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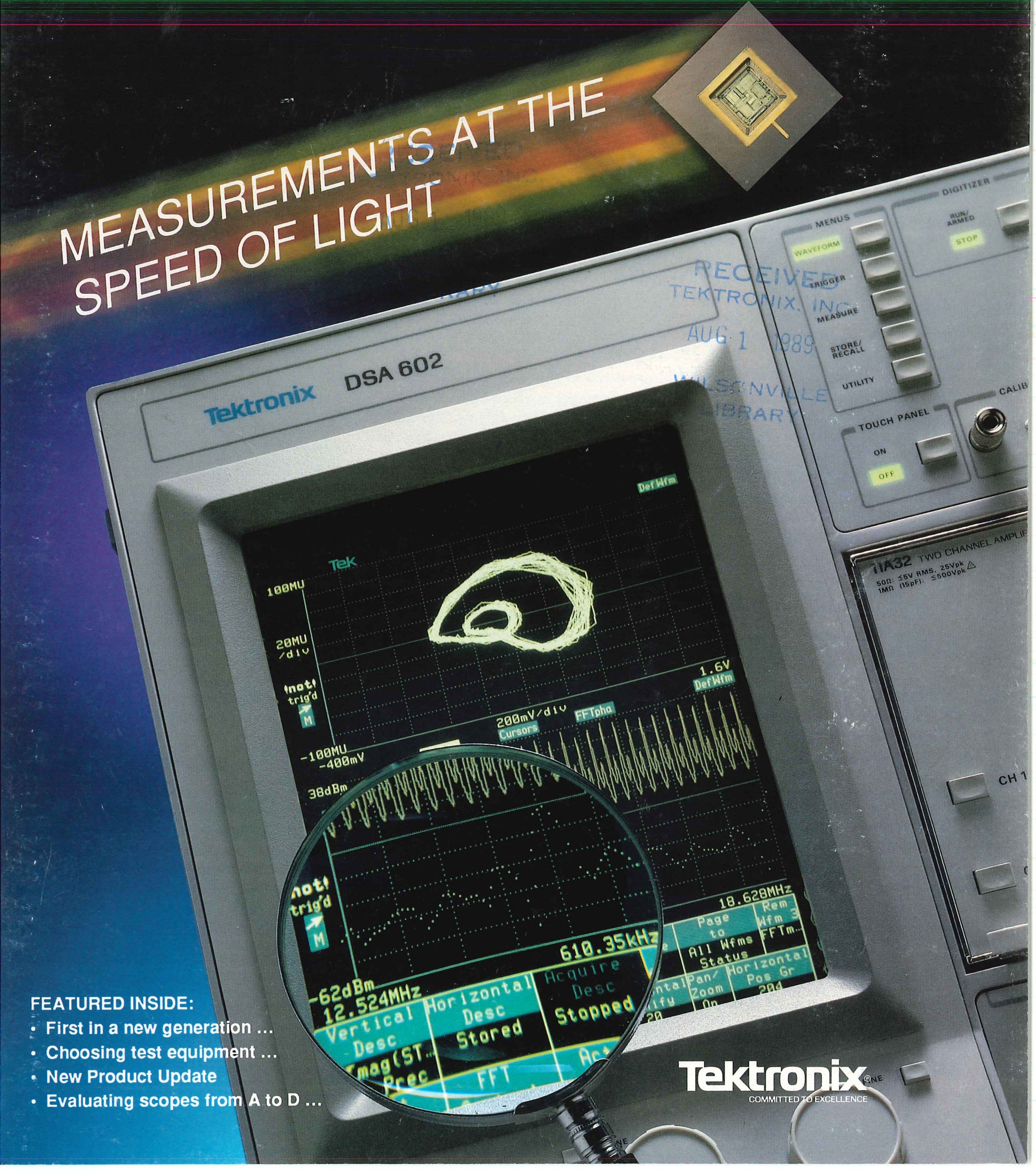
TEK HANDSHAKE™

THE VISIBLE EDGE IN MEASUREMENTS

MEASUREMENTS AT THE SPEED OF LIGHT



FEATURED INSIDE:

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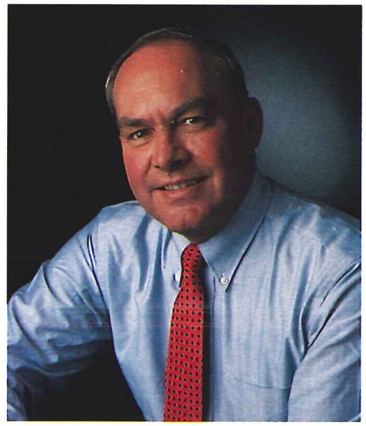

Providing solutions is what Tektronix *is all about. Sure, we make and sell test and measurement equipment, but that's really only a small part of our purpose.*

Understanding your needs is the first part. What types of electrical impulses do you measure? What test signals do you need and how will you use the information obtained? What form should the findings take so they're easy to understand and use? If we do our homework and build the right features into an affordable, easy-to-use product, we've done part of our job. And in the process, we've given you an edge over your competition.

Providing the right instructional materials and applications information is another part of our job. Just getting you to buy our products isn't our objective... showing you how to use our products to solve your specific testing needs is. Engineering and research on the "cutting edge" of technology isn't always easy. We know that. But our goal is to show you ways to make your job easier — to provide the "how to" information you need and to share techniques others are using to meet the same challenges you face. By providing you this information, you can do your job faster, more efficiently, and more effectively. And by doing that, you're providing an edge over your competition.

Developing technology to meet your future needs in the areas of acquisition, processing, storage, and display of signals and images is also a part of our job. Guaranteeing the next generation of measurement capability through such advanced products as the DSA 600 Series Digitizing Signal Analyzer, the 2782 Microwave Spectrum Analyzer, and the PRISM 3000 Series Logic Analysis System provides an edge for your measurements.

Product reliability is also important. Our reliability track record is among the best in the industry. But frankly, unless the products you buy from us work like they're supposed to right out of the box, you don't care what our record states. It's another part of our job to prove our reliability over and over again in each Tektronix *product you buy. And that reliability is backed by a world-wide service and support organization that guarantees that someone is there to help you long after the "shine" is gone from your new* Tektronix *product. We're still supporting some of the earliest* Tek *products, so you can rest assured that we'll stand behind the product you buy today. Having the assurance that your instrument will be ready and capable when needed keeps you on the measurement edge.*

When you buy from Tektronix, *you get more than a product. Our people, our technology, our products, our quality, our reliability, our engineering, our service, our support... all provide an edge. We don't want you to have to guess at what edge we provide. We want that edge to be apparent —* ***the visible edge.*** *When you think of* Tektronix, *we'd like you to visualize how we as a company help you stay on the edge of whatever measurement or application field you're in — whether its high-tech or low-tech. As a partner with you, we want to join you on* ***the visible edge.***

To keep you informed of Tektronix *test and measurement products with* ***the visible edge,*** *we're sending you* **HANDSHAKE.** *Each issue will tell you about new products and new measurement techniques, as well as information on measurement technologies to help you do your job better — to maintain that edge in your measurement capabilities.*

Tektronix — *The Visible Edge in Measurements!*

David P. Friedley
President, Tektronix, Inc.

FOR MORE INFORMATION:

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A look inside

Measurements. That's the reason **HANDSHAKE** exists — to bring you information on new products and techniques to make measurements better, faster, and at less cost. The feature article, **First in a new generation of lab instruments — the DSA 600 Series Digitizing Signal Analyzers** describes just such an instrument. The DSA 600 Series can literally make measurements at the speed of light. And this not only includes displaying a waveform, but also simultaneously performing "live" waveform processing on the signal.

Choosing the right test equipment for your application is not an easy task. To help you make an educated choice, to select the right test instrument with the right measurement technology and the right features, we've included a three-part article on **Choosing test equipment to match your application.** This article will guide you through the sometimes confusing array of specifications encountered when evaluating an oscilloscope, logic analyzer, or spectrum analyzer for your measurement. A companion article, **Evaluating scopes from A to D ...**, provides six important questions you should ask when choosing a digitizing oscilloscope. This article takes you beneath the "banner specs" so often used to promote a low-cost alternative to look at all of the important features required for reliable and repeatable measurements.

You'll find our second edition of the **New Product Update** in the center of this issue. Here you'll find information on ten new products, four new software packages, and two new accessory products to help with your measurements.

With this issue, we introduce Tektronix as **The Visible Edge In Measurements.** We'd like to show you that visible edge. For help with any of your test and measurement applications, contact your local Tektronix Field Office or sales representative. And tell them **HANDSHAKE** sent you!

A. Dale Aufrecht
HANDSHAKE Editor

For information or prices on products described in this issue, call the Tektronix National Marketing Center 1-800-426-2200

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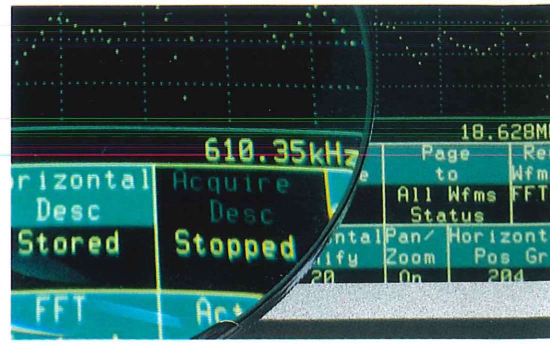

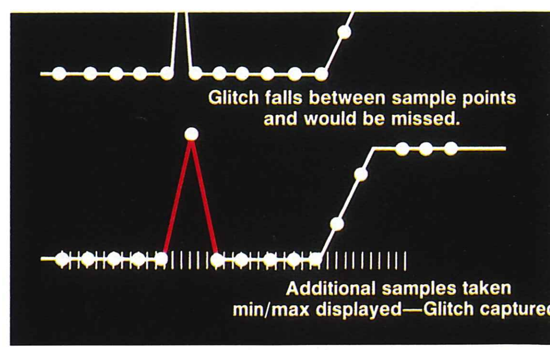

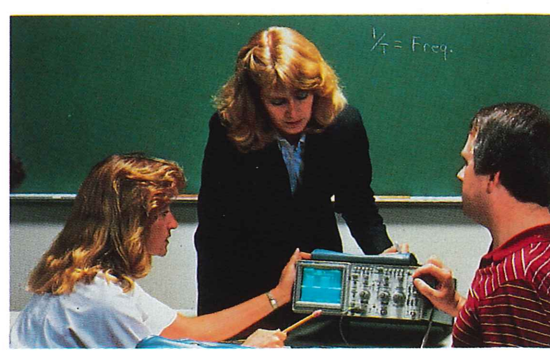

PRODUCT FEATURE

First in a new generation of lab instruments — the DSA 600 Series Digitizing Signal Analyzers

Portland State University uses a CW Xenon laser to study chaotic behavior in lasers. Here, Dr. Manuelo Tarraja displays both the time-domain signal and its equivalent frequency-domain representation to verify the laser output as well as the frequency of the pulsations.

Nellie Brock
Product Marketing Manager
Laboratory Instrument Products
Tektronix, Inc.

Unlike any instrument before, the Tektronix DSA 601 and DSA 602 Digitizing Signal Analyzers are distinguished by their ability to apply complex waveform processing and analysis functions to the acquired time-domain data — in real-time.

By incorporating proprietary advances in digital signal processing technology into an improved 11400 Series acquisition platform, Tektronix designers have gone beyond simply improving the oscilloscope. With the DSA 600 Series Digitizing Signal Analyzers, the user can, for the first time, see "live" updates of not only the acquisition, but also the results of complex waveform processing and analysis functions.

With these Digitizing Signal Analyzers, Tektronix has taken the first step into a new arena which integrates the capabilities of the digital oscilloscope into a broader and more powerful class of instruments — instruments which go beyond acquisition into the realm of live waveform measurement and analysis.

Why a new class of lab instrumentation?

The growth in digital oscilloscope acquisition capabilities has in many ways outstripped existing waveform analysis capabilities. With maximum bandwidths in the gigahertz range, sampling rates in the gigasamples/second range, long record lengths, and high dynamic resolution, a new problem has arisen: How can we economically process and interpret the vast quantities of acquired data fast enough and accurately enough to yield timely and meaningful results?

Conventional practice is to connect the oscilloscope to a host computer via the IEEE-488 bus and apply complex and expensive support software to analyze the data. But this "solution" takes time: Time to acquire, digitize, and store the waveform record; time to transfer the data over an external bus; time to process the data; and time to analyze and display the results. And during this time, the scope waits to make the next acquisition.

To solve this problem, engineers at TEKLABS developed the TriStar Digital Signal Processor specifically for implementation of live waveform measurement and analysis functions aboard the DSA 600 Series mainframes. TriStar is a proprietary, high-speed CMOS, RISC (Reduced Instruction Set Chip) processor designed specifically for digital signal processing aboard the DSA 600 Series Digitizing Signal Analyzers. It consists of an arithmetic unit, an address computation unit, and an instruction fetch unit (see Figure 1).

These three units operate in parallel to simultaneously process data in a single clock cycle. For example, complex operations such as 16 bit by 16 bit multiplication can be performed in the same clock cycle as register shifts.

TriStar's powerful digital signal processing capabilities are maximized in the unique architecture of the DSA 600 Series. Building upon the multiple microprocessor control platform of the 11400 Series Digitizing Oscilloscopes, Tektronix designers added a TriStar processor in a direct data transfer pipeline between the acquisition and display processors (see Figure 2). All communications occur over high-speed internal buses, allowing complex measurements and functions to be applied to the acquired time-domain data prior to display, in real-time — a feat that simply couldn't be done until now.

