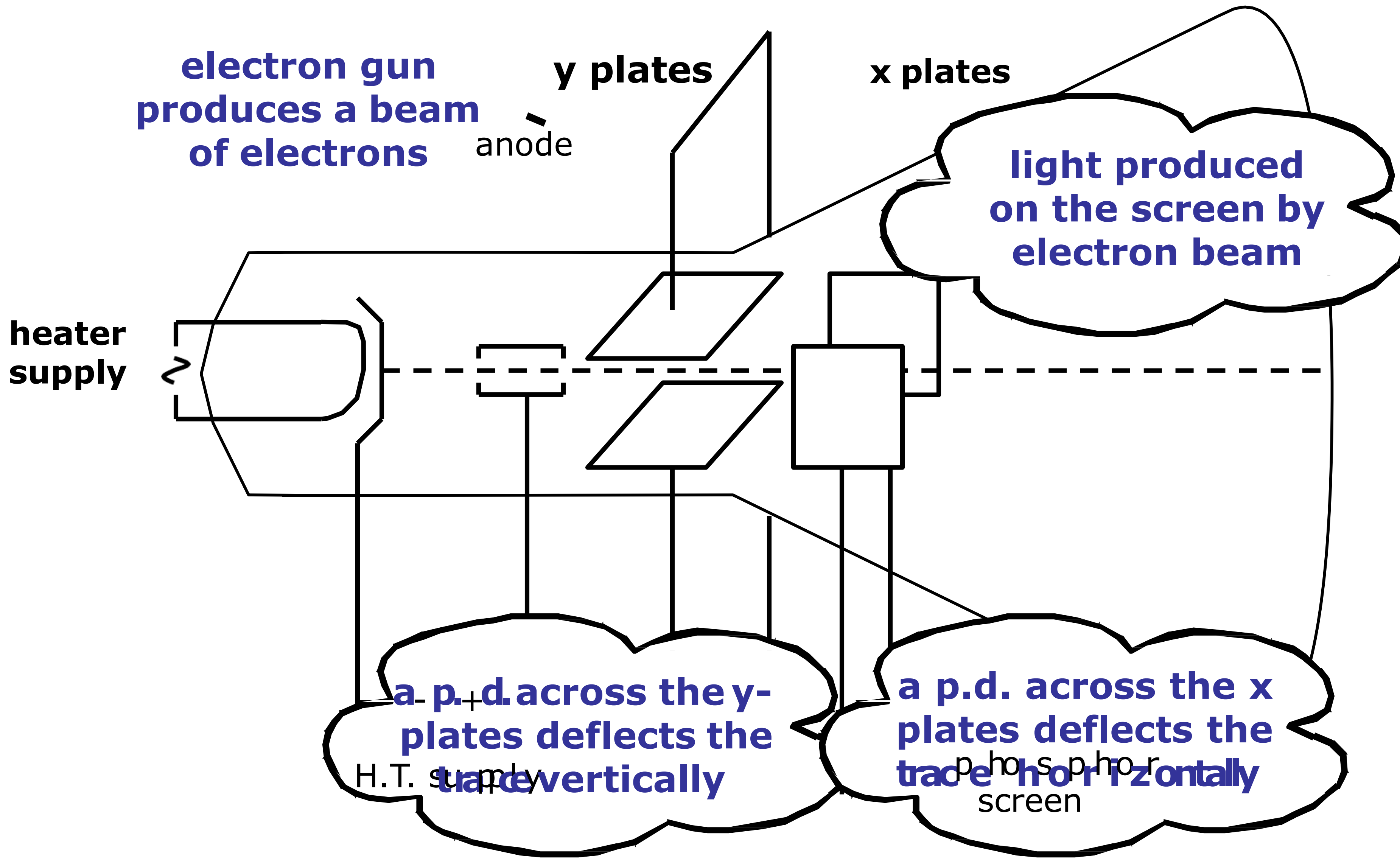
Internal Structure of CRT



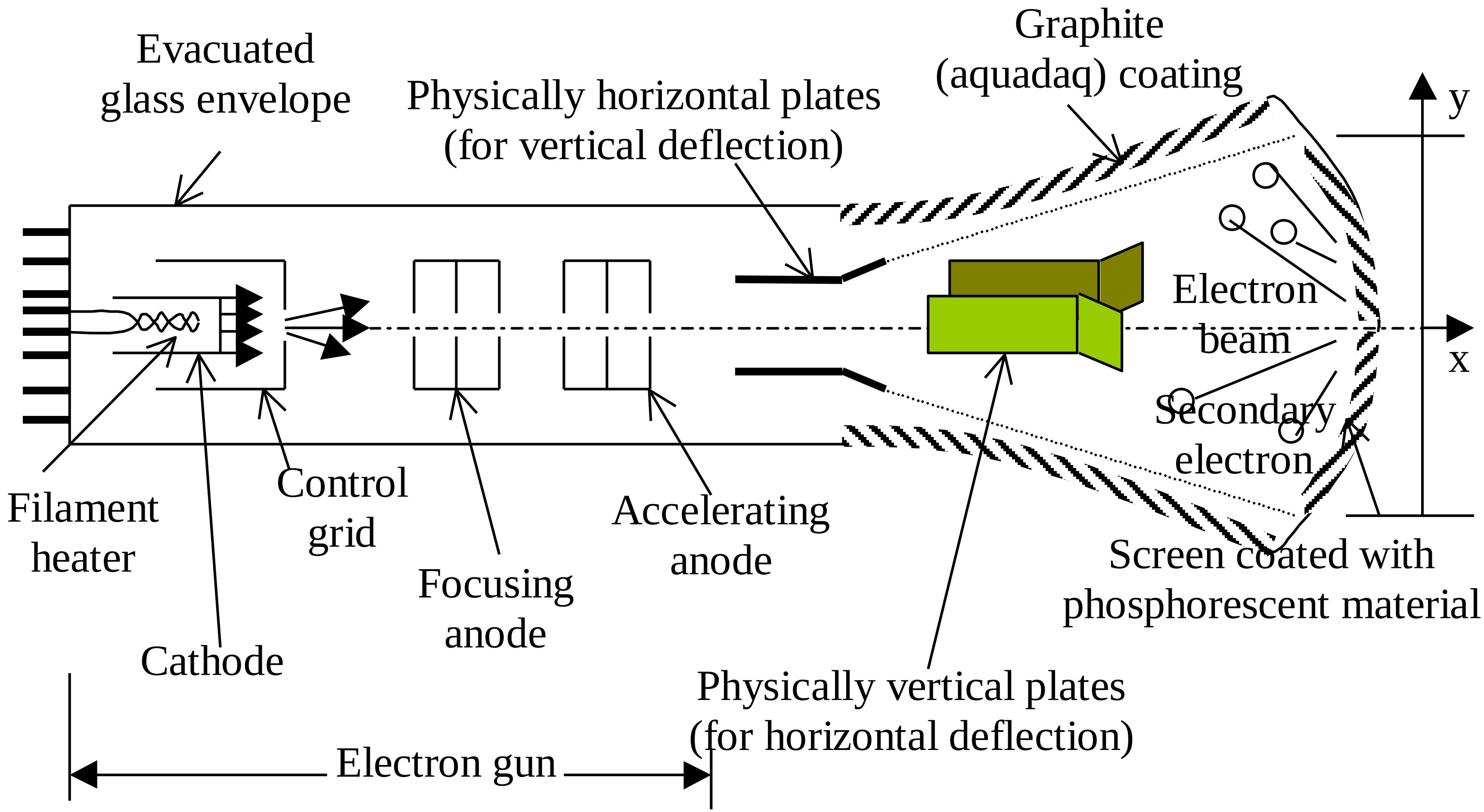
Photograph of electron gun



Function of Components of CRT

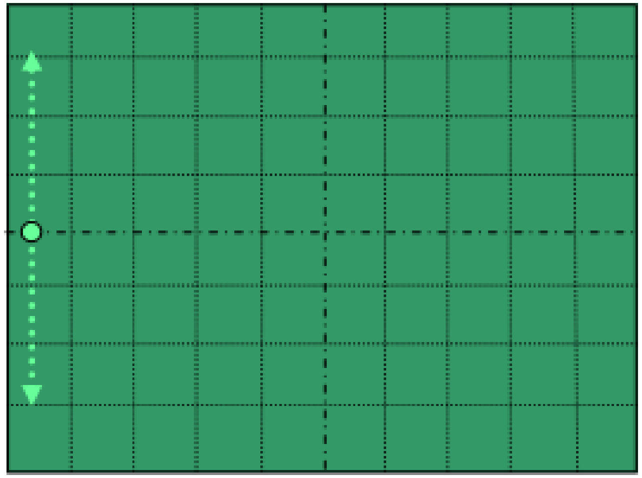


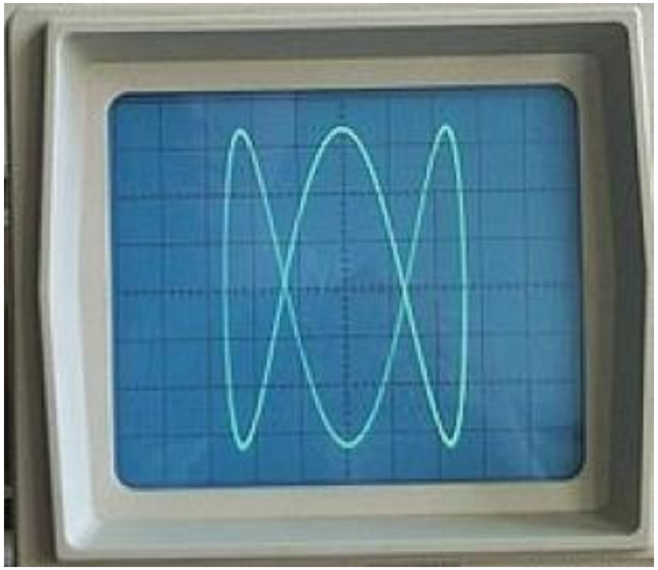
Basic Elements of CRT: Detailed



The Screen

- **Fluorescence**: property of some crystalline materials to emit light when stimulated by radiation.
- **Phosphorescence**: property of material to continue light emission even after the source of excitation is cu-off.
- **Persistence**: duration of phosphorescence.
- **Luminance**: the intensity of light emitted from the CRT screen. It is affected by
  - Number of bombarding electrons/sec. (the beam current).
  - Spot size.
  - Energy of bombarding electrons (accelerating potential)
  - Sweep speed (how long the electron keeps bombarding a given spot before progressing to the neighboring one).
  - Characteristic of the phosphor itself.





The Screens

- Micro Channel Plate: When displaying fast one-shot events the electron beam must deflect very quickly, with few electrons impinging on the screen; leading to a faint or invisible display. Oscilloscope CRTs designed for very fast signals can give a brighter display by passing the electron beam through a micro-channel plate just before it reaches the screen. Through the phenomenon of secondary emission this plate multiplies the number of electrons reaching the phosphor screen, giving a significant improvement in writing rate (brightness), and improved sensitivity and spot size as well.

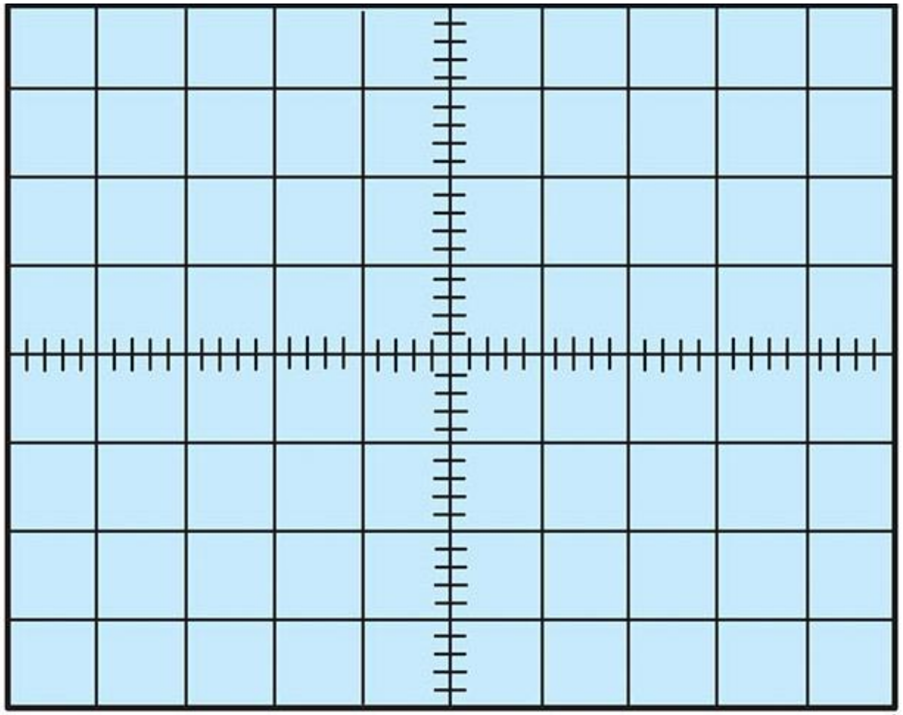
- Color CRT: Color tubes use three different phosphors which emit red, green, and blue light respectively. Color CRTs have three electron guns, one for each primary color, arranged either in a straight line or in a triangular configuration (the guns are usually constructed as a single unit). A grille or mask absorbs the electrons that would otherwise hit the wrong phosphor. A shadow mask tube uses a metal plate with tiny holes, placed so that the electron beam only illuminates the correct phosphors on the face of the tube.

CRT

- **Advantages of CRT**
  - The cathode rayed tube can easily increase the monitor's brightness by reflecting the light.
  - They produce more colours
  - The Cathode Ray Tube monitors have lower price rate than the LCD display or Plasma display.
  - The quality of the image displayed on a Cathode Ray Tube is superior to the LCD and Plasma monitors.
  - The contrast features of the cathode ray tube monitor are considered highly excellent.

- **Disadvantages of CRT**
  - They have a big back and take up space on desk.
  - The electromagnetic fields emitted by CRT monitors constitute a health hazard to the functioning of living cells.
  - CRTs emit a small amount of X-ray band radiation which can result in a health hazard.
  - Constant refreshing of CRT monitors can result in headache.
  - CRTs operate at very high voltage which can overheat system or result in an implosion
  - Within a CRT a strong vacuum exists in it and can also result in a implosion
  - They are heavy to pick up and carry around

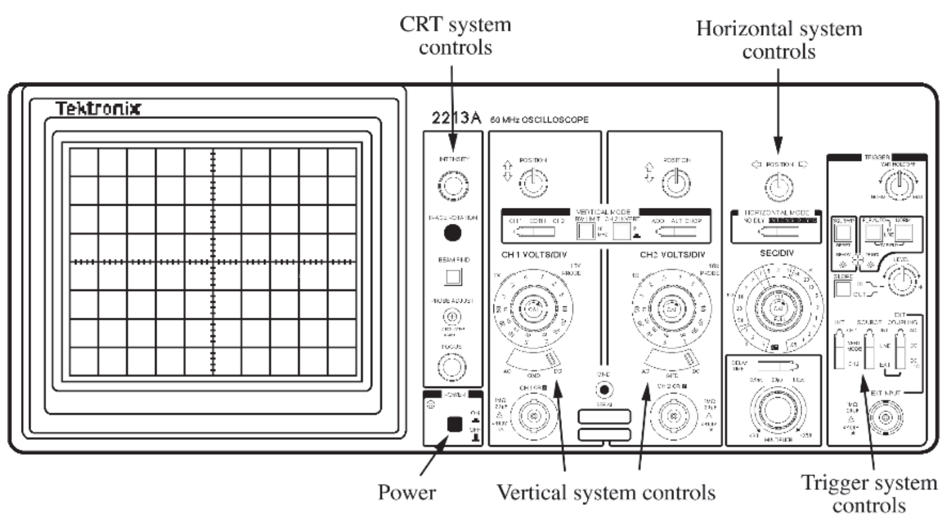
Oscilloscope Principle



How this screen works and how the graphs are presented live.

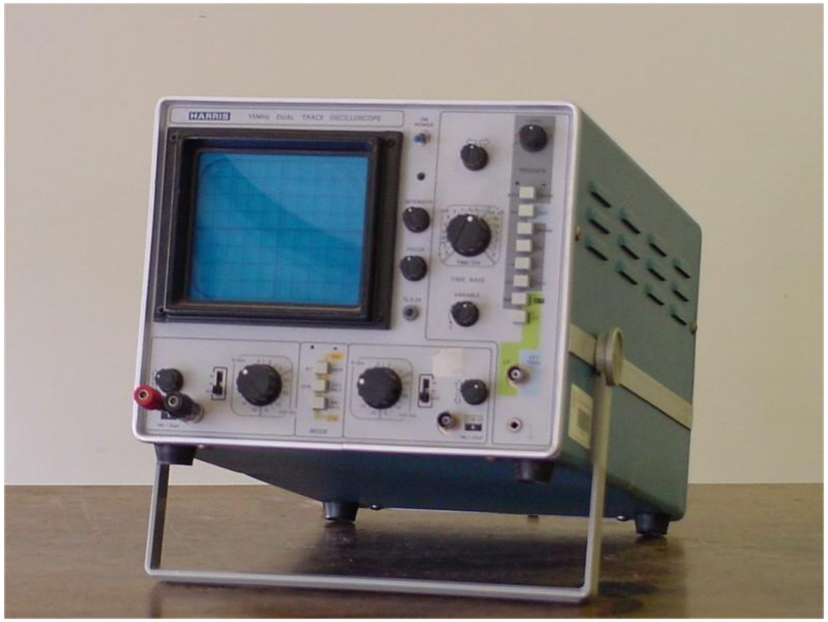
An Oscilloscope

- **Oscilloscope** (**scope**) is a visual voltmeter with a timer (**clock**) that shows when a voltage changes.
- An analog scope uses a **cathode ray tube (CRT)** similar to a television screen to display voltage patterns.

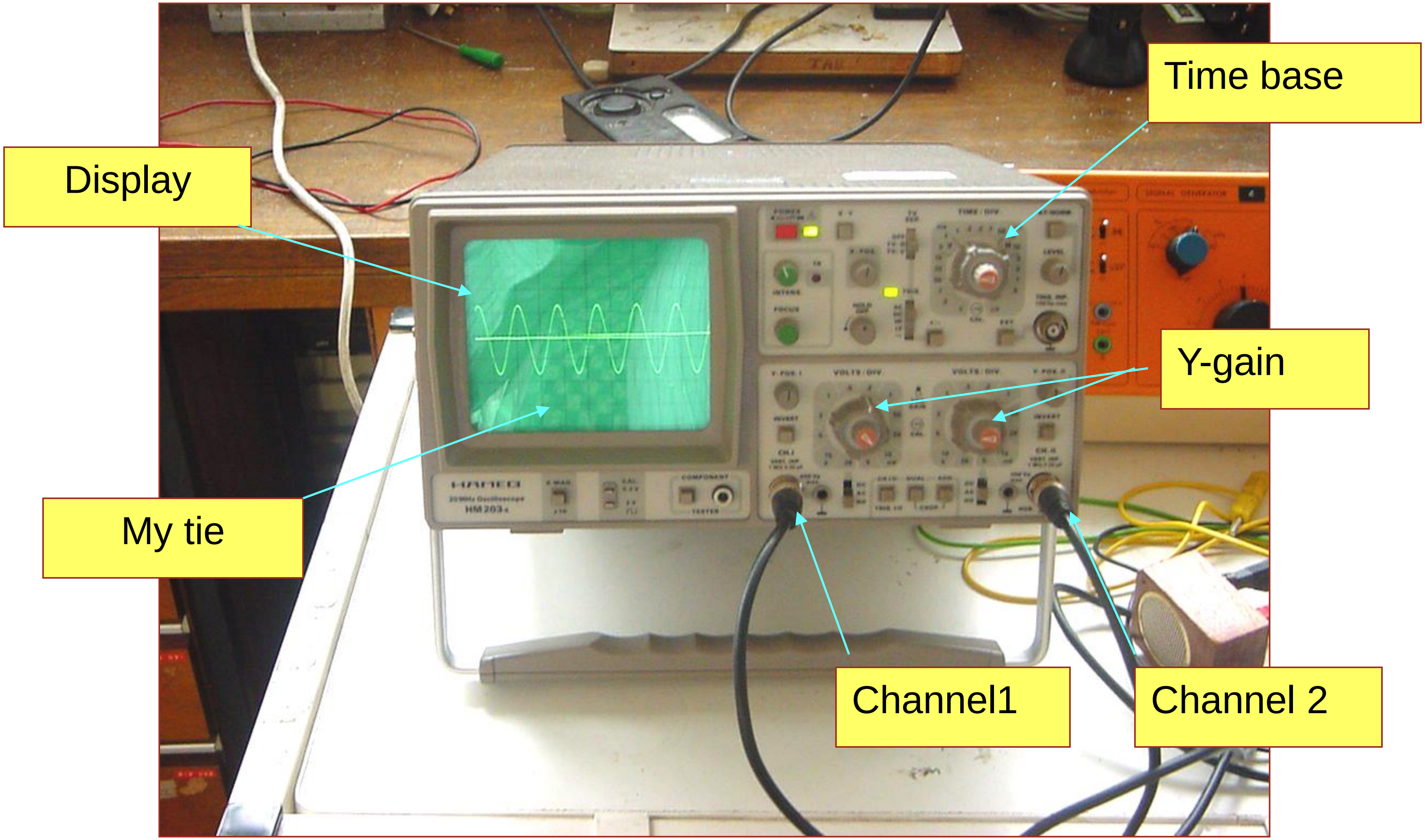


Cathode Ray Oscilloscope

- For display, measurement and analysis of waveform



Cathode Ray Oscilloscope (CRO)



How does it work?

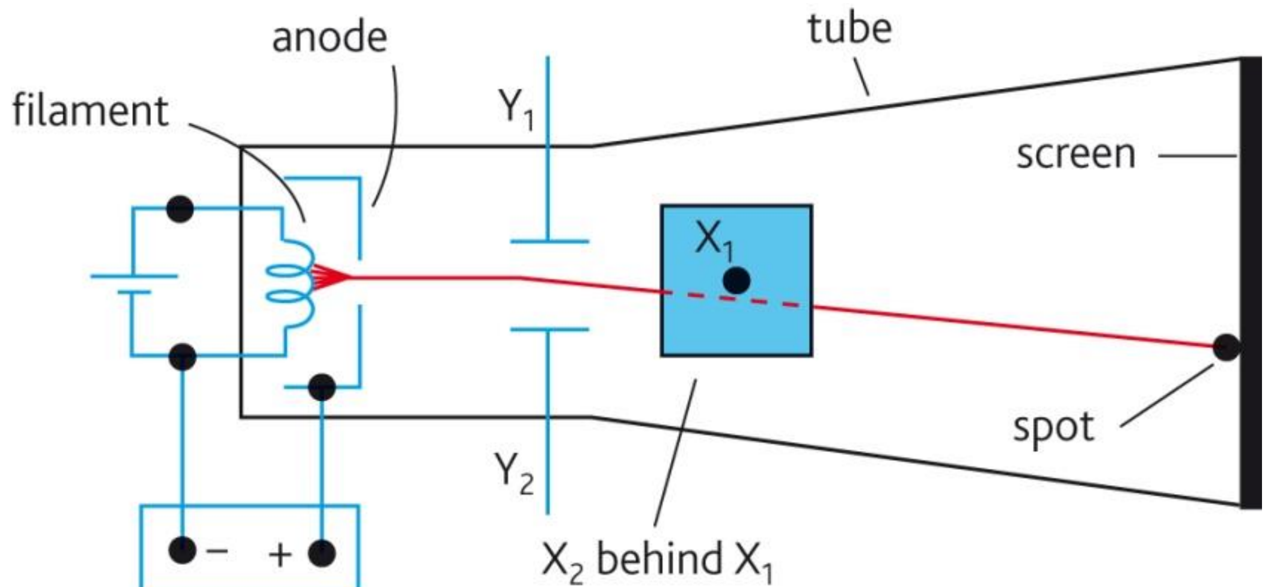
- An oscilloscope consists of a specially made electron tube and associated control circuits.
- An electron gun at one end of the glass tube emits electrons in a beam towards a fluorescent screen at the other end of the tube.
- Light is emitted from the spot on the screen where the beam hits the screen.
- When no p.d. is applied across the plates the spot on the screen is stationary.
- If a pd is applied across the X-plates the beam of electrons is deflected horizontally and the spot moves across.
- pd across Y-plates → spot moves up and down.

Using an Oscilloscope

Describe how an oscilloscope can be used

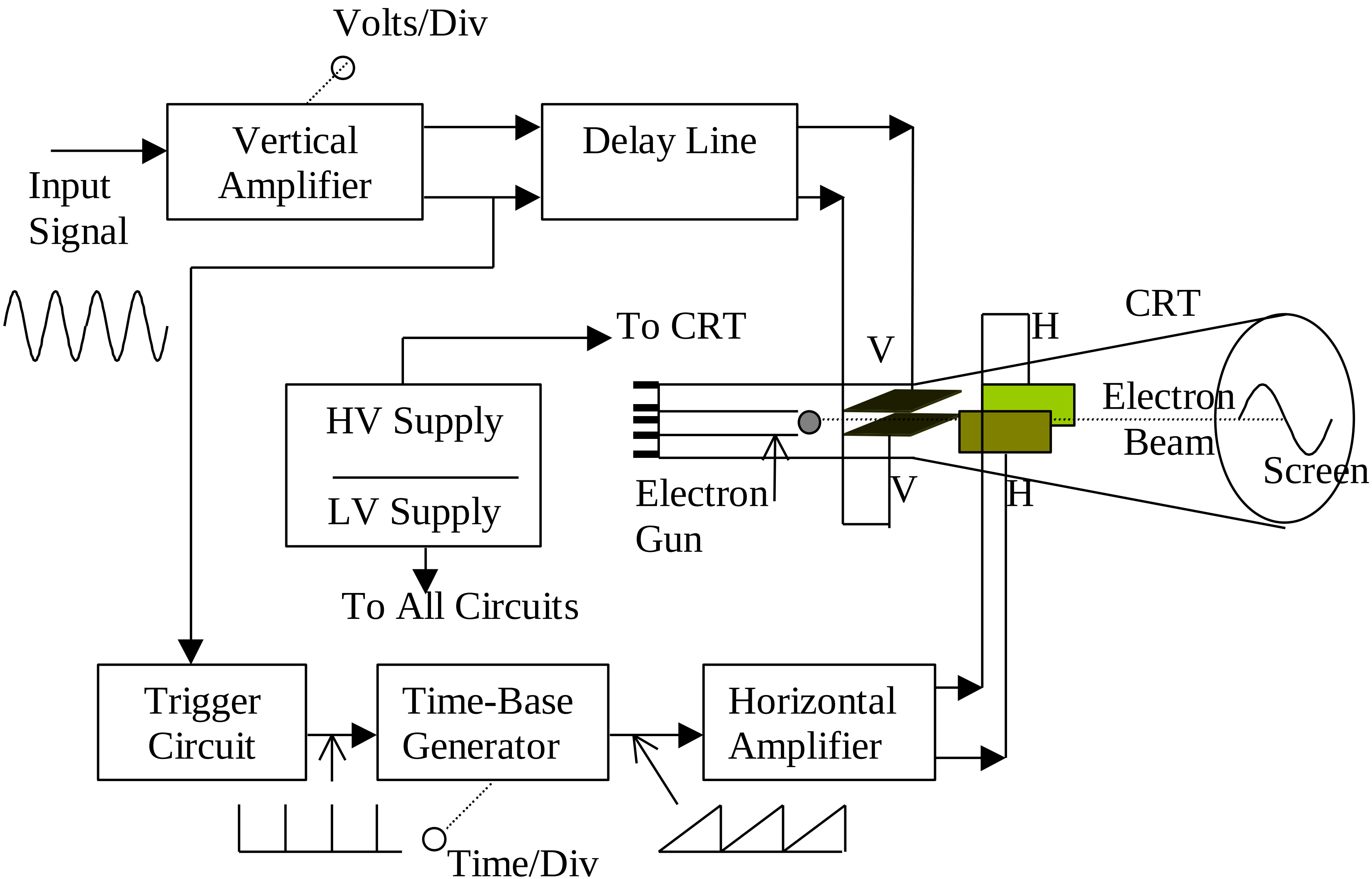
Interpret waveforms on an oscilloscope to give Peak wavelength or voltage

Understand how to use the time base for a calculation

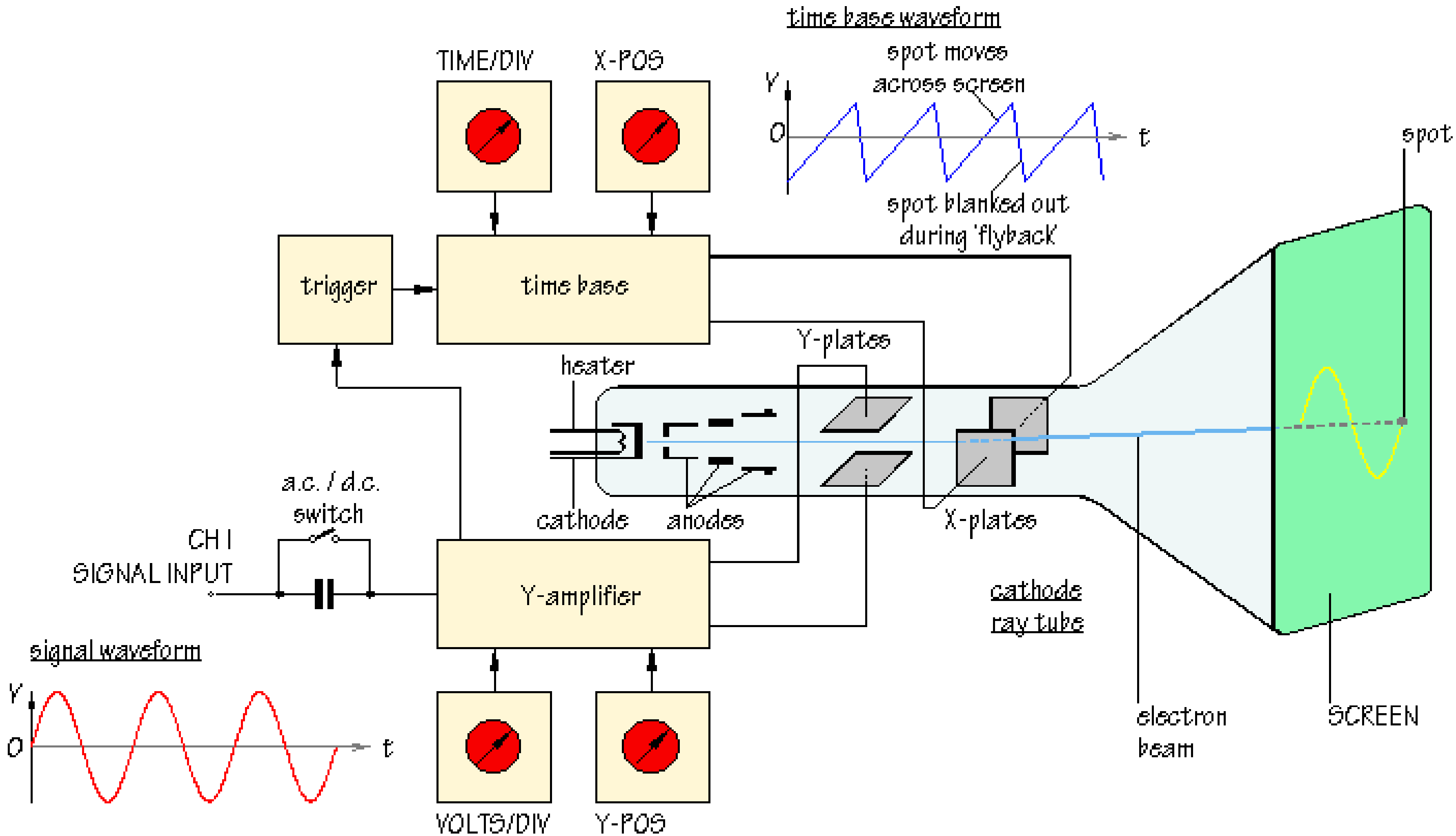


Can you explain what is happening here?

