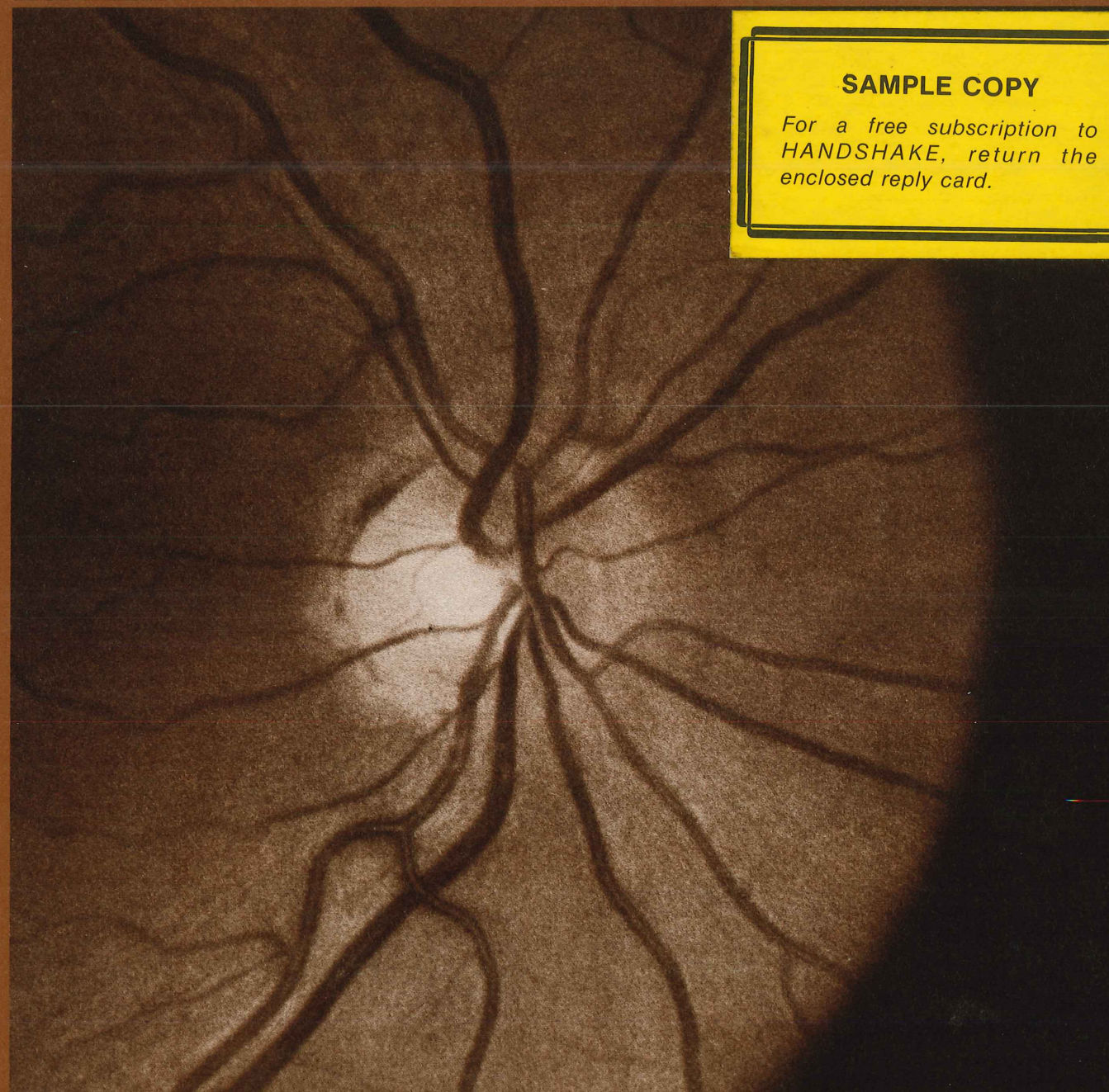


HANDSHAKE

NEWSLETTER OF SIGNAL PROCESSING AND INSTRUMENT CONTROL

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Putting Digitizers to work in R & D.

