EXP. 33 Oscilloscope Operation

1. Section Purpose:

Understand the principle of oscilloscope and apply it to measure voltages and frequencies of signals.

2. Introduction

(1) Oscilloscope

1. Introduction to cathode ray tube

   Cathode Ray Oscilloscope (or simply Oscilloscope) is an important device in many different fields. Oscilloscope allows us to measure and analyze signals generated from various electronic circuits. Typically, oscilloscope consists of cathode ray tube, screen, and some controlling circuits. The cathode ray tube derives its name from the fact that inside an evacuated glass tube, a beam of cathode rays (electrons) is directed to various parts of a screen to produce a "picture". A simple cathode ray tube is diagrammed in Figure 1. Electrons emitted by the heated cathode and accelerated by a high voltage applied between the anode and cathode. The electrons pass out of the accelerator through a small hole in the anode, and finally strike the screen and present as a tiny bright spot. The electron beam is made to move over the screen horizontally and vertically by changing voltages applied to the horizontal and vertical deflection plates. Figure 2 plots the results in the various conditions of applied voltages. Figure 2(a) shows that if no voltages are applied, the bright spot locates at the middle of the screen, and Figures 2(b) and 2(c) show that the electron beam moves horizontally or vertically when voltages are applied to the horizontal or vertical deflection plates. Finally, Figures 2(d), 2(e), 2(f), and 2(g) illustrate the results when voltages are applied to both horizontal and vertical deflection plates.