Oscilloscope Circuits



The CRO

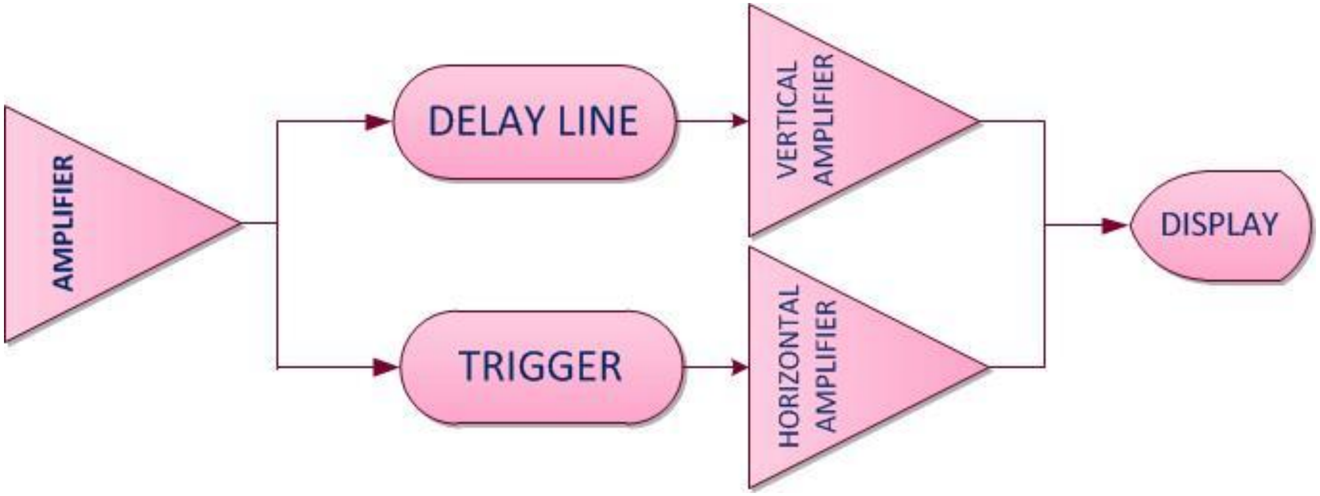

time base waveform
spot moves
across screen
Y
0
t
spot blanked out
during 'flyback'
spot
TIME/DIV
X-POS
trigger
time base
Y-plates
heater
cathode
anodes
X-plates
a.c. / d.c.
switch
CH I
SIGNAL INPUT
Y-amplifier
cathode
ray tube
signal waveform
Y
0
t
VOLTS/DIV
Y-POS
electron
beam
SCREEN

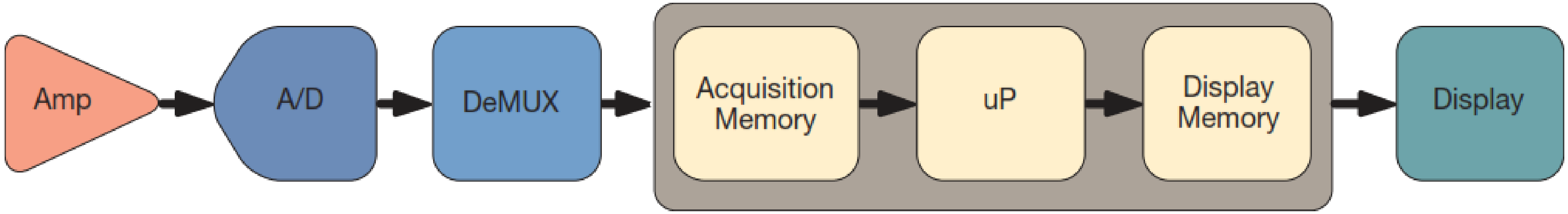
Type of Oscilloscope

- Analogue Oscilloscope
- Digital Storage Oscilloscope
- Digital Phosphor Oscilloscope
- Digital Sampling Oscilloscope

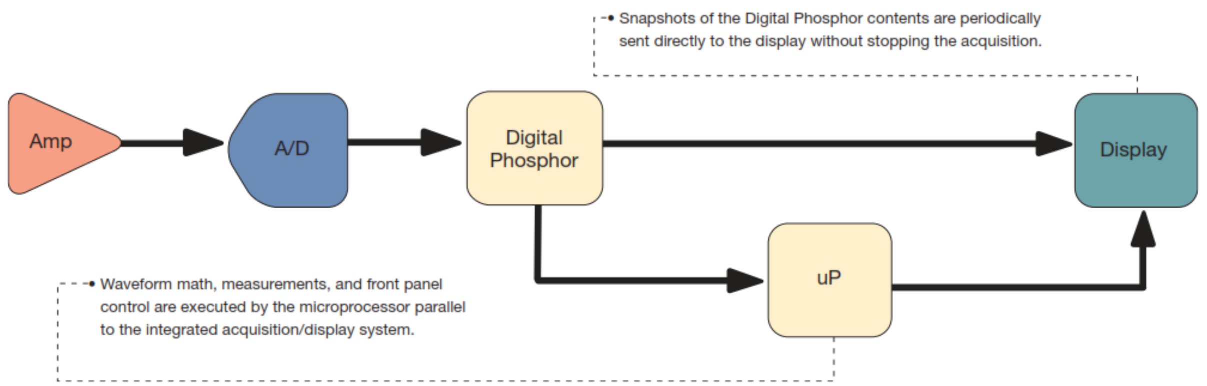
Type of Oscilloscope

Analogue Scope



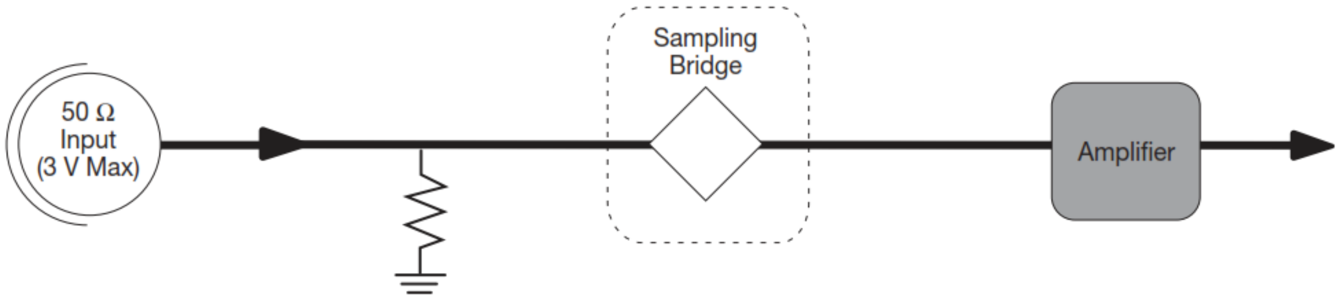


Digital Storage Scope

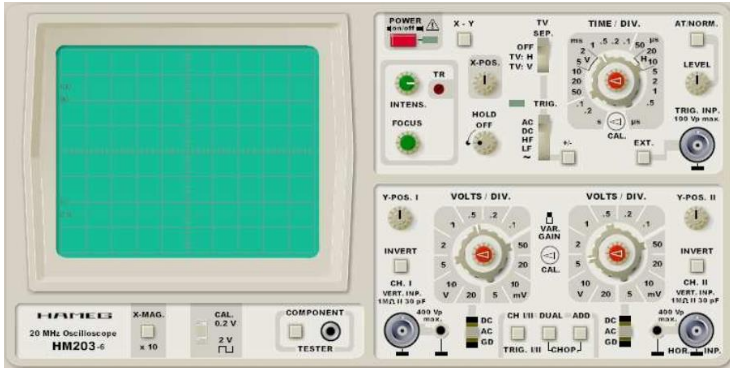


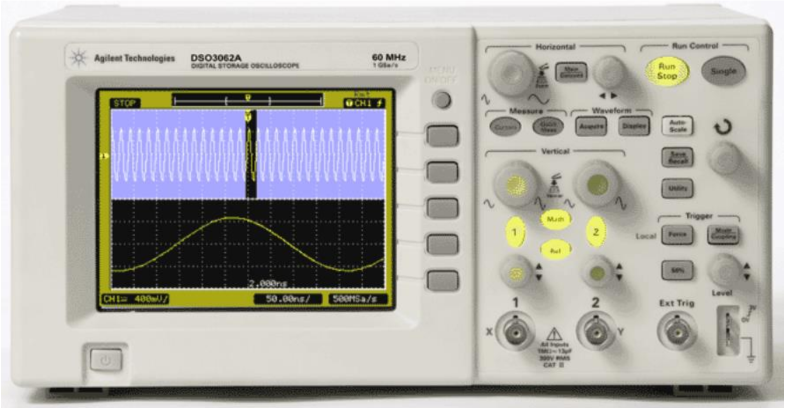
Digital Phosphor Scope

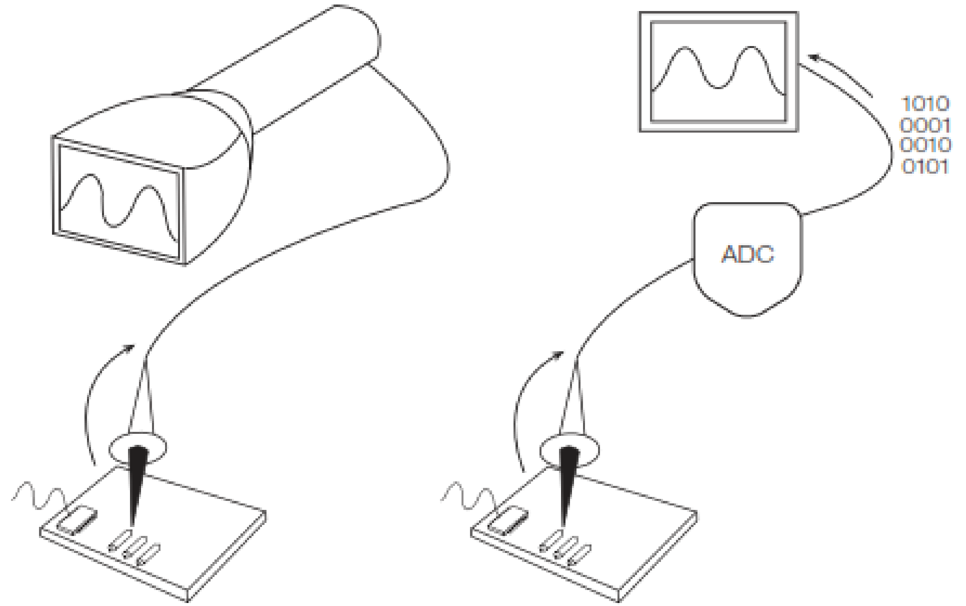
Digital Sampling Scope



Analog versus Digital Oscilloscope



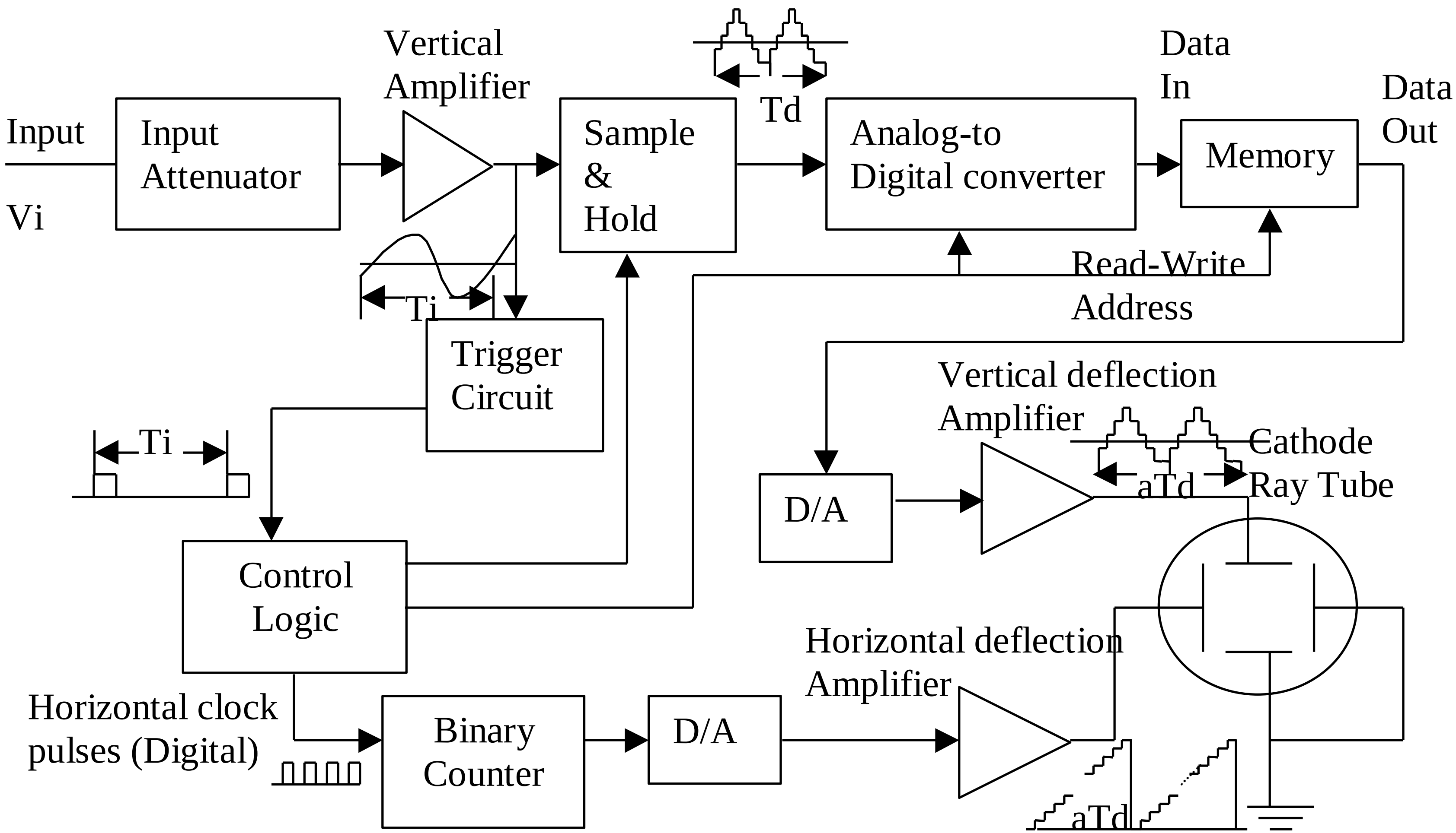




Analog Oscilloscopes
Trace Signals

Digital Oscilloscopes Samples
Signals and Construct Displays

Digital Storage Oscilloscope



Oscilloscope Controls

- The x-plates are connected to a time base circuit which is designed to make the spot move across the screen in a given time → then back again much faster. → a bit like a trace on a heart monitor.
- The y-plates are connected to the Y-input and this causes the spot to move up or down depending on the input pd.

Oscilloscope (Scope) Connectors (Input):

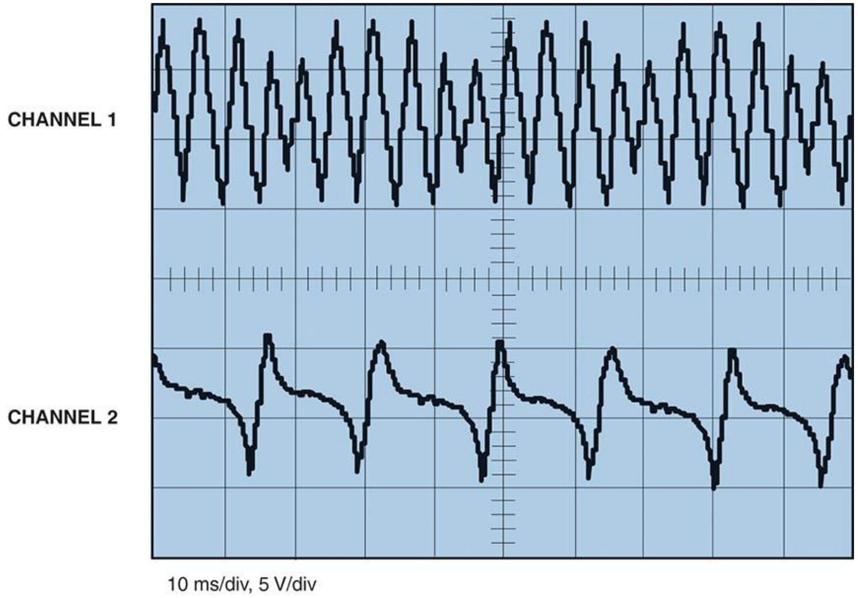
- CH 0 BNC Connector: The input for channel 0 of the oscilloscope.
- CH 1 BNC Connector: The input for channel 1 of the oscilloscope.

SYNC (Output):

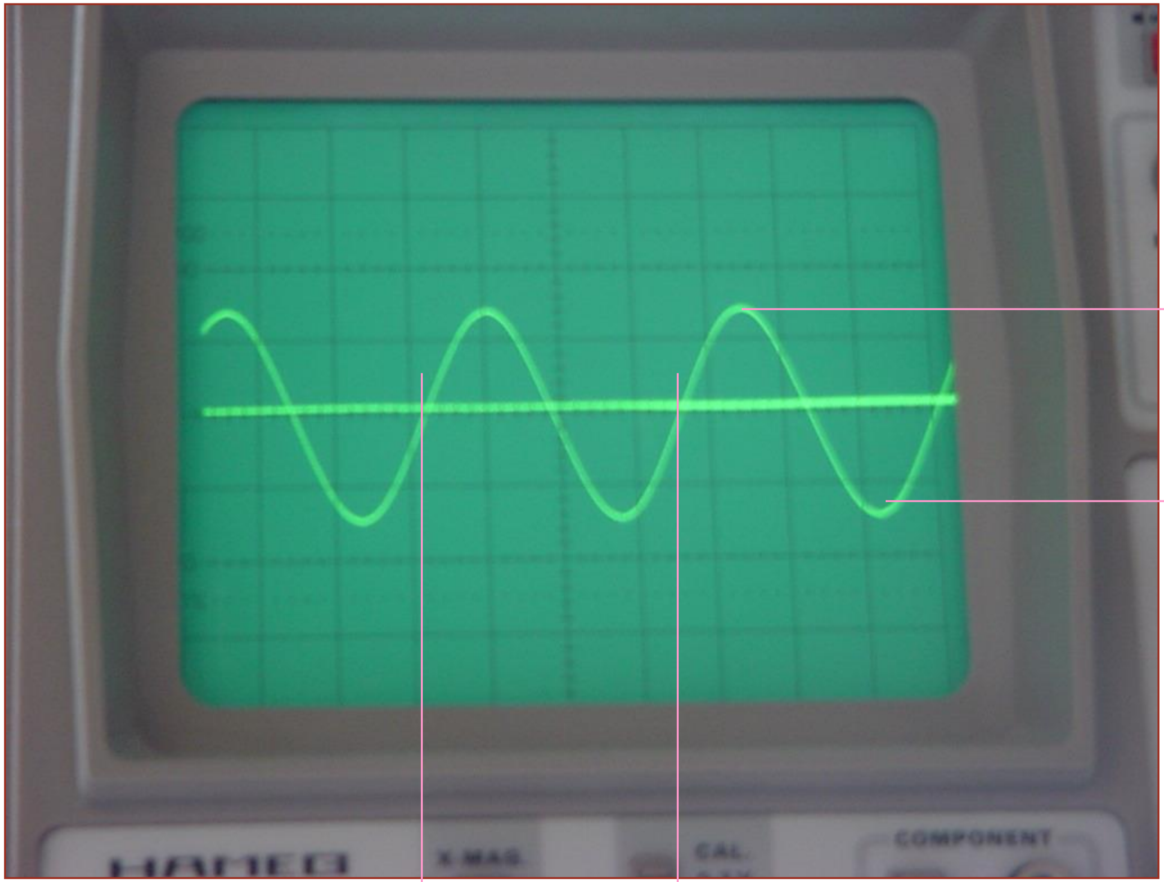
- 5V TTL signal synchronized to the FGEN signal.
- This signal is most used as a trigger signal for the oscilloscope.

NUMBER OF CHANNELS

- Single Channel
  - A single-channel scope is capable of displaying only one sensor signal waveform at a time.
- Two Channel
  - A two-channel scope can display the waveform from two separate sensors or components at the same time.
- Four Channel
  - A four-channel scope allows the technician to view up to four different sensors or actuators on one display.



Reading the CRO 1

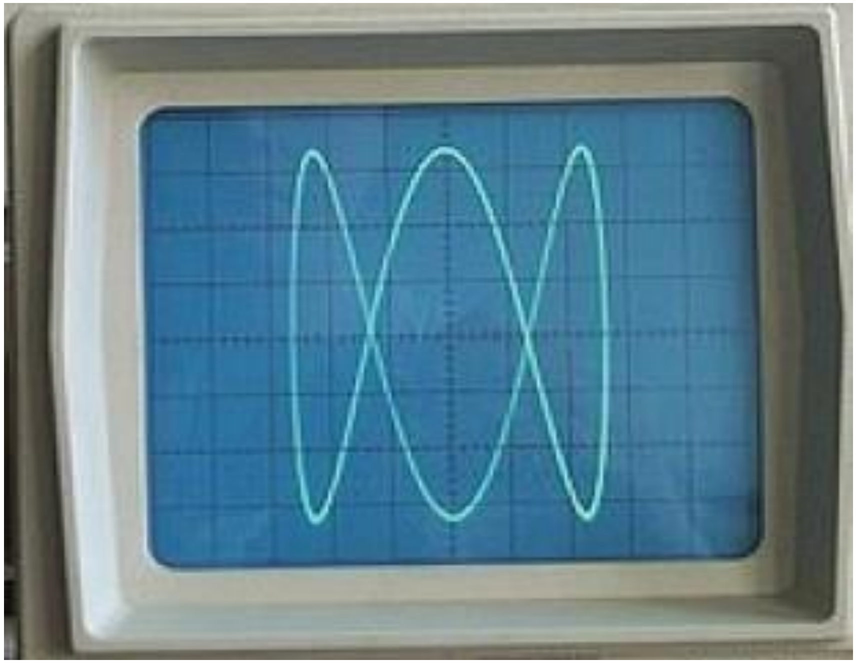


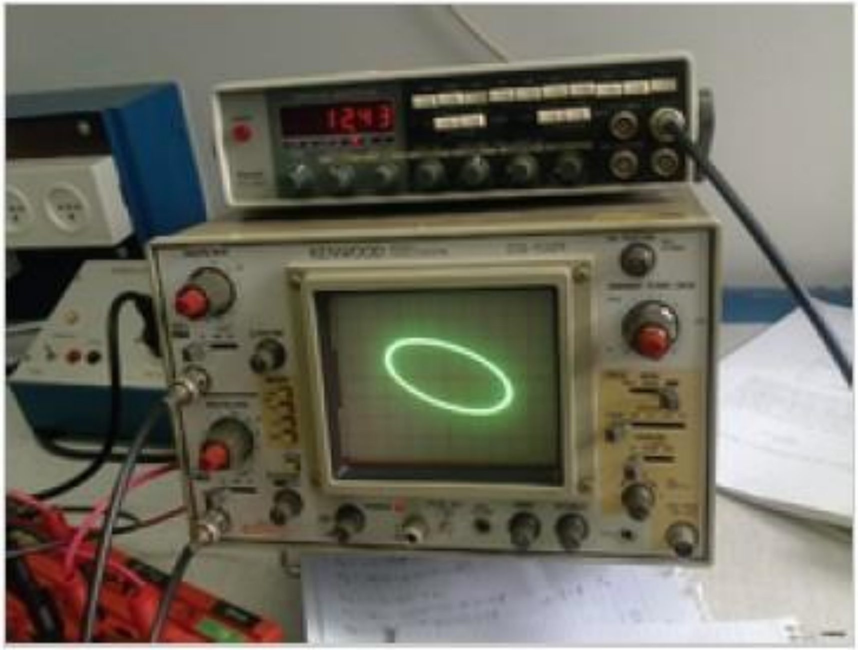
Peak-to-Peak voltage

Time Period (ms)

To get the time period you need to measure this distance and convert it to time by multiplying by the time base setting

Screen: Let's characterize the waveform



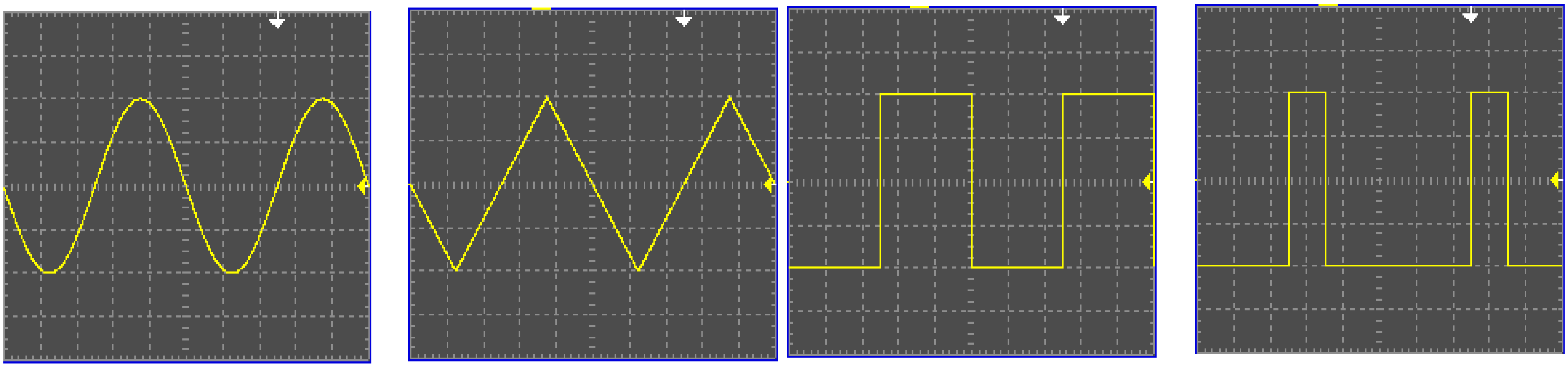


Very fast X-Y plotters (Lissajous pattern)

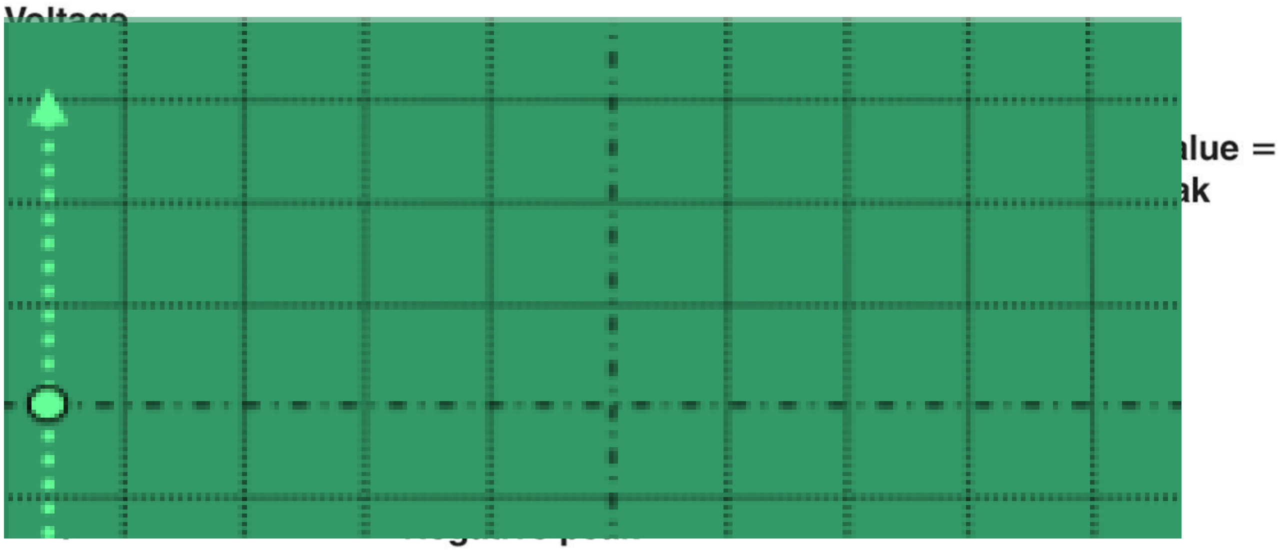
We need to understand the properties of a waveform or signal before using such device

Time Series Measurement

- A waveform shows the changes in amplitude over a certain amount of time. The amplitude of the signal is measured on the y-axis (vertically), while time is measured on the x-axis (horizontally).
- Typical waveform shapes include the sine-wave, sawtooth wave and square wave.



