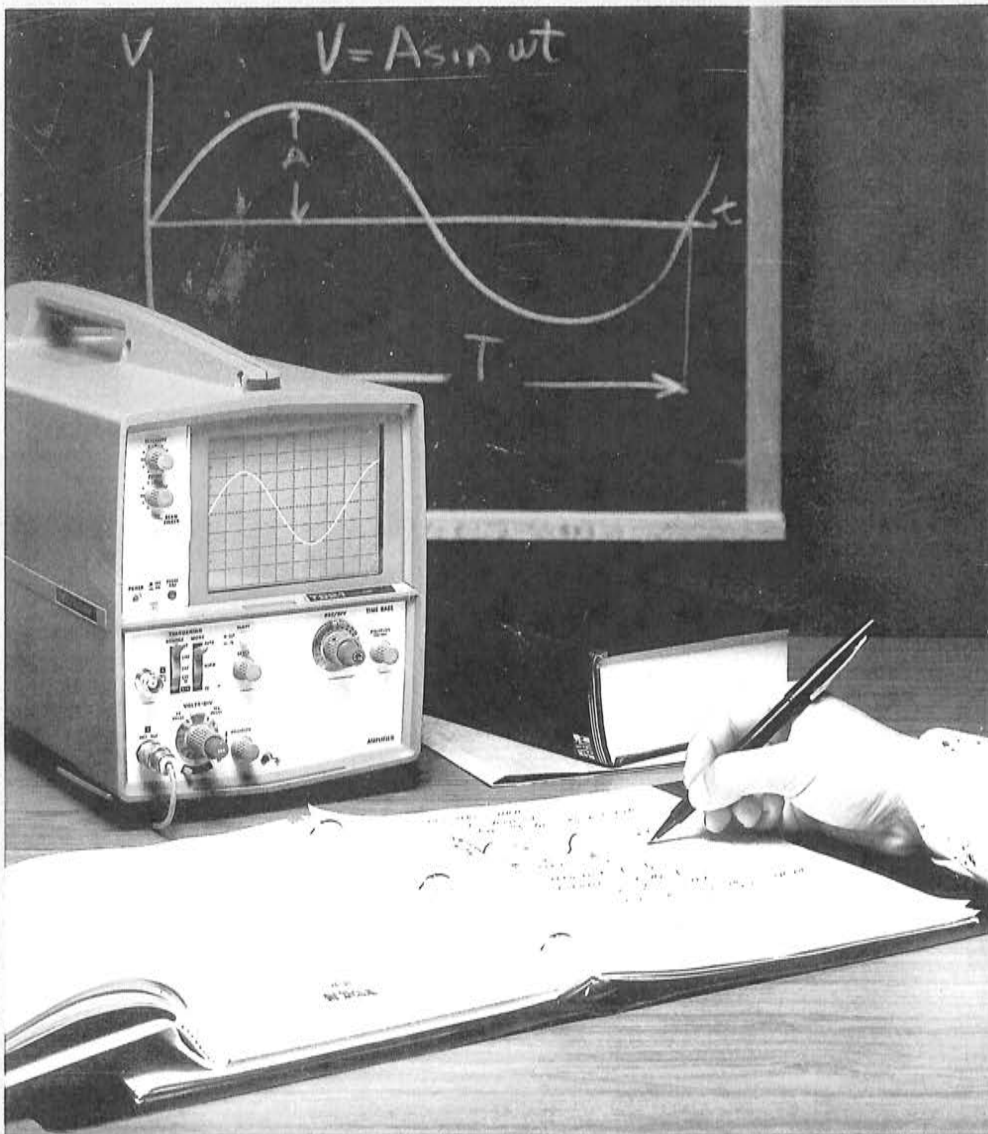
BASIC OSCILLOSCOPE OPERATION



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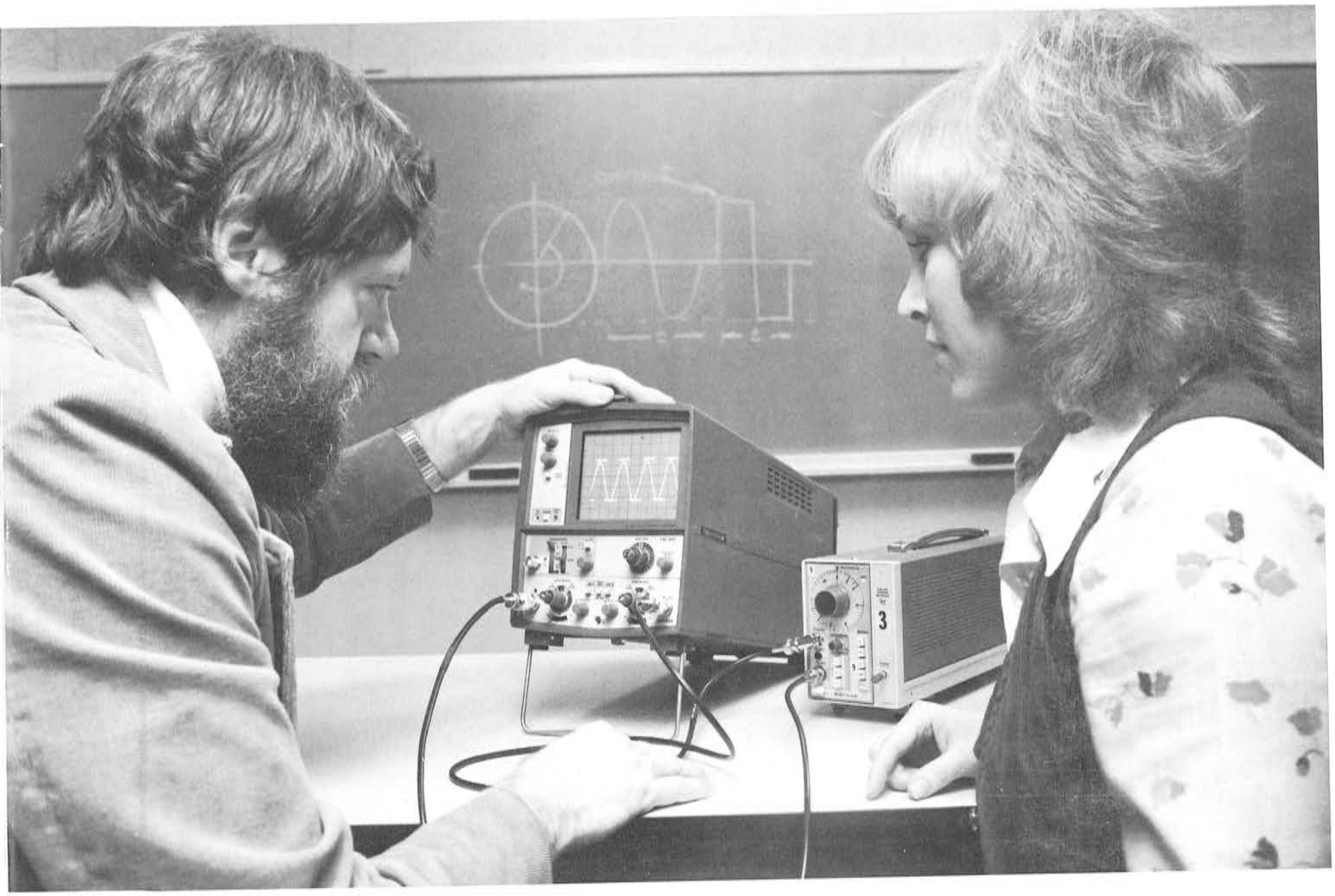


Many oscilloscope users and potential users have been held at arm's length by the "mysterious" workings of the oscilloscope. This needn't be the case. For a variety of scientific disciplines, the oscilloscope performs a function somewhat analogous to that which an x-ray machine performs for a doctor. Both the oscilloscope and the x-ray machine provide visual presentations not possible with the unaided eye. The doctor needn't understand the inner workings of the x-ray machine to be able to use the data it provides. Nor does the oscilloscope user need an in-depth understanding of the oscilloscope's circuitry to be able to make measurements with one.

In this booklet, we will introduce you to the controls, theory, and operations of a general-purpose oscilloscope that are necessary to make and interpret measurements. Our emphasis will be on operations and not on oscilloscope circuitry. We'll concern ourselves with those features most commonly encountered on general-purpose oscilloscopes, run through a simple experiment, and then discuss some features of more sophisticated oscilloscopes.

We have included a glossary at the end of the text as an aid in reading literature about oscilloscopes.

This booklet may be read in conjunction with hands-on oscilloscope operations or by itself. All oscilloscopes illustrated in the text are from the low-cost TEKTRONIX T900 Series. All the operational procedures use the T921 as a specific model. The dual-trace T922 and the dual-time-base T935 are then used as examples of more sophisticated oscilloscopes.

CHAPTER I
Common Oscilloscope Operations and Controls

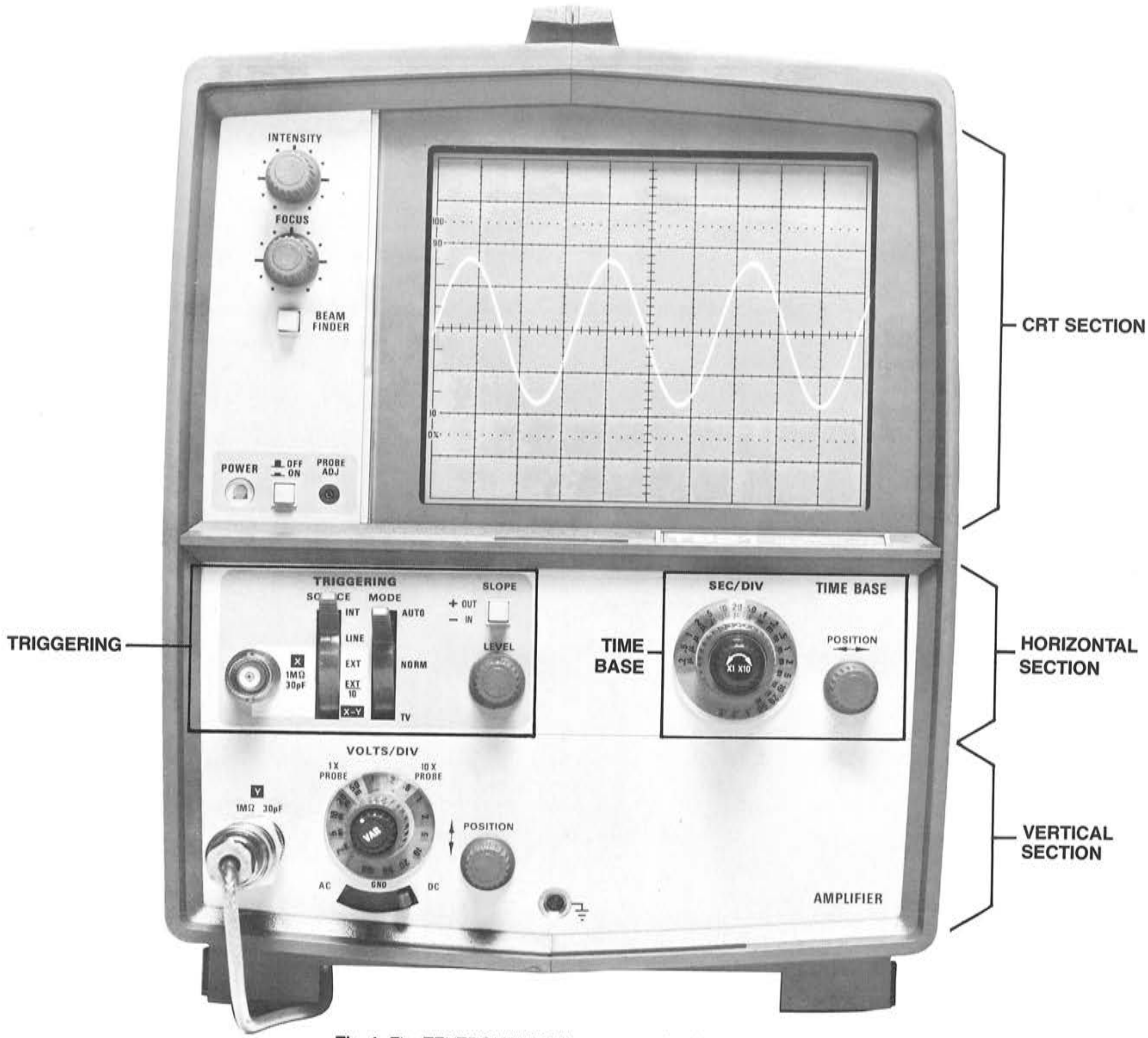


Fig. 1 The TEKTRONIX T921 is an example of a general-purpose oscilloscope.

The General-Purpose Oscilloscope

The TEKTRONIX T921 Oscilloscope, pictured in Figure 1, is an example of an easy-to-operate, general-purpose oscilloscope. It is inexpensive, yet it has good measurement capabilities. The "human engineering" in the instrument's design results in functionally-related controls being grouped together for convenience and color coded for easy identification. Of course, the front panels of all oscilloscopes are not organized in this fashion, nor do they all contain identical features. However, there are basic similarities.

The front panel of the T921 can be divided into four functionally related areas. The upper portion contains the cathode-ray tube and its associated controls. The cathode-ray tube (crt) is the device that provides us with a visual display of the electrical phenomenon being examined. (Figure 2 shows that this display may originate as an electrical phenomenon or as any phenomenon whose information is translated into an electrical signal.) The mid-section, or horizontal section, of the front panel is divided into two areas, one containing the time-base function and the other the triggering function. The lower part of the front panel contains the vertical section, the part of the oscilloscope to which the signal being examined is applied.

