

The Oscilloscope

Vision is the art of seeing things invisible.

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OBJECTIVE

To learn to operate a cathode ray oscilloscope.

THEORY

The oscilloscope, or scope for short, is a device for drawing calibrated graphs of voltage vs time very quickly and conveniently. Such an instrument is obviously useful for the design and repair of circuits in which voltages and currents are changing with time. There are also many devices, called transducers, which convert some non-electrical quantity such as pressure, sound, light intensity, or position to a voltage. By using a transducer the scope can make a plot of the changes in almost any measurable quantity. This capability is widely used in science and technology.

The heart of the oscilloscope is a cathode ray tube or CRT, of the sort you have already studied. Looking at the face of the instrument, you are viewing the screen that the electron beam strikes. Electronic circuits in the scope apply voltages to one set of deflection plates to sweep the beam across the screen from left to right at a constant rate, thereby providing the time axis. Other circuits amplify or attenuate the input signal as needed, and apply voltages to the other set of deflection plates to move the beam vertically, providing the voltage axis. Controls are provided to select the time and voltage scales needed for any given situation.

At the end of each sweep, the beam is shut off and the horizontal deflection voltage is reset so the beam would start at the left edge of the screen again. Since a scope is usually used to plot a rapidly changing quantity, one sweep and therefore one plot may last only a few microseconds. If the phenomenon we are studying can be made repetitive, we can repeat the sweep sequence many times to get a display suitable for a more leisurely examination. A special circuit, called a trigger circuit, examines the incoming voltage signal and starts the sweep at the same point in the repetitive cycle for each new sweep. This results in a visually steady display of the input. Several controls are provided to set the trigger as needed.

The scope you will use is a very flexible instrument, typical of those available in a research laboratory. It has two channels, so that two different voltages may be plotted simultaneously for direct comparison, and a variety of triggering options. The front panel, shown in Fig. 1, is correspondingly formidable at first glance. Fortunately, the myriad of controls can be

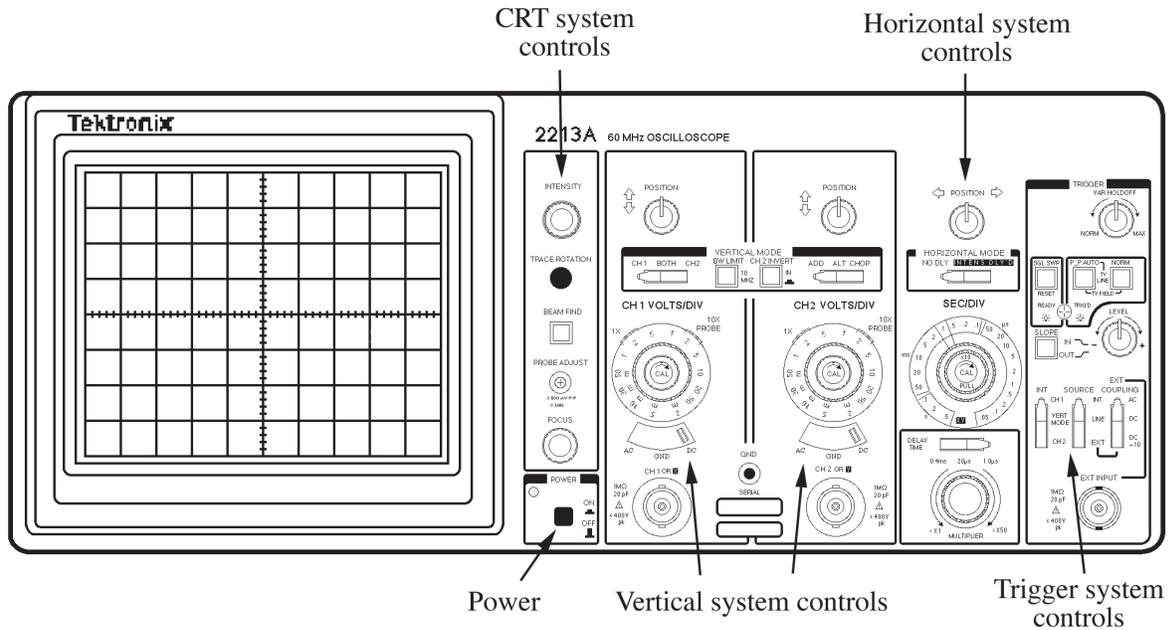


Fig. 1. Oscilloscope front panel with functional blocks marked.