Advanced waveform processing

TriStar makes possible comprehensive waveform analysis functions such

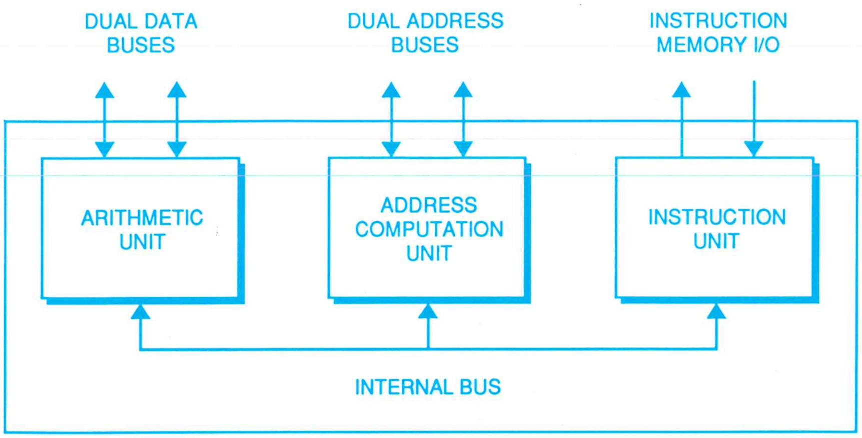

Figure 1. *TriStar is a RISC-based digital signal processor designed with three functional units that operate in parallel, performing complex operations in a single clock cycle.*

as live FFT magnitude and phase, Act on Delta, and signal dejitter. Advanced waveform calculations such as area and energy; a multitude of timing measurements, including rise and fall times, time between main and window triggers, and propagation delay; amplitude measurements, including gain and RMS; real-time integer and floating-point math operations; and live measurement and updating of waveform parameters are also part of the DSA 600 Series processing package. Table 1 lists the waveform processing capabilities of the DSA 600.

These capabilities make the DSA 600 Series Digitizing Signal Analyzers the ideal tools for experimental data collection and waveform characterization applications, prototype troubleshooting and debugging operations, general test and measurement applications, and troubleshooting of existing equipment.

Let's take a closer look at some of these advanced processing capabilities.

FFT (Fast Fourier Transform). If you need to examine the frequency spectrum of a waveform, TriStar's FFT function provides a means to transform time-domain acquisitions into the frequency domain for spectral analysis. Both the magnitude and phase of the acquired signal's frequency components can be examined, and measurement cursors can be used for basic magnitude and frequency measurements. Both time- and frequency-domain signals can be acquired single-shot.

The DSA 600 Series allows the user to select from six FFT windowing functions: Rectangular, Triangular, Hamming, Hanning, Blackman, and Blackman-Harris. The windowing function used depends upon what is to be accomplished in the frequency domain. The DSA 601 and DSA 602 automatically generate and apply the selected windowing function to the acquired time-domain signal. Noise floor is –60 dB and can be improved to –70 dB with averaging prior to the FFT.

Act on Delta. The Act on Delta function lets users automatically compare an acquired waveform against either a displayed or stored envelope waveform or template. It also initiates a user-defined action when an out of range event occurs. The user defines an event by specifying both the total number of points and the number of consecutive points which must fall outside the template. When an event occurs, acquisition stops and the DSA 600 Series automatically initiates any user-defined combination of the following five actions:

- Save screen as a stored waveform
- Sound chime
- SRQ over IEEE-488
- Hardcopy of screen
- Repeat

If repeat is selected, the mainframe

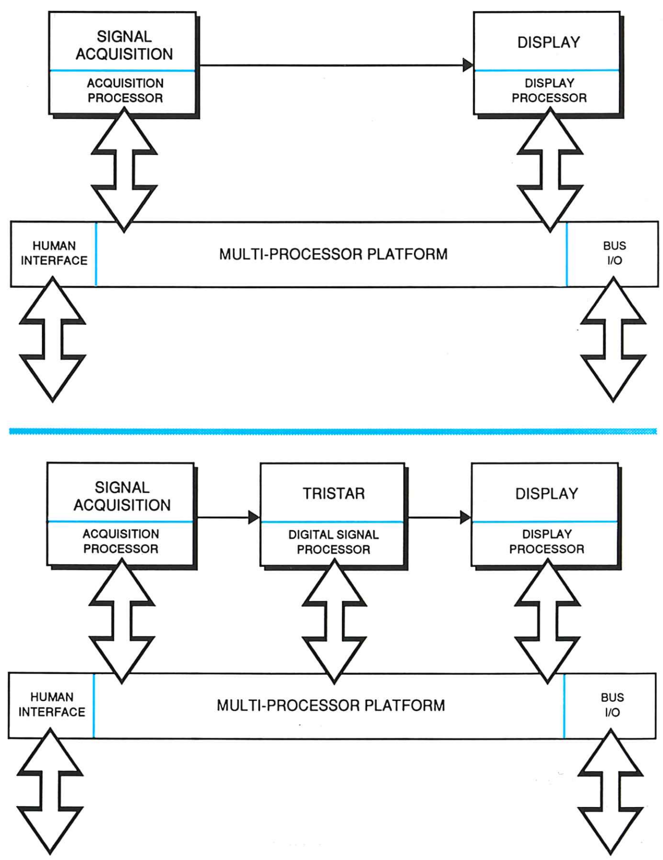

Figure 2. *The* Tektronix *11400 Series was the first instrument to use dedicated microprocessors for acquisition and display control (top). In the DSA 600 (bottom), TriStar is located in a direct pipeline between acquisition and display, providing "live" waveform measurement and analysis functions.*

repeats the other four actions when the out-of-bounds condition is met.

With the Act on Delta function, the instrument can effectively "stand guard", monitoring a circuit for unpredictable transients or anomalous events and recording them as they occur. This combination is perfect for digital design and debug, or manufacturing test pass/fail applications.

Dejitter. The dejitter function reduces the effect of time jitter in repetitive signals caused by a noisy input signal (see Figure 3). Dejitter is especially beneficial when used in conjunction with signal averaging. Because time jitter in a signal has the effect of rapidly changing the phase, averaging the signal normally smooths out what may be very important high-frequency components in a jittery display. This results in an inaccurate measurement.

With the dejitter function enabled, random noise due to an unstable trigger source is averaged out, but the high-frequency components are retained, resulting in a more accurate measurement.

Averaging and smoothing. Fast averaging and smoothing selectively remove noise from the display giving the user visibility into the true behavior of circuits and devices never before seen without extensive delayed signal processing. Averaging rates of up to 180 waveforms/second for repetitive integer waveforms and up to 90 waveforms/second for repetitive floating-point waveforms are possible. Single-shot acquisitions can be smoothed by the TriStar processor at up to 30 waveforms/second. This exceptional smoothing rate is particularly beneficial to the performance of integration and differentiation operations.

Math operations and functions. Integer waveforms, addition, subtraction, and negation operations are processed at a maximum rate of about 150 waveforms/second. All other math operations convert the integer waveform array to a floating-point array. All floating-point math operations, with the exception of averaging and enveloping, are processed at a maximum rate of about 30 waveforms/second.

Envelope acquisition. An envelope display is constructed by storing both the maximum and minimum values for each data point of the acquired waveform. This shows how a signal varies over time. The resulting envelope can be used as a template for the Act On Delta function. For integer arrays, envelope acquisition is possible at a maximum rate of about 140 waveforms/second. For floating-point arrays, the maximum rate is about 80 waveforms/second.

Interpolation. The interpolate function replaces null points (data points not yet acquired or defined) with the linear interpolation of the two nearest valid points, one from each side of the null point. TriStar enhances interpolation speed over the world's most advanced oscilloscopes by more than 30 times.

This increased speed is particularly noticeable in equivalent-time acquisitions with a very fast sweep speed, a low trigger repetition rate, or a long record length. Without interpolation the waveform record may fill very slowly. Using interpolation, the record between acquired points is filled rapidly until actual acquired values replace the interpolated values.

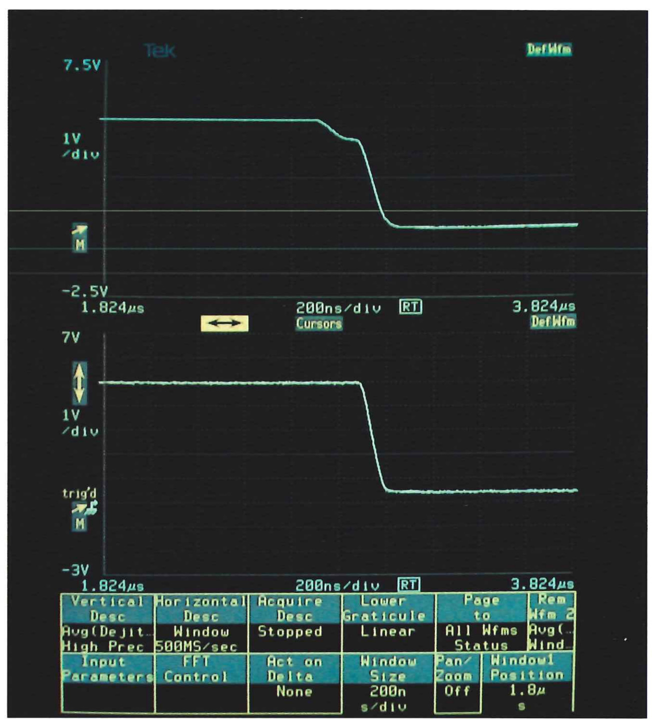

Figure 3. *With dejitter, averaging produces an accurate representation of the input as shown in the lower trace. The top trace shows a waveform being averaged. Because of time jitter, an aberration is introduced.*

Increased interpolation speed is also important for single-shot, real-time acquisitions when the time/division is set too fast to allow a complete record to fill. In this case, the DSA 600 interpolation function fills the points between valid data.

Digitizing at up to 2 gigasamples/second

The flexible architecture of the DSA 600 Series digitizing system makes it equally useful for high-speed real-time

Table 1

The DSA 600 Series Measurement and Analysis System

Arithmetic Operations	Addition, subtraction, multiplication, division.
Waveform Functions	Differentiation, integration, square root, logarithm (base 10 and natural log), exponentiation, absolute value, summation (signum), dejitter, smooth, average, interpolate, envelope.
Amplitude Measurements	Minimum value, maximum value, midpoint, mean, gain, peak-to-peak, RMS.
Timing Measurements	Risetime, falltime, period, frequency, width, delay, main to window trigger time, phase, propagation delay, cross.
Area and Energy	Area +, area –, energy, power.
FFT	Magnitude, phase; choice of six window functions.
Act on Delta	Save, chime, SRQ, hardcopy, repeat.

acquisition, or for precision equivalent-time sampling of repetitive signals.

The DSA 601 has two 8-bit, 500 megasamples/second digitizers. These digitizing "pipes" can be configured through instrument controls to allow simultaneous, 500 megasamples/second, single-shot acquisition from two channels; or, they can be interleaved in order to obtain a 1 gigasample/second sample rate from a single channel. Interleaving is a process in which the digitizers are internally linked such that the net sampling rate equals the sum of the rates of the individual digitizers.

The DSA 602 has four 8-bit digitizers, each capable of 500 megasamples/second simultaneous single-shot acquisition on four independent channels. With interleaving, you can achieve 1 gigasample/second on two channels, or 2 gigasamples/second on a single channel — that's two samples in less time than it takes light to travel across this page!!

With both the DSA 601 and the DSA 602, up to 12 channels can be acquired simultaneously for repetitive signals. Either real-time sampling or multipoint, random, equivalent-time sampling is internally selected, depending upon sweep speed, record length, and number of channels being acquired, to optimize acquisition accuracy.

Repetitive single-shot acquisition

In single-shot mode, the DSA 600 Series captures as many data points as possible from a single trigger event. The captured waveform is displayed on the CRT, the acquisition stops, and further trigger events are ignored until the instrument is re-armed. In single-shot mode, the user manually stores the waveform and re-arms the instrument.

With repetitive single-shot acquisition, the DSA 600 Series automatically captures, stores, labels, time/date stamps the waveform, re-arms the trigger, and then repeats the process up to 918 times, at a rate of up to 60 repetitions/second.

Automatic repetitive capture means that more waveforms can be captured in real-time faster than ever before, making the DSA 600 Series an ideal tool for single-shot applications in fields such as laser research, digital design, medical research, fiber-optic cable testing, and atmospheric testing (LIDAR), to name just a few.

Multiple windowing capability

Dual independent time bases allow acquisition of two window records for each main record acquired. (Main and window records are similar to main sweep and delayed sweep acquisitions in analog oscilloscopes.) Window records are not simply a close-up of a portion of the main record, but are separate acquisitions of defined portions of the main waveform with their own sample rate and record length settings.

Flexible triggering

The DSA 600 Series has highly sophisticated triggering capabilities which give the user unmatched flexibility for acquisition set-up to allow highly accurate timing measurements such as propagation delay and customized main to window determinations.

Each of the dual independent time bases has a separate dedicated trigger circuit which can derive a trigger source from any one of the plug-in compartments, or from the internal AC source. In addition, channels within a plug-in can be combined through addition or subtraction to define the trigger source.

Triggering capabilities are divided into two categories: Basic triggering and extended triggering. For basic trigger operation, one trigger is associated with the main record, and the other is associated with the window record(s).

