

# Experiment 1

## The Oscilloscope

### 1.1 Preface

This simple experiment will help you gain familiarity with one of the most useful and most widely used instruments in any physics lab, the oscilloscope. In addition, you will compare the oscilloscope with the digital multimeter (DMM).

### 1.2 Review of Basic Oscilloscope Functions

#### 1.2.1 Basic Structure

Despite its apparent complexity, the oscilloscope, in its most frequent application, may simply be considered as a voltmeter which visually displays the input voltage signal as a curve in time. Visual representation of the signal is provided by means of a cathode-ray tube (CRT) and two pairs of deflecting electrode plates which control the vertical and horizontal movement of the CRT electron beam. When a signal appears at the input, it is first amplified, then split in two. One part is applied to the vertical-deflection plates, while the other is used to trigger a generator which applies a linear ramp voltage to the horizontal-deflection plates. This latter voltage causes the beam to be swept horizontally across the screen at a constant speed. Since the beam is now also being deflected vertically in proportion to the input signal, a curve representing the waveform of the signal in time is produced. This is the simplest and most important operation mode of the oscilloscope. Examples of further applications are given later.

#### 1.2.2 Bandwidth and Risetime

One of the most important operating characteristics of the oscilloscope is the bandwidth of the vertical amplifier. This parameter essentially governs how fast a signal can be

accepted and correctly displayed by the oscilloscope without distortion. This is especially important for signals from detectors such as photomultipliers which can emit pulses of nanosecond risetime. Because of the finite bandwidth of the amplifier, the oscilloscope has an intrinsic risetime of its own, i.e. a signal with a perfectly vertical rising edge (0 risetime) will be displayed as a signal with a finite risetime ( $t_{osc}$ ). A rough relation between the bandwidth and this risetime is given by the formula  $t_{osc}[ns] = 350/f_{3db}[MHz]$ , where  $f_{3db}$  is the bandwidth of the oscilloscope in Megahertz. The risetime displayed for a signal with a risetime  $t_{pulse}$  will thus be a combination of the risetime of the pulse and the oscilloscope risetime. An approximate formula for  $t_{disp}$  is given by  $t_{disp}^2 = t_{pulse}^2 + t_{osc}^2$ . A 3 ns risetime pulse on a 100 MHz oscilloscope ( $\rightarrow$  3.5 ns risetime) will thus be displayed as a pulse with a 4.6 ns risetime. Similarly, if a 10 ns risetime is measured on the same oscilloscope, the true risetime of the signal is  $t_{pulse} = 9.4$  ns.

### 1.2.3 Controls and Operating Modes

#### Input Coupling

As in any good voltmeter, the input impedance of the oscilloscope is very high (make sure you understand why!), usually  $1M\Omega$ , in parallel with a small capacitance on the order of 10-20 pF. For fast signal viewing from  $50\Omega$  cables, some oscilloscopes also provide a switch which allows selection of a  $50\Omega$  input impedance so as to obviate cable termination. Otherwise this termination can easily be achieved with a BNC T and a  $50\Omega$  terminator - make sure you know how this is done. On most oscilloscopes two (sometimes more) inputs are available allowing the simultaneous display of several signals. Depending on how triggering is performed, this allows a visual comparison of two or more signals. At each input, the type of coupling may be selected:

AC - In this mode any constant dc level is suppressed and only nonzero ac frequencies are displayed.

DC - dc constant levels, as well as ac frequencies are displayed. Thus varying signals superimposed onto a constant dc level may be seen.

GND - The input signal is directly shunted to ground.

#### Vertical and Horizontal Sensitivity

VERTICAL SENSITIVITY - This controls the vertical scale. On most oscilloscopes a vernier control is available which allows a continuous adjustment between the indicated markings. Note that these markings are only valid when the vernier is in the *calibrated* position!

TIME - This determines the speed at which the beam is swept across the screen and thus the horizontal scale. Again, the indicated settings are only valid in the *calibrated*

position.

DELAYED SWEEP - In this mode the time sweep is made after a certain delay time determined by the delay setting dial.

EXTERNAL X - When in this position, the time base generator is disconnected allowing the horizontal deflection of the beam to be controlled by an external voltage applied at the EXT-X or channel-2 input.