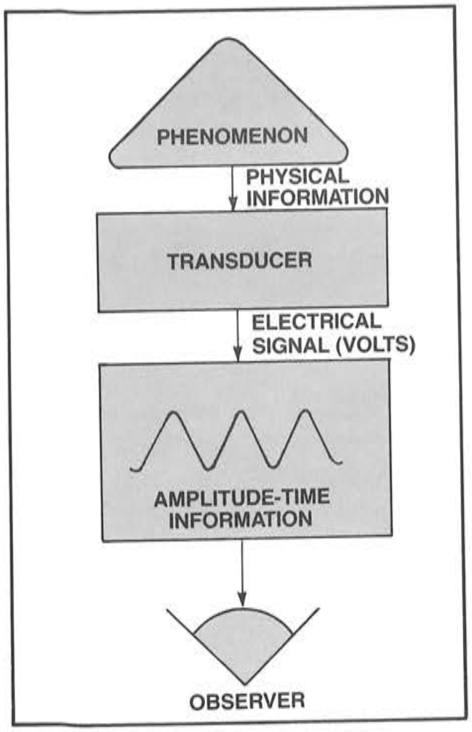


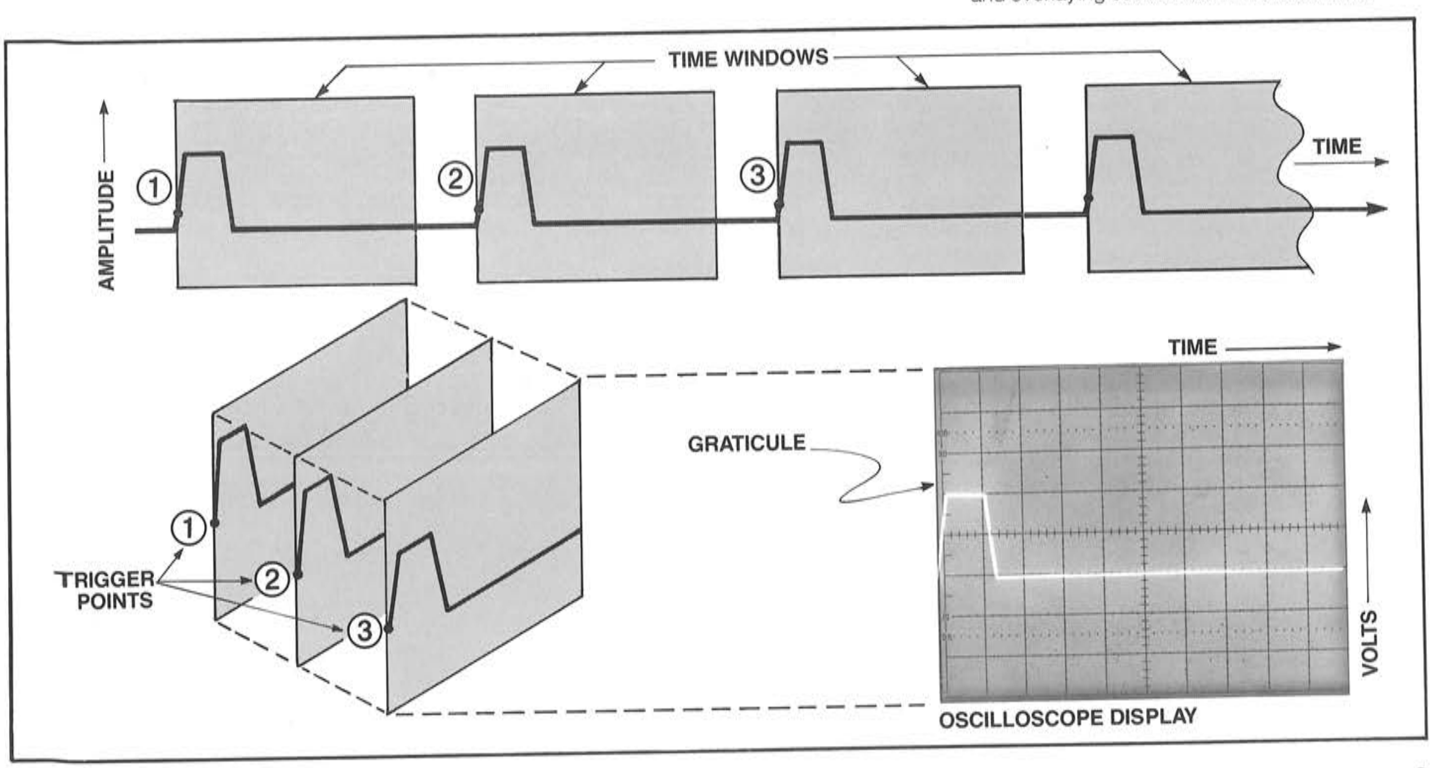
Fig. 2 The essential elements of an oscilloscope-based measuring system.

The oscilloscope (or scope for short) creates a crt display by capturing and overlaying successive windows of time, each window beginning at the same point, the trigger point, on the signal being examined. (See Figure 3.)

The time base determines how much time each horizontal division in the crt display represents. The triggering function determines when each time window begins, which results in a stable display. The vertical section controls the amplitude of the information displayed. It determines how many volts are represented by each vertical division in the display.

Before we start our discussions of the crt, vertical amplification, the time base and triggering, let's run through a quick turn-on procedure. This allows you to obtain a display on the crt, which is the basis for making measurements.

Fig. 3 A crt display is constructed by capturing and overlaying successive windows of time.



First-Time Operation

Before actually turning on the oscilloscope, there are a few controls that you can preset to facilitate the turn-on procedure. The circled numbers refer to the controls shown in Figure 4.

1. Turn the crt INTENSITY control to full off (counterclockwise). ①

2. Set the triggering SOURCE switch to INT (internal). ②

3. Set the triggering MODE switch to AUTO (automatic). ③

4. Set the SEC/DIV control to 1 ms. ④

5. Set the VOLTS/DIV control to its least sensitive (largest number) position. ⑤

6. Set the input coupling switch to the GND position. ⑥

There needn't be a signal connected to the scope to obtain a display. We'll discuss the role of each of these controls a little later, so don't be concerned about the "why" of this procedure right now.

7. If the oscilloscope has a three-pronged plug on the power cord, connect it to a properly grounded outlet. (If you are unsure that the outlet is properly grounded, have it checked by a qualified electronics technician.) If the oscilloscope does not have a three-pronged plug on the power cord, plug the cord into the outlet and ground the scope according to the manufacturer's directions. Now turn on the oscilloscope. ⑦

8. Press the BEAM FINDER. ⑧ Hold it in while increasing the INTENSITY ① until a display shows up on the crt. ⑨

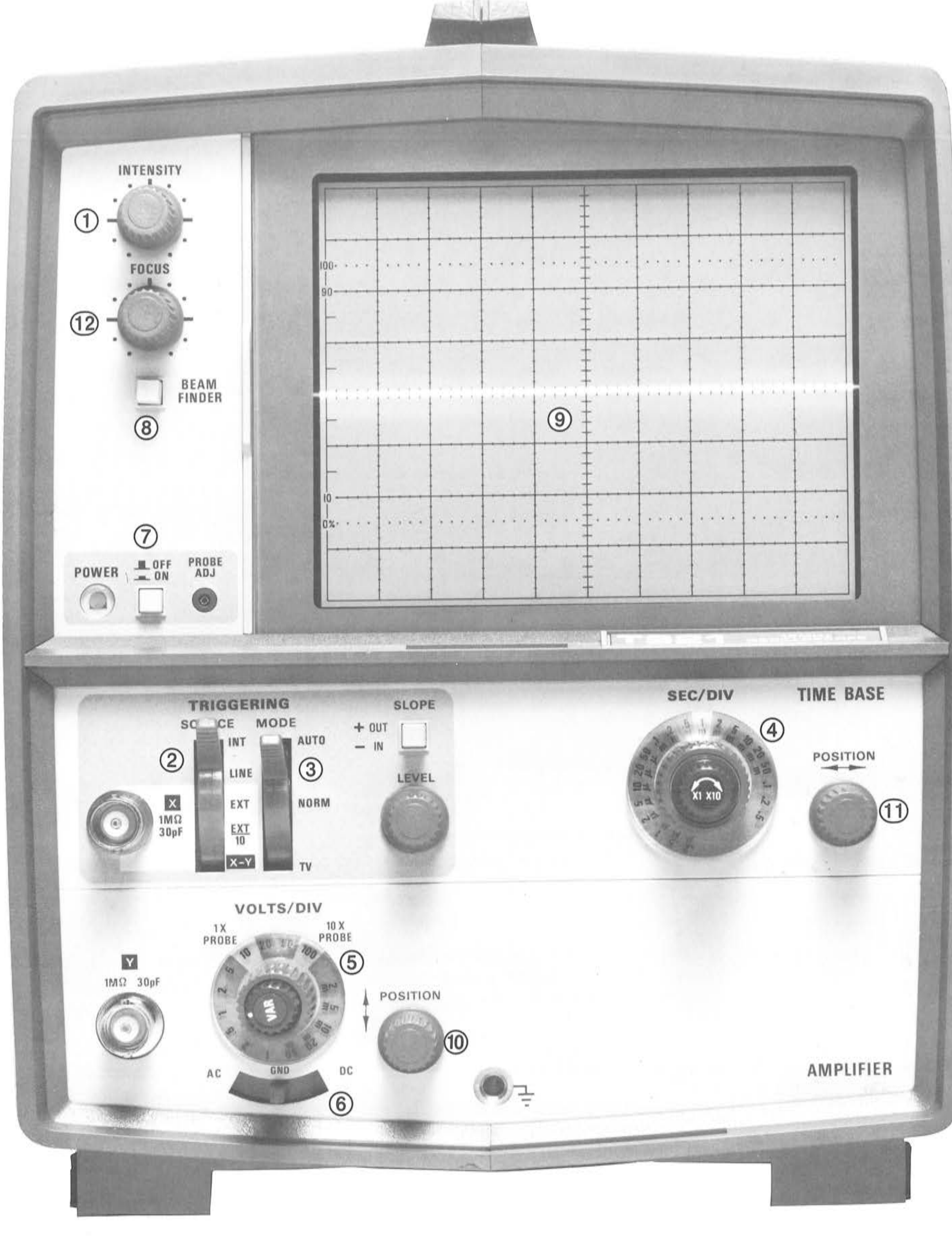
9. While still depressing the BEAM FINDER, use the vertical and horizontal POSITION (⑩ and ⑪) to center the display on the crt.

10. Release the BEAM FINDER. ⑧

11. Adjust the FOCUS ⑫ for a sharply focused display.

You now have the most basic display: a free-running trace. (See figure 4.) Once this is obtained you have the basis for most oscilloscope measurements. All that remains is to apply a signal to the vertical input and select the VOLTS/DIV (or VOLTS/CM or SENSITIVITY) and the SEC/DIV (or TIME/DIV) settings to display the signal.

Fig. 4
A TEKTRONIX T921 with controls keyed to the first-time operation. The display shows a free-running trace.


INTENSITY
FOCUS
BEAM FINDER
POWER
OFF
ON
PROBE ADJ
TRIGGERING
SLOPE
MODE
INT
LINE
EXT
EXT/10
X-Y
AUTO
NORM
TV
+ OUT
− IN
LEVEL
X
1MΩ
30pF
SEC/DIV
X1 X10
TIME BASE
POSITION
VOLTS/DIV
1X PROBE
10X PROBE
VAR
Y
1MΩ 30pF
POSITION
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(ACTUAL SIZE)

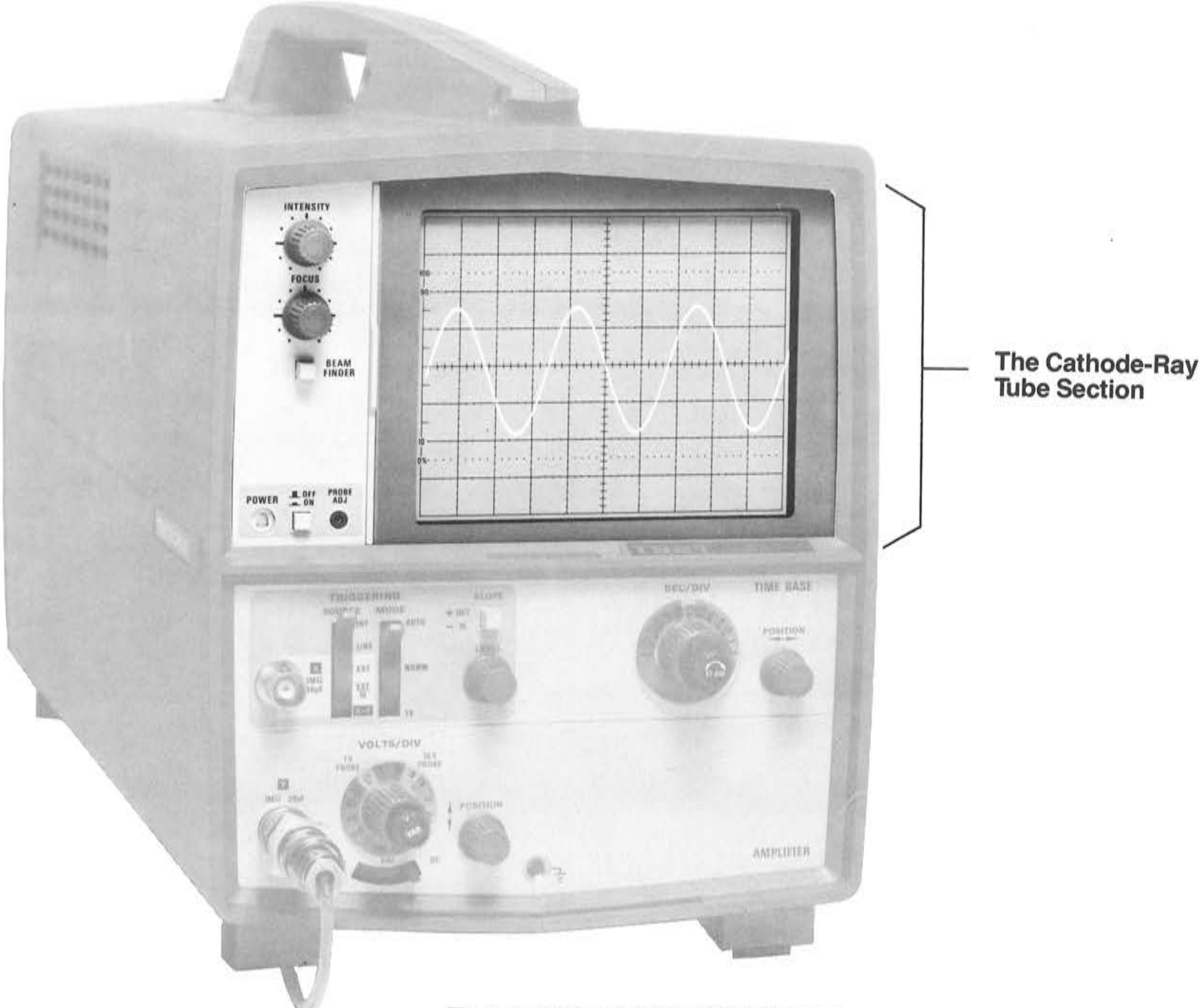


Fig. 5 The crt section of the T921 front panel.

