Thirteenth Annual Instrumentation-Automation Conference
1958 Instrument Maintenance Clinic

USING THE OSCILLOSCOPE
as an
INSTRUMENTATION MAINTENANCE AID

Discussion notes presented by:

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1. What is the modern oscilloscope?

Basically, a modern cathode-ray oscilloscope is an electronic device using a cathode-ray tube as its indicator, and providing a graphical dynamic display of physical phenomena with respect to time.

2. Information presented by a cathode-ray oscilloscope

The display we get from a cathode-ray oscilloscope is ordinarily a graph (Fig. 1) in which the instantaneous voltage of a wave is plotted against time. Elapsed time is indicated by horizontal distance, from left to right, across the cathode-ray-tube screen. The instantaneous voltage of the waveform is measured vertically on the screen.

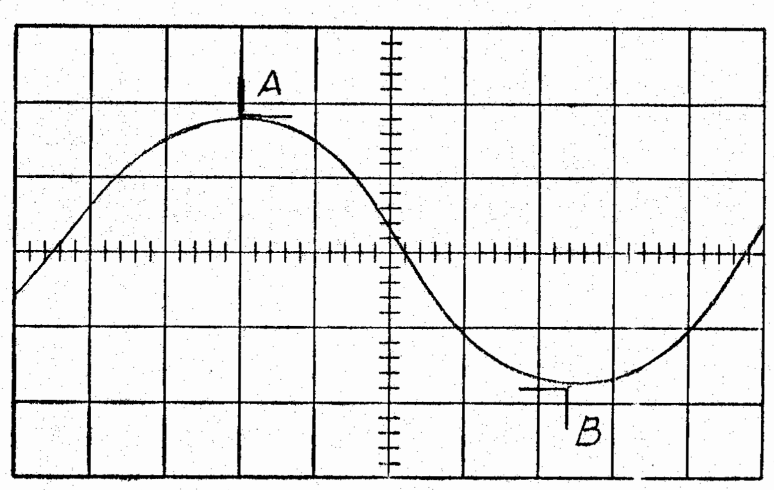


Fig. 1. Oscilloscope display

To find the elapsed time between two points on the graph (such as points A and B), multiply the horizontal distance between these points in major graticule divisions by the setting of the TIME/DIV control. This control sets the horizontal sweep rate of the cathode-ray-tube spot. In Fig. 1, the distance between points A and B is 4.4 major divisions. If the TIME/DIV control is set at 100 microseconds per division, then the elapsed time between points A and B must be 4.4 x 100 = 440 microseconds. In general,

Elapsed time

= (horizontal distance in divisions) x (TIME/DIV setting)

If a MULTIPLIER control is associated with the TIME/DIV control, multiply the above result by the setting of the MULTIPLIER control. If a MAGNIFIER is used, divide the result by the amount of magnification.

To find the voltage difference between any two points on the graph (such as points A and B), multiply the vertical distance between these points in major graticule divisions by the setting of the VOLTS/DIV control, which sets the vertical deflection factor or "sensitivity" of the oscilloscope. In Fig. 1, the vertical distance between points A and B is 3.6 divisions. If the VOLTS/DIV control is set at 0.5 volts per division, for example, then the voltage difference between points A and B must be 3.6 x 0.5 = 1.8 volts. In general,

$$\text{Voltage difference} = (\text{vertical distance in divisions}) \times (\text{VOLTS/DIV setting})$$

The repetition frequency of a waveform displayed on the oscilloscope can be calculated by this relation:

$$\text{Repetition frequency} = \frac{1}{(\text{number of horizontal divisions occupied by 1 cycle}) \times (\text{TIME/DIV setting})}$$

This result is given in cycles per second.

The oscilloscope is also used to picture changes in quantities other than simply the voltages in electric circuits. If an electric current waveform is of interest, for example, it is usually satisfactory to send the current through a small series resistor and to look at the resulting voltage wave across the resistor with the oscilloscope. Other quantities such as temperatures, pressures, displacements, speeds, accelerations, and strains can be translated into voltages by means of suitable transducers, and then viewed on the oscilloscope.

3. Typical operating specifications

The typical medium-priced oscilloscope will provide:

Nominal vertical-deflection-system frequency response from dc to several megacycles.

Selected linear horizontal sweep rates in the microsecond, millisecond, and second regions.