### **Triggering(Synchronization)**

Triggering or synchronization is the most important adjustment to be made when using the oscilloscope. As we have seen, the horizontal sweep of the oscilloscope is activated only when there is a triggering signal satisfying certain conditions. This triggering signal may be the input signal itself or some other external signal, depending on the mode selected. The conditions for a trigger include the slope of the signal and its amplitude. In this manner a precise point on the signal may be selected for the beginning of the sweep. For a repetitive signal such as a sine wave, for example, this produces a steady trace on the display screen, always starting at the same point on the signal.

#### *Signal Source*

INTERNAL - Triggering is done by the input signal itself as outlined above. This is the normal mode of operation.

EXTERNAL - Triggering is made by an externally applied signal at the EXT. Trig. input.

LINE - Triggering is made on the ac line voltage.

#### *Trigger Conditions*

SLOPE - Selects the slope of the signal on which triggering should be made. Normally, positive signals are triggered on the positive slope and negative signals on the negative slope.

LEVEL or THRESHOLD - This defines the voltage level at which triggering of the sweep begins. Signals not reaching this minimum level are therefore not displayed. For most beginners, failure to obtain a trace is usually due to setting this level incorrectly.

#### *Trigger Modes*

NORMAL - In this mode no sweep is made unless a triggering signal satisfying the desired conditions is present. At all other times the screen remains blank.

AUTO - A continuous sweep is performed even if no signal is present at the input. This is useful for finding the trace and adjusting its position on the screen. When a signal is present, synchronization is as in the normal mode.

SINGLE SWEEP - Only one single sweep is made.

EXTERNAL or X-INPUT - In this position the internal ramp generator is disconnected and the horizontal movement of the beam is controlled by the voltage at the X-input.

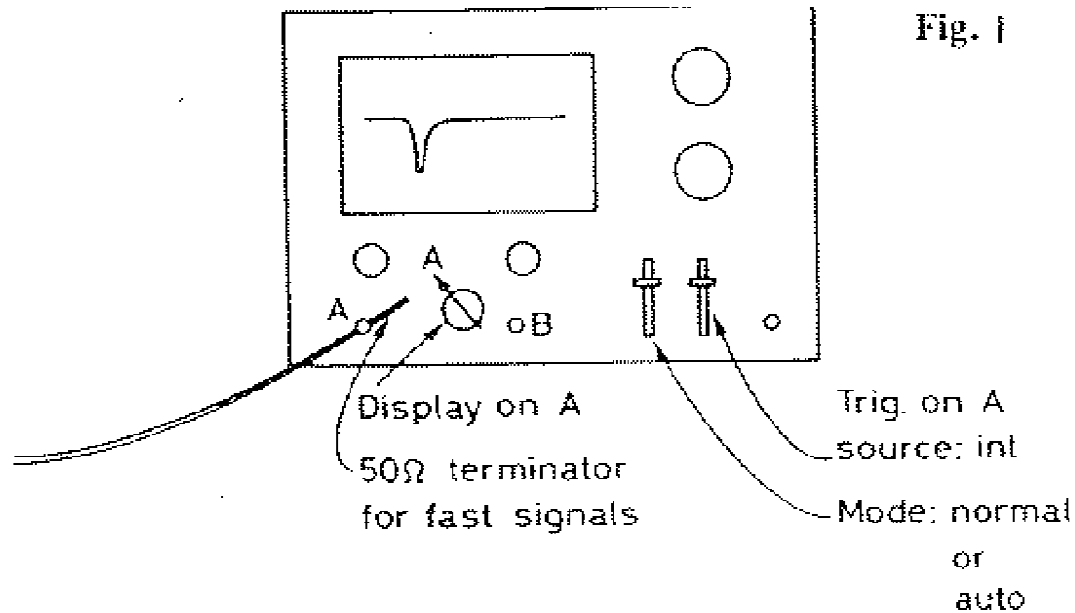


Figure 1.1: Normal signal viewing

### Display Modes

CHANNEL 1 - Displays channel 1 only.

CHANNEL 2 - Displays channel 2 only.