Oscilloscopes, from the simplest to the most complex, provide us with two basic pieces of information: "how much" and "how long." They provide this information in the form of a graph. We're probably all familiar with graphs of the type produced by strip-chart recorders like the one in Figure 6. These graphs are very similar to those produced by oscilloscopes since they plot both "how much" (amplitude) on the vertical (Y) axis, and "how long" (time) on the horizontal (X) axis.

Strip-chart recorders, however, can only respond to slow signals because of the difficulty in trying to move the mass of the pen rapidly. The crt offers a solution to this problem. The cathode-ray tube is a graphing mechanism capable of responding to extremely fast signals. Using the phosphor-coated faceplate of the crt as a piece of graph paper, the electron beam becomes a very low-mass, low-inertia pen which draws the graph.

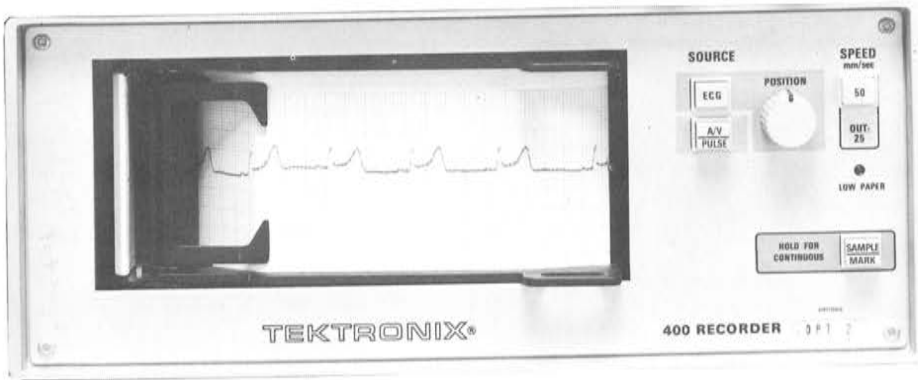


Fig. 6 An example of a TEKTRONIX 400-Series Recorder making a permanent record of a patient's ECG.

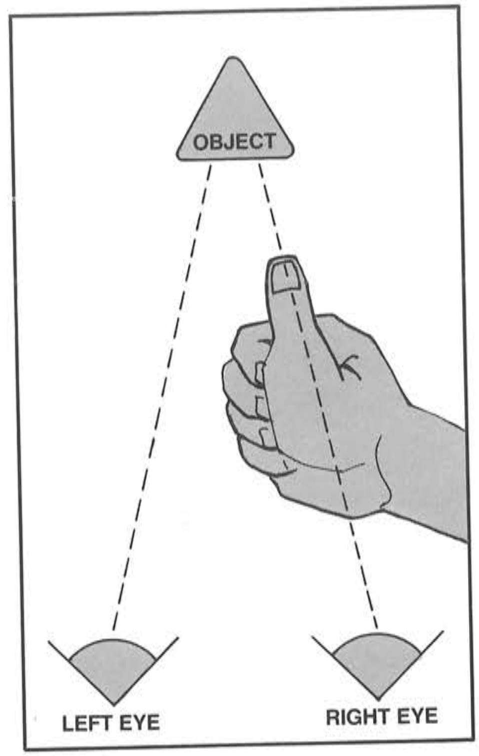


Fig. 7 An example of parallax. The object appears in different positions relative to the thumb when viewed from different locations.

The GRATICULE is a grid etched on the crt faceplate. On older oscilloscopes, this graticule was a piece of plexiglas which had a ruled scale inscribed on one of its surfaces. The piece of plexiglas was placed over the crt faceplate. Some crt's had the graticule etched directly on the outside surface of the crt faceplate. Newer crt's have the graticule etched directly on the inside surface of the faceplate on the same plane as the phosphor. This is preferable because it eliminates parallax errors.

Parallax is an optical phenomenon that results when the viewer's eye is not in line with two items being viewed (in this case, with a point on the graticule and a point on the waveform on the crt display). An easy way to visualize parallax, illustrated in Figure 7, is to close your left eye and look at an object about fifteen feet away. Cover the object with your thumb held out at arm's length. Now, without moving your thumb, open your left eye and close your right eye. You can see the object again. For one eye, the object and your thumb line up, but for the other eye they don't. When you make a reading from the display and compare the signal position to the graticule, make sure that you eliminate the possibility of parallax error.

There are four controls associated with the crt that are usually present on every oscilloscope. The INTENSITY control varies the light level of the trace on the crt display and should be adjusted with moderation. On any oscilloscope, if the intensity level is set too high for too long, you run the risk of damaging the crt and having your display permanently burned into the phosphor.

The ASTIGMATISM and FOCUS controls are closely related because they are adjusted in conjunction with each other to achieve a sharply focused display. The ASTIGMATISM control adjusts the shape of the electron beam being used to create the display. The FOCUS control adjusts the beam size as small as possible. The ASTIGMATISM control is not always available on the front panel. For example, on the T921 it's a screwdriver adjustment accessible through the side of the instrument case. The TRACE ROTATION control allows the alignment of the free-running trace with the horizontal reference line of the graticule (this is also a screwdriver adjustment through the side of the T921).

The BEAM FINDER is another crt-associated control generally found on later model oscilloscopes. Occasionally, no matter how furiously you twiddle the knobs, you won't be able to obtain a display. This may be because of misadjusted controls or the wrong signal amplitudes. When this happens, push the BEAM FINDER button and slowly increase the crt INTENSITY level until you get some sort of display.

The BEAM FINDER control compresses the display to within the crt graticule area regardless of display positioning or signal amplitude. For example, if you are unable to obtain a display, push the BEAM FINDER. The resultant display may be deflected to the top of the crt. This might be because the vertical POSITION control is misadjusted. Rotating the control would bring the display back into the center of the crt area.

The Vertical Section

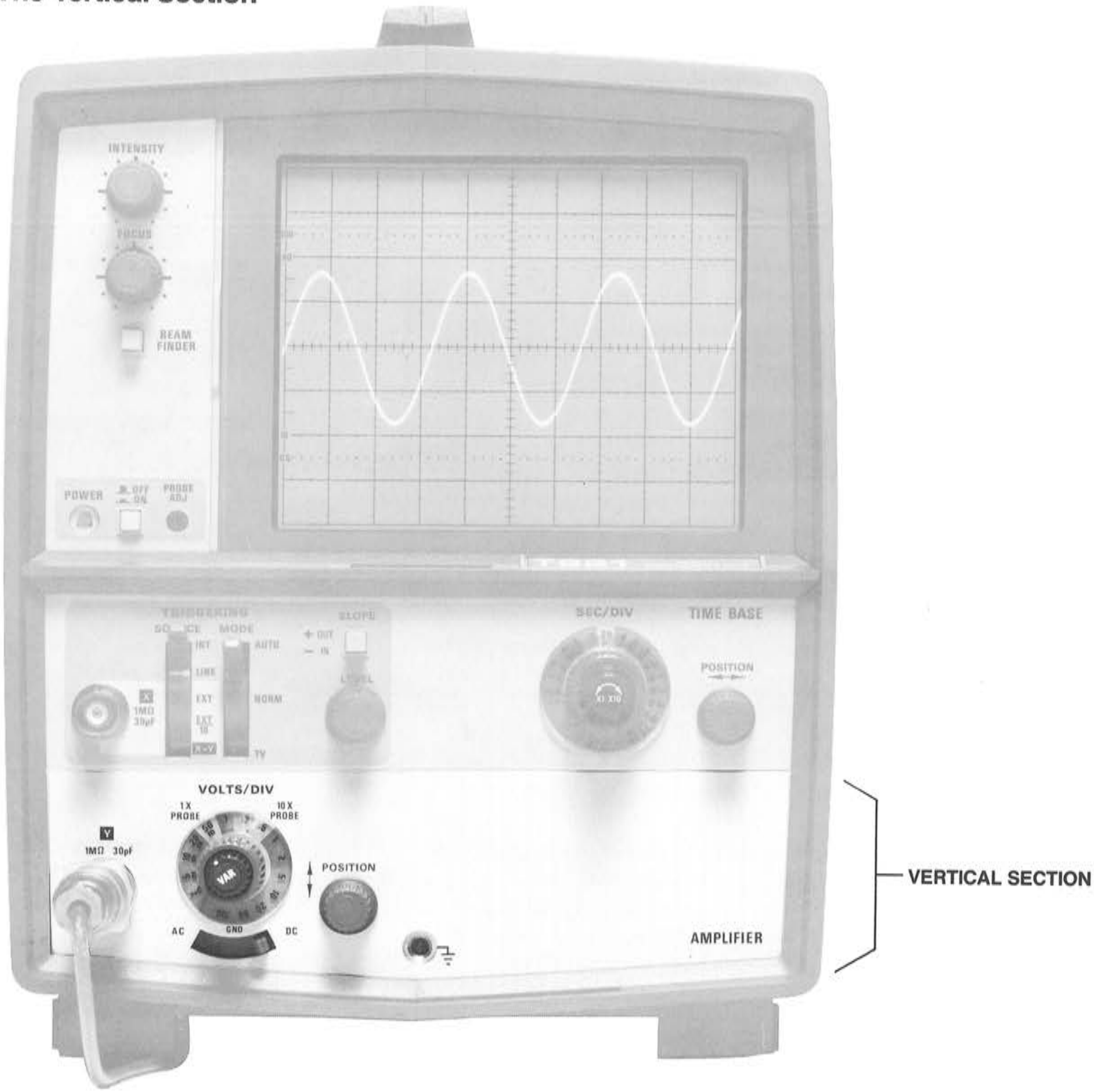
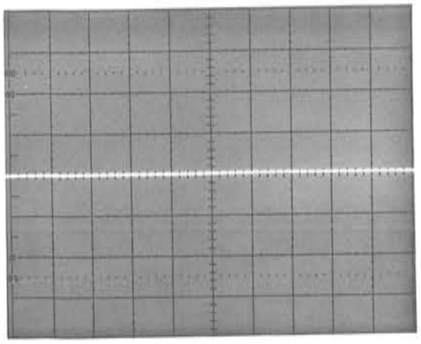


Fig. 8 The vertical section of the T921 front panel.

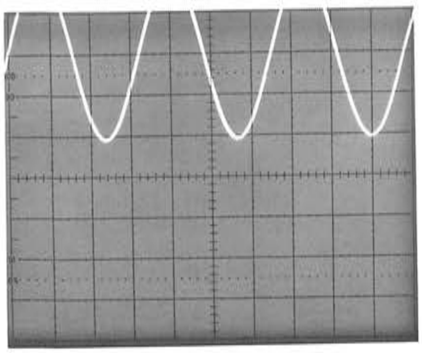
Any phenomenon that can be converted into a voltage can be measured by an oscilloscope. The voltage that represents the unknown being measured connects to the vertical section of the oscilloscope (highlighted in Figure 8) via the vertical input connector (labeled Y on the T921).

The VERTICAL INPUTS to oscilloscopes are usually characterized by specifying their input impedances. These characteristics are significant because they can alter the amplitude or the shape of the waveform being examined, depending on the nature of the signal. Be aware that there is the possiblility that the display is a distortion of the information due to impedance mismatching. This topic is beyond the scope of this booklet, but is well addressed in the electronics measurements and instrumentation literature.

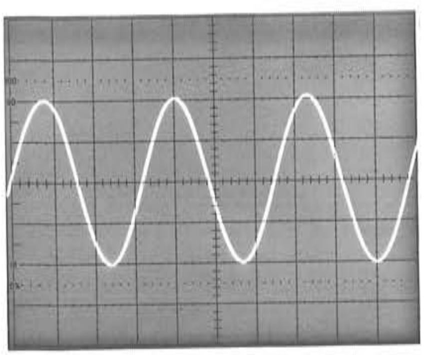
The INPUT-COUPLING switch determines the manner in which the signal being examined is connected to the vertical section of the oscilloscope. There are normally three positions available on the switch: GND (ground), DC, and AC. The GND position connects ground (usually the oscilloscope chassis ground) to the input of the vertical section in place of the signal. Since all input signals are referenced to the oscilloscope chassis ground, this provides a convenient way of establishing a zero-volt reference level on the crt display. In the AC position, a capacitor is connected between the input connector and the vertical section of the oscilloscope. The capacitor prevents constant voltages (dc voltages) from being applied to the vertical section but allows time varying signals (ac voltages) to be passed to the vertical section. This method of coupling is useful when attempting to observe low-amplitude signals that are superimposed on relatively large dc voltages that might otherwise cause the display to be deflected off the screen. In the DC position, all signals applied to the input connector are passed to the vertical section.



GND COUPLING
.2 VOLTS/DIV



DC COUPLING
.2 VOLTS/DIV



AC COUPLING
.2 VOLTS/DIV

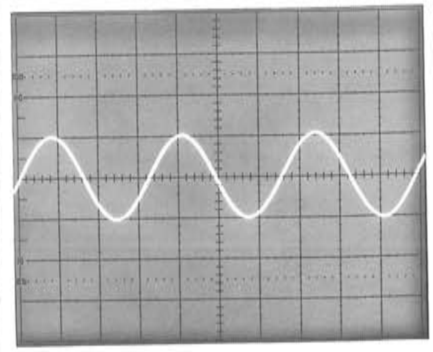
Fig. 9 An example of the effect on the crt display due to different input-coupling methods.

Figure 9 illustrates the display of a signal that is composed of a constant component and a time variant (wave) component. The constant component causes the resultant signal to have the same shape as the wave, but to be displaced from the ground reference line. The DC coupling shows the signal as it is, while the AC coupling shows just the time variant part of the signal.