In the more sophisticated extended trigger operation, trigger sources are compared to their trigger levels, or thresholds, and are determined to be either high- or low-logic levels. The user may then choose to combine the trigger sources using Boolean algebra, qualify one with a transition of the other (level-qualified triggering), qualify one or both by time (time-qualified triggering), or qualify one or both by an event count (event triggering) to form the main and window triggers. All of these extended trigger operations may be used alone or in combination for added flexibility in defining trigger events.

In addition, many of the DSA 600 Series features — e.g., extended triggering, Act On Delta function, and repetitive single-shot acquisition — can be combined to create a powerful tool for capturing selected events within complex signals, or for capturing anomalous events within repetitive signals.

Record length and memory

Record length is selectable from 512 to 32K points, with 256K points of memory available for waveform acquisition and storage of waveforms and settings. A memory enhancement option is available which provides more than 450K points of dedicated non-volatile memory for storage of waveforms and settings, leaving 256K points available for waveform acquisition. This allows the capture and storage of even the longest single-shot or repetitive events in all their detail, and enhances the instruments capacity to acquire and store long records from multiple channels.

Waveform labeling

The waveform labeling function provides a method to assign a unique name of up to 10 characters to each displayed or stored waveform and instrument setting. Once assigned, the label appears in all menus that contain a list of waveforms or settings. In addition, when a waveform is displayed, its label appears next to it, tracking the waveform as it moves.

When in the repetitive single-shot acquisition mode, the DSA 600 Series automatically assigns a unique label to each acquired waveform for ease of reference. The user can then use the stored waveform scan feature to "page" through a sequence of stored waveforms.

11000 Series plug-in compatibility

The DSA 600 Series is designed to be compatible with all 11000 Series plug-ins and associated probes. These accessories complement the DSA 600 Series, providing capabilities such as 1 GHz bandwidth with the 11A71 and 11A72, 12-channel signal acquisition with three 11A34s, true differential measurements with the 11A33, calibrated DC offset with fast overdrive recovery, unsurpassed accuracy, clean response, low noise, and automatic probe identification.

The human interface

The DSA 600 Series employs a menu-oriented color touch-screen interface as the primary means of instrument control (see Figure 4). The use of color simplifies the identification of superimposed waveforms, clearly distinguishes the selected waveform (the waveform on which measurements are being made), and highlights selectable options and functions.

The touch screen is supported by a minimum of front-panel pushbuttons and just two control knobs to provide an ingeniously simple way to set up and control the instrument's complex capabilities.

The touch-screen interface provides a menu format that allows the operator to set up for acquisition, measurement, and analysis in simple, logically connected steps. All information needed to completely configure the scope and perform detailed analysis of waveforms is available in the major or sub menus. However, a menu action is never more than two menus deep.

Full GPIB and RS-232-C programmability

The DSA 600 Series is equipped with both GPIB and RS-232-C ports. All controls and functions are fully programmable from a host computer or controller. All communication through the GPIB and RS-232-C ports uses the ASCII Command Set in compliance with the Tektronix GPIB Codes, Formats, Conventions, and Features Standard.

Software support

The DSA 600 Series is supported by several easy to use, menu-driven software packages:

- **11000 Series Utility Software** provides complete GPIB or RS-232-C control of the DSA 600 Series from an IBM PC or compatible. Waveform acquisition, measurements, and instrument settings can all be controlled from the PC function keys, and can be transferred between the PC, the DSA 600, and diskfiles.
- **i-Pattern Software** is available for telecommunications applications — specifically "eye diagram" analysis (see **A new method of viewing and extracting information from digital signals** in the Winter 1988/89 **HANDSHAKE**).
- **DSA 600 Driver for ASYST** links the powerful analysis capability of ASYST software with the high performance of the DSA 600 Series.
- **Tektronix Template/Waveform Processing Program** allows the creation or editing of waveform templates on an IBM PC or compatible for use with the Act on Delta function of the DSA 600 Series.
- **EZ-TEST PC** is an easy to use, cost-effective test procedure generator for users planning to incorporate the DSA 600 Series into GPIB-based test and measurement systems (see **Making test procedure generation quick and EZ!** in the Fall 1988 **HANDSHAKE**).

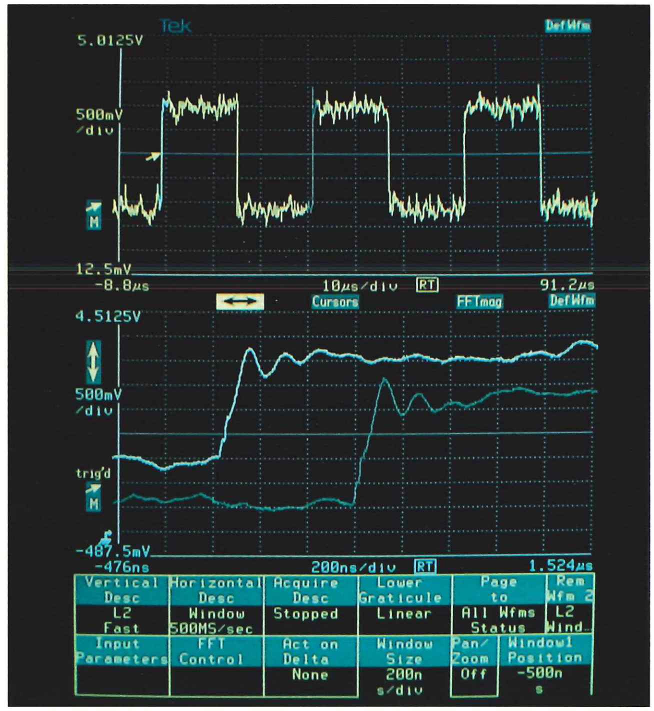

Figure 4. *Color display helps identify waveforms in the measurement display. Note that the windowed portions of the main waveform are highlighted with the colors of the corresponding window.*

For more information

This has only been an overview of the DSA 600 Series Digitizing Signal Analyzers. To get a complete picture of their capabilities, contact your local Tektronix field office or sales representative for a demonstration. U.S. customers can call the Tektronix National Marketing Center toll free for prices, additional information, or to order — 1-800-426-2200. And be sure to tell them that you read about the DSA 600 in **HANDSHAKE.**

Literature corner

The following technical briefs provide additional information on the topics and instruments discussed in this article. Copies are available from your local Tektronix Field Office or sales representative:

Act on Delta	47W-7431
Advanced Waveform Processing	47W-7432
ASCII Interface	47W-7439
Averaging	47W-7444
Color Display	47W-7434
Dejitter	47W-7429
FFT Spectral Estimation	47W-7435-1
Hardcopy Support	47W-7427
Interpolation	47W-7442
Labeling	47W-7438
Multi-Channel Concurrent Acquisition	47W-7441
Plug-ins and Probes	47W-7443
Repetitive Single Shot Acquisition	47W-7430
Scanning Stored Waveforms	47W-7426
Smoothing	47W-7436
Software Support	47W-7437
Triggering	47W-7428

Choosing test equipment to match your application

Sometimes the most difficult part of a measurement is choosing the right test equipment. Often, several measurement technologies can do the job, so you must make a choice that is best for your current measurement needs as well as future needs. Once you've chosen the appropriate technology, then you're faced with what can sometimes appear as a confusing array of features — again you must choose what is best for today's measurements as well as tomorrow's.

While we can't make those difficult choices for you, in this series of articles we would like to give you some decision criteria that will help you toward that right choice. Tektronix makes test equipment that covers a broad spectrum of measurements — logic analysis, spectrum analysis, as well as digital and analog waveform acquisition, processing, display, and storage.

Once you've read through these articles and would like to talk about specific instruments that would best fit your measurement needs, we invite you to call your local Tektronix Field Office or sales representative. Tektronix has field offices and sales representatives located in major cities around the world. For the name of the nearest Tektronix sales office, check your local phone book or call 1-800-835-9433.

Making an educated choice ...

A guide to selecting the appropriate oscilloscope technology for your application

The selection process

With the array of oscilloscope technologies, feature sets, specifications, and costs available today, choosing the right scope for your application can be a confusing experience. In this article, we'd like to outline the oscilloscope selection process, independent of any specific product or application. Then, with these guidelines, you'll know what to look for when faced with that difficult choice.

Each type of signal imposes a different set of requirements for optimal signal capture. Therefore, the first and most critical step of the selection process is to clearly describe and understand the characteristics of your signal. Only then can you look at scope technologies in terms of what you need and what you don't need. Giving up what you don't need and keeping what you do is the key to making the appropriate scope selection.

Once you've identified the right technology, you can then evaluate the various feature sets of the qualifying scopes.

Characterizing your signal

Repetition rate. The first thing to determine about the signal you're interested in is its repetition rate. Is it a one-time, single-shot event, like lightning, or ESD? Or, is it low rep rate, like laser pulses? Or, is it a highly repetitive signal, such as a carrier signal, a digital clock signal, or a repeating sequence of events?

When you're dealing with repetitive signals, be careful not to assume that there's no other information present. Your repetitive signal could be a mixture of a periodic component and low-rep rate aberrations — such as glitches, metastability, power-supply coupling, or cross talk.

Bandwidth. After repetition rate, consider your bandwidth requirements. To do this you need to know the bandwidth or risetime of the highest frequency component of your signal, whether it's continuous, periodic, low rep-rate pulsing, or a one-time glitch.

You can specify either bandwidth or risetime because (assuming a Gaussian response) there's a mathematical relationship between these terms:

$$\text{Bandwidth} = 0.35 / \text{risetime}$$

For example, a risetime of 700 picoseconds equals a bandwidth of about 500 MHz.

Remember, you must consider the entire system bandwidth — scope, probe, and circuit-under-test. Bandwidths combine for a total bandwidth equal to the square root of the sum of the squares. Also, the signal is attenuated by as much as 30% at the bandwidth limit. A rule of thumb is to specify a system bandwidth 3 to 5 times higher than the highest frequency to be measured.

Vertical requirements. Next, characterize your signal in terms of its vertical requirements. What is its dynamic range, i.e., the largest voltage swing you need to view? Zero to 50 volts? Or just zero to five volts? Or microvolts?

What about vertical resolution? What's the smallest increment of voltage you need to discern? And don't forget DC offset. How far is your signal from ground?

Horizontal requirements. When considering horizontal resolution requirements you'll want to know the largest time window you need to view, and the smallest increment of time you need to view it in. This is the timing resolution you'll need.

Record length is an important horizontal specification for digital oscilloscopes. It can be expressed as:

$$\text{Record Length} = \frac{\text{Time Window}}{\text{Time Resolution}}$$

For example, if you need a 10 microsecond time window and 500 picoseconds of resolution, 20,000 points would be required to accurately describe your signal. Therefore the record length would have to be 20K.

Another important consideration is the amount of your signal you want displayed prior to the trigger event. This is called pretrigger viewing. Different technologies feature varying degrees of pretrigger flexibility.

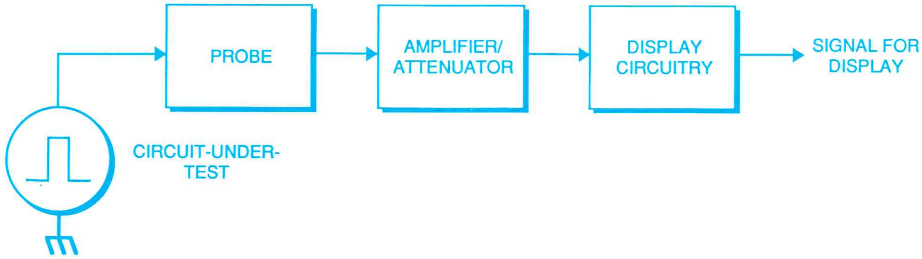

Figure 1. *Probing and signal conditioning are critical in acquiring accurate data, regardless of whether an analog or digital scope is being used. The displayed signal is a result of the interaction between the circuit-under-test, the probe, the amplifier/attenuator, and the display circuitry.*

Storage requirements. Finally, consider your storage requirements. Do you just need to view the data, as is often the case with repetitive signals? Do you need to hold the trace on-screen, which is often true of single shot and low rep-rate events? Or do you need to capture the data in digital form for measurement, waveform processing, or hard copy output?

Once you know these things — repetition rate, bandwidth, vertical and horizontal requirements, and your storage requirements — it's easy to evaluate different oscilloscope technologies in terms of the advantages and limitations each will bring to your particular job.

First things first

The first point in choosing any acquisition system is to consider its "front end" components — probing and signal conditioning (see Figure 1). In order to acquire accurate data, you must not overlook these components.

Probing. Never underestimate the importance of probing. When a probe touches a circuit it becomes a part of that circuit, and the effects of its loading capacitance and resistance must be taken into account.

Using a probe that is not designed to meet the requirements of your application can erode signal fidelity at the probe tip, and negate your investment in high performance signal acquisition instrumentation.

Signal conditioning. Virtually every scope, digital or analog, includes amplifiers or attenuators that condition the signal before it actually reaches the acquisition, display, and storage subsystems. If the signal conditioning functions of your scope are second rate, nothing you do down the line can compensate for it.

Keeping these basic concepts in mind, we're ready to look a little deeper into the selection process. Here, we need to choose between the two major technologies — analog and digital.

Analog

In the basic analog scope, the input is split between the signal path and the trigger path (Figure 2). A delay line is added to the signal path to permit viewing of the triggering event. This allows the sweep of the beam to start across the display before arrival of the triggering event for display.

Analog scopes provide particularly fast update rates because only a beam retrace and trigger rearm are required between sweeps. This happens thousands of times faster than transferring data into and out of memory, as required by other technologies. As a result, the analog scope is an excellent choice for capturing all types of signals that contain both continuous and low rep-rate components.

