EXPERIMENT 11	MEASUREMENTS WITH A CATHODE RAY OSCILLOSCOPE

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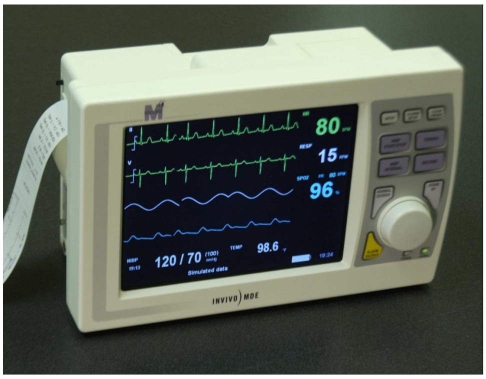
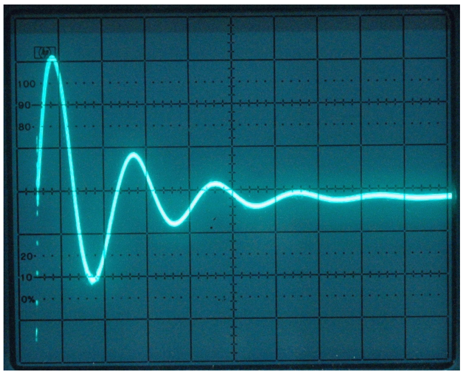
Structure





11.1 INTRODUCTION

A Cathode Ray Oscilloscope, abbreviated as CRO and referred to as oscilloscope, in short, is now a basic, important and versatile instrument in every electronics and electrical engineering laboratory. In the previous experiment, you got opportunities to measure voltages of a dc-source and an ac-source using a voltmeter and a multimeter. If you study time variation of these voltages, you will observe that the dc voltage remains constant with time (the curve is a straight line parallel to the x-axis in a voltage versus time graph), whereas ac voltage varies sinusoidally with time. While an ac-voltmeter or multimeter can give us information about the magnitudes of the voltages, details on the nature of waveform (of an ac or dc signal) remain hidden. To display a signal or a waveform of any type, we have to use an oscilloscope. This characteristic of CRO makes it a vital tool in medical diagnostics and care.

On a CRO, you can measure important characteristic parameters of a signal like voltage amplitude, frequency, period and shape of the waveform. On a CRO screen, a luminous spot enables us to study the instantaneous value of input voltage. For this reason, an oscilloscope can also be viewed as a plotter or a recorder.

In this experiment, you will learn basic functions of an oscilloscope. In particular, you will measure frequency of an alternating signal and phase difference between two sinusoidal waveforms.

Objectives

After performing this experiment, you should be able to:

- explain the basic functions of various controls on the front panel of the CRO;
- display a waveform/signal on the screen of the oscilloscope;
- measure the dc-voltage of a source;
- measure the peak-to-peak voltage and frequency of a sinusoidal waveform; and
- measure the phase difference between two sinusoidal waveforms.

11.2 FAMILIARISATION WITH AN OSCILLOSCOPE

Fig.11.1 shows one of the commonly available oscilloscopes. A CRO is essentially an assembly of a cathode ray tube (CRT) and specific electronic circuits. The CRT is the major component of the CRO. It produces a sharply focussed high speed electron beam, which can be moved on the screen using appropriate voltages for deflection. The front panel consists of the CRT screen and various control knobs, which are used for different purposes. The functions of these control knobs are discussed later in this section.

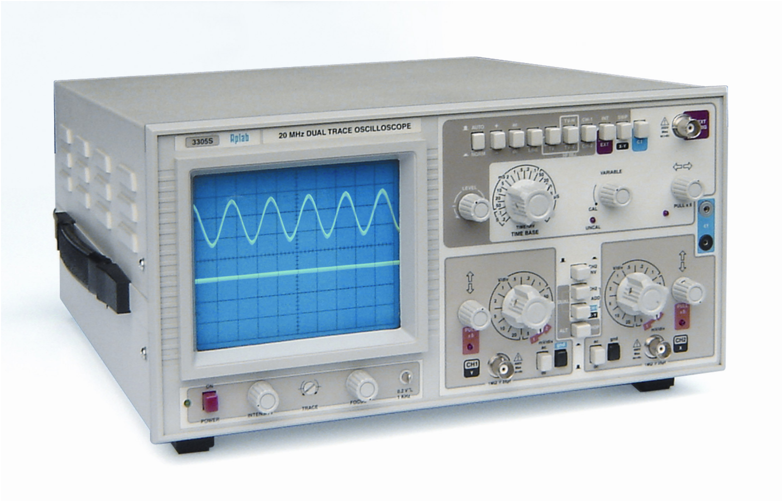


Fig.11.1: A typical CRO (Printed with permission from M/s Aplab Ltd.)

