Technology Update

OSCILLOSCOPES

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The Evolution Of Scopes: Faster Than Any Other Type Of Test Equipment

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Today's sophisticated oscilloscopes are a far cry from the first rudimentary scopes of 50 years ago. In fact, scopes have probably evolved further than any other type of general-purpose test and measurement equipment. And, in the process, they have continued to remain the most versatile and universally applied test and measurement tool.

Where there were once only modest-performance, realtime, analog oscilloscopes available from a few manufacturers, there are now high-performance scopes having greater functionality in several major categories (with some degree of overlap) that are available from many different manufacturers.

Tektronix's 7854 waveform processing oscilloscope is an example of the trend of combining processing power with programmability and the ability to be tailored to specific situations via plug-ins.

Oscilloscopes can be categorized into realtime, CRT storage, digital storage, digitizing and sampling; digitizing scopes are also known as waveform digitizers.

Realtime oscilloscopes are still the most general purpose of scopes, and the best choice for many applications. They offer bandwidths up to 1 GHz, rise times to 350 ps, sweep speeds to 200 ps per division, sensitivity down to 10 μV per division, common-mode rejection up to 100,000 to 1 for differential measurements and writing rates to 20,000 cm per microsecond. They also offer a wide variety of options and functions, which might include plug-in or piggyback counter timers, digital multimeters (DMMs) and logical or Boolean trigger selection.

The writing rate is a key specification not only for analog oscilloscopes but for CRT storage scopes as well. Yet, it is often misunderstood.

Writing Rate Meaning

The term "writing rate" describes the rate at which a beam can move with enough light output to display the input waveform (visual writing rate), the waveform that can be photographed (photographic writing rate) or to store a waveform in a storage CRT (stored writing rate).

The velocity of the electron

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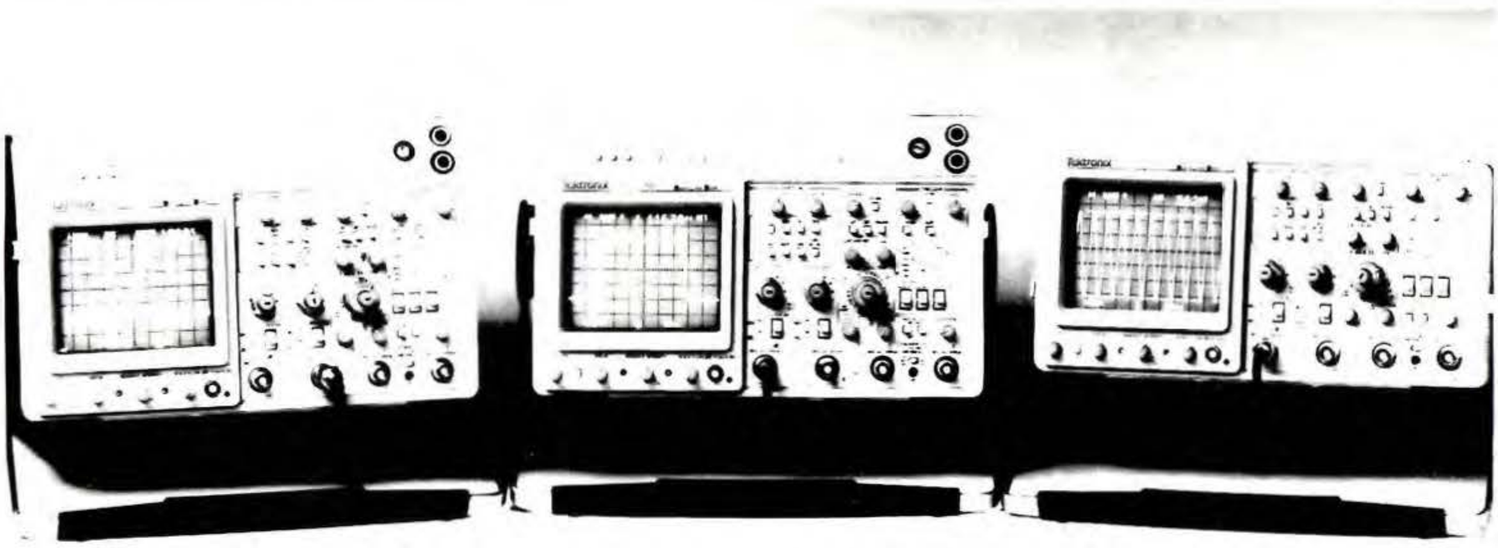


