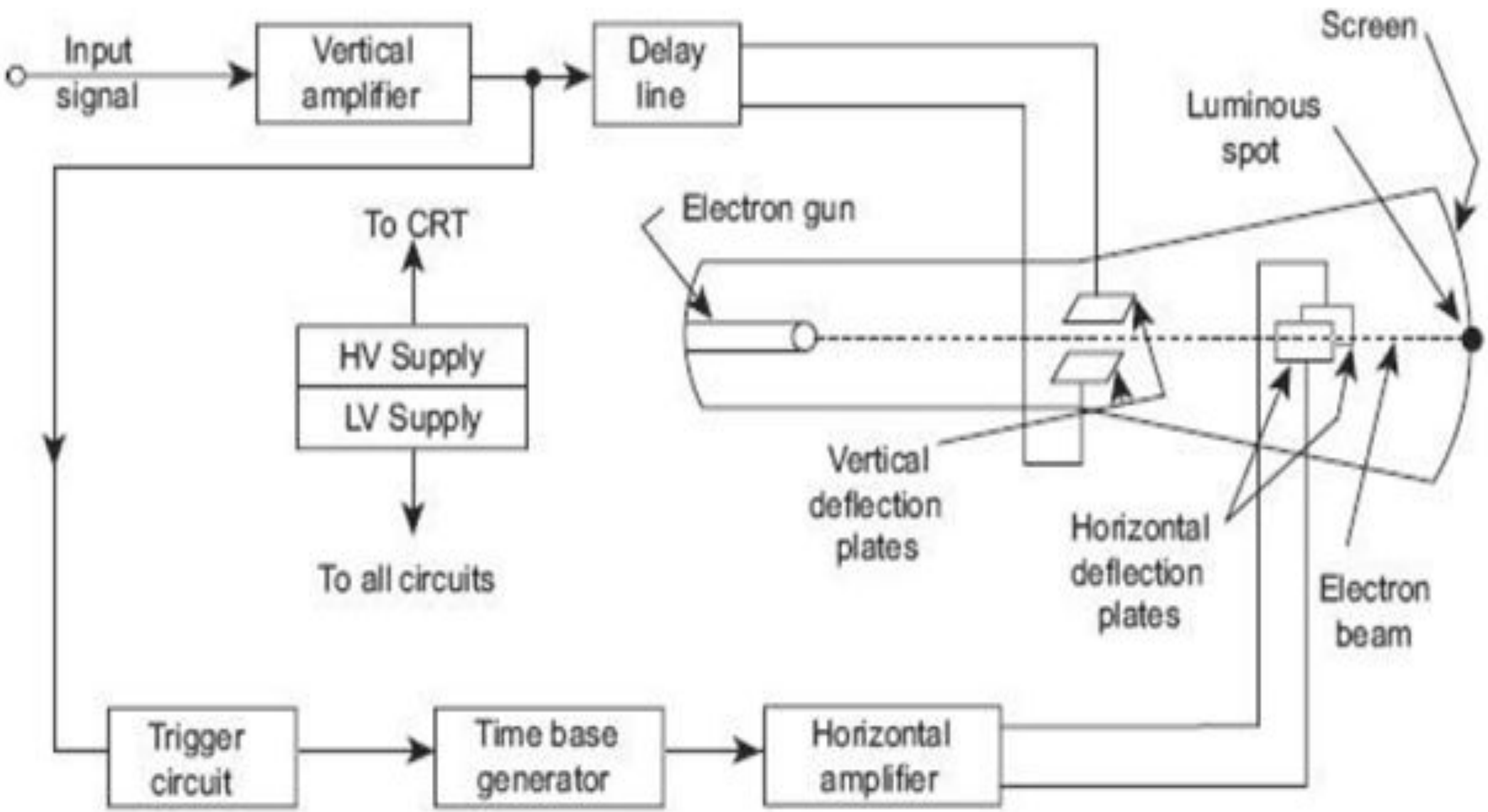
Cathode Ray Oscilloscope

?What is an Oscilloscope

- **Oscilloscopes** are very fast *X*-*Y* plotters, displaying an input signal versus time.
- The **stylus** of this **plotter** is a luminous spot which moves over the display area in response to an input voltage.
- The luminous spot is produced by a beam of electrons striking a fluorescent screen. The extremely low inertia associated with a beam of electrons enables such a beam to be used following the changes in instantaneous values of rapidly varying voltages.
- It is used for ***displaying, measurement, and analysis of waveform*** such as ***peak value, rise time, fall time, frequency, phase difference, pulse width.***

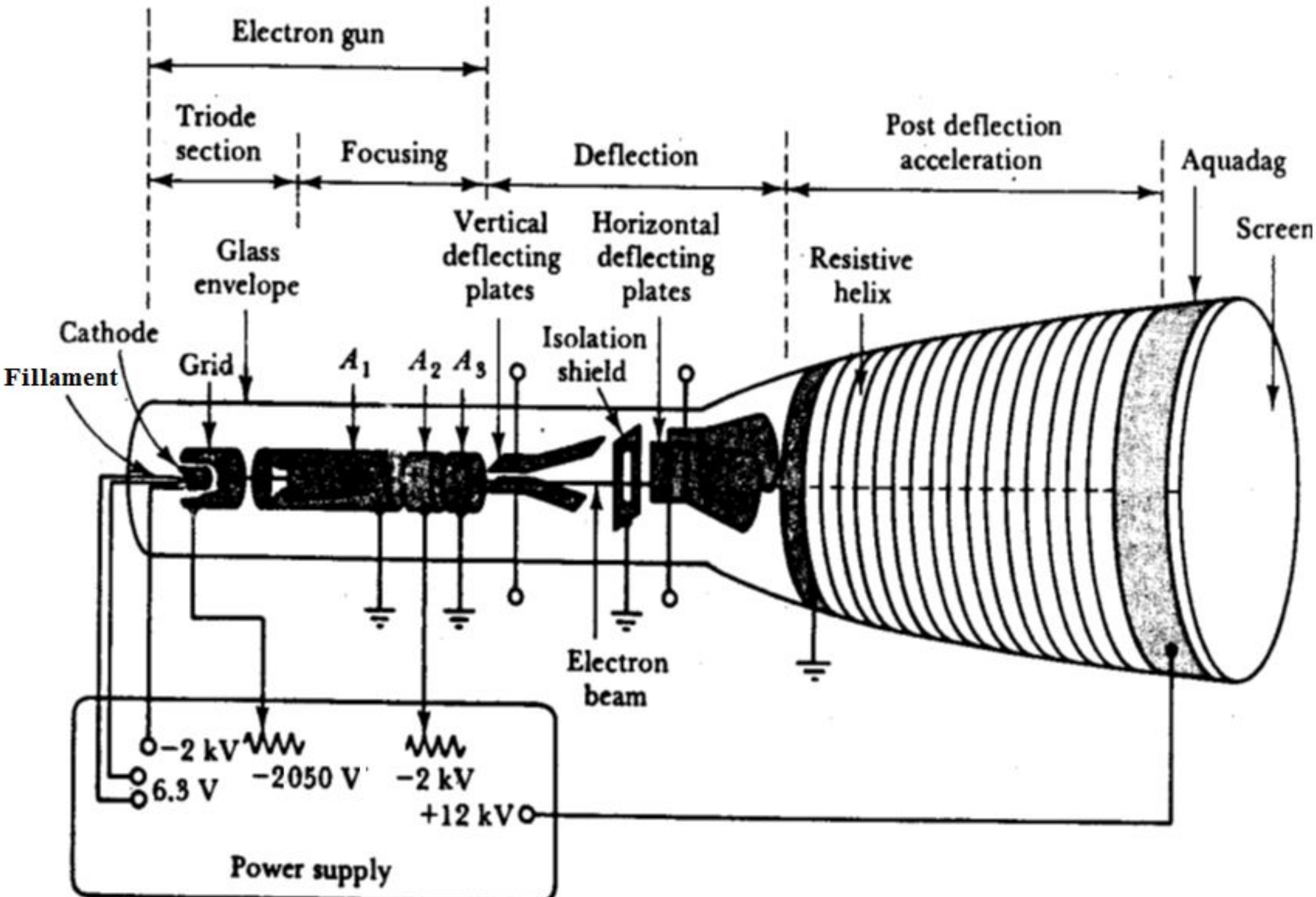
Block diagram of CRT oscilloscope



How does CR Oscilloscope work?

- The normal form of a CRO uses ***a horizontal input*** voltage which is an internally generated ***ramp voltage called 'time base'*** applied to the ***horizontal deflecting plates***. The **horizontal voltage** moves the luminous spot periodically in a horizontal direction from **left to right** over the display area or screen.
- The ***vertical input*** to the CRO is the ***voltage under investigation*** which is applied to the vertical deflecting plates. The vertical input voltage moves the luminous spot up and down according to the instantaneous value of the voltage.
- The luminous spot thus traces the waveform of the input voltage with respect to time. When the input voltage repeats itself at a fast rate, the display on the screen appears stationary on the screen.

