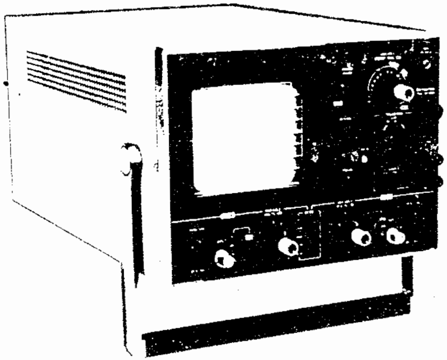

GUIDE TO OSCILLOSCOPES

How to weigh the functions and performance that you need for your application in choosing this instrument.

BY CLAYTON HALLMARK

EVERYONE who gets into electronics, either vocationally or as a hobby, hopes to own an oscilloscope. This isn't surprising, considering that the scope is one of the most versatile test instruments ever to become available. Not only can an oscilloscope display a "picture" of the actual signal in a circuit under test, it can also measure the signal's amplitude, frequency, and time period.

The oscilloscope represents a sizable investment, but it is worth every penny you invest if you buy what you need and use it wisely. Here are some basic scope guidelines you should know before buying the instrument, including operating principles and specifications.

Curves and Measurements. The oscilloscope's usefulness in measuring time and voltage is illustrated in Fig. 1. Horizontal distances on the screen represent time by a fixed amount per graticule square, while vertical distances represent voltage, also by a fixed amount per square.

A TIME/DIV (typical) control on the scope can be used to set the width of the displayed image. The calibration markings on this control permit the elapsed time between any two points on the display to be determined by mutliplying the horizontal spacing in divisions by the numerical value of the TIME/DIV control setting. For example, the horizontal division between points A and B in Fig. 1 is five divisions. If the TIME/DIV setting is 100 μs/division, the elapsed time between A and B is $100\ \mu s \times 5 = 500\ \mu s$.

The VOLTS/DIV (typical) control on the scope is used to set the height of the display. The vertical distance tells the magnitude of the voltage of the displayed waveform in much the same manner as the horizontal distance tells the time be-

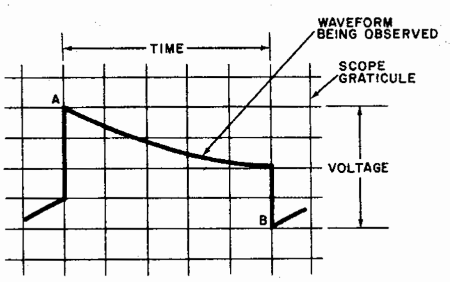

Fig. 1. Displayed waveform is plot of voltage versus time.

tween any two points. The voltage (vertical) difference between points A and B in Fig. 1, therefore, is four divisions. Now, if the VOLTS/DIV control is set to 0.5 volts/division, the voltage difference is $0.5 \times 4 = 2$ volts.

Basic Scope. A simplified diagram of an oscilloscope is shown in Fig. 2. Electron beam deflection is accomplished by controlling the charges on two sets of deflection plates within the CRT. One pair is for vertical deflection, and the other pair, mounted at right angles to the vertical plates, is for horizontal deflection of the beam.

The horizontal sweep generator supplies a sawtooth waveform that is voltage amplified and applied to the two horizontal deflection plates. The amplified sawtooth waveform then forces the CRT electron beam to move at a uniform rate across the CRT phosphor-coated screen. The action of the electron beam impinging on the phosphor causes a dot of light to appear on the CRT, thus the horizontal sweep produces a line of light across the screen, which moves in a left-to-right direction.

When the sweep sawtooth reaches the "retrace" portion, it causes the electron beam to "snap" back to its origin (the left side) and await the start of another sweep. During this retrace interval, special circuits within the scope "blank" the electron beam so that it is not visible on the CRT screen.

During the relatively slow left-to-right progression of the electron beam on the CRT screen, whatever signal is applied to the vertical input is amplified and causes the CRT electron beam to be deflected up and down in step with the input signal. If the input signal is a steady dc voltage, the display is a straight line as shown in Fig. 3A. If one cycle of a sine wave, whose time interval is exactly the same as the sweep time interval, is used as the vertical input to the scope, the resultant CRT display will be a single sine wave (Fig. 3B). And, if the input sine wave time interval is only half of the sweep time, then two cycles of the input waveform will be seen on the CRT screen as shown in Fig. 3C.