Table of contents

<i>NBS details deconvolution techniques</i>	<i>page 2</i>
<i>Basics of choosing a waveform digitizer</i>	<i>3</i>
<i>Characterizing electromagnetic transients discussed</i>	<i>11</i>
<i>7D20 offered in new monolithic digitizer configuration</i>	<i>14</i>
<i>7912AD used in semiconductor pulsed-laser annealing studies</i>	<i>14</i>
<i>Sony/Tektronix 336 Digital Storage Oscilloscope</i>	<i>15</i>
<i>Putting waveform digitizers to work in R&D</i>	<i>16</i>
<i>Article explores digital storage in biomedical research</i>	<i>21</i>
<i>Digitizers evaluated for recording high-voltage impulses</i>	<i>21</i>
<i>Getting the most out of TEK BASIC graphics—High resolution contour plotting with TEK SPS BASIC</i>	<i>22</i>
<i>New ROM speeds and enhances 4050-series graphics</i>	<i>24</i>
<i>New MI 5010 cards offer 12-bit digitizing, 16K memory</i>	<i>26</i>
<i>7A42 brings logic analyzer triggering to digitizers and oscilloscopes</i>	<i>27</i>
<i>Floating measurement safety offered by A6902A Isolator</i>	<i>28</i>

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NBS details deconvolution techniques

Put a broadband signal into an unknown system or circuit, acquire the resulting output signal, then deconvolve the two. The result is a complete characterization of the system in terms of its impulse response.

The usefulness of deconvolution techniques is wide ranging. Unknown systems can be defined for a variety of purposes. A communication link can be deconvolved to get the impulse response and the impulse response fast Fourier transformed to get the frequency response. The testing can be done with standard signals, without disruption of the system. Also, test systems themselves can be analyzed with deconvolution techniques to characterize their effects on captured signals. And, ultimately, the test system's effects on measurements can be removed from the measurement data.

This latter application, removing system effects from test data, is covered by N.S. Nahman and J.R. Andrews (Electromagnetic Technology Div., National Bureau of Standards Labs, Boulder, CO) in "Research Improves Time-Domain Calibrations," *Electronics Test*, July 1981. An even more detailed account of deconvolution techniques and applications is presented in **Deconvolution of Time Domain Waveforms in the Presence of Noise**, N.S. Nahman and M.E. Guillaume, NBS Technical Note 1047, Oct. 1981. Copies of this 122-page technical note are available for \$11.00 each from the National Technical Information Service (NTIS), Springfield, VA 22161.

The NBS technical note provides an overview of deconvolution followed by a detailed account of methods and application. Included is a discussion of a digital filtering technique for reducing random error in the data. As the authors point out, digital deconvolution is an estimation process that in theory is very simple. The major work in practical applications is in simply trying to improve the estimates. The NBS Technical Note 1047 will go a long way in helping you to understand and successfully apply deconvolution techniques. 

Basics of choosing a waveform digitizer

Waveform digitizers have come of age. Most manufacturers of waveform acquisition instruments have at least one digitizer in their product offering. Many offer several types. The result is a wide, and sometimes confusing, variety of waveform digitizing techniques and features to choose from.

So the question becomes: Which waveform digitizer is best for your particular needs? Or, maybe even before that: Do you even need a waveform digitizer? Perhaps your needs would still be better served by the traditional analog oscilloscope.

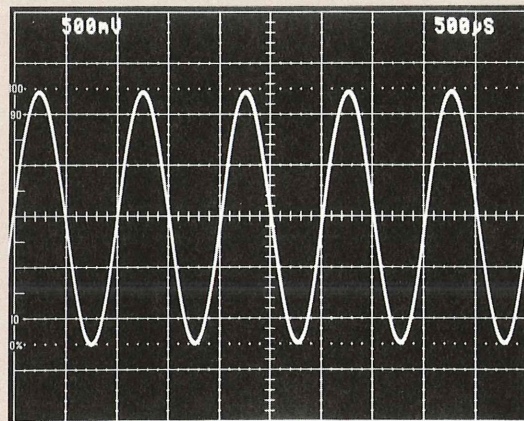
You don't need to be a digitizer expert to resolve these questions. But you do need a basic understanding of the concepts involved and how they affect your measurements. Not only will this help you make the right instrument choice, but it will help you more effectively use your digitizer.