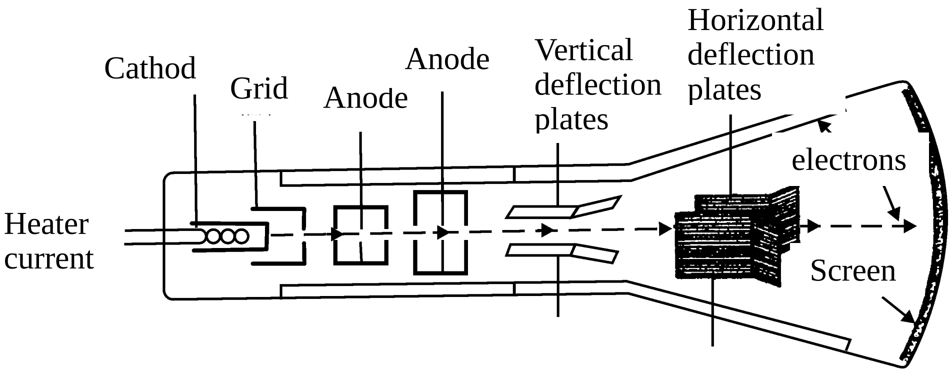

Figure 1

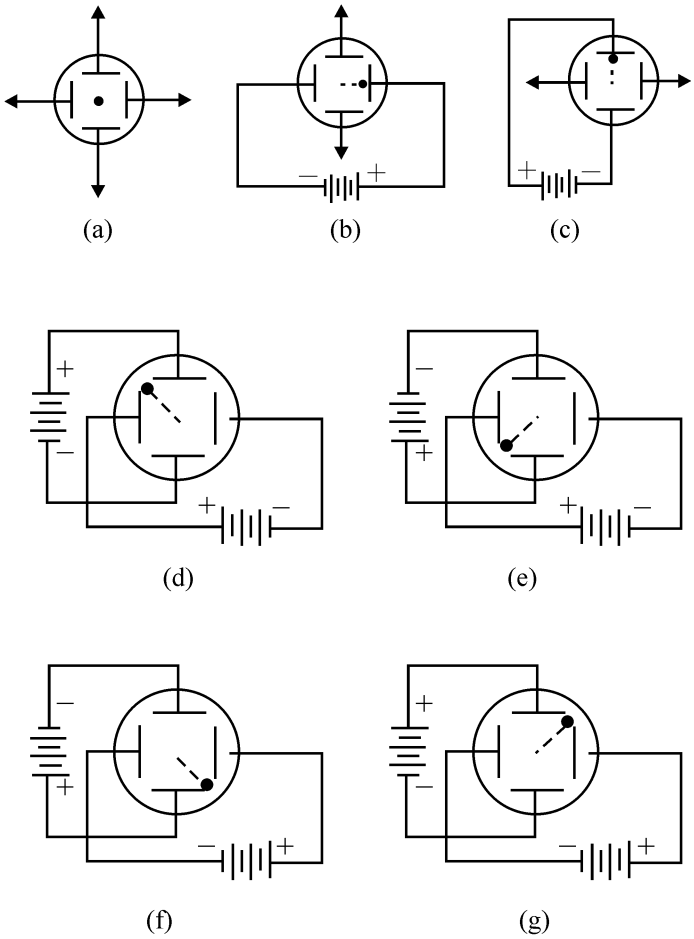

Figure 2

2. Introduction to Oscilloscope

   An Oscilloscope is a device for amplifying, measuring, and observing an electrical signal as a function of time. But what is the underlying mechanism? Kinetic analyses show us that the deviating distance of the electron beam depends on the magnitudes of voltages applied on the deflection plates. Consequently the striking locations of the electron beam at the vertical axis (or the horizontal axis) indicate the voltages of the measured signals. Now apply a signal presenting sine voltages (Figure 3) to the vertical deflection plates, and then the signal is displayed on the screen as a line sweeping vertically (Figure 4). If the voltages on the horizontal deflection plates are simultaneously varied at uniform rate in time (sawtooth wave form in Figure 5), the electron beam can sweep across the screen in a succession of horizontal lines and a sine signal can be presented successfully. Typically, the sawtooth wave form is produced by the electronic circuits inside the Oscilloscope. Figure 6 illustrates a typical result in which a sine signal (voltage is varied from -2V to 2V with a period of 4 ms) is applied to the vertical deflection plates and a sawtooth wave (voltage is varied from -2V to 2V with a period of 4 ms) is applied to the horizontal deflection plates. This is the reason why the horizontal axis is always regarded as the time axis.