Fig.11.2 shows a schematic diagram of a CRT. It is an evacuated glass envelop with the following essential components:

- an electron gun;
- deflection plates; and
- a fluorescent screen.

The electron gun comprises the following parts:

- a heater or a cathode that emits electrons;
- a control grid to control the current;
- a focusing electrode to produce pencil-like electron beam; and
- accelerating and pre-accelerating electrodes to provide high velocity to electrons, which, on striking the screen, may cause secondary emissions.

The deflection assembly comprises a set of vertical and horizontal plates separated at a distance. The CRT has a fluorescent material such as ZnS. In a CRO, the electron beam emanating from the electron gun undergoes deflection before striking the screen.

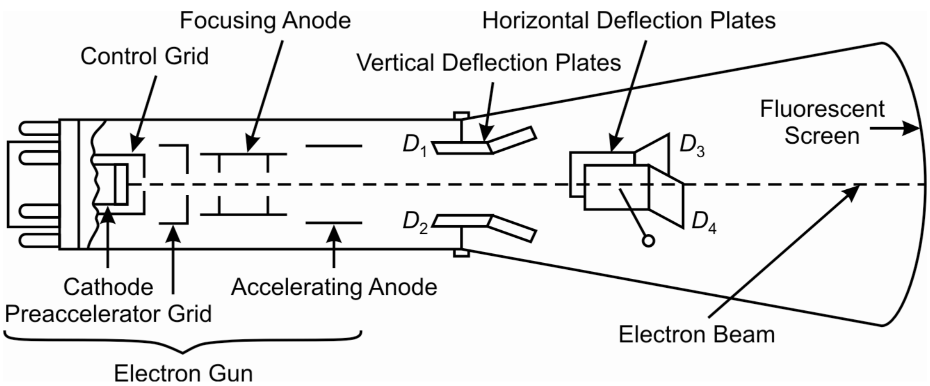


Fig.11.2: Schematics of a CRT

Since electrons are charged particles, deflection of electron beam can be effected either electrostatically or magnetically. In most of the oscilloscopes, the deflection of the beam is generally caused electrostatically. You may note that the potential applied across the plates D_1 and D_2 would deflect the beam vertically, whereas a potential applied to plates D_3 and D_4 would deflect the beam horizontally. Further, the magnitude of the deflection is proportional to the voltage applied across these plates. In a CRT, with display screen of about 10 cm, under ordinary conditions, a deflection of about 2.5 cm could be obtained for a potential of about 100V. Since the signals are well below 100V in a real situation, we need to amplify signals. Therefore, deflection amplifiers are provided for each pair of deflection plates.

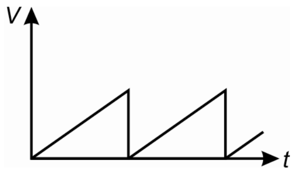


Fig.11.3: Sawtooth waveform

You may now like to understand how waveform is displayed in an oscilloscope. For a dc-voltage applied to plates D_3 and D_4 (horizontal deflection plates), the spot on CRO screen will move either to the left or to the right, depending on whether D_3 is at a lower or higher potential than D_4. In order to generate a straight line on CRO display screen, a linearly increasing voltage with time (called ramp waveform) is applied between D_3 and D_4. This shifts the spot from extreme left to extreme right of the screen. If the voltage is brought to zero and again applied, the motion of electron beam (spot on the screen) may be repeated from left to right. Such a waveform is called a saw-tooth waveform, as shown in Fig. 11.3. If this process is repeated at a faster rate, you will see a straight line formed by the moving spot due to persistence of vision.

When a dc-voltage is applied to plates D_1 and D_2 (vertical deflection plates), you may see the spot moving up or down on the screen depending on the potential of D_1 relative to D_2. If we apply a time varying waveform like sinusoidal, square, triangular etc. across the vertical deflection plates, it will also appear as a spot moving up and down on the screen. However, application of a saw-tooth waveform to the horizontal deflection plates gives rise to display along the time axis. Let us now understand how display evolves on time scale.