Construction of Cathode Ray Tube



Triode Section

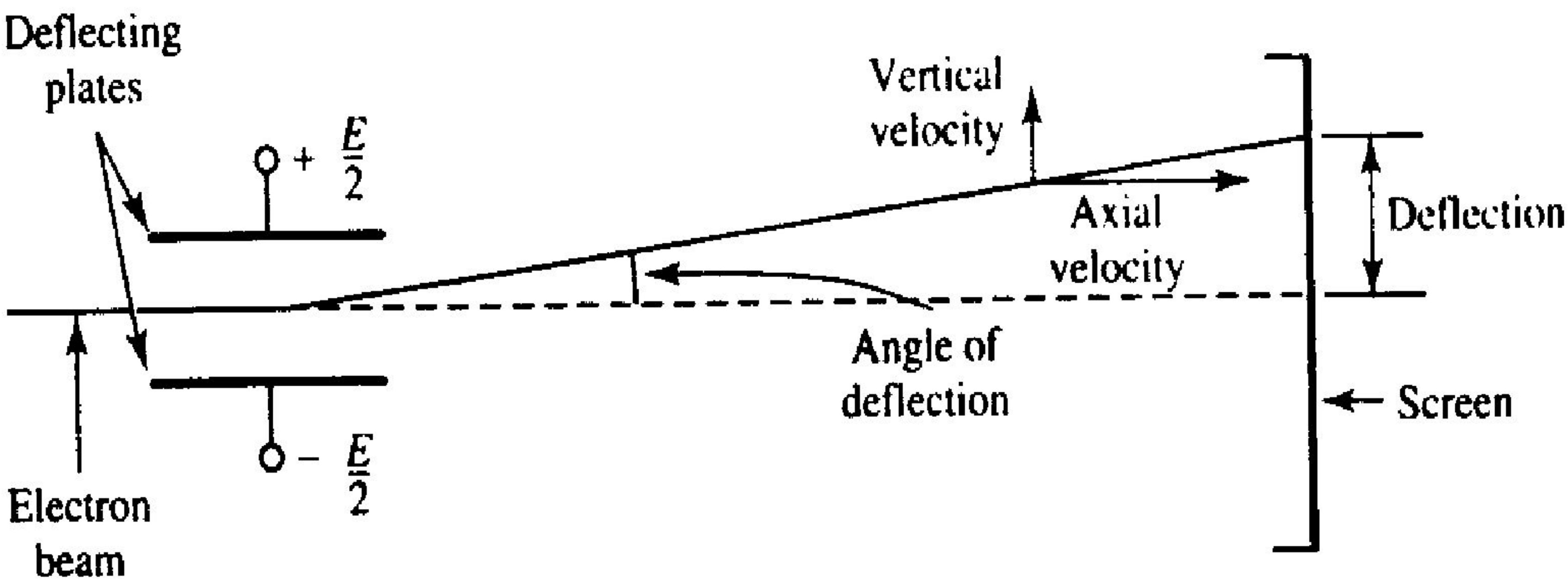
- ***The triode*** section of the tube consists of *a* ***cathode*, a *grid*,** and an ***anode***.
- ***The grid***, which is a nickel cup with a hole in it, almost completely encloses the cathode.
- ***The cathode*** (made of nickel), is cylinder shaped with a flat, oxide-coated, electron emitting surface directed toward the hole in the grid.
- ***Cathode heating*** is provided by an inside ***filament***.
- The cathode is typically held at approximately -2 kV, and the grid potential is adjustable from approximately -2000 V to -2050 V.
- The ***grid-cathode potential*** controls the number of electrons directed to the screen.
- A large number of electrons striking one point will cause the screen to glow brightly; a small number will produce a dim glow.
- Therefore, **the grid potential control the *brightness*** of the trace.

Focusing Section

- **The first anode** (A1) is cylinder shaped, open at one end and closed at the other end, with a hole at the center of the closed end.
- Since A1 is grounded and the cathode is at a high negative potential, **A1 is highly positive with respect to the cathode**. **This causes electrons to be accelerated from the cathode through the holes in the grid and anode to the focusing section of the tube.**
- **The focusing electrodes A1, A2, and A3** are sometimes referred to as an **electron lens**.
- **The function of the electron lens is to focus** the electrons to a fine point on the screen.
- **A1 provides the accelerating field** to draw the electrons from the cathode, and the hole in A1 limits the initial cross section of the electron beam.
- A3 and A1 are held at ground potential while the A2 potential is adjustable around -2 kV.

Deflection Section

If the horizontal and vertical deflecting plates were grounded, the beam of electrons would pass between each pair of plates and ***strike the center*** of the oscilloscope screen. This would produce a bright glowing point.

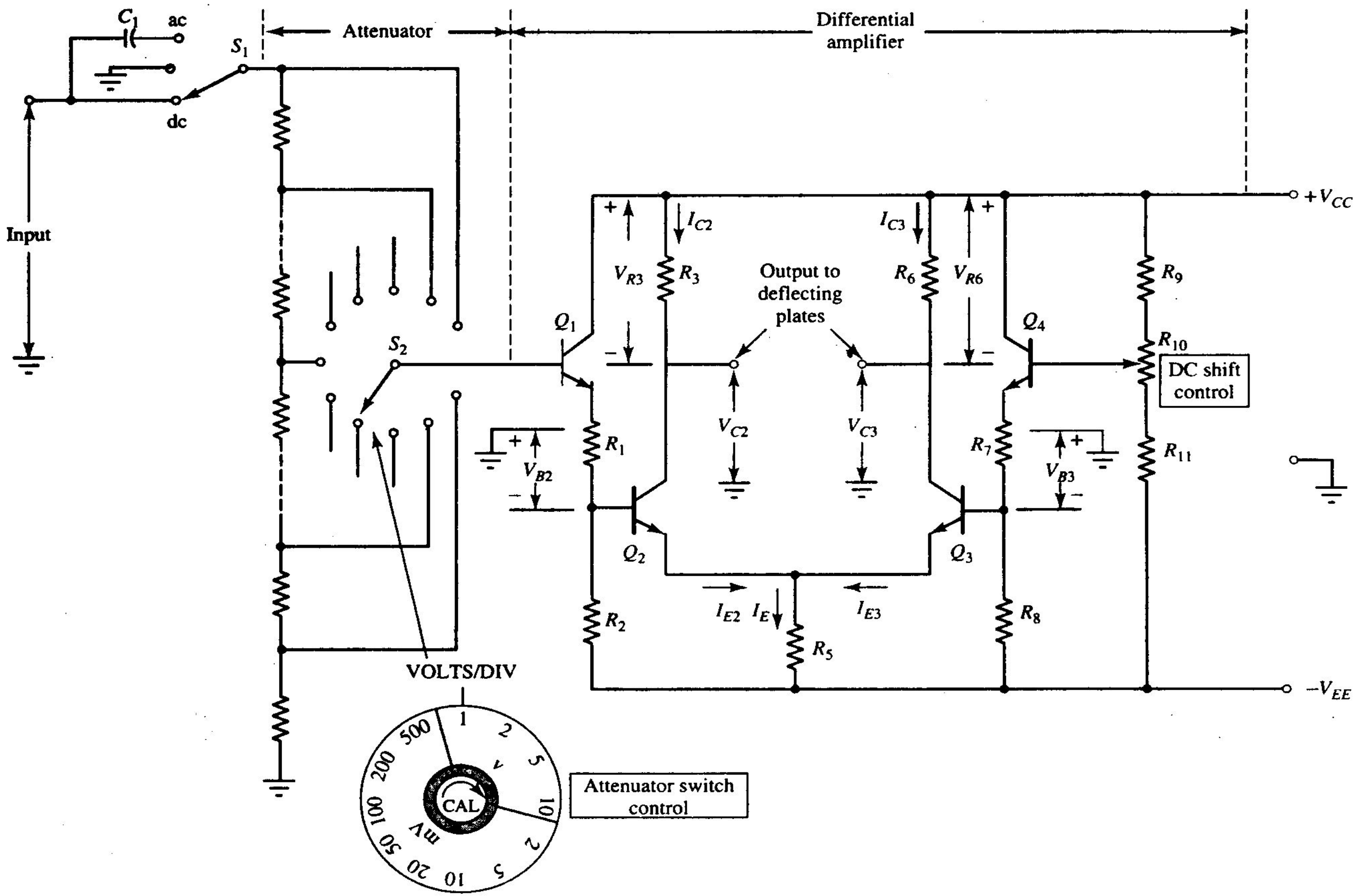


Deflection Section

- When one plate of a pair of deflecting plates has a positive voltage applied to it, and the other one has a negative potential, **the electrons in the beam are attracted toward the positive plate and repelled from the negative plate**. The electrons are actually accelerated in the direction of the positive plate.

- The **tube sensitivity** to deflecting voltages can be expressed in **two ways**. The voltage required to produce one division of deflection at the screen (V/cm) is referred to as the **deflection factor** of the tube. The deflection produced by 1 V (cm/V) is referred to as the **deflection sensitivity**.