The increased need for portable oscilloscopes in field service, and competitive pressures among manufacturers, are both serving as driving forces behind the development of technologically advanced, lower-cost oscilloscopes. The photo shows a series of new portable scopes.

beam across the CRT's phosphor display area can sometimes be very fast. In a scope with extremely wide bandwidth, it can appear to move more quickly than light. The beam's velocity can be so high that there are not enough electrons with ample energy striking the CRT phosphor to generate an adequate amount of photons for the waveforms to be displayed, photographed or stored (in the case of a storage CRT). If this is the situation, then it is less important that the rest of the oscilloscope is processing an input waveform properly.

Most realtime oscilloscopes have adequate writing rates to display most input waveforms. However, only realtime oscilloscopes employing microchannel plates have sufficient writing rates for single-shot, low-repetition-rate input waveforms that require fast sweep speeds.

Microchannels For Speed

A microchannel plate is a device that is placed between the deflection plates of a CRT and the phosphor. It acts as an electron multiplier and can result in as much as a 10,000-fold increase in the number of electrons and 100 to 1,000 times increase in visual or photographic writing rates. The conventional CRTs employed in most general-purpose scopes have writing rates on the order of 100 cm per microsecond.

Conventional CRTs without microchannel plates can have visual writing rates on the order of 1,000 cm per microsecond. When P11 high-speed phosphor, very fast cameras, high-speed films and other techniques to enhance writing rates are employed, writing rates on the order of 2,000 to 3,000 cm/μs can be achieved.

But a microchannel-plate CRT with conventional P31 phosphor can attain writing rates of 20,000 to 30,000 cm/ms without using those techniques. By applying this technology, low-repetition-rate, even single-shot waveforms, can easily be seen or photographed at the highest sweep speeds.

It should be remembered that a writing rate of 1 cm/ns does not mean that a sweep speed of 1 cm/ns can be used. The vertical component of deflection must also be considered.

Microchannel plates have another important characteristic—they tend to normalize intensity. If an input waveform has a relatively high repetition rate, but some component of the waveform—say, a glitch or noise—has a lower rate, the intensity of the high-repetition-rate component will wash out the lower-rate component. This prevents it from being seen with a CRT that does not have microchannel plates.

The electron output of a microchannel plate does not increase linearly with electron input. There is a tendency to saturate. As a result, high- and low-repetition-rate components of a waveform have nearly equal intensity. This can be very important when the low-repetition-rate component is what the user is trying to see, as is often the case.

Storage Scopes

Storage oscilloscopes are used mainly to capture relatively fast, single-shot events and display them for longer periods of time than conventional scope-CRT phosphors permit. These scopes are also used to display very slow waveforms that cannot otherwise be viewed in their entirety. A conventional non-storage oscilloscope with a camera can accomplish the same thing. But it is much less convenient and, depending on the number of photographs, may be more expensive.

It is still necessary to use a conventional scope and camera to capture the fastest waveforms. This is because the stored writing rate of even the fastest storage scope is not as high as the photographic writing rate of a conventional scope and camera.

There are two basic kinds of storage oscilloscopes: CRT and digital storage. CRT storage scopes are realtime analog scopes that employ special

CRTs that can store the input waveform. Digital storage oscilloscopes (DSOs) digitize the waveform, store the digitized data in memory and display the contents of memory on a conventional CRT.

Storage CRT Comparison

There are three different types of storage CRTs: bistable, variable persistence and fast transfer.

Bistable storage CRTs use a phosphor that can have two stable states—stored or unstored. Once a waveform is stored on a portion of the phosphor, it can be displayed for long periods of time—up to several hours—or until erased.