ALTERNATE - Displays channels 1 and 2 on alternate sweeps, i.e. one *full* sweep is made alternatively for each channel. This mode is useful for comparing the relation between two signals.

CHOP - In this mode the display is alternated between channels 1 and 2 *during* a sweep. This is usually done at a high frequency on the order of 500 kHz. The two signals are thus “*chopped*” in appearance.

ADD - The signals in channels 1 and 2 are added and displayed.

## 1.2.4 Applications and Examples

### Signal Viewing

Figure 1.1 shows the scheme for normal signal viewing. If no signal is observed, check the following (not necessarily in the order listed!)

- 1) Check slope and trigger level.
- 2) Check that the trigger is on internal (or external, if that is what you are using).
- 3) Is the trace positioned on the screen? Put on *Auto* (if not already) and position trace with the horizontal and vertical position knobs. If there is still no trace, check the

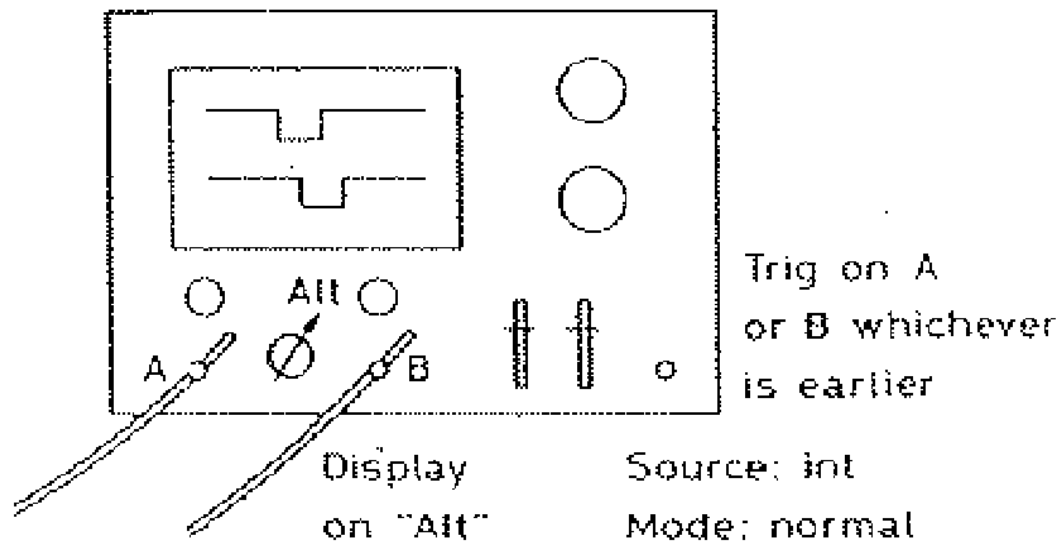


Figure 1.2: setting a coincidence

intensity.

- 4) Check the horizontal and vertical scales. Are they about the right order of magnitude for the signal you are observing?
- 5) Check that the input is not on OFF or GND.
- 6) Are you sure of your input signal? Try one that you know exists.

### Comparison of Signals

Signals may be compared in time and amplitude using the setup in Fig. 1.2. The oscilloscope sweep is triggered by either A or B according to the selection on the trigger source. With the display on *Alternate*, the relation in time of the second signal can be seen. This is the usual method for setting coincidences.

If the oscilloscope is not equipped with two channels an alternate scheme is to use the external trigger, shown in Fig. 1.3.

A second example of signal comparison is checking the threshold of a discriminator or setting the levels of a Single Channel Analyzer (SCA). This is shown in Fig. 1.4. The output of the SCA or discriminator is used to trigger the scope for viewing the linear signal. Note that a delay must be added in order to take into account the processing time of the SCA or discriminator. Quite

obviously only those linear signals which pass through the discriminator will be displayed since only these signals will have a trigger. In this way a certain amplitude may be selected