Digitizing—an old concept, new packaging

Waveform digitizing is a natural technological evolution from the oscilloscope. In fact, any waveform measurement taken from an oscilloscope is indeed done by a limited form of digitizing.

Consider, for example, the oscilloscope display shown in Fig. 1a. By just looking at the display, you can make some qualitative judgements about the waveshape. It's a sine wave. But, to draw any quantitative information from the waveform, you have to pick some points off the display. Often, the values picked off are relative. For example, differences between points can be used to get peak-to-peak amplitude or the value of the waveform's period. But to get absolute values, such as peak amplitude, a zero-reference level must be established for the waveform.

A zero reference is established by grounding the scope input. The result is a display of a zero level or ground signal, which is usually aligned with one of the graticule lines for measurement convenience. In the case of Fig. 1a, the center graticule line is the zero-reference level. With this known, absolute values can be picked from any part of the waveform. In fact, that is what was done to build the table shown in Fig. 1b.



a. Standard oscilloscope display with vertical (500 mv/div) and horizontal (500 μ s/div) scaling.

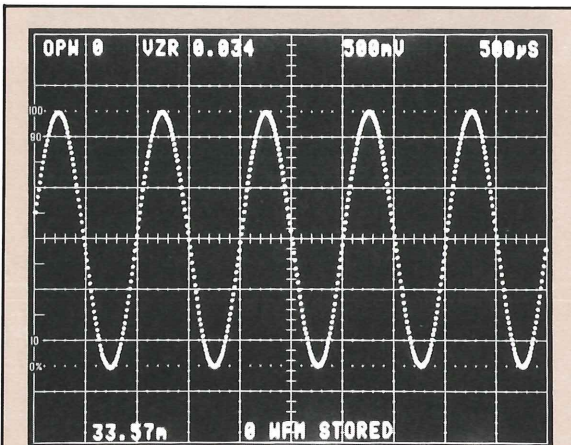
Time	Amplitude
0	200.00 mv
50 μ s	450.00 mv
100 μ s	750.00 mv
150 μ s	1.05 v
200 μ s	1.18 v
Peak 225 μ s	1.22 v
250 μ s	1.20 v
300 μ s	1.13 v
350 μ s	950.00 mv
400 μ s	500.00 mv
450 μ s	250.00 mv
500 μ s	-60.00 mv
.	.
.	.
.	.

b. Hand digitized values taken over the first horizontal division.

Fig. 1. A standard oscilloscope display with scaling can provide a substantial amount of measurement data, including tables of values for entry into computer analysis systems.

Figure 1b is the result of hand digitizing a waveform. The values from the table can be entered into a computer as an array and processed along with arrays from other waveforms digitized in the same manner. Individual arrays can be integrated, differentiated, etc., or waveform arrays can be added, subtracted, multiplied, or divided on an entry-by-entry basis.

Figure 2 shows the same waveform after being captured by a waveform digitizer. There's essentially no difference in concept between Figs. 1 and 2. Both are digitized waveforms. The practical differences, however, are that the waveform digitizer is substantially faster, it provides substantially more points, and it is infinitely more convenient than hand digitizing.



a. Dot display of a waveform digitized and stored with a DSO.

Time	Amplitude
0	265.800 mv
9.766 μ s	344.500 mv
19.530 μ s	416.300 mv
.	.
205.100 μ s	1.228 v
214.800 μ s	1.234 v
Peak 224.600 μ s	1.236 v
234.400 μ s	1.233 v
.	.
459.000 μ s	83.010 mv
468.800 μ s	15.260 mv
478.500 μ s	-54.320 mv
.	.
.	.

b. A few of the digitally stored values from the first horizontal division of the displayed waveform.

Fig. 2. Waveforms captured and digitized with a DSO become available as a set of numbers with greater resolution, both in amplitude and time, than what can be obtained visually from a standard oscilloscope display.

Digitizer or oscilloscope?

While waveform digitizing offers some distinct advantages over traditional oscilloscopes, it's dangerous to form any premature conclusions about digitizers replacing oscilloscopes.