Older, and inexpensive present-day scopes, have a SWEEP FREQUENCY control that permits the horizontal frequency to be adjusted to an exact submultiple of the vertical frequency. If this is not done, and if the starts of successive sweep ramps occur at different points on the input signal (positive peak, negative peak, start of positive alternation, etc.), the jumbled pattern shown in Fig. 4 results. In these "recurrent-sweep" scopes, the sweep signal voltage is generated by a sawtooth oscillator that is usually synchronized to the input signal by feeding it a sample of the input signal from the vertical circuits.

More modern and expensive oscilloscopes employ "triggered-sweep" instead of recurrent-sweep design (Fig. 5). The sweep generator is inactive until a trigger signal, derived from the input signal, starts it operating. When the input signal reaches the selected polarity and amplitude, the trigger circuit delivers a pulse to the sweep generator, which then produces *one* cycle of sweep. The sweep generator then "rests" until the input is again at the selected polarity and amplitude. If the input is a continuous sine wave, a continuous sawtooth is generated, as in a recurrent-sweep scope, but in sync with the input signal so that the display "stands still". If there is no input signal, no sweep occurs. Triggered-sweep scopes can be set so that they do not produce a trace in the absence of a vertical signal. Also, if the input consists of random pulses, the sweeps occur only when there are pulses.

Because triggered-sweep scopes use an extremely linear (with time) ramp, they provide an accurate way of measuring the time between events on a waveform. These scopes are thus said to use a "time base" instead of a horizontal oscillator. The time base's control is calibrated in *time/division* instead of *frequency.* In addition, the triggered-sweep scope provides a means for measuring small portions of pulse trains, random events, single events, and signals of rapidly changing frequency.

Recurrent-sweep scopes are far from extinct and certainly have their place today, especially where instrument cost

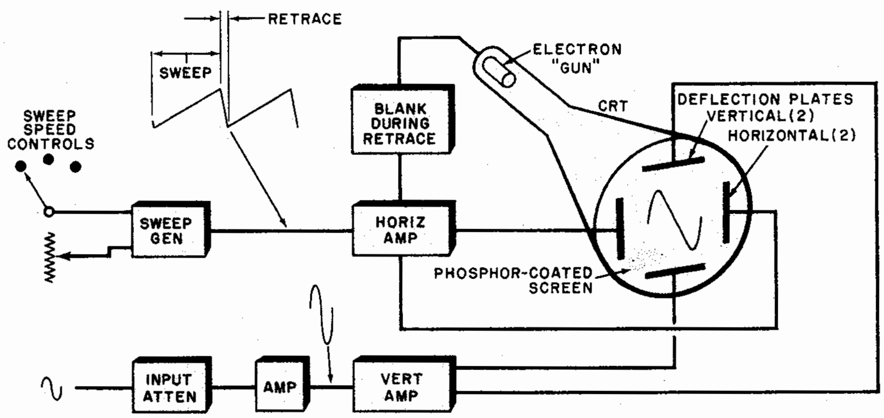

Fig. 2. Simplified diagram of how an oscilloscope works. Two sets of plates deflect the electron beam.

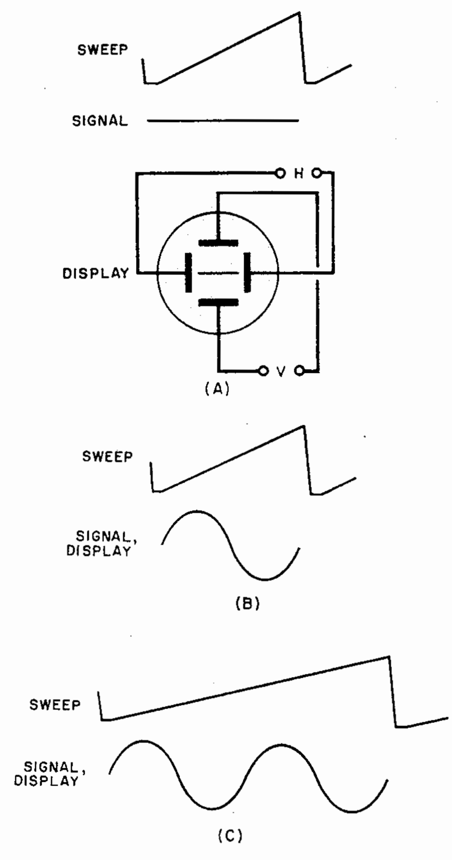

Fig. 3. Display depends on horizontal input and sweep.