Measure Waveforms



Amplitude: maximum voltage (high point) of the waveform; sometimes called peak voltage $\mathbf{V_P}$; measured in volts (v)

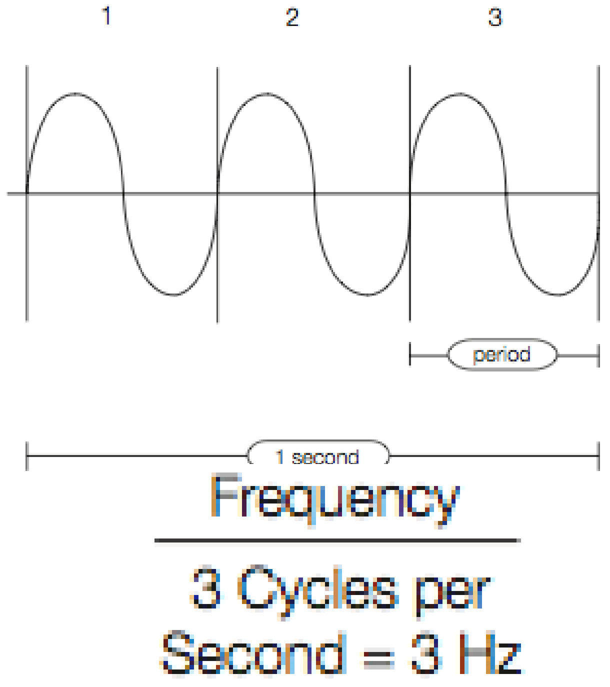
Peak-to-Peak Voltage: $\mathbf{V_{P\text{-}P}}$ takes into consideration both the highest and the lowest points of the wave

Frequency: number of cycles per second; measured in hertz, kilohertz and megahertz

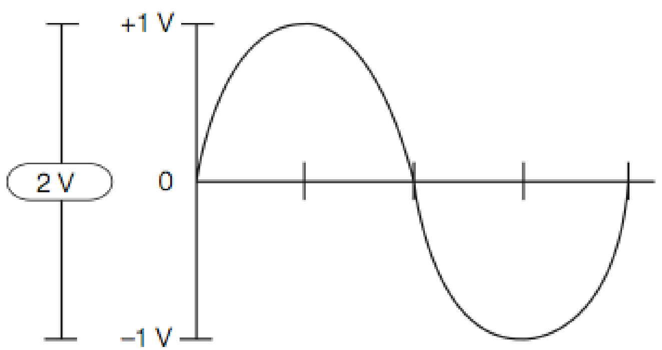
Pulse Width: the amount of time the pulse takes to go from low to high and back to low again

Phase Shift: when cycles are out of synch—sometimes on purpose, such as in a 3-phase electrical power transmission system

- If a signal repeats, it has a frequency.
- The frequency is measured in Hertz (Hz) and equals the number of times the signal repeats itself in one second, referred to as cycles per second.
- A repetitive signal also has a period, which is the amount of time it takes the signal to complete one cycle.
- Period and frequency are reciprocals of each other,

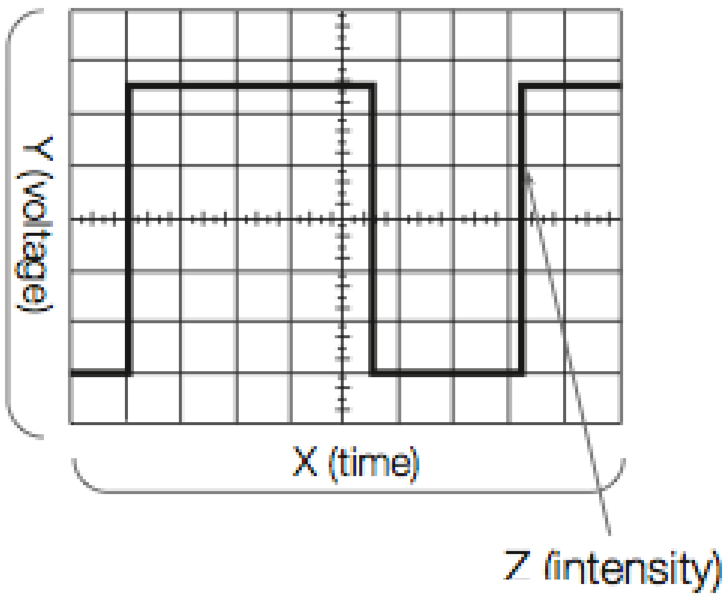


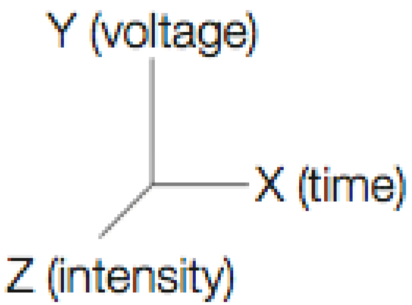
- One may measure the amplitude from th maximum peak to the minimum peak of waveform, referred to as the peak-to-pea voltage.



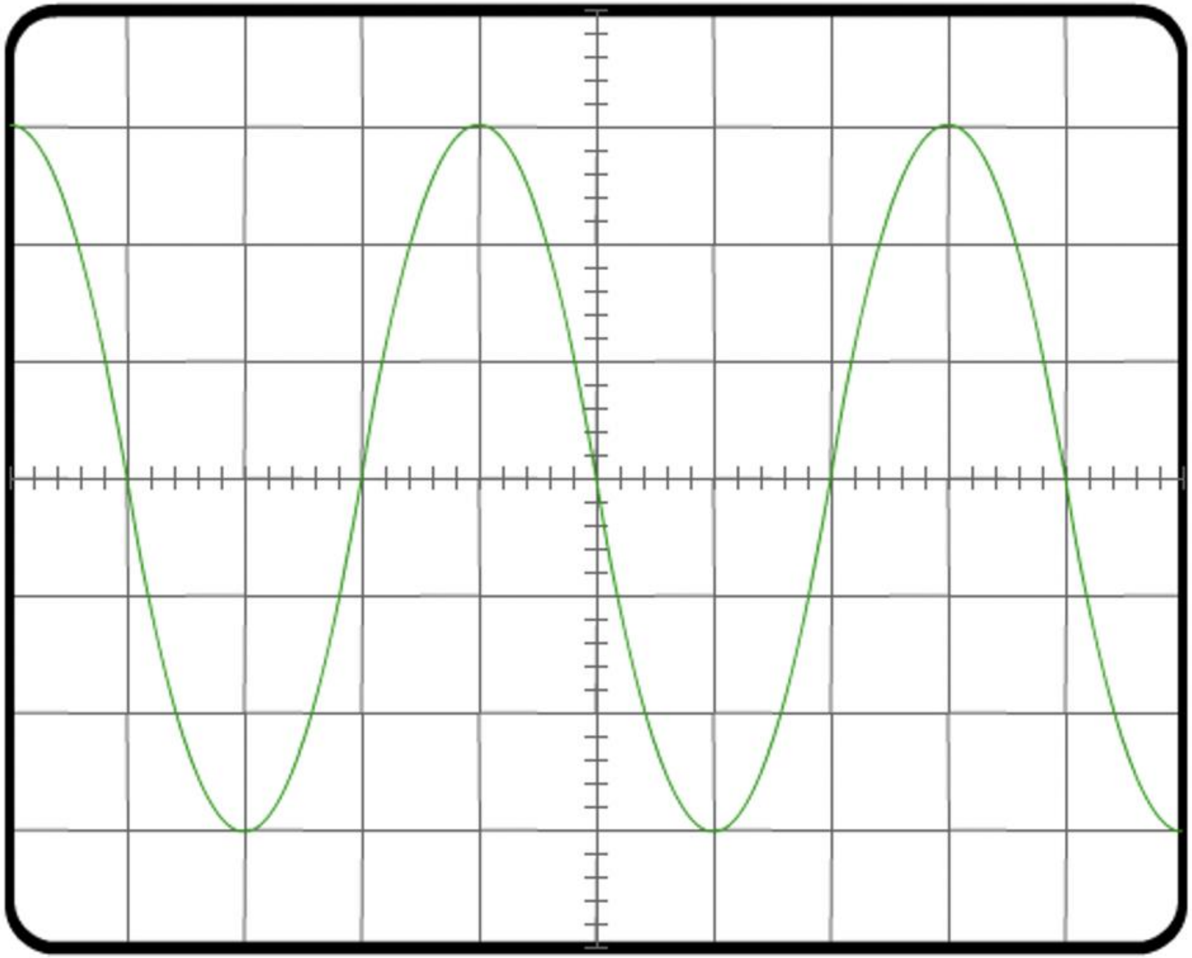
The Oscilloscope

- The oscilloscope is basically a graph-displaying device.
- The graph shows how signals change over time.
- The vertical (Y) axis represents voltage and the horizontal (X) axis represents time. The intensity or brightness of the display is sometimes called the Z axis, as shown in figure.





A display



So, what is the unit of x-axis and y-axis

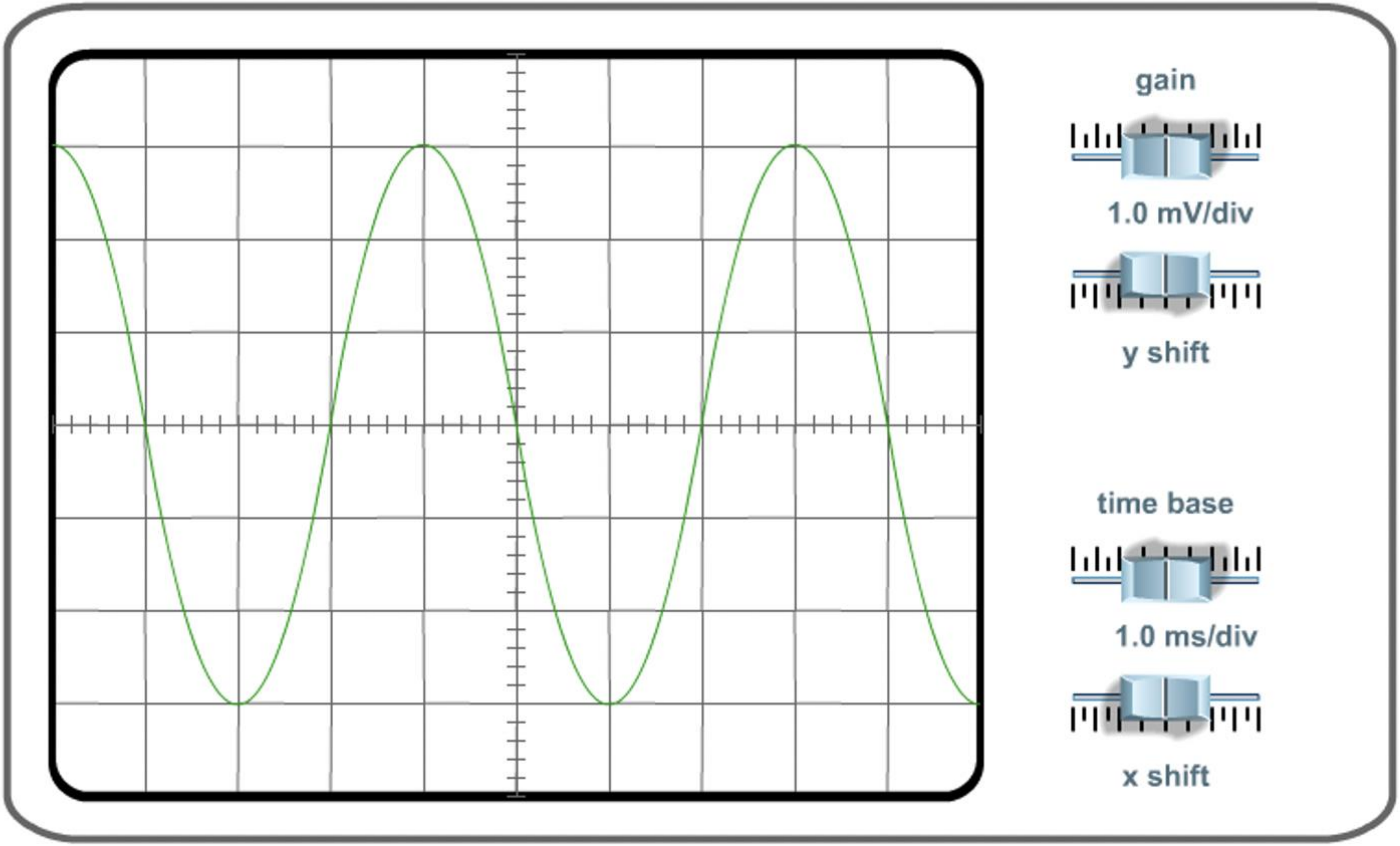
X-axis: Time
Y-axis: Voltage?

What about if I want to measure Current

I need to have another Screen?

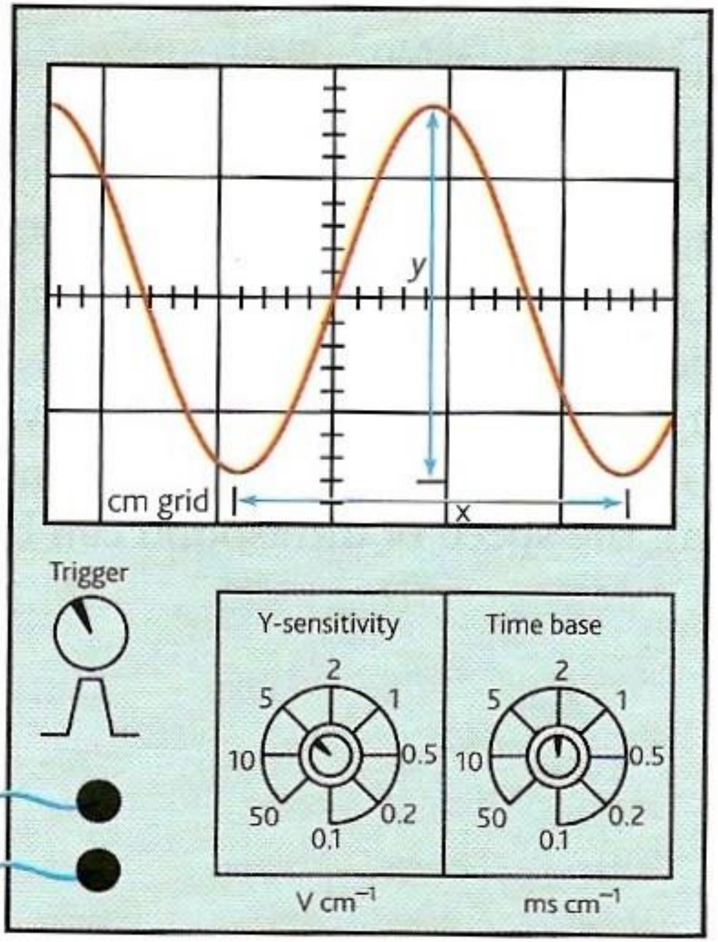
What About is voltage is too high and time is too large?

A display



Let's see what are parameters to be measured

Displaying a waveform: The time base



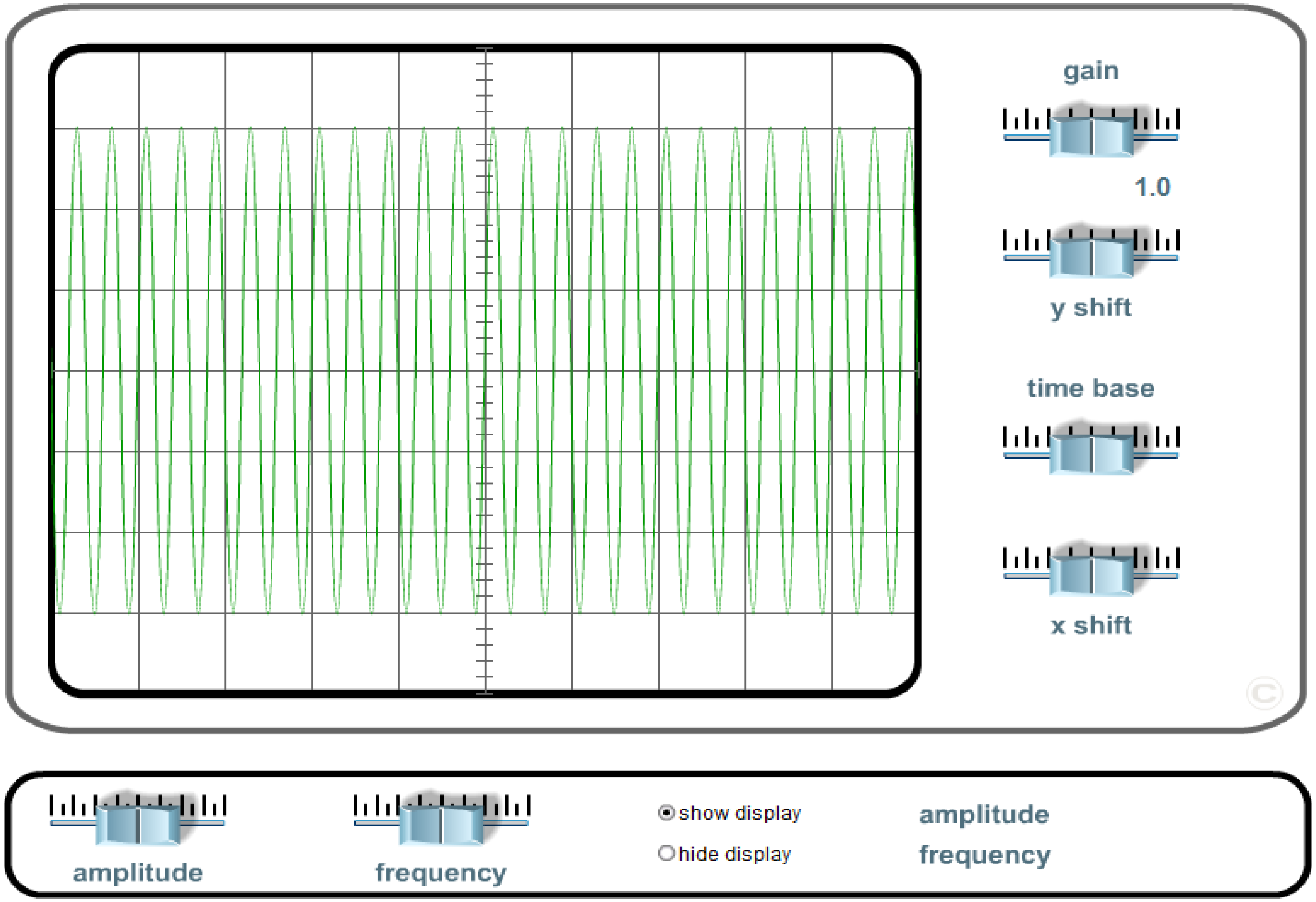
- The X-plates are connected to the oscilloscope's time base circuit.
- This makes the spot move across the screen, from left to right, at a constant speed.
- Once the spot reaches the right hand side of the screen it is returned to the left hand side almost instantaneously.
- The X-scale opposite is set so that the spot takes two milliseconds to move one centimetre to the right.

  (2 ms cm^{-1}).

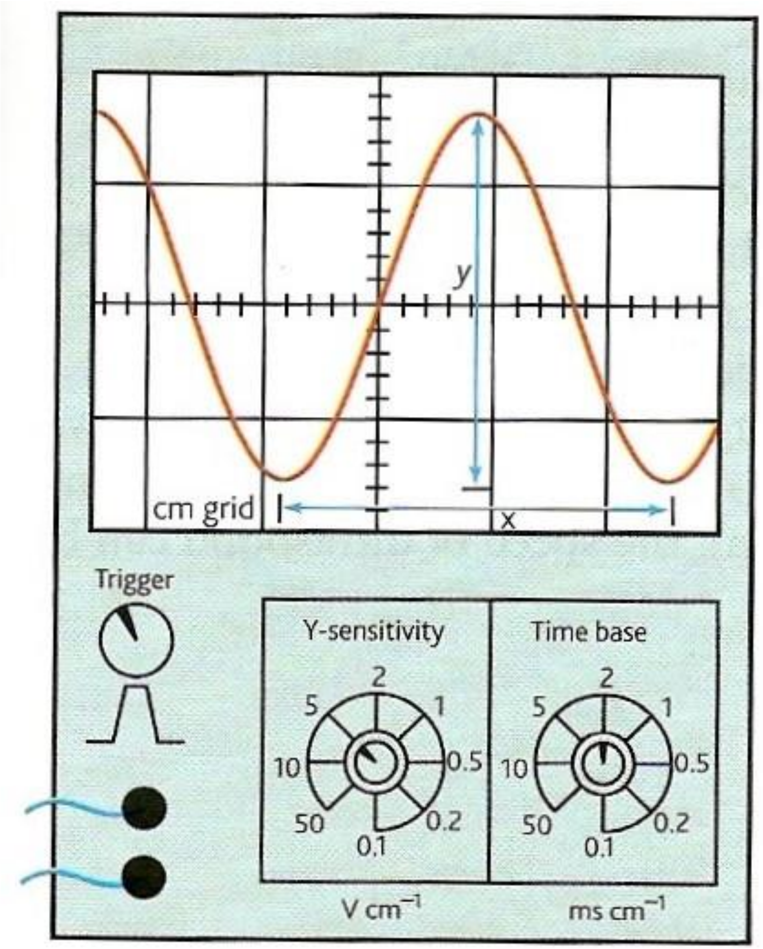
[NTNU Oscilloscope Simulation]

[KT Oscilloscope Simulation]

Gain and Time-Base Controls



Displaying a waveform: Y-sensitivity or Y-gain

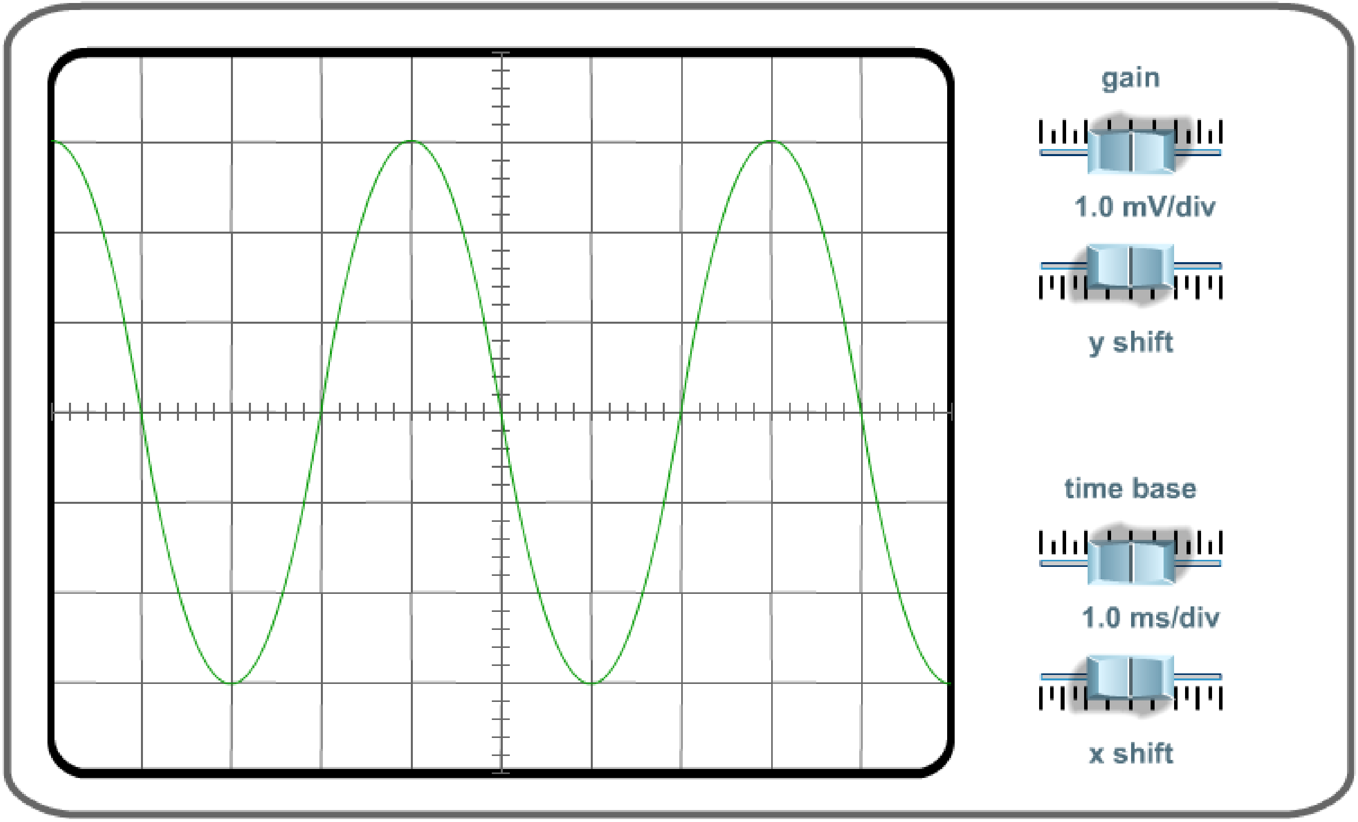


- The Y-plates are connected to the oscilloscope's Y-input.
- This input is usually amplified and when connected to the Y-plates it makes the spot move vertically up and down the screen.
- The Y-sensitivity opposite is set so that the spot moves vertically by one centimetre for a pd of five volts ($5\ V\ cm^{-1}$).
- The trace shown appears when an alternating pd of 16V peak-to-peak and period 7.2 ms is connected to the Y-input with the settings as shown.