The standard analog oscilloscope is a core laboratory and maintenance tool. It's unsurpassed as a familiar and straightforward means for making quick qualitative observations of waveforms. And its display accuracy is sufficient for many standard measurements, such as peak levels, rise times, fall times, etc. Also, oscilloscopes have the advantage of a real-time display, which makes the effects of circuit adjustments immediately observable. Waveform digitizers, on the other hand, may have a longer display update time dictated by the digitize-store-display cycle.

It is becoming common, however, to combine digitizing with standard oscilloscopes. Sometimes referred to as a digital storage oscilloscope or DSO, these instruments give you the option of use either as a standard oscilloscope or as a waveform digitizer.

The simplest type of DSO uses a digitizer and digital memory only for waveform storage. Stored waveforms are displayed clearly and crisply without the background flooding common to screen storage methods. This makes waveform viewing and photography easier. And, where sufficient memory and internal processing is provided, numerous viewing and storing options can be provided beyond what analog scopes offer. More than one waveform can generally be stored, with memory locations frequently provided for four or more waveforms. Also, the stored waveforms can be called up, singly or in combination, as many times as desired for viewing or comparison. Waveforms can be viewed in a scope mode, a stored mode, or a mode combining both a real-time scope display and one or more digitally stored waveforms.

So, at its simplest, a DSO offers several waveform storage enhancements over the typical analog oscilloscope. But waveform digitizing offers far more potential than just providing a new type of storage oscilloscope. Digitizing is perhaps the most significant advancement in oscillography since the time-amplitude calibrated display was introduced several decades ago.

Cursors pick off data

With digital storage, waveform values become available as a table or array of values. These values are used to re-create the waveform as a dot display or a vectored display (dots connected). These values are also selectively available for readout on the oscilloscope screen.

A common method of selecting values for readout is to provide screen cursors on the DSO. The cursor dots are moved around on the stored waveform and the values at their location displayed. In some cases a single cursor is provided. When this is done, two waveform values are indicated by the cursor: time from the beginning of the display, and amplitude from the zero reference. When two cursors are used, the outputs are the differences in time and amplitude between the cursors. Examples of single-cursor and double-cursor operation are illustrated in Fig. 3.

What cursors do for you is automate standard oscilloscope measurements. Instead of counting graticule lines, trying to resolve small differences, and multiplying by scale factors, just move the screen cursor to the points of interest on the stored waveform. Then read the values from the screen readout.

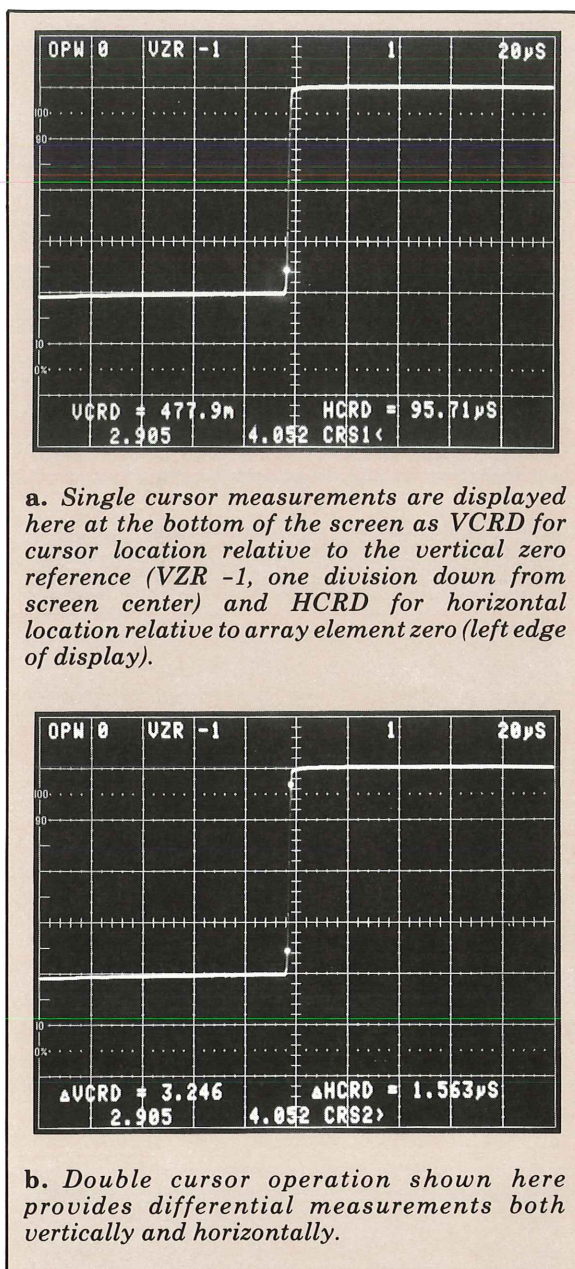
Cursors make your oscilloscope measurements much faster, more repeatable, and to a higher degree of resolution than ever before. Having cursors is like moving from a slide rule to an electronic calculator.