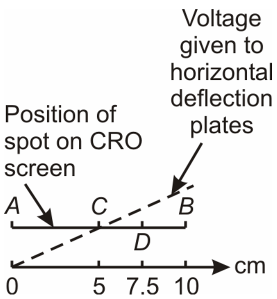


Fig. 11.4: Horizontal time base of CRO

The time period of a saw-tooth wave of frequency 50 Hz, applied to the horizontal deflection plate (Fig. 11.3) is 20 ms. Suppose that it traces a line of length AB = 10 cm on CRO screen, as shown in Fig. 11.4. Then at t = 0, the spot will be located at the point A. After 10 ms, it will be at the point C as the saw-tooth voltage increases to half of its peak value. After 15 ms, the spot will reach the point D such that AD is three fourth of the line AB. In this way, you can calibrate line AB in time, i.e., half of it to 10 ms; quarter of it to 5 ms and so on.

Consider that a sinusoidal signal of frequency 50 Hz shown in Fig. 11.5a is applied to vertical deflection plates. At the same time we apply a saw-tooth voltage of the same frequency across the horizontal deflection plates (Fig. 11.5c). The trace obtained on the CRO screen is shown in (Fig.11.5b). Note that at A_1, the sinusoidal wave has zero voltage and so there will be no deflection in the vertical direction. The horizontal input corresponds to the lowest voltage at A_1' and thus the spot moves to the extreme left point A on the screen. After 5 ms, the vertical input will correspond to A_2. This will move the spot upward. Since at the same time the horizontal input is less negative at A_2', the spot moves rightwards as well. This results in the position B of the spot on the CRO screen. After 10 ms, the vertical and the horizontal inputs will correspond to points A_3 and A_3', respectively; the voltage will be zero. This leads the spot to move to point C on the screen. Continuing the same way, we finally obtain the points A, B, C, D and E on the CRO screen corresponding to points A_1, A_2, A_3 A_4 and A_5 on the vertical input and A_1', A_2', A_3', A_4' and A_5' on the horizontal input.

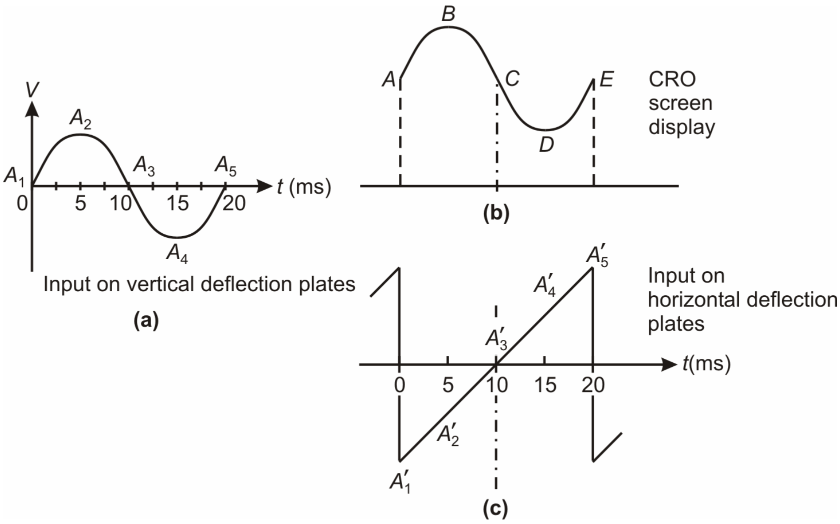


Fig.11.5: Display of 50 Hz sinusoidal wave on CRO: a) input to vertical deflection plates; b) trace on the CRO screen; and c) input on the horizontal deflection plates.

From the above discussion, you can conclude that for **an oscilloscope to display the variation of an electrical signal in the vertical direction as a function of time, a voltage varying linearly with time such as a saw-tooth wave will have to be applied on the horizontal deflection plates**. An oscillator which generates such a voltage is called a saw-tooth oscillator or a sweep generator. The block diagram of a general purpose oscilloscope with its vital components/features is shown in Fig.11.6.