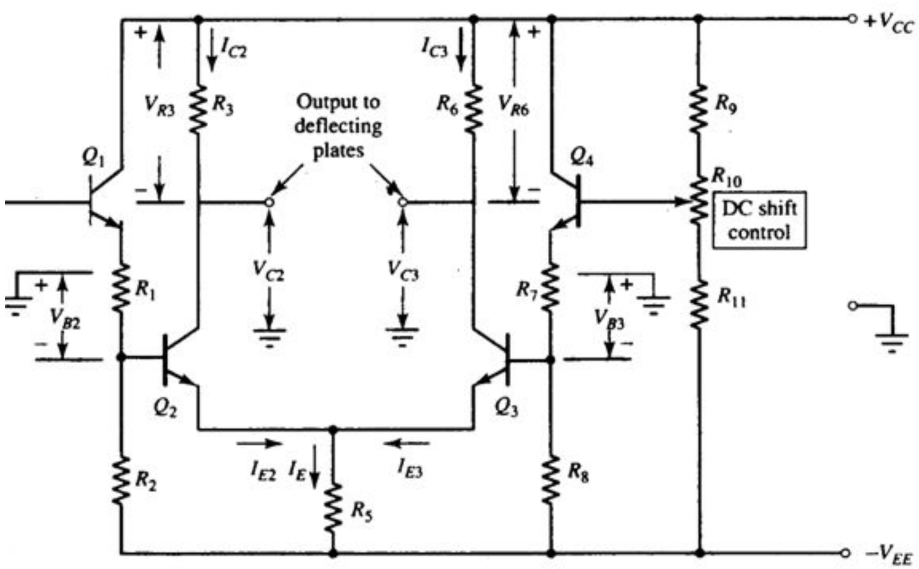
Deflection Amplifiers



Deflection Amplifiers

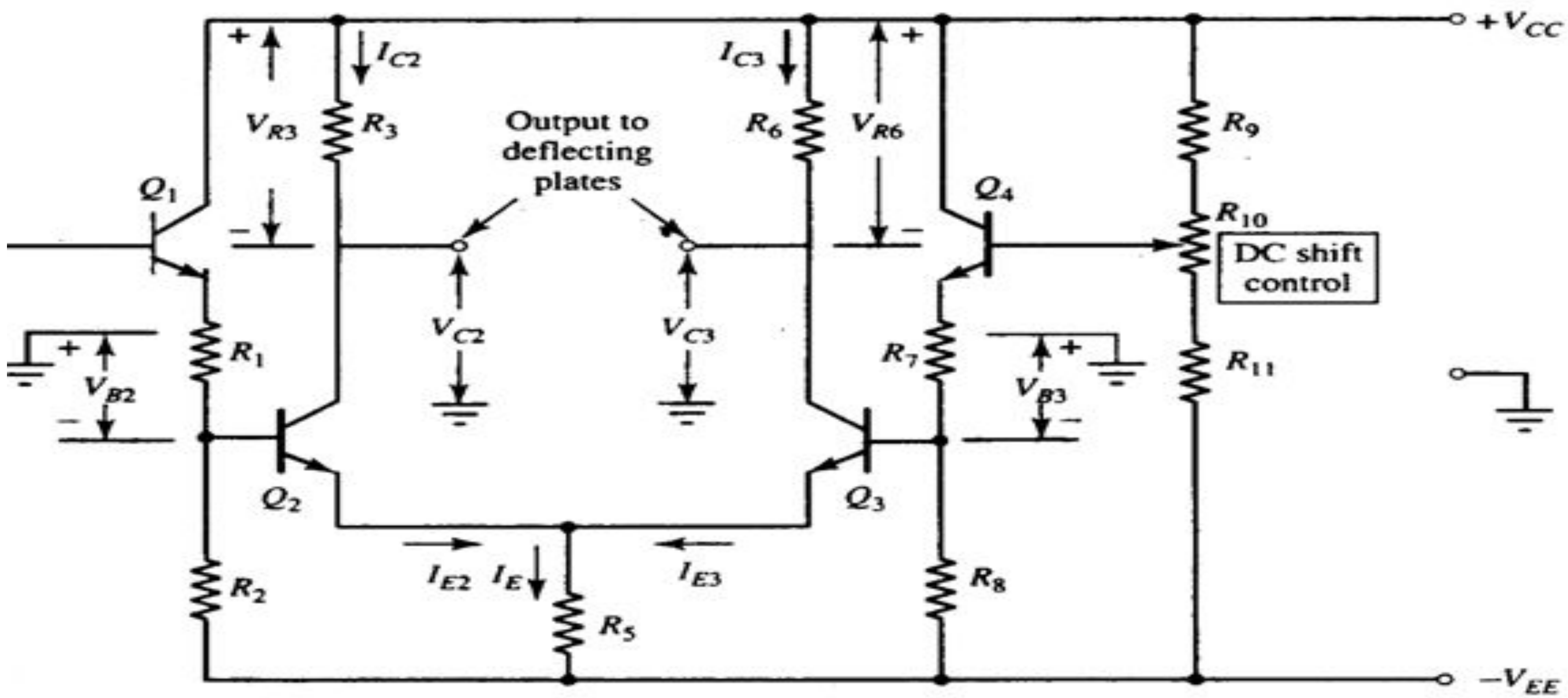
- Any voltage that is to produce deflection of the electron beam must be converted into two equal and opposite voltages, *+E/2* and *–E/2*.
- This requires a **differential amplifier** that accepts an (**ac or dc**) input and provides **differential** outputs.
- Transistors Q2 and Q3 form an **emitter-coupled amplifier**. Q1 and Q4 are **emitter followers** to provide high input resistance.

- When the input voltage to the attenuator is zero, the base of Q1 is at ground level. If Q4 base is also adjusted to ground level, Q2 and Q3 bases are both at the same negative potential with respect to ground ($-V_{B2} = -V_{B3}$). Also, $I_{C2} = I_{C3}$ and the voltage drops across R3 and R6 set the collectors of Q2 and Q3 at ground level. These collectors are the amplifier outputs, and they are connected directly to the deflection plates.



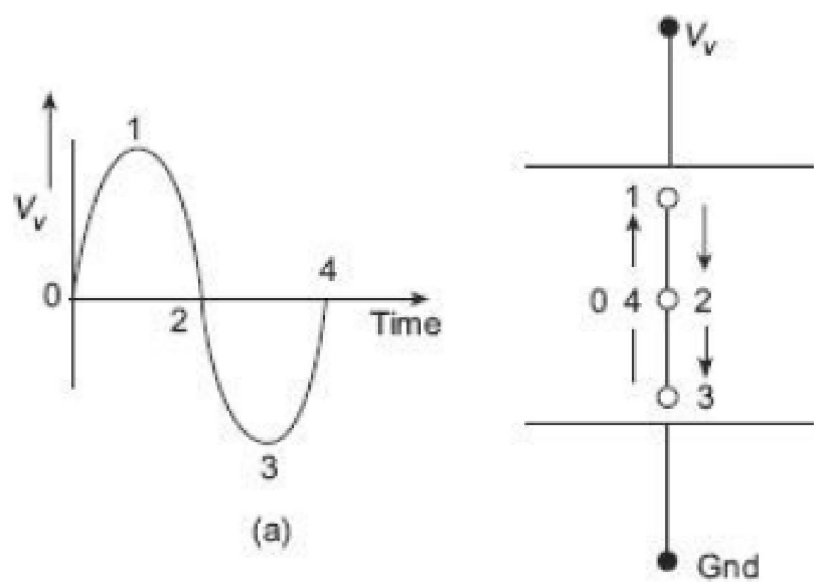
Deflection Amplifiers

- A positive-going input voltage produces a positive-going voltage at Q2 base, and causes I_{C2} to increase and I_{C3} to decrease (since $I_E = I_{C2} + I_{C3}$ and R_5 is acting as current source). The I_{C2} increase causes output V_{C2} to fall below its normal ground level, and the I_{C3} decrease makes V_{C3} rise above ground. If the change in V_{C2} is $\Delta V_{C2} = -1$ V, then $\Delta V_{C3} = +1$V.
- When the input to the attenuator is a negative-going quantity, I_{C2} decreases and I_{C3} increases. Now ΔV_{C2} is positive and ΔV_{C3} is an equal and opposite negative voltage.



Waveform display

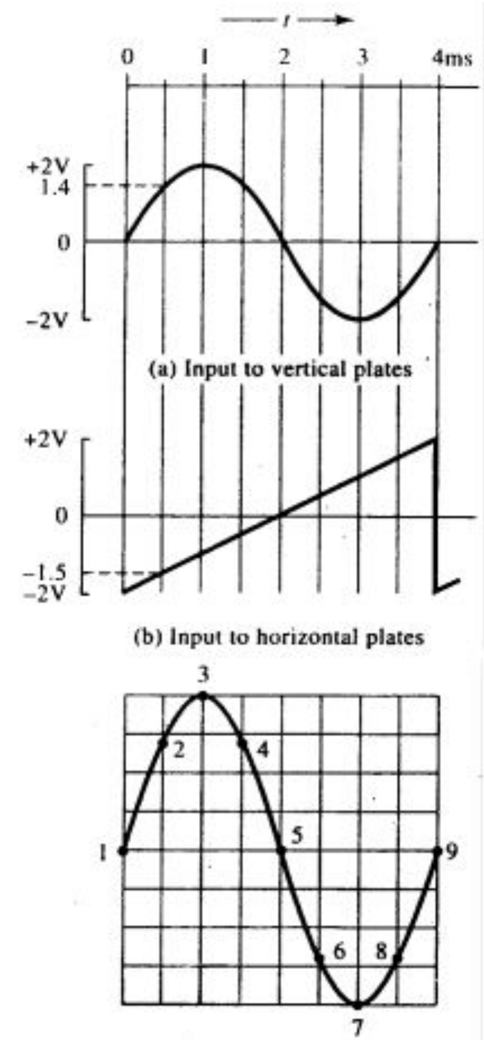
- When a **sinusoidal voltage** is applied to the **vertical deflecting** plates and **no input is applied to the horizontal plates**, the spot on the tube face moves up and down continuously tracing a vertical line in the middle of the screen.