Triggered operation of the horizontal deflection system, capable of responding to triggering signals in the millivolt region, whether the triggering signals are recurrent or transient in nature.

4. What is triggering?

In older types of oscilloscopes, the horizontal-deflection system produced a recurrent or "free-running" trace. The only method available for obtaining a stable display of the observed waveform was to make the rather critical adjustment of setting the repetition frequency of the horizontal-deflection signal, generated within the oscilloscope, to the repetition frequency of the displayed waveform, or to some submultiple of the repetition frequency of the displayed waveform. This type of oscilloscope, in other words, employed a "synchronized" horizontal sweep--a sweep that was synchronized in some mode with the displayed vertical signal. One of the disadvantages of this type of operation was that the synchronized sweep could not generally be used successfully for single transient waveforms.

The modern oscilloscope, on the other hand, provides for "triggered" operation of the horizontal-deflection signal, or sweep. In simplest terms, triggering is defined as the starting of the horizontal sweep of the cathode-ray-tube spot at some predetermined point on the waveform being displayed (or some predetermined point on some other input "triggering" signal having a time relation to the displayed waveform). When the displayed waveform (or other triggering signal) goes through the predetermined "triggering" point, the internal horizontal-deflection system of the oscilloscope responds by producing one complete horizontal sweep of the cathode-ray-tube spot. No further sweeps are produced until the next time the displayed (or triggering) signal goes through the predetermined triggering point.

Selection of the triggering point on a displayed waveform is illustrated in Figs. 2-5. Two items are involved in selecting the triggering point:

1. Do we want the display to start, at the left-hand end of the graticule, when the waveform is rising (has a positive slope), or do we want the display to start when the waveform is falling (has a negative slope)? This part of the selection of the triggering point is accomplished by setting the TRIGGER SLOPE switch respectively to either "+" (rising) or "-" (falling).

2. At what height on the displayed waveform do we want the display to start at the left-hand end of the graticle? This item is chosen by setting the TRIGGERING LEVEL control. If we turn the TRIGGERING LEVEL control from its left-hand (or "-") region towards its right-hand (or "+") region, we successively raise the height of the point on the displayed waveform at which the display begins.

In Figs. 2 and 3, we have set the TRIGGER SLOPE switch to "+" (rising), so that the display starts at the left-hand end of the graticule while the displayed waveform is rising. In Figs. 4 and 5, we have set the TRIGGER SLOPE switch to "-" (falling), so that the display starts while the displayed waveform is falling. In Figs. 2 and 4, we have set the TRIGGERING LEVEL control towards the "+" (positive) part of its range, so that the display starts at a high point on the displayed waveform. In Figs. 3 and 5, we have set the TRIGGERING LEVEL control towards the "-" (negative) part of its range, so that the display starts at a low point on the displayed waveform.

5. How can the oscilloscope help me in instrument maintenance?

In addition to its ability to perform waveform analysis at a specific point in an electric circuit, the oscilloscope can also function as a dc voltmeter or as a peak-reading ac voltmeter.

Through the use of a "dual-trace" feature available on certain oscilloscopes, we can compare simultaneously the input and the output waveforms of electronic systems.

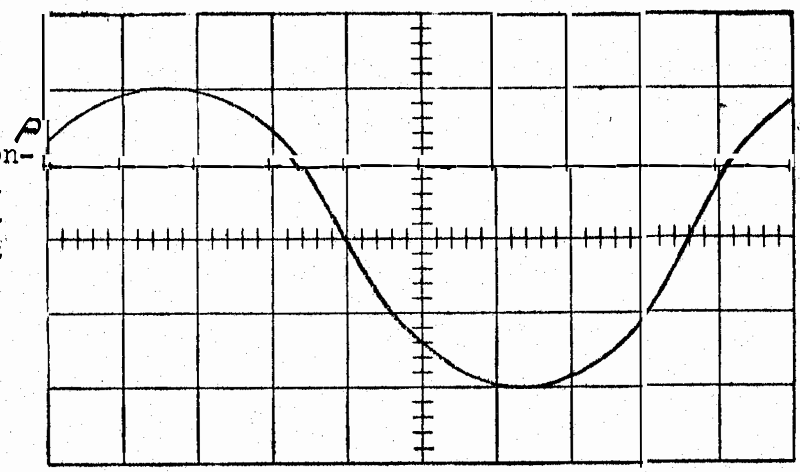
There are countless specific applications that are available as consequences of one or more of the oscilloscope characteristics that have been previously mentioned.