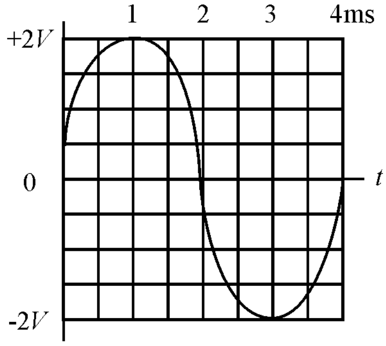

Figure 3

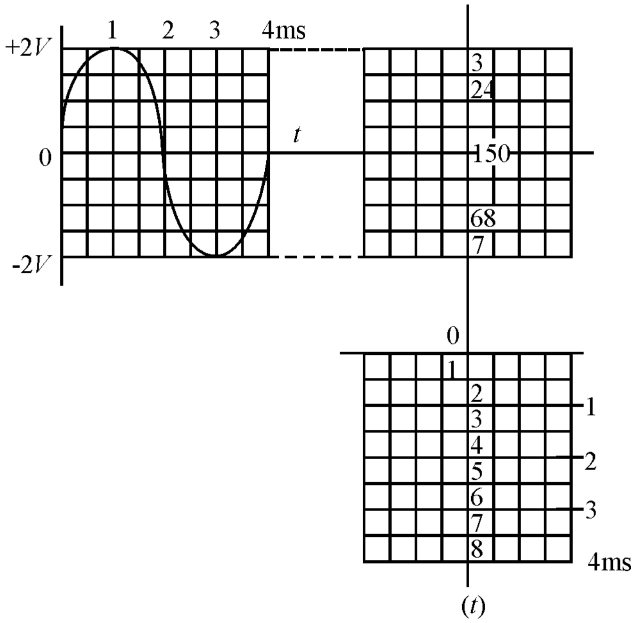

Figure 4

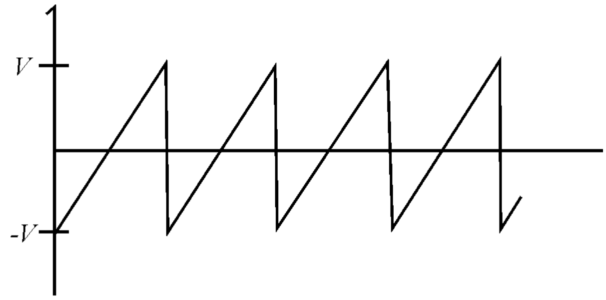

Figure 5

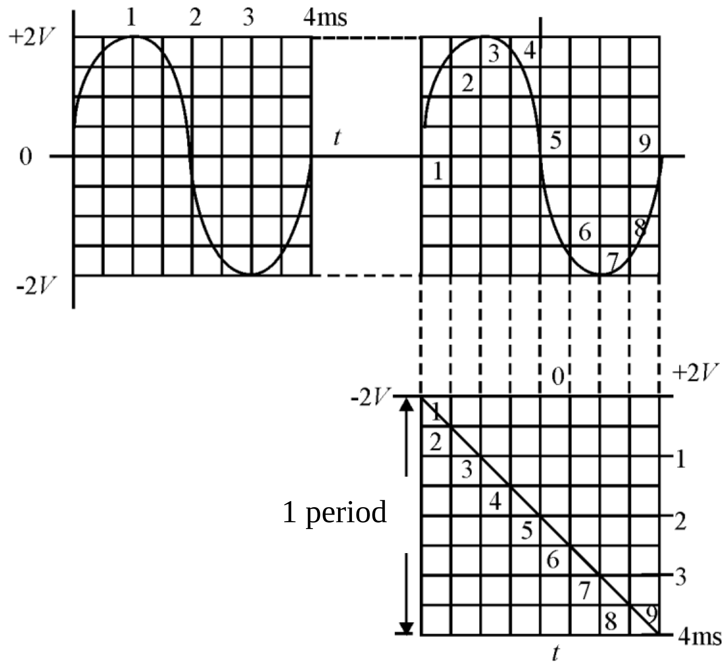

Figure 6

3. Time base and period

Based on the aforementioned concept, if the sawtooth wave (8ms) is twice the period of the measured sine signal (4 ms), the vertical variation would repeat twice within a single period of the horizontal sweeping. Consequently, a sine signal with double periods will appear on the screen. If the sawtooth wave is ***n*** times (***n*** is an integral) the period of the measured sine signal, similarly a sine signal with n periods will appear. The sawtooth wave and the measured signals are synchronized in those situations, *i.e.*, the functional relation between the sawtooth wave and the measured signal is fixed with respect to time scale. But if these two signals are unsynchronized, then the wave form presented on the screen will become unstable. As shown in Figure 8, the visible wave form on the screen is a right-moving sine when the period of sawtooth wave is lower than the period of measured sine signal. On the contrary, the wave form on the screen is a left-moving sine when the period of sawtooth wave is higher than the period of measured sine signal.

