Inside the OSCILLOSCOPE PT.2

The differences between oscilloscopes can be found in their specifications and features. This article describes the characteristics that affect performance.

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Examine the catalogs of any test-equipment manufacturer or distributor and you will find a multitude of different oscilloscopes. The reason for that, of course, is that each oscilloscope is better for some particular application than others. At one end of the scale, you'll find the inexpensive "hobbyist" models that are suitable for occasional workbench use. At the other end, you will find the multi-thousand dollar laboratory models. The differences between them are features and specifications. But what are those features and specifications, and which ones are most important in determining which scope is right for you? We will answer those questions for you in this article.

Bandwidth

The most basic oscilloscope specification is vertical bandwidth. When deciding between scopes, that specification is your best indication of whether or not a particular scope is suitable for your application.

The vertical amplifier of an oscilloscope is designed so that its frequency response remains more or less the same until it reaches some point, known as the 3dB, or half-power, point. At that point, the displayed vertical signal is down 3dB (or at −3dB) with respect to a low-frequency reference voltage (see Fig.9). At frequencies higher than the 3dB point, the oscilloscope's response will roll off at a rate of approximately 6dB-per-octave.

Oscilloscopes that have a roll-off that is considerably higher than 6dB-per-octave will have trouble reproducing the high-frequency components of complex waveforms. Those with a roll-off rate that is considerably lower than 6dB-per-octave will suffer from overshoot on pulse signals.

It is obvious that the wider the bandwidth the more versatile the oscilloscope. Also, it is obvious that the wider the bandwidth, the more expensive the oscilloscope. That is so because it is expensive to produce a vertical amplifier that has nearly flat response across a wide bandwidth. Thus, unless you have money to spare, it pays to consider carefully how much bandwidth you really need. For general experimentation, or occasional TV or audio equipment troubleshooting, a bandwidth of 15MHz or so should suffice. If you regularly service video equipment, or work with digital equipment, a higher bandwidth will probably be needed.

Comparing oscilloscope bandwidth ratings is not always as simple as it should be. That's because all manufacturers do not quote the specification in the same manner. While most use the 3dB point as the upper bandwidth limit, some use 3.5, 4 and even 6dB. While the specification might be accurate, a bandwidth that is specified as being 4dB down at 50MHz is not the same as one specified as 3dB down at 50MHz. Use of non-standard specifications can stretch the bandwidth by 50%, or even more.

When working with computers, or other digital equipment, a second specification, closely related to bandwidth, becomes important. That specification is *risetime*. Risetime is defined as the period required for the leading edge of a pulse to rise from 10% to 90% of its ultimate level (see Fig.10). It is related to bandwidth as follows:

$$T_R = 0.35/f$$

where T_R is the risetime in microseconds, and f is the bandwidth in MHz.

To examine short-duration pulses, such as the rapidly changing digital logic-levels within a computer, you need a scope with a wide enough bandwidth to display those pulses without distortion. For example, to see pulses with a 5-nanosecond (ns) risetime, an oscilloscope with a 70MHz bandwidth is required ($0.005 = 0.35/f$; $f = 0.35/0.005 = 70$).

Oscilloscopes come with vertical amplifiers that are AC coupled, via a coupling capacitor, or both AC and DC coupled (no coupling capacitor). The chief difference between the two is that the DC component is filtered out when the scope is used in the AC mode. Generally, all but low-cost units offer both coupling modes.

When operated in the AC-coupled mode, the oscilloscope will have an upper 3dB point determined by the vertical-amplifier's frequency response, and a lower 3dB point that is determined by the low-frequency reactance of the coupling capacitor. That lower 3dB point is generally between 2-10Hz. In addition, in the AC coupling mode, the peak input must be specified. That peak input is typically 400-600 volts AC plus DC.