6. What are the major limitations of the oscilloscope?

One limitation that must be considered is the linearity of the vertical- and the horizontal-deflection systems of the oscilloscope. Typically, these characteristics are within 2 percent.

Another limitation of the oscilloscope is the frequency response of the

Fig. 2. Slope switch is set at "+" so display starts (point P) when waveform is rising. Triggering level control is set at positive part of its range, so display begins (point P) on upper part of waveform.



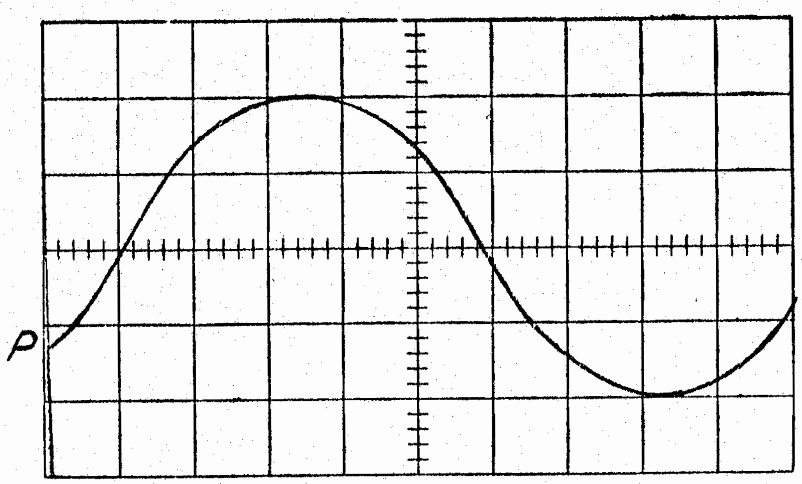


Fig. 3. Slope switch is set at "+" so display starts when waveform is rising. Triggering level control is set at negative part of its range, so display begins on lower part of waveform.

Fig. 4. Slope switch is set at "-" so display starts when waveform is falling. Triggering level control is set at positive part of its range, so display begins on upper part of waveform.

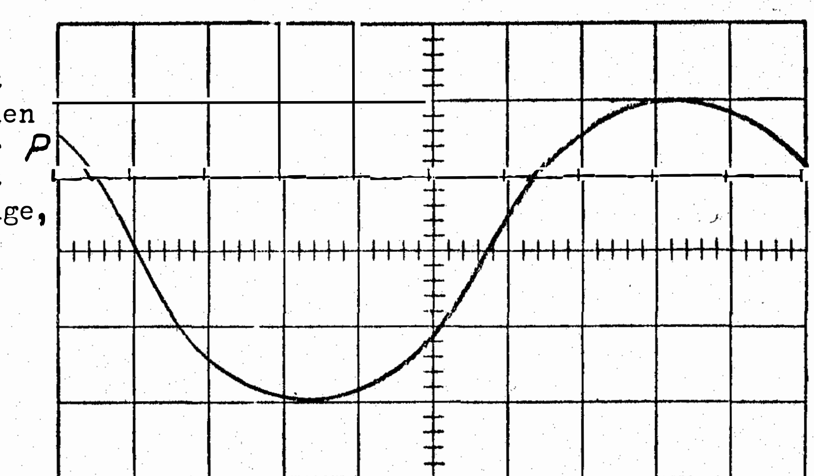
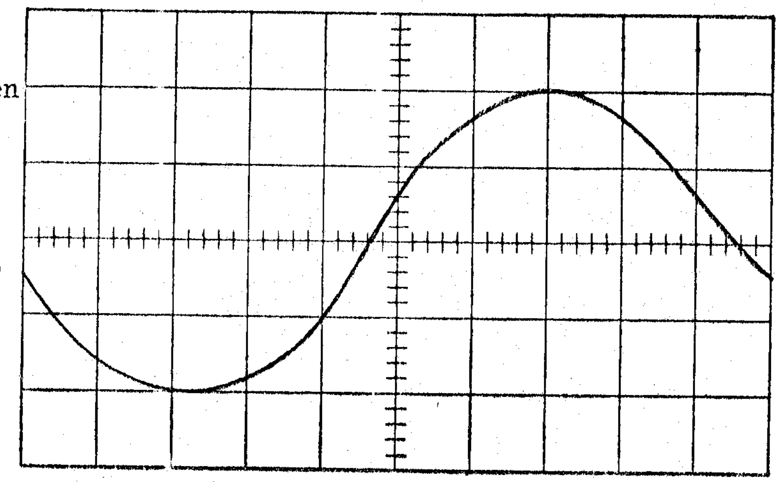