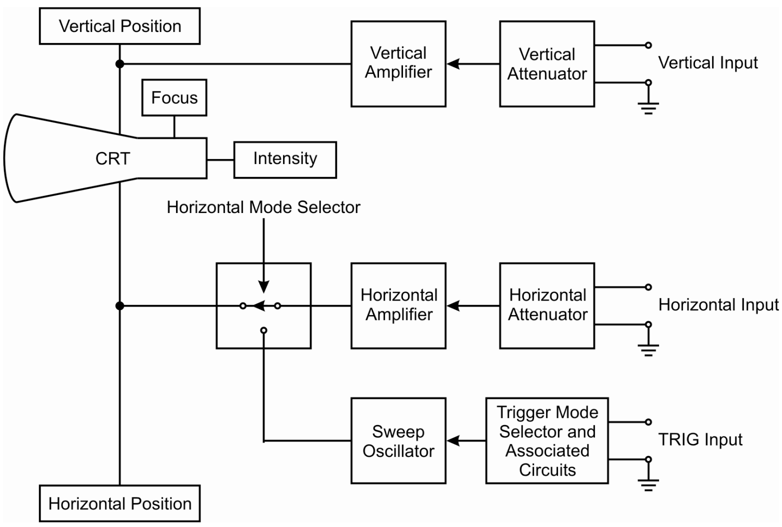


Fig.11.6: Block diagram of a general purpose CRO

To provide a more stable trace, an additional feature in the form of a *trigger* is provided in present day oscilloscopes. While using a trigger, the CRO pauses in each cycle when the sweep reaches extreme right side of the screen and retraces back to the left hand side of the screen. Then it waits for a specified event before starting the next trace. The trigger event is usually the input waveform reaching some user-specified threshold voltage in a specified direction (going positive or negative).

For proper operation of an oscilloscope, all the controls are mounted on the front panel. Fig.11.7 depicts the location of various controls on the front panel of a typical general purpose dual beam oscilloscope. In such a CRO, two signals can be viewed simultaneously on two separate channels. We may add here that the location of different controls can vary from one make to another.

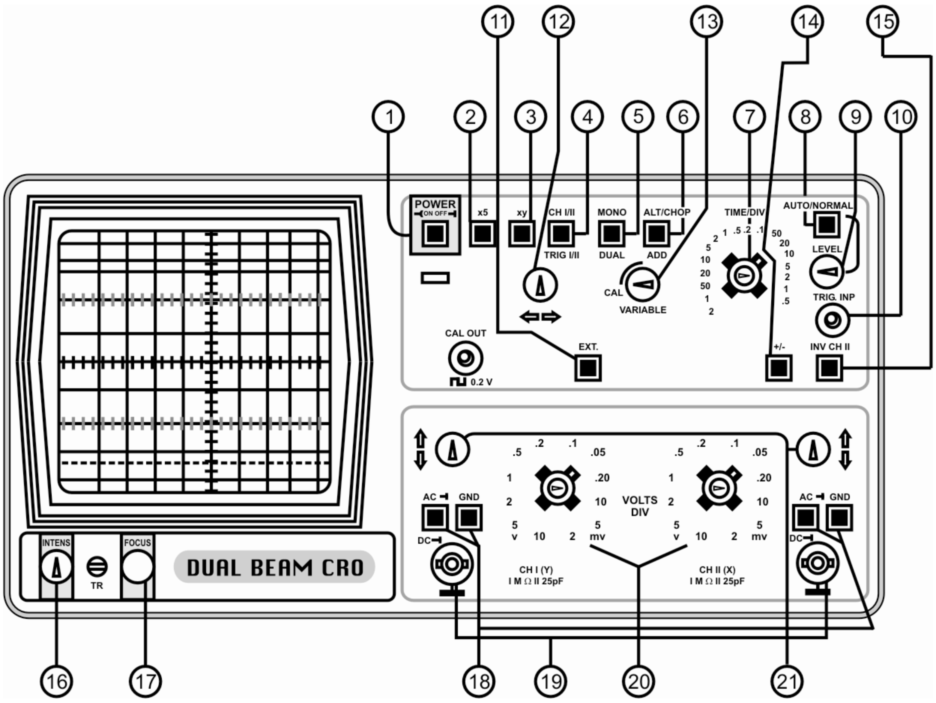


Fig.11.7: Schematic diagram of front panel of a general purpose CRO

You must carefully read and understand the function of each control. Then, you should see for yourself how some of the basic controls on the front panel affect a given trace. For this, first switch *on* the oscilloscope and obtain a horizontal line on the CRO screen. (In case of a dual trace oscilloscope, you should obtain two straight lines.) You need not have any connections to the vertical input sections at this stage. Now adjust the controls listed in Table 11.1 and record your observations.

Table 11.1: Some basic controls on CRO front panel

Control	Observed effect
Intensity	--
Focus	--
Y-position	--
X-position	--

Table 11.2 describes the function of each control shown in Fig. 11.7.