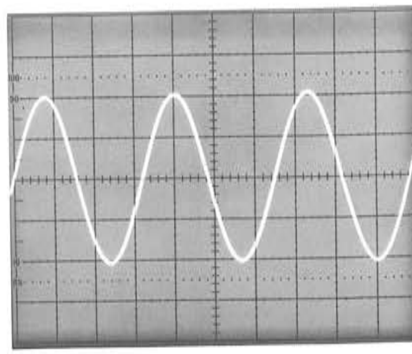
When first applying a signal to an input channel of an oscilloscope there may exist high voltage transients which can cause circuit damage. The potential for this damage can be reduced by precharging the input-coupling capacitor to the average dc level of the signal. This is accomplished in the T900 Series by placing the input coupling control in the GND position, touching the probe to the oscilloscope ground connection (discharging the previous level), applying the probe to the test point (charging to the present level), and switching the input coupling control to its appropriate position. When in the GND position with the signal applied, the input coupling capacitor in the T900 Scopes is charged to the average dc level of the signal. Some scopes require a fourth input coupling position (usually labeled PRE-CHARGE) to provide this capability.

The VOLTS/DIV (or VOLTS/CM, or SENSITIVITY) control of an oscilloscope varies the sensitivity of the vertical section so that signals from a few millivolts to several hundred volts in amplitude can be displayed and measured. The numbers on the control indicate vertical sensitivity in terms of volts (or fractions of a volt) per vertical division of the graticule in the crt display. The vertical scale factors selected by the VOLTS/DIV control are specified to be accurate within some nominal tolerance (typically within 3%). Figure 10 illustrates the effect on the display of a signal caused by changing the VOLTS/DIV control.

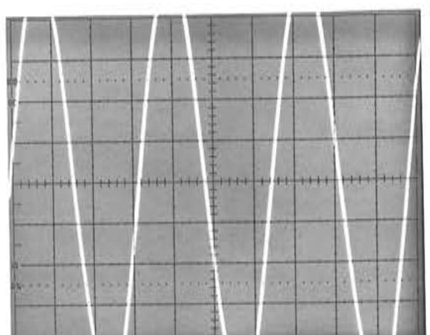
The VARIABLE VOLTS/DIV (VAR) control also adjusts the sensitivity of the vertical section, but in an uncalibrated manner. The scale factors achievable by the variable control are relatively arbitrary and adjustable according to the needs of the measurement being made. Typically the variable control allows continuous adjustment between the calibrated settings of the VOLTS/DIV control.



1 VOLT/DIV



.5 VOLTS/DIV



.2 VOLTS/DIV

Fig. 10 The effect on the display of varying the VOLTS/DIV setting for the same signal.

The VERTICAL POSITION control allows you to move the presentation up and down on the crt display. Moving the presentation permits aligning points of interest on a waveform with the crt graticule lines, making accurate interpretation of the display easier.

The Horizontal Section

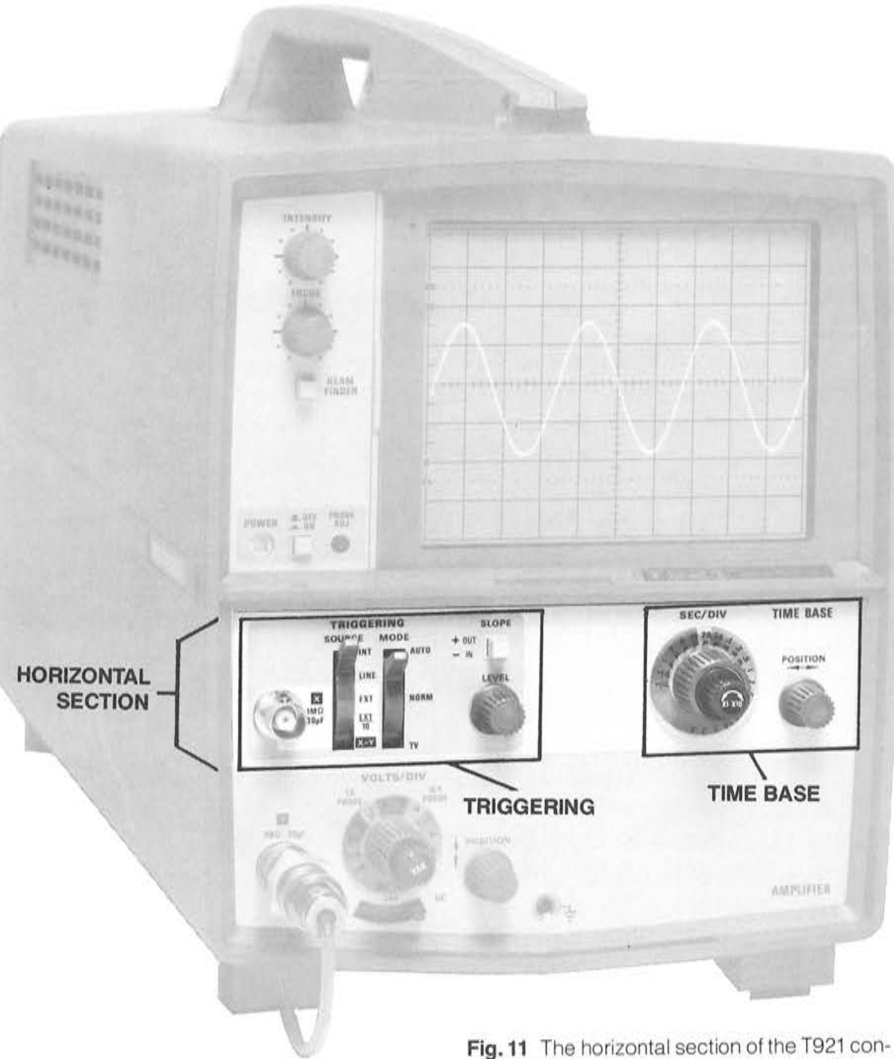


Fig. 11 The horizontal section of the T921 contains the triggering and time-base controls.

Time Base

The TIME BASE controls the "how-long" (time) portion of our graph, while the vertical section controls the "how-much" (amplitude) portion. The time base establishes the horizontal scale factor or SEC/DIV. This is similar to the scale factors on a set of maps, where, for example, 1 cm equals 50 km. As the scale factor gets smaller the distance covered by the map gets smaller and the features portrayed on the map get larger. Thus, when you are viewing an oscilloscope display, as you decrease the setting on the SEC/DIV control, you see the time dependent features of the signal in more detail and you view less of the total signal. The SEC/DIV control selects these scale factors over a wide range and in a calibrated manner. Horizontal timing is typically specified to be accurate within 3% to 5% and occasionally 1%.

The VARIABLE (VAR) control associated with the SEC/DIV control allows you to use uncalibrated horizontal scale factors. When the variable control is rotated out of the detent position, the horizontal time-per-division factor is no longer calibrated. The control usually allows continuous adjustment between the calibrated settings of the SEC/DIV control. On some instruments, the VAR control reduces the time per division and on others it increases it. On the T921, the variable control reduces the time per division and provides a factor-of-ten horizontal magnification when it is rotated fully clockwise. Almost all oscilloscopes offer some form of horizontal magnification; some use the variable control, and some use a switch. The magnification offered is usually a factor-of-ten but can be as high as 100.

The POSITION control associated with the time base allows you to move the display back and forth horizontally. Moving the display permits aligning specific points of interest on a waveform with the crt graticule lines, which makes accurate horizontal (time) measurements easier.

Triggering

Triggering is responsible for creating stable crt displays, and thus properly overlaying the windows of time. After the completion of one time window, it determines when the next window is started. If the same point on each period of a repetitive waveform is selected for the trigger point, then all the windows will overlay the same signal and give one picture of the signal (a stable display). When the triggering is derived directly from the signal being displayed, the display remains stable, so long as there is an adequate signal present. If the trigger point is not the same for all windows, then the time window overlay does not match and the display is a jumble of traces (an unstable display). Figure 12 illustrates a stable and Figure 13 an unstable display of the same signal.

A signal that is selected as the trigger signal (the trigger source) should be time related to the displayed signal. The trigger source could be the displayed signal itself, the power line voltage signal, or an external signal.

The SOURCE switch selects the origin of the signal from which triggering is derived. Typically, the sources are:

INT(internal) — The triggering is derived from the signal being displayed.

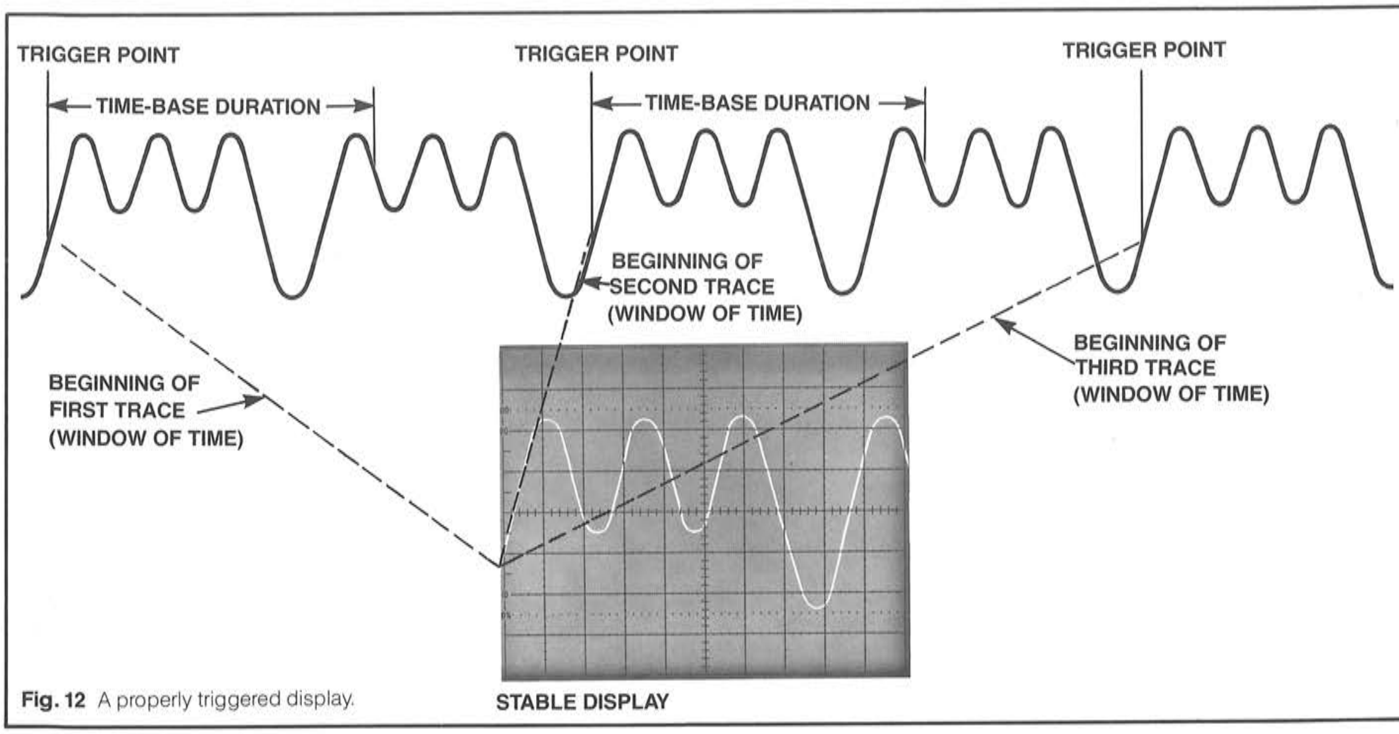


Fig. 12 A properly triggered display.

LINE — A sample of the ac power line voltage to which the oscilloscope is connected is used to derive the triggering. This trigger source is particularly useful when troubleshooting power-supply circuits because it eliminates the need for an additional signal connection between the oscilloscope and the circuit under test.

EXT(external) and EXT (external) ÷ 10 — These positions select the signal connected to the external-input connector as a trigger source. The EXT (external) ÷ 10 position provides times-ten (X10) attenuation for overly large external signals. Any external signal used to derive triggering should be time related to the display signal in order to have a stable display.

X-Y (although not strictly a trigger source) — Permits an x versus y display. The horizontal (x) signal is connected through the X (horizontal) input connector. The vertical (y) signal is connected through the Y (vertical) input connector. This setting allows you to make frequency comparisons of two signals such as Lissajous figures (see Glossary).

Once you have selected a trigger source, then you need to define the point on that signal that is to start the time window. This is called the trigger point. It is specified by the signal's amplitude (level) and slope (positive or negative).