The basic analog scope, however, provides no facility for waveform storage. And, at the fast sweep speeds required to capture single-shot events, the displayed waveform becomes dim or even invisible. This is because there may not be enough beam energy in one sweep to illuminate the screen phosphor. To address these limitations CRT storage and transient intensifying technologies were developed.

CRT storage. CRT storage oscilloscopes have the ability to store events on the face of the screen itself. And, because the writing rate is faster than with basic analog, CRT storage is ideal for capturing fast transient events. It's an excellent choice for viewing slowly changing signals, too.

CRT storage, however, does not digitize the signal. In addition, the update rate in storage mode is slower than basic analog. And the CRT storage display isn't as crisp as some other choices.

Transient intensifying. Transient intensifying oscilloscopes use another technology that was developed to answer the need for low-rep rate and single-shot capture — the microchannel plate (MCP) display. Because of the bright trace provided, these scopes are known as "BrightEye".

The addition of a microchannel plate behind the CRT phosphor intensifies dim portions of a waveform over a thousand times (see Figure 3). Electrons are multiplied as they pass through micro-

(cont'd on page 11)

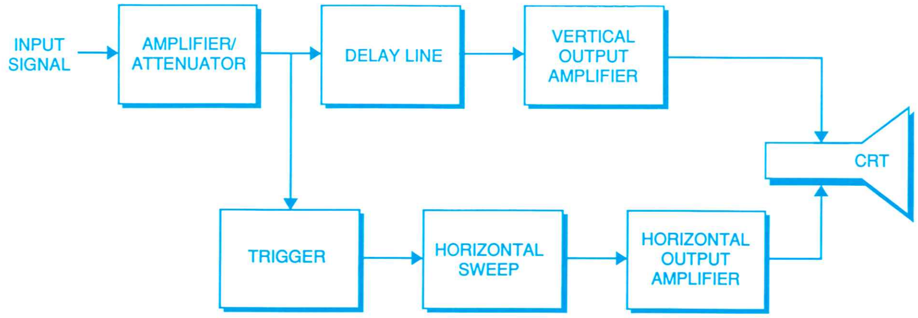

Figure 2. *Basic analog scope block diagram. Other scope technologies "build" upon this basic configuration.*

VOL 1 NO 2, SUMMER 1989

TEK NEW PRODUCT UPDATE

TEST AND MEASUREMENT PRODUCTS FROM TEKTRONIX

PRISM 3000 Series Logic Analysis System

Providing system designers and integrators with tightly integrated:

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- **Timing analysis**
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- **Digital waveform analysis**
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Price — Starting at $8,600 (U.S.)

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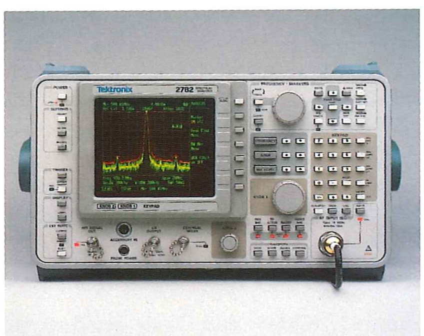
Digital system designers can now quickly focus on system integration problems and solutions with a single analysis tool — the Tektronix PRISM 3000 Series.

Whatever the system analysis task — software/firmware debug or optimization, hardware/software integration, timing analysis, or digital waveform analysis — the PRISM 3000 Series offers a tightly integrated set of application-focused solutions. With a single module, designers can control, observe, and trace software/hardware interactions in 8-, 16-, or 32-bit systems. State, timing, or microprocessor control can be viewed individually, or combined into a single, integrated display for comparison and analysis.

Displays are completely time correlated. System control and analysis functions are all seen in their actual timing relationships. Such capabilities are only possible through tightly integrated probing, data capture, time stamping, and analysis under a single master clock. This tight integration also allows modular expansion of capabilities for multi-processor system analysis and other applications.

2782 Spectrum Analyzer



- **Coaxial frequency range of 100 Hz to 33 GHz**
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- **Rugged, portable package**

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The Tektronix 2782 Microwave Spectrum Analyzer sets new performance standards of measurement with wider frequency range, higher accuracy, and many new and advanced features. All of this is provided in a rugged, portable package.

Instrument and measurement setup is through a combination of dedicated function keys, on-screen menus, and assignable function knobs. Often-used operations are permanently assigned to convenient front-panel knobs. Less-used or optional functions are readily accessible through on-screen menus.

Multiple waveforms — both analog and digital — can be displayed simultaneously. A color display, based upon liquid-crystal color-shutter technology, allows quick and simple interpretation of complex measurement displays.

The 2782 is fully programmable for ATE applications. Two GPIB interfaces allow the 2782 to be controlled by an ATE host as well as act as a secondary controller for other instruments.

Supplement to **HANDSHAKE** — Test and Measurement Newsletter from Tektronix, Inc. Produced by the HANDSHAKE Group, Tektronix, Inc., Group 157 (M/S 94-150), Box 4600, Beaverton, OR 97076, (800)835-9433, Ext 157.

For additional information on products and services listed in this edition of the New Product Update, use the reply card in the accompanying issue of **HANDSHAKE** or call your local Tektronix field office or sales representative. Tektronix has field offices or sales representatives located in major cities around the world. For the location of the nearest Tektronix sales office, check your local phone book or call (503)627-7111.

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COMMITTED TO EXCELLENCE

PEP 201 Instrument Controller

Price — $3,995 (U.S.)

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- **1 Mbyte of RAM, 120-nanosecond, single-wait-state**
- **20 Mbyte hard disk, 70-millisecond access time**
- **720 Kbyte 3.5-inch floppy disk**
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- **640 x 480 EGA graphics**
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- **Free GURU II Software Subscription (first year)**
- **Standard software**
  - **Tektronix GURU II**
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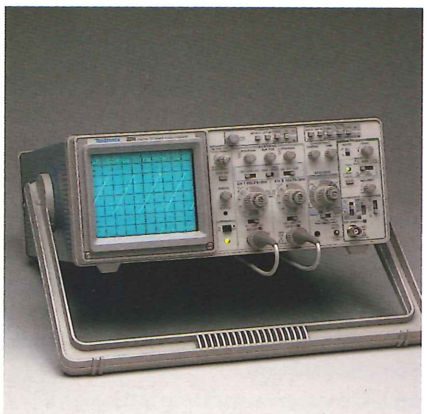
The Tektronix PEP 201 Instrument Controller with its 12 MHz Intel™ 80286 processor takes its place along side the PEP 301, 16 MHz and the PEP 303, 20 MHz Intel 80386 processors. Overall, the PEP 201 provides the low cost answer to your automated test equipment (ATE) and instrumentation control requirements.

First, there's the advantage of factory integrated instrument interfaces and control software in an IBM PC™ MS-DOS™ compatible environment. All ATE and instrumentation control software is pre-installed and configured on the hard disk for your convenience.

Then, there's the security of Tektronix support. All PEP-family controllers include the security of Tektronix worldwide support. Up to four hours assistance with a Tektronix-trained Applications Engineer means you are up and running quickly. The Tektronix 800-hotline support keeps you up and running. All this and the added security of the Tektronix one-year warranty too! ATE and instrumentation software doesn't come any better!

2211 Digital Storage Oscilloscope



Price — $2,395 (U.S.)

To order, or for information, call 1-800-426-2200

- **50 MHz Bandwidth**
- **20 Megasamples/second sampling rate**
- **8-bit vertical resolution**
- **4K record length/channel**
- **Dual channel digitizers**
- **Simultaneous store and non-store mode cursors**
- **CRT readout**
- **Delta voltage, delta time, and 1/delta time measurements**
- **Trigger-level voltage readout**
- **RS-232-C Interface**
- **Supports HPGL™ compatible printers and plotters**

The Tektronix 2211 Digital Storage Oscilloscope provides advanced features with both digital and analog capabilities. This is the ideal product for applications that require digital storage and documentation of physical measurements.

The 2211 offers 50 MHz bandwidth and 20 megasamples/second sampling rate per channel. Dual digitizers simultaneously acquire each channel, allowing very accurate timing measurements between channels. The 4K record length per channel provides a high-resolution display, or X50 magnified view.

On-screen waveform cursors ensure accurate and repeatable measurements of delta voltage, delta time, and 1/delta time in store mode. The voltage level of the trigger and readout of scale factors are displayed on screen to allow precise setting of the trigger point and quick reference.

An RS-232-C interface allows output to an HPGL™ compatible plotter or printer. Waveforms can also be downloaded to a host controller for analysis or archiving.

LTS2000 Laser Diode Test System

Price — $11,800 (U.S.)
Requires PEP 301 or equivalent

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- **Automatic 3-D and 2-D plots**
- **Test at up to 250 milliamps forward current**
- **Tests 850 to 1550 nanometer wavelengths**
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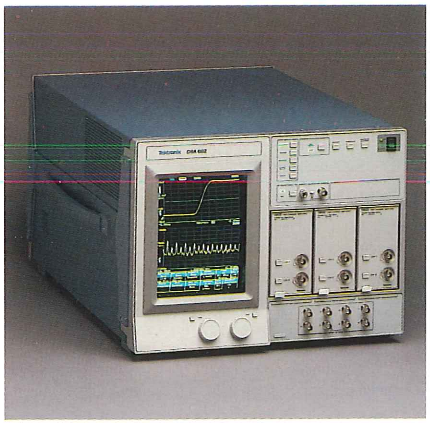
- **User programmable**
- **Test parameters and techniques comply with Bellcore Technical Advisory TA-TSY-000469**
- **Data logging to disk**
- **Optional printer/plotter for permanent records**

The Tektronix LTS2000 Laser Diode Test System automates laser diode testing and characterization. This integrated, low-cost system allows manufacturers and users to automatically perform laser diode measurements and simultaneously compare current and light at multiple temperatures on a single 3-D Shmoo plot. Up to three measurement parameters (e.g., light output, forward current, and temperature) can be compared in a single 3-D Shmoo plot. Similar analysis with 2-D plots requires one plot for each temperature — a more complicated and time consuming process.

Measurement data is organized by the system into data-logging arrays including forward current, light power, temperature, monitor current, dark current, thermal electric cooler power and voltage, or user-specified parameters. These arrays can be used in any combination for 2-D or 3-D plots, linked to a central database, or used to perform pre- and post-burn-in comparisons.

The C-based operating software can be customized to fit the user's test needs.

DSA 600 Series Digitizing Signal Analyzers



Price — $21,025 (U.S.) (DSA 601)
$27,125 (U.S.) (DSA 602)

To order, or for information, call 1-800-426-2200

- **2 Gigasamples/second (DSA 602)**
- **1 Gigasamples/second (DSA 601)**
- **1 GHz bandwidth**
- **Live FFT magnitude and phase displays**
- **Simultaneous acquisition of up to four signals**
- **Waveform record lengths from 512 to 32K points**
- **Extended triggering functions**
- **High-resolution color display**
- **Touch-screen human interface**
- **Accepts Tektronix 11000 Series plug-ins**
- **Hardcopy output**
- **Fully programmable via GPIB and RS-232-C**

The Tektronix DSA 600 Series Digitizing Signal Analyzers are the ideal instruments for those complex signal acquisition and processing applications. Featuring built-in waveform processing routines — including FFT, Act on Delta, dejitter, averaging and smoothing, interpolation, integer and floating-point math, and more — the DSA 600 Series can perform "live" waveform processing simultaneous with signal acquisition and without an external controller.

The 2 Gigasamples/second sample rate, 1 GHz bandwidth, and 8 bit vertical resolution makes the DSA 602 the ideal tool for laser or high-energy research. The versatile triggering capabilities of the DSA 600 Series provide the support needed for debugging complex digital designs. The 1 GHz bandwidth, the time-qualified trigger, and the long record lengths of the DSA 600 are useful for looking at extended bit patterns in high-speed data communications. Complete programmability over the RS-232-C and GPIB interfaces, Act on Delta, and qualified triggering are ideal for manufacturing test applications.

LV 500 ASIC Verification System

Price — $55,000 (U.S.)

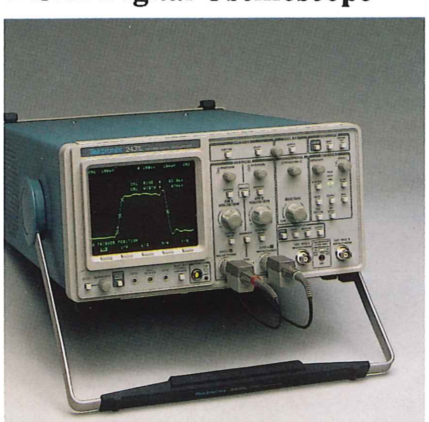
- **Benchtop ASIC verification to 50 MHz**
- **Turnkey simulation-to-test conversions**
- **Color graphics vector editing**
- **Up to 256 I/O channels with 16 clocks (32 programmable edges)**
- **Per-cycle/per-pin programmable**
- **500-picosecond timing resolution**
- **64K-deep pattern memory**
- **Two programmable DUT supplies**
- **Real-time compare**
- **Schmoo plotting**

ASIC designers can quit dreading prototype device verification. Test and debug have become quicker, simpler, and benchtop-convenient with the Tektronix LV 500 ASIC Verification System.

The LV 500's affordability means design teams can now have their own test resource. Simple, yet powerful capabilities mean quicker verification of complex devices. For example, there's direct downloading and conversion of simulation files to test vectors. Vectors can be easily edited or generated in simple spreadsheet and template formats with no test language to learn.