considered in several independent groups, which are marked in the figure. In the remainder of this section we will examine each group in turn, concentrating on the controls we will need in subsequent experiments. The experimental procedure section will then take you through a series of measurements designed to demonstrate the operation of each section.

At the left side of the instrument, the CRT screen is divided into a one centimeter grid, ruled on the inside surface of the tube. Each solid line is one division for the horizontal and vertical deflection. The dotted lines are provided for pulse rise-time measurements. Moving across the panel, we come to the power switch and the CRT controls. The trace rotation and probe adjust are used only when repairing the instrument. The intensity control should be set to give a visible trace, but excessive brightness will defocus the spot and may damage the screen. Both the intensity and focus may need to be adjusted when the sweep rate is changed drastically. The beam finder is provided as an aid to setting the scope. When pushed, it reduces the deflection voltages enough that the beam will always appear on the screen. The position controls are then used to center the spot, and you should obtain a display suitable for final adjustments when the beam finder button is released.

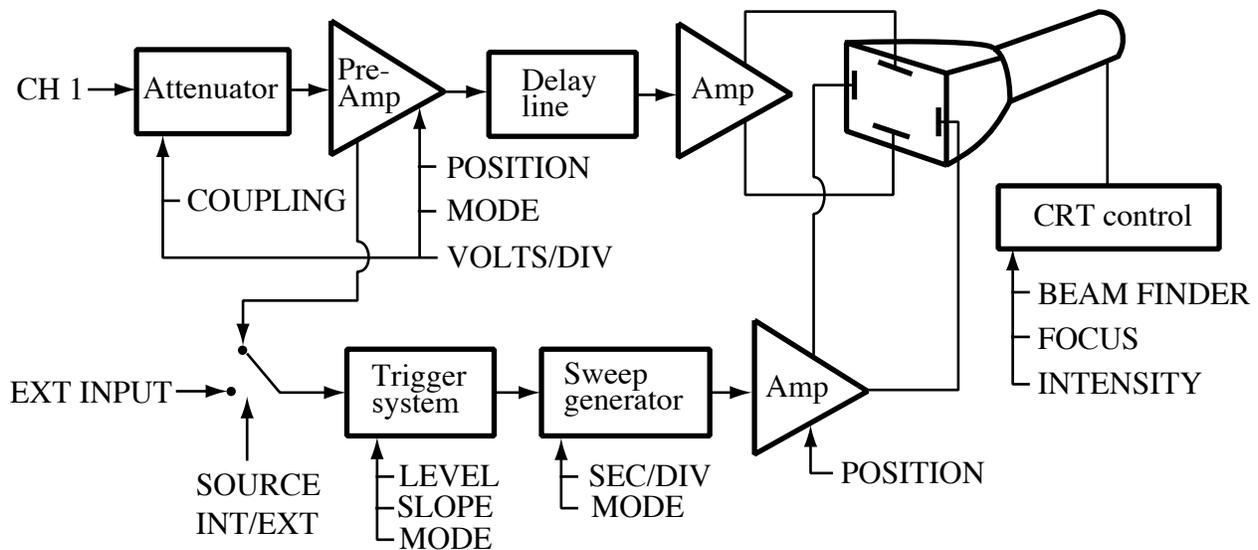


Fig. 2. Block diagram of the oscilloscope, showing the control functions

The vertical system accepts input signals and develops appropriate deflection voltages for the CRT. Because this is a two-channel scope there are two identical sets of vertical controls, one for each trace. The block diagram in Fig. 2 shows the flow of signals in one channel. Voltages are applied between a grounded terminal labeled GND and either CH 1 or CH 2 for the channel desired. The coupling switch allows the input circuit to accept all signals when set at DC, or only the time-varying part when set for AC. The middle position, GND, connects the vertical amplifier input to ground, so that you can see where the zero-voltage height is on the screen. (Using the GND setting does not connect the external input terminal to ground, so your circuit will not be disturbed.) The position control allows you to place the trace on the screen as desired, for example aligning the zero-voltage position with one of the grid lines.

The vertical sensitivity control, labeled VOLTS/DIV is used to set the vertical scale factor. For example, when the 50m marking is next to the 1X symbol, the scope is set for a vertical scale of 50 mV per centimeter, and a deflection of 2 cm, equal to 2 large divisions, would indicate an input voltage of 100 mV. This control is normally set to make the vertical part of the signal a convenient size on the screen. The red knob in the center of the control allows you to continuously vary the vertical scale factor, rather than using the fixed settings. This feature is occasionally useful for relative measurements, but for quantitative work you need to know the calibration, and you must use the fixed steps. Turning the red knob fully clockwise sets the control for the fixed steps marked on the main control.