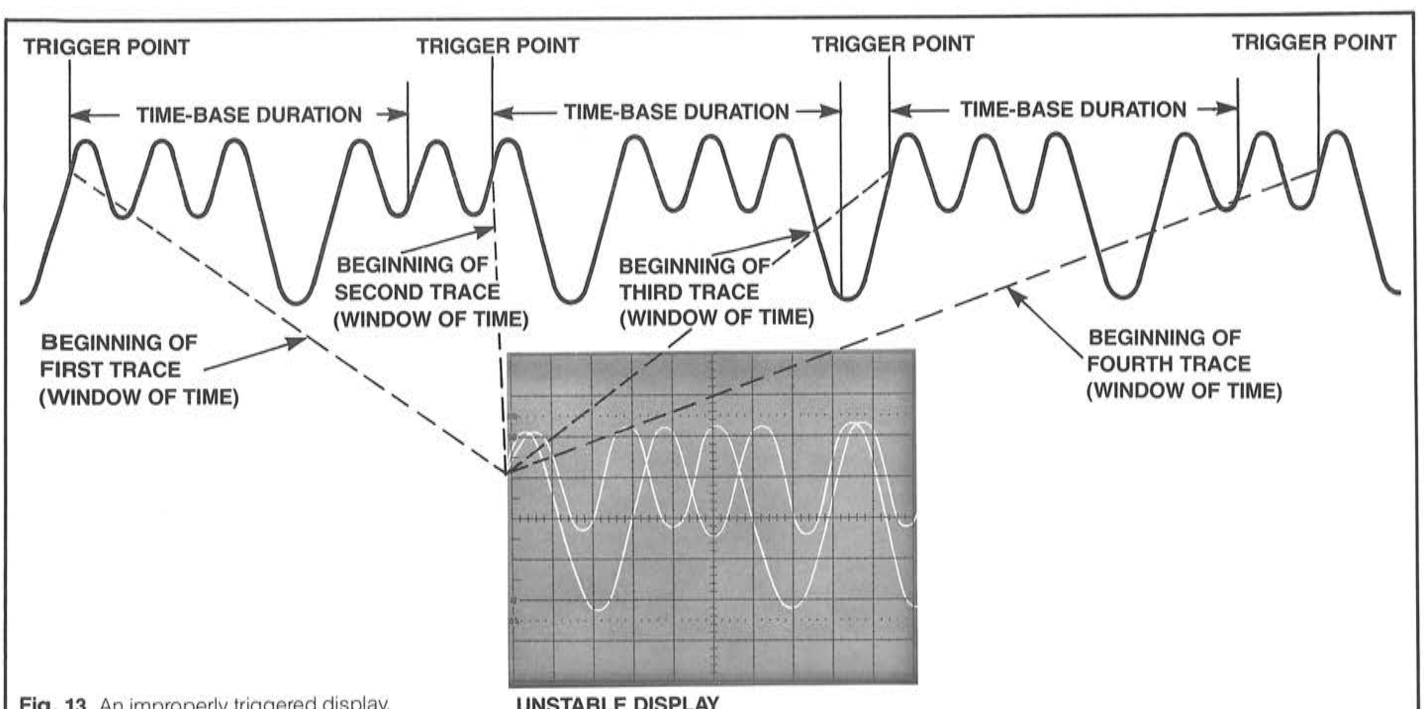


Fig. 13 An improperly triggered display.

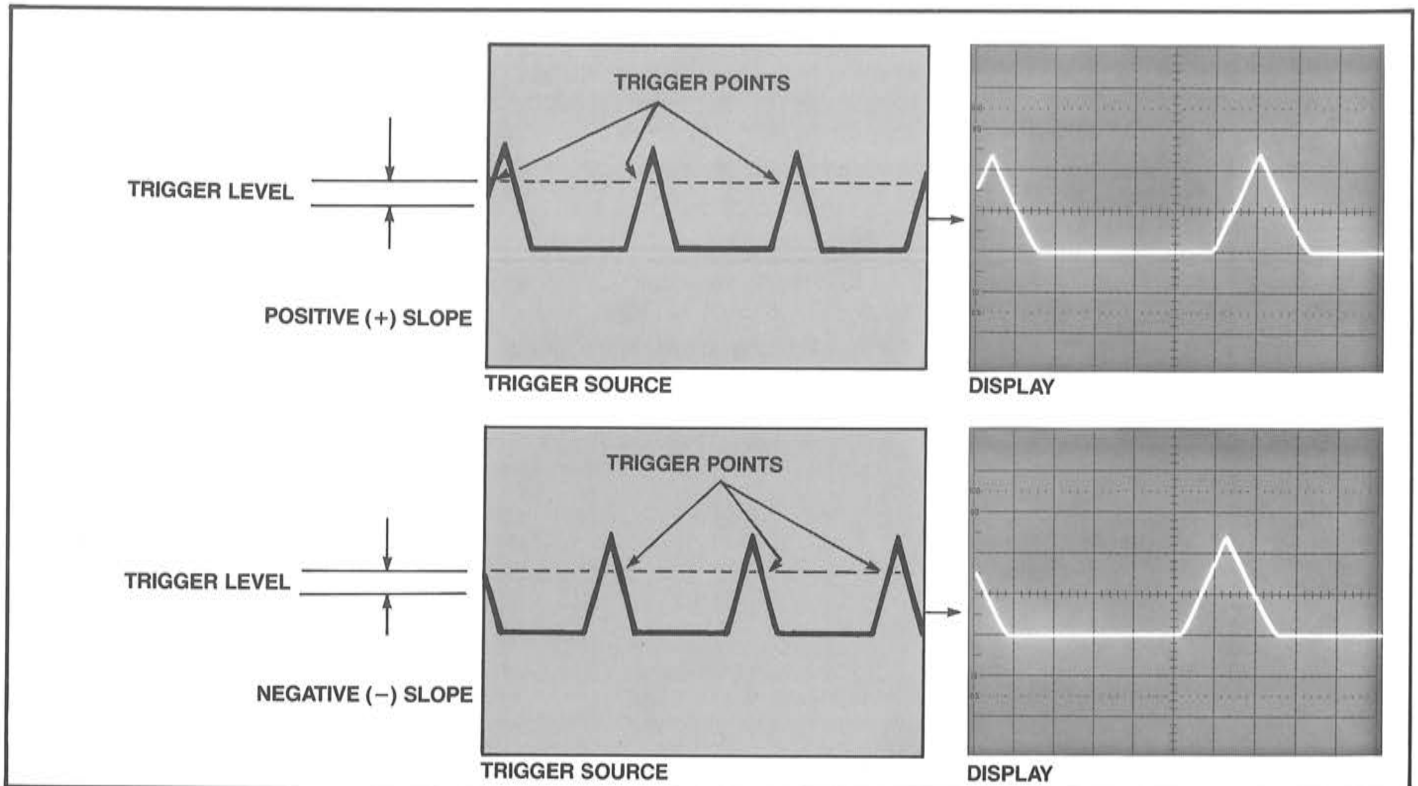


Fig. 14 Here the trigger source is the same as the signal that is being displayed. A trigger occurs when the trigger-source signal passes through the level (set by the LEVEL control) with the proper slope (set by the SLOPE switch).

Depending on the nature of the signals being examined, you may wish to have the oscilloscope display begin on either the rising or falling edge of the signal. The SLOPE switch allows this selection with "+" meaning rising signal (positive-going) and "−" meaning falling signal (negative-going). The LEVEL control selects the specific amplitude point on the waveform at which the time window is to begin. Figure 14 illustrates the selection of a trigger point.

The MODE switch determines how triggering is accomplished. The two most commonly encountered modes are AUTO (automatic) and NORM (normal). You can't tell one of these two modes from the other when you have a triggered display. The difference shows up when the trigger signal does not meet the selected parameters of slope and level. In the NORM (normal) mode, when the trigger signal is inadequate or when the LEVEL control is misadjusted, there is no display at all. Under the same conditions, the AUTO (automatic) mode provides a free-running reference display which may not be stable.

In a SINGLE-SWEEP mode (not shown on the T921) only one time window is displayed and additional time windows are disabled until the single-sweep is reset. This is useful when the signal to be displayed is not repetitive or varies in amplitude, shape, or time. Single sweep also facilitates photographing non-repetitive waveforms.

The T921 has a trigger mode not found on many instruments: the TV mode. This mode is useful when examining the signals found in a television system. It allows triggering on a TV frame or line.

The TRIGGER COUPLING switch is used to determine how the trigger signal is connected to the triggering section of the oscilloscope. Different methods of coupling offer various operational advantages. As does the input-coupling switch for the vertical section, the TRIGGER COUPLING switch offers both AC and DC coupling. In the AC position, a capacitor in series with the signal path blocks constant voltages but allows time-varying signals (depending on signal frequencies) to pass to the triggering section of the oscilloscope. In the DC position, all components of a trigger signal are passed on to the triggering section.

The Oscilloscope Probe

A PROBE is the only additional piece of equipment that you normally need to make a measurement with an oscilloscope. The probe is a separate unit connected by a flexible cable which transmits the signal from the source to the input of the scope. You connect the probe cable to the input of your oscilloscope and then attach or touch the probe tip to the signal source.

The information we have just developed in the preceeding section enables you to approach a general-purpose oscilloscope, turn it on, obtain a free-running trace, input a signal, and get the desired representation of that signal in the display.

The steps required to accomplish this task are:

1. Turn on the oscilloscope and get a free-running trace.

2. Input the desired signal to the vertical channel.

3. Select the desired VOLTS/DIV setting.

4. Select the desired SEC/DIV setting.

5. Select the trigger source, coupling, and mode.

6. Select the trigger level and slope.

7. Interpret the signal in the displayed time window.

CHAPTER II
A 60 Hz Experiment with an Oscilloscope

Fig. 15 The set up for the 60 Hz experiment.

A simple experiment that you can perform to exercise your understanding of oscilloscopes involves the fields that are present in the environment. In modern society we are nearly always surrounded by 60 Hz (or 50 Hz in some parts of the world) electromagnetic fields from the power lines in our homes, neighborhoods, buildings, etc. You can detect and display the interaction of these fields with your body by using an oscilloscope.

The first step in this investigation (or any investigation) is to make sure that your oscilloscope is properly grounded. If the oscilloscope has a three-pronged plug on the power cord, make sure that it is connected to a properly grounded outlet. (If you are unsure that the outlet is properly grounded, have it checked by a qualified electronics technician.) If the oscilloscope does not have a three-pronged plug on the power cord, ground the oscilloscope according to the manufacturer's instructions. Next obtain a free-running trace as outlined in the "First-Time Operation" procedure. Now attach a probe to the input (vertical or Y) of the oscilloscope. Set the input coupling switch to AC. Set the time base (SEC/DIV) control to 5 ms/div. Touch the probe tip to your finger and adjust the VOLTS/DIV (sensitivity) control until a signal appears. (See Figure 15.)

Make sure that both the SEC/DIV and VOLTS/DIV controls are in their "cal detent" (calibrated) positions. If the display is not steady, set the trigger mode to normal, select the positive (+) slope in the triggering section and adjust the trigger level until you have a steady display. The signal that is now displayed is the 60 Hz field picked up by your body as compared with the oscilloscope ground. An example of the 60 Hz field as picked up by the human body is given in Figure 16.

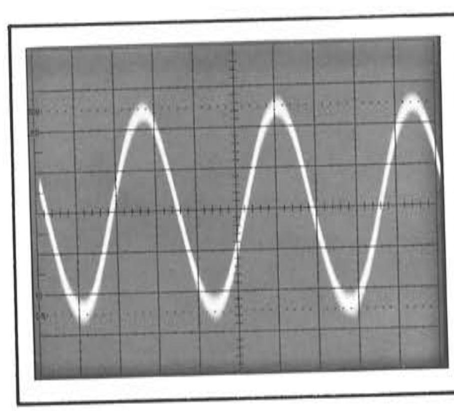


Fig. 16 The waveform of the displayed 60 Hz signal depends on the characteristics of the antenna (you) and the field. The waveform will vary from person to person and as the individual changes position in the field.

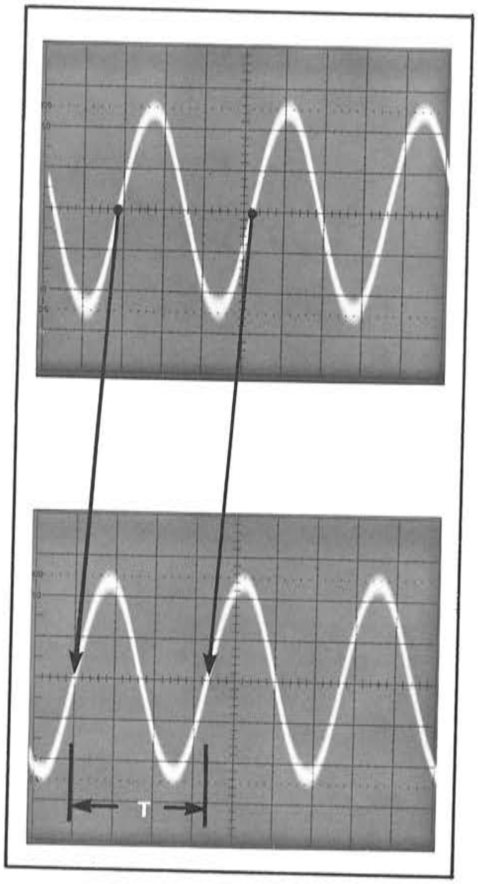


Fig. 17 The waveform is shifted by using the horizontal (time-base) position control until it crosses one of the major vertical divisions and the horizontal reference line. T measures the number of major divisions for one period.

We will use this signal to demonstrate the effects of some of the controls.

Increase the SEC/DIV (time base) control setting and you should see more complete waves appear in the display. Decrease the SEC/DIV control setting until you have about two complete waves in the display. Move the displayed wave horizontally until a zero crossing of the wave is at the first vertical line from the left. Now count the number of major divisions to the next zero crossing that corresponds to the same point on the next cycle. (See Figure 17.)

Multiply this reading by the SEC/DIV setting. The result is the period of the wave. Frequency is the inverse of the period. The frequency should be nearly 60 Hz.

PERIOD = T x SEC/DIV

$$\text{FREQUENCY} = \frac{1}{\text{Period}}$$

EXAMPLE (FIG. 17):

PERIOD = $3.35 \times 5 \times 10^{-3}$ = .01675 sec

FREQUENCY = 1/.01675 = 59.7 Hz

Now use the vertical POSITION control to move the bottom of the troughs to lie on a horizontal line. Use the horizontal POSITION control to move a peak onto the major vertical line. Count the number of vertical divisions between the troughs and the peaks. (See Figure 18.)

To obtain the peak-to-peak voltage multiply the number of divisions from the trough to peak by the VOLTS/DIV setting. One half of this value is the amplitude of the signal present in the body.