Yet, for all its simplicity and small size, the LV 500 offers many big system capabilities. There's up to 256 I/O channels with up to 16 clocks and multiple data formats. Per-pin and per-cycle programmability provide further test flexibility and power. while giving the designer debug control, for example, to break out individual bus pins and time them differently. Plus there's Schmoo plotting to characterize device operating regions over timing, voltage, or current variables — all in a truly benchtop package.

2431L Digital Oscilloscope



Price — $7,250 (U.S.)

To order, or for information, call 1-800-426-2200

- **250 megasamples/second digitizing rate**
- **300 MHz bandwidth**
- **8 bits vertical resolution**
- **Automatic set-up and measurement**
- **Auto pass/fail waveform testing**
- **Full GPIB programmability**

The Tektronix 2431L Digital Oscilloscope is the newest member of Tektronix' industry standard 2400 Series of portable oscilloscopes. It offers the built-in automation features that Tektronix has pioneered to help users make faster, more accurate, and repeatable measurements. With its high sampling rate and full 8 bits of vertical resolution (11 bits with greater than 8 averages), the 2431L delivers extremely accurate results, even on complex signals. The 2431L is a streamlined instrument suited for large and small test systems and as a general purpose stand-alone instrument.

The 2431L is available for immediate ordering with six-week delivery.

2622 Personal Fourier Analyzer

Price — $7,950 (U.S.)

To order, or for information, call 1-800-234-1256

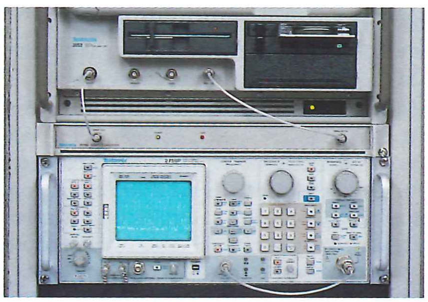
- **20 kHz input bandwidth**
- **6 milliHertz resolution**
- **28 millisecond FFTs**
- **5 kHz realtime bandwidth**
- **75 dB dynamic range**
- **12 pounds (5.5 kilograms)**
- **Easy-to-learn user interface**
- **Standard analysis operations include: power spectra, transfer function, coherence, impulse response, correlation, and orbit (X-Y) displays**
- **Optional software available for additional analysis**

The Tektronix 2622 Personal Fourier Analyzer provides extensive analysis of analog signals up to 20 kHz. The 2622 uses a PC as a smart terminal, providing high-quality color graphics, keyboard, and mass storage. Combined with the 2622's two channels of precision acquisition hardware and dedicated signal processors, the PC becomes part of a high-quality measurement system.

The 2622 includes turn-key spectrum, frequency response (network), and waveform analysis. Optional software provides additional analysis capabilities such as production test automation, system identification, realtime third-octave analysis, spectral maps, and a waveform math calculator for nearly limitless data manipulation.

At just 12 pounds (5.5 kg), the 2622 can be combined with a laptop computer to provide a complete signal analysis system weighing less than 29 pounds.

RF160 Down Converter



Price — $9,950 (U.S.)

- **Extends range of 3052 Digital Spectrum Analyzer to RF and microwave frequencies**
- **Enables modulation analysis to 21 GHz in coax**
- **Enables modulation analysis to 325 GHz using waveguide mixers**
- **Low profile package conserves valuable rack space**

The Tektronix RF160 Down Converter accepts standard IF frequencies from popular receivers and Tektronix RF and microwave spectrum analyzers and converts them to signals appropriate for the Tektronix 3052 Digital Spectrum Analyzer. This allows the powerful modulation measurement capabilities of the 3052 to be extended into RF and microwave areas. Some of these areas include difficult satellite downlink measurements, wideband spur searches on radar systems, RF signal monitoring and analysis, and manufacturing ATE.

The RF 160 is designed to occupy a minimum of space and can be mounted in an equipment rack along with the 3052 and associated microwave and RF equipment.

NEW SOFTWARE

- **TekWAVES Software**

Tektronix TekWAVES Software provides a software link between ASIC design and test. It features graphical stimulus editing coupled with file conversion for all popular CAE simulators and automatic test program generation for the Tektronix LV 500 ASIC Verification System.

Price — $5,000 (U.S.)

- **TeleServicing Support Software (S41TSS1)**

Tektronix TeleServicing Support Software incorporates three teleservicing functions in one package — data communication, data management, and waveform graphics. It is designed for use with the Tektronix 2230 Digital Storage Oscilloscope, Hayes™-compatible modems, and IBM™ personal computer (XT™/AT™ or compatible). Provides dialing directory for modem parameters and automatic dialing of telephone numbers. Captured waveforms can be sent to and retrieved from a remote site, displayed and annotated on the PC, and stored to disk for later use.

Price — $295 (U.S.)

- **ASYSTANT™ GPIB Software**

ASYSTANT GPIB provides the scientific user with a menu-driven seamless environment for GPIB data acquisition, statistics, numerical analysis, and modeling, along with broad graphical presentation capabilities. It is a complementary package to ASYST™.

Price — $695 (U.S.)

- **LabWindows® GPIB Software**

LabWindows is an interactive programming environment for GPIB acquisition, analysis, and graphics. A function-panel interface and an instrument library containing modules for many popular GPIB instruments make this a very powerful development environment.

Price — $595 (U.S.) (Standard Software)
$895 (U.S.) (Advanced Analysis Library)

NEW ACCESSORIES

- **TMP9600 Microwave Probe**

The Tektronix TMP9600 Microwave Probe provides a frequency range from DC to 40 GHz, return loss greater than 10 dB, and insertion loss less than 2.5 dB at 40 GHz. Each probe is equipped with a female K connector; a female OS-50 connector is optional.

Price — $979 (U.S.)

- **Peltola™ RF Interconnect System**

The Tektronix Peltola™ RF Interconnect system offers equipment manufacturers a proven, reliable, cost-effective solution for cable to circuit board connections. It's available in either 50- or 75-ohm impedance options. Peltola systems use a proprietary, solderless method to achieve excellent electrical connections for RF signals up to the 1-2 Gigahertz range. This RF cable/connector system may be used internally in a variety of electronic equipment to link circuit boards to other circuit boards or to the back side of a panel.

Price — Varies with length and quantity.

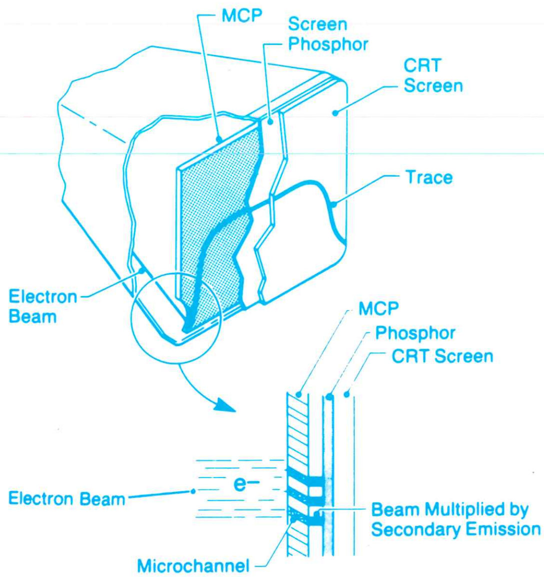


Figure 3. *Electrons are multiplied and accelerated as they pass through the microchannel plate, dramatically increasing the writing rate of BrightEye analog scopes.*

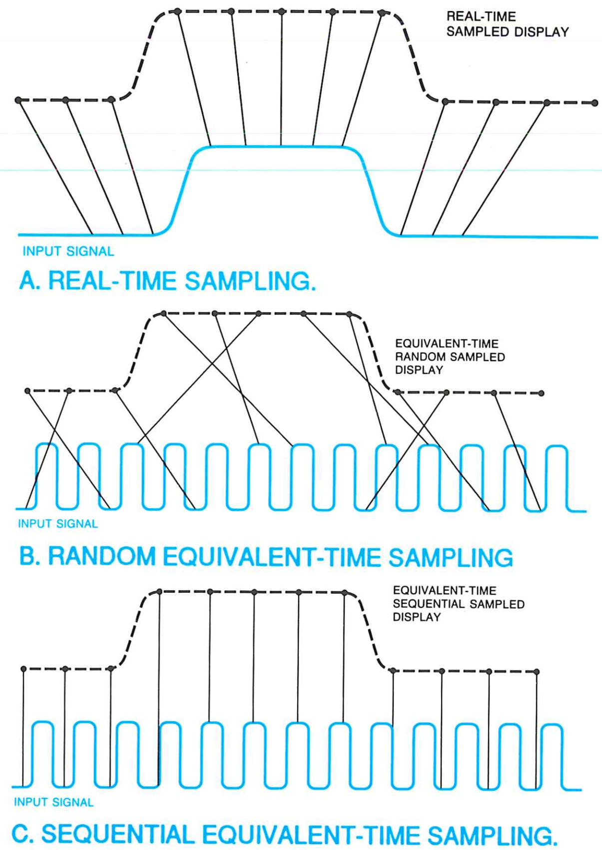


Figure 4. *Comparison between real-time sampling (A), random equivalent-time sampling (B), and sequential equivalent-time sampling (C).*

channels, or holes, in this plate and are accelerated onto the phosphor. This dramatically enhances the writing rate.

And because the channels may also saturate under high beam-current conditions, BrightEye multiplies a few electrons much more than it multiplies many electrons. This is called adaptive intensity.

BrightEye analog scopes are superb for viewing all signal types at all sweep speeds and at all rep rates. You get the fast update rate of basic analog and the highest writing rate available. Single-shot events can be captured up to the scope's bandwidth on an extremely sharp display.

There's really only one major limitation of the BrightEye analog scope — its lack of digital waveform storage. This limitation can be answered with scan conversion technology.

Scan conversion. One implementation of scan conversion is the CCD-based digitizing camera, which mounts on the front of an analog scope. A signal can be written very fast on a BrightEye CRT, and then scanned and digitized by the CCD camera at a much slower rate.

You get very high vertical resolution, high oversampling, plus the automatic measurements, waveform processing and hard copy features made possible with digital storage.

The tradeoffs that come with scan conversion are limited record lengths — normally less than 1000 points — and a slower update rate than analog, due to digitizing and transferring data.

The key components of scan conversion form the basis of another class of instruments known as the digital storage oscilloscope (DSO).

Digital

The two basic classes of digital storage oscilloscopes, real time and random equivalent time, are distinguished by the digital sampling process they use.

Real-time digital storage oscilloscopes. In real-time DSOs, the digitizer samples the entire input waveform in one pass — with a single trigger. Acquisition and display occur in the same time frame (see Figure 4A).

This makes real-time DSOs ideal for single-shot applications — as long as the Nyquist sampling criteria is obeyed. This criteria states that you must sample at greater than twice the rate of the highest frequency component of your signal or aliasing (false, lower repetition rate signals) can occur.

If you're dealing with very fast, single-shot signals, you need an extremely high sampling rate. However, you can get around this high sample rate requirement if you're dealing with repetitive signals. The technique used to capture repetitive signals with a DSO is called equivalent-time sampling.

Random equivalent-time DSOs. Equivalent-time sampling takes advantage of the nature of a truly repetitive signal, which gives you a virtually limitless number of identical repetitions that can be sampled. In random equivalent time, a few samples are taken for each trigger, over a large number of triggered events. The samples are random with respect to the trigger — hence the term "random" equivalent time — but equally spaced for any given pass (see Figure 4B).

Sampling occurs on both sides of the trigger point. The trigger doesn't initiate the sampling — it only determines proper placement of the sample point within the waveform record, so you have very flexible pretrigger capability. Random equivalent-time digitizers offer excellent timing resolution because sample intervals can be made very small.

Both real-time and equivalent-time DSOs offer flexible pretrigger, long record lengths, and all the advantages of digital storage. However, both also have limitations.

Inputs that are a mix of high-rep and low-rep signals can pose problems for DSOs due to inherent update rate limitations. And, if you undersample any signal, you'll run into aliasing problems. Single-pass sampling also limits the time resolution of the real-time digitizer.

With random equivalent-time sampling you trade high-speed single-shot capture for higher accuracy. Aliasing is possible. And, the update rate is dependent upon rep rate, sweep speed, and architecture so responsiveness can vary widely among scopes.

Even though equivalent-time sampling seems to solve sample rate limitations of real-time DSOs, why can't we digitize any repetitive signal, regardless of it's frequency? There are two reasons: 1) The front end signal conditioning components — the attenuators and amplifiers — are bandwidth limited; and, 2) When dealing with very high-frequency signals, greater time resolution is required, more than random equivalent-time sampling allows.