The controls labeled VERTICAL MODE select several related functions. Starting at the left, you can display the signal from channel 1, channel 2 or from both channels. The switch at the right determines how the display is done when both channels are in use. In CHOP mode the beam

is switched back and forth between the channels very rapidly, drawing many short pieces of the voltage-time graph for both channels as the sweep proceeds. In ALT mode, an abbreviation for alternate sweep, the channel 1 signal is displayed for one full sweep, the channel 2 signal is displayed on the next sweep, and so forth. If the sweep time is short, ALT mode appears to display two steady graphs, but if the sweep time is long you will see an irritating flicker as one line and then the other is swept. The CHOP mode is therefore better for slow sweeps because it draws both traces together, although it cannot switch quickly enough to handle very fast signals. As a general rule, use ALT mode unless the display is slow enough to be irritating, and then switch to CHOP. The third setting, ADD, algebraically adds the input of channel 1 and 2. We will not have much use for this feature.

The BW LIMIT (bandwidth limit) button allows you to cut off signals with frequencies higher than 10 MHz, so that they do not appear on the display. Most of our signals are at lower frequencies, so leaving this button in will cut out some noise without losing any information. The CH 2 INVERT button inverts the signal from channel two, so that increasing positive voltages are plotted downward, rather than upward. This button should be out for normal operation.

The horizontal system controls the time scale of our plots. The main control, labeled SEC/DIV, works much like the vertical sensitivity controls, with a series of fixed settings and a red variable control. Note that the scale is divided into regions for seconds, milliseconds and microseconds per division. When set for 1 ms/division, as in the figure, each one centimeter division on the screen corresponds to one millisecond. The position labeled X-Y disables the timed sweep, and allows you to plot the voltage applied to channel 2 vs the voltage applied to channel 1. The horizontal mode switch and the delay time controls are used only for special tricks, which we will not need. Leave the mode switch at NO DLY for no delay. The position knob works just like its vertical counterpart.