Oscilloscopes that offer both AC and DC coupling have an input mode selector switch. This will usually have a third position labelled "ground". This position disconnects the vertical amplifier from the input connector and simultaneously grounds the input to that

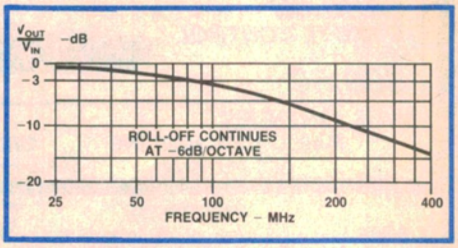
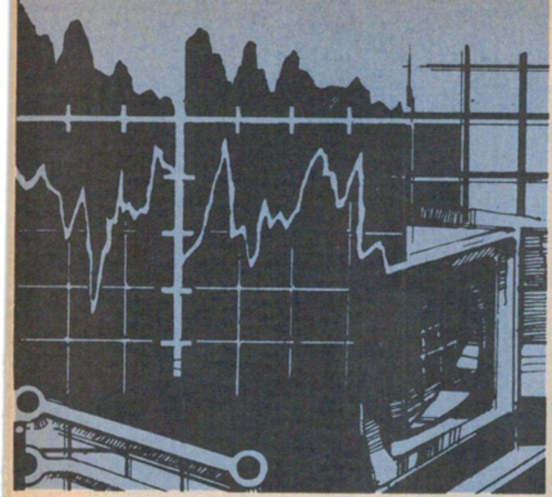


Fig.9: the vertical amplifier of an oscilloscope is designed so that its response is reasonably flat to a point known as the 3dB point. That point defines the oscilloscope's bandwidth.



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amplifier. This setting allows the 0-volt position of the trace to be noted.

Sensitivity

Almost as important as bandwidth is the specification known as *input sensitivity*, or *deflection*. This specification refers to the minimum signal voltage required to produce a usable deflection on the scope's CRT display. Generally, this deflection is defined as one graticle division (usually 1cm).

As should be obvious, a scope with a sensitivity specification of 2mV/cm is more sensitive than one with a sensitivity of 5mV/cm. But sensitivity specifications are given in both peak-to-peak (p-p) and root-mean-square (rms) voltages. There is a significant difference. To make a meaningful comparison, you can convert rms to p-p by multiplying the rms rating by 2.8. For example, a scope rated at 2-volts rms would be rated at 5.6-volts p-p (2.8 x 2). Thus, a scope rated at 2-volts rms is not as sensitive as one rated at 5-volts p-p (5.6- vs. 5 volts).

Bear in mind that it is difficult to do any meaningful analysis of signals that are only one divison high. Usually, you will want the signals to be at least two divisions in height; four divisions of height will allow you to see most signal details. On the other hand, the higher the sensitivity, the more expensive the scope.

You can determine the sensitivity of the scope by looking at the vertical amplifier control. The lowest setting on that control is the vertical sensitivity of the oscilloscope. If the scope has a vertical magnifier, divide that lowest setting by the magnification factor. Thus, an oscilloscope that has a minimum setting of 5mV/cm, and a 5 x magnifier, has a minimum sensitivity of 1mV/cm.

Input impedance

For almost all applications, an oscilloscope with a high input impedance is desirable. That prevents the oscilloscope from affecting the circuit that it is being used to test. These days, almost all oscilloscopes have an input impedance of one Megohm (one-million ohms).

Triggering

Most sophisticated oscilloscopes provide several trigger options to make the unit more versatile. Those options include positive- or negative-slope triggering, triggering level, trigger signal source (external, internal, power-line, etc), and more.

As with the vertical amplifier, sensitivity and bandwidth are used to describe trigger circuitry performance. Generally speaking, sensitivity should be sufficient to allow a stable trace of one division or less to be displayed. Trigger bandwidth defines the highest frequency that can be displayed with any degree of stability at the oscilloscope's minimum deflection. That specification determines the ability of an oscilloscope to trigger on complex waveforms, and the stability of the display of such waveforms. Generally, the trigger bandwidth should be at least as wide as the vertical bandwidth. Anything less than that will provide unacceptable results when viewing complex waveforms. On the other hand, a trigger bandwidth of twice the vertical bandwidth will provide outstanding results.

Features

As important as specifications are, it is often the features that make an oscilloscope either suitable or unsuitable for a particular application. Let's briefly go over some of those features and their use.