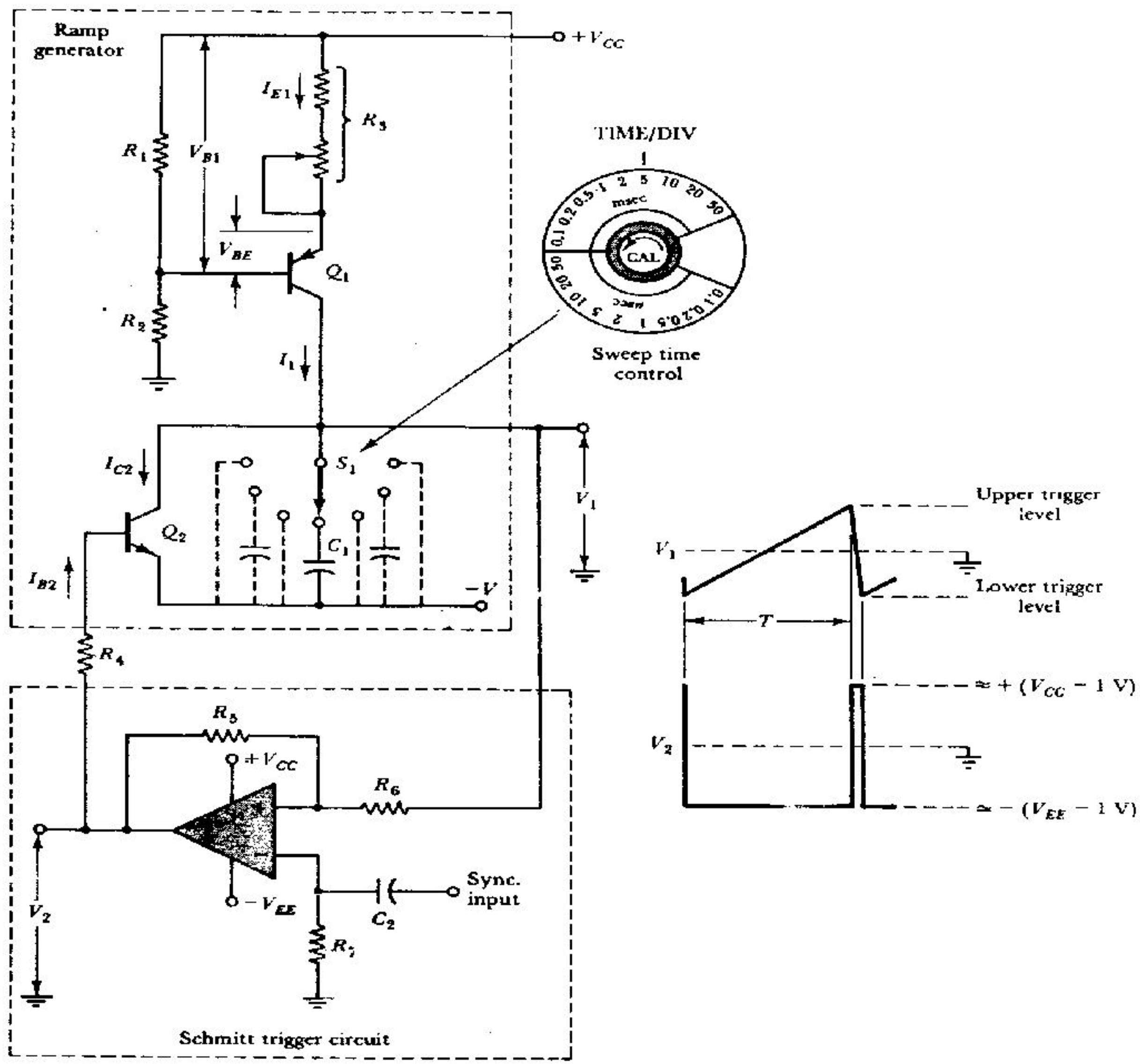
- If a **constantly increasing (ramp) voltage** is also applied to the **horizontal deflecting plates**, then, as well as moving vertically, the spot on the tube face moves horizontally.

Waveform display

- Consider the following Figure, in which a **sine wave** is applied to the **vertical deflecting plates** and a **sawtooth** (or **repetitive ramp**) is applied to **the horizontal plates**
- If the waveforms are **perfectly synchronized**, then **at time t = 0,** the **vertical deflecting voltage** is **zero** and the **horizontal deflecting voltage** is **-2 V**.
- Therefore, assuming a **deflecting sensitivity of 2 cm/V** the **vertical deflection is zero** and **the horizontal deflection is 4 cm left** from the center of the screen (**point1**).
- . ***At*** **t = 0.5 ms**, the **horizontal deflecting voltage** has become **-1.5 V**, i.e, the **horizontal deflection** is **3 cm left** from the screen center. The **vertical deflecting voltage** has now become **+1.4 V**. and this causes a **vertical deflection** of **+2.8 cm above** the center of the screen. The **spot is now 2.8 cm up and 3 cm left from the screen center** (**point 2**).

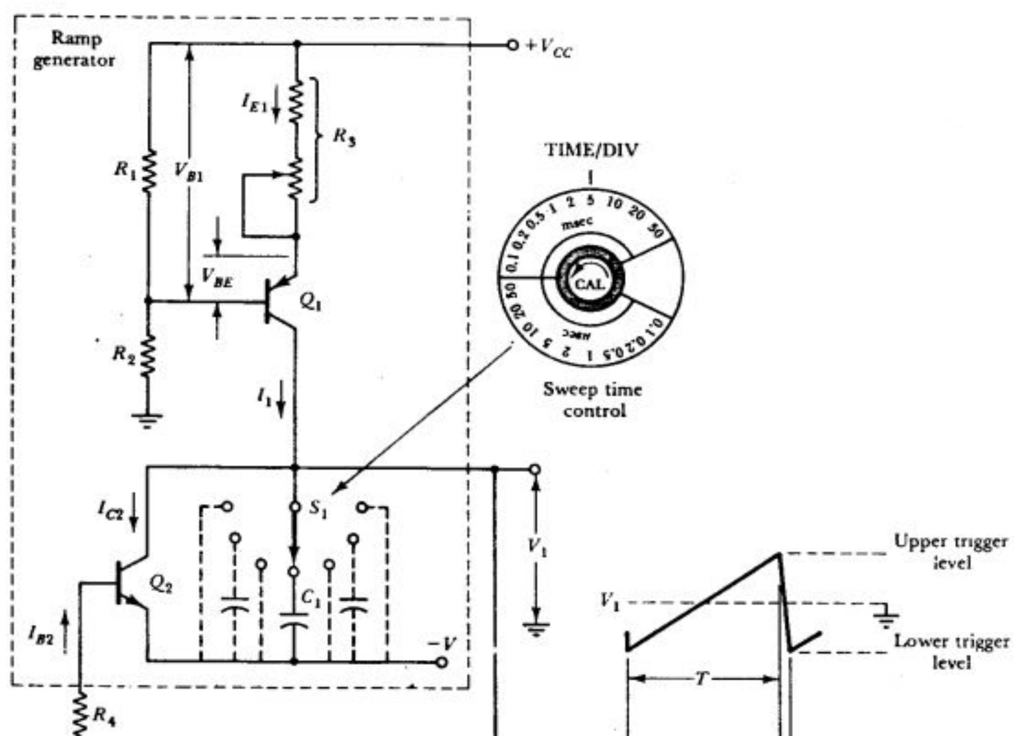


Oscilloscope time base
Horizontal Sweep Generator



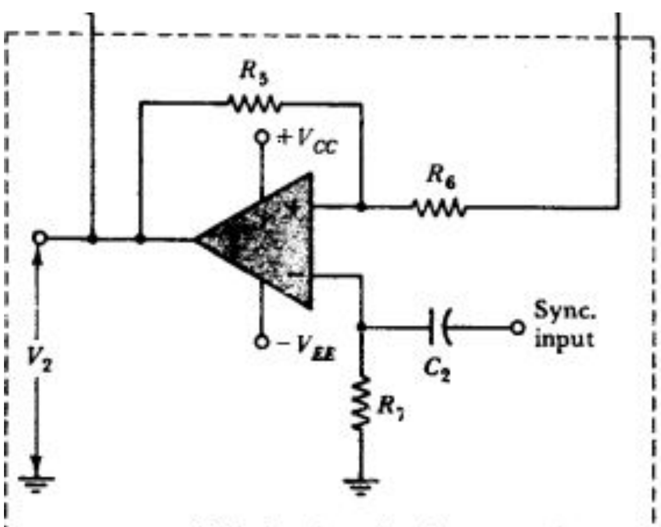
Horizontal Sweep Generator

- The sweep generator consists of two major components: **a ramp generator** and a **non-inverting Schmitt trigger circuit**.
- The **ramp generator** consists of Q1 which is a constant current source. The capacitor (C1) which is selected by S1 switch is charged by the collector current of Q1. Hence a ramp voltage is generated across C1.



Schmitt trigger circuit

- The **Schmitt trigger circuit** consists of the operational amplifier.
- The inverting input terminal of the operational amplifier is grounded via resistor R7.
- The input voltage to the Schmitt is the ramp generator output (V1), applied via resistor R6.
- Because the op-amp has a very large voltage gain (typically 200000), a very small difference between the inverting and non-inverting terminals causes the Schmitt output to be saturated. This means that the output voltage is very close to either the positive or the negative supply voltages. Typically, the saturated output voltage is $+(V_{CC} - 1V)$, or $-(V_{EE} - 1V)$.

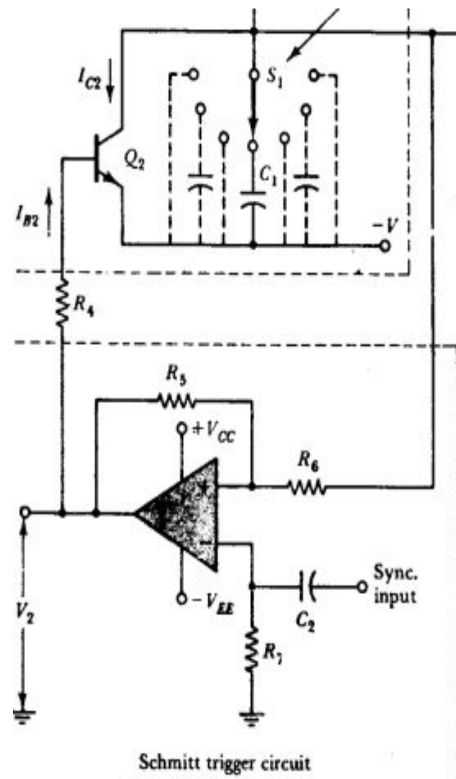


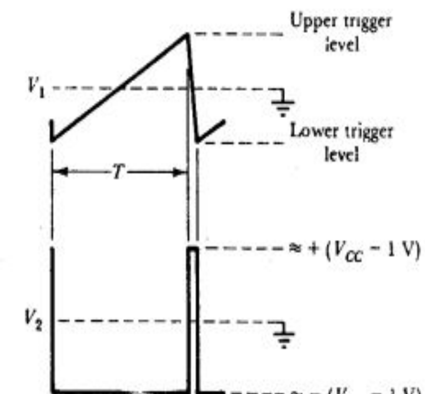
Schmitt trigger circuit

Horizontal Sweep Generator

Assume that the Schmitt input is negative, and that the ramp input to the Schmitt is at its minimum level. The voltages at both ends of potential divider *R5, R6* are negative, so the junction of *R5* and *R6* must also be negative. Thus, the op-amp non-inverting terminal voltage is below the level of the (grounded) inverting terminal, and the op-amp output remains saturated in a negative direction. This keeps Q2 biased off.