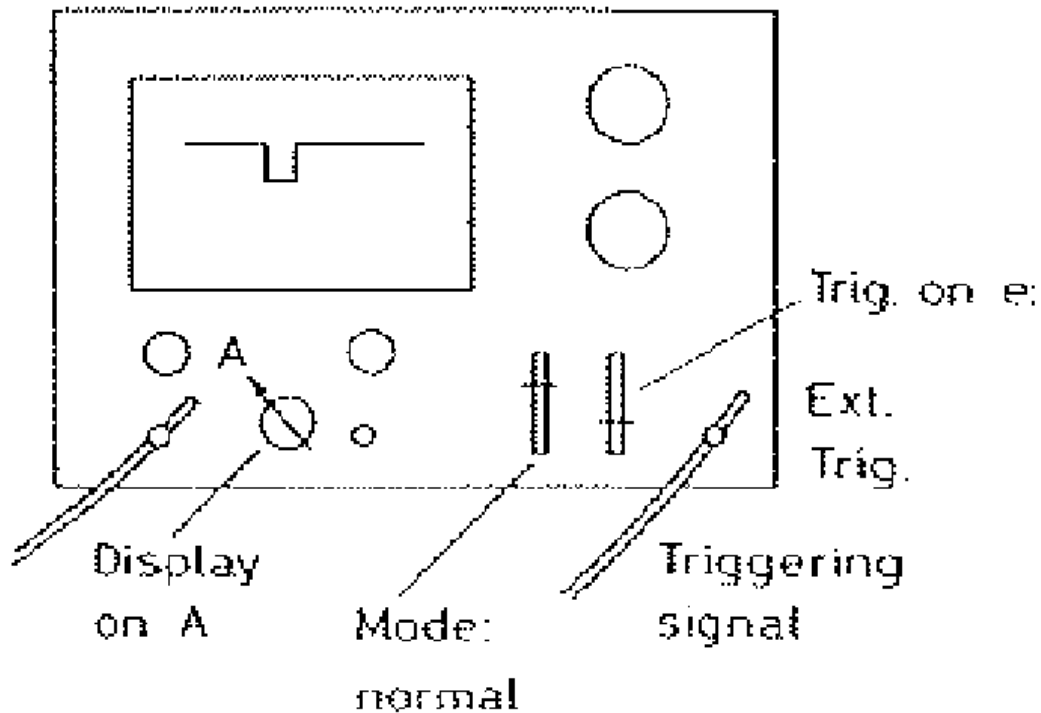


Figure 1.3: using the external trigger

or the level of the discriminator checked with respect to the noise.

### 1.3 Procedure

Review Ohm's law, Kirchoff's two laws, and simple circuit analysis. You will need to be thoroughly familiar with those topics. In class we will also discuss the idea of complex impedance for AC circuits – resistance ( $R$ ) and reactance ( $X$ ):  $Z(\omega) = R + iX(\omega)$ . In this formalism, one can apply Kirchoff's laws to AC circuits with capacitors and inductors just for DC circuits with resistors. The current and voltage are now frequency dependent (the real part of complex  $V, I$ ). Pure capacitive elements contribute a reactance to the circuit  $X = 1/(i\omega C)$ , and pure inductive elements a reactance  $X = i\omega L$ .

You will be using the Heathkit ET-1000 Circuit Design Trainer from the 308 lab of next semester as a signal generator and a power supply. Familiarize yourself with its layout and its options. Also make sure that any potential switch on the scope probe is in the  $\times 1$  position.

