# Understanding Modern Oscilloscopes

Many hams have <u>some</u> grasp of how a 'scope works. K7OWJ takes us, in simple language, one step further.

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Did you ever wonder what distinguishes a good oscilloscope from an inferior one? Or why various types perform in different ways? It seems that there is a scarcity of information that tells how to distinguish between types of oscilloscopes. And yet there are many hams who would like to know more about these instruments. Here are a few guidelines to help you understand some of the characteristics.

The oscilloscope graphs voltage along a vertical axis against time on a horizontal axis. This can give the user a valuable designing or troubleshooting tool. Since it shows graphically what a circuit is doing, the oscilloscope is perhaps the most useful single piece of test equipment available to the radio amateur.

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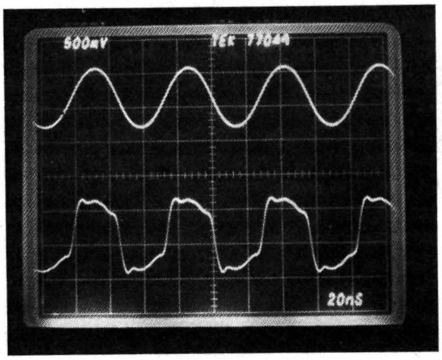
Although there are many different oscilloscope models, there are some common characteristics of all models that the user must evaluate in order to determine how faithfully the instrument will represent the waveform under study. Some of these common characteristics are bandwidth, rise time, sensitivity, maximum sweep speed, and the number of traces available.

A distorted 18-MHz signal is shown under two different oscilloscope bandwidth conditions. In the upper trace, frequency response of the oscilloscope has been limited to 20 MHz. Note the slight loss of amplitude and the apparent "cleanness" of the signal. In the lower trace, the bandwidth of the oscilloscope is 160 MHz. Note the clipping and distortion not apparent in the upper trace.




### Understanding Bandwidth

Bandwidth is a commonly misinterpreted specification. Users frequently purchase, for example, a 5-MHz oscilloscope in anticipation of accurately measuring 5-MHz sine waves, or checking 5-MHz amplifiers for clipping. Neither of these measurements can properly be done with a 5-MHz instrument.

What does "bandwidth" actually mean, then? Vertical amplifiers do not, in general, begin abruptly attenuating signals at their specified bandwidth. Rather, attenuation begins at frequencies much below the specified bandwidth, and increases with frequency. The specified bandwidth refers to the frequency at which the voltage shown on the screen is 0.707 of the actual voltage, or, in other words, is 3 dB down from actual. Hence, a 10-volt, 10-MHz sine wave applied to the input of an oscilloscope with 10-MHz bandwidth would produce about a 7-volt display on the screen.

Since clipping introduces 3rd, 5th, 7th, and higher order harmonics, a circuit operating near the bandwidth of the oscilloscope used to test it will appear nearly free of clipping even if the clipping is actually quite severe. As the bandwidth of the oscilloscope is exceeded, even square waves begin to look very sinusoidal.

A good rule of thumb in selecting an oscilloscope is, that for accurate measurements, the bandwidth of the oscilloscope should exceed the maximum frequency of interest by a factor of five. For some uses, a factor of three may be adequate.

Once the frequency roll-off characteristics are determined, the rise time is also determined. Bandwidth and rise time are approximately related by the formula: Bandwidth times rise time equals 0.35. If pulse rise times are the measurement of interest, the rise time of the oscilloscope should be five times faster than those of the pulses to be measured.

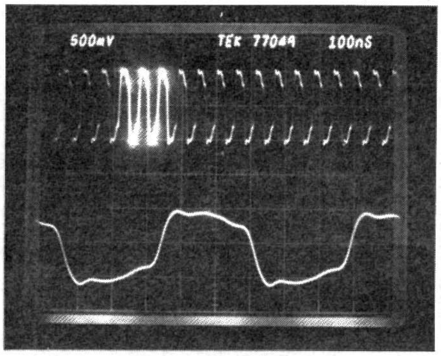
It should be noted that bandwidths and rise times are usually specified when the signal is fed from a 50-ohm source through 50-ohm coaxial cable, and terminated in 50 ohms at the scope, or when the signal is applied through a probe attached to a terminated 50-ohm signal source. As these conditions change, so will the apparent rise time and bandwidth. In other words, the rise time displayed on the screen, or the apparent bandwidth of the scope, will vary according to the specified bandwidth *and* the characteristics of the circuit under test.

The main factor in this phenomenon is the input capacitance of the oscilloscope. The rise time of the combination of the circuit under test and the oscilloscope will not be less than $2.2 \times R \times C$, where $R$ is the source impedance of the circuit under test and $C$ is the combined capacitance of the oscilloscope, the input cable, and the stray capacitance of the circuit under test. For example, suppose the input cable contributes 125 pF, and the oscilloscope input contributes 27 pF. Suppose this combination is attached to the collector of a grounded-emitter amplifier stage, and that the stage contributes 3 pF of stray capacitance, and that the load resistor of the stage is about 1000 ohms. An infinitely fast rise time pulse applied through this combination would appear on screen as being no faster than $2.2 \times 155 \times 10^{-12} \times 10^{3}$ seconds, or 0.341 microseconds. The fastest rise time that can be accurately measured under these circumstances is about 1.7 microseconds. Carrying this a step further, the maximum -3 dB bandwidth is $(0.35/0.341) \times 10^{-6}$ seconds, or about 1 MHz, regardless of the specified bandwidth of the oscilloscope alone.