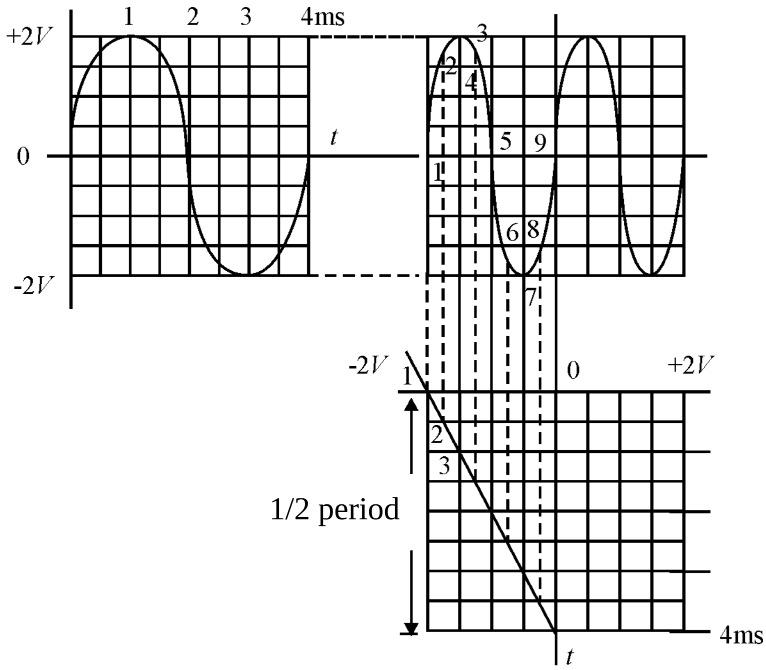

Figure 7

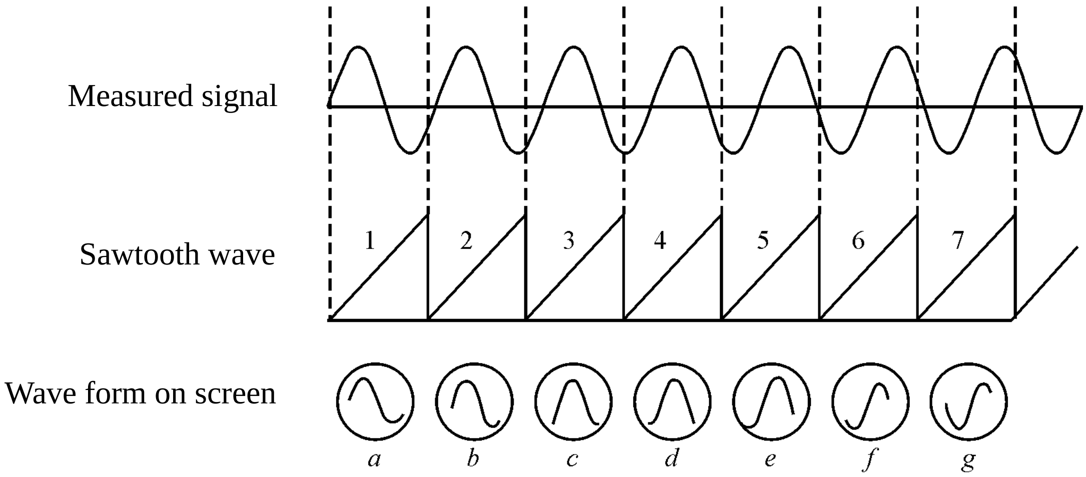

Figure 8

4. Trigger

In order to stabilize the visible wave form on the screen, a trigger circuit is required to enforce the sawtooth wave and the measured signal to achieve synchronization. Practically, the sawtooth wave is triggered by the input vertical signal (INT) or an external signal (EXT). The trigger circuit is combined with vertical (horizontal) amplifier, cathode ray tube, power supplier, and time base generator, as plotted in

Figure 9.

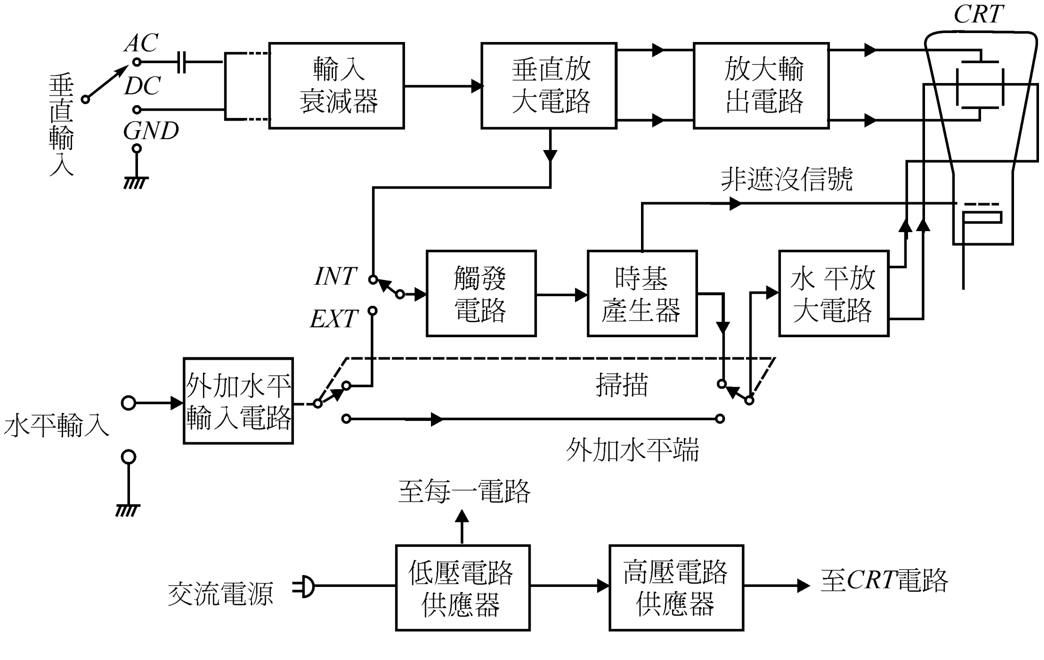

Figure 9

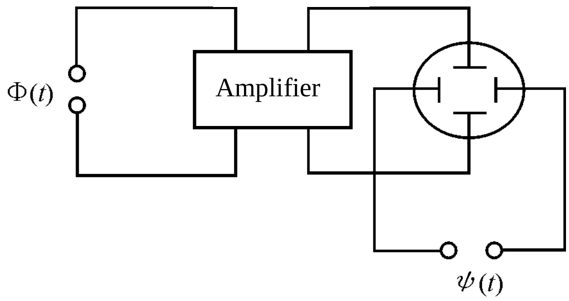

Figure 10

(2) Lissajou's curves:

Sometimes we are not interested in the time series of the measured signals, but are interested in the relations between two measured signals. Therefore we may input the two external signals, $\Phi(t)$ and $\Psi(t)$, via the vertical deflection plates and the horizontal deflection plates respectibvely. As aforementioned, if these two signals are unsynchronized, the wave form presented on the screen is unstable. Suppose $\Psi(t) = A_x \sin(\omega_x t + \phi_x)$ and $\Phi(t) = A_y \sin(\omega_y t + \phi_y)$ (where A, ω, and ϕ indicating the amplitude, angular frequency, and phase of the signals individually) indicate the sine signals applied to the vertical and horizontal deflection plates, and then the condition of a stable and closed pattern appearing on the screen is

$$\frac{\omega_x}{\omega_y} = \frac{f_x}{f_y} = \frac{n_y}{n_x} \qquad (1)$$

where ω is the angular frequency, f is the frequency $(\omega = 2\pi f)$, and $n>0$ is an integral. The stable and closed pattern is referred to as Lissajou's curve.