New modes, more flexibility

Digitizing, digital storage, and cursor operation require some minimal processing power within the DSO. Generally, this processing is provided by a microprocessor. And, since the microprocessor is there, it's also often used to provide additional processing for more capabilities.

Signal averaging is just one additional capability often supplied in DSOs. Basically, the operation is to take many different acquisitions of a repetitive waveform and compute their average. The result is a dramatic cleanup of any noise on the waveform, as illustrated by the CRT photos in Fig. 4.

If you find yourself dealing with low-level, noisy signals, signal averaging is a feature that will make your measurement job much easier.



a. Single cursor measurements are displayed here at the bottom of the screen as VCRD for cursor location relative to the vertical zero reference (VZR -1, one division down from screen center) and HCRD for horizontal location relative to array element zero (left edge of display).

b. Double cursor operation shown here provides differential measurements both vertically and horizontally.

Fig. 3. Screen cursors—displayed as bright dots—can be moved around waveform displays singly or as a pair to pick off points or point differences for measurements.

Enveloping is another feature sometimes provided by DSOs. Again, this operates on repetitively triggered signals. What enveloping does is store the maximum and minimum excursions of each waveform point over many waveform acquisitions. The result of this is shown in Fig. 5 and offers you the capability of monitoring signals for amplitude, time, or frequency drift.

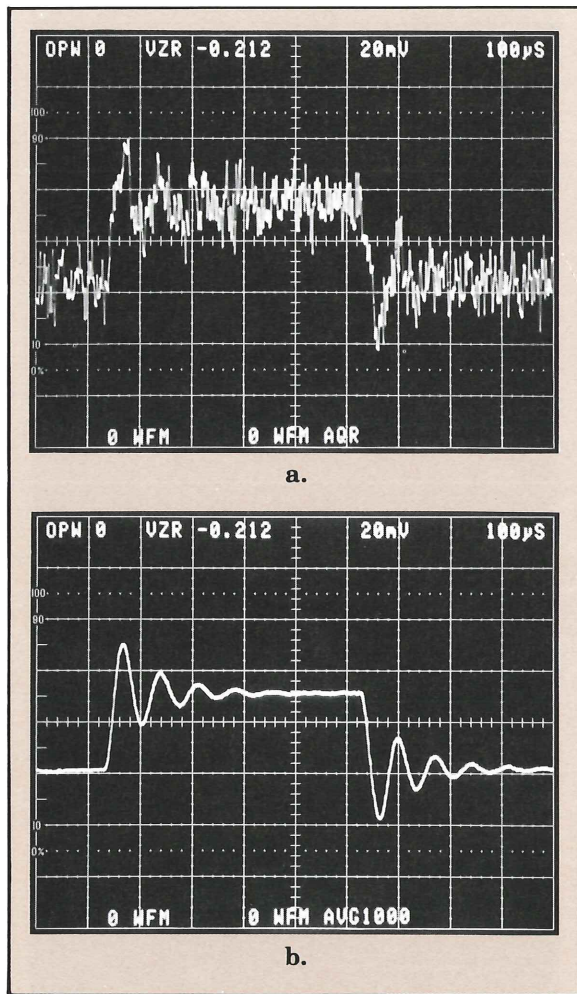


Fig. 4. A noisy signal is shown acquired in a. In b, the same signal has been acquired through signal averaging 1000 times for a significant improvement in signal-to-noise ratio.