NTNU Oscilloscope Simulation

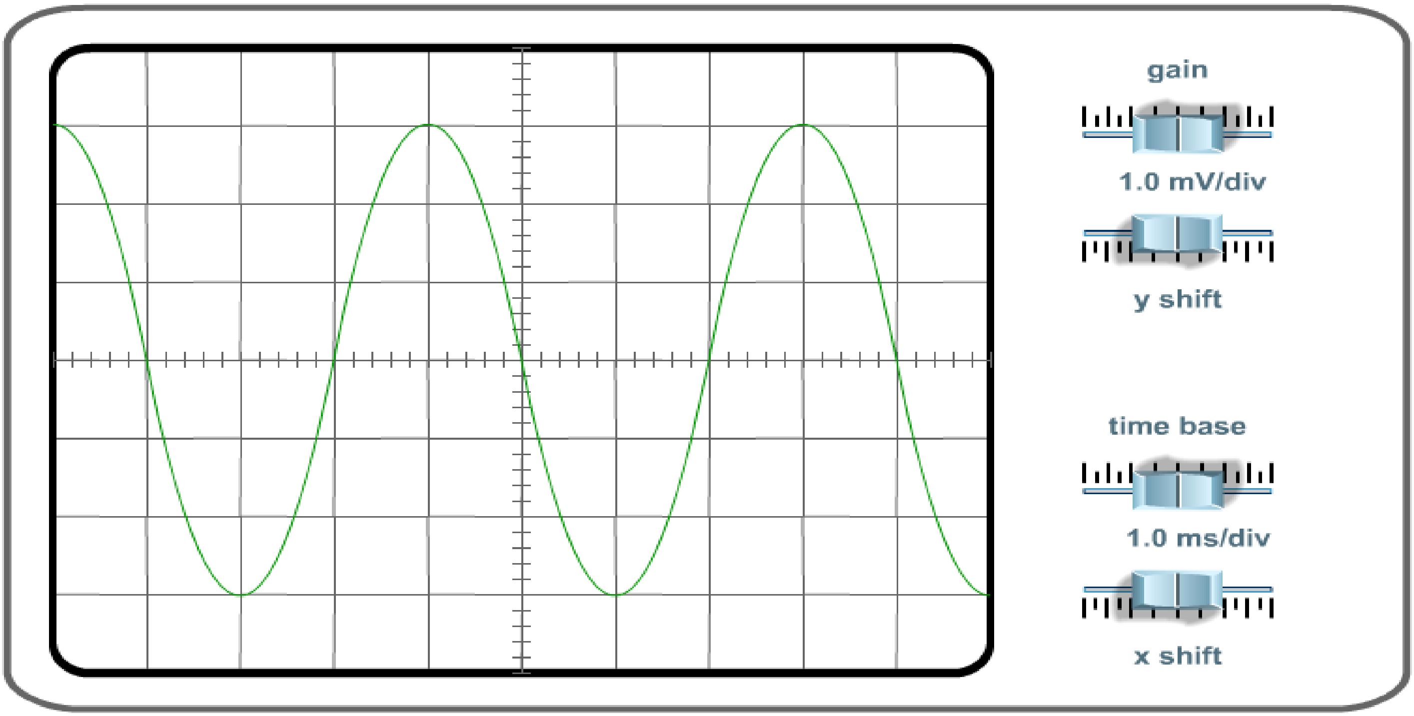
KT Oscilloscope Simulation

Peak Voltage



Peak p.d. = 3 Divisions x 1.0 mV/div = 3.0 mV

Period & Frequency



period = 4.0 divisions x 1.0 ms/div = 4.0 ms
frequency = 1 / period
frequency = 1 / 0.004 s
frequency = 250 Hz

Measuring DC potential difference

All three diagrams below show the trace with the time base on and the Y-gain set at 2V cm^{-1}.

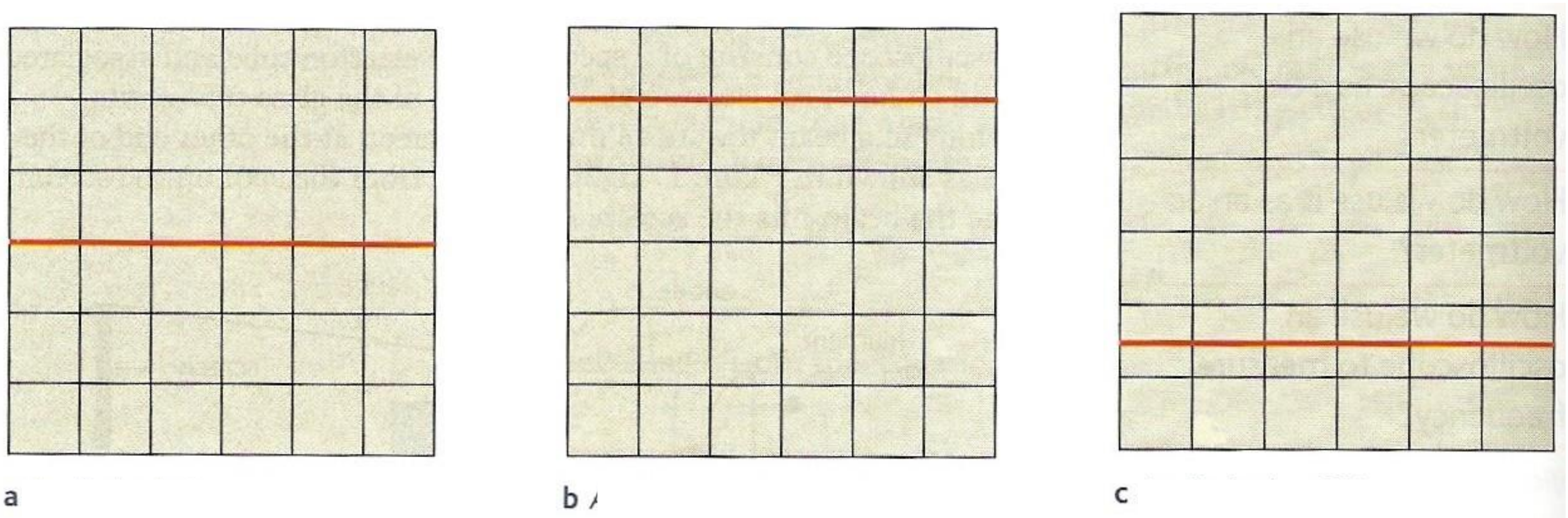
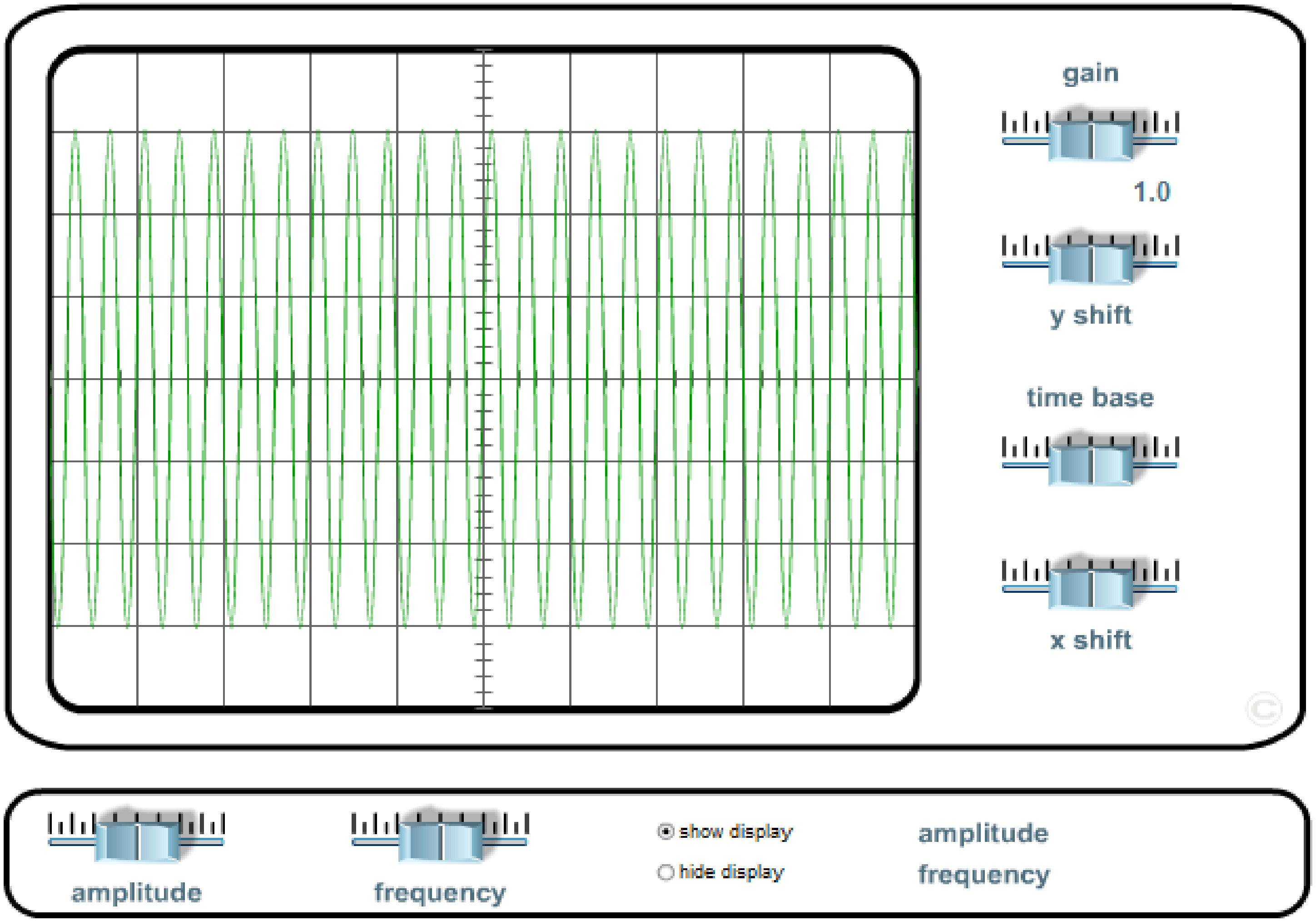


Diagram a shows the trace for pd = 0V.

Diagram b shows the trace for pd = +4V

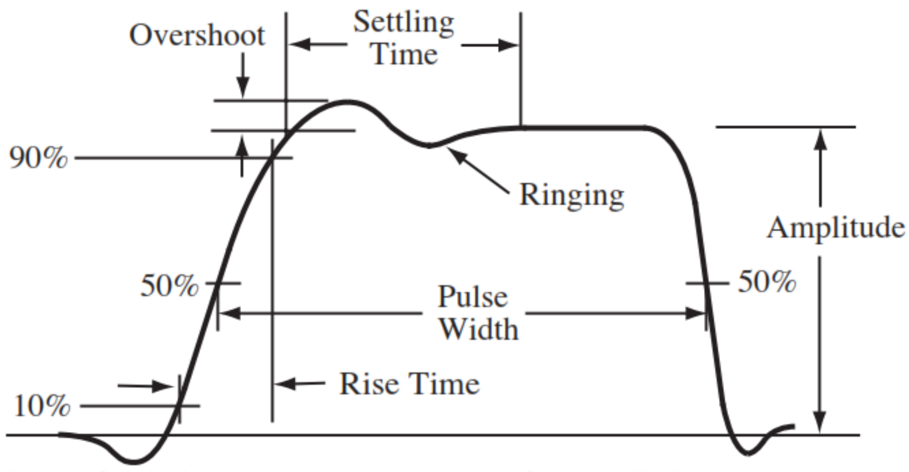
Diagram c shows the trace for pd = -3V.

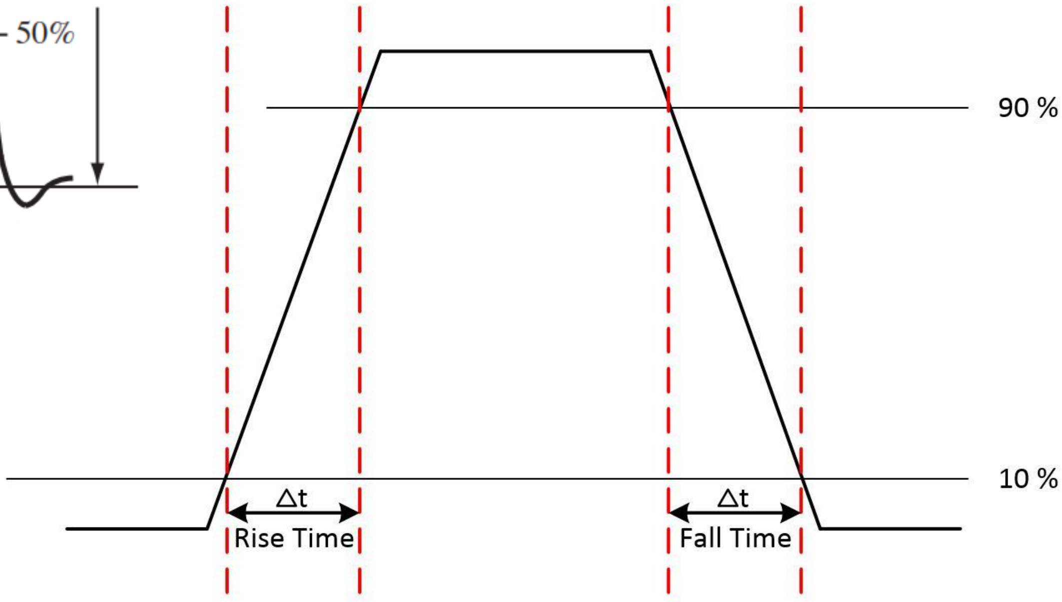
Self Test


gain
1.0
y shift
time base
x shift
amplitude
frequency
show display
hide display
amplitude
frequency

Oscilloscope: Signal parameters

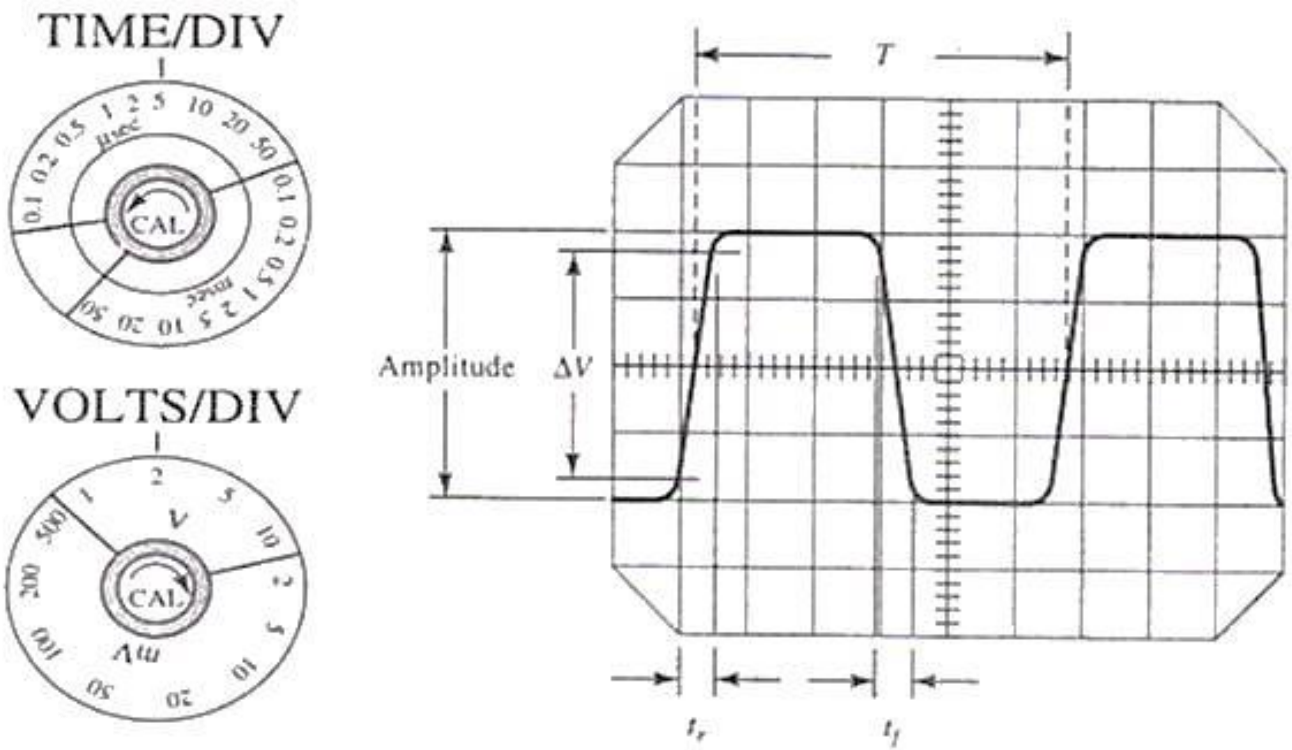
- RISE TIME: Time for the signal to go from 10% to 90% of its peak-to-peak voltage. But the percentage can be changed arbitrarily
- FALL TIME: Similarly, the time for the signal to go from 90% to 10% of its peak-to-peak voltage.





Oscilloscope: Signal parameters

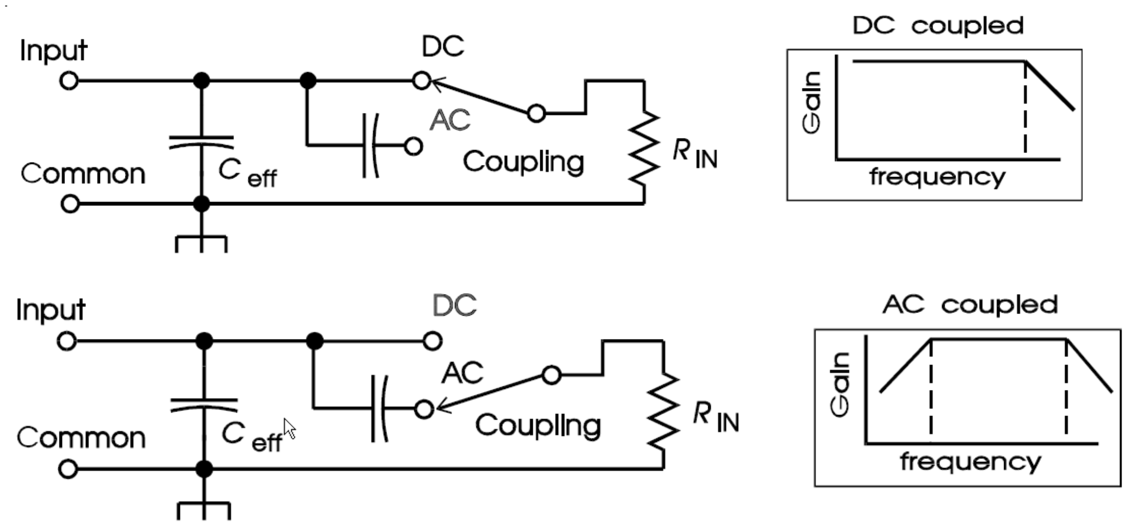
- Determine the pulse amplitude, frequency, rise time and fall time of the waveform in the figure below

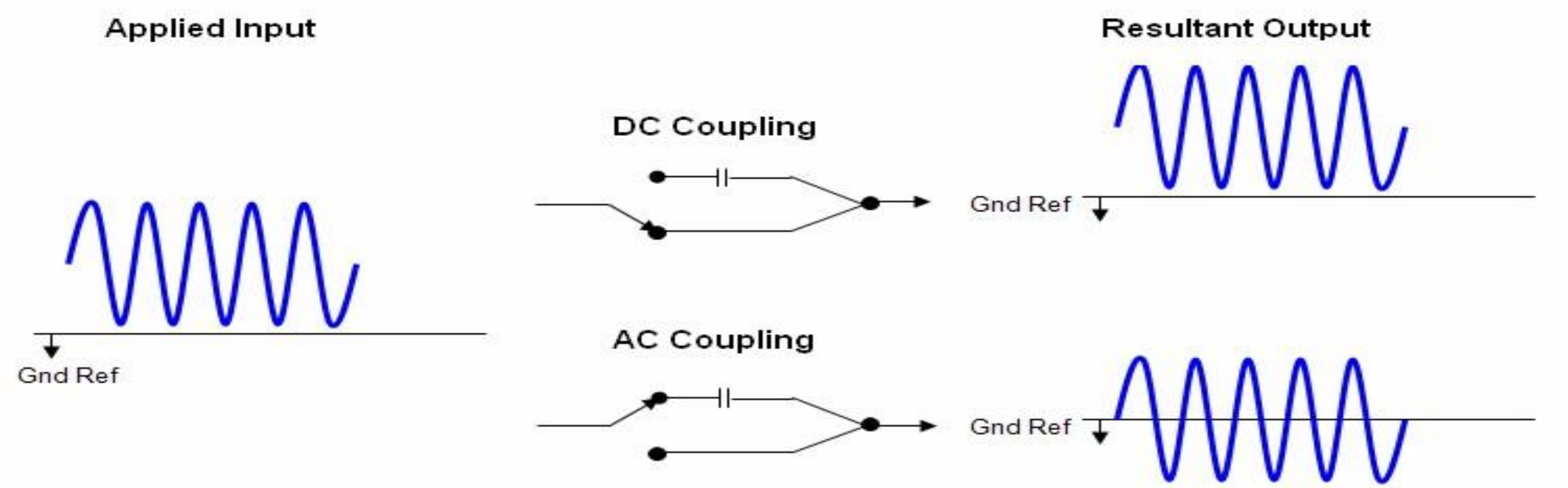


pulse amplitude = 4 x 2 V = 8V
T = 5.6 x 5 μs /div = 28 μs
Frequency, f = 1/T = 1/28 μs = 35.7 kHz
rise time, tr = (0.5) x (5 μs /div) = 2.5 μs

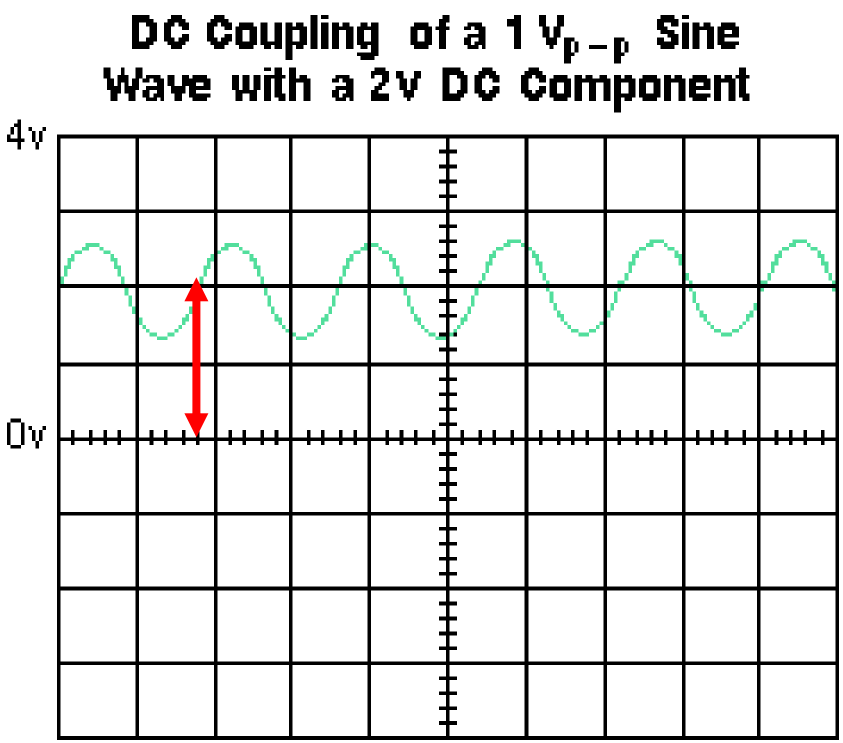
AC & DC Coupling

DC coupling is the most used position on a scope because it allows the scope to display both AC and DC voltage signals present in the circuit. When AC coupling is selected, a capacitor is placed into the meter lead circuit, which effectively blocks all DC voltage signals but allows the AC portion of the signal to pass and be displayed

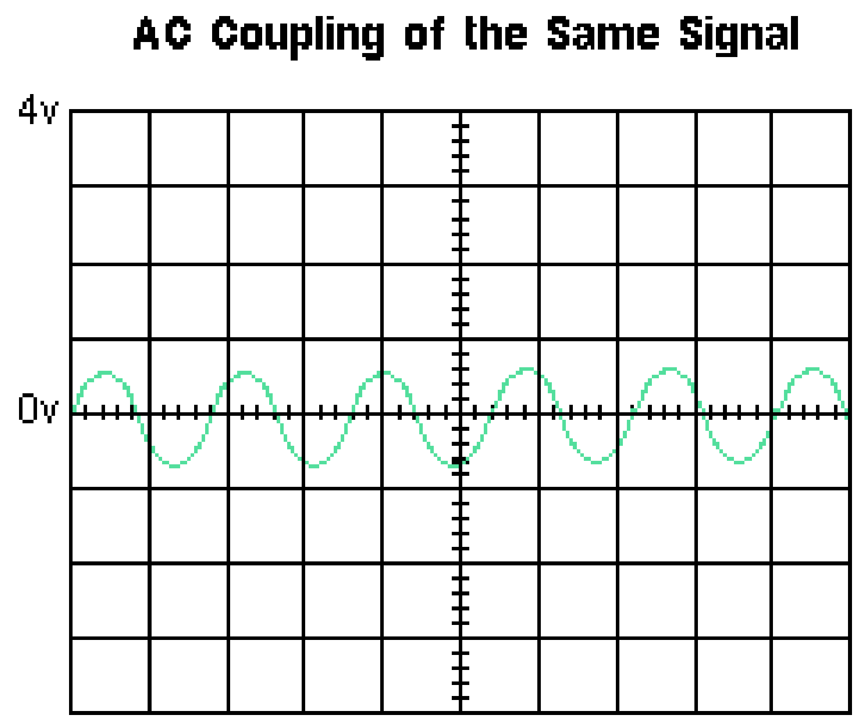




How to check in Oscilloscope



2 V DC offset

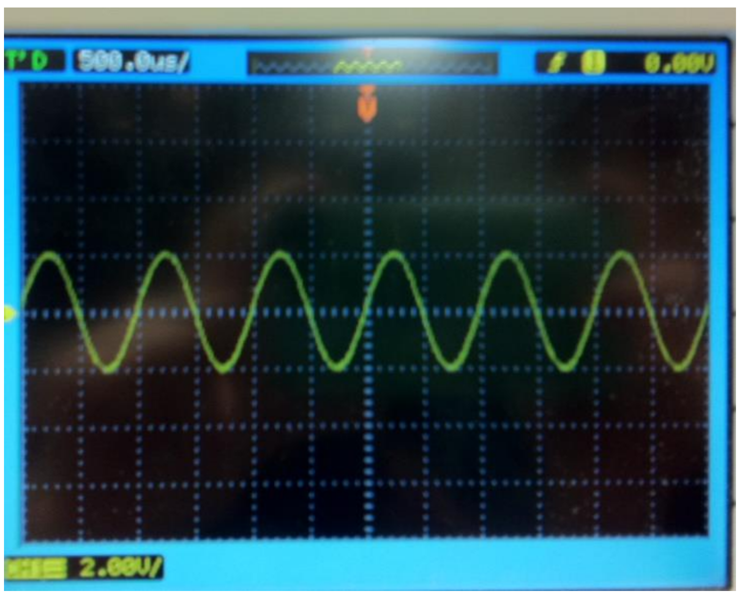


0 V DC offset

- What is the difference between AC and DC coupling?
- When the AC coupling position is selected, a capacitor is placed into the meter lead circuit, which effectively blocks all DC voltage signals, but allows the AC portion of the signal to pass and be displayed.

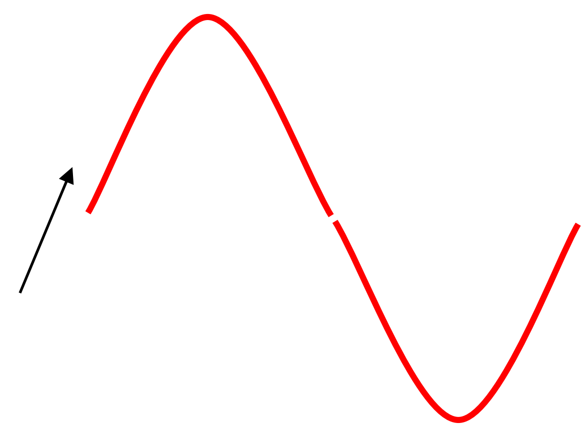
Triggering

- We want to tell the oscilloscope when it is the best time for it to "refresh" the display
- In our wave below, we tell the scope to "trigger" or 'capture' the signal when it is going upward AND hits 2.0Volts



SO, 'trigger' condition is:
When we're

Going up!