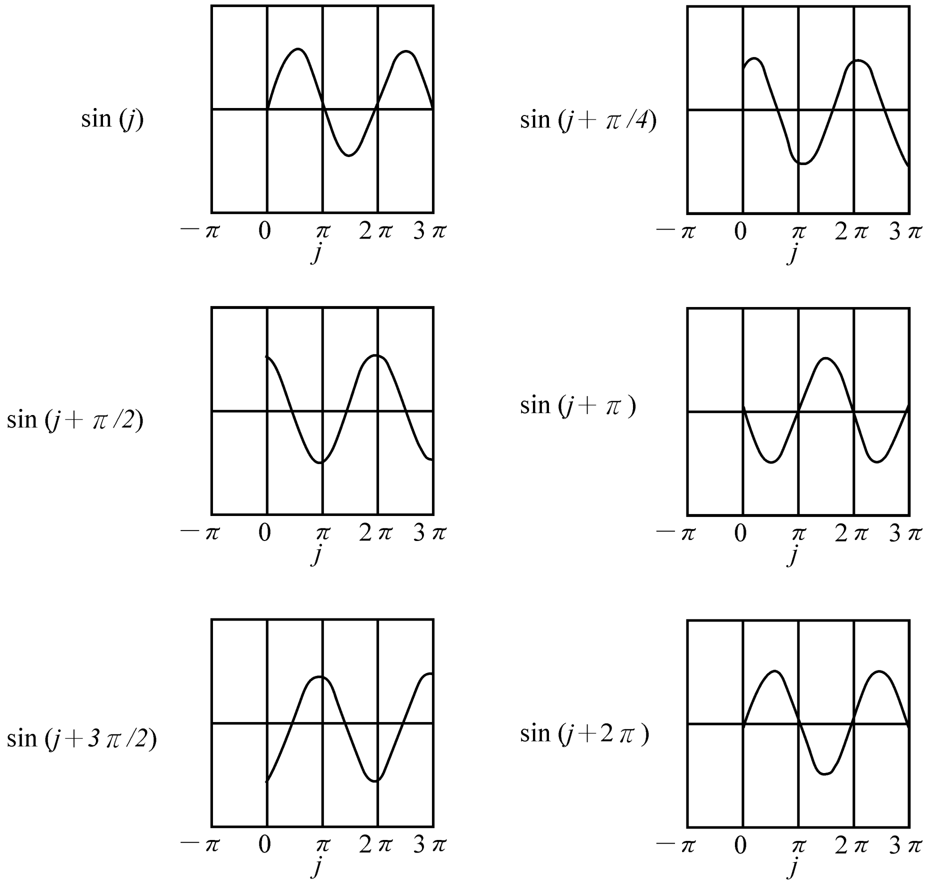

Figure 11

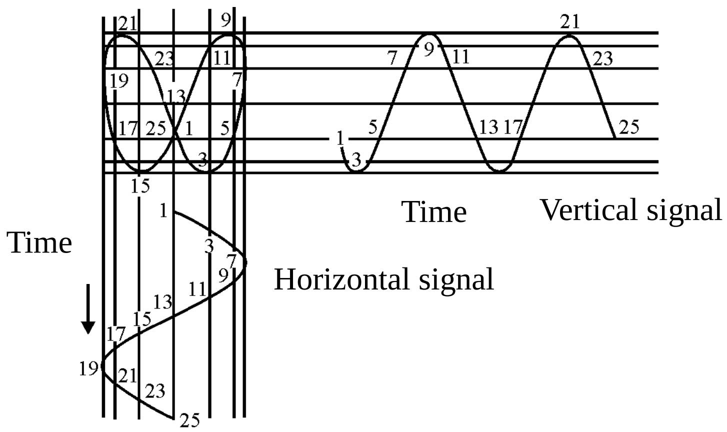

Figure 12

The vertical and horizontal inputs are not always phasesynchronized (i.e., $\phi_x \neq \phi_y$). Therefore we can define the phase difference between two inputs as $\phi (\phi \equiv \phi_y - \phi_x)$. Assume that the vertical input is presented in the form of $\Phi(t) = A\sin(\omega t + \phi_y)$, and the horizontal input is in the form of $\Psi(t) = A\sin(\omega t)$. Then the phase difference between the two inputs becomes $\phi = \phi_y - 0 = \phi_y$. Figure 11 shows various waveforms of $\Phi(t)$ in the conditions of $\phi_x = 0$ and ϕ (or ϕ_y) = 0, $\pi/4 \ldots 2\pi$. If the vertical and horizontal inputs are presented on the screen simultaneously, the phase difference between the two inputs can be obtained via the analysis of Lissajou's curves. In Figure 12, the points 1, 3, …, 25 demonstrate how the Lissajou's curve is constructed (where $\omega_x : \omega_y$ = 1:2). Figure 13 illustrates the Lissajou's curves in the condition of identical amplitudes, identical frequencies, and various phase differences of $\Phi(t)$ and $\Psi(t)$.

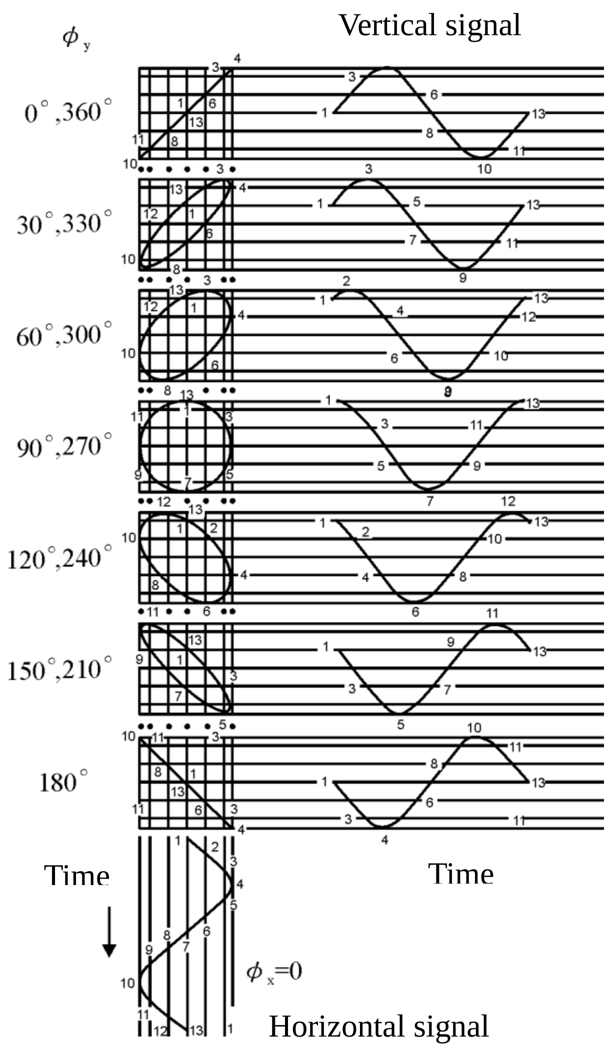

Figure 13

Lissajou's curve can be also applied to measure the frequency of the input signal. Suppose that the frequency of the horizontal input (f_x) is unknown, and the frequency of the vertical input (f_y) is variable. Then we can modulate the value of f_y to obtain a stable Lissajou's curve on the screen. The times of Lissajou's curve passing across the X axis (n_x) and the Y axis (n_y) satisfy the following equation:

$$f_x = f_y \cdot \frac{n_y}{n_x} \qquad (2)$$

and the unknown frequency f_x can be solved accordingly. Figures 14 illustrate the Lissajou's curves in the condition of identical amplitudes, various phase differences (0 to 2π), and various ratios of frequencies, f_x/f_y = 1:1, 2:1, 3:1, and 3:2.