Fig. 5. Slope switch is set at "-" so display starts when waveform is falling. Triggering level control is set at negative part of its range, so display begins on lower part of waveform.



vertical-deflection system. The frequency-response characteristics of the oscilloscope are specified by the manufacturer.

The ability of the oscilloscope to produce a trace that can be photographed for publication or for engineering records is important. The maximum rate of cathode-ray-tube spot travel that provides a photographically reproducible indication is called the "writing rate" of the oscilloscope. This characteristic depends not only upon the oscilloscope but also upon the photographic equipment, materials, and techniques used. Writing rate might be specified, for instance, in centimeters per microsecond.

Another limitation of the oscilloscope is its portability. Precise, reliable oscilloscopes, of light weight and of small size, are available for portable use. The larger and heavier oscilloscopes, on the other hand, are more likely to be desirable for research use, although their maintenance applications are often very important.

7. Block diagram of a typical oscilloscope

Figure 6 is a block diagram of a typical oscilloscope, omitting power supplies. The waveform A to be observed is fed into the vertical-amplifier input. The calibrated VOLTS/DIV switch sets the gain of this amplifier. The push-pull output (B and C) of the vertical amplifier is fed through a "delay line" to the vertical-deflection plates of the cathode-ray tube. The purpose of the delay line will be explained later.

The time-base generator or "sweep generator" develops a sawtooth voltage (F) that is used as a horizontal-deflection voltage. The rising or positive-going part of this sawtooth, called the "runup" portion of the wave, is linear. That is, it rises through a given number of volts during each unit of time. This rate of rise is set by the calibrated TIME/DIV control. The sawtooth voltage is fed to the time-base amplifier. This amplifier includes a phase inverter so that the amplifier supplies two output sawtooth waveforms (H and J) simultaneously--one of them positive-going, like the input, and the other negative-going. The positive-going sawtooth is applied to the right-hand horizontal-deflection plate of the cathode-ray tube, and the negative-going sawtooth is applied to the left-hand deflection plate. As a re-