Table 11.2: Controls on CRO front panel

No.	Control	Function
1.	Power	Turns mains power on/off.
2.	$\times 5$	When pressed, gives five times magnification of the signal.
3.	*X*-*Y*	It cuts off the time base fed to the horizontal plates when pressed and allows access to the horizontal signal fed through CH-II. It is used for *X*-*Y* display.
4.	CH-I/CH-II/Trig I/Trig II	It selects and triggers CH-I when it is out. On pressing, it selects and triggers CH-II.
5.	Mono/Dual	A switch to select the single/duel beam operation.
6.	Alt/Chop/Add	It selects alternate or chopped in DUAL mode. If mono is selected, it enables addition or subtraction of signals on two channels.
7.	Time/Div.	It selects time base speeds.
8.	AUTO/NORM	AUTO mode enables trace when no signal is fed at the trigger input. In NORM position, the trigger level can be varied using LEVEL control.
9.	LEVEL	It allows setting of the trigger level between peak-to-peak amplitude of the input signal.
10.	TRIG IN	A socket that is used to feed external trigger signal in EXT mode.
11.	EXT	Switch that allows External triggering signal to be fed from the socket marked TRIG IN.
12.	*X*-POS	This knob controls the horizontal position of the beam trace.
13.	VAR	Controls the time base speed in-between two steps of TIME/DIV switch.
14.	+/–	This switch selects the slope of triggering.
15.	INV CH.II	This switch when pressed inverts the signal at CH.II.
16.	INTENS	It controls the trace brightness.
17.	FOCUS	It controls the sharpness of the trace.
18.	DC/AC/GND	Coupling switch for each panel. In AC mode, the signal in coupled through 0.1μF capacitor.
19.	CH-I (*Y*) and CH-II (*X*)	BNC connectors serve as *Y*-input connections for CH-I and CH-II. CH-II input connector also serves as Horizontal external signal on using *X*-*Y* control.
20.	Volts/Div.	A switch to select the sensitivity of each channel.
21.	*Y*-Pos I and II	These controls are provided for vertical deflection of trace for each channel.

Let us now understand how a CRO enables us to make measurements.

11.3 VOLTAGE MEASUREMENT

You can use an oscilloscope to measure both dc-voltage and ac-voltage. To measure dc-voltage, you should first keep the DC/AC/GND switch in the GND (ground) position to establish the ground (zero-volt) level on the screen. Next you change the DC/AC/GND selector switch to the DC position to measure dc-voltage level. You should then place the leads of the oscilloscope across the unknown dc-voltage and note the deflection of the trace in the vertical direction. You can then measure the dc-voltage by using the relation

dc voltage = vertical deflection of the trace (cm) × vertical sensitivity (V/cm)

To measure ac-voltage, connect it to the channel-I input, keeping the DC/AC/GND switch in the AC mode. On the screen you will observe the waveform corresponding to the input signal. Now you measure the vertical distance between the maximum and minimum levels of the signal using the graduated scale on the screen, as shown in Fig. 11.8. If you multiply this distance (in cm) by the sensitivity you have selected (V/cm), you will get the magnitude of peak-to-peak voltage of the applied ac-voltage ($V_{p\text{-}p}$). You can calculate the root mean square (rms) value of the voltage by dividing $V_{p\text{-}p}$ by $\sqrt{2}$.

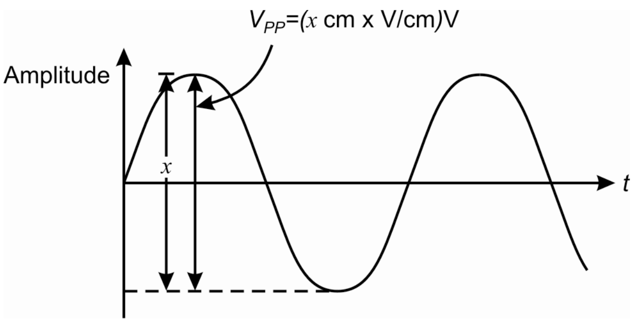


Fig.11.8: Peak-to-peak voltage measurement for ac-signal using CRO

We now discuss how CRO can be used to measure frequency of an input signal from an oscillator or a function generator. In other words, we can use the oscilloscope to make fine adjustments on the frequency set by the dials/knob of the oscillator/ function generator.

11.4 FREQUENCY MEASUREMENT

For this part of the experiment, you need a general purpose function generator, which can generate sinusoidal, triangular and square waveforms with adjustable frequency and amplitude, as shown in Fig. 11.9.

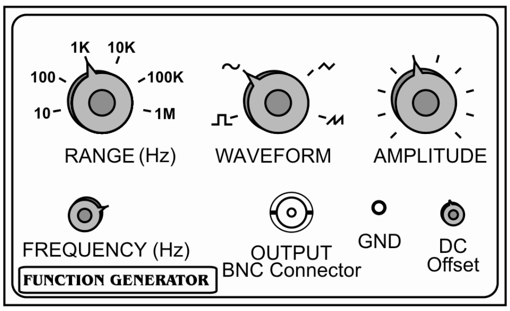


Fig. 11.9: Front panel of a typical function generator

A typical function generator has control knobs listed in Table 11.3.