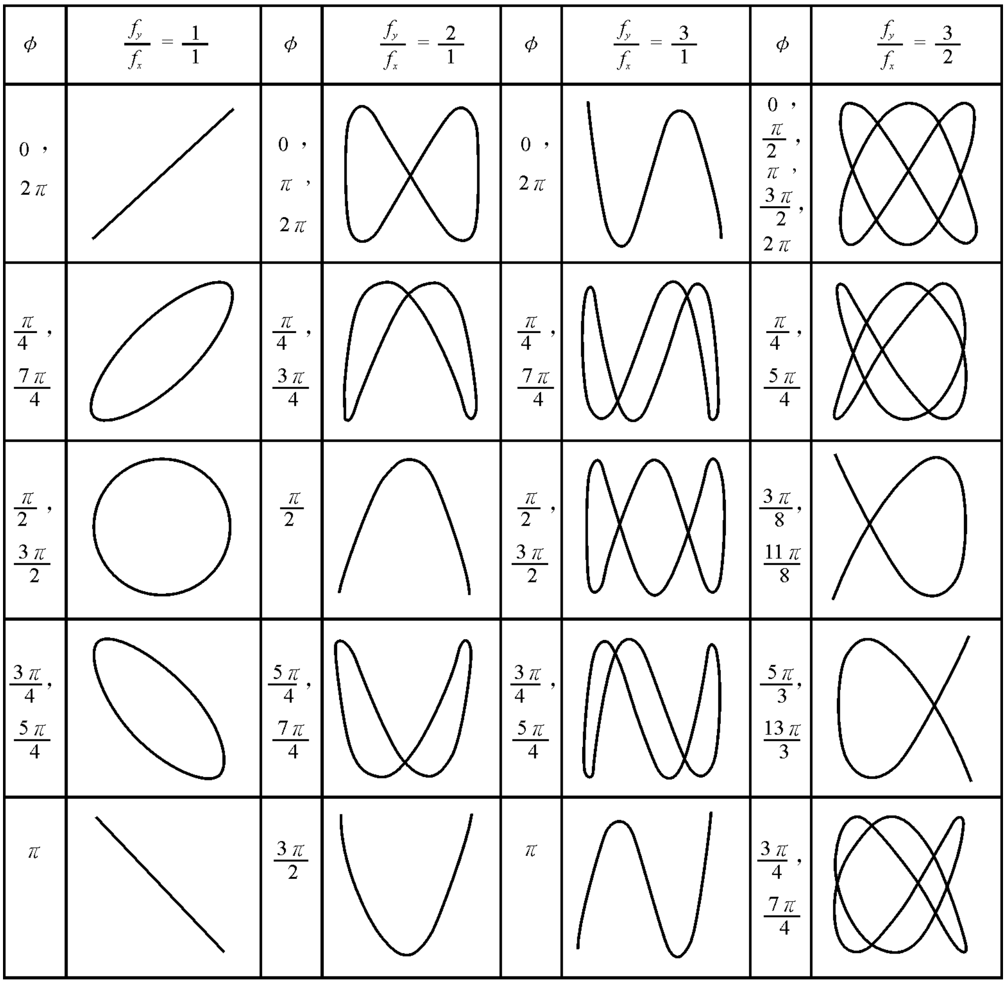

Figure 14

(3) Introduction to front panel

A brief introduction to the GW GOS-622B Oscilloscope, including the horizontal input, vertical input, swithes and controls of the instrument, is shown in the appendix of Exp.33.

3. Instruments Required

An Oscilloscope, two function generators, a digital desktop barometer, some connection cords.

4. Steps to the Experiment

(1) Operation

1. Before turning on the main power switch (3) (see the appendix of Exp. 33), set the swithes and controls of the instrument as the following table.

(3)	OFF	(20)	Mid-position
(4)	Clockwise (3-o'clock position)	(22)	LOCK(counterclockwise)
(6)	Mid-position	(21)	NORM (counterclockwise)
(9)	Mid-position	(26)	CH1
(10)	GND	(25)	AC
(12)	0.5 V/DIV	(24)	+
(13)	CAL (clockwise position)	(28)	AUTO
(14)	CH1	(30)	0.5 ms/DIV
(16)	0.5 V/DIV	(31)	CAL(clockwise), pushed in
(17)	CAL (clockwise position)	(32)	Mid-position
(19)	GND		

2. Turn-On the POWER switch and align the trace with a horizontal center line of graticule by adusting the INTEN control (4), FOCUS control (6), CH1 POSITION control (9), and HORIZONTAL POSITION control (32).
3. Change the VERT MODE to CH2. Align the trace with a horizontal center line of graticule by adusting CH2 POSITION control (20).
4. Trought this experement, set the swithes and controls as shown in the following table.

Swithces and Controls (No.)	Setting
VARIABLE (31)	CAL(clockwise)
MODE (SWEEP) (28)	AUTO
ALT (5)	Pulled Out
HOLDOFF/LEVEL (21, 22)	Counterclockwise
CH1、CH2（13，17）	Clockwise

(2) Calibrating square wave and calibration of probe

The CAL terminal (1) delivers the calibration voltage of 2 $V_{p\text{-}p}$, approximately 1 kHz, positive square wave. The square wave can be applied to calibrate the probes:

1. Connect two probes to CH1 input (11) and CH2 input (18) with BNC connectors.
2. Connect alligator clips of the probes to the CAL terminal (1), and set the switched and controls of the instrument as the following table.