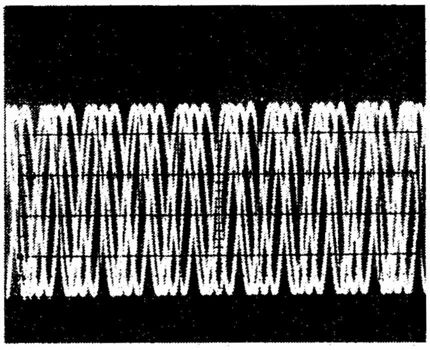

Fig. 4. Out-of-sync scope produces this meaningless pattern.

must be kept at a minimum. Aside from lower cost, the recurrent-sweep scope may be easier to use than the triggered-sweep scope. Some scopes even offer both types of sweep at the flip of a switch. (Providing both types of sweep are handy for establishing the baseline in the absence of an input signal.)

Two Scopes in One. Sometimes we are interested in measuring the time between events on two different signal paths. This can be done with a time-base (triggered-sweep) oscilloscope if there is a way of simultaneously displaying the two wave-forms. Many modern triggered-sweep scopes, therefore, have dual-trace capability to fill this need. With such a scope, the input and output waveforms (for example) of a circuit can be viewed at the same time and compared for time (phase) differences, distortion, and other differences.

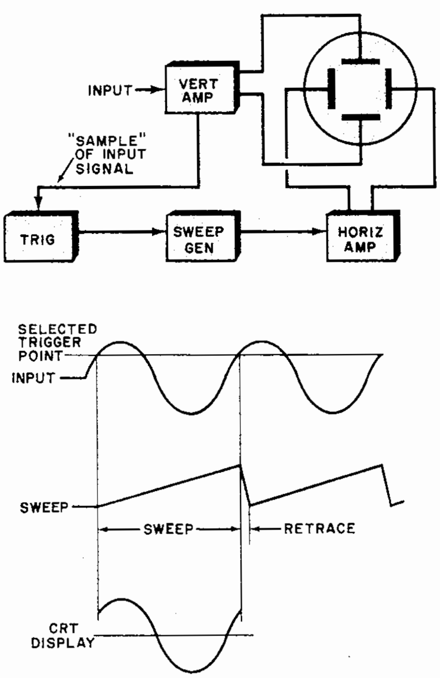

Fig. 5. Triggered-sweep scope and waveforms involved.

A dual-trace scope has two independent input channels that are fully controllable independently of each other, and whose electrical characteristics are carefully matched. The two signals are fed to the vertical-deflection plates via an electronic switch (Fig. 6).

The vertical amplifier circuit can be switched between the two channels in either of two ways. With the scope in its alternate mode, as in Fig. 6, switching occurs during sweep retrace; sweep one displays signal A, sweep two signal B, sweep three signal A, etc. The persistence of the CRT screen phosphor leaves an afterglow when a given trace is not being drawn causing the waveform to linger on the screen during alternate sweeps. Consequently, both waveforms appear to be displayed simultaneously. However, if the sweep rate is set sufficiently slow, as for viewing low-frequency signals, one waveform may begin to fade while the other is being traced on the CRT screen, and the display will flicker. This calls for the "chop" mode of operation.

In the chop mode, a relatively high-speed square-wave oscillator alternates the electronic switch rapidly *during* sweeps. This produces a display such as that shown in Fig. 7. In practice, the traces are made up of so many segments that the integrating mechanism of the eye makes each appear as a continuous waveform.

Front-panel switches on dual-trace oscilloscopes permit selection of either the *alternate* or *chop* modes as desired. In a few scopes, the mode automatically changes from chop to alternate when a sweep speed of 1 ms/cm or slower is selected. This prevents flickering and speeds setup time when using the scope.