Bistable storage is the least expensive type of CRT storage, and it features long-lasting displays. However, it has a lower stored writing rate and less contrast between the stored and non-stored portions of the display.

Split-screen viewing is another advantage of bistable storage. Half of the CRT display area can be in a storage mode, while the other half is in a non-storage mode. Or both halves can store and display two different waveforms simultaneously, even when they occur at two different points in time.

Variable-persistence CRT-storage scopes allow the user to vary the persistence or display time of the display. A mesh between the deflection plates and phosphor stores the input waveform. The charge on the mesh and, therefore, the intensity can be varied by the user. High intensity is normally at the expense of storage time.

When the persistence of the display is varied, one sweep begins to appear just as the previous sweep is disappearing, a useful feature in some applications. These scopes also have a somewhat faster writing rate than bistable storage scopes, and a higher contrast between the stored and non-stored portions of the display.

The fast-transfer storage scope uses a second target mesh, optimized for speed, in the CRT. The waveform is stored on this second mesh. But this mesh will not hold the stored charge for very long. So, the stored waveform is transferred to a second mesh similar to the mesh in a variable-persistence CRT.

The primary advantage of this approach is faster stored writing rate—about 3,000 to 4,000 cm/μs. However, the trade-off is higher cost due to increased complexity.

The mesh to which the waveform is moved in a fast-transfer CRT can be designed to operate in both the bistable and variable-persistence modes. This results in multimode CRT storage, in which the CRT can be operated in either the bistable or variable-persistence mode.

Digitizing Technology

Analog realtime scopes—both storage and non-storage types—still outperform DSOs and digitizing oscilloscopes. But digitizing instruments are closing the gap.

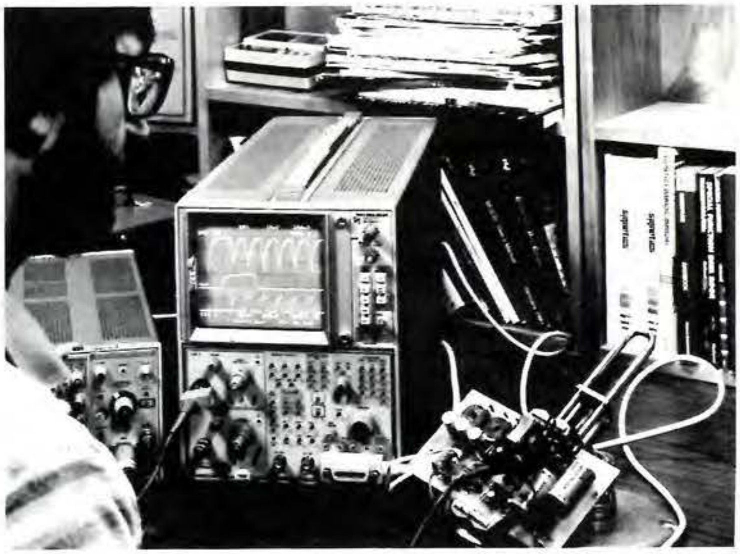
The distinction between DSOs and digitizing scopes can be somewhat arbitrary, but is usually based on the primary purpose for digitizing. In a DSO, the digitizing is done primarily for waveform storage, so the waveform can be displayed for longer periods of time than is possible with realtime oscilloscopes. Digitizing in digitizing oscilloscopes, on the other hand, is performed so that the data can be transferred to a computer for processing and analysis.

Since different performance trade-offs are made and they usually employ various digitizing techniques, the distinction between DSOs and digitizing scopes is important. There is, however, some overlap between them.

DSOs are primarily intended for the same applications as analog-storage oscilloscopes, although the latter have higher stored-writing rates. DSOs, however, are usually less expensive and offer capabilities not found in their analog counterparts.

For example, in DSOs there is no fading or blooming of the

Only realtime scopes employing microchannel plates have sufficient writing rates for single-shot, low-repetition-rate input waveforms requiring fast sweep speeds—microchannel plates act as electron multipliers for CRTs and can result in a 100- to 1,000-time increase in visual or photographic writing rates.