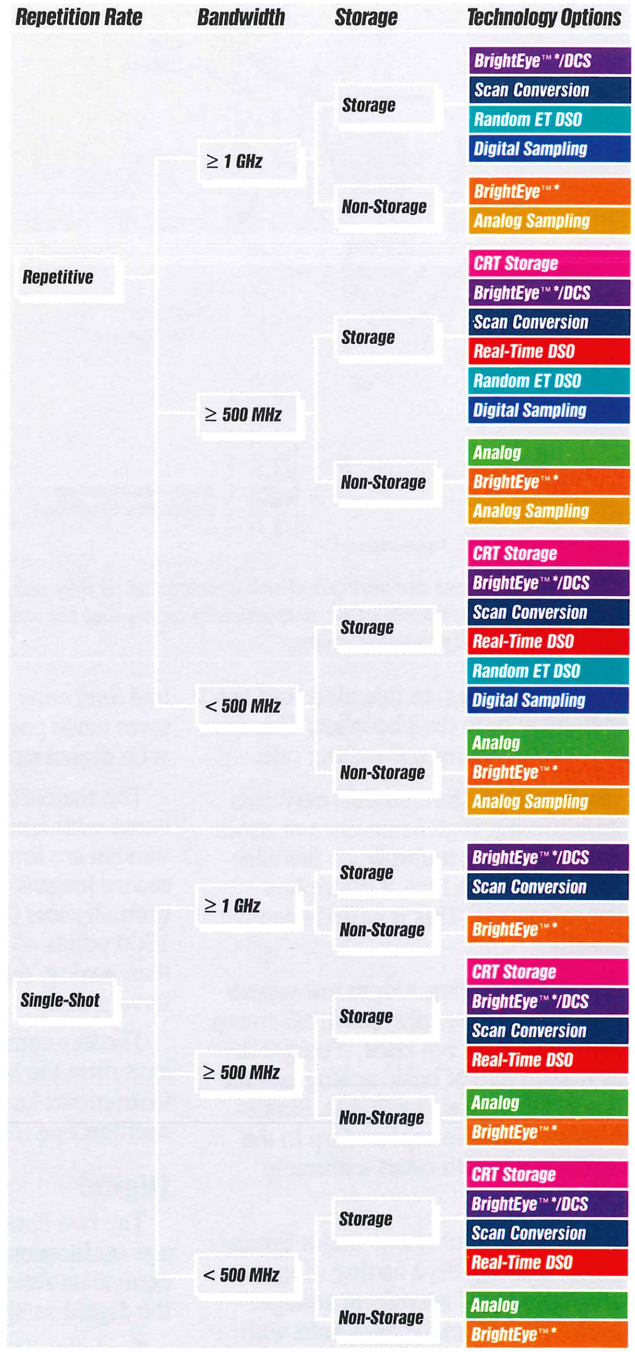
So methods were developed to solve both problems. Signal conditioning is eliminated and the input is fed directly to the equivalent time sampler. With this modification, extremely high bandwidths are possible. To allow for better time resolution, sequential equivalent-time sampling is used.

Sequential equivalent-time sampling. As with random equivalent-time, a repetitive signal is required for sequential sampling. The difference is that only one sample is acquired for each trigger — at some constant delay after the trigger (see Figure 4C). For each subsequent sample, the trigger-to-sample interval is increased by a fixed time. This fixed time interval can be made as small as femtoseconds, providing phenomenal timing resolution.

Analog sequential samplers simply amplify the voltage after sampling, and then display it on a CRT. Digital sampling oscilloscopes employ the same sampling technique at the front end, but add an analog-to-digital converter, digital memory, and microprocessor control before the display.

The benefits of sequential equivalent-time scopes are high vertical resolution, extremely tight timing resolution, and high bandwidth sampling — which makes them ideal for such applications as time domain reflectometry (TDR).

The tradeoffs are that you lose dynamic range and input protection — the signal input is limited to a few volts and is sensitive to static damage. No pretrigger information is available since all samples are taken after the trigger point (unless a delay line is added). However, pretrigger may not be an issue, when dealing with repetitive signals.



*Transient Intensifying Oscilloscope based on MicroChannel Plate CRT

Figure 5. *Selecting the right scope for your needs begins with characterizing your signal and then selecting the technology appropriate to your measurement needs.*

Summary

As you can see, each scope technology offers specific benefits and limitations. With this knowledge along with an understanding of your signal characteristics, you can make an educated choice of the oscilloscope that best fits your application. Figure 5 summarizes the benefits and limitations of each technology, as we've discussed here, and can help to guide you to the right technology for your measurement needs. For a copy of a printed selection guide or a video tape to aid in the selection of an oscilloscope, check the appropriate box on the reply card.

Making an educated choice ...

A guide to matching logic analysis capabilities to your application

The selection process

The decade of the '80s has seen phenomenal growth and expansion of digital system techniques and applications. Today, even traditional analog applications typically rely on some underlying digital technology for greater economy or breadth of capability. As a result, virtually anyone involved in designing, manufacturing, or servicing electronic equipment is going to be faced with selecting and using some type of logic analysis system.

The question is: What logic analysis system should you choose for your particular needs?

To begin to answer this question, you need to first consider some basic acquisition requirements. How fast is the data? What's the data width (number of channels) that you need to view? And how much data do you need to see (memory depth) on each channel?

However, data speed, width, and depth are only the beginning issues. How the data is analyzed and formatted for viewing are equally important. Making decisions here depends largely upon your specific application needs. For example, do you just need to look at bus activity? Or are you concerned with hardware and software integration in a microprocessor-based system? Depending upon your application, you may be able to use a general-purpose logic analyzer or you may require a more comprehensive logic analysis system.

Acquisition considerations

Whatever your application, a logic analysis system must provide accurate acquisition and representation of the data. This begins with high-fidelity, minimum-load probing that maintains timing relationships across all channels. Additionally, the probing must be easy and convenient to use, even as channel counts rise.

After probe quality and convenience, you also need to review your acquisition needs in terms of the following general analyzer capabilities.

Channel counts. The basic consideration for analyzer channel count is the number of microprocessor bus lines and timing channels that you need to view simultaneously. In short, how much of the system do you want to see?

Typically you won't need as many high-speed timing channels as state channels for looking at a full bus. But be sure to consider future needs as well as today's needs. As digital system complexities increase, can you modularly expand your analysis capabilities to keep pace?

Sampling speed. The basic speed criteria are the clocking and data rates of the system-under-test. For synchronous sampling, the analyzer speed must at least match the data rate of the system-under-test. However, it's wise to have some margin for future higher speed systems.

For asynchronous sampling, you need to consider the desired typical resolution for timing measurements. As a rule, asynchronous sampling speed needs to be at least four times the fastest signal being observed (i.e., four samples over the signal cycle).

Memory depth. Memory depth determines the amount of logic activity that you can capture and store for analysis, observation, and comparison. The key issue is distance between logic problems and symptoms. As logic system complexity increases, analysis memory depth needs to increase also.

Some analyzers offer increased memory depth, but at the expense of channel count. Be sure that your analyzer selection supports adequate memory depth for today's channel counts as well as future channel expansion.

Triggering. True acquisition power resides here, in the analyzer's ability to selectively trigger data storage on desired states or events. With a single word recognizer, you can trigger on one set of states. With multiple word recognizers, multiple levels of IF-THEN-ELSE qualifications, counter/timers, range recognizers, and glitch detection, your triggering power and flexibility multiplies. Extensive fault triggering allows you to trigger and view data when your system encounters a hardware or software fault. This capability makes the difference between just looking at a "haystack" of data or letting the logic analyzer find the one "needle" in that haystack.

Other considerations. Depending upon your application, there may be other equally important acquisition considerations. For example, if you need to do high-speed, high-resolution timing analysis, will the analyzer support a high-speed timing module, and how fast is that module?

Also, with the number of microprocessor-based designs today, some sort of microprocessor support is almost an absolute necessity for today's logic analyzers. The degree of this support is highly application dependent.

Microprocessor application support

Key application areas requiring special microprocessor support considerations include the following:

- Hardware test and debug
- Software/firmware debug, verification, and optimization
- Hardware/software integration, verification, and optimization

For many microprocessor applications, an inexpensive microprocessor disassembly probe may be just the solution. It's an even better solution when the logic analyzer provides correlated disassembly and timing displays.

When software/firmware debug is the focus, a higher-level view of microprocessor activity is needed. Examples would be tracking program flow symbolically through levels of subroutine hierarchy or tracking actual control flow within individual routines. Along with this, a debug monitor or emulator might be used to add processor control and direct access to registers and memory.

Another effective alternative is provided by the PRISM 3000 Series. These new analyzers add microprocessor control and real time performance analysis to microprocessor analysis and timing analysis — all tightly integrated into a logic analyzer environment with automatic time-correlated displays.

Performance analysis is particularly important for verifying and optimizing software. It serves this need by showing graphical summaries of regions of program activity or various execution times of software routines.

Integrating software into the target system often requires the most comprehensive support. Microprocessor bus activity correlated to detailed timing information of the control lines or the activity of other microprocessors provides a system-wide perspective of what's going on and what's needed to make it all work together. The modular architecture of all Tektronix logic analysis products provides the foundation for tightly integrated solutions to complex analysis tasks.

Making the final choice

Whatever your logic analysis application, from general-purpose hardware test to multi-processor system integration, there's a wide range of capabilities to choose from. The accompanying Tektronix Logic Analyzer Summary Chart will give you an idea of the breadth of these capabilities. However, to zero in on a specific logic analysis system for your needs, call your local Tektronix Sales Engineer or representative. With information on your specific application needs for today as well as projected future needs, your Tektronix Sales Engineer can configure the best system for you, both for now and the future.

Tektronix Logic Analyzer Summary Chart

System	DAS 9200	PRISM 3002	1241	1230
Number of Slots	28	10	4	1
Module Types	8	2	2	1
Time Correlation	Time Stamp	Time Stamp	Time Stamp	Trigger Point
Mass Storage	80 Mbyte Hard Disk	20 Mbyte Hard Disk	RAM Pack	NV RAM
Communication Ports	RS-232, GPIB, LAN	RS-232	RS-232, GPIB, Parallel Printer	RS-232, GPIB, Parallel Printer
Synchronous Acquisition				
Maximum Speed	750 MHz	90 MHz	50 MHz	25 MHz
Maximum Channels	384	1050	72	64
Maximum Depth	128K	8K	2K	2K
Asynchronous Acquisition				
Maximum Speed	2 GHz	200 MHz	200 MHz	100 MHz
Maximum Channels	540	90	72	16
Maximum Depth	128K	2K	2K	2K
Triggering				
States/Levels	16 States	7 States	14 Levels	14 Levels
Counter/Timers	4	8	2	1
Range/Recognizers	4	8		2 word recognizers
Glitch Detection	To 1.5 nanosecond		To 5 nanoseconds	To 3 nanoseconds
Microprocessor Support	8, 16, 32 bit, RISC	8, 16, 32 bit	8, 16, 32 bit	8, 16 bit
Microprocessor Control		PDT		
Multi-Microprocessor Support	Up to 6	Up to 10	1	1
Performance Analysis	Statistical	Real Time	Statistical	
Pattern Generation				
Maximum Speed	100 MHz			
Maximum Channels	1792			
Maximum Depth	16K			
Maximum Resolution	1 nanosecond			
Probes				
Number of Probe Types	9	3	2	2
Minimum Loading	To <1 pF	To <11 pF	5 pF	1 Mohm, 8 pF

Making an educated choice ...

A guide to choosing a spectrum analyzer

Choice criteria

The objective in choosing a spectrum analyzer, as in selecting any measurement instrument, is to select the best match for the application. In this article, we'd like to guide you through that choice process and help you consider the tradeoffs involved.

Technical performance. Nothing else matters if you can't find, display, or measure the signal of interest. Basic technical performance can run from just a few primary requirements to over 20 secondary requirements. The primary spectrum analyzer requirements are:

- **Frequency range.** The upper frequency range of current products varies from tens of kilohertz to 325 GHz. The low frequency end starts at a few hertz up to 10 MHz. In some cases, basic instrument performance can be enhanced by add-on mixers or other external devices.
- **Resolution capability.** Spectrum analyzers are rarely used to look at a single-frequency signal. The ability to distinguish between, or resolve, multiple-frequency signals is important. It's also important to faithfully respond to wideband signal characteristics. Best signal resolution for currently available microwave spectrum analyzers varies from 3 Hz to 1 kHz.
- **Sensitivity.** If small signals cannot be found they cannot be measured. Sensitivity and narrowband resolution usually go together — the narrower the bandwidth, the less the noise level. Sensitivity can be improved by using a preamplifier.
- **Dynamic range.** The ability to analyze large and small signals together is important for most applications. Less sophisticated instruments provide 70 dB dynamic range; more advanced units provide 80 dB. The most advanced spectrum analyzers, offer a dynamic range of 100 dB.

Physical characteristics. In many instances, the physical characteristics of the spectrum analyzer can determine whether a measurement can or cannot be made. A spectrum analyzer that can't withstand rough handling will have performance failure problems if it has to be used on-site in many locations. If the product weighs 200 pounds, it'll be difficult to capture the signal at the top of an antenna tower. A unit optimized for laboratory temperature control is not an ideal choice for outdoor use. Following are the basic physical configuration characteristics of spectrum analyzers.

- **Bench or laboratory level products.** These units usually have limited immunity to extremes of temperature or physical abuse. However, they sometimes provide additional performance features, have larger front panels for less cluttered controls, and are configured for a lower profile or stackable bench arrangement. Often, bench configuration units are easier to rack-mount, and occupy less rack space.
- **Rugged portables.** Made to withstand harsh environments, these units are also configured for easier carrying up ladders, to be rained upon, operate on their side or standing up, etc.
- **General portables.** Not as rugged as the previous class of products, but they are smaller, lighter, and less costly.

Intelligent features. Most modern spectrum analyzers incorporate some level of operating intelligence. This usually involves housekeeping functions to assure that various control settings are compatible. Many units also include other advanced level functions derived from the use of microprocessors. This includes frequency counting, automated signal type recognition, marker manipulation, automated signal bandwidth determination, waveform storage and retrieval, etc. The more advanced or complicated the application, the more these features become important. For instance, automatic computation of noise power density per Hz may save hours of work and eliminate possible errors if oscillator phase noise stability measurement is the primary application.