Some dual-trace scopes have a switch for exchanging the horizontal amplifier for one of the vertical amplifiers. In this XY mode of operation, the matched vertical amplifiers are used for both vertical (channel-A) and horizontal (channel-B) input signals. A plot of the Channel-A signal versus the channel-B signal results. One signal is plotted on the X (horizontal) axis, while the other is plotted on the Y (vertical) axis. Both signals are treated in the same manner by the amplifiers, and both can be measured in volts per centimeter (V/cm) by using the calibration controls.

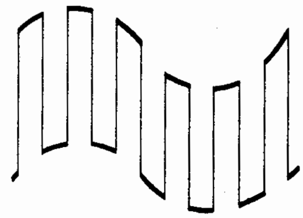

Fig. 7. Display with electronic switch in chop-mode operation.

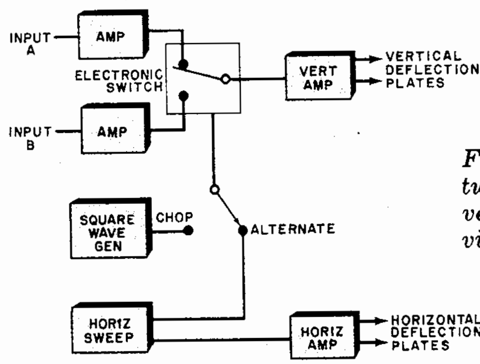

Fig. 6. In dual-trace scope, two signals are fed to vertical-deflection plates, via an electronic switch.

A phase-relationship (or Lissajous) pattern appears on the screen when the scope is used in the XY, or "vectorscope," mode. One of the simplest loops to be obtained in this mode is shown in Fig. 8. The slant of the loop reveals the phase relationship of the signals. This mode can also produce a more complex loop, which looks like a "daisy" (Fig. 9), for checking the chroma circuits in a color-TV receiver. (A special CRT graticule is used with the daisy pattern to provide accurate color-TV receiver vectorscope

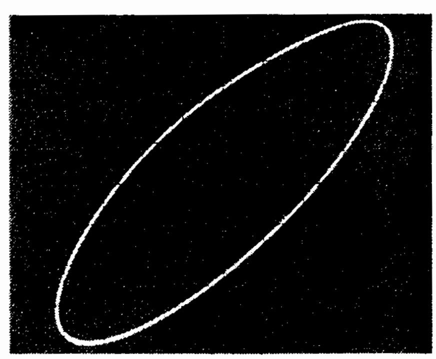

Fig. 8. Lissajous figures are used for phase measurements.

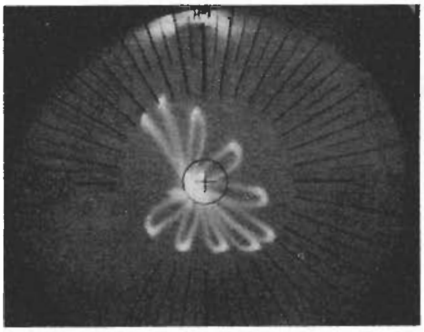

Fig. 9. Vectorscope pattern is useful in checking color TV.

operation.) Such a scope configuration can also "draw" the load line of a power supply or transistor.

Looking at Specifications. As with all electronic gear, and particularly electronic test equipment, it is important that you understand the various technical specifications used for oscilloscopes. Let us, therefore, list the various tech specs of a scope and explain what each means.

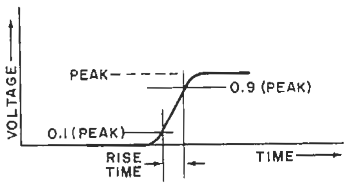

Fig. 10. Diagram shows how risetime of a wave is defined.

Frequency Response. The 3-dB-down frequency response, or bandwidth, of the vertical channel is the most important factor in the price and applicability of a given oscilloscope. The usable response of a scope just for radio work might not have to be greater than the audio range, but a TV repairman might need a scope that can display signals from 30 Hz to beyond 4 MHz. For more exhaustive and demanding tests, scopes with responses out to 10, 15, 50, or even 100 MHz might be required. Needless to say, you should select a scope according to the type of work you expect to be performing. You would not, for example, select a scope with a 100,000-Hz (100-kHz) range to do servicing on color-TV receivers. Conversely, a 100-MHz scope's range would be wasted if all you plan to work on is audio circuits.