Table 11.3: Controls of a typical function generator

No.	Control	Function
1.	WAVEFORM SELECTOR	Type of waveform/signal: a square wave, sinusoidal, triangular or saw-tooth waveform selection switch
2.	RANGE (Hz)	Frequency range selection switch (10-100-1K-10K-100K-1M)
3.	FREQUENCY	Frequency adjustment knob
4.	AMPLITUDE	Amplitude adjustment knob
5.	OFF SET	DC voltage can be added to the ac signal
6.	OUTPUT	BNC terminal giving out generator signal

To begin the experiment, connect the OUTPUT terminal of the function generator to the *Y*-input of the CRO. Select the time base on CRO at 0.5 ms/cm. Select the frequency of input signal to be 1 kHz and limit its amplitude to about 4V. Since the time period of the applied signal is 1/1000 = 1ms, one complete wave of the signal should appear in exactly two horizontal divisions. If it does not, you may fine tune by adjusting the frequency controls of the generator till the desired result is achieved. At this point, you have set the output frequency of the function generator to 1000 Hz.

To measure an unknown frequency, you have to essentially measure the period of the signal on the CRO screen. The period of the signal is the length of one cycle of signal on time (horizontal) axis in cm multiplied by the (time/div) setting. The frequency is given by the inverse of period.

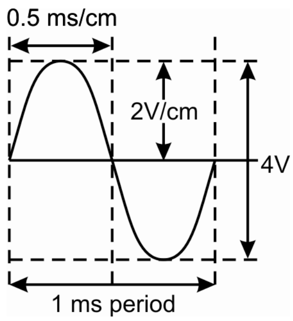


Fig.11.10: 1 kHz 4V ac signal on CRO

If the vertical gain control of the CRO is set at a deflection sensitivity of 2 V/cm, the ac-signal will be confined within a vertical length of 2 cm. Then we can write height of the trace (cm) = $V_{p\text{-}p}$/vertical sensitivity. This is shown in Fig. 11.10.

Observation Table 11.4: Measurement of frequency

$V_{p\text{-}p}$ of the input signal = ...V

S.No.	Selected frequency *f* (Hz)	Horizontal sensitivity *S* (s cm^{-1})	Extent of single cycle x (cm)	Period of signal $T = x \times S$ (s)	Measured frequency (Hz)
1.					
2.					
3.					
4.					
5.					

You may make necessary adjustments to get the waveform of say 2 V peak-to-peak from the function generator at different frequencies. We may denote these by *f*. For each of these sinusoidal waveforms, change the horizontal sensitivity (time/div) and obtain the number of divisions in centimetre horizontally occupied by the wave. Using the method described above, calculate the frequency of the signal. You may repeat the procedure using different horizontal sensitivities and compare the results obtained with known frequency. Record your observations in the Observation Table 11.4.

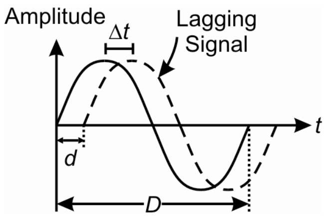


Fig.11.11: Phase difference measured on dual-trace CRO

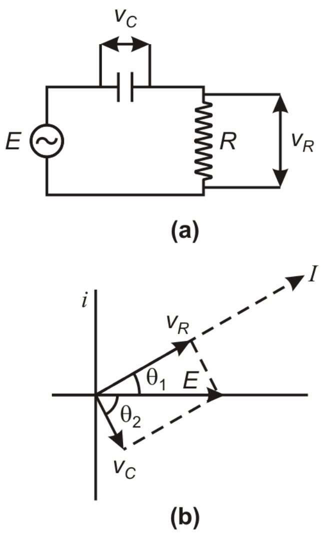


Fig.11.12: a) Phase shifting circuit; and b) Phasor diagram

11.5 DETERMINATION OF PHASE DIFFERENCE

You can use an oscilloscope to determine the phase difference between two signals of same frequency by two methods:

- dual-beam/trace comparison with a calibrated time base; and
- Lissajous pattern method.

We now discuss these in the following sections.