Peak-to-peak volts = H x VOLTS/DIV

AMPLITUDE = ½ Peak-to-Peak

EXAMPLE (FIG. 18):

AMPLITUDE = ½(4.8x.2) = .48 Volts

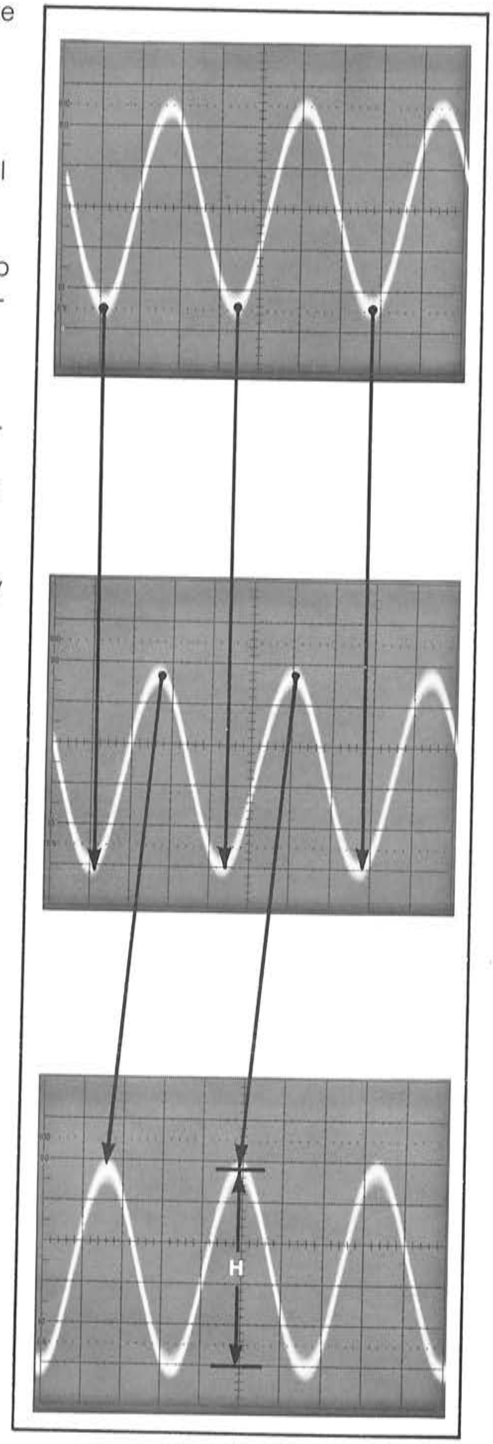


Fig. 18 The waveform is shifted by using the horizontal and vertical position controls until the troughs are lined up with a horizontal line of the graticule and a peak lies on the vertical reference line.

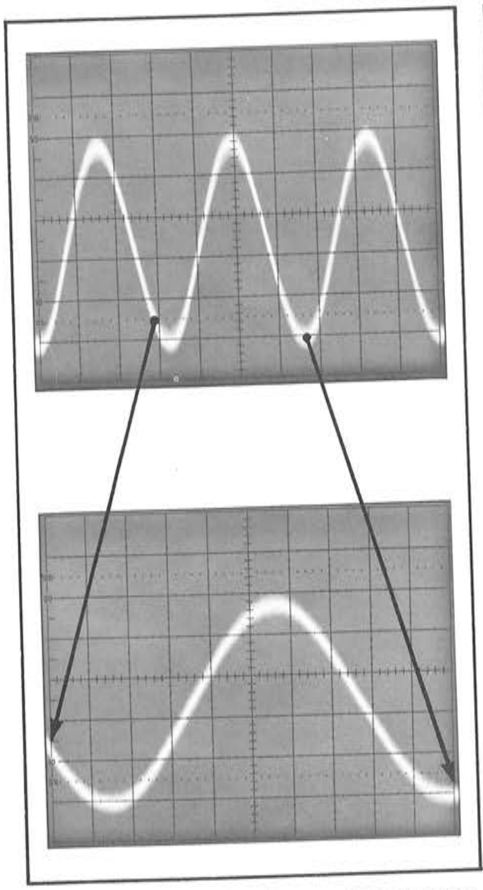


Fig. 19 By taking the time-base control out of "cal detent" and adjusting it, the waveform is expanded. The expansion shown is approximately three to one.

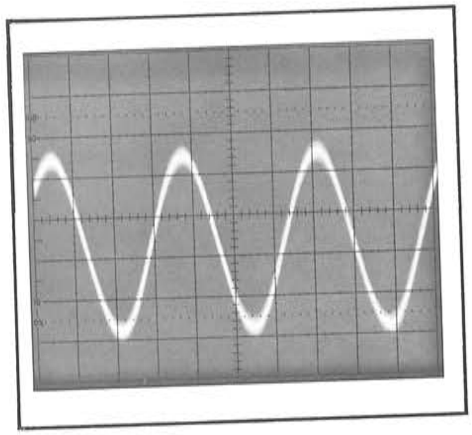


Fig. 20

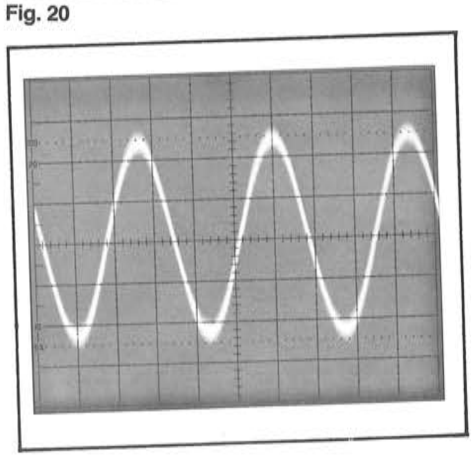


Fig. 21

Turning the variable time-base control uncalibrates the time base and expands the wave horizontally. This allows you to look at the form of the wave in more detail. (See Figure 19.)

Adjust the horizontal POSITION control until the left end of the trace is lined up with the left-most vertical line of the graticule. Set the triggering contols (SOURCE to INT, MODE to NORM, and SLOPE to +) and apply the signal (touch the probe tip), and the signal displayed will look something like the waveform in Figure 20.

If you keep all the controls set as they are, but change the SLOPE to negative (−), the resulting display will look something like the waveform in Figure 21.

Note that the beginning of the first trace (Figure 20) has a positive slope and the beginning of the second trace (Figure 21) has a negative slope.

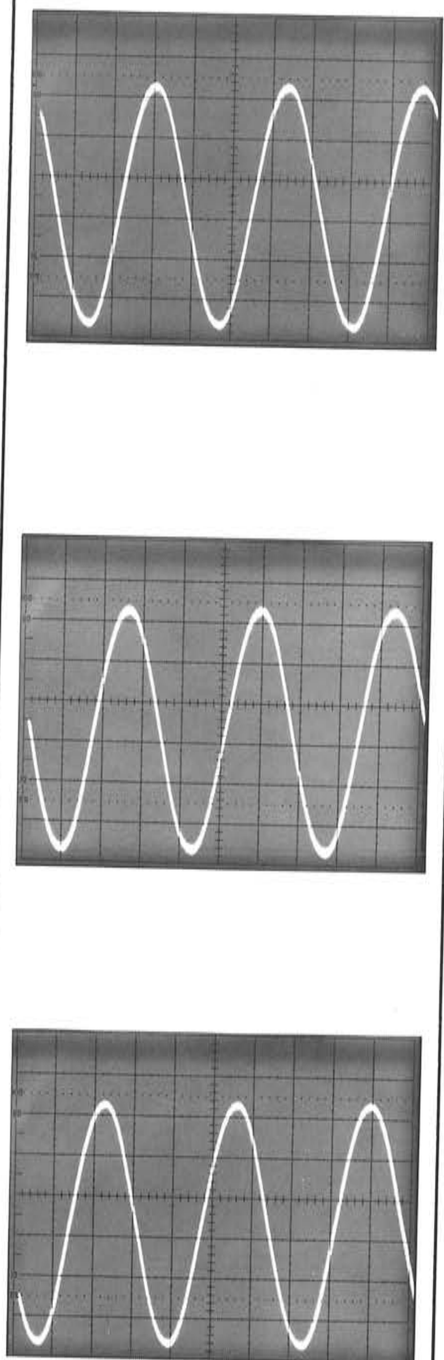


Fig. 22 In each of the displays the slope control was set to negative (−) and the level was decreased.

Now vary the setting of the LEVEL control and note the effect on the displayed signal. As you decrease the level, you change the point on the signal that starts the trace. If the level is decreased below the minimum signal level, there is no trigger and no trace appears. The displays in Figure 22 represent a sequence of decreasing trigger levels.

By adjusting the LEVEL control in conjunction with the SLOPE controls, you are able to select a point on the waveform as the starting point of the trace, the trigger point.

Whenever you use an unfamiliar oscilloscope, this 60 Hz signal can help you become familiar with the functions of its controls.

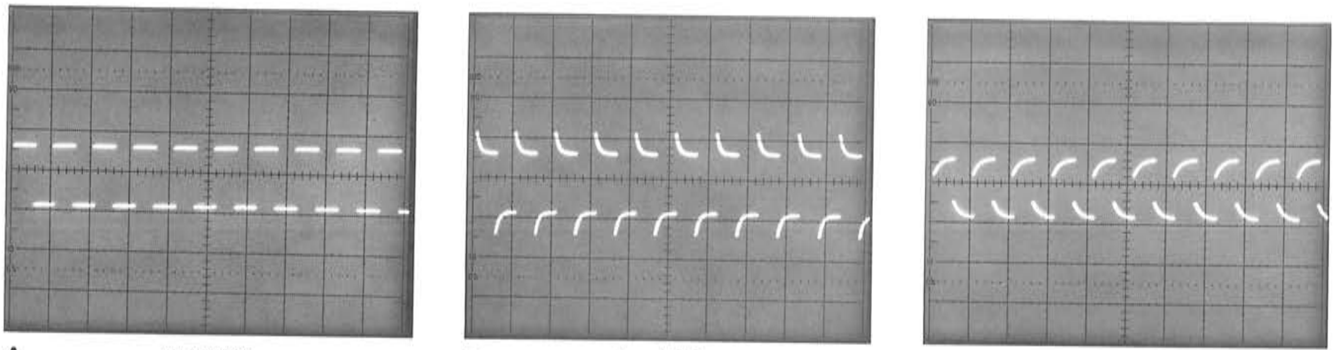
CHAPTER III
More Sophisticated Oscilloscope Features and Controls

Fig. 23 A X1 probe is attached to the Y input of a T921. A X10 probe is shown in the foreground.

Oscilloscope Operations

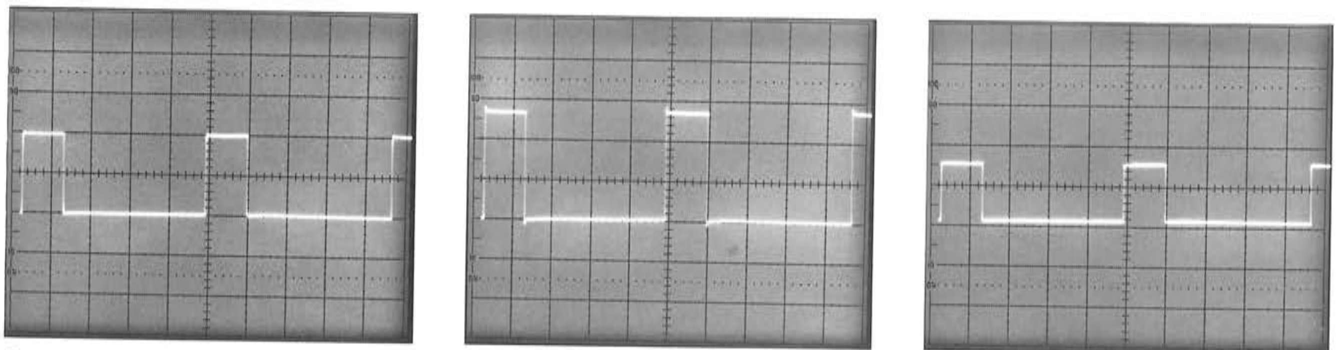
Making a measurement with an oscilloscope is usually a straightforward process. Turn the oscilloscope on, input the signal to be measured, select the triggering parameters, select the SEC/DIV, select the VOLTS/DIV, and then view and analyze the displayed results. Be aware, however, of a few operational pitfalls. These pitfalls are not difficult to avoid.

For CALIBRATED OPERATION, make sure that variable controls are in their "cal detent" positions. Probably the most common problem that occurs is that an operator makes a series of measurements and then discovers that the vertical sensitivity or the horizontal time-per-division control is uncalibrated. That is, the variable controls have been rotated out of their calibrated-detent positions. Sometimes, however, we intentionally use the variable controls to achieve scale factors other than those offered by the VOLTS/DIV and SEC/DIV controls. Another common problem involves the use of signal PROBES. Most oscilloscopes offer a voltage probe as an accessory. Two typical probes are shown in Figure 23. The probe provides a medium for the transfer of the signal energy from the source to the input of the oscilloscope without disturbing the source and without changing the structure of the transferred energy. This is the ideal situation. In reality there is always some loading of the circuit under test and some distortion of the signal. One way to minimize the circuit loading is to use higher-impedance probes. These, however, attenuate the signal and require higher sensitivity in the vertical section of the oscilloscope.



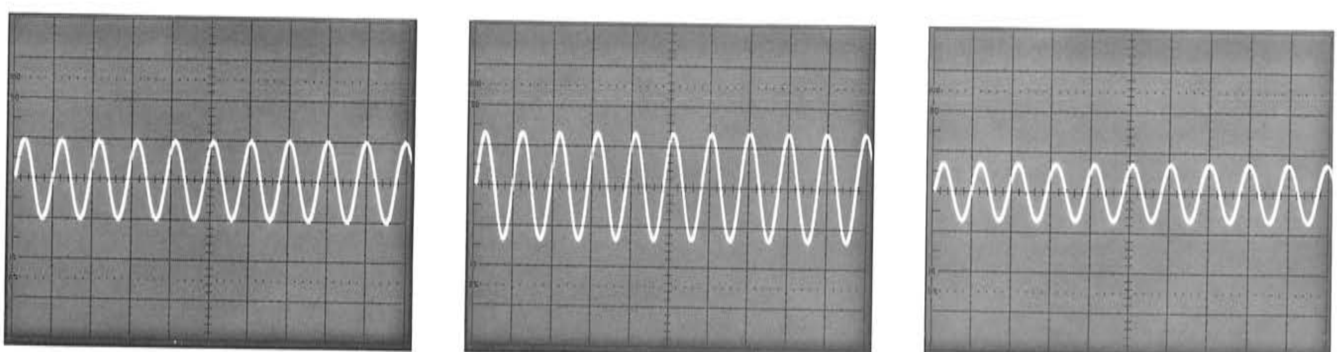
A 1 ms/DIV B 1 ms/DIV C 1 ms/DIV

THE CALIBRATION SIGNAL DISPLAYED WHEN: A—THE PROBE HAS BEEN PROPERLY COMPENSATED (NO DISTORTION)
B—THE PROBE HAS BEEN OVER-COMPENSATED
C—THE PROBE HAS BEEN UNDER-COMPENSATED



A 1 μs/DIV B 1 μs/DIV C 1 μs/DIV

A ONE MICROSECOND PULSE DISPLAYED WHEN: A—THE PROBE HAS BEEN PROPERLY COMPENSATED
B—THE PROBE HAS BEEN OVER-COMPENSATED
C—THE PROBE HAS BEEN UNDER-COMPENSATED



A 20 μs/DIV B 20 μs/DIV C 20 μs/DIV

A 50 kHz SINE WAVE DISPLAYED WHEN: A—THE PROBE HAS BEEN PROPERLY COMPENSATED
B—THE PROBE HAS BEEN OVER-COMPENSATED
C—THE PROBE HAS BEEN UNDER-COMPENSATED

Fig. 24 The effect of probe compensation on various signals.