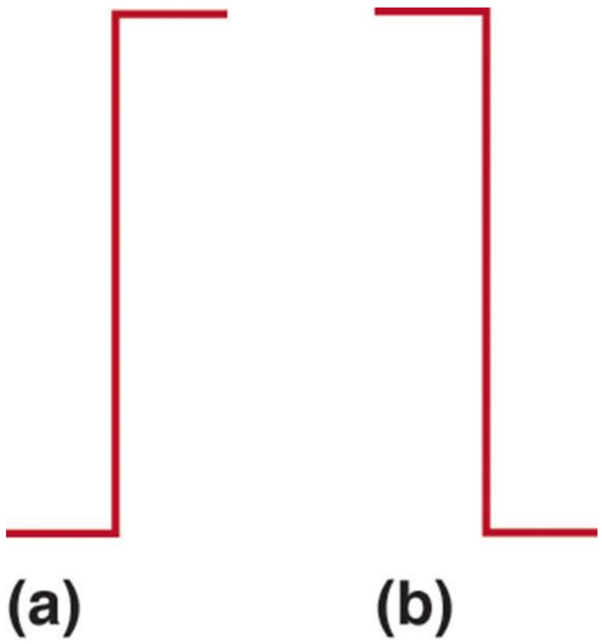


AND

When at 2.0 Volts on our waveform!

TRIGGERS

- External Trigger
  - An external trigger is when the waveform starts when a signal is received from another external source, rather than from the signal pickup lead.
- Trigger Level
  - Trigger level is the voltage that must be detected by the scope before the pattern is displayed.
- Trigger Slope
  - The trigger slope is the voltage direction that a waveform must have in order to start the display.



(a) A symbol for a positive trigger—a trigger occurs at a rising (positive) edge of the signal (waveform). (b) A symbol for a negative trigger—a trigger occurs at a falling (negative) edge of the signal (waveform)

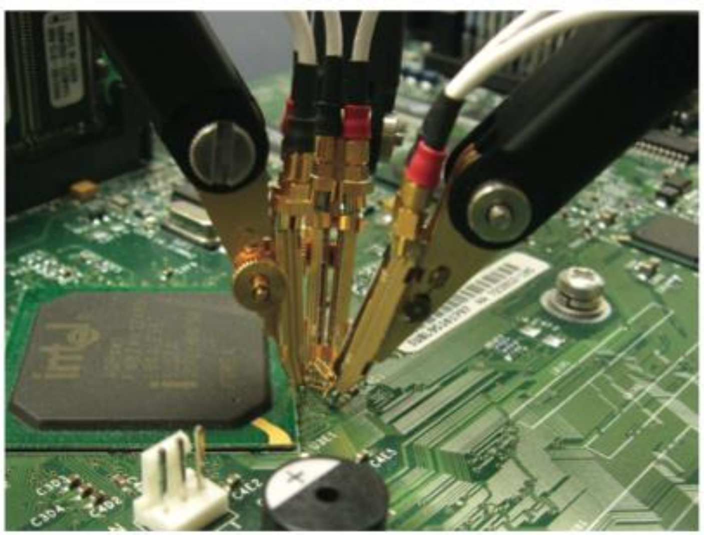
Probe types

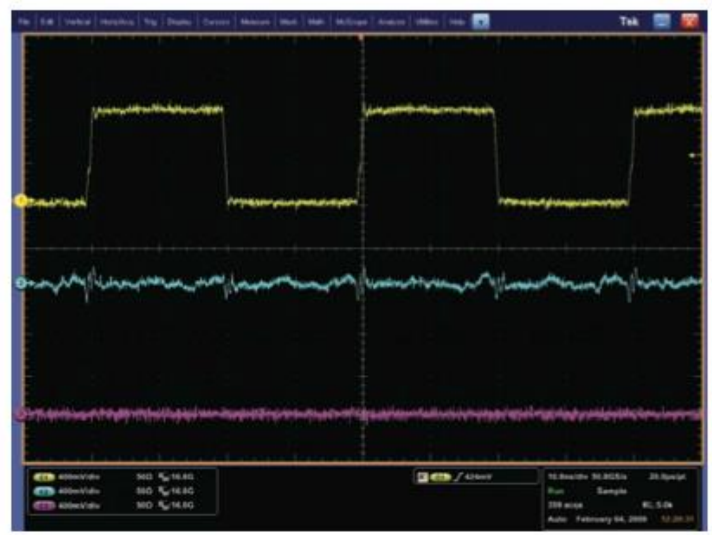
Passive Probes

Active & Differential Probes

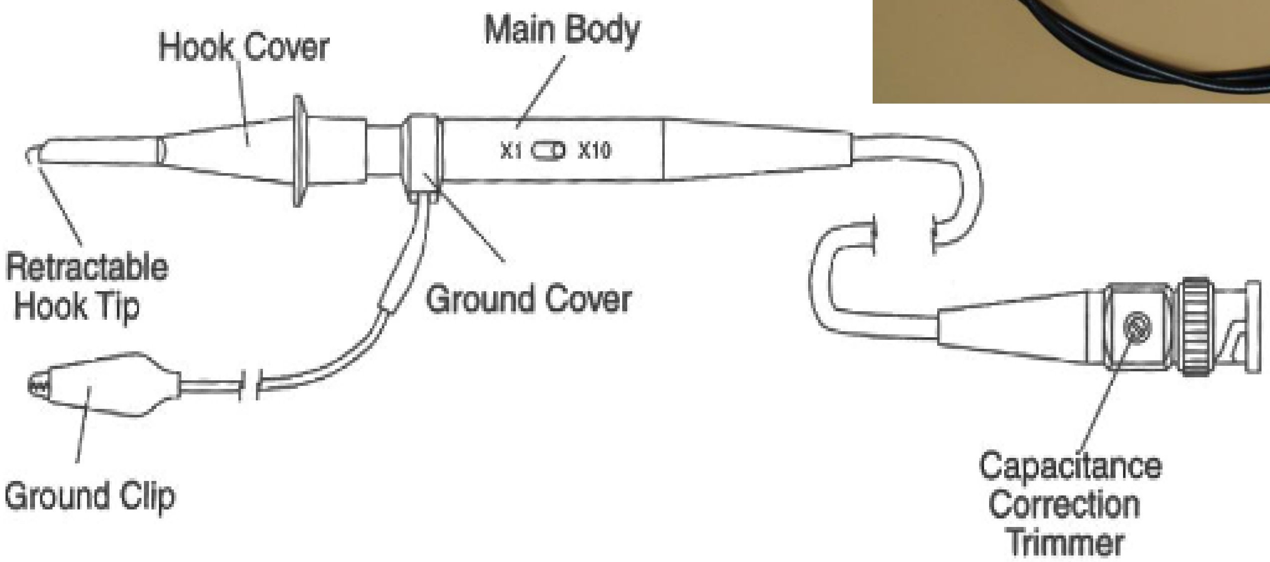
Logic Probes

Specialty Probes



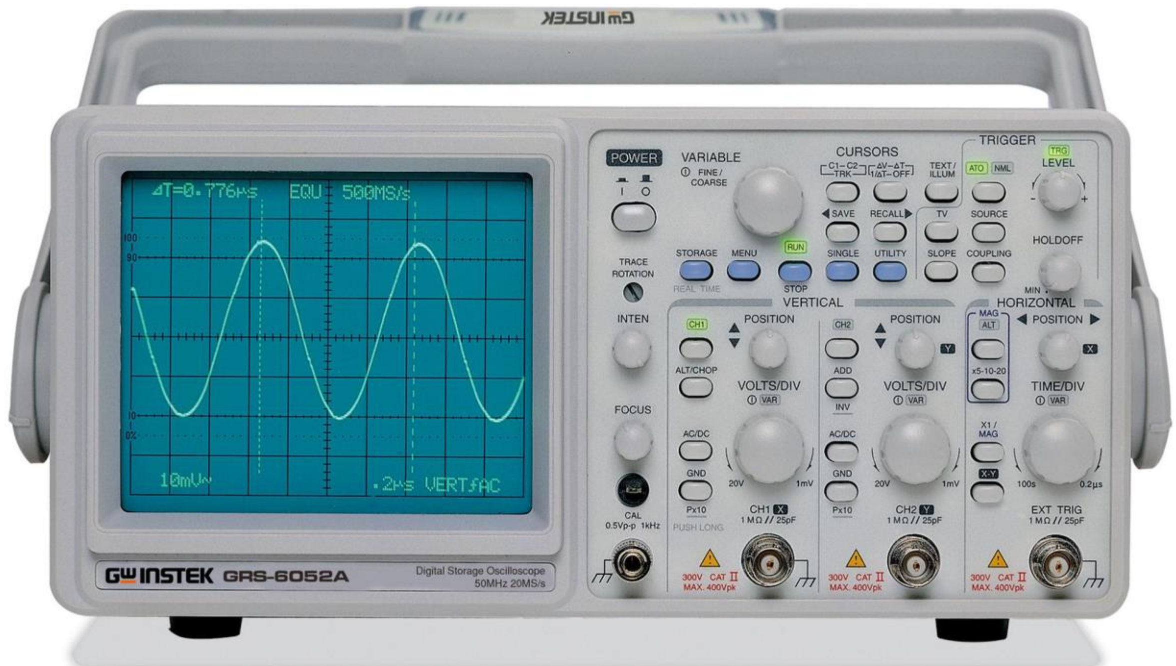


- We usually use three types of connecters in our lab.
  - BNC
  - Banana
  - Mini-Grabber

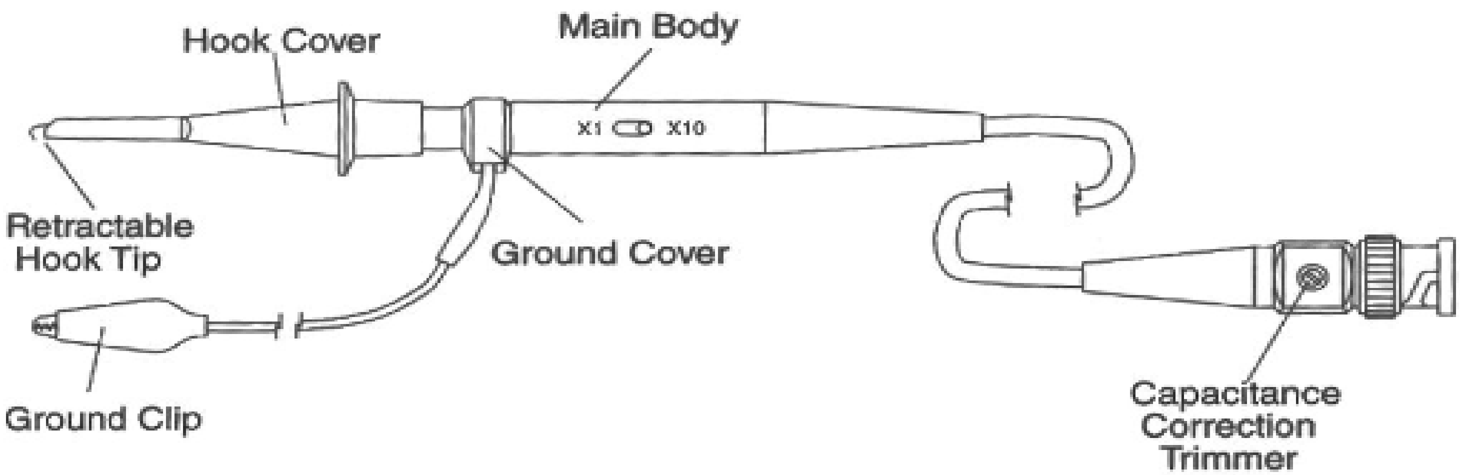


Probes

- Test leads are likely to pick up interference or noise, so they are not suitable for low level signals. Furthermore, the leads have a high inductance, so they are <u>not suitable for high frequencies</u>.



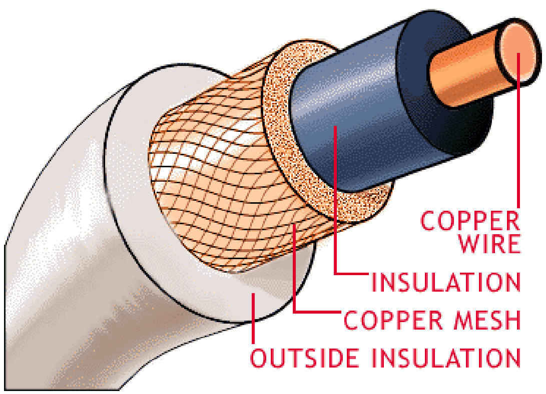
Probes



- Recall that impedance is opposition to current flow in an alternating current circuit. It is made up Resistance (R) + Reactance (X).
- The probe provides a high input impedance, proper shielding from noise, and capacitive correction.
- Ground clip should be used to help reduce "electrical noise" on the signal.

Solution

So to solve this, we use coaxial cables



The coaxial cable consists of an insulated central conductor surrounded by a braided circular conductor which is covered by an outer layer of insulation

The central conductor carries the input signal, and the circular conductor is grounded so that *it acts as a screen to help prevent unwanted signals being picked up by the oscilloscope input.*

- Using the coaxial cable, oscilloscope probes may be categorized into two main types, and they can fall into one of two main areas:

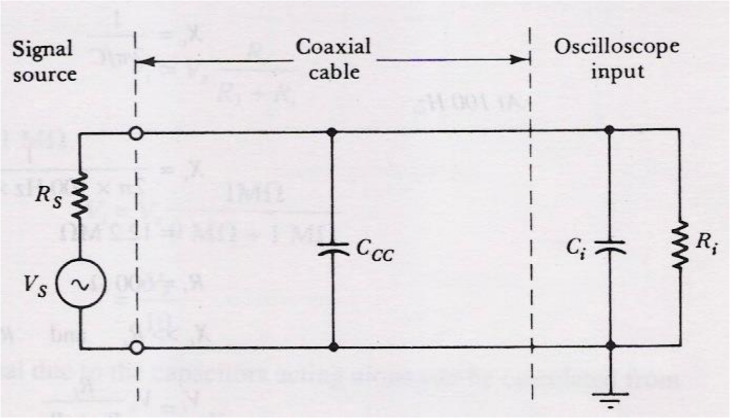
- *Passive oscilloscope probes:*
- This type of probe is the one that is in most widespread use.
- It only includes *passive elements* and may provide 1:1, i.e. straight through connectivity from the point under test, to the scope input.
- Other types may provide a defined *degree of attenuation.*

1X scope probe (1: 1 attenuation ratio)

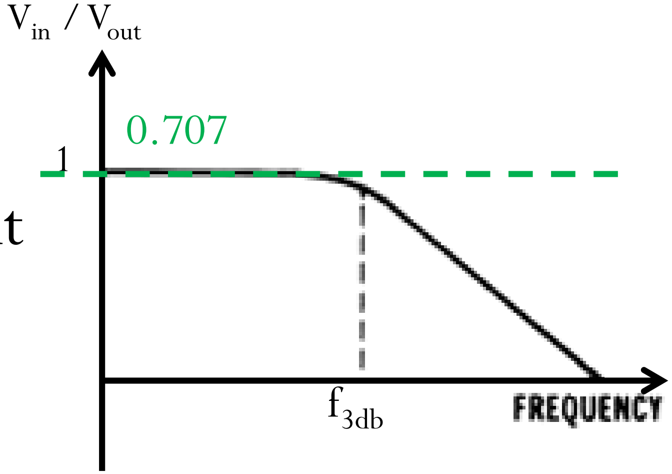
- The input impedance of the oscilloscope at the front panel is typically R_i in parallel with C_i.

- The coaxial cable connecting the probe to the oscilloscope has a capacitance (C_{cc}) (typically 90 -100 pF) which can <u>overload a high-frequency signal source.</u>

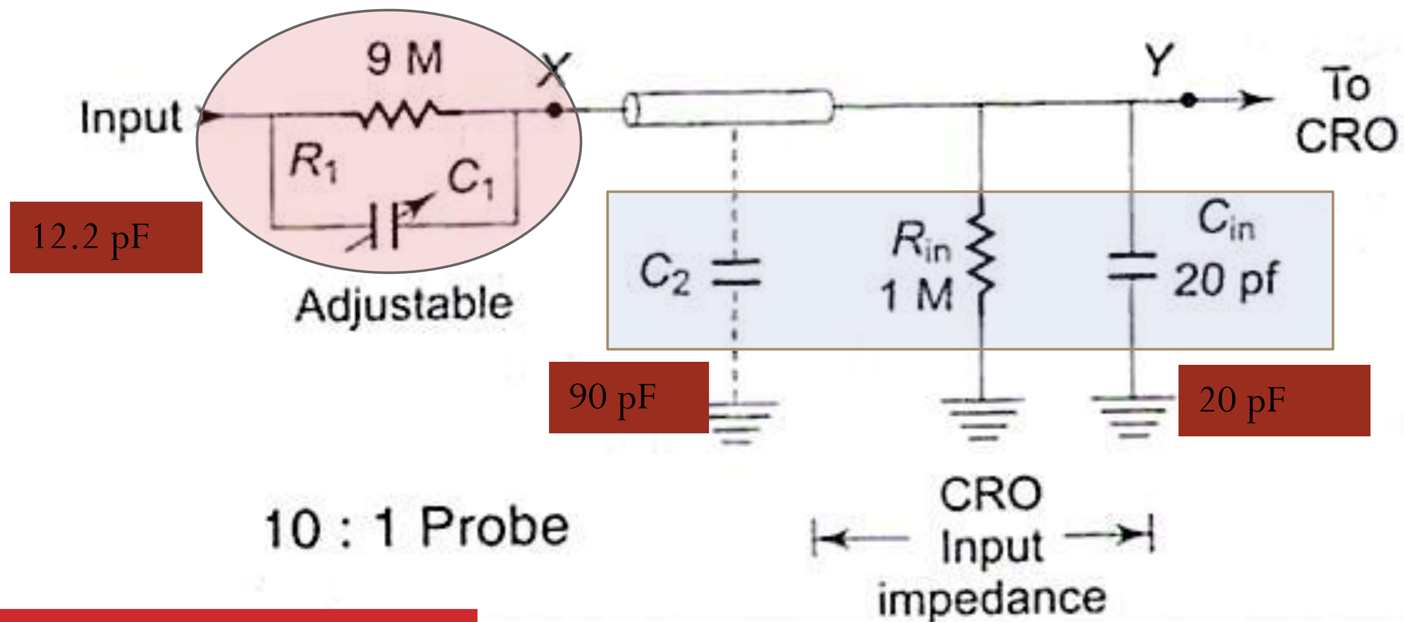
- Hence, this probe is suitable to be used for signals from 6 MHz to 10 MHz



- At high frequency or high impedance signal, loading effect occurs.
- Basically what happens is that the output is no longer a correct representation of the input waveform



Hence, the 10X scope probe is introduced in order to control the attenuation factor.

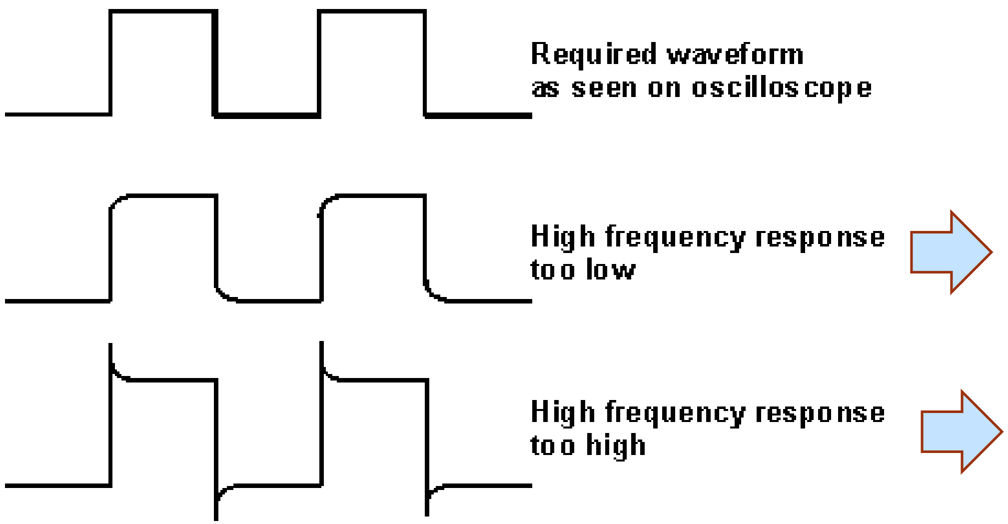


Time constant,
$RC = C_1 \times 9\ M$
$1.1 \times 10^{-4} = C_1 \times 9\ M$
$C_1 = 12.2\ pF$

Time constant,
$RC = (20 + 90)\ pF \times 1\ M$
$RC = 1.1 \times 10^{-4} = 110\ ms$

Calibration

- It is important that every probe be correctly adjusted when it is first connected for use with a particular oscilloscope - CALIBRATION



Value of adjustable capacitor is too low

Value of adjustable capacitor is too high

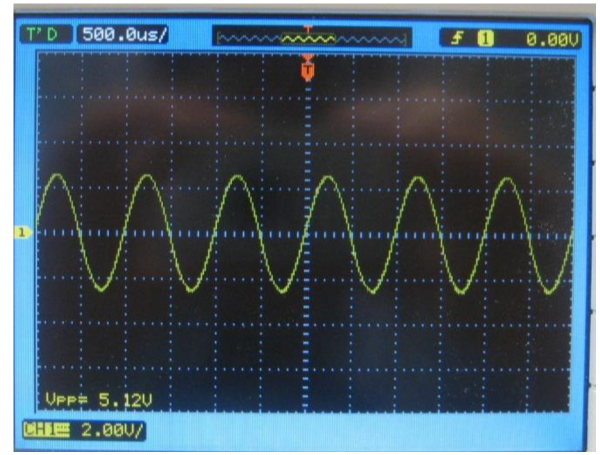
It is generally accepted that for general-purpose mid-to-low-frequency (less than around 500-MHz) measurements, the 10:1 probe is the most suitable option.

Oscilloscope: Some Handson

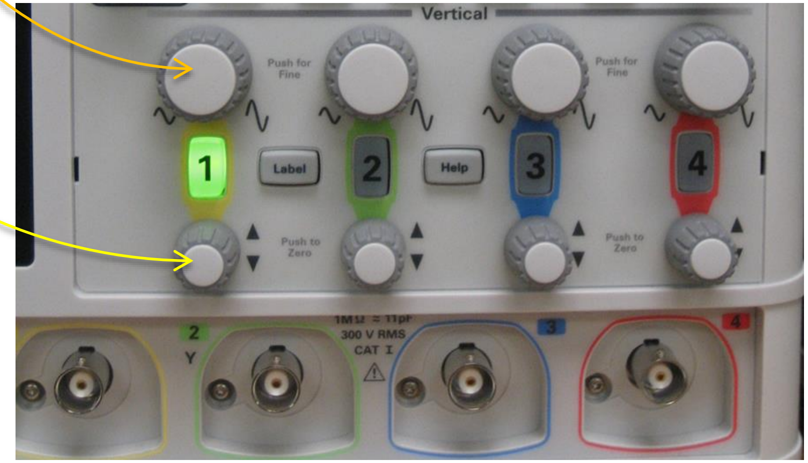
- What must the X-Axis represent?
- What must the Y-Axis represent?

Making the Connection

- Set the Volts/Division to 2. Turn the dial CCW to increase and CW to decrease.
- Use the Position dial to raise or lower the image until it is centered on the screen.

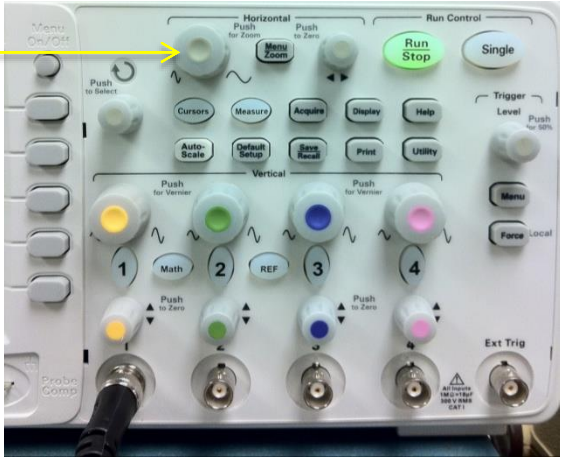


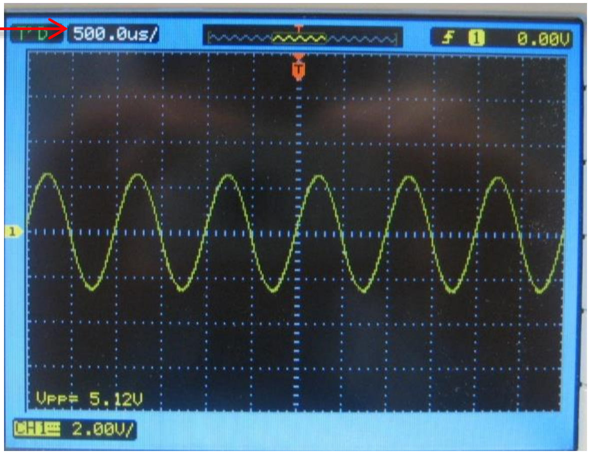
- Set the Volts/Division to 2. Turn the dial CCW to increase and CW to decrease.
- Use the Position dial to raise or lower the image until it is centered on the screen.



Making the Connection

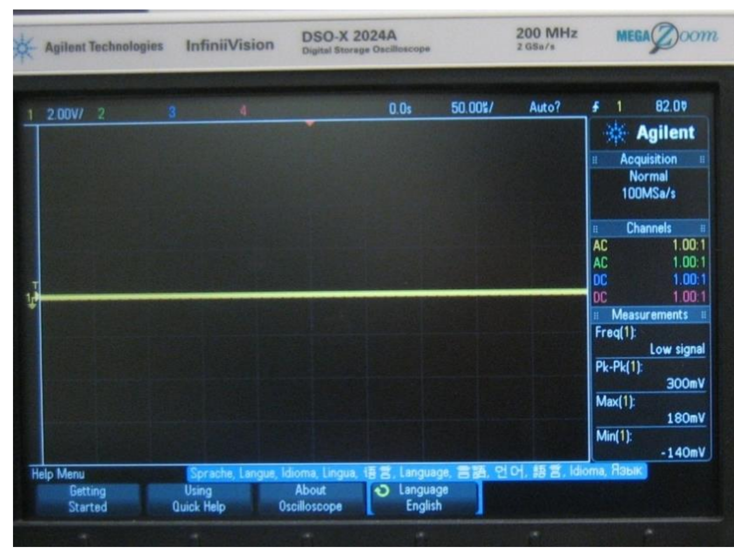
- The Time/Division dial corresponds to the amount of time in each division along the X-direction. Turn CCW to increase and CW to decrease.
- Set this dial to 0.5ms.
- With 10 divisions per screen, what is the total time span represented?





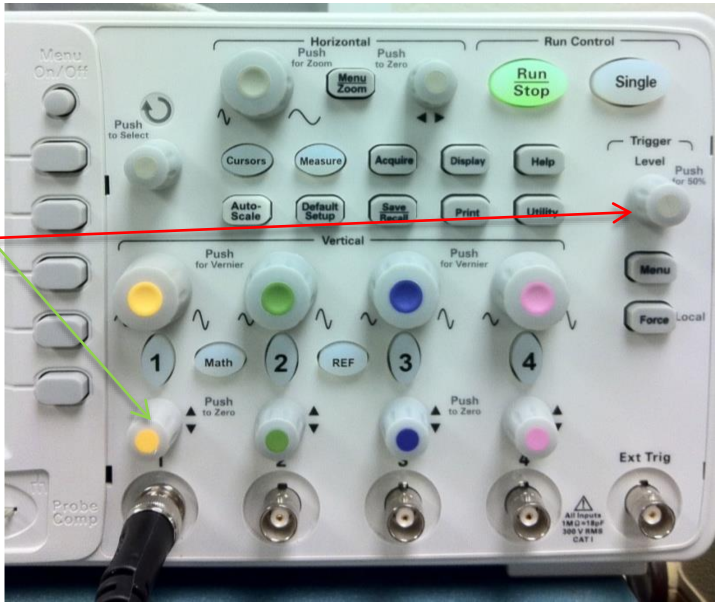
Making the Connection

- The Time/Division dial corresponds to the amount of time in each division along the X-direction. Turn CCW to increase and CW to decrease.
- Set this dial to 0.5ms.
- With 10 divisions per screen, what is the total time span represented?