Support features. The ease and confidence with which some measurements are made is determined by the support features. Is the spectrum analyzer phase-locked for less frequency drift? (This will determine the ease with which closely spaced signals can be measured, or whether the measurement can be made at all.) Does the spectrum analyzer include a preselector to eliminate spurious responses? Can the internal frequency reference be locked to an external reference to improve stability? Is there digital storage to eliminate display flicker? Can the digital storage display be turned off to display gray scale for complex spectra? Can an external plotter be used to plot the display? Can the plotter be used to plot signals from memory while the unit is measuring something else? These, and other similar questions relate to the support features.

Human factors. Interaction of controls; depth of menus; CRT display annotation; type of operating systems — knobs, menus, markers, cursors, step setting; automated operation; speed of making the measurement... all affect the comfort, accuracy, and ability to make a measurement. Many of these factors relate to a multiplicity of functions. And many times it's not just a matter of convenience and comfort, but a question of being able, or not able, to make a measurement. For example, the Tektronix 3052 Digital Spectrum Analyzer can run through a 1000-point complex spectrum in just 200 microseconds with a 2 MHz instantaneous (real-time) bandwidth. This may be considered a convenience feature to save measurement time and cost. However, if the spectrum record length is not much more than 200 microseconds, then nothing slower can make the measurement.

Cost. Cost is a legitimate decision factor — the best usually costs more. The key is to find a product within your budget that will also do the job. This is not as easy as it sounds. The needed application may not be fully understood, or future needs may not be fully known. Often, the best the user can do is to look at all the decision criteria to assure that nothing important has been missed. The user also needs to look at available products to find the best available fit. The accompanying Spectrum Analyzer Product Select Guide lists the various selection criteria for Tektronix spectrum analyzers.

Summary

Unfortunately, we can't provide an automatic "by the numbers" method to choose the best spectrum analyzer for your application. Instead, what we've tried to do here is provide an aid to a user who has an application and a budget in mind.

When making that critical choice, look at the criteria and concentrate on the important ones for you. For one person it may be price, for someone else it may be frequency stability, and someone else may be willing to pay almost anything to get the needed speed, phase noise, or whatever. Pick the best candidates and then check for consistency among the criteria. Does it cover the needed frequency range at a price you can afford? If it's not important, it doesn't matter that drift due to lack of phase-lock makes it impossible to view that close-to-the-carrier signal.

Finally, don't be shy. Ask your Tektronix Sales Engineer or representative for information or a demonstration on your actual signal. That's the best way to stay informed on what's currently available and what's best for your measurement application.

SPECTRUM ANALYZER PRODUCT SELECTION GUIDE

DIGITAL SPECTRUM ANALYZER

Model	Frequency Range	Displayed Bins	Signal Resolution	Reference Level Range	Sensitivity	A/D Converter	Amplitude Accuracy	Center Freq & Marker Accuracy	Interface
3052	Center Frequency Range DC to 10 MHz. Frequency Spans: 1 kHz to 2 MHz (Real Time); 5 to 10 MHz (Batch). 1024 pt complex conversion every 200 µs (max).	800 (1024 Real and 1024 Imaginary are calculated)	≤3 bin widths (also holds for one signal at reference level and the other at ≤70 dBc)	+33 to −140 dB	−150 dBm/Hz (7 nV√Hz at 100 kHz) 1/f noise corner at 20 kHz	25.6 MS/s 10 bits	±0.2 dB at 12.5 kHz ±0.5 dB at all frequencies, with error correction	≤1×10⁻⁹ per day and ≤1×10⁻⁷ per year of value displayed	RS232 standard GPIB optional

MICROWAVE SPECTRUM ANALYZERS

Model	Counter	Frequency Range: Coaxial Input	Frequency Range: w/Exter. Mixers	Frequency Accuracy	Ref Accuracy	Resolution Bandwidth	AverageNoise Level (Min RBW)	Amplitude Meas. Range	GPIB	Config.
2782	Y	100 Hz to 33 GHz	325 GHz Operates to 1.2 THz	Freq (Ref + 10⁻¹⁰) +5N Hz	7×10⁻⁹/day 1×10⁻⁶/year	3 Hz min to 10 MHz max	−135 dBm	+30 dBm to −135 dBm	Yes 2 parts	Portable
2756P	Y				10⁻⁹/day 10⁻⁷/year	10 Hz min to 3 GHz max	−131 dBm	+30 dBm to −131 dBm	Yes	Lab
494AP	Y								Yes	Portable
2755AP	Y	10 kHz to 21 GHz	325 GHz	Freq X Ref Accuracy +0.2 X (Span/div or Resolution Bandwidth) +(2N+25) Hz	5×10⁻⁷/year 10⁻⁶ @ 25°C within 30 minutes	100 Hz min to 3 MHz max	−120 dBm	+30 dBm to −120 dBm	Yes	Lab
492BP	Y								Yes	Portable
2754	N	50 kHz to 21 GHz	N/A		10⁻⁵	1 kHz min to 1 MHz max	−110 dBm	+30 dBm to −110 dBm	Plot	Lab
2754P	N								Yes	
NEW 492PGM	N	10 kHz to 21 GHz	N/A		10⁻⁵	1 kHz min to 3 MHz max	−110 dBm	+30 dBm to −110 dBm	Yes	Portable
VHF/UHF SPECTRUM ANALYZERS										
2753P	Y	100 Hz to 1800 MHz		Freq X Ref Accuracy +0.2 X (Span/div or Resolution Bandwidth) +15 Hz	10⁻⁹ /day 10⁻⁷ /year	10 Hz min to 3 MHz max	−131 dBm	+30 dBm to −131 dBm	Yes	Lab
495	Y				10⁻⁹ /day 10⁻⁷ /year				Plot	Portable
495P	Y								Yes	
2710	*1	10 kHz to 1800 MHz		Freq X Ref Accuracy ±5 kHz without counter; ±10 Hz with counter	3x10⁻⁶/year typical	3 kHz min to 5 MHz max	−117 dBm −129 with preamp	+20 dBm to −129 dBm	*2	Portable
Opt 01				Freq X Ref Accuracy ±700 Hz without counter; ±10 Hz with counter	2X10⁻⁶/year typical	300 Hz min to 5 MHz max	−127 dBm −139 with preamp	+20 dBm to −139 dBm		

*1 *With Option 02.* *2 *Centronics plot option.*

Evaluating scopes from A to D . . .

Six important questions to ask when buying a digitizing oscilloscope

Digitizing oscilloscopes (also known as digital storage oscilloscopes or DSOs) have evolved from partial solutions for a limited range of measurement problems into general-purpose measurement tools. They offer waveform storage, waveform transfer, and waveform analysis capabilities as well as the convenience of automatic measurements and quick hardcopy documentation.

Because of their many advantages, digitizing oscilloscopes have gained wide popularity. However, their popularity should not overshadow the fact that, while they can solve a growing set of problems, they are not a universal answer to all measurement needs. More unsettling is the realization that not all digitizing oscilloscopes are equally equipped to solve your measurement problems.

Proceed with care

In selecting a digitizing oscilloscope, you need to evaluate performance in a sometimes confusing array of features, capabilities, specifications, and trade-offs. For example, some digitizing scopes may feature one or two highly publicized "banner specs" at a price that appears to be a bargain. Only an in-depth evaluation or actual usage reveals the trade-offs made to reduce the price. With a little "homework" before the purchase, you can find out these things — before you make a wrong, and often costly, choice.

This will also help you avoid the disappointment and frustration of selecting a digitizing oscilloscope that doesn't fit your application needs. Always remember to evaluate a digitizing oscilloscope's "analog" features as well as its uniquely "digital" features. Every digitizing oscilloscope includes an analog front-end that captures and performs the initial processing of the signal. Many of the features and specifications that are important in an analog scope apply equally well to a digitizing scope.

A matter of choice

The companion article in this issue — **A guide to selecting the appropriate oscilloscope technology for your application** — guides you through the details of selecting the right technology for your application: analog real-time, microchannel plate, or digitizing.

If you choose digitizing technology as the best solution for your application, then consider the following six questions. They'll help you decide whether a particular digitizing scope is right for you. If you can't consistently answer "yes" to these questions, then the digitizing scope you are considering will not prove to be the reliable measurement instrument that an experienced user expects.

1. Will the scope miss important events between samples? Real-time digitizing scopes sample signals at regular intervals, but what happens to your waveform if an event occurs between sample points? Understanding the behavior of the circuit-under-test may depend upon capturing a certain glitch or viewing unwanted high-frequency noise. For example, if your scope samples every 4 nanoseconds, but a 2 nanosecond glitch occurs, will you see it? Maybe, maybe not. Figure 1 illustrates this problem.

Another point to keep in mind when evaluating digitizing oscilloscopes is

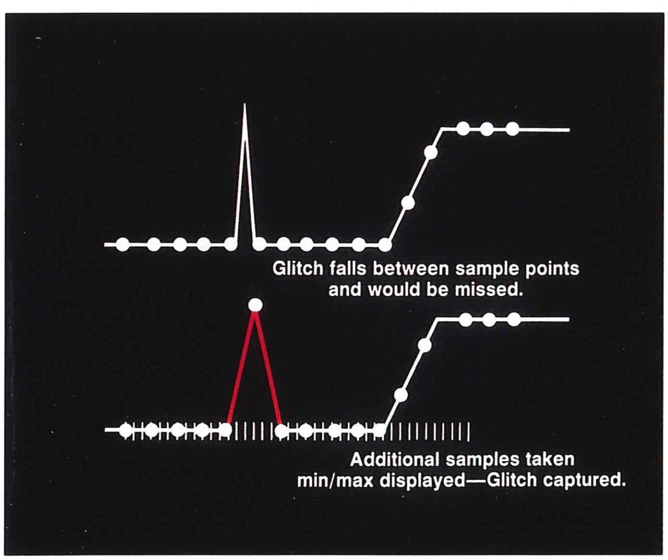


Figure 1. *Digitizing scopes can miss events between samples unless they are equipped with special peak detection capabilities. Most DSOs use lower sample rates at lower sweep speeds. This Tektronix scope samples at its highest sample rate at all sweep speeds.*

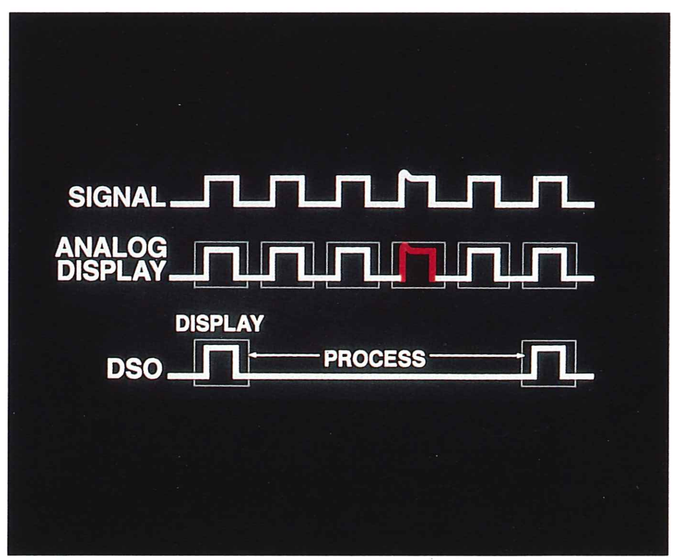


Figure 2. *Digitizing scopes spend some time acquiring data, but more time processing the data. This update rate is a key factor to consider when selecting a digitizing scope. A digitizing scope with high update rate cuts the dead time between acquisitions and increases the likelihood of acquiring occasional events.*

that the highest sample rate offered is not always available at all the slower time-base settings. At microsecond or millisecond settings, you might be selecting kilosample performance. To overcome that problem, special peak detection hardware and software can help the scope acquire and display events between samples. Tektronix has patented several peak detection circuits/methods such as the one shown in Figure 1.

A related display technique is envelope mode, also patented by Tektronix. This mode enables the scope to display signal extremes captured by the peak detector. It also prevents the aliased display of undersampled waveforms. Of course, a higher sampling rate, which reduces the interval between samples, will help. The trade-offs, however, may be higher costs or lower vertical resolution, or both.

2. Will the scope watch for signals most of the time? Digitizing scopes acquire data for some period of time, then they spend time processing and displaying the data they have acquired. The number of acquisition/processing/display sequences per second is the update rate.

What happens if the event you want to examine appears while the digitizing scope is processing earlier data? You may miss the event altogether, as Figure 2 shows. This is particularly a problem with infrequent events. You may miss the event altogether, or you may require several hours — or even a day — to capture it if your scope has a low update rate.

If your scope is in an ATE environment, low update rate can greatly decrease throughput to your controller. This may cost you dearly in test time.

Update rate also affects the response time of a scope, determining whether the scope has a "live" feel or not. For example, try moving the vertical position knob or compensating your probe. If the scope responds immediately, you have a good update rate. If it lags, causing you to over-compensate, this could be an annoying problem throughout the lifetime of your scope.

Analog scopes have update rates reaching hundreds of thousands of times per second. Tektronix has developed special digital signal-processing integrated circuits that allow our digitizing scopes to deliver the highest update rates available — 50 or more waveforms/second.

3. Are the bandwidth and sample rate high enough? Superficially, this question seems easy to understand and answer. The reality is different. Take bandwidth for example. You actually need two measures of bandwidth.

Repetitive bandwidth is a measure of the scope's ability to acquire and display repetitive signals without significant loss of the signal (see Figure 3). A high single-shot bandwidth allows a scope to faithfully capture a single event such as a high-speed laser pulse. If the single-shot bandwidth is too low, then the waveform detail is compromised or lost altogether. Tektronix has developed digitizing scopes that offer high repetitive, single-shot, and trigger bandwidths. Relying on the combination of bandwidths, rather than a single "banner spec" ensures that you will be able to use your scope over a broader range of signals.