If the probe you use is a X1 probe (no attenuation), there's no problem with compensation. If, however, it's an attenuation probe (X10, etc.), it will most likely require compensation. Compensation is an electrical adjustment that matches the probe to the oscilloscope to ensure uniform signal-handling capabilities over the probe's specified frequency range. Figure 24 illustrates the effect of different probe compensations on the display of known waveforms.

Most oscilloscopes make a signal available to facilitate probe compensation. The signal will probably be a square wave because that kind of a waveform contains both low-frequency and high-frequency information. To compensate a probe, connect it to the vertical input connector to be used, and touch the probe tip to the compensation-signal source. (See Figure 23.) Set the appropriate VOLTS/DIV control to a position that produces two or three divisions of signal amplitude in the oscilloscope display. Adjust the probe's compensation to achieve the best flat-top square wave. This compensation procedure should be a regular part of a measurement routine. The adjustment may not always be necessary, but the check doesn't take much time. It's a small price to pay to avoid much aggravation.

Reliable oscilloscope measurements require both a signal lead and a common-reference (or "common") lead between the oscilloscope and the system under test.

The CIRCUIT COMMON may be established through the power line connection which allows measurements to be made, but quite likely they will contain errors. For the most reliable signal common, use an additional lead such as the ground lead attached to the signal probe. (See Figure 23.) Be aware, though, that this lead is ground, for it's connected to the oscilloscope chassis. Connecting this lead into the circuit under test at points that are not at ground might result in circuit damage.

CIRCUIT LOADING is a less obvious source of error. Sometimes measurement results aren't quite what you expect, and the reason isn't clear. It may be that the input impedance of the oscilloscope vertical section is loading the signal source and distorting the signal information. Only under ideal conditions — which don't exist — would no loading occur. However, most of the time the effects of loading are so negligible that for all practical purposes they can be ignored. A good rule of thumb is to make a measurement at a low-impedance point (a few hundred ohms or less) in the test circuit. If this can't always be done, then be aware of the possibility of circuit loading and the fact that some circuit analysis may be necessary to determine true circuit activity.

Dual-Trace Oscilloscopes

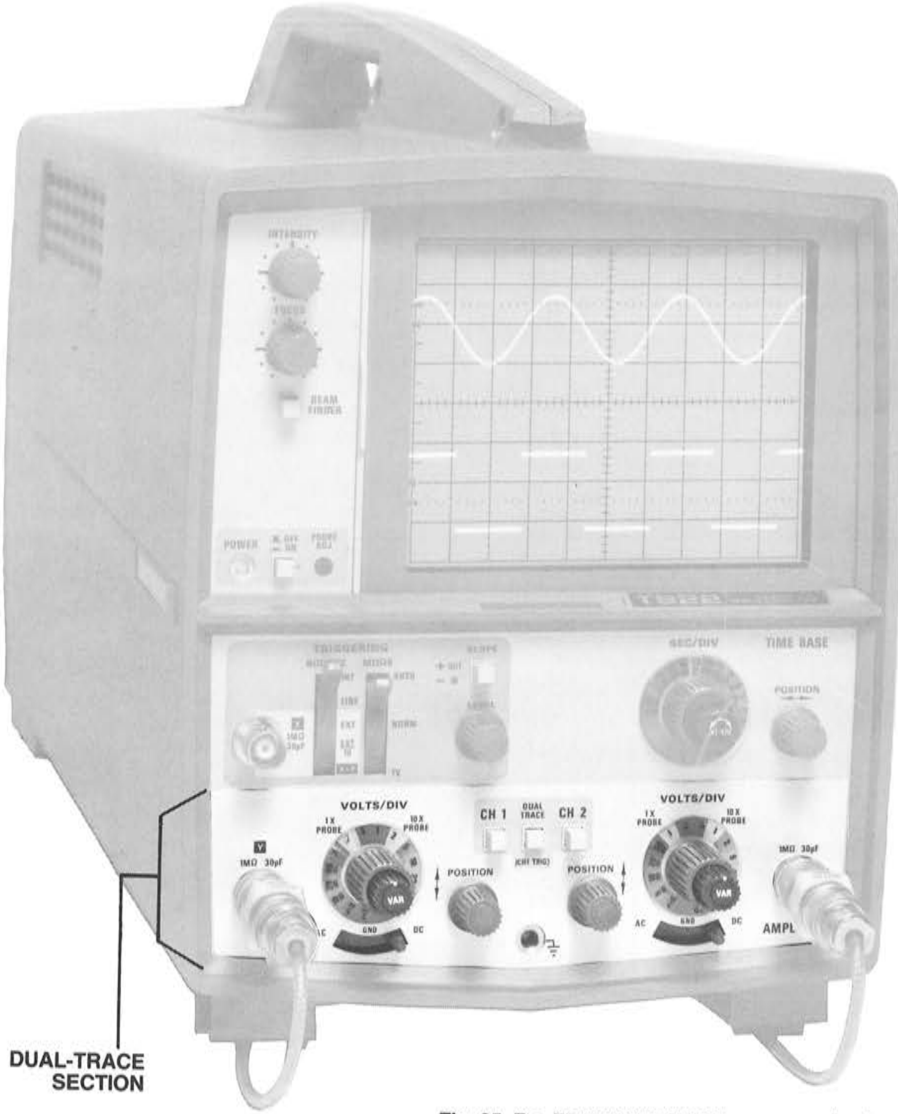


Fig. 25 The TEKTRONIX T922 is an example of a dual-trace oscilloscope.

DUAL TRACE is a useful feature that is found on many general-purpose oscilloscopes. A dual-trace oscilloscope contains two independent signal-input connectors in the vertical section. This allows the direct comparison of the two signals on the display at the same time. Figure 25 shows the T922, which is an oscilloscope that offers the dual-trace feature.

Oscilloscopes are referred to as dual trace because they can produce two apparently simultaneous traces on the crt display. There are five possible modes of vertical operation for dual-trace scopes. Not all dual-trace oscilloscopes have all five modes. The first two modes are single-trace modes which display either input signal by itself. The third is also a single-trace mode called ADD. The crt presentation for this mode represents the algebraic sum of the amplitudes of two input signals (CH 1 + CH 2). Often the oscilloscope will have the ability to invert the polarity of one of its input signals. Then in the ADD mode, the resultant display will be the difference (CH 1 − CH 2) of the two input signals.

ALTERNATE and CHOP, the last two dual-trace modes, display both input signals. The display is apparently simultaneous, but in reality is accomplished on a time-shared basis by electronically switching the display mechanism back and forth between the two signals. In ALTERNATE mode operation, the switching rate is determined by the setting of the SEC/DIV control (switching occurs at the end of each time window). ALTERNATE is the preferred dual-trace mode for faster sweep rates. In CHOP mode operation, the switching rate is fixed by internal oscilloscope circuitry and is the preferred dual-trace mode for slower sweep rates. Figure 26 illustrates the dual-trace modes of operation.

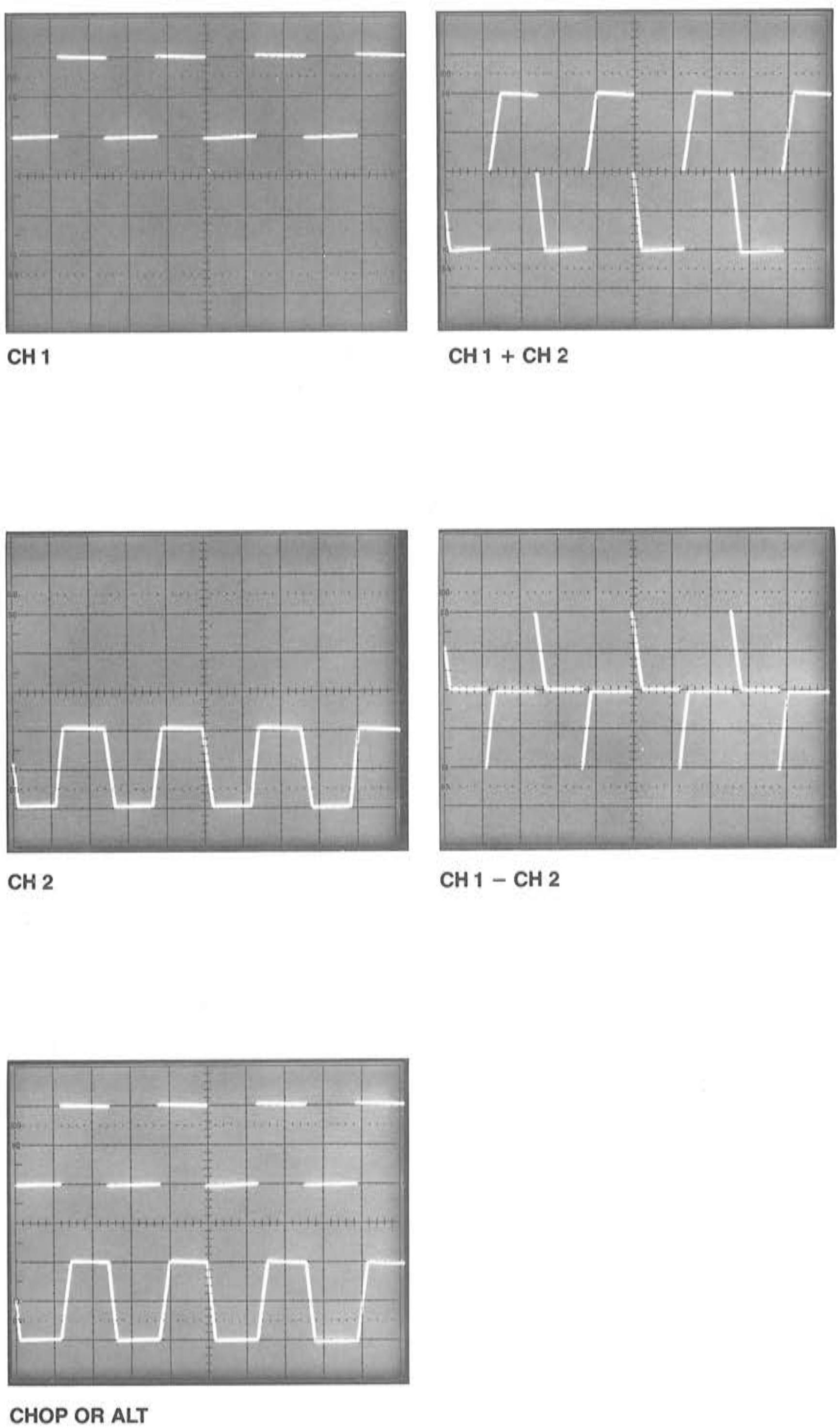


Fig. 26 Independent signals are applied to the two channels. Here they are displayed one at a time, as the sum of the signals, as the difference of the signals, and simultaneously.

Dual-Time-Base Oscilloscopes

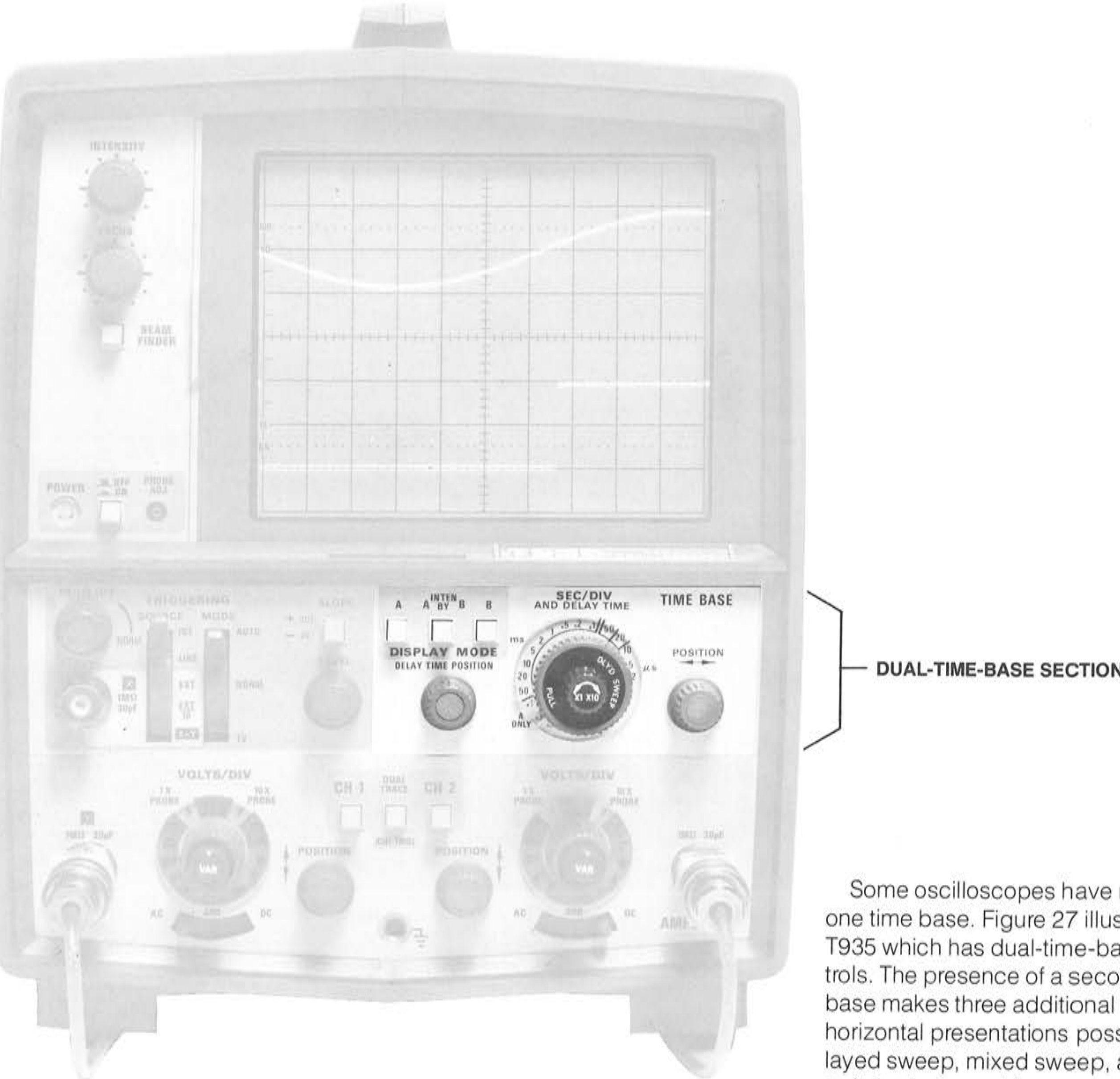


Fig. 27 The TEKTRONIX T935 is an example of a dual-time-base oscilloscope.