Triggering: Setup

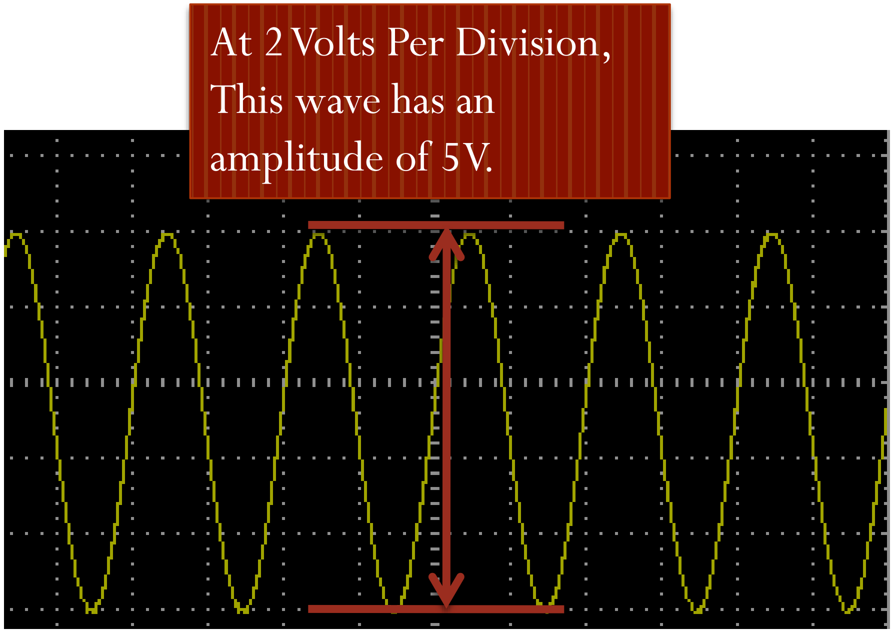
- If it isn't already, set the Trigger Source to CH1. The active channel should be lit green.
- Push the Trigger knob to auto set.
- In some cases, this is enough to produce a clear output, but often we will need to adjust the Trigger Level.
- If the output is unstable, turn the triggering knob until it stabilizes.



- Press "Trigger" on the O-scope
- Using the softkeys, select edge triggering, source 1, and a rising slope
- You can then use the trigger knob to manually adjust the triggering level. (Ask me if this doesn't make sense)

Measuring the Voltage

- Using the CH1 Position Dial, move the wave until the bottom lines up with one of the division lines.
- Measure the number of divisions from the bottom to the top.

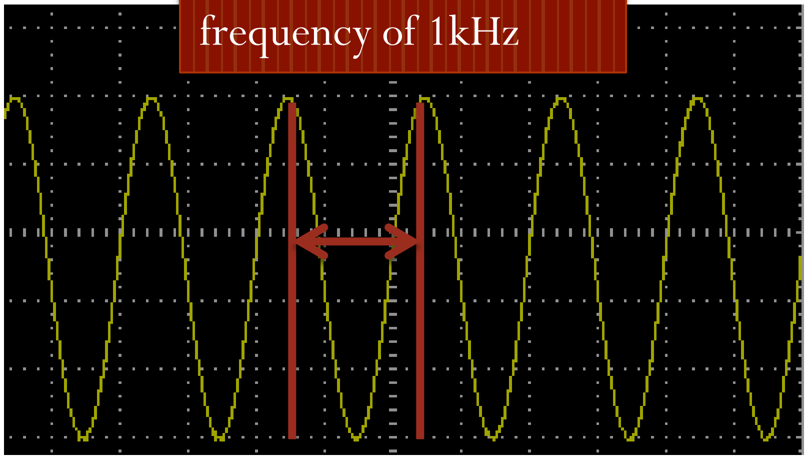


Peak to Peak Voltage = (Volts/Division) *(# of Division)
Amplitude = (1/2) * Peak to Peak Voltage

Measuring the Frequency

- Position to wave so that the beginning lines up with one of the vertical division markers.
- Count the number of divisions until the beginning of the next wave.

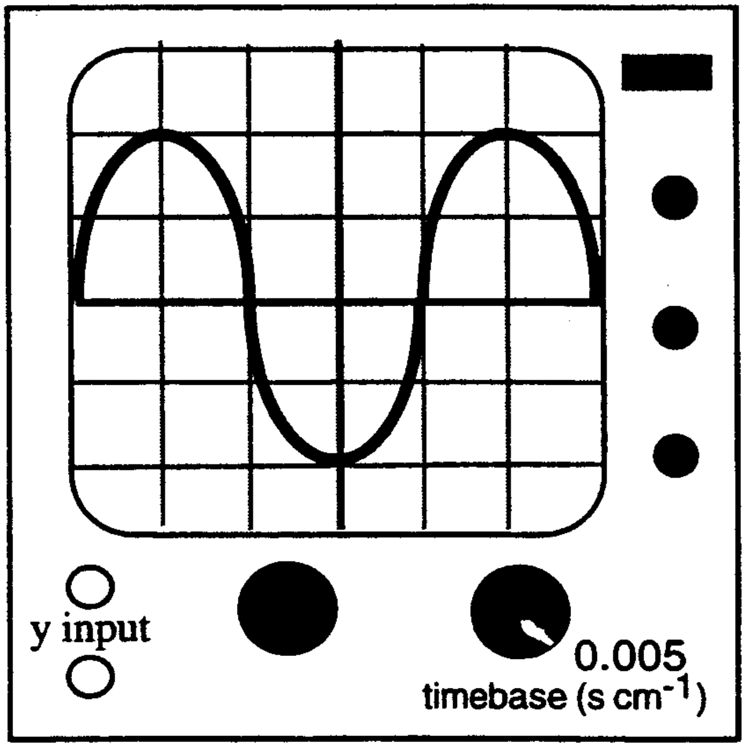
With 0.5ms/division, this wave has a frequency of 1kHz



Period = (Time/Division) *(# of Division)
Frequency = 1/Period

An oscilloscope can be used to find the frequency of an a.c. supply.

Example 1



The timebase setting on the oscilloscope is set to 0·005 s cm^{-1}. This means the dot on the oscilloscope takes 0·005 s to travel each centimetre to the right across the screen.

Each cycle (1 wave) is completed in 4 cm so the total time for 1 cycle is; $0{\cdot}005 \times 4 = 0{\cdot}020$ s.

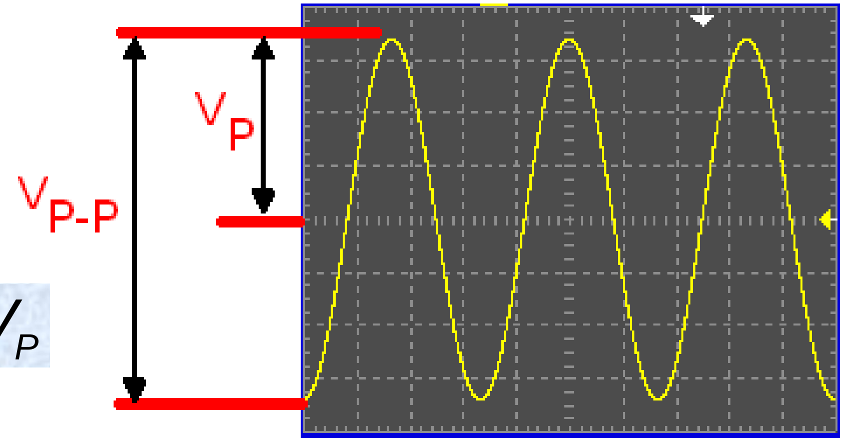
This time is called the period.

$\Rightarrow \quad f = 1/T$

$\Rightarrow \quad f = 1/0{\cdot}02$

$\Rightarrow \quad f = 50$ Hz

Oscilloscope: Amplitude

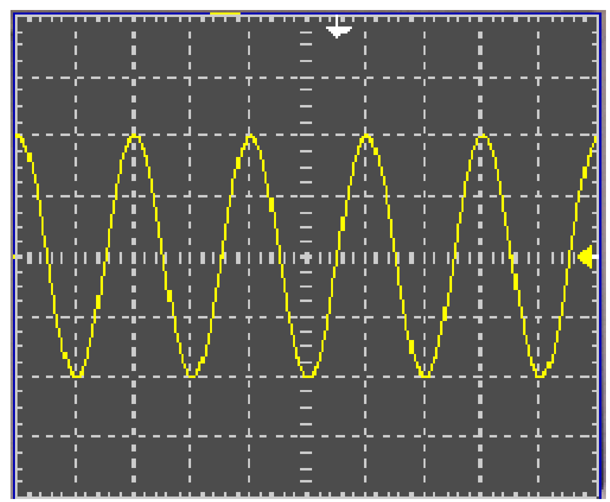


$$V_{RMS} = 0.707 V_P \qquad V_{P-P} = 2 x V_P$$

$$5\frac{V}{Div}$$

$$2\ Div\ x\ \frac{5V}{Div} = 10Vp$$

$$10Vp\ or\ 20Vp - p$$

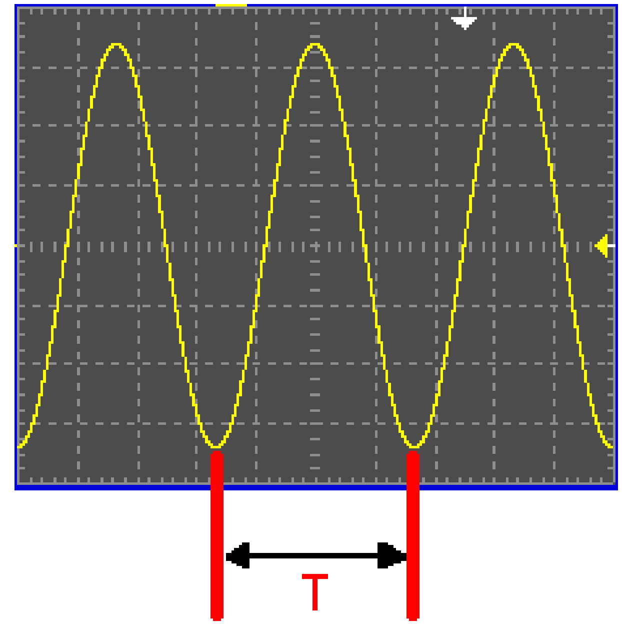


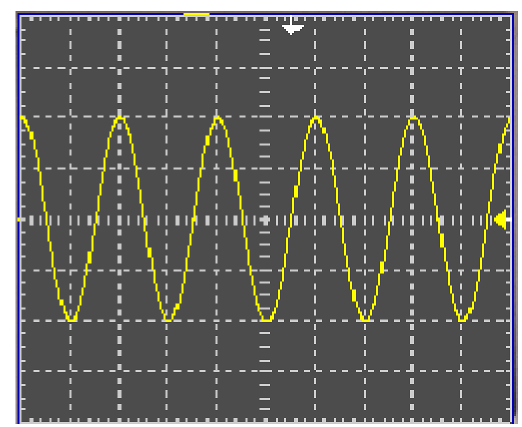
Oscilloscope: Frequency

- **Frequency is the number of cycles per second**
- **T = time period in seconds**

$$Frequency = \frac{1}{\text{Period of the waveform}}$$

$$f(Hz) = \frac{1}{T(s)}$$





$$1\frac{mS}{Div}$$

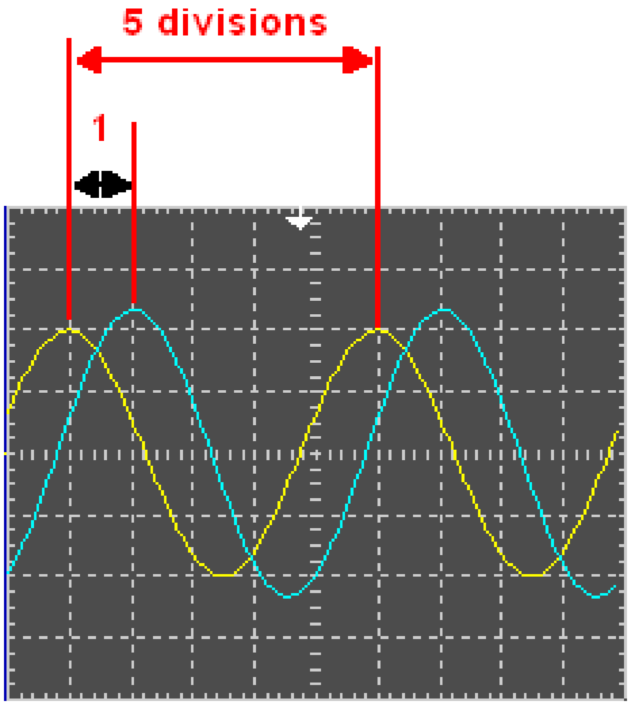
$$Period = 2\,div\ x\ \frac{1mS}{Div} = 2\,mS \qquad Frequency = \frac{1}{Period} = \frac{1}{2\,mS} = 500\,Hz$$

Oscilloscope: Phase Shift

$$\theta° = \frac{\Delta\ divisions}{Total\ \ divisions}\, x\, 360°$$

$$\theta° = \frac{1\, divisions}{5\ divisions}\, x\, 360°$$

$$\theta° = 72°$$



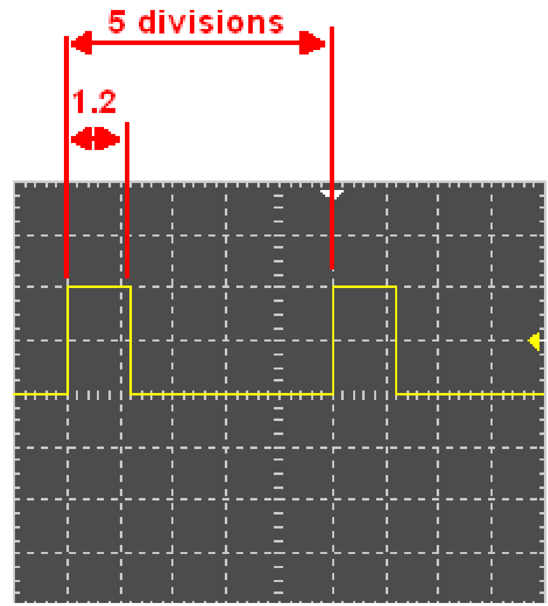
Note: a full cycle = 360°

Oscilloscope: Duty Cycle

$$\%D.C. = \frac{\text{divisions "On"}}{\text{Total divisions}} x100$$

$$\%D.C. = \frac{1.2 \text{ divisions}}{5 \text{ divisions}} x100$$

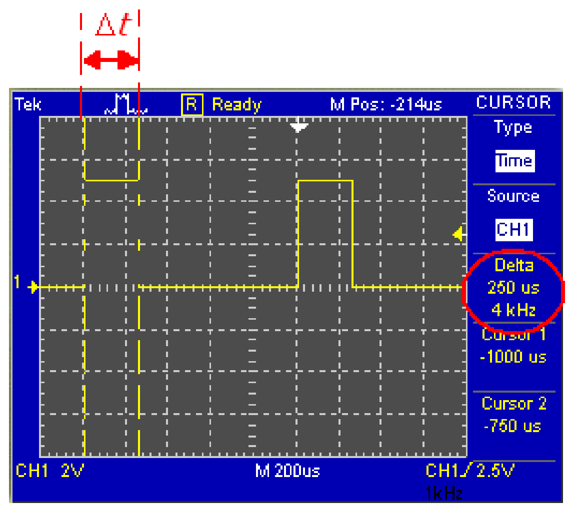
$$Duty\ Cycle = 24\%$$

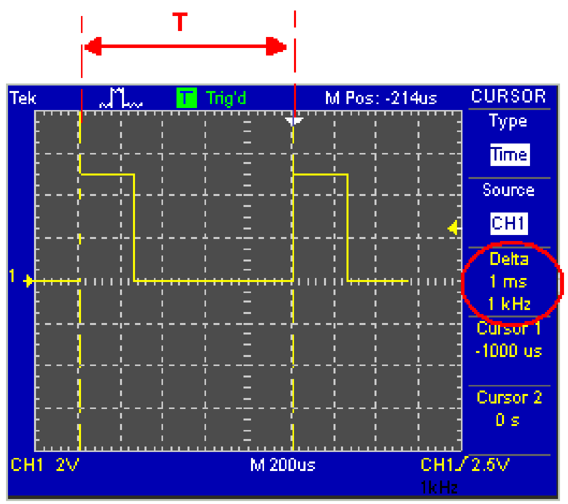


$$\%D.C. = \frac{\Delta t}{Period(T)} x100$$

$$\%D.C. = \frac{250\ \mu S}{1mS} x100$$

$$Duty\ Cycle = 25\%$$



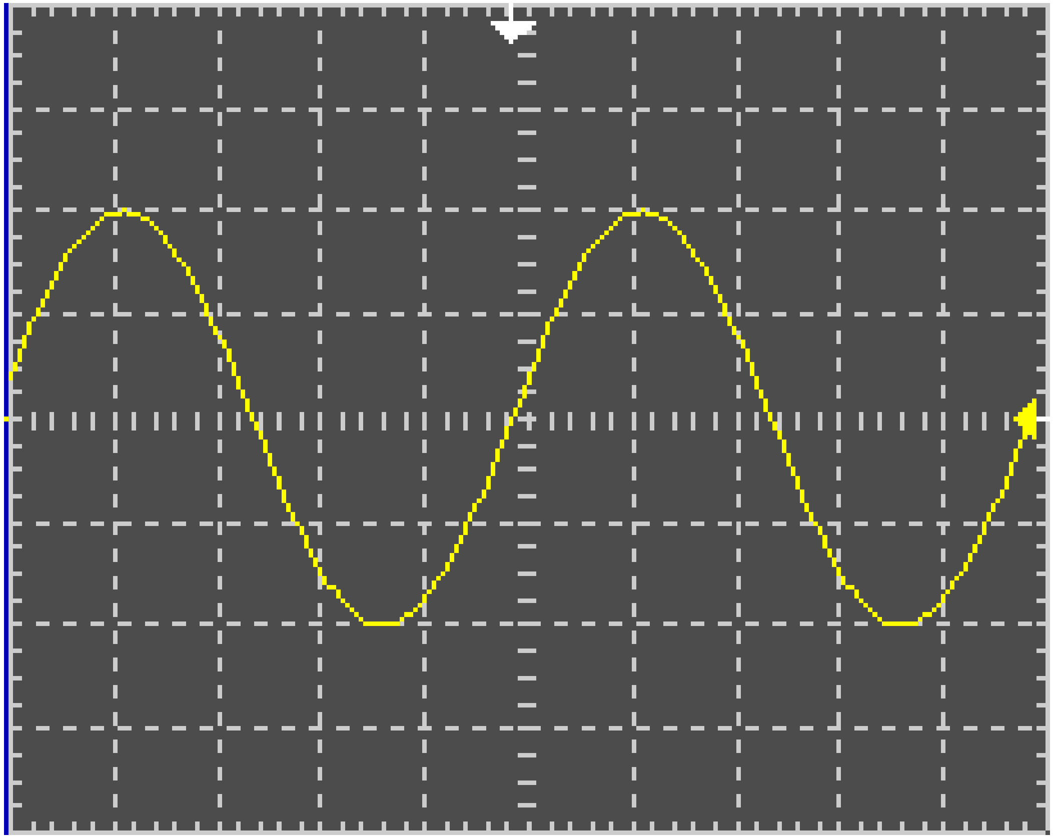


Oscilloscope: Task-1

- **Determine the amplitude of the signal**

Oscilloscope Settings

100 mV/div, 200 uS/div

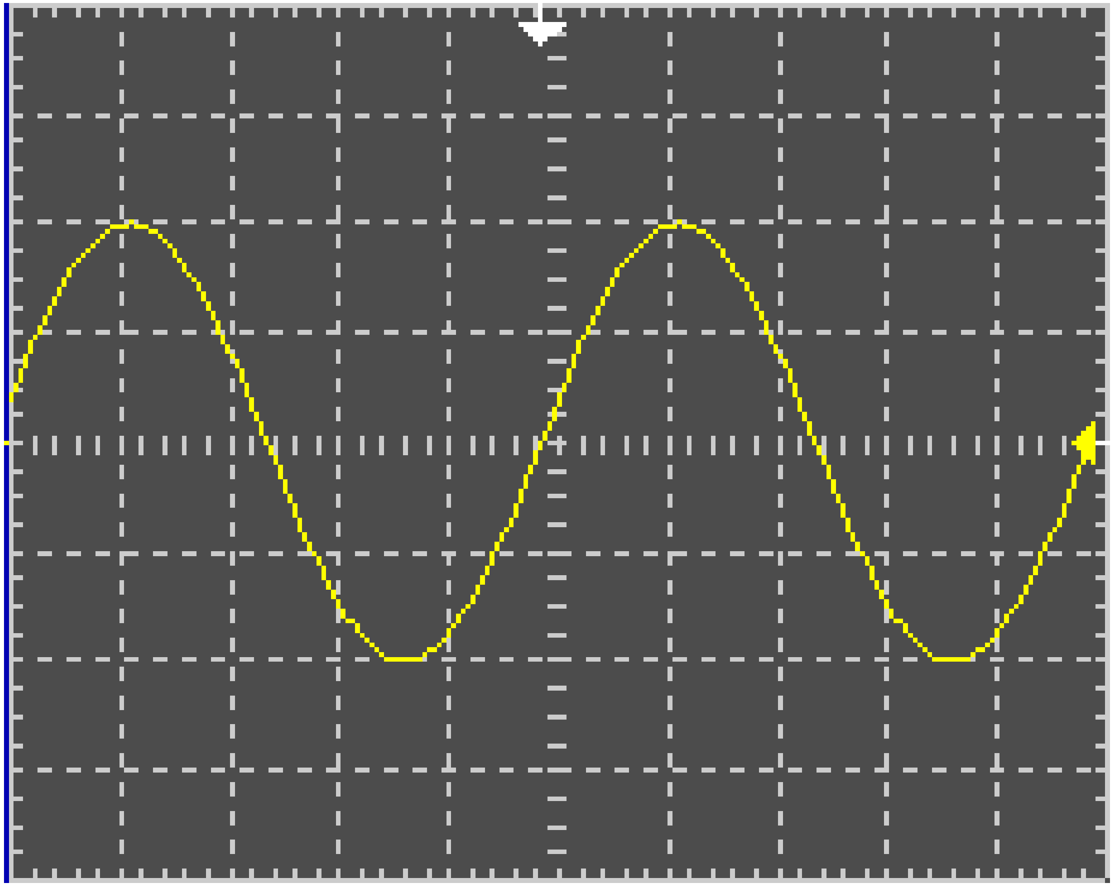


Oscilloscope: Task-2

- **Determine the Period of the signal**

Oscilloscope Settings

5 V/div,   200 uS/div

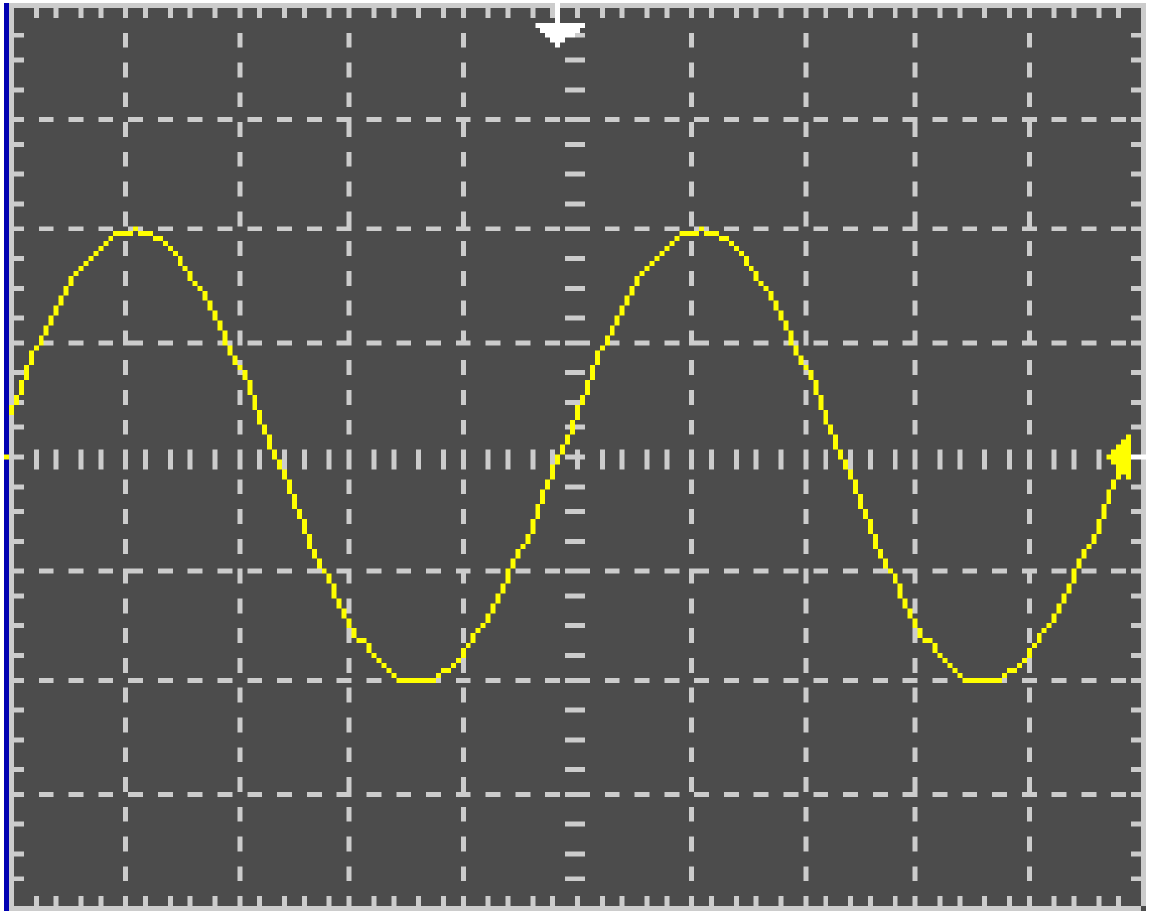


Oscilloscope: Task-3

- **Determine the Frequency of the signal**

Oscilloscope Settings

5 V/div,   200 uS/div



Oscilloscope: Task-4

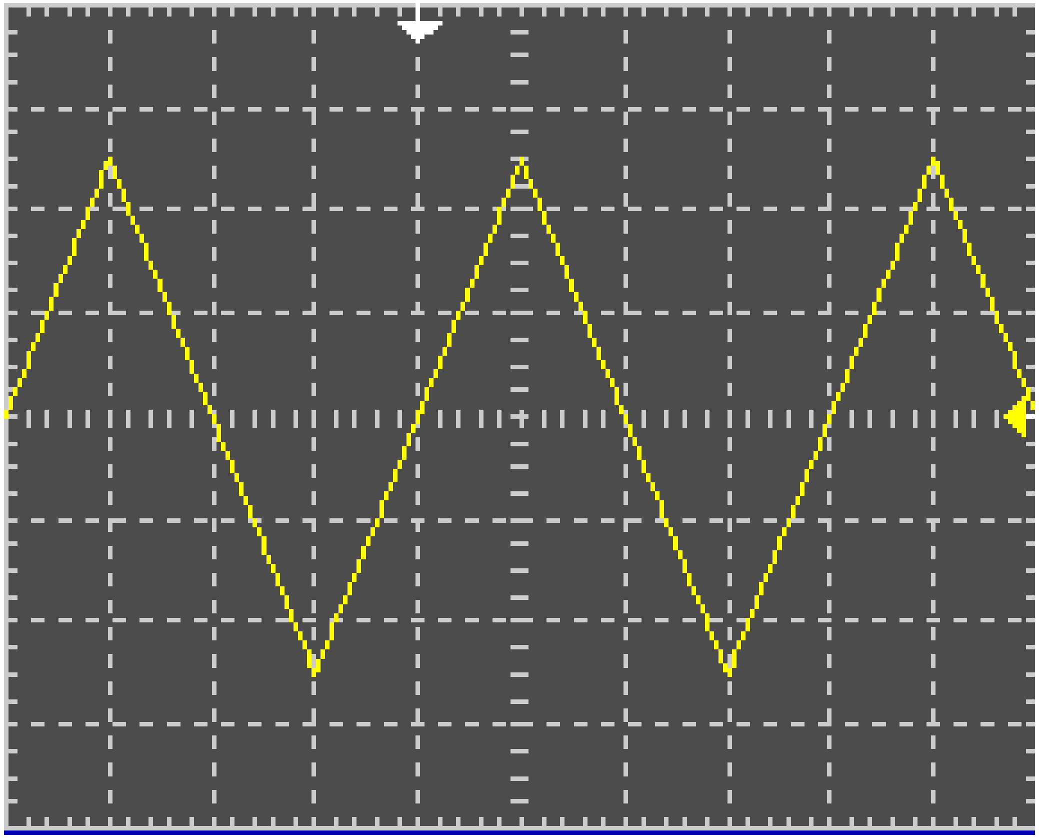
- Determine the amplitude of the signal

Oscilloscope Settings

2 V/div, 500 uS/div

$$2.5\ div\ x \frac{2V}{div} = 5Vp$$

$$2\,x\,5Vp = 10Vp - p$$



Oscilloscope: Task-5

- **Determine the Period of the signal**

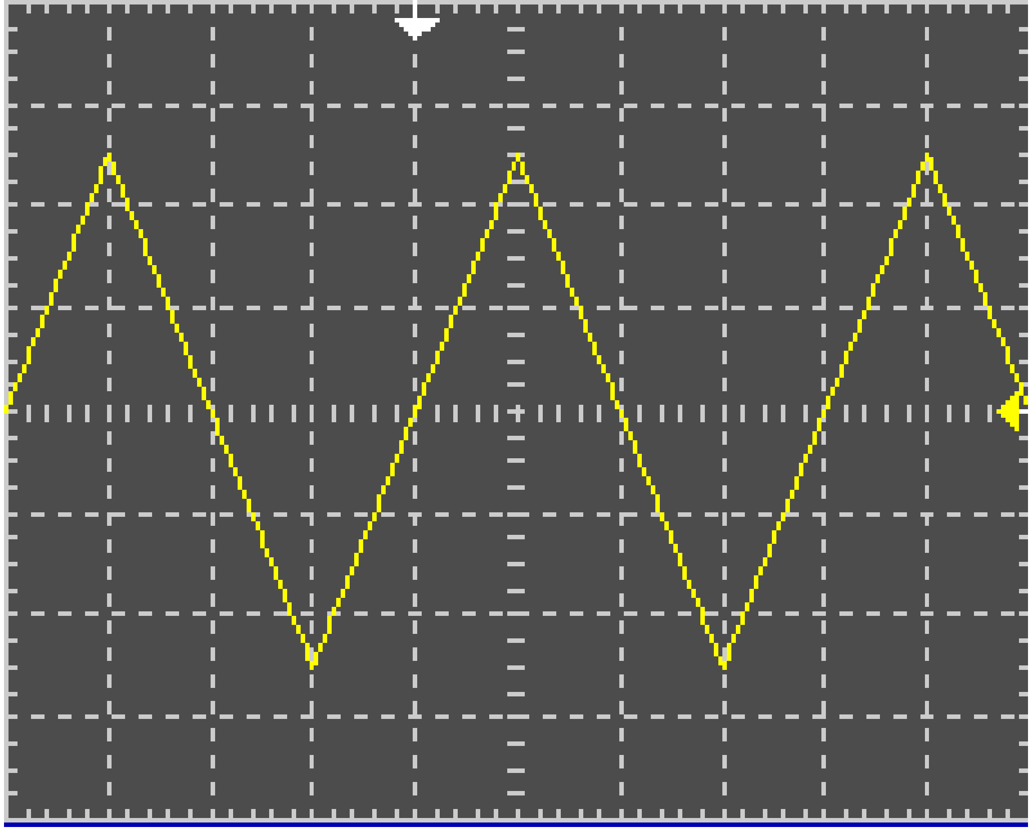
Oscilloscope Settings

2 V/div, 500 uS/div

Answer:

$$4\ div\ x \frac{500\ \mu S}{div} = 2000\ \mu S$$

$$2000\ \mu S\ = 2\, mS$$



Oscilloscope: Task-6

- **Determine the Frequency of the signal**

Oscilloscope Settings

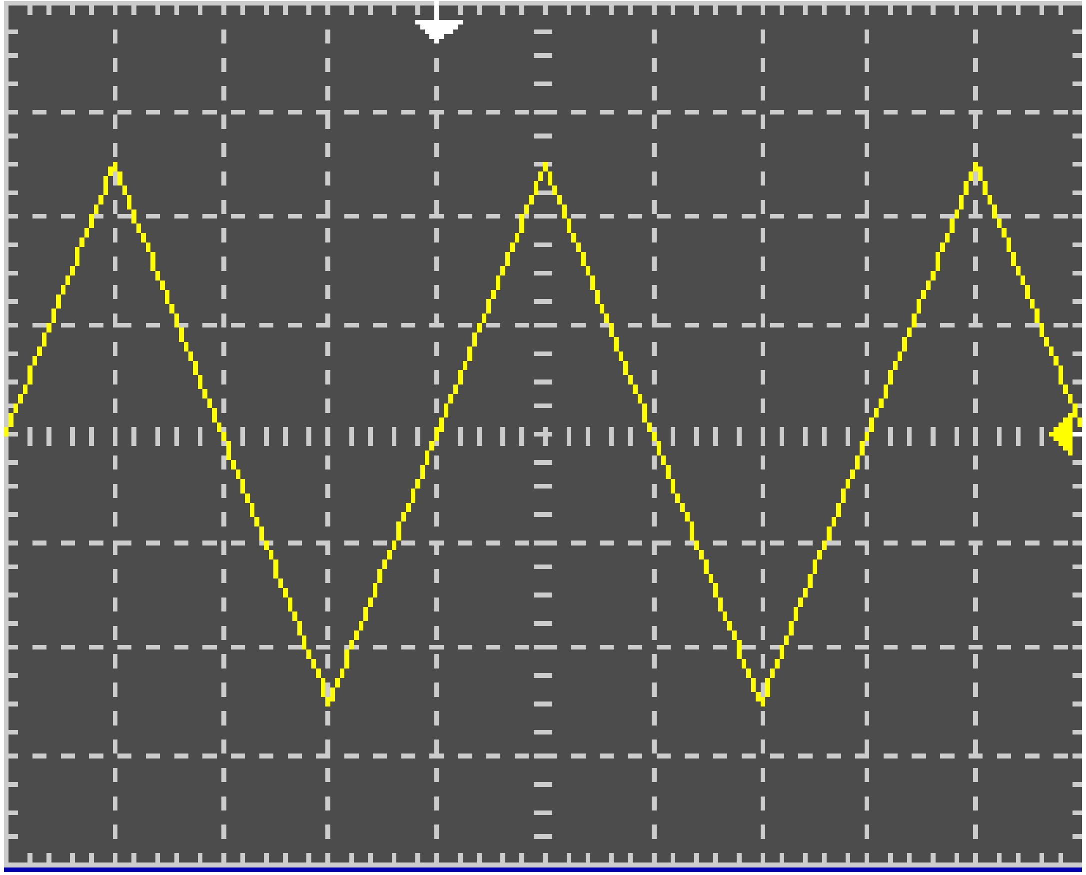
2 V/div, 500 uS/div

Answer:

$$Freq. = \frac{1}{Period}$$

$$Freq. = \frac{1}{2\,mS}$$

$$Freq. = 500\ Hz$$



Oscilloscope: Task-7

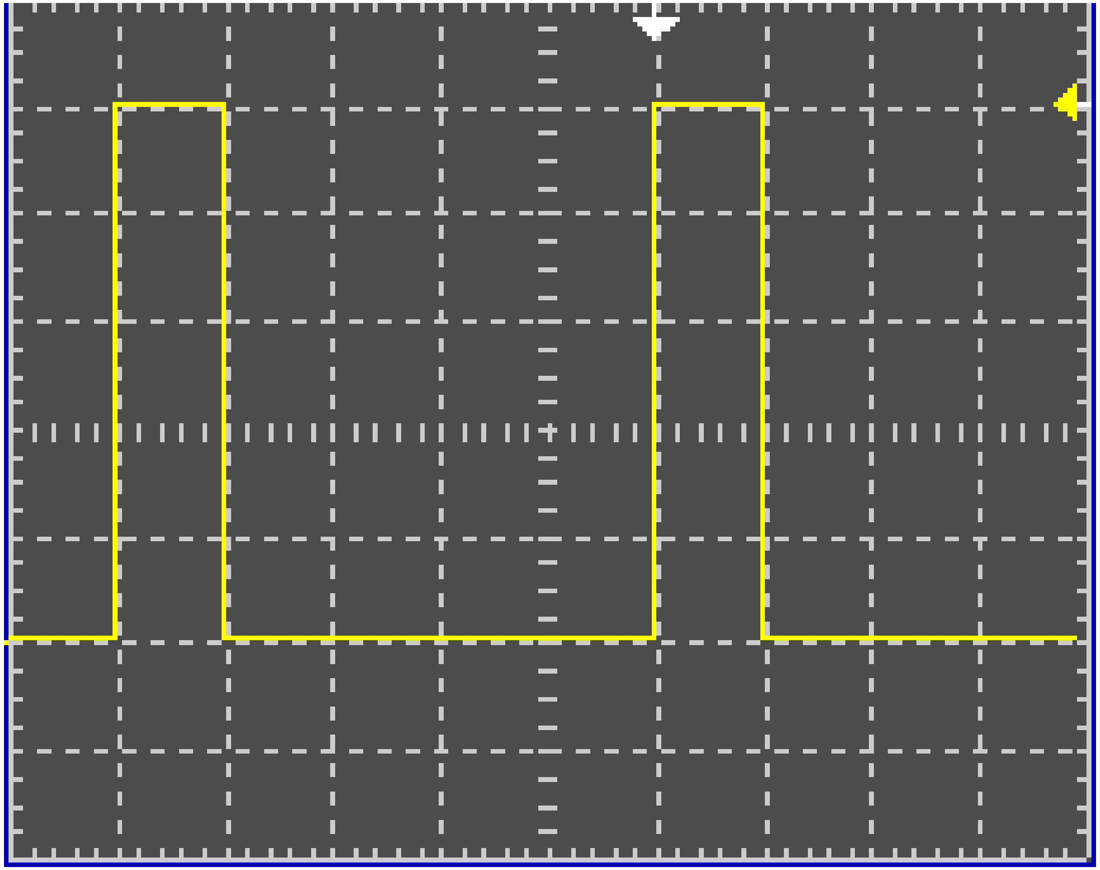
- **Determine the amplitude of the signal**

Oscilloscope Settings

1 V/div, 2 mS/div

Answer:

$$5\ div\ x \frac{1V}{div} = 5Vp$$



Oscilloscope: Task-8

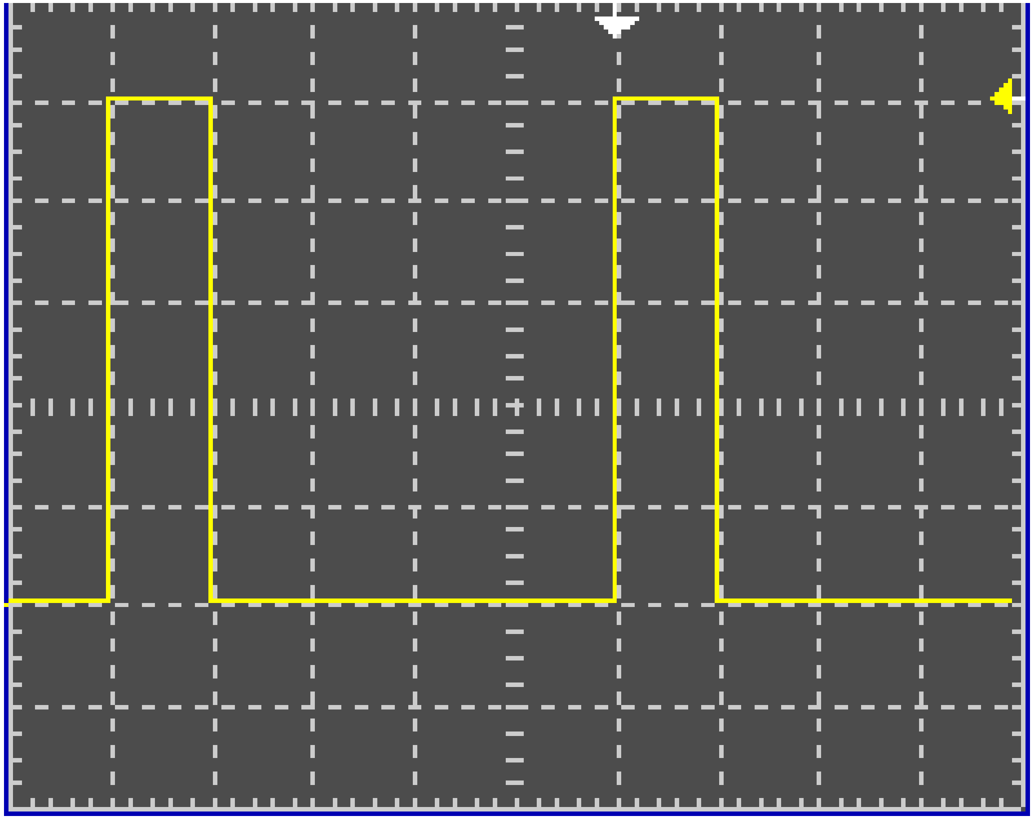
- **Determine the Period of the signal**

Oscilloscope Settings

1 V/div,   2 mS/div

Answer:

$$5\ div\ x\,\frac{2\,mS}{div} = 10\,mS$$



Oscilloscope: Task-9

- **Determine the Frequency of the signal**

Oscilloscope Settings

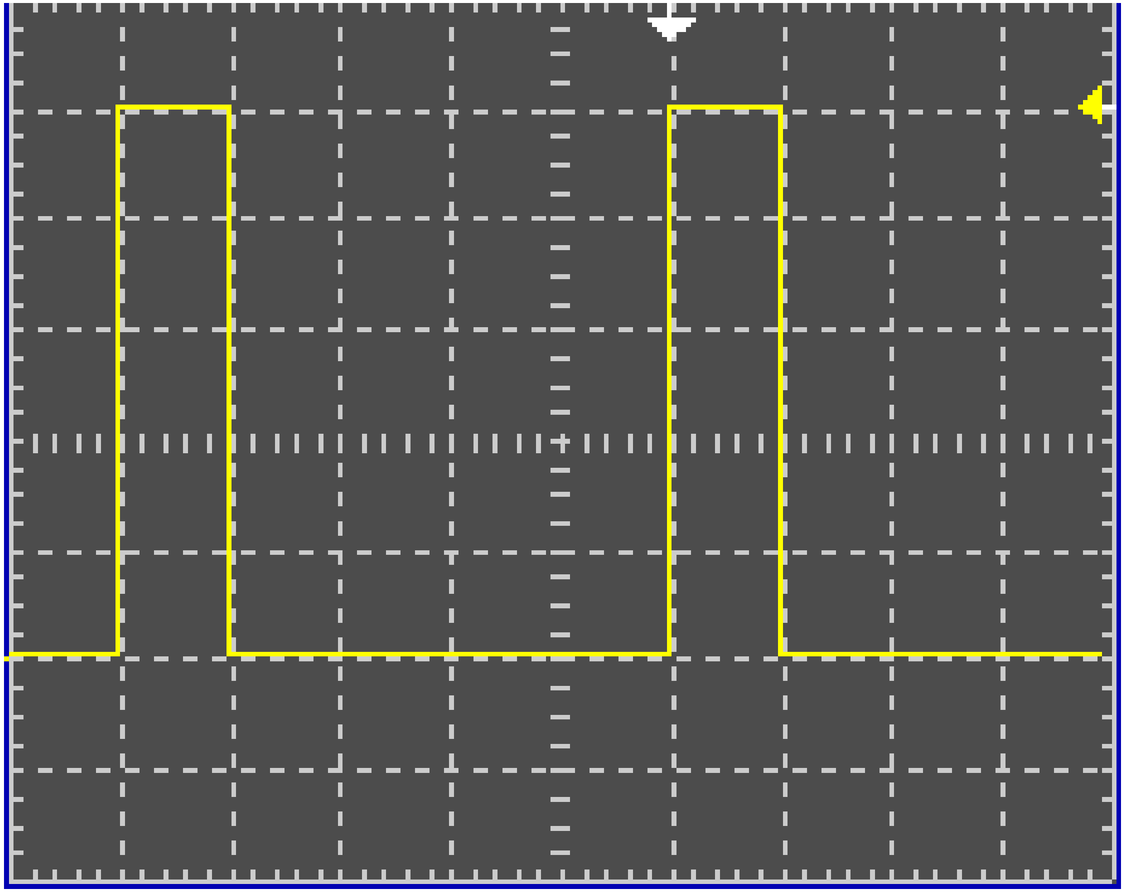
1 V/div,   2 mS/div

Answer:

$$Freq. = \frac{1}{Period}$$

$$Freq. = \frac{1}{10\,mS}$$

$$Freq. = 100\,Hz$$



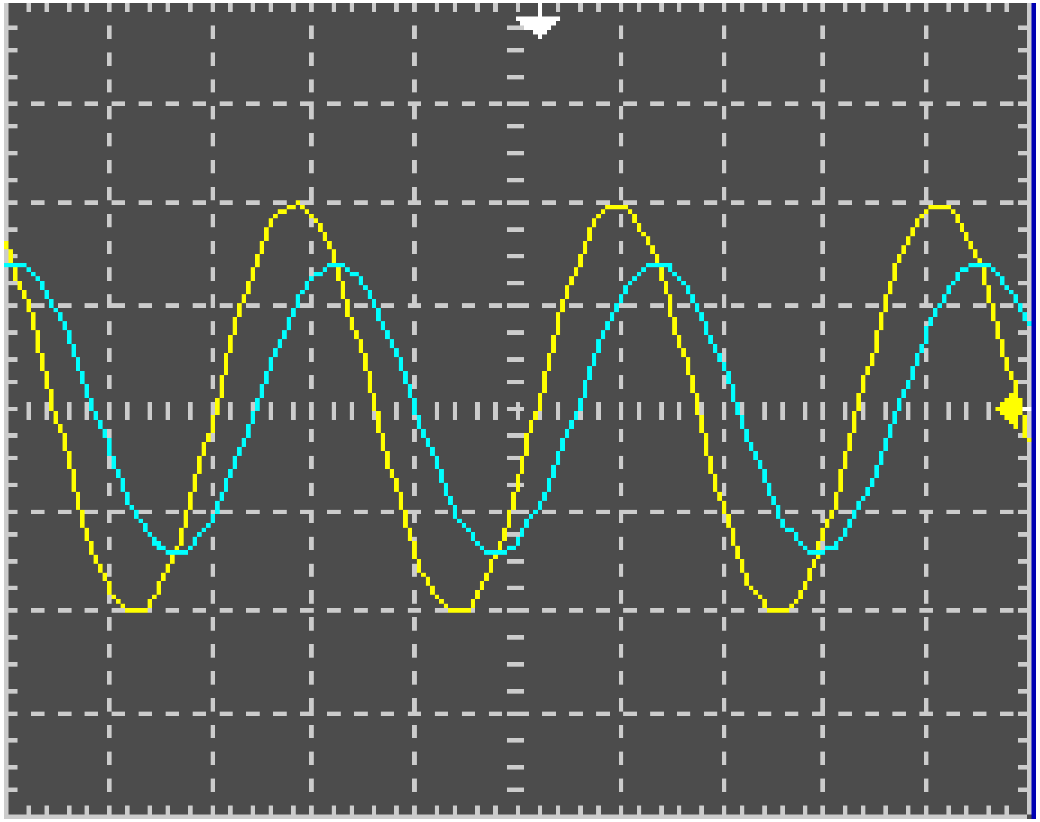
- **Determine the Phase Shift of the signal**

Answer:

$$\theta^\circ = \frac{\Delta\ divisions}{Total\ \ divisions} x\, 360^\circ$$

$$\theta^\circ = \frac{0.4\ divisions}{3.2\ divisions} x\, 360^\circ$$

$$\theta^\circ = 45^\circ$$



Oscilloscope: Task-6

- **Determine the Duty Cycle of the signal**

Oscilloscope Settings

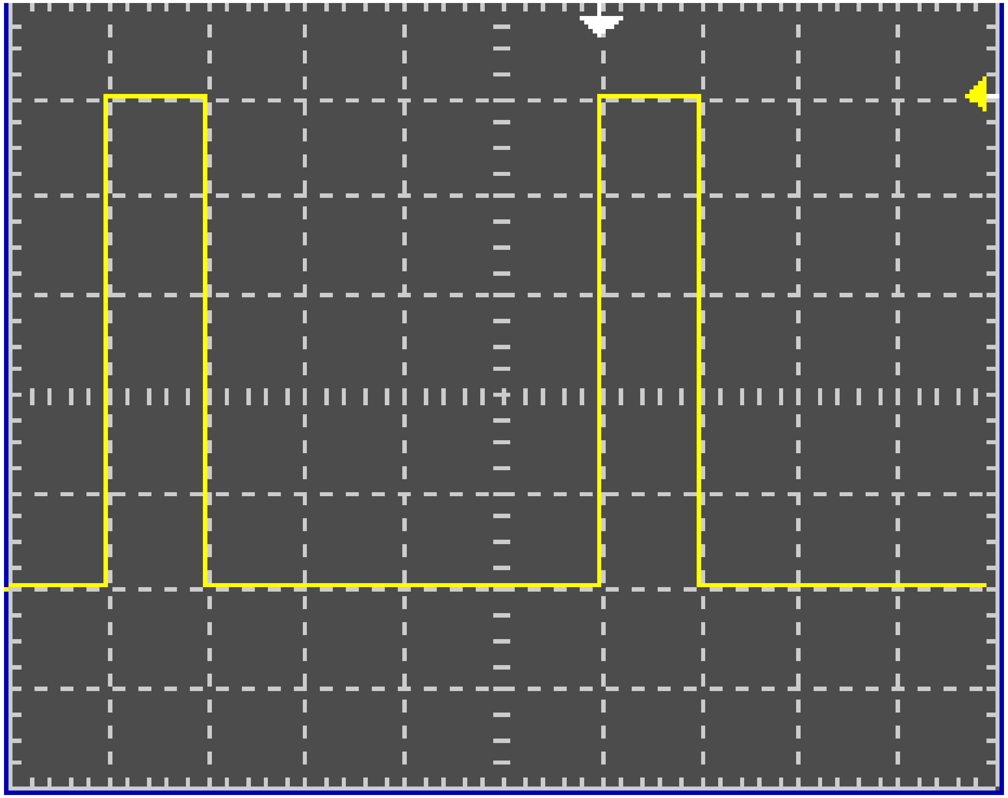
1 V/div,   2 mS/div

Answer:

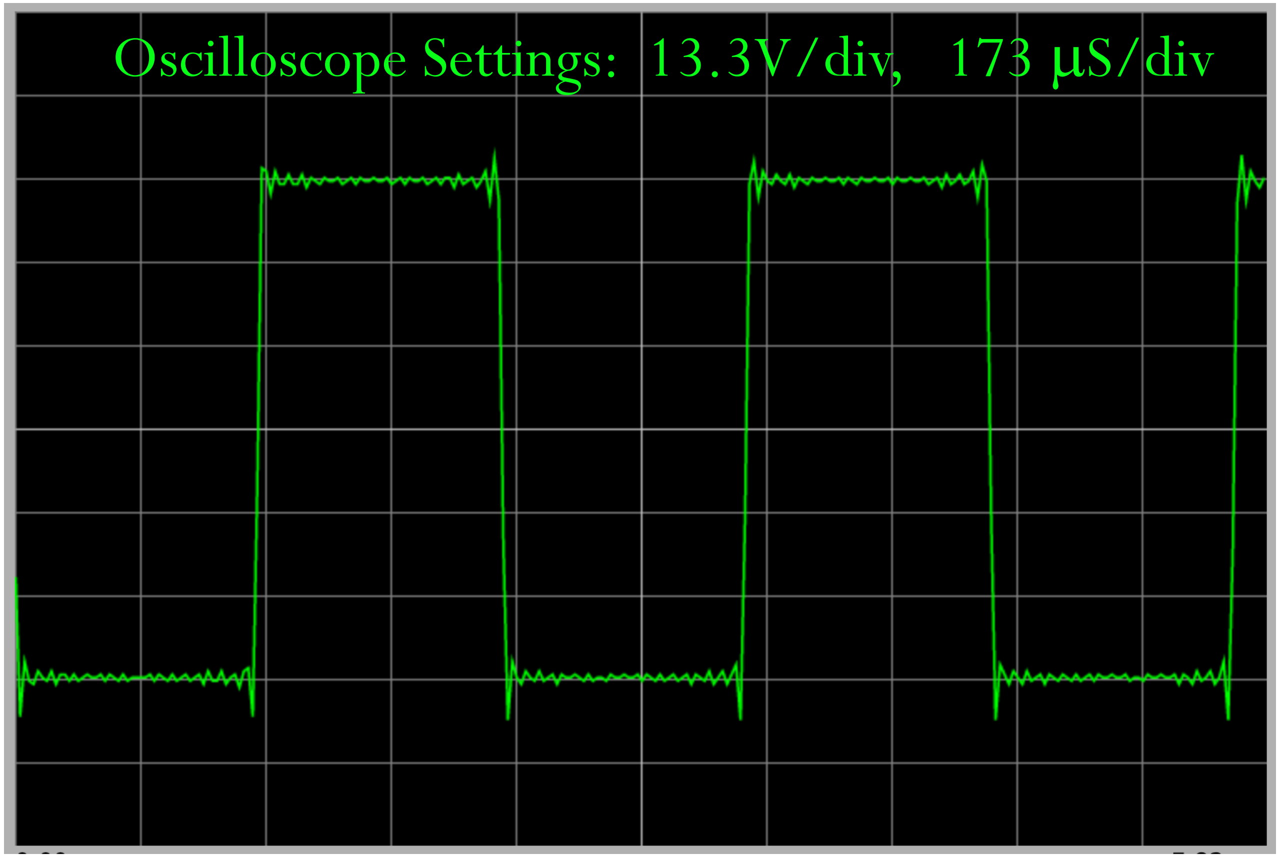
$$D.C.(\%) = \frac{Divisions\ "on"}{Total\ \ divisions} x100$$