As the ramp voltage grows, the voltage at the junction of *R5* and *R6* rises toward ground. When the ramp reaches a high enough positive level, the non-inverting input terminal is eventually raised slightly above ground. This causes the op-amp output to switch rapidly from the negative saturated level to saturation in the positive direction.

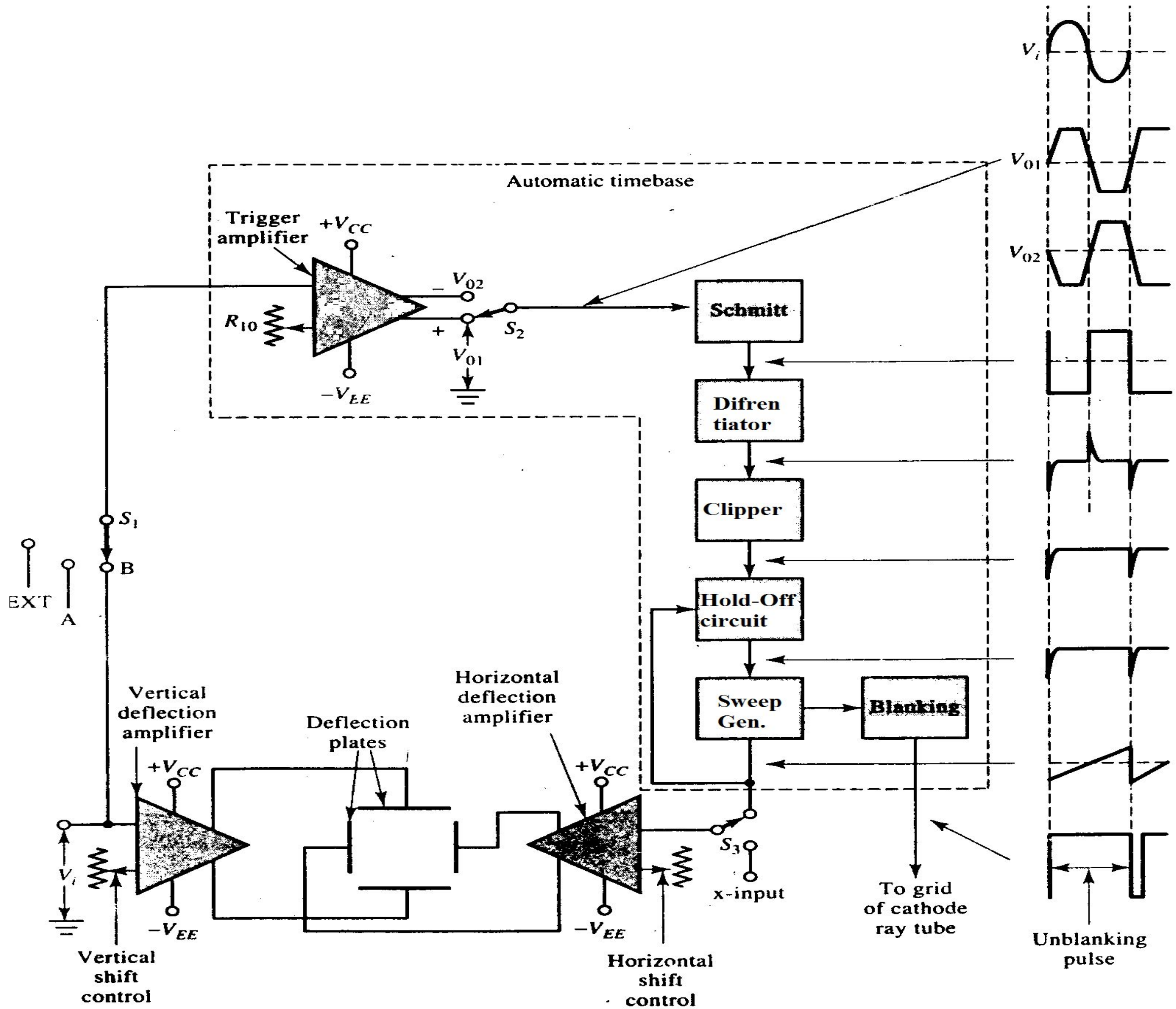




Automatic Time Base

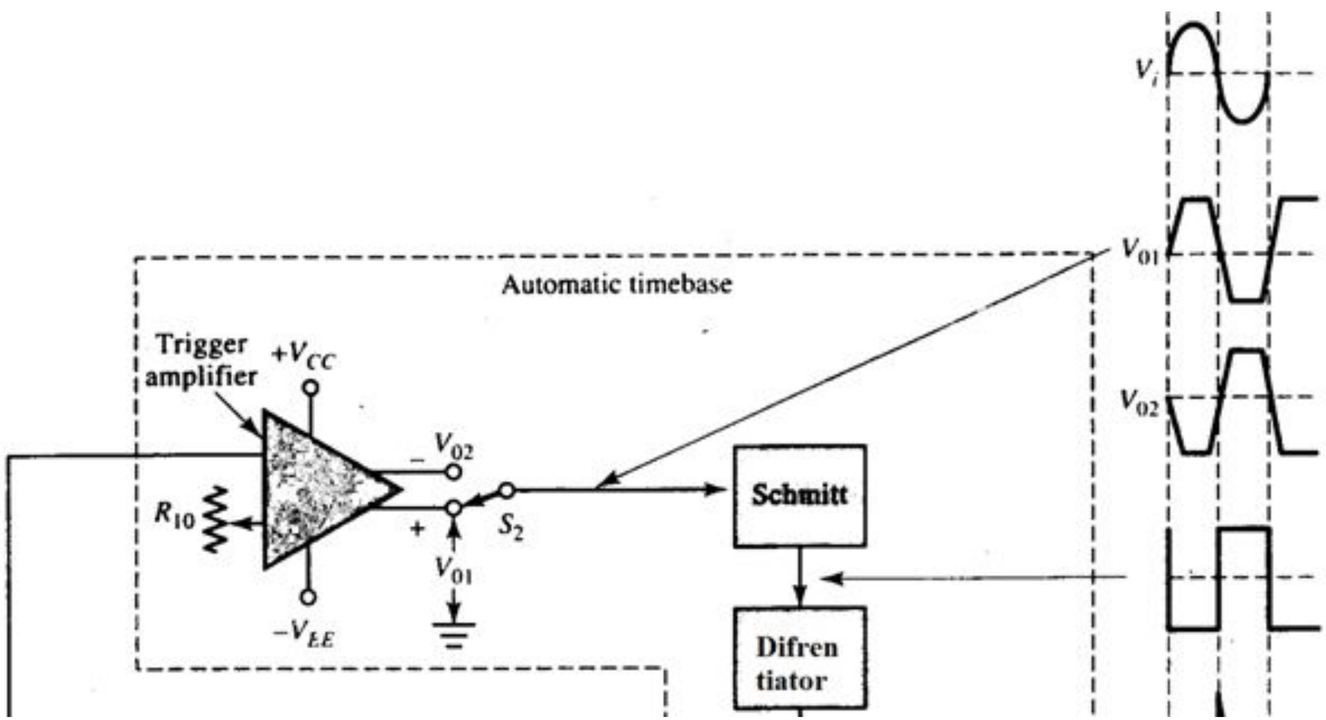
- For a waveform to be displayed correctly on an oscilloscope, it is important that the ramp voltage producing **the horizontal sweep begin at the same time the displayed waveform goes positive**.
- The ramp wave must be **synchronized** with the input waveform. If the input and ramp waveforms are not synchronized, the displayed wave will appear to continuously slide off to one side of the screen.
- Synchronization is accomplished by means of the **sync input** to the Schmitt trigger in the previous figure, and by the other components of the **automatic time base** in the following figure.