The trigger system is used to start successive sweeps at corresponding points on the input waveform on each successive sweep. This operation is indicated schematically in Fig. 3. The

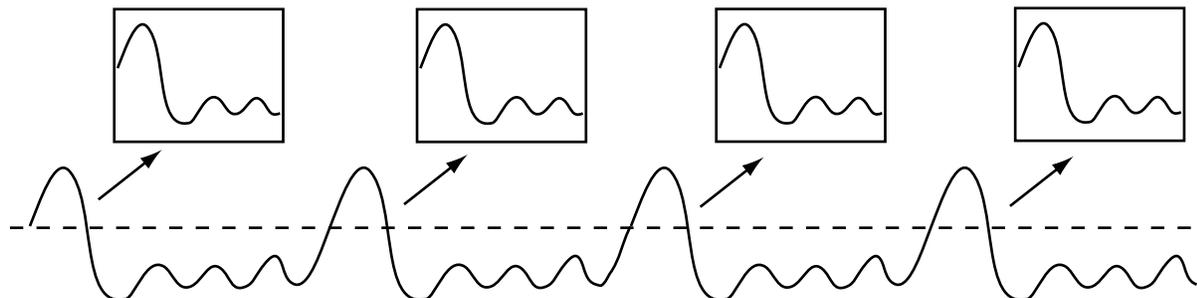


Fig. 3. A continuous input waveform and four successive sweeps on the scope screen. The trigger is set for positive slope with the trigger level at the dashed line.

LEVEL knob controls the voltage at which the trigger starts the sweep. The SLOPE button is used to specify whether the signal should have a positive or negative slope at the trigger voltage. The source of the triggering signal is chosen with a set of switches. You may choose to trigger off the signals applied to the vertical channels, off the power lines, or off of a signal applied to the EXT INPUT connector. Internal triggering is most common, and you may choose to use channel 1 or channel 2, independently of which one you are displaying at the time. VERT MODE triggering is odd, in that the trigger is obtained, in ALT sweep, from whichever channel is supposed to start next. This is usually confusing, and we will not use it. Triggering from the power lines is useful if you want to study something that might be synchronized with the AC power. External triggering is useful when your experiment produces a signal that occurs a fixed time before the signal of interest, since you can then see the early parts of your signal easily.

The other three buttons set the sweep mode. In SGL SWP, for single sweep, the trace moves across the screen only once, and then waits until the button is pressed again. This is an archaic feature formerly used when photographing the trace. P-P AUTO, for peak-to-peak automatic is the standard mode, since it will almost always produce a usable trace. If the trace is not stable in P-P AUTO you can try NORM, for normal mode. This is useful for slowly varying signals, and for situations where the triggering is tricky, for example because of noise. The LEVEL control must be set carefully to get a trace in NORM mode, so a small light is provided to tell you when the scope has found a satisfactory trigger. If the light is on but you have no trace, something other than triggering is the problem. Other trigger modes are provided for television service work, but we will not use them. The VAR HOLDOFF control is usually left full counterclockwise. Its use will be explained when needed.

EXPERIMENTAL PROCEDURE

Turn on the scope and allow it to warm up for a minute or so. Meanwhile, set the controls according to Table 1. All of the knobs and switches move easily, so if something seems stiff check that you are moving it the right way.

These settings should produce two straight lines on the scope screen. Adjust the intensity for a comfortable display, and try the effect of the focus and position controls. Next, slow the sweep to 0.1 sec/div and note the effect of changing the vertical mode from ALT to CHOP.

We will usually use the scope to look at rapidly changing voltages, as produced by the function generator, for example. Reset the controls as in Table 1. Connect the grounded black terminal on the function generator to GND on the scope and the red terminal to CH 1. Set the function generator for about 500 Hz output with the variable amplitude knob at mid-range. There will be a signal on channel 1 but nothing on channel 2, so switch the VERTICAL MODE to CH 1 only. Try changing the various controls on the function generator and observing the changes in

INTENSITY	mid-range
VOLTS/DIV	5 (both channels)
COUPLING	DC (both channels)
VERTICAL MODE	BOTH, ALT
BW LIMIT	in
CH 2 INVERT	out
HORIZONTAL MODE	NO DLY
SEC/DIV	1 ms
TRIGGER	P-P AUTO, INT, CH 1,
LEVEL	mid-range
VAR HOLDOFF	NORM
POSITION	mid-range (all three)

Table 1. Start-up settings for oscilloscope

the output. (The scope is difficult, although probably not impossible, to damage electrically so don't worry about the effects of improper settings.) In this exercise, you are plotting many different signals on the same scales. You can also try plotting the same signal on many different scales by leaving the function generator set, and changing the VOLTS/DIV and SEC/DIV controls on the scope. Play with various combinations until you are confident of the effects of the various voltage and time scale controls on the scope and the function generator.