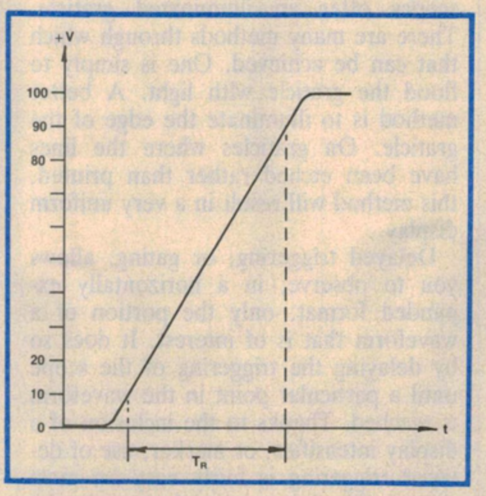

Fig.10: risetime is defined as the time it takes for a pulse to go from 10% of its ultimate value to 90% of that value.

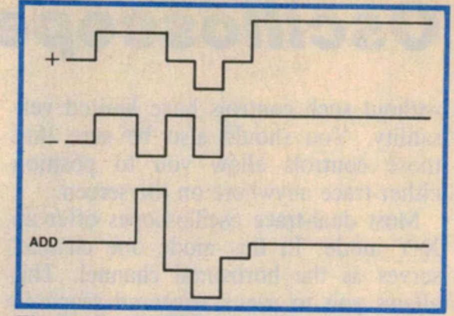

Fig.11: in the add mode, the two channels are added together algebraically. If one of the channels is inverted, that mode is useful in comparing the two input signals.

Last time, we looked at the two methods oscilloscopes use to display two simultaneous traces — alternate and chopped. In addition, all dual-trace scopes are capable of displaying only one channel at a time.

More sophisticated oscilloscopes offer yet another option, called *add*. In this mode, the two signals are added algebraically, and displayed as a single trace. Most often, oscilloscopes equipped with this option also provide a control that allows you to invert the polarity of one of the traces. When that is done, and the signals are added, the parts of the signal that are common to both inputs are not displayed — only the parts of the signal that are different are seen (see Fig.11). This allows for easy comparison of the inputs.

Voltage calibrators are found on many oscilloscopes. They provide the user with an easy way to check the accuracy of the oscilloscope's vertical amplifier and permit compensation of the probes. (If probes were ideal, no such compensation would be needed. However, real probes have some capacitance that can cause distortion of the displayed waveform. As a result, most oscilloscopes use probes that have a compensation adjustment to counteract that effect.)

If you expect to see the fine details of the display, you need a trace that is as sharp as possible. A trace that is unacceptably thick can hide such things as ringing and overshoot. Most scopes have adjustments that are used to control the characteristics of the trace. Those are focus, intensity, and astigmatism. The purpose of the first two of those is self explanatory. The astigmatism control is used to shape the beam into a perfectly round dot.

Most oscilloscopes have controls that allow you to adjust the horizontal and vertical position of the traces. Units without such controls have limited versatility. You should also be sure that those controls allow you to position either trace anywhere on the screen.

Most dual-trace oscilloscopes offer an X-Y mode. In this mode one channel serves as the horizontal channel. This allows you to use a triggered scope in the same manner as an older recurrent-sweep oscilloscope with separate horizontal and vertical inputs and is useful for examining Lissajous figures, phase differences, vectorscope displays, etc.