Among the features being added to some new digital oscilloscopes are signal averaging to reduce uncorrelated noise, envelope displays for comparing dynamic waveform characteristics, and pre- and post-triggering during equivalent-time sampling. The cost of these scopes can run in excess of $8,000.

stored waveform, which sometimes happens with improper application of analog storage. In addition, some DSOs offer features such as pretrigger viewing, which is not possible with analog storage. Pretrigger viewing displays a portion of the waveform that occurred before the trigger event. Since the trigger can stop as well as start signal acquisition, this mode may be used for babysitting.

DSOs can also do signal averaging to reduce the effects of noise. They can output the digitized data over RS-232 or GPIB interfaces too. These capabilities, however, begin to blur the distinction between DSOs and digitizing scopes.

Digitizing For Transfer

Digitizing oscilloscopes or waveform digitizers (as opposed to DSOs) are optimized for transferring data to a processor or computer. The digitizing technique is usually of much higher performance than what is used in DSOs and so, consequently, are more expensive.

Once the digitized data are transferred to the processor, they are normally processed by waveform-processing software. Here, an almost limitless number of operations can be performed on the data. For example, a Fourier transform can be performed so the digitized waveform can be analyzed in the frequency domain, even though the waveform was acquired in the time domain.

Two primary digitizing techniques are employed in digitizing oscilloscopes and DSOs: realtime sampling and equivalent-time sampling.

With the realtime method, the sampling normally takes place as fast as the DAC can digitize the samples. The sampling speed is unrelated to the input repetition rate.

Realtime sampling can capture single-shot waveforms. However, theory dictates that the sampling rate must exceed twice the highest frequency component in the waveform to avoid the loss of information or aliasing (falsifying) information. Practical considerations mandate that the sampling rate should be four or five times the highest-frequency component.

Conventional A/D converters that are practical and cost-effective for oscilloscopes can run as high as 100 MHz, but this means the effective bandwidth for single-shot waveforms when realtime sampling is employed is only 20 MHz to 25 MHz.

A partial solution to the problem is available with scan converters that can acquire the information very rapidly and then output it more slowly for the A/D converter to digitize. With this technique, waveform digitizers are available today with effective bandwidths to 1 GHz. The disadvantage is that they are very complex and expensive.

With equivalent-time sampling, one or more samples are taken each time a trigger is generated from the input waveform, with the waveform being reconstructed in equivalent time. The waveform reconstruction technique of equivalent-time samplers allows capture of much higher bandwidth signals than is possible with realtime samplers, but the waveforms must be repetitive.

A disadvantage of equivalent-time sampling is that it cannot capture random or aperiodic elements (such as noise or glitches) that are sometimes of interest in repetitive waveforms.

Sampling Scopes

Equivalent-time oscilloscopes, called sampling oscilloscopes, have been available for some years. These have effective bandwidths up to 14 GHz for repetitive waveforms.

In a sampling oscilloscope, the width of the sample determines the effective bandwidth of the circuit. Currently, sample gate times as low as 25 ps are available. However, only one sample occurs per trigger, and the triggers can occur at a maximum rate of only about 100 kHz.

Sampling scopes have found universal application where the waveforms and all components of the waveform of interest are very high speed and repetitive.

The Future

There is a growing need for faster, more sophisticated and versatile oscilloscopes. The availability of higher-speed devices, primarily semiconductor devices, are basically what is enabling the development of these higher-performance oscilloscopes.

But device technology is also serving to impose performance limits on these new oscilloscopes. Of course, this has been true of analog and digitizing oscilloscopes. For example, the bandwidth vs. sensitivity trade-off of analog oscilloscopes has an equivalent trade-off in digitizing oscilloscopes—digitizing speed vs. bits of vertical resolution.