11.5.1 Dual-Beam/Trace Method

This method for determining phase difference between two waveforms of same frequency and equal or different amplitudes is quite accurate. It involves displaying both the signals on the CRO screen simultaneously. The distances (in time scale divisions) between two identical points on two traces (Fig.11.11) are measured. Here we choose one signal as a reference, that is, with zero-phase angle. Therefore, the signal being compared is said to be leading by an angle θ if it is to the left of the reference signal and lagging if it is to the right of the reference signal. The lead indicates +ve value of phase and vice versa. Now follow the following steps:

To begin with, obtain traces of both waveforms on the CRO screen, as shown in Fig. 11.11. For this you may use AC switch to set both patterns in the vertical centre of the display screen. Measure the horizontal distance D (cm) required for one full cycle of either waveform and calculate the scale factor $S = 360°/D$. Next, measure the horizontal distance d (cm) between corresponding positive slopes of the two waveforms. The phase angle θ between the two waveforms is therefore obtained by:

$$\theta = S.\, d = \left(\frac{d}{D}\right) 360^{\circ}. \tag{11.1}$$

In order to obtain two sinusoidal waves of equal frequency but differing in phase, you should use the circuit shown in Fig.11.12a. It is an *R*-*C* circuit, and you may recall that the current i at any instant would lead the applied voltage, as shown in the phasor diagram (Fig. 11.12b). Here the voltage v_R is in phase with i and the voltage across the capacitor v_c will lag the voltage E. Therefore, to obtain two sinusoidal waves with a phase difference, you may take the voltage E and choose either voltage v_R or v_c and feed them to two vertical channels of the oscilloscope. You may select the mode of operation-ALT or CHOP depending on the frequency of the signals. If the frequency of the input signal is less than 50 kHz, use CHOP mode. ALT mode is selected for frequencies greater than 50 kHz.

Refer to Fig. 11.13 and obtain the trace of the two signals. In this network, an ac-voltage of 8V (peak to peak) and frequency of 200 Hz has been taken from the function generator. This network shows that the voltages v_R and E have been fed to channels-I and II, respectively.

Initially, set the potentiometer R' to zero ohm. Choose a frequency f_0 Hz (say 200 Hz), and calculate the reactance $X_C = 1/(2\pi f_0 C)$. Record it in Observation Table 11.5.

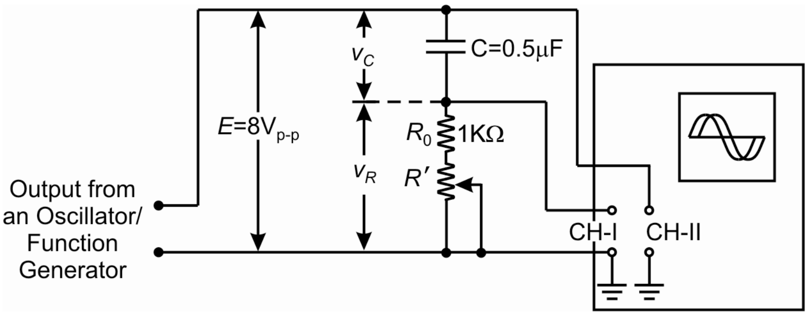


Fig.11.13: The network for measuring phase difference

Now change the potentiometer settings to vary the resistance value and measure the peak-to-peak voltages of the signals and record them. Also measure the phase difference on the screen in each case, as described earlier. The resistance values listed in the Observation Table are only representative of the real setting.

Observation Table 11.5: Measurement of phase difference

Input frequency, f_0 =....................Hz
Number of horizontal distance, D =....................
$S = 360^{\circ}/D$ = ...
Capacitive reactance, X_C =....................Ω
Constant resistance, R_0 = 1000 Ω

Potentiometer setting (R') (Ω)	**$R = R' + R_0$** (Ω)	**E (V)**	**v_R**		**θ_1**	
			Measured (V)	**Calculated (V)**	**Measured *s.d***	**Calculated**
0	1000					
1000	2000					
2000	3000					
4000	5000					

Now, for different values of R, you can calculate v_R and θ_1 using the following formulae:

$$|v_R| = \frac{E R}{\sqrt{R^2 + X_C^2}}, \qquad (11.2)$$

and

$$\theta_1 = \tan^{-1} \frac{X_C}{R}. \qquad (11.3)$$

Compare your calculated values with your observed values.

You must remember here that direct measurement of two traces can be done only if you have a CRO with double beam display facility (i.e. more than one channel). However, if this facility is not available, we use the method of Lissajous figures to determine the phase difference.

11.5.2 Lissajous Figures Method

A Lissajous figure could be obtained on the CRO screen when two sinusoidal waves are applied at the same time to both pairs of deflection plates. This method is also termed as *X*-*Y* phase measurement.

Suppose that two sinusoidal waves having the same frequency but different phases are superimposed. If θ denotes the phase difference, these may be written as

$$v_1 = a \sin \omega t$$

and

$$v_2 = b \sin (\omega t + \theta).$$

You may apply the voltage v_1 to the vertical deflection plate and v_2 to the horizontal deflection plate. From Unit 2 of Oscillations and Waves course, you may recall that depending on the value of θ, the resultant pattern will be either an ellipse or a straight line. In this experiment, you have to ensure that you obtain an ellipse on the CRO screen, as shown in Fig. 11.14.