Automatic Time Base



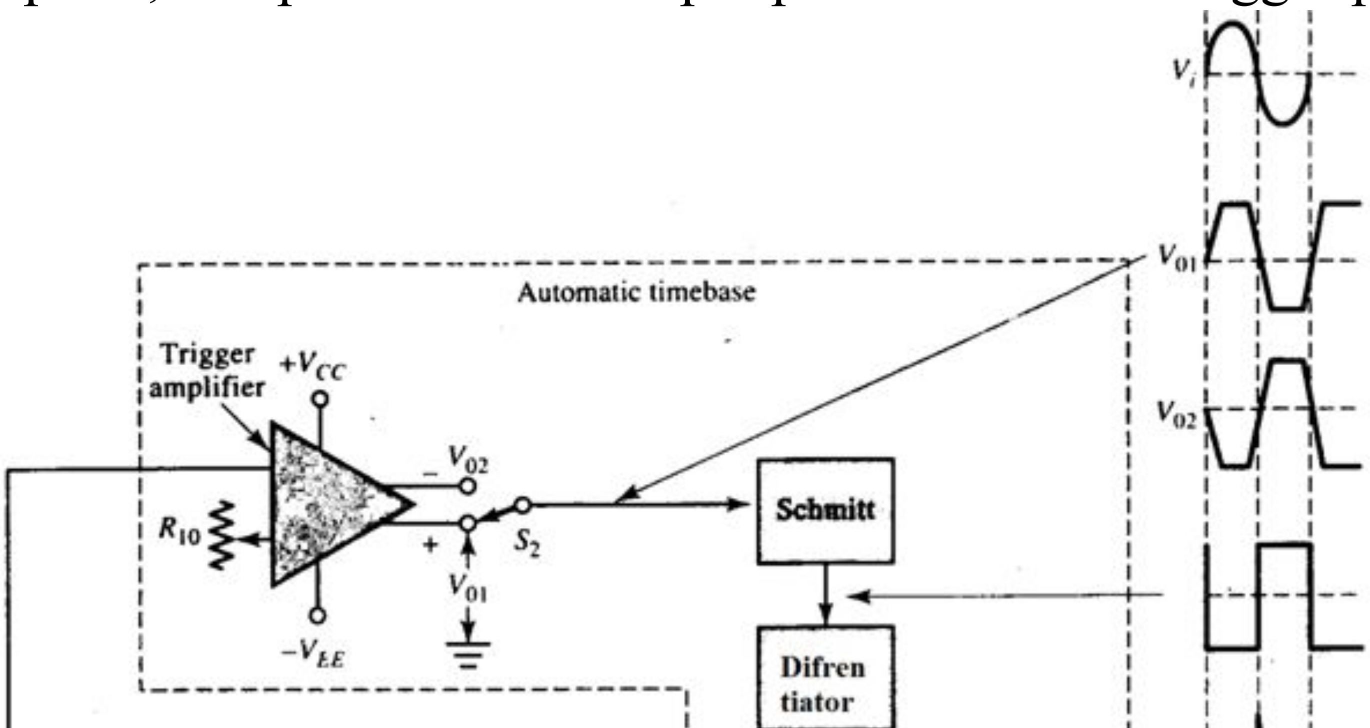
Automatic Time Base

- The voltage waveform to be displayed (V_i) is applied to the **vertical amplifier** and to the time base **triggering amplifier**.
- Like the vertical amplifier, the triggering amplifier has differential outputs. These provide two identical but antiphase voltage waveforms (V_{O1} and V_{O2}). In the **triggering amplifier** the input is amplified so much that its peaks are cut off by saturation of the amplifier output stage. So the output waveforms are almost square.



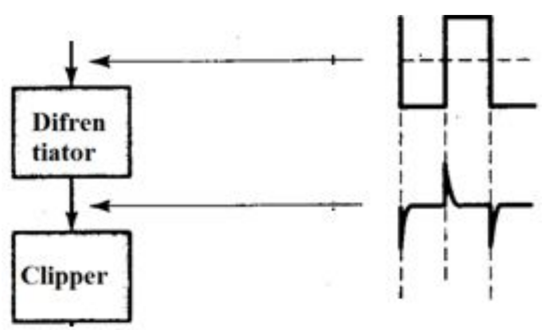
Automatic Time Base

- One of these waveforms is passed via switch S2 to the input of an inverting Schmitt trigger circuit.
- The Schmitt is designed to have upper and lower trigger points slightly above and below ground.
- With this condition, it is often called (**zero-crossing detector**) The Schmitt output rapidly goes negative as the input passes the upper trigger point, and positive as the input passes the lower trigger point.



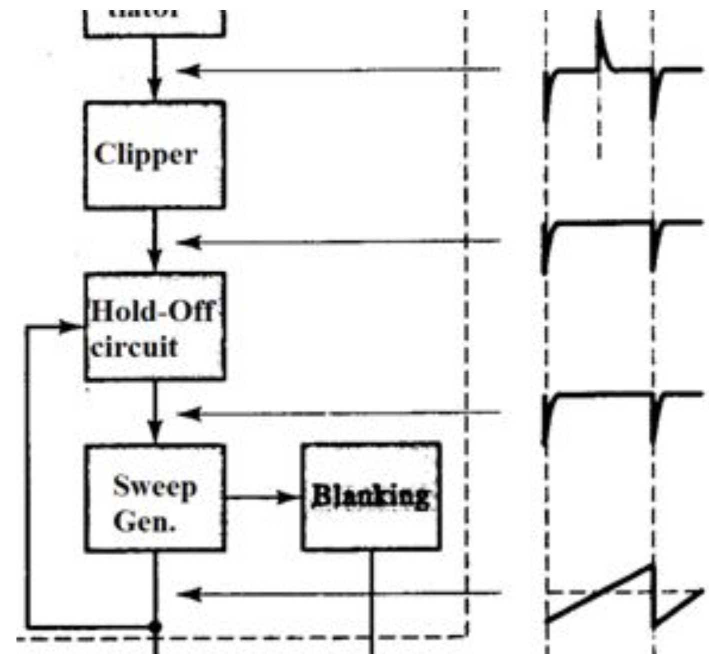
Automatic Time Base

- The output from the Schmitt circuit is a square waveform exactly in antiphase with the input wave to be displayed.
- This square wave is applied to a ***differentiating circuit***. The output produced by the differentiator is proportional to the rate of change of the square wave.
- During the times that the square wave is at its constant positive level or at its constant negative level, its rate of change is zero. So the differentiator output is zero at these times.
- At the positive-going edge of the square wave, the rate of change is a large positive quantity.
- At the negative-going edge, the rate of change is a large negative quantity. Therefore, the differentiated square wave is a series of positive spikes coinciding with the positive-going edges of the square wave, and negative spikes coinciding with the negative-going edges.



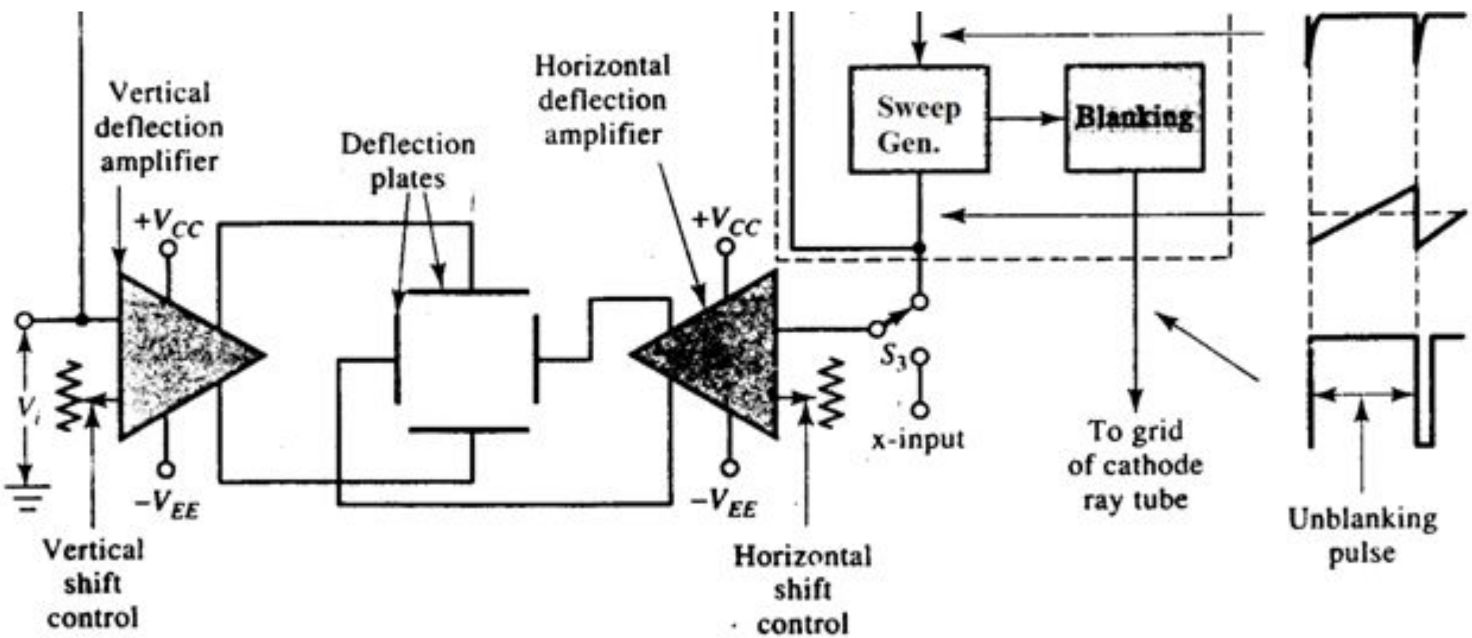
Automatic Time Base

- The spike waveform is now fed to a **positive clipper circuit.** This is essentially a rectifier circuit that passes the negative spikes but blocks (or clips off) the positive spikes.
- The negative spikes (which coincide with the commencement of each cycle of the original input) are passed via a **hold-off circuit** to the sync input of the sweep generator.



Automatic Time Base

- It is seen that the train of negative spikes causes the ramp output of the sweep generator to be synchronized with the input waveform that is to be displayed.
- The ramp commences at the beginning of each positive half-cycle of the input.
- The ramp output from the sweep generator is fed to the horizontal deflection amplifier.



Dual-trace oscilloscopes

•Most oscilloscopes can display ***two waveforms***. This allows waveforms to be compared in terms of amplitude and phase or time.

•Two input terminals and two sets of controls are provided, identified as channel *A* and channel *B*.

