

THE CATHODE RAY OSCILLOSCOPE

PHYSICS 359E

INTRODUCTION

The cathode ray oscilloscope is a vital piece of diagnostic lab equipment for observing and measuring electrical signals at frequencies ranging from dc to GHz. For this experiment, it will be assumed that you are familiar with the basic operation of the cathode ray tube, which forms the heart of the oscilloscope. The procedure will be devoted to refining your skills of using the oscilloscope, which are essential for this course.

PRE-LABORATORY PREPARATION

Review Secs. 3.1 through 3.3.1 and 3.4 of Reference 2, paying special attention to Sec 3.3.1 and 3.4.

OPERATION OF AN OSCILLOSCOPE

Sinusoidal signals

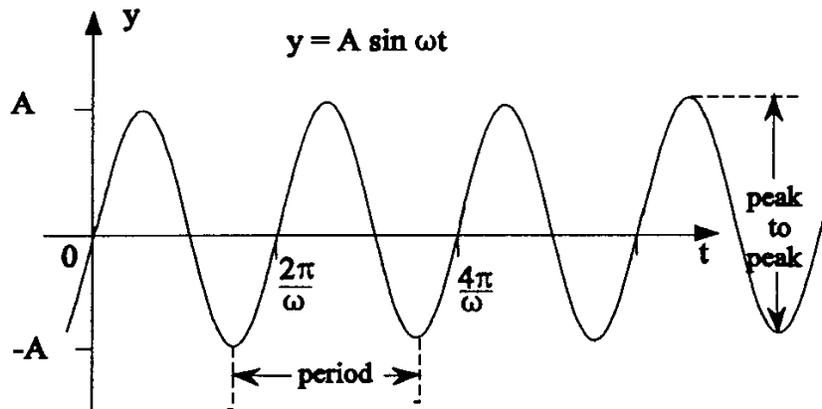


Figure 1: Parameters of a sinusoidal signal

A sine wave is completely characterized by its frequency, phase, and amplitude. Instead of amplitude (zero-to-peak value), it is common to encounter two other measures of its size: the peak-to-peak value, and the rms value. The peak-to-peak value is just the vertical spread between a positive and negative peak, i.e. twice the amplitude. The rms current is that dc current which

would cause the same power dissipation in a resistor R as the actual ac current. For a current $i = I_0 \sin \omega t$, the average power dissipation is given by

$$\langle P \rangle = \frac{1}{T} \int_0^T i^2 R dt = \frac{I_0^2 R}{2}.$$

We define the rms current I_{rms} by $I_{\text{rms}}^2 R = \langle P \rangle$, so that $I_{\text{rms}} = I_0/\sqrt{2}$.

Voltmeters and ammeters capable of measuring ac signals are almost always calibrated in terms of rms readings to facilitate comparison with dc meter readings.

Pulse signals

A single pulse can be described by its amplitude, rise and fall times, and width. One way to define the rise time is the time interval for the pulse voltage or current to rise from 10% to 90% of full amplitude. Similarly, the width is often defined as the time interval between the 50% points. If the pulses repeat periodically, we can also specify the repetition rate as the number of pulses per second, and the duty cycle as the fraction of time that the pulse is "on". The duty cycle is given by the pulse width times the repetition rate.

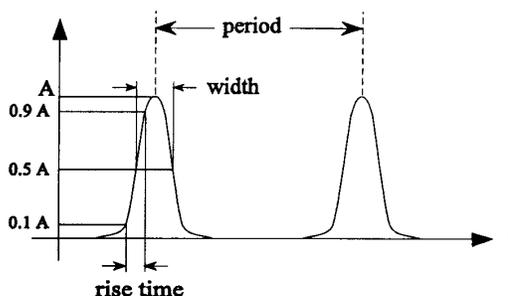


Figure 2: Parameters of a pulse waveform

Operation

There are three basic sets of controls on any scope: the horizontal sweep, the triggering of that sweep, and the vertical amplifier(s).

Vertical amplifier

Since the signals normally observed with an oscilloscope range from a few volts to a few millivolts, the scope has an amplifier on each signal input. The gain of the amplifier is selectable and calibrated in V/division or V/cm. It is the input amplifier that limits the maximum frequency (bandwidth) and minimum signal size (sensitivity) of the scope. Note that the coupling of the input signal to the amplifier may be dc or ac. In the ac case, any non-zero average of the signal (the dc component) is suppressed by the use of an input coupling capacitor. This is useful when you want to observe a small time-varying signal on a large dc background. Beware of using ac coupling when observing a very slowly varying signal; it will be badly distorted.