Then what about the sample rate? The higher the better, right? Yes, but this specification isn't sufficient by itself to ensure that you get the measurement results you want. A digitizing scope that has a high sample rate, but low vertical resolution, an inaccurate or limited interpolation method, and no peak detection circuits may not reveal as much waveform detail as a scope that combines these features with a lower sampling rate. Figure 4 shows the recommended sample rate required to capture single-shot signals.

4. Will it trigger when you want it to? A scope that has a high sample rate and a high repetitive bandwidth is useless without the ability to trigger on the signal you want to examine. For exam-

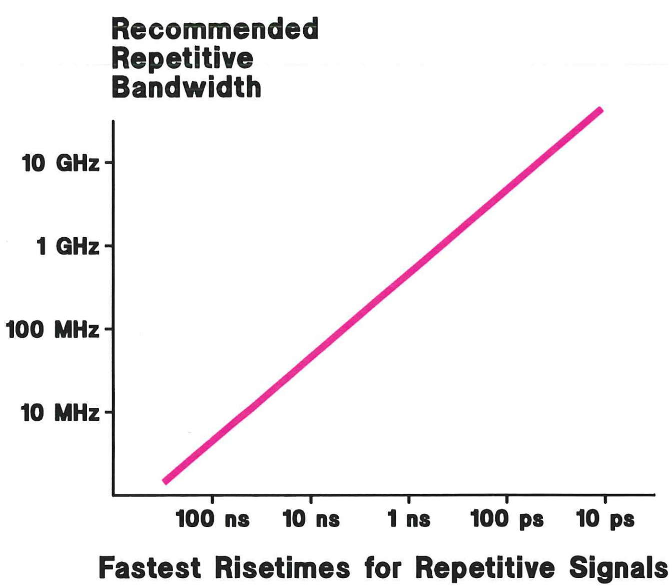


Figure 3. *Graph showing the approximate bandwidth your scope needs in order to accurately acquire, display, and measure repetitive signals.*

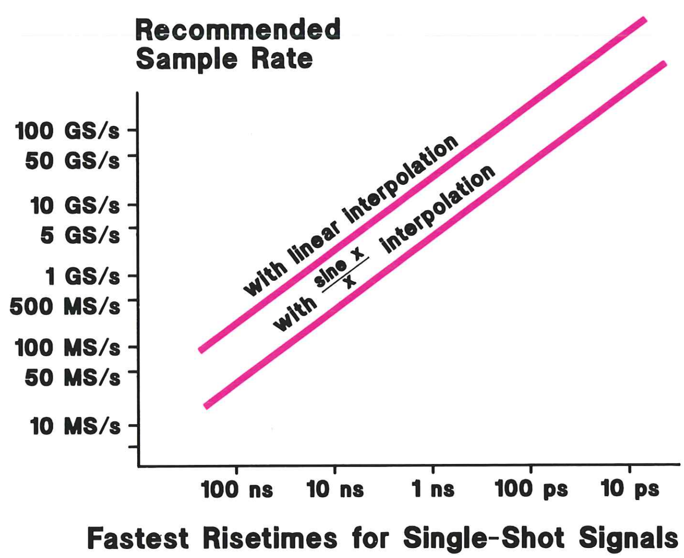


Figure 4. *This graph indicates the approximate sample rate (digitizing rate) you should use to accurately acquire, display, and measure single-shot signals.*

ple, signals are seldom "clean," so the oscilloscope often needs the ability to generate a stable trigger from a noisy signal.

To ensure that you can quickly display a stable waveform on screen, you may need trigger functions such as: high-frequency rejection, low-frequency rejection, noise rejection, AC and DC coupling, or extended functions such as video triggering and logic triggering. Tektronix scopes are well known for their superior triggering capabilities.

5. Does the waveform faithfully reproduce the signal? All digitizing scopes take samples of the signal to be examined. The faithfulness of the waveform reconstructed on screen depends upon the accuracy of the analog-to-digital conversion process and the accuracy of the analog circuits in the "front-end" of the scope. Both analog and digital oscilloscopes need to faithfully reconstruct the signal — a basic quality sometimes downplayed in the specifications for digitizing oscilloscopes. Also important is the performance of the analog circuits in their specifications for linearity, cross-talk, gain, offset, and aberrations.

Make sure the digitizing scope you are evaluating offers both dot mode (sample points only) and vector mode (connecting the sample points), for flexibility in examining data. Tektronix provides both.

6. Will the measurements be accurate? Your success in designing, testing, or troubleshooting circuits may depend on the accuracy of your measurements. If the accuracy is too low or not clearly specified, then you might inaccurately measure timing as well as amplitude values.

Accuracy is a function of several variables: vertical resolution, horizontal resolution (sampling rate), the interaction between vertical and horizontal resolution, and the use of automatic measurements. Vertical resolution determines the number of levels displayed on the screen and stored in memory and the level of waveform detail. The more vertical resolution the scope has, the more accurately you can place cursors and the more accurately you can use the auto measurements.

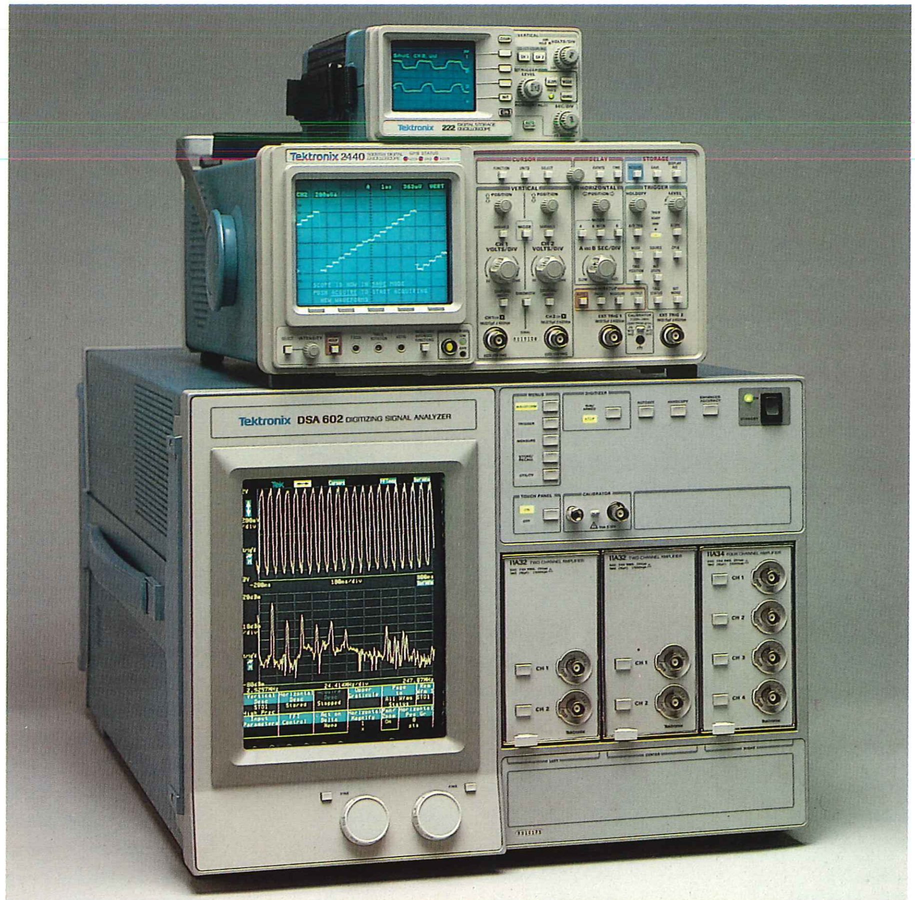


Figure 5. *Tektronix offers the widest range of oscilloscopes from hand-held to laboratory models, as well as a variety of data acquisition and display technologies: analog real-time, microchannel plate, and digitizing scopes.*

Tektronix provides at least 8 bits of vertical resolution, because that's usually the required level for most applications. While "number of bits" is the accepted and preferred specification, you may see vertical resolution specified in percentages. Here's the relationship between the two methods:

Bits	Levels	% Resolution of Full Scale
6	64	1.56%
8	256	0.4%
10	1024	0.1%
12	4096	0.024%

When dealing only with repetitive signals, vertical resolution can be improved through the use of signal averaging.

What's the next step?

For more than 15 years, Tektronix has developed the digitizing technologies that have made our digitizing oscilloscopes the best choice for more and more applications. From the most affordable digitizing oscilloscopes to the most sophisticated ones, Tektronix has test and measurement solutions to meet your needs.

For more information about digitizing scopes for your particular application, consult your local Tektronix sales and application engineers. They are specially trained to help you select from the variety of technologies and scope packages available.

For technical details on specifications and capabilities of Tektronix digitizing oscilloscopes, check the appropriate boxes on the reply card in this issue of HANDSHAKE.

CLASSES AND SEMINARS

Tektronix offers classes and seminars for the convenience of customers with application, operational, or service training needs. Workshop and class sizes are limited. We recommend that you enroll early. Other classes are planned beyond this schedule. We retain the option to cancel or reschedule classes, seminars, or workshops.

Measurement application technology seminars

Tektronix Advanced Measurement Technology Seminars provide a hands-on opportunity to explore the strengths and weaknesses of digital and analog real-time oscilloscopes side-by-side. These 3 1/2-hour seminars help to put the terminology and specifications in perspective. Seminars are designed for engineers, senior technicians, and managers concerned with selecting the right tools to improve, productivity, repeatability, and accuracy. There is no charge for these seminars, but reservations are required due to limited class space. Call the number listed below and ask for the T&M Seminar Coordinator to reserve a space today.

Philadelphia, PA	(215) 825-6400	Aug 2, 3
Harrisburg, PA	(215) 825-6400	Aug 4
Baltimore, MD	(301) 771-6400	Aug 7, 8
Washington, DC	(301) 948-7151	Aug 9, 10, 11
Hampton, VA	(804) 865-1588	Aug 14, 15
Charlottesville, VA	(804) 865-1588	Aug 17
Pittsburgh, PA	(412) 244-9800	Aug 21, 22
Scranton, PA	(315) 455-6661	Aug 24
Binghamton, NY	(315) 455-6661	Aug 25
Utica, NY	(315) 455-6661	Aug 28
Syracuse, NY	(315) 455-6661	Aug 29
Rochester, NY	(716) 383-0070	Aug 30, 31
Buffalo, NY	(716) 383-0070	Sep 5, 6
Cleveland, OH	(216) 447-5050	Sep 8
Detroit, MI	(313) 478-5200	Sep 11
Grand Rapids, MI	(313) 478-5200	Sep 12
Saginaw, MI	(313) 478-5200	Sep 13
Columbus, OH	(513) 859-3681	Sep 15
Dayton, OH	(513) 859-3681	Sep 18
Cincinnati, OH	(513) 859-3681	Sep 19
Lexington, KY	(513) 859-3681	Sep 20
Indianapolis, IN	(317) 872-3708	Sep 22, 25
Ft. Wayne, IN	(317) 872-3708	Sep 27

Product service training classes

Tektronix Service Training provides new technicians the skills and techniques required for effective maintenance of Tektronix products. In addition, it brings experienced technicians up-to-date on maintenance of new products. Call Tektronix Service Training, 1-800-835-9433, Ext. WR1407 to register for the following classes.

GURU II/GPIB Data Communications	Atlanta, GA	Oct 16-20
Personal Computer (PC) User/DOS Familiarization	Beaverton, OR	Aug 9-11
	Beaverton, OR	Oct 11-13
	Atlanta, GA	Oct 11-13
Time Domain Reflectometer (TDR) User	Beaverton, OR	Sep 14-15
TM 500 Calibration Package	Boston, MA	Nov 6-10
TM 5000 Digital Counter/Multimeter	Beaverton, OR	Sep 18-22
465B/475A Portable Oscilloscope	Irvine, CA	Aug 7-11
3052 Digital Spectrum Analyzer	Beaverton, OR	Aug 14-Sep 1
2215/2235/2236 Portable Oscilloscopes	Irvine, CA	Aug 14-18
2230/2232 Digital Storage Oscilloscopes	Beaverton, OR	Aug 21-Sep 1
2245/2246/2247 Portable Oscilloscopes	Irvine, CA	Aug 21-25
2465/2467 Microprocessor Based Scope	Irvine, CA	Oct 30-Nov 10
7854 Waveform Processing Oscilloscope	Beaverton, OR	Oct 30-Nov 17
7904/7633 Lab Storage Oscilloscopes	Atlanta, GA	Sep 11-22
7912HB Programmable Digitizer	Beaverton, OR	Sep 11-22
1130x Analog Programmable Scope	Beaverton, OR	Oct 16-20
1140x Digitizing Programmable Scope	Beaverton, OR	Oct 23-27
1180x Digital Sampling Oscilloscope	Beaverton, OR	Jul 24-28

In addition to classroom instruction, Tektronix Service Training has a variety of training packages and video tapes available for self-study. Classes are also available for maintenance of other Tektronix products. Call for further information.

New self-study training packages

These self-study training packages consist of a workbook, a video tape, and a signal-source board to demonstrate the signal measurement concepts.

Operating the 2445A/2465A	068-0262-xx
Operating the 2445B/2465B/2467B	068-0261-xx
Operating the 11301A/11302A	068-0264-xx

Order self-study training packages through your local Tektronix field office or the Tektronix National Marketing Center — 1-800-426-2200. Other self-study training packages are available. For a complete listing, check the **HANDSHAKE** Reply Card. ☛

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