$$D.C.(\%) = \frac{1\ div}{5\ div} x100$$

$$D.C. = 20\%$$



Oscilloscope: Task-7

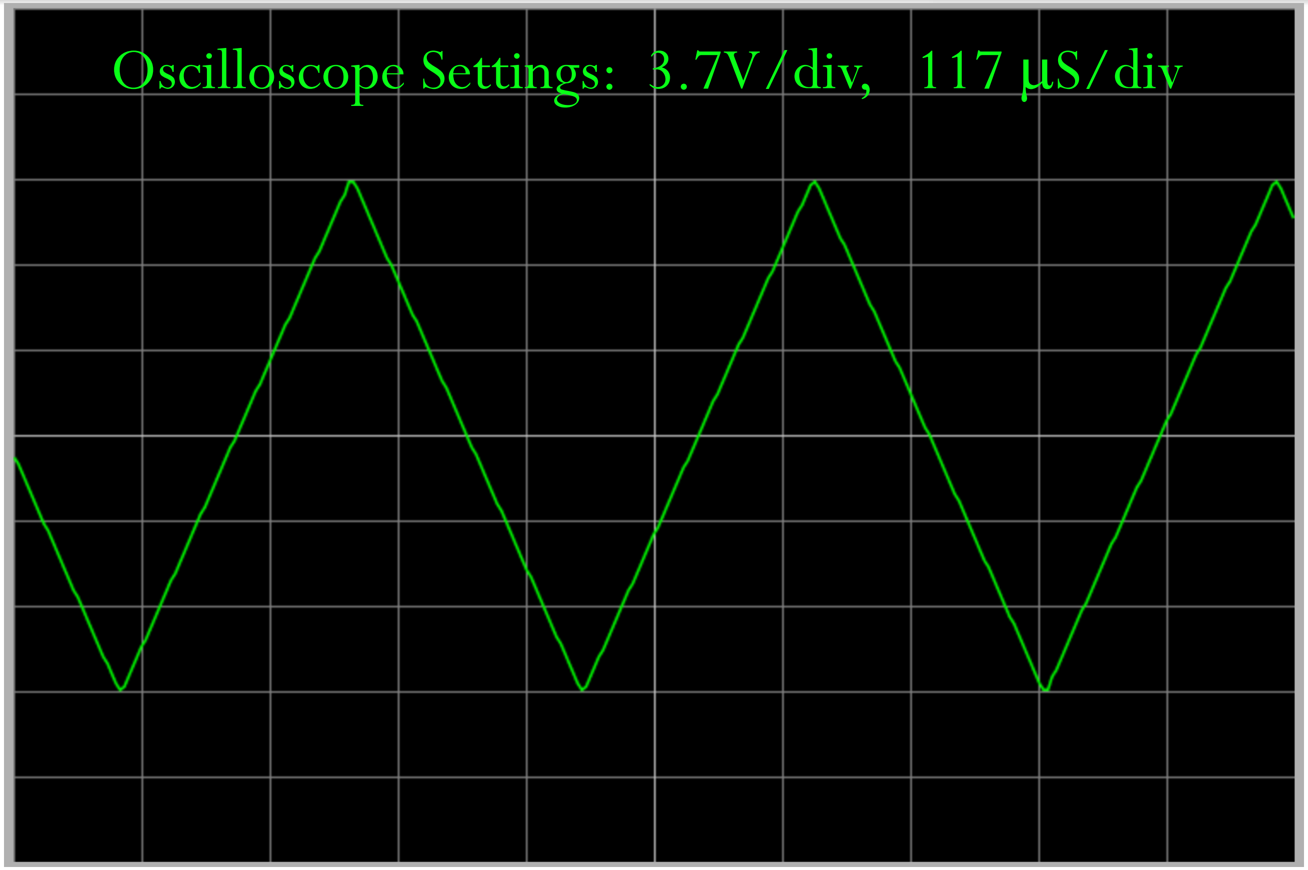


A. Determine the Period of the signal

B. Determine the amplitude of the signal

C. Determine the Frequency of the signal

Oscilloscope: Task-8

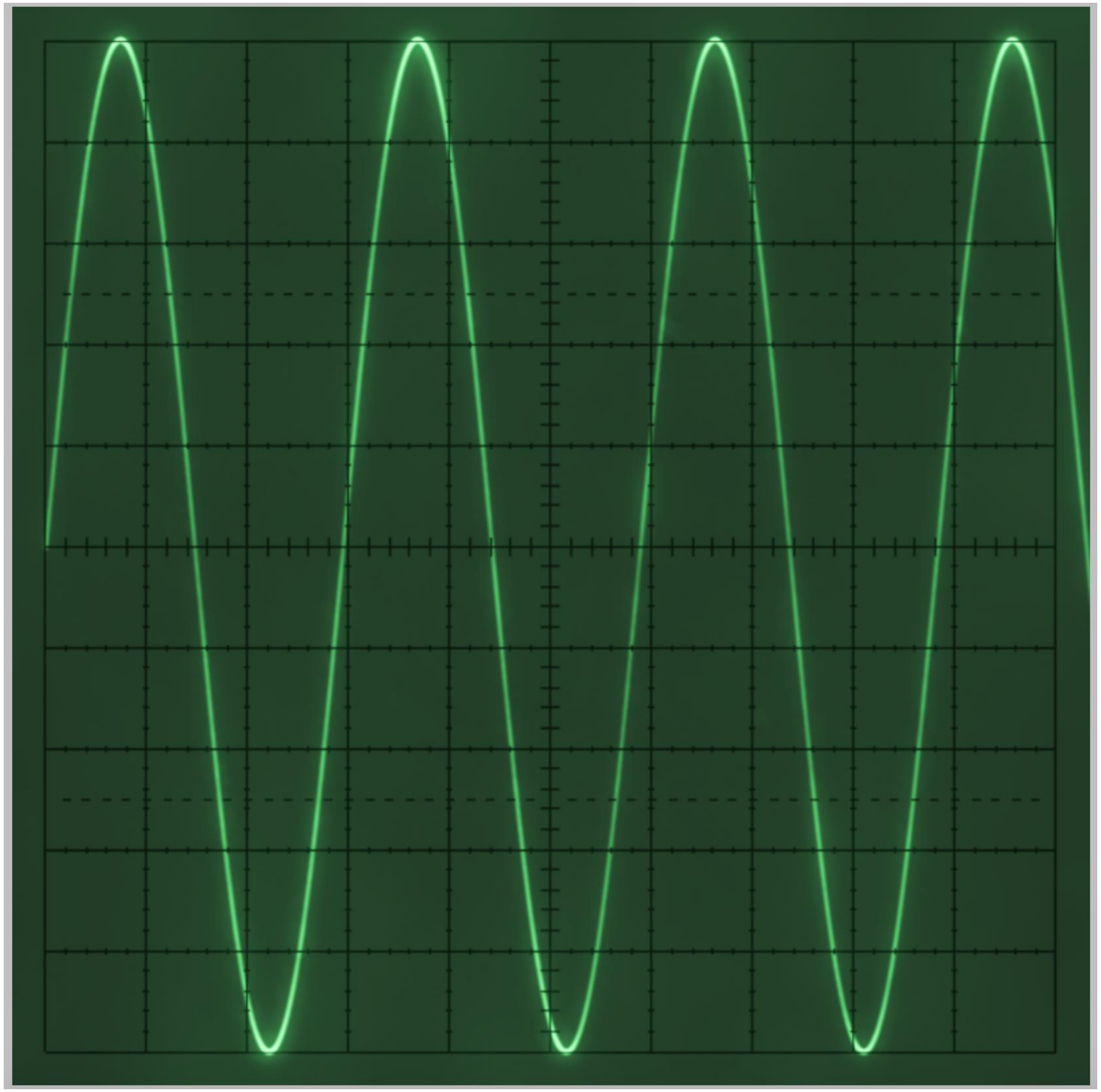


A. Determine the Period of the signal

B. Determine the amplitude of the signal

C. Determine the Frequency of the signal

Oscilloscope: Task-9



Oscilloscope Settings:

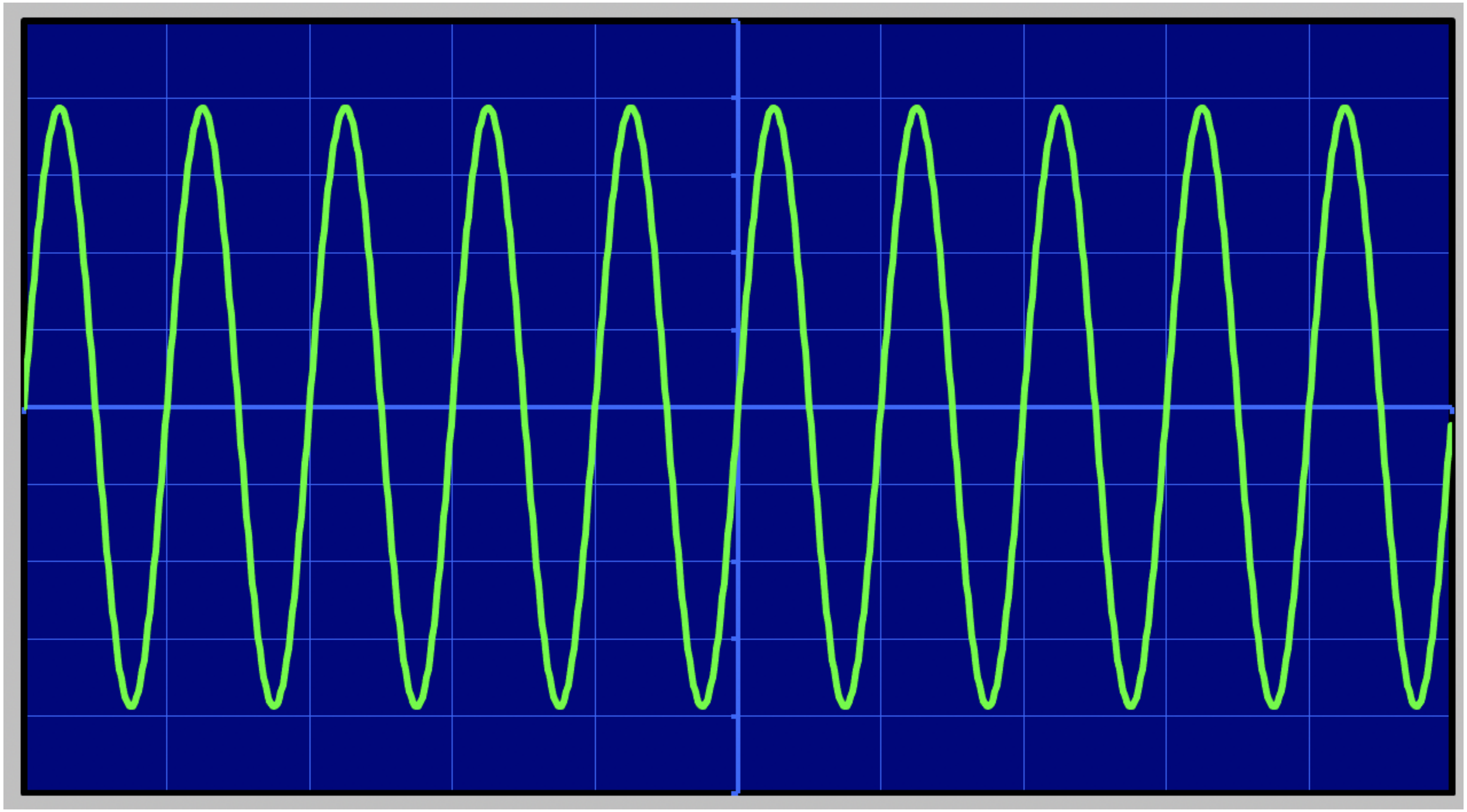
2.1V/div,

117 μS/div;

Estimate the rise time.

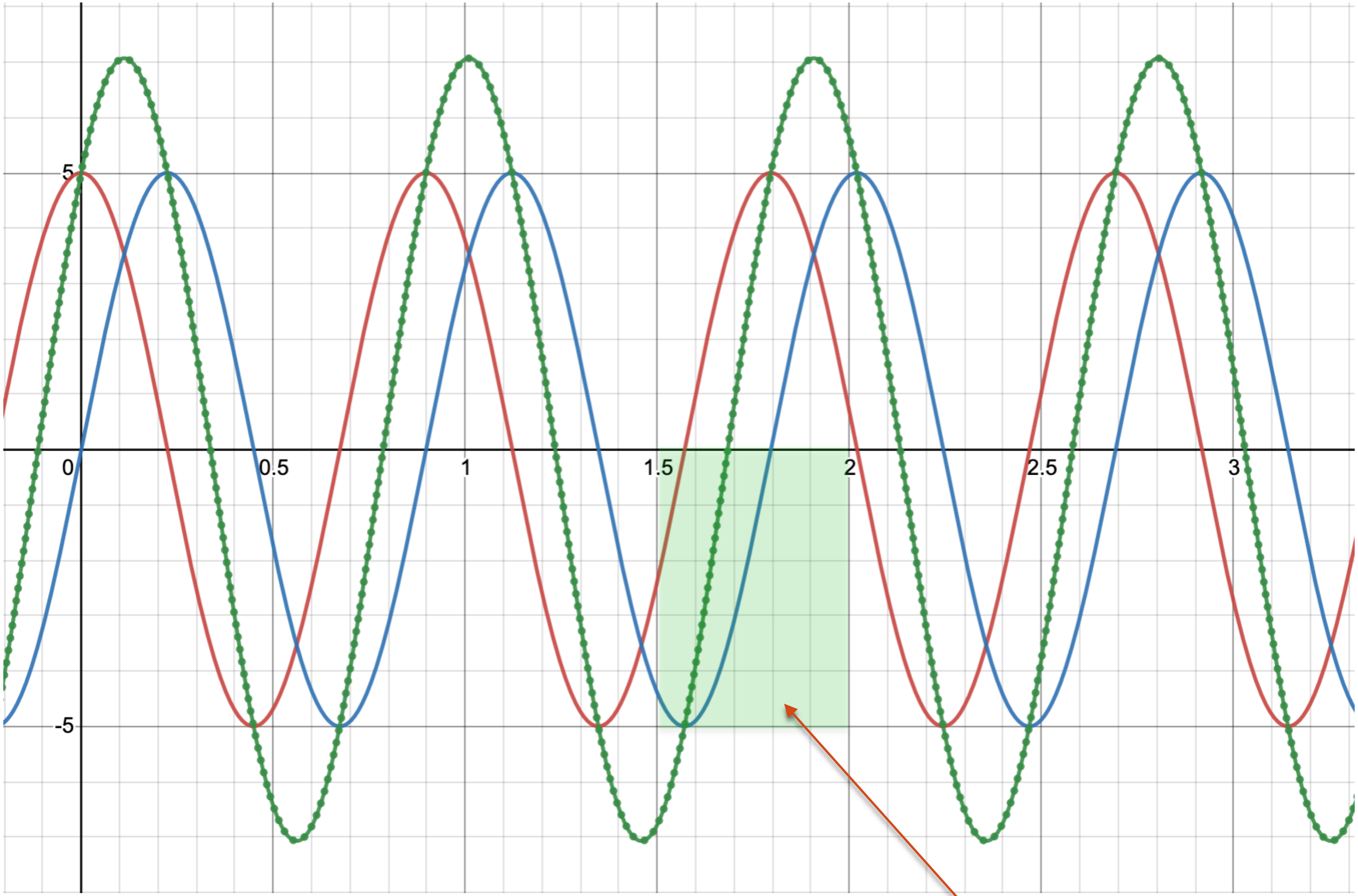
There is a little bit of error in single amplitude

Oscilloscope: Task-10



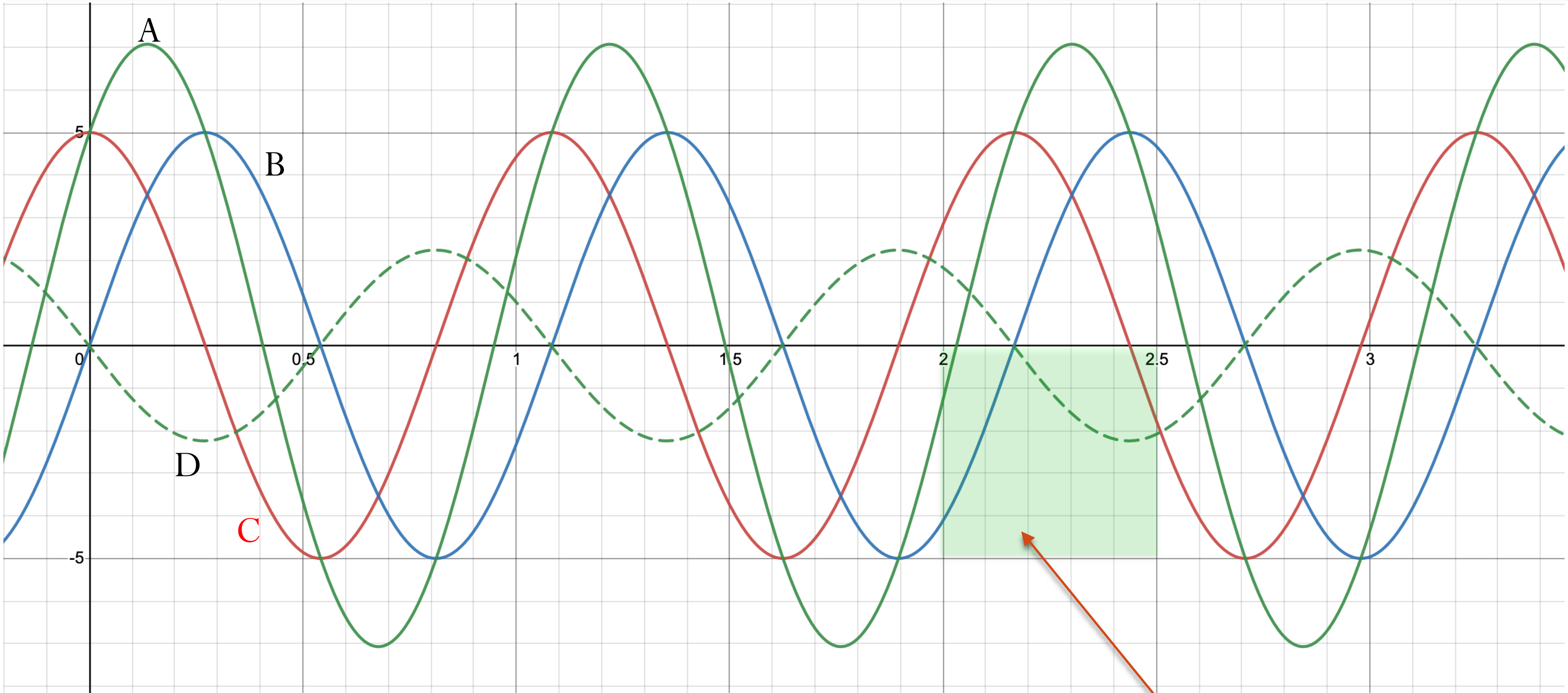
Oscilloscope Settings: 2.2V/div, 300 μS/div; What is the RMS values

Oscilloscope: Task-11



Find out the phase shift between each curve, 2.1V/div, 50 μS/div [one division means a big division]

Oscilloscope: Task-12



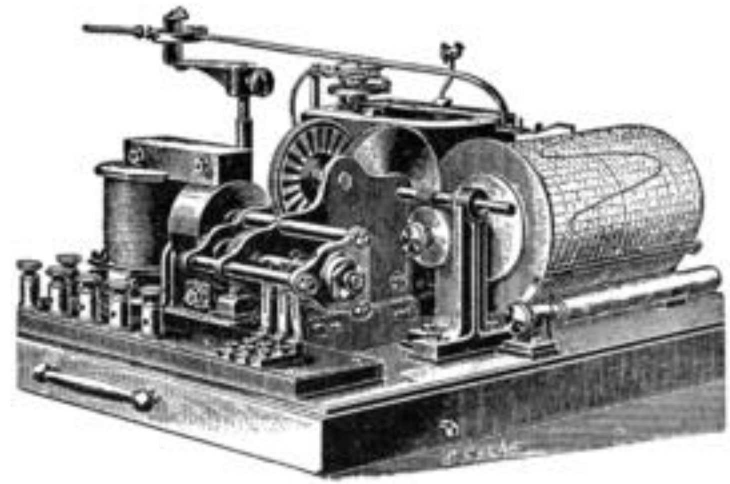
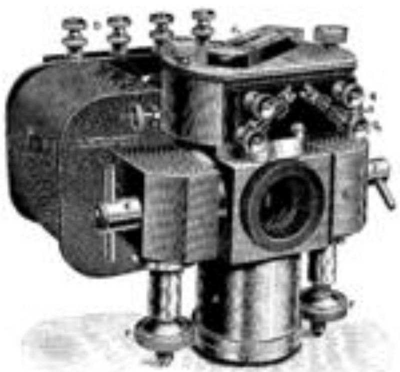
2V/div, 50 μS/div [one division means a big division]

1) Find out the phase shift between each curve
2) Find out the frequency and Time periods
3) Find out the amplitude of each signals

Backups

Timeline of Oscilloscope Developments

- ScopeInfo
- Wikipedia
- toolboom





History of Oscilloscope

1897	Karl Ferdinand Braun built the first cathode ray tube (CRT) and the first CRT based oscilloscope for physical experiments.
1920s	First cathode ray tubes (CRT) used for measurements.
1931	General Radio Company (later renamed to GenRad) develops one of the first oscilloscopes (Electron Oscillograph Type 535-A it was in two parts: tube and power supply).
1932	A.C.Cossor Ltd. (UK) developes its first oscilloscope.
1933	Rohde & Schwarz was founded by Lothar Rohde and Hermann Schwarz in Munich, Germany.
1934	General Radio Company (GenRad) introduces the first commercial one box cathode-ray oscilloscope (Type 687-A). Some years later the company developed the Type 770-A which was never sold. A few years later GR dropped the production of oscilloscopes.
1935	Hewlett-Packard was founded by Bill Hewlett and Dave Packard near Palo Alto.
1938	First dual beam oscilloscope developed by A.C.Cossor in UK.

History of Oscilloscope

1939	DuMont introduces the DuMont 164 general purpose Oscillograph. In the 1940s DuMont was the leader in the oscilloscpe market.
1943	Allen DuMont invents frequency trigger and sweep, Model 224-A features 3 inch CRT, one channel and 2 MHz bandwidth.
1946	Tektronix was founded by Howard Vollum and Jack Murdock.
1945	DuMont launches 248 featuring 5 MHz bandwidth and 5 inch CRT.
1947	Tektronix introduces its first time base triggered oscilloscope (Model 511) featuring automatic triggering, calibrated readings and high accuracy.
1954	Tektronix introduces the Model 535 which includes an own developed and produced CRT. This model was sold over 22 years.
1956	Tektronix introduces the Model 545 with 24 MHz bandwith, 2 channels and a modular plug-in concept.
1956	Hewlett-Packard (HP) presents its first oscilloscope, the HP 130A with 300 kHz bandwidth.
1957	Tektronix introduces time-delayed trigger.

History of Oscilloscope

1957	HAMEG was founded. First product is a 5 MHz one channel oscilloscope.
1959	Hewlett-Packard (HP) enters the European market with sales and support offices in Germany and Switzerland and a factory in Germany.
960	Hewlett-Packard (HP) invents the sampling technology. First product was launched in 1960, the HP 185A with a bandwidth of 500 MHz.
1961	Tektronix introduced Model 321, the first portable oscilloscope (6MHz, one channel, line and battery operation)
1962	Hewlett-Packard (HP) increased with the HP 185B the bandwith to 1000 MHz. This was the first GHz oscilloscope.
1964	Tektronix introduces the Model 564 the first storage oscilloscope and the high performance Model 547.
1964	LeCroy was founded by Walter LeCroy.
1965	Tektronix introduces the Series 400 of portable oscilloscopes and the Model 647 a fully transistorized und ruggedized military version of the Model 547.
1966	Hewlett-Packard (HP) introduces the Series 180, a complete family of oscilloscopes with a choice of mainframes, display sizes, plug-ins and accessories.

History of Oscilloscope

1969	Tektronix lauchned the completely redesigned Serie 7000 (e.g. Model 7704 with a bandwidth of 150 MHz).
1969	Hewlett-Packard (HP) introduces the HP 1200A an all solid-state oscilloscope with 500 kHz bandwidth.
1971	Hiro Moriyasu (Tektronix) invents the digital oscilloscope.
1971	LeCroy built the first real-time digital oscilloscope (WD 2000). Memory depth: 20 samples, sampling rate: 1 ns.
1980?	Digital storage oscilloscope invented by Nicolet Test Instrument (1 MHz bandwidth).
1982	Hewlett-Packard introduced the first full digital and microprocessor-based oscilloscopes, the HP 1980A/B with two 100 MHz channels. It was also programmable over the HP-IP bus.
1983	Hewlett-Packard launched its last analog oscilloscopes, the HP 1745A (extra large screen) and the HP 1746A.
1985	LeCroy presented the high-speed digital storage oscilloscope Model 9400 (dual 165 MHz, 8 bit). It used a large standard TV CRT with magnetic deflection which shows both the input signal and a computed Fourier spectrum including grid, characters and traces.
1980s	First digital sampling oscilloscopes appeared.

History of Oscilloscope

1990	Hewlett-Packard introduced a digitizing oscilloscope with 500 MHz bandwidth (HP 54xxx). The HP 54500 Series was also the first oscilloscope featuring a FFT analysis (Fast Fourier Transfor) to perfom a frequency domain analysis.
1991	Pico Technology was founded and introduced first PC-based oscilloscope named ADC-10 and pioneered also digital triggering. The ADC-10 featured one channel with 10 kS/s sample rate and was connected via parallel port to a PC.
1991	LeCroy introduced a hi-resolution oscilloscope with 10 bit vertical resolution and 100 MHz bandwidth
1992	Hewlett-Packard introduced the HP 54600A. For the first time a digital 100 MHz oscilloscope was available for the same price as a 100 MHz analog oscilloscope.
1992	Pico Technology launched the first (PC-based) oscilloscope with 12 bit resolution (ADC-12 with parallel port PC interface).
1993	LeCroy introduced the first PC-based digital oscilloscope.
1994	Tektronix offers the TLS216 Logic Scope, a combination of digital storage oscilloscope and logic analyser. It offers a 500 MHz bandwidth, 2GS/s sampling rate and 16 input channels with enhanced triggering. So the TLS216 might be the first mixed-signal oscilloscope (MSO).
1996	Hewlett-Packard introduces the first mixed-signal oscilloscope (MSO) with two 100 MHz analog channels and 8 or 16 digital logic channels - the HP 54645.

History of Oscilloscope

1997	CRT display was more and more replaced by LCD. Tektronix launched the TDS210 with 60MHz bandwidth and backlit monochrome 4,7" LCD (320 x 240 px).
1998	Tektronix invented the digital phosphor oscilloscope (DPO).
1998	Hewlett-Packard introduced the first members of the Series HP 54800 Infinium oscilloscopes with 5 models featuring a bandwidth of 500 MHz to 1.5 GHz and sample rates of up to 8 GS/s. This was the first Windows based oscilloscope.
1999	Rigol launched its first product, a digital storage oscilloscope. The company was founded in 1998 in Beijing/China. Agilent Technologies created by a spin-off of all non-computing products from Hewlett-Packard.

2002	Siglent was founded in Shenzen (China).
2005	Rohde & Schwarz acquired HAMEG.
2006	With the PicoScope 5000 Series Pico Technology released the first USB-connected oscilloscope with 1GS/s realtime sample rate and 250 MHz bandwith.
2007	Tektronix acquired by Danaher Corporation.
2009	Tektronix introduces the MSO70000 mixed-signal oscilloscope with up 4 analog channels with up to 20 GHz bandwith and 50 GS/s and 16 digital channels.

History of Oscilloscope

2009	LeCroy developed the Wavemaster 8Zi with 20 GHz bandwidth and 40 GS/s.
2010	LeCroy introduces first oscilloscope with 45 GHz bandwidth and 120 GS/s sample rate (WaveMaster 8Zi-A).
2010	Tektronix announced the DPO/DSA/MSO70000C Series of digital and mixed signal oscilloscopes reaching a 100 GS/s sampling rate.
2010	Rohde & Schwarz enters the oscilloscope market with two families R&S RTO with up to 2 GHz bandwidth and R&S RTM with up to 500 MHz bandwidth.
2011	Rigol Technologies opened subsidary in Europe in Munich/Germany.
2011	Tektronix introduced the Series MDO4000 mixed domain oscilloscopes (MDO) a combination of oscilloscope and spectrum analyzer.
2011	LeCroy introduced the first oscilloscope with 65 GHz bandwidth the LabMaster 10Zi. Up to 20 acquisition channels with 65 GHz bandwidth could be synchronized.
2011	LeCroy launched the first oscilloscopes with 12 bit vertical resolution of the ADCs and sample rate 2.5 GS/s the Series HDO4000 and HDO6000 offering 16 times more vertical resolution than traditional oscilloscopes.
2012	Teledyne acquired LeCroy. New name is Teledyne LeCroy.
2012	Yokogawa presented the first mixed-signal oscilloscope with 8 analog channels(DLM4000).

History of Oscilloscope

2013	Pico Technology launched the first oscilloscope with flexible resolution from 8 to 16 bits. (PicoScope 5000).
2013	Teledyne LeCroy demonstrates the first 100 GHz realtime oscilloscope.
2013	Pico Technology released the first USB 3.0 oscilloscope.
2014	Yokogawa introduced the first combination of oscilloscope and power analyzer the PX8000.
2014	Tektronix introduced the first 6-in-1 oscilloscope including a digital multimeter, arbitrary signal generator, spectrum analyser, logic analyser, and protocol analyser, the MDO3000 Series.
2014	Agilent split into two companies and test & measurement branch renamed to Keysight Technologies.
2014	Teledyne LeCroy: the first 100 GHz realtime oscilloscope (already demonstrated in 2013) with 240 GS/s is commercial available: the LabMaster 10-100Zi.
2015	Tektronix launched a compact 70GHz oscilloscope with 200 GS/s sample rate (DPO70000SX).
2016	Rohde & Schwarz enters handheld oscilloscope market with R&S Scope Rider combining 5 instruments.
2017	Tektronix introduced FlexChannel technology in 5 Series oscilloscopes. Each channel can be used either as analog or as 8 digital channels.

History of Oscilloscope

2018	Teledyne LeCroy announced the WavePro HD high-definition oscilloscopes, which combine for the first time 12-bit technology high vertical resolution and 8 GHz bandwidth.
2018	Keysight announced the Infiniium UXR Series oscilloscopes featuring a new bandwidth record of 110 GHz and a sample rate of 256 GSa/s.
2019	Rohde & Schwarz announced in February 2019 that from now on most oscilloscopes are delivered with a high definition mode (HD) featuring 16-bit vertical resolution.

2020	Tektronix announced with TekDrive, the first native oscilloscope-to-cloud software solution to facilitate global data collaboration directly on an oscilloscope, PC, phone or tablet.

Technonix DPO77002SX 70 GHz ATI Performance Oscilloscope, 200GS

LabMaster 10 Zi-A, Teledyne Lecroy Up to 65 GHz Up to 80 Channels @ 36 GHz Up to 160 GS/s

Keysight Infiniium UXR-Series, real-time analog bandwidth 110Ghz, 256 GSa/s sampling