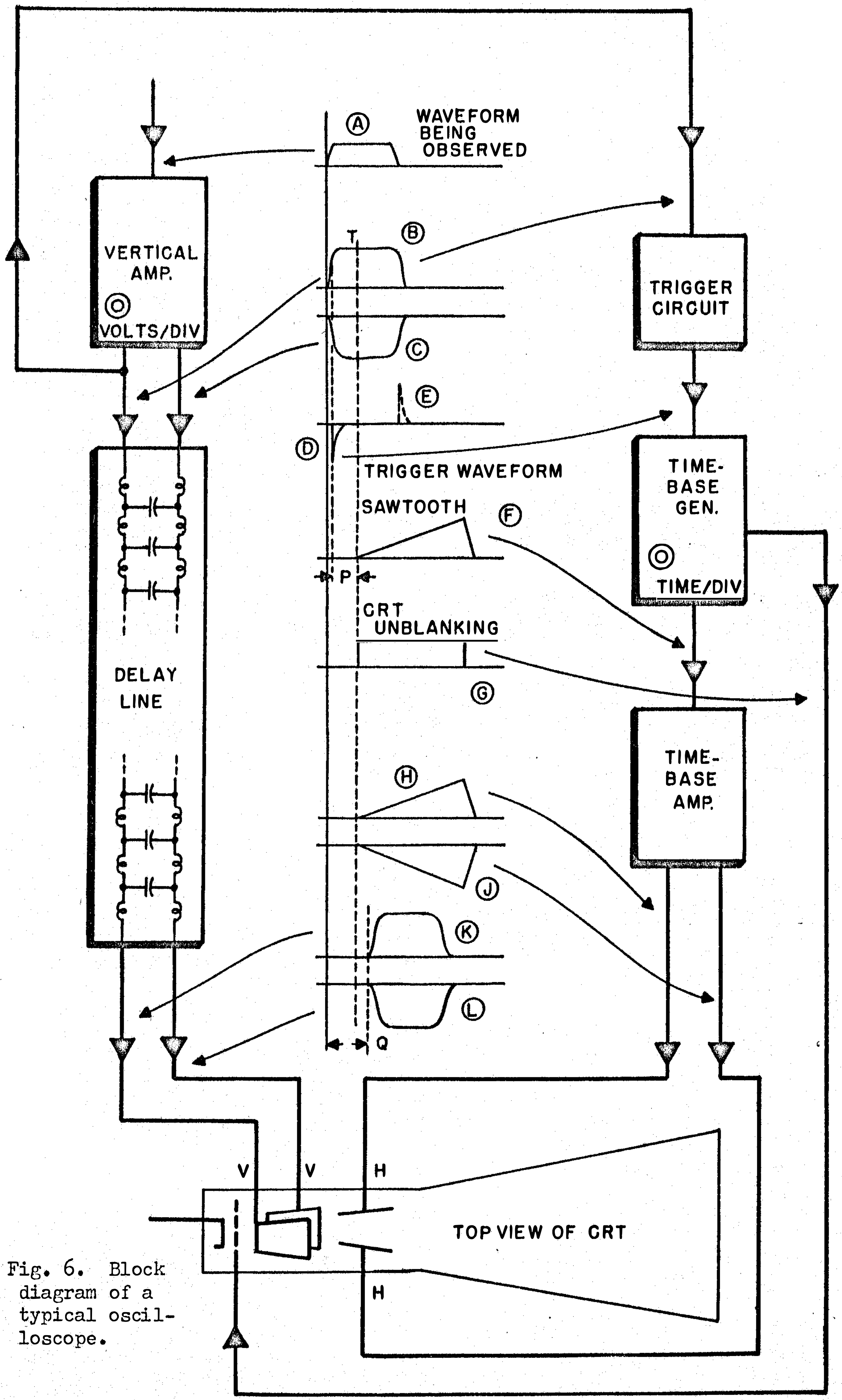


Fig. 6. Block diagram of a typical oscilloscope.

sult, the cathode-ray-tube beam is swept horizontally to the right through a given number of graticule divisions during each unit of time--the sweep rate being controlled by the TIME/DIV control.

In order to maintain a stable display on the cathode-ray-tube screen, each horizontal sweep must start at the same point on the waveform being displayed. To accomplish this, a sample of the displayed waveform is fed to a "trigger" circuit, which gives a negative output voltage spike (D) at some selected point on the displayed waveform. This triggering spike is used to start the runup portion of the time-base sawtooth. As far as the display is concerned then, "triggering" can be taken as synonymous with the starting of the horizontal sweep of the trace at the left-hand end of the graticule.

(Incidentally, the trigger circuit also develops a <u>positive</u> spike (E) later than the useful negative trigger waveform D. But the positive spike has no essential function in the operation of the oscilloscope.)

A rectangular "unblanking" wave (G) derived from the time-base generator is applied to the grid of the cathode-ray tube. The duration of the positive part of this rectangular wave corresponds with the duration of the positive-going or runup part of the time-base output, so that the beam is switched off during its right-to-left retrace.

In many cases the leading edge of the waveform being displayed is used to actuate the trigger circuit. Yet we may want to observe the leading edge on the screen--and the triggering and unblanking operations require a measurable time P, often about 0.15 microsecond. To permit us to see the leading edge, a delay Q of about 0.25 microsecond is introduced by the delay line in the vertical-deflection channel, after the point where the sample of the vertical signal is tapped off and fed to the trigger circuit.

To summarize the purpose of the delay line, it is to retard the application of the vertical-deflection signal (the observed waveform) to the vertical-deflection plates until the trigger and time-base circuits have had an opportunity to get the unblanking and horizontal-sweep operations under way. This permits us to view the leading edge of the desired waveform--even though the leading edge itself was used to actuate the trigger circuit in the horizontal-deflection system. If the delay line were not used, we should be able to view only that part of the displayed waveform occurring after the instant marked T in the figure.

TEKTRONIX, INC., is pleased to have had the opportunity to present this information in the interest of increasing the efficiency of your operations. We stand ready to provide any further assistance at our command.