Triggering

Now examine the triggering controls. Set the function generator for 1 kHz sine wave output and adjust the scope scales so that two or three cycles roughly fill the screen. Try various settings of the trigger LEVEL and SLOPE controls. Describe the results in your report.

Function generator characteristics

For practice, we will measure some characteristics of the function generator. First, you will notice that the sine wave displayed is not exactly a sine wave. Sketch the wave shape, and point out some of the small differences from a true sine wave. Switch the FUNCTION control to look at the triangle and square waves, and sketch them also, noting any deviations from the ideal.

As an example of a quantitative measurement, we will determine the rise time of the square wave output. This is defined as the time required for the voltage to change from 10% to 90% of its final value, as shown in Fig. 5. By speeding up the sweep enough you should be able to find the 10% and 90% points and read the time between them from the calibrated scales. If the

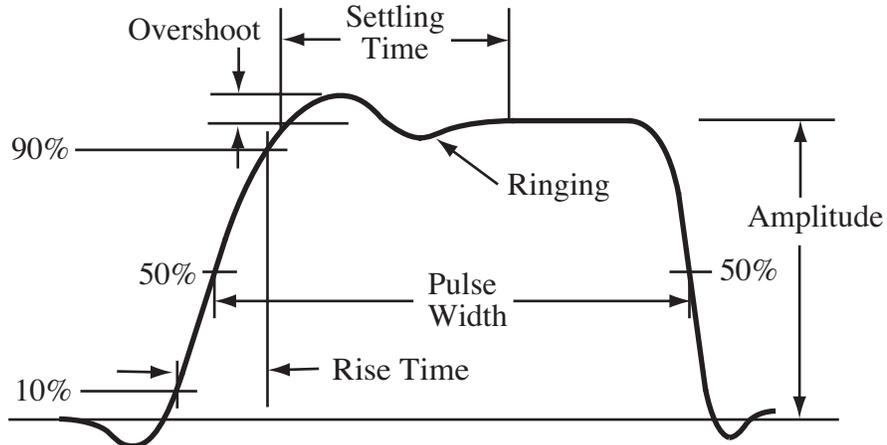


Fig. 5. Definition of rise-time and other parameters for a realistic pulse or square wave.

trace is too dim, increase the function generator frequency. Measure the rise time with the BW LIMIT switch both in and out. Sketch the oscilloscope trace corresponding to either case.

X-Y mode

In the x - y mode, the scope uses one of its input channels, instead of the internal time base generator, to control the horizontal deflection. We will demonstrate this feature by using two function generators to display Lissajous figures, which appear when the inputs are sine waves. The other channel provides vertical deflection, as before, so the scope plots

$$x(t) = A_x \sin \omega_x t \quad \text{and} \quad y(t) = A_y \sin \omega_y t$$

Connect the output of the first generator to CH 1 (x) and the second to CH 2 (y). Set both generators to produce a sine wave at a few hundred Hz and about 5 V amplitude. Set the scope controls as follows:

SEC/DIV	: x-y	CH 1 VOLTS/DIV : 1V
TRIG SOURCE	: INT, CH 1	CH 2 VOLTS/DIV : 1V

Adjust one function generator frequency until the trace is a steady ellipse. Are ω_x and ω_y now equal? Try varying the generator frequency to observe other figures, which occur for certain relationships between ω_x and ω_y .