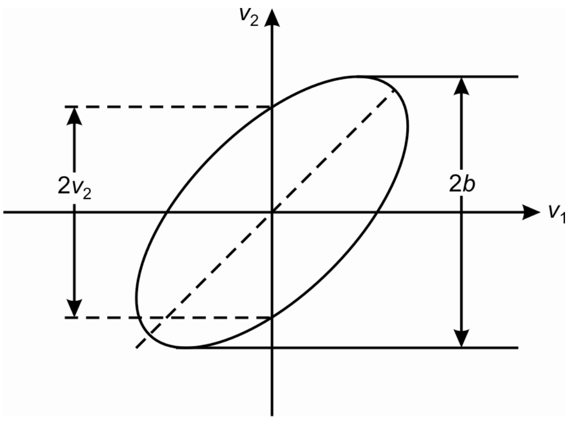
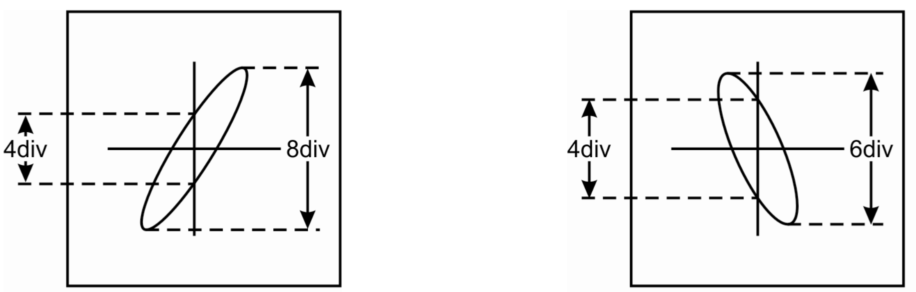


Fig.11.14: Phase measurement using Lissajous pattern

At $t = 0$, you have $v_2 = b \sin \theta$ and therefore $\sin \theta = v_2/b$ i.e. $\theta = \sin^{-1}(v_2/b)$. Note that b corresponds to the maximum value of v_2.

Fig.11.15 illustrates two possible patterns on the screen of a CRO. These figures depict possible phase difference between the two sinusoidal signals.



$\theta = \sin^{-1} 4/8 = 30°$ or $360° - 30° = 330°$

(a)

$\theta = 180° - (\sin^{-1} 4/6) \simeq 138°$ or $360° - 138° = 222°$

(b)

Fig.11.15: Phase measurements

You may now construct the network given in Fig. 11.16 to determine the phase angle between two sinusoidal waves/signals of the same frequency. The phase angle between E and v_R for different values of R may be computed from the ellipse obtained in each case following the method described in Fig. 11.15.

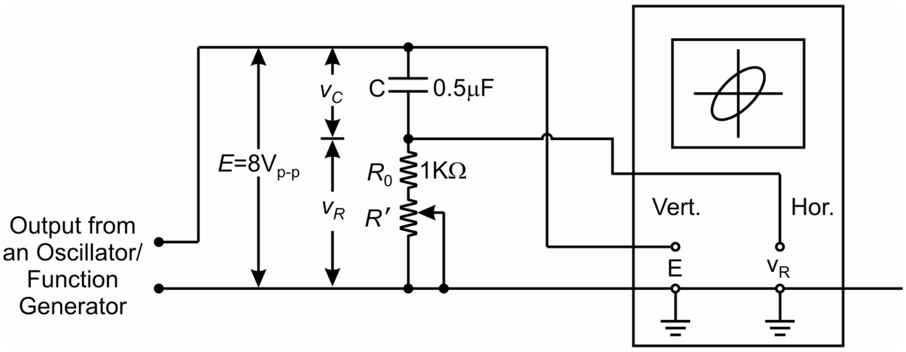


Fig.11.16: Lissajous method of phase measurement

You may now set the value of R by varying the potentiometer R' but keeping R_0 = 1 $k\,\Omega$. Record the value of R in Observation Table 11.6. Measure v_2 and b in each case and calculate the value of the phase angle θ.

Observation Table 11.6: Phase difference determination by Lissajous figures constant resistance, $R_0 = 1000\ \Omega$

Potentiometer setting R' (Ω)	**$R = R_0 + R'$ (Ω)**	**v_2**	**b**	**$\theta = \sin^{-1}(v_2/b)$**
0	1000			
1000	2000			
2000	3000			
4000	5000			

Compare these values of the phase angle with those obtained earlier by direct comparison of two traces on dual beam CRO.