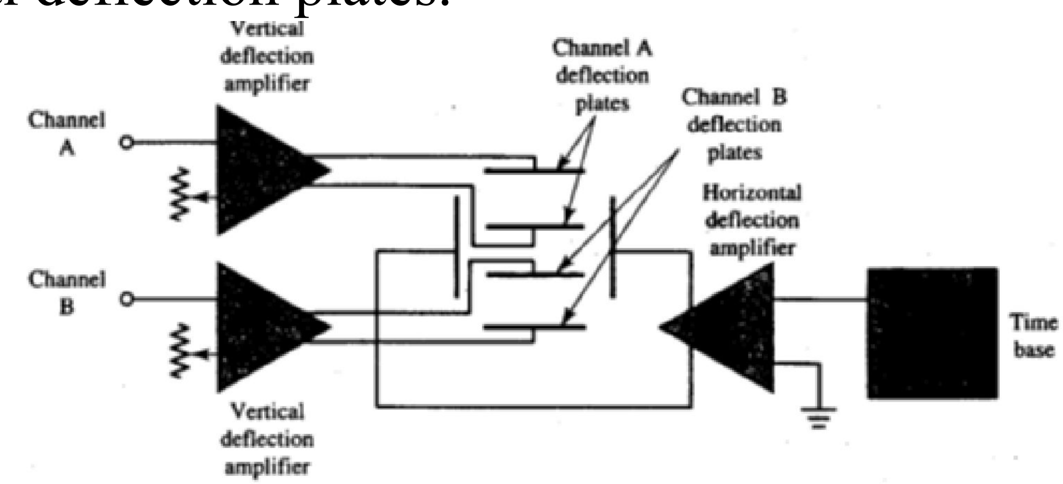
•The construction of a dual-trace CRT involves two complete electron guns are contained in a single tube, and the instrument can be termed as ***dualbeam*** *oscilloscope.*

Dual-trace oscilloscopes

•In another type of dual-trace CRT, a single electron gun is involved, but the beam is split into two separate beams before it passes to the deflection plates. This is referred to as a ***split-beam*** CRT.

•The ***dual-beam and split-beam*** instruments each have, only ***one set of horizontal deflection***. The sawtooth wave from the time base is applied to the ***single set of horizontal deflection plates,*** and both beams are made to sweep across the screen simultaneously.

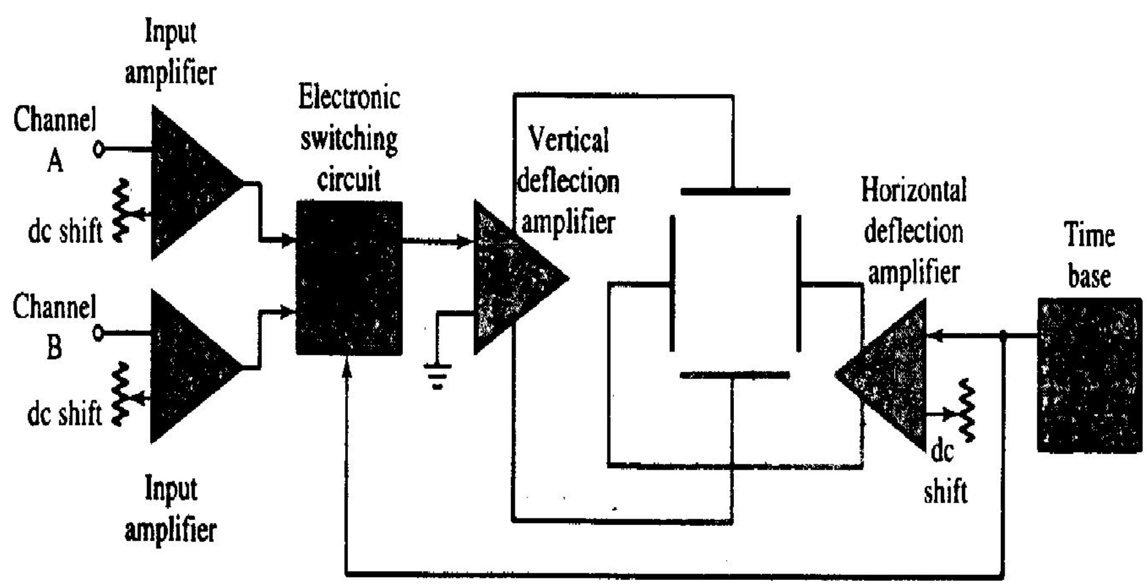
•There are ***two completely separate vertical inputs***: channel *A* and channel *B*. ***Each channel has its own deflection amplifier*** feeding ***one pair*** of vertical deflection plates.



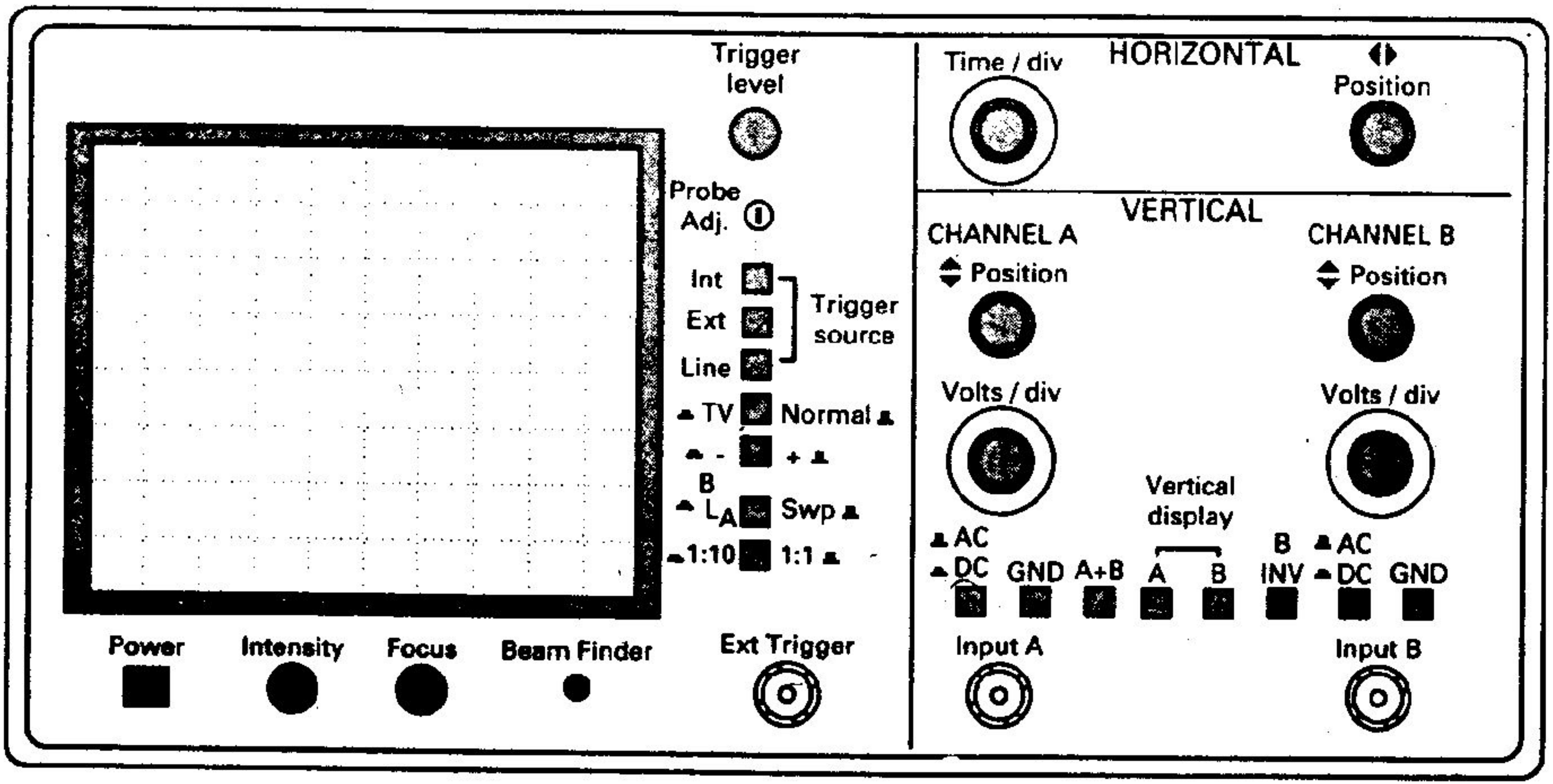
Dual-trace oscilloscopes

•Another common type of ***dual trace*** oscilloscope is (**the switched single beam**). ***A single-beam CRT*** with only ***one set of vertical deflection plates***. ***Two separate (channel A and channel B) input amplifiers*** are employed, with ***a single amplifier feeding the vertical deflection plates***.

•The input to this amplifier is alternately ***switched*** between channels *A* and *B,* and the switching frequency is controlled by the time base circuit.