This situation can be remedied by avoiding high source impedance test points such as drains, plates and collectors, or by reducing the input capacitance presented to the circuit under test, or by some combination of the two. A practical approach to reducing capacitance is the use of a 10-times attenuating probe, since many 10-times probes present a total circuit loading capacitance of less than 15 pF when attached to an oscilloscope. This is why the probes most often used with an oscilloscope are the 10-times attenuating type.

The maximum sensitivity available in modern oscilloscopes may be as great as 10 microvolts/division in some cases. Usually, however, the maximum sensitivity in ordinary oscilloscopes is 5 to 10 millivolts/division, which is adequate for many common measurements, even with a 10-times probe.

Very inexpensive oscilloscopes use an oscillator type of horizontal sweep, where the sweep speeds are indicated in frequency. This type of sweep is much less useful than sweeps linearly calibrated in units of time, such as are found in most present-day instruments. In fact an accurate, calibrated time base was one of the innovations that helped popularize the oscilloscope as a measuring tool. Usually, the fastest sweep speeds are achieved by "horizontal magnification" or increase in horizontal amplifier gain. This is done at some sacrifice in horizontal accuracy, but the additional expansion is usually worth the expense and loss of accuracy.




The upper trace shows the main sweep, intensified. In the lower trace, delayed sweep has been selected and the intensified portion of the upper trace is shown at a higher sweep speed.

Somehow the sweep must be synchronized with the incoming signal. This can be accomplished either by a synchronization circuit or by a trigger circuit. Synchronization circuits work only with repetitive signals and are used mainly in inexpensive instruments or at very high frequencies where triggering is almost impossible. Trigger circuits will work equally well with repetitive or single-shot events, and tend to be used in medium priced and better oscilloscopes. The trigger circuit can be adjusted to trigger at any point on the incoming wave, and on either the positive-going or negative-going slope.

There is some delay in getting the sweep started and the CRT unblanked, so, unless something is done, the leading edge of the displayed waveform will be lost. This is usually not too important in sine-wave measurements, but it can be a nuisance in pulse work. In faster oscilloscopes, a delay line is inserted between the output of the vertical amplifier and the vertical plates of the CRT, so the signal transit time through the vertical system is longer than through the horizontal system. The sweep actually begins before the event that triggered it appears on the screen, so this system allows examination of the leading edge of the triggering waveform.

Frequently it is useful to examine two signals, such as the input and output of an amplifier, on screen at the same time. This can be accomplished either through dual-gun or dual-trace techniques.

The dual-gun technique calls for the sealing of two electron guns in one CRT envelope and for using two separate vertical amplifiers. This technique is expensive but has the advantage when two single-shot events are to be studied.

For repetitive phenomena, such as radio signals, the dual-trace technique is much less expensive and just as satisfactory. One gun is sealed in the CRT, and two amplifiers are fed to the gun either by chopping or alternating between the two amplifiers.

In the chop mode, the trace is switched back and forth between the two amplifiers at a rate of a few hundred kilohertz. Blanking is applied to the CRT during the switching, so switching is invisible, and the single gun appears to supply two simultaneous traces. Since the chopping frequency does not vary with sweep speed, a point is reached where the chopping may begin to break up the trace, so chopping is mainly useful for slower sweep speeds.

For faster sweep speeds, the trace is simply alternately controlled for one sweep by each amplifier. This restores the illusion of two simultaneous traces at higher sweep speeds and, where the trigger circuit is sufficiently sophisticated, will allow the apparently simultaneous display of two non-time related signals. Chopping or alternating can be used to create four or more traces if that is required.

Where accurate time measurements are desired, or where it is desired to display one portion of a trace greatly expanded, delayed sweep is useful. Delayed sweep uses two separate time bases, one delayed by the other. The second, or delayed, sweep runs at a speed faster than the first, or delaying, sweep. The point where the delayed sweep begins is controlled by a potentiometer, and, if the potentiometer is accurately calibrated, time measurements accurate to about 1 percent are possible.

If the main, or delaying, time base is selected, a normal display is presented. If the intensified mode is selected and the delayed time base is set to sweep faster than the main time base, a portion of the sweep will be displayed more brightly than the rest. The beginning point on the graticule of this intensified zone is set by the delayed-sweep potentiometer, and its length is set by the sweep speed selected for the delayed sweep. When delayed sweep is selected, the intensified portion of the sweep will be displayed across the full width of the CRT. In this mode, the delayed-sweep potentiometer can conveniently be used to move the beginning-of-sweep point so portions of the sweep downstream from the beginning of the main sweep can be easily examined in great detail.

The oscilloscope is a very powerful tool, capable of giving a great deal of information about the workings of a circuit. When designing or troubleshooting, it can be almost indispensable, and its proper selection and operation are well worth the investment of time.