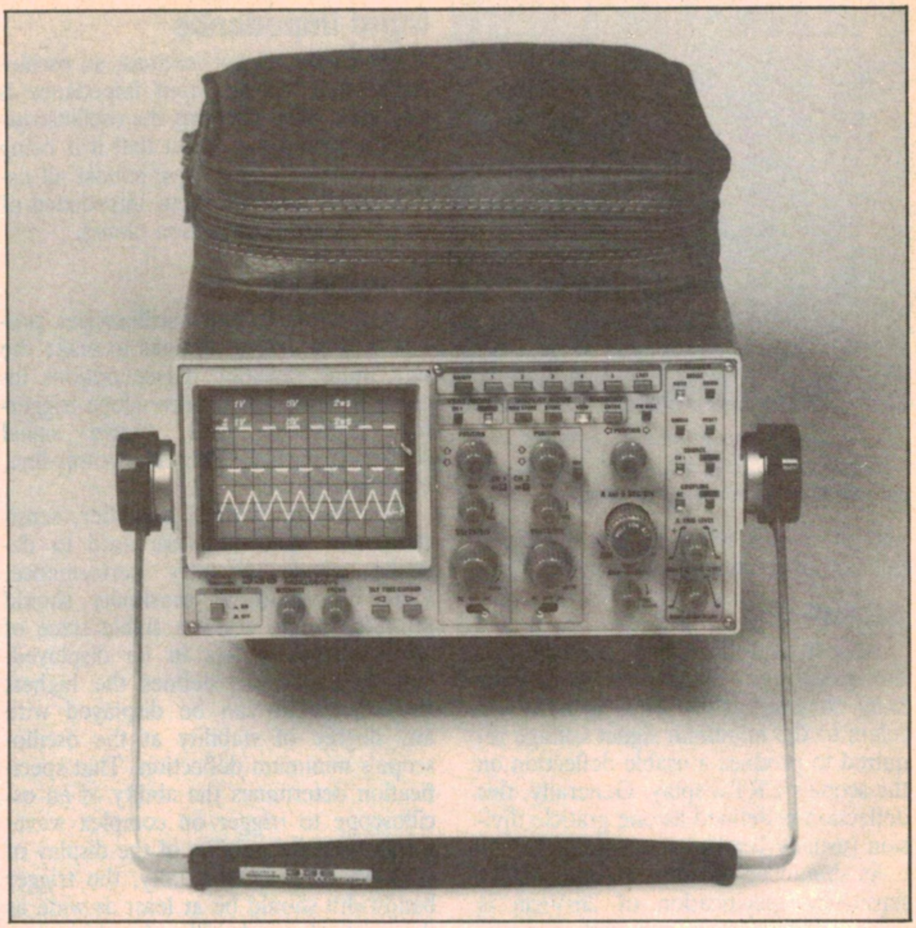
Fig.12: the Tektronix/Sony 1336. This scope features an on-screen alphanumeric display and digital trace storage.

As we saw last time, the graticle is the grid that is placed on the face of the CRT. But how that grid is placed there can sometimes affect the accuracy of the oscilloscope. If there is any space at all between the graticle and the face of the CRT, a considerable parallax error can be introduced. Because of that, the graticle must be placed as close to the face of the CRT as possible. In addition, a parallax error can even be caused when the graticle is placed directly on the face of the CRT. This error is caused by the thickness of the glass itself. (Remember, the display is generated by exciting phosphors that are located on the inside surface of the glass). Thus, the most accurate displays are obtained on oscilloscopes that have their graticle etched on the inside surface of the glass. However, such tubes are expensive.

To make the lines of the graticle stand out, some more expensive oscilloscopes offer an illuminated graticle. There are many methods through which that can be achieved. One is simply to flood the graticle with light. A better method is to illuminate the edge of the graticle. On graticles where the lines have been etched rather than printed, this method will result in a very uniform display.

Delayed triggering, or gating, allows you to observe, in a horizontally expanded format, only the portion of a waveform that is of interest. It does so by delaying the triggering of the scope until a particular point in the waveform is reached. Thanks to the inclusion of a display intensifier, or marker, use of delayed triggering is fairly easy on most scopes. The latter is used to mark the portion of the waveform that is of interest. Once that is done, the delay time, which is actually the timebase you wish to use to view the selected portion of the waveform, is chosen. You then activate the delayed triggering option and the display opens up and shows the selected portion of the waveform in detail.

The above are some of the more basic oscilloscope features; there are, of course, many more. Some oscilloscopes include built-in DMMs. Others offer on-screen alphanumeric readouts (see Fig.13), colour displays, the capability to store traces in memory, multiple-trace (4, 8, or even more) displays, and just about anything else you can think of. Some of the newest oscilloscopes are even using digital signal-processing techniques. In such a scope, a measured trace can be manipulated and displayed in an almost unlimited number of ways. Unfortunately, those oscilloscopes are prohibitively expensive at present for most applications.

Now that we know how an oscilloscope works, and what its various specifications and features mean, it's time to learn how to use one to its best advantage. This will be the subject of our final article next month. EA