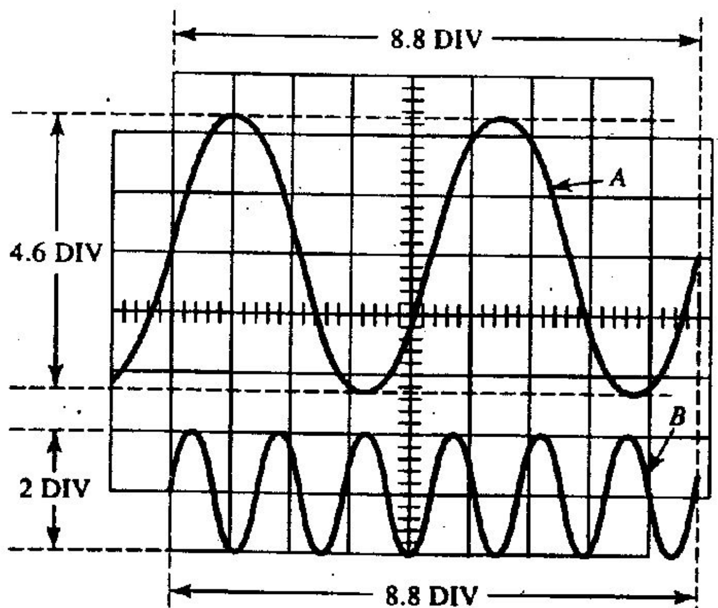
Oscilloscope control switches



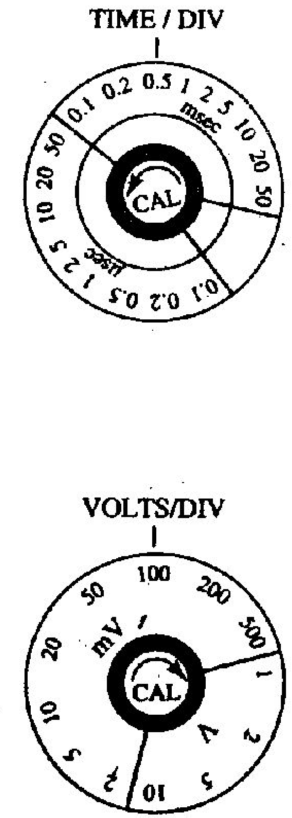
Measurement of Voltage

•**The peak-to-peak amplitude** of a displayed waveform is very easily measured on an oscilloscope.

•*The central vernier knob on the VOLTS/DIV control* ***should be put in its calibrated (CAL) position*** *before measuring the waveform amplitudes.*



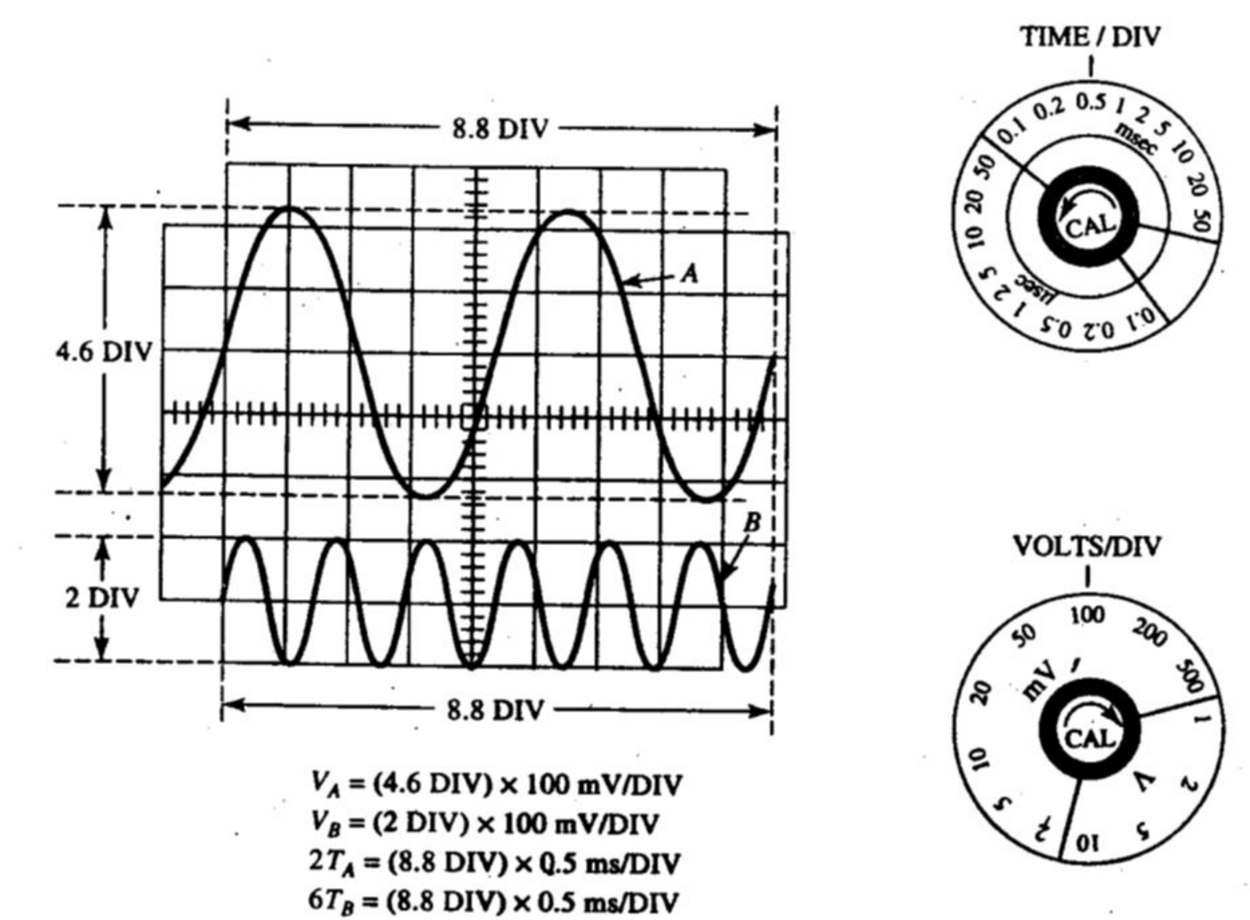
V_A = (4.6 DIV) × 100 mV/DIV
V_B = (2 DIV) × 100 mV/DIV
$2T_A$ = (8.8 DIV) × 0.5 ms/DIV
$6T_B$ = (8.8 DIV) × 0.5 ms/DIV



Measurement of Voltage

- Waveform *A* has a peak-to-peak amplitude of 4.6 vertical divisions on the screen,
- Waveform *B* has 2 vertical divisions peak-to-peak.

Peak to peak voltage = (vertical p-to-p divisions) x (VOLTS/DIV)



Frequency Determination

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

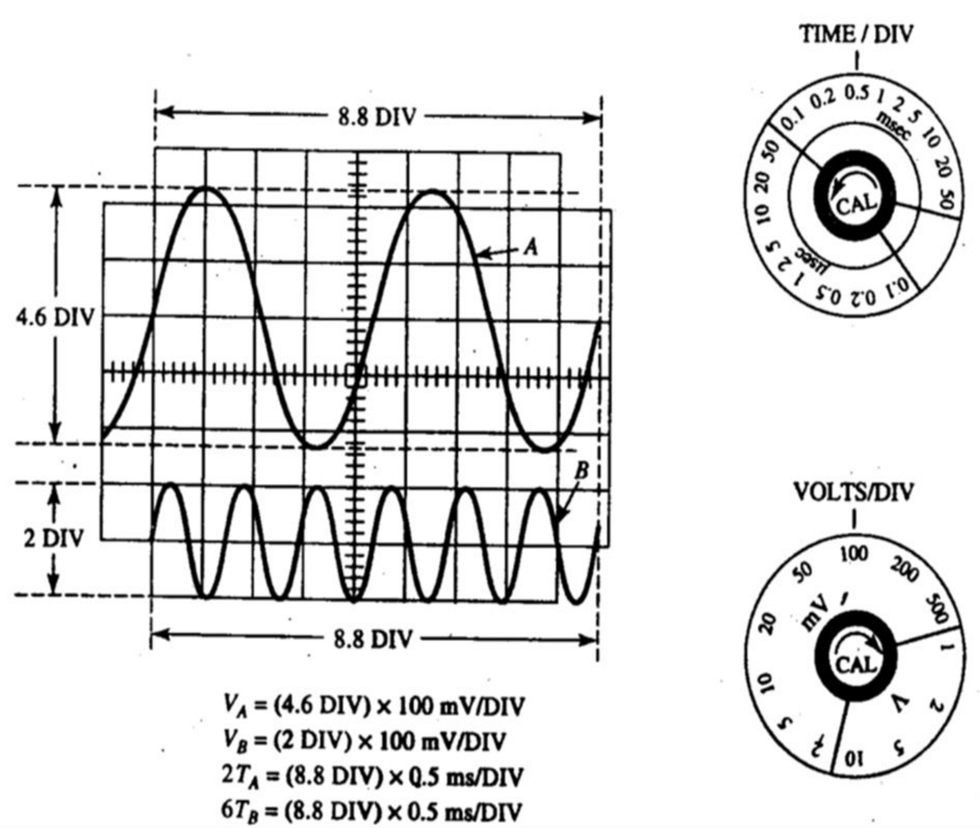
The time period T = (horizontal divisions/cycle) x (TIMEIDIV)

Wave *A*, $T = \dfrac{(8.8 \text{ divisions}) \times 0.5 \text{ ms}}{2 \text{ cycles}} = 2.2 \text{ ms}$

$f = \dfrac{1}{2.2 \text{ ms}} \simeq 455 \text{ Hz}$

Wave *B*, $T = \dfrac{(8.8 \text{ divisions}) \times 0.5 \text{ ms}}{6 \text{ cycles}} = 0.73 \text{ ms}$

$f = \dfrac{1}{0.73 \text{ ms}} \simeq 1.36 \text{ kHz}$



Phase Measurement

•The phase difference between ‘two waveforms is measured by the method illustrated in the following Figure.

•Each wave has a *time period of **8** horizontal divisions*, and the *time between commencement of each cycle is **1.4** divisions*.
One cycle = 360°. Therefore, 8 div = 360° and

$$1 \text{ div} = \frac{360^\circ}{8} = 45^\circ$$

Thus, the phase difference is $\phi = 1.4 \text{ div} \times (45^\circ/\text{div})$

$$= 63^\circ$$

$$\phi = (\text{phase difference in divisions}) \times (\text{degrees/div})$$