RC circuit

For a more physical example, consider the circuit of Fig. 6. Using the square-wave output of the function generator, the capacitor charges to one polarity, then the source reverses and charges the capacitor to the opposite polarity. The whole cycle repeats at any rate we find useful. The resistor R acts as a transducer, allowing the scope to display a voltage proportional to the current through the capacitor on channel 1. Based on the general properties of RC circuits we expect the current to be large whenever the polarity changes, and to then decay exponentially to zero. Channel 2 will display the driving voltage V_S for comparison with this expectation.

Wire the circuit for measuring V_R as shown in Fig. 6, with $R = 1.5 \text{ k}\Omega$. Be careful to connect the grounds as indicated. Set the function generator for a square wave at about 200 Hz. The scope will display V_R on channel 1, and V_S on channel 2. Set up the scope to trigger on channel 2, and then set the controls so that you can clearly see the current (V_R) and source (V_S) waveforms. You may need to adjust the frequency or amplitude of the function generator output to get a satisfactory display. Ideally, you will be able to see both the decay and the flat area that defines the zero level of current. Sketch the two waveforms, being careful to show the time relation between them.

Power supply

The scope is also useful for studying the behavior of circuits. The circuit shown in Fig. 7 is a simplified version of a power supply, a device used to convert alternating current from the power company to direct current to supply an electronic device. The crucial component is a diode, shown with an arrow and bar symbol. Diodes allow current to flow in one direction, but block reverse flow. To demonstrate this phenomenon, wire the circuit of Fig. 7, but omit the capacitor for now. Set the function generator for a sine wave at a hundred hertz or so. Use the scope to sketch the voltage across the resistor, being careful to mark the zero level. Are your observations consistent with the idea that a diode allows current flow in only one direction? What happens if you reverse the diode in the circuit?

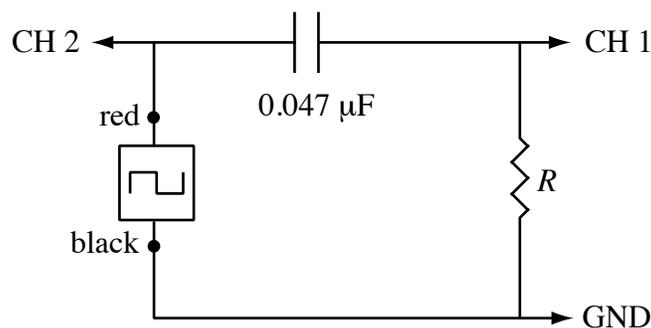


Fig. 6. Circuit for measuring V_R in an RC circuit.

Now connect the capacitor as shown, set the function generator to a frequency of 50-60 Hz, and sketch the new waveform. Has the addition of the capacitor changed the waveform substantially? Raise the function generator frequency to 5-6 kHz and sketch the waveform again, carefully noting the zero-volt level. Can you describe the result as a small variation about a positive value? In a real power supply the resistor would be the load we wish to drive, and the capacitor would be chosen to be large enough to make the variations (“ripple”) as small as needed for the particular application.

Other signals (optional)

Finally, if you have time at the end, you can look at musical signals. We have adapters that will let you connect the analog output of your audio device to the scope.

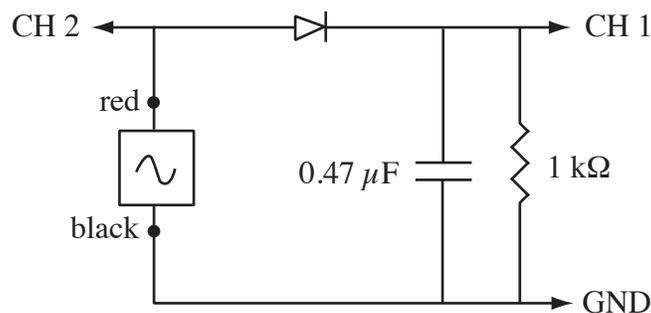


Fig. 7 Model of a power supply circuit. The diode should be one of the devices labeled “rectifier diode” on the circuit board.