Swithces and Controls (No.)	Setting
VERT MODE (14)	CH1
VOLT/DIV of CH1、CH2(12, 16)	0.5V/DIV
AC-GND-DC of CH1、CH2 (10,19)	DC
TIME/DIV (30)	0.5msec/DIV
SLOPE (24)	+
COUPLING (25)	AC
SOURCE (26)	CH1

3. Now, a square wave appears on the screan, as shown in the figure 16.

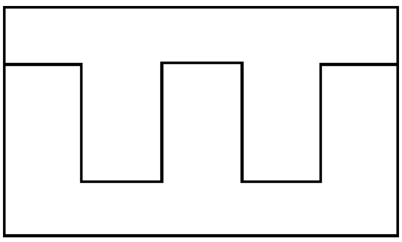

Figure 16

4. Read the divisions of the standard square wave acrossing the vertical axis in the conditions of 0.5 V/DIV and 1 V/DIV, and apply the following formulation to determine the

magnitude of the square wave, $V_{p\text{-}po}$:

$$\text{Voltage} = \text{the number of vertical divisions} \times \text{the position of VOLT/DIV} \quad (3)$$

5. Read the divisions of the one-period standard square wave acrossing the horizontal axis in the conditions of 0.5 msec/DIV and 0.2 msec/DIV, and apply the following formulation to determine the period T and the frequency $f(f = 1/T)$ of the square wave:

$$\text{Period} = \text{the number of horizontal divisions} \times \text{the position of ms/DIV} \quad (4)$$

6. If the errors between the measure values and stardard values exceed ±5%, please show Professor or TA the results.
7. Change the VERT MODE (14) to CH2. Observe the square wave appearing on the screan.
8. Repeat the steps 4 and 5, record voltage and frequency of the square wave.

(3) The waveform from the signal generator:

1. Set the swithes and controls of the instrument as the step (2)-2.
2. Generate a sine wave of 1 kHz by means of a function generator, and apply a digital desktop barometer to measure its voltage. Modulate the Amplitude (17) in the function generator to make the root-mean-square voltage (Vrms) of the sine wave equal to 1 V. Note that the relation between V_{rms} and $V_{p\text{-}p}$ is:

$$V_{rms} = \frac{V_{p-p}}{2\sqrt{2}}$$

3. Input the sine wave to CH1 of the oscilloscope, and recorded its $V_{p\text{-}p}$ and frequency (f).
4. Change the sine wave as $f \approx 500$ Hz, $V_{rms} = 2\ V$, and recorded its $V_{p\text{-}p}$ and f by means of the digital desktop barometer and the oscilloscope.
5. Change the sine wave as $f \approx 10$ kHz, $V_{rms} = 4\ V$, and repeat the step 4.

(4) Dual-channel operation

1. Input two identical sine waves of frequency $fx = fy \approx 1$ kHz and voltage $V_{rms} = 2\ V$ to CH1 and CH2 of the oscilloscope. The sine wave inputted to CH1 is referred to as the horizontal signal, and the other one is referred to as the vertical signal.
2. Set the swithes and controls of the instrument as the step (2)-2, but change the VERT MODE (14) to DUAL state. Now the two sine waves are displayed on the screen. (You can modulate POSITION (9) and (20) to separate the two waves and facilitate observation).

(5) Lissajou's figure：

1. Connet horizontal and vertical function generators (generating horizontal and vertical signals) to two different oscilloscopes. Ensure two sine waves appearing on the secreen normally.
2. Choose a oscilloscope and change VERT MODE to CH2(X-Y), TIME/DIC (30) to X-Y|EXT HOR, and SOURCE (26) to CH1(X-Y). Now a stable Lissajou's figure is shown on the sreen (sine waves still appear on the other oscilloscope).
3. Record the phase difference $(\phi \equiv \phi_y - \phi_x)$ and frequency ratio (fy/fx) between vertical and horizontal signals. Compare your results with the Figure 14.
4. Change the phase difference between two signal and oberserve its effects on the Lissajou's figure. Compare your results with the Figure 14.
5. Change the frequency ratio between two signal and oberserve its effects on the Lissajou's figure. Compare your results with the Figure 14.

5. Discussions

(1) Change VERT MODE to ADD position and observe the presented results on the screen. What is the function of ADD? Explain your reasons.

(2) Try to change ALT (5). Can you understand its function? Explain your reasons.

(3) In some situation, the wave form appearing on the screen become unstable. What is the mechamism?