Many scopes have two separate vertical amplifiers, with inputs usually labelled CH1 and CH2, or A and B. By switching the vertical deflection of the beam between CH1 and CH2 at high frequency (chopping) or by displaying CH1 and CH2 on successive traces (alternating), the scope appears to display two signals at the same time. This feature is useful in comparing two signals with respect to phase or timing.

Horizontal sweep

This is normally a sawtooth waveform whose frequency can be changed to suit the waveform being studied. This frequency, often called sweep speed, is calibrated in $\mu\text{s}/\text{div}$, ms/div , s/div .

Most scopes also have provision for injecting an external sweep signal which may have any time variation. In this mode, the scope is equivalent to an X - Y recorder where the vertical signal (Y) is plotted on the screen as a function of the horizontal signal (X).

Triggering

In order that the pattern of a repetitive waveform remain stationary on the scope screen, or that a pulse which occurs randomly be observed, it is necessary to synchronize the start of the horizontal sweep with the vertical signal. This synchronization is achieved by triggering the sweep when the vertical signal exceeds some preset value, known as the trigger level. You can adjust this level to initiate triggering for a particular vertical signal. If the signal is too small, you will have to increase the gain of the vertical amplifier and adjust the trigger level in order to get stable triggering. In NORMAL trigger mode, you will see nothing on the screen if the scope is not triggered; in AUTO trigger mode, you will always see at least a horizontal trace free-running.

The source for the trigger may be the vertical signal on either CH1 or CH2, as implied above, or the 60 Hz LINE voltage, or an EXTERNAL signal. (As an example of external triggering, consider an experiment with a pulsed laser; since the desired signal will occur after each laser pulse, you can use a signal derived from the laser pulse to trigger the scope trace.) There is also a choice about what part of the trigger signal is to be compared with the trigger level: on dc coupling, the entire signal is used, whereas on ac, the dc part is suppressed.

PROCEDURE

1. Turn on the scope. Set the sweep speed to 1.0 ms/div, the trigger source to CH1, the trigger mode to AUTO, and the vertical display mode to CH1. Obtain a focused trace in the centre of the screen. If a halo appears around the trace, the intensity is too high.
2. Now set the vertical display to CHOP. Adjust the vertical position knobs of both channels and verify that you can see two traces. Note that you can also control the horizontal position of the traces.
3. Connect the function generator to the CH1 input. Set its frequency to about 30 kHz and its amplitude to about 1 V. Set the sweep speed to 0.1 ms/div and observe both the sine and square wave outputs of the generator. Observe the effect of changing the sweep speed and the CH1 gain.
4. Set the frequency to about 100 Hz and measure the rms voltage of the sine wave with both the scope and an ac voltmeter. The values should be the same.
5. Measure the frequency of the generator using the calibration of the scope sweep and compare it with the generator dial reading. Repeat at 5 or 6 frequencies between 10 Hz and 1 MHz. Record your results.
6. Use the scope to measure output signals from each of the 'mystery boxes' provided in the lab. You should consider the following aspects when describing the signals you see: amplitude, frequency, repetition rate, rise time, duty cycle, pulse width. Make a sketch in your lab book of each waveform. (Turn off the switches when not using the boxes.)

7. Build the following low pass filter circuit on a breadboard.

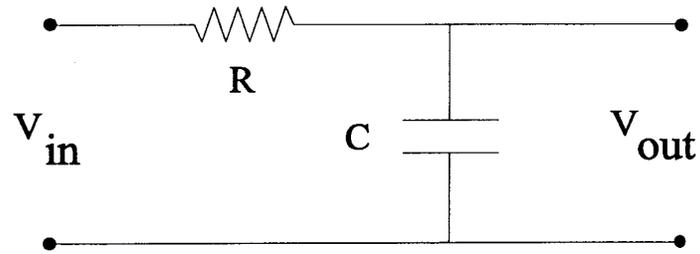


Figure 3: A low pass filter

Using $R = 10 \text{ k}\Omega$ and $C = 1.0 \text{ }\mu\text{F}$, plot v_{out}/v_{in} vs. frequency for a dozen or so frequencies between 10 Hz and 1000 Hz. The *half-power frequency* is that frequency for which $(v_{out}/v_{in})^2 = 0.5$, and should be about 16 Hz here. Derive an expression for v_{out}/v_{in} and confirm this (see Ref. 2, Sec 3.1, or Ref. 1, pp 30–32).

References

1. P. Horowitz and W. Hill 1980, The Art of Electronics (Cambridge Univ. Press).
2. A. C. Melissinos & J. Napolitano 2003, Experiments in Modern Physics (San Diego, CA: Academic Press).