Some oscilloscopes have more than one time base. Figure 27 illustrates a T935 which has dual-time-base controls. The presence of a second time base makes three additional modes of horizontal presentations possible: delayed sweep, mixed sweep, and switched sweep. However, not all dual-time-base oscilloscopes are capable of all three modes. The delayed-sweep mode is the one most commonly encountered. The dual-time base allows accurate magnification of a portion of a signal at some specific time after the trigger.

In all three modes, the initiation of the time window for one time base is delayed for some period of time determined by the other time base. Each mode offers a different display presentation.

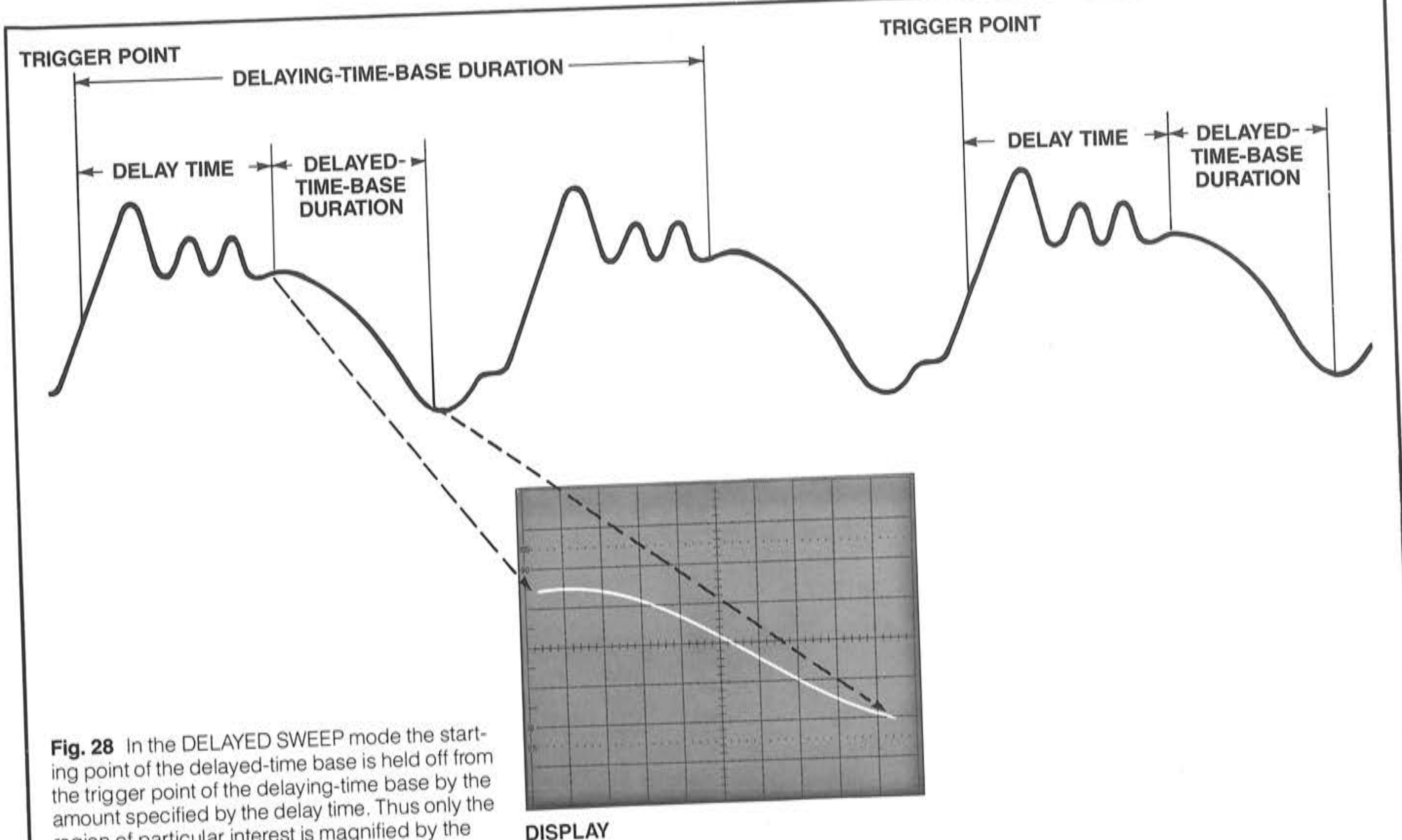


Fig. 28 In the DELAYED SWEEP mode the starting point of the delayed-time base is held off from the trigger point of the delaying-time base by the amount specified by the delay time. Thus only the region of particular interest is magnified by the delayed sweep. The region is picked by the DELAY TIME control.

In the delayed-sweep mode, the display has a uniform time-per-division factor across the display which is determined by the delayed time base. The delayed-time base (second time base) occurs during the delaying-time base (first time base) duration. The delayed-time base is set so that the SEC/DIV magnifies the time-dependent characteristics of the displayed signal as compared with the delaying-time base. The delay time determines the "trigger point" for the delayed sweep. The delayed-sweep mode is an accurate method of magnifying the displayed portion of the wave form. Figure 28 illustrates the magnification of a wave form that takes place after the specified delay time.

Most dual-time-based oscilloscopes have an additional control called DELAY-TIME MULTIPLIER (or DELAY-TIME POSITION). This control permits you to make time measurements with a higher degree of accuracy than can be achieved using a conventional display.

In this booklet, we have presented a broad view of the general-purpose oscilloscope. This presentation has centered on the basic oscilloscope controls and their effects on the display. The actual measurement techniques and applications are the subjects for other forms of literature. Since no single document is able to adequately anticipate the differences and subtleties of each instrument, the best source of information is the documentation that is provided by the manufacturer. In addition to the Operator's Instruction and Service manuals, Tektronix, Inc. has other publications that address specific subjects. Feel free to consult your local Tektronix Field Engineer for more information on the availability of publications about subjects that interest you. Or write Tektronix, Inc. P.O. Box 500, Beaverton, OR 97077. In Europe, write Tektronix Limited, P.O. Box 36, St. Peter Port, Guernsey, Channel Islands.

GLOSSARY

Ac Signal The time-variant portion of voltage or current.

Active Transducer A transducer that produces a voltage in response to a measurand without excitation by an external source of electrical energy.

Alternate Sweep A mode of operation for a dual-trace oscilloscope. The signal from the second channel is displayed after the signal from the first channel. Each has a complete sweep and the display continues to alternate. Use for SEC/DIV settings of less than 1 ms/div (faster).

Alternating Current (ac) An electric current whose instantaneous value and direction change periodically. The term is usually used to refer to sinusoidally shaped current or voltage waves.

Astigmatism Any deviation of the spot on a crt from a circular shape. The astigmatism control on an oscilloscope is used to shape the spot.

Attenuation The decrease in amplitude of a signal during its transmission from one point to another.

Bandwidth A range of frequencies within which performance, with respect to some characteristic, falls within specified limits; commonly defined at the points where the response is 3 decibels less than the reference level.

Blanking The process of making the trace or parts of a trace invisible.

Calibration The process of comparing an instrument or device against a standard to determine its accuracy or to make a correction.

Capacitance That property of a system of conductors and dielectrics which enables the system to store electricity when a voltage exists between the conductors; expressed as the ratio of the electrical charge stored and the voltage across the conductors. The basic unit is the farad.

Capacitor An electrical component consisting of two conducting materials separated by an insulating material which is capable of storing an electrical charge.

Cathode-Ray Tube (crt) An electron-beam tube in which the beam can be focused to a small cross section and varied in position to produce a visible pattern.

Chop A mode of operation for dual-trace oscilloscopes in which the display is switched between the two channels at some fixed rate. CHOP should be used for slow sweep rates.

Common The potential level which serves as the ground for a given circuit.

Compensation The controlling elements which compensate for, or offset, the undesirable characteristics of the process to be controlled in a system.

Coupling The association of two or more circuits or systems in such a way that power or information may be transferred from one to the other.

Direct Current (dc) Current that flows in only one direction and is of constant value.

Delayed Sweep A sweep which is started after a defined interval of delay following a triggered pulse; a function of a dual-time-base oscilloscope.

Delay Time The amount of time by which the DELAYED SWEEP has been delayed.

Detent A stop or other holding device, such as a pin, lever, etc., on a ratchet wheel. Switch action is typified by a gradual increase in force to a position at which there is an immediate and marked reduction in force.

Display The visual representation of a signal on a crt screen.

Distortion An undesired change in a waveform.

Dual-Channel (Dual-Trace) Oscilloscope An oscilloscope which has two independent input connectors and vertical sections and can display them both at once.

Dual-Sweep (Dual-Time-Base) Oscilloscope An oscilloscope which can display a signal with two independent SEC/DIV settings.

Focus The control on an oscilloscope that determines the sharpness of the display. It is used in conjunction with the ASTIGMATISM control.

Free-Running Trace A trace which is displayed without being triggered, and with or without a signal applied.

Graticule The grid lines on the front of the crt of an oscilloscope used for measuring displayed signals.

Ground (GND) 1. A metalic connection with the earth to establish a reference potential level. 2. The voltage reference point in a circuit.

Hertz (Hz) The unit of measure for frequency; cycles per second.

High Pass Filter An electrical filter that severly attenuates frequencies from dc up to the lower cutoff frequency, while passing frequencies above this cutoff frequency with very little attenuation.

Impedance The total opposition a circuit offers to the flow of alternating current at a given frequency.

Line Voltage The voltage level of the main power supply to the equipment.

Lissajous Figures Patterns produced on the screen of an oscilloscope when signals of different voltages, frequencies, and phases are applied to the horizontal and vertical inputs.

Low-Pass Filter An electrical filter that passes frequencies from zero up to some cutoff frequency with very little attenuation and severely attenuates frequencies above the cutoff frequency.

Measurand A physical quantity, property, or condition which is being measured.

Megahertz (MHz) A frequency of one million Hz (cycles per second) or 10^6 Hz.

Mixed Sweep The mode of operation in a dual-time-base oscilloscope in which a signal is displayed at two different rates during the same sweep. One rate follows the other on the same trace.

Noise An unwanted voltage or current in an electrical circuit.

Oscilloscope An instrument for making visible the "instantaneous" values of one or more rapidly varying electrical quantities as a function of time, or of another electrical or mechanical quantity.

Parallax An optical illusion which makes an object appear to be displaced when viewed from a different angle.

Passive Transducer A transducer whose electrical characteristic changes with the measurand and does not produce any voltage without excitation.

Phase Angle (or Phase Shift) The difference between corresponding points on input and output waveforms.

Probe An input device for an oscilloscope made as a separate unit and connected by a flexible cable which transmits the measurand to the oscilloscope.

Reset Control Readies the sweep circuitry on an oscilloscope to single sweep on the next trigger.

Rise Time The time it takes for the leading edge of a pulse to rise from 10% to 90% of its final value.

Scope Shortened form of oscilloscope.

Screen The surface of the crt upon which the visible pattern is produced; the display area.

Sensitivity The ratio of the change in output to the change in the value of the input.

Signal A visual, audible, electrical, or other indication of information.

Single Sweep The ability of an oscilloscope to display just one window of time.

Slope The ratio of the change of the vertical quantity (Y) to the horizontal quantity (X).

Spot The illuminated area that appears where the electron beam strikes the screen of a crt.

Storage Oscilloscope An oscilloscope that has the capability of retaining the image of a waveform on the screen of the crt.

Strip Chart Recorder A device that makes a permanent record of varying signals, usually voltages, on a strip of paper.

Sweep The motion of the electron beam across the phosphor of a crt which gives the time dependent information.

Time Base The ciruitry by which a spot displacement depending on time is obtained. The time dependence is set by the SEC/DIV control.

Time Constant The value of T in the exponential response term $Ae^{-t/T}$.

Trace The display of an individual signal on a crt.

Trace Rotation The control on an oscilloscope that allows the alignment of the trace with the horizontal graticule lines.

Transducer A device which provides a useable output in response to a specific physical quantity, property, or condition which is measured.

Transient A phenomenon caused in a system by a sudden change in conditions which persists for a relatively short time after the change.

Trigger The signal that initiates the sweep on an oscilloscope and determines the beginning point of a trace.

Trigger Holdoff Inhibits the trigger circuit from looking for a trigger for some specified time after the end of the trace.

Trigger Level The level which the trigger source signal must reach before a trace is initiated by the trigger circuit.

Volt The unit of potential difference in the International System of Units. The volt is the potential difference between two points when current passing through these two points is one ampere and the power dissipated between these two points is one watt.

Voltage The difference in electrical potential between two points.

Waveform A graphic presentation of the variation of a quantity as a function of time.

X-Y A graphic representation of the relationship of the X signal, which controls the horizontal position of the beam in time, and the Y signal, which controls the vertical position of the beam in time.

Z Axis The Z axis of an oscilloscope refers to the input signal that controls the brightness or blanking of the electron beam as it forms the trace.