1. Start by examining a low DC voltage (say +5 V) on the scope. Then examine sine

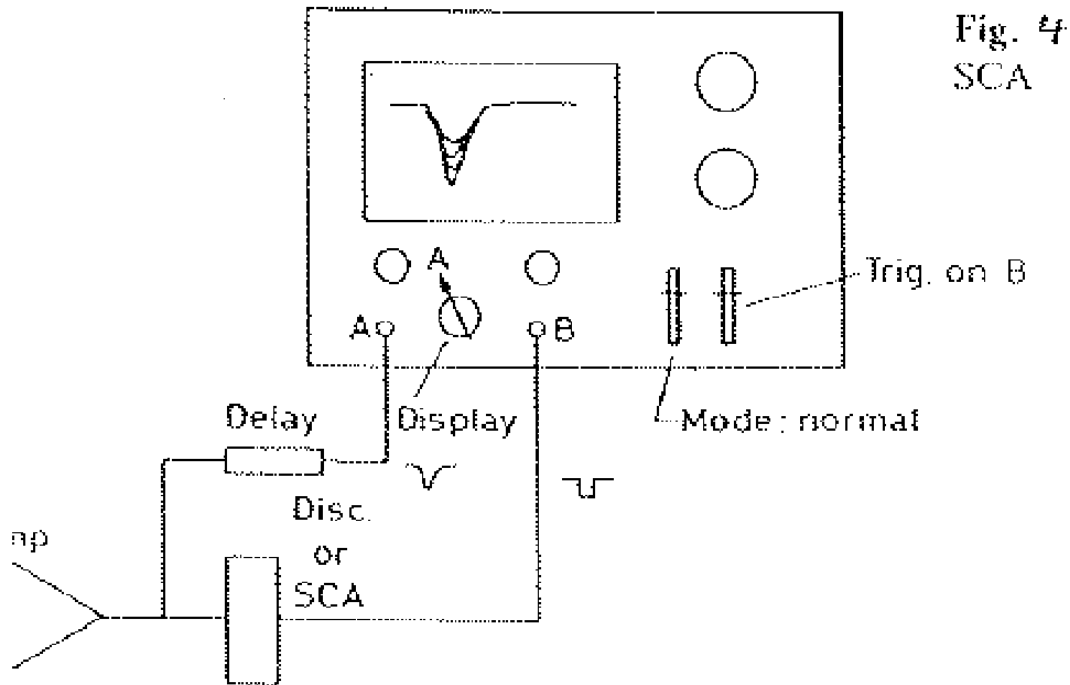


Figure 1.4: setting the levels of a discriminator (SCA)

and triangular waves of different frequencies, and compare the measured frequency with the dial setting on the Heath Trainer. Always compare your measured result with your expectation.

2. Compare (for relatively low frequencies,  $\approx 100$  Hz) the sine wave on the scope with the DMM reading of the same sine wave. Why are the two measurements different, i.e. what is actually measured in the two instruments? For the scope measurements is there any noticeable difference between using AC and DC coupling?
3. Study the difference between AC and DC coupling by looking at a sine wave from our Wavetek Function Generator. Make sure that the DC offset is initially set to zero. Now vary the DC offset on the Function Generator and carefully observe the difference on the scope between AC and DC coupling. Note how with AC coupling the scope display is independent of the DC offset of the input signal, whereas under DC coupling you can move the sine wave up/down the scope display by varying the DC offset. Make sure you understand the implications of using AC/DC coupling and how one can disentangle AC and DC components of a signal or waveform.

4. Take a low voltage DC power supply and with the scope examine and measure its AC “ripple”, i.e. the (hopefully small!) AC component sitting on top of the DC.
5. Build a voltage divider from two  $10\text{K}\Omega$  resistors.
6. Derive an expression for  $V_{out}$  as a function of  $V_{in}$ . Use  $V_{in}$  around 20V and 10k for the two resistors.
7. With a DMM measure the actual values of  $R_1$ ,  $R_2$ ,  $V_{in}$ ,  $V_{out}$ , and the current  $I$ . Compare  $V_{out}$  and  $I$  with your calculated expectations and comment.
8. Now for a quantitative comparison of the input impedances of DMM (typically  $10\text{M}\Omega$ ) and scope (typically  $1\text{M}\Omega$ ). Measure  $V_{out}$  also with the scope, compare with the DMM reading, and comment.
9. Now change  $R_2$  in such a way that you would expect a difference in  $V_{out}$  between scope and DMM readings. Compare both readings with the expected  $V_{out}$ , and explain the differences.
10. Build an AC circuit by replacing in the voltage divider  $R_1 \rightarrow Z_1 = 1/(i\omega C)$  and  $Z_2 = R$ . What is the characteristic frequency of the circuit? Plot the circuit gain and phase as a function of frequency. (I suggest using MATLAB for the plotting.) Now choosing appropriate values for C and R measure the gain and phase shift with your scope and a waveform generator. Does it agree with your calculation? If time permits, repeat with  $Z_1 = R$  and  $Z_2 = i\omega L$ .

## 1.4 References

- [1] Melissinos and Napolitano, Ch. 3.