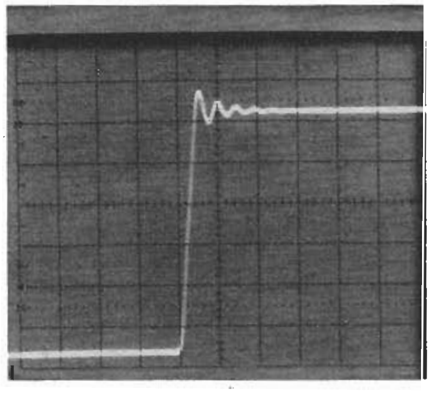

Fig. 11. Excessive overshoot caused by scope's poor response.

Risetime. Those of us who do a lot of work on digital circuits are particularly interested in the risetime of a scope. As illustrated in Fig. 10, the risetime of a pulse is the time it takes for the leading edge of a square wave to rise from 10% to 90% of its peak value. If, for example, it is necessary to measure within 3% a waveform risetime known to be in the 0.04-μs range, an oscilloscope with a risetime of not more than 0.01 μs would be required.

When comparing oscilloscopes, it is sometimes necessary to convert a specification from one form to another to determine how each scope measures up. If the bandwidth (BW) is known and you wish to know the risetime (t_r), or vice versa, just divide the known quantity into 0.35. The general formula is $BW \times t_r = 0.35$. Bear in mind, however, that this formula works only if the response of the scope rolls off smoothly, until it is close to 12 dB down at twice the −3-dB frequency. If the scope does not follow this Gaussian curve, excessive overshoot (more than 2% or 3%) occurs as shown in Fig. 11. If the scope does have a Gaussian response, it may be usable at frequencies up to twice the rated limit.

Deflection Factor. This is a measure of the oscilloscope's sensitivity or ability to display low-level signals. It indicates the signal amplitude required to cause the trace beam to be deflected one graticule division. The deflection factor is commonly given in millivolts peak-to-peak per division (mV p-p/div.). For some scopes, 10 mV/cm is common. Again, in comparing scopes, their specifications must be converted to a common term. If the voltage is given in rms, multiply by 2.828 to obtain peak-to-peak; if the division is 1", divide by 2.54 to obtain the centimeter equivalent.

Most modern scopes have adequate sensitivity. However, remember that, in comparing scopes, the lower the deflection factor, the easier it is to display low-level signals.

Accuracy. This is really calibration accuracy. It is comparable in meaning and percentage to the accuracy of an analog meter. Accuracy is generally in the range of 3% to 5%. The accuracy of the vertical calibration tells how closely the input voltage level can be measured, while the horizontal accuracy refers to the time (and frequency) measurements.

OSCILLOSCOPE MANUFACTURERS

B&K Precision, Dynascan Corp.
6460 W. Cortland Ave.
Chicago, IL 60635

Ballantine Laboratories, Inc.
Box 97
Boonton, NJ 07005

Dumont Oscilloscope Laboratories, Inc.
40 Fairfield Pl.
W. Caldwell, NJ 07006

Eico Electronic Instrument Co., Inc.
282 Malta St.
Brooklyn, NY 11207

Heath Company
Benton Harbor, MI 49022

Hewlett-Packard Co.
1501 Page Mill Rd.
Palo Alto, CA 94304

Hickok Electrical Instruments
10514 Dupont Ave.
Cleveland, OH 44108

Leader Instrument Corp.
151 Dupont St.
Plainview, NY 11803

Lectrotech Inc.
5810 N. Western Ave.
Chicago, IL 60659

Philips Test and Measuring Inst. Inc.
400 Crossways Park Dr.
Woodbury, NY 11797

Sencore Inc.
3200 Sencore Dr.
Sioux Falls, SD 57107

Systems Electronics, Inc.
9727 Inglewood Ave.
Inglewood, CA 90301

Telequipment Div. of Tektronix
Box 500
Beaverton, OR 97005

VIZ Manufacturing Co.
335 E. Price St.
Philadelphia, PA 19144

Vu-Data Corp.
7170 Convoy Ct.
San Diego, CA 92111