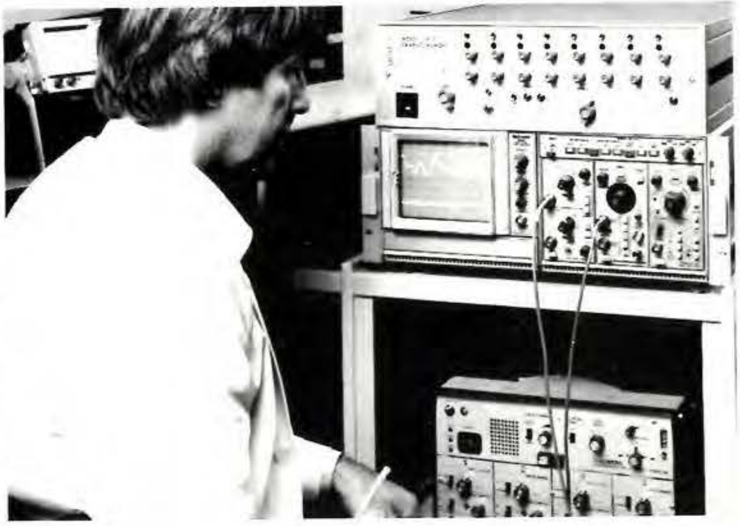
As electronic devices become faster and more complex, the instruments that test them must keep pace. In the future, scopes will have higher bandwidth capabilities and greater measurement versatility.

While scope performance is improving, the cost of owning one with significantly more capabilities is going down. This is due primarily to advances in semiconductor and manufacturing technologies. The result will be a better price/performance ratio.

The increased need for portable oscilloscopes in field service, and competitive pressures among manufacturers, are both serving as a driving force to develop technologically advanced, lower-cost oscilloscopes. This is being accomplished by incorporating VLSI circuits into scopes and streamlining manufacturing processes for high-volume production.

Though analog-storage scopes are still better for capturing high-speed, random, aperiodic or single-shot signals, DSOs and digitizers have their

Digital storage oscilloscopes (DSOs) digitize waveforms, store the digitized data in memory, and display the memory-stored data on a CRT. DSOs are primarily intended for the same applications as analog-storage scopes; and although they are usually less expensive than the latter, they also have lower stored writing rates.



Though analog-storage scopes are still better for capturing high-speed, random, or single-shot signals, DSOs and digitizers are beginning to close the performance gap.

own set of advantages and are beginning to close the performance gap. As their performance increases over the next three to five years, they will be used in a growing number of applications.

Scope Channels Added

The shift in emphasis from analog to digital applications has brought with it the need for additional scope channels to look at a growing amount of simultaneously occurring events. Today, two to four channels is fairly standard, with scopes having the ability to trigger on up to eight or more channels. In the next few years, the number of channels should climb even higher.

Incorporating more features, such as integrated counters/timers/DMMs, has been in direct response to the need for greater measurement accuracy. With this development, oscilloscopes are evolving from what was primarily a *qualitative* measurement tool into a significantly more *quantitative* tool.

As measurements have become more complex, there has been an ongoing effort to make the oscilloscope an easier instrument to use. Some specific advances regarding this goal include menu-driven oscilloscopes, fewer front-panel controls and application-specific software.

A product's life-cycle cost is also becoming an increasingly important consideration to buyers. Besides the initial purchase price, several other factors contribute to life-cycle cost, including frequency and price of repair, warranty length and mean time between failures.

In addition, features such as self-test and internal diagnostics are being incorporated into oscilloscopes with growing frequency.

Overcoming Hurdles

The basic A/D conversion process is the primary limitation in DSOs and digitizing oscilloscopes. Higher digitizing rates are necessary to increase the single-shot bandwidth and time resolution of digital oscilloscopes. And more bits of resolution are required to increase effective sensitivity and dynamic range.

Today, it appears that the solution for most applications may lie with better scan converters for digitizers and faster charge-coupled devices (CCDs) for DSOs. In the future, however, faster basic semiconductor devices—possibly based on gallium arsenide—and different A/D conversion techniques may make significantly faster A/D conversion possible.

In the past, writing speed was a major limitation for oscilloscopes. Very fast events that were single shot or had low-repetition rates were difficult, or impossible to view. Microchannel-plate technology has eliminated this limitation in laboratory oscilloscopes. It is, however, an expensive technology. But, as with most device technology, higher volume will lead to lower cost and greater universal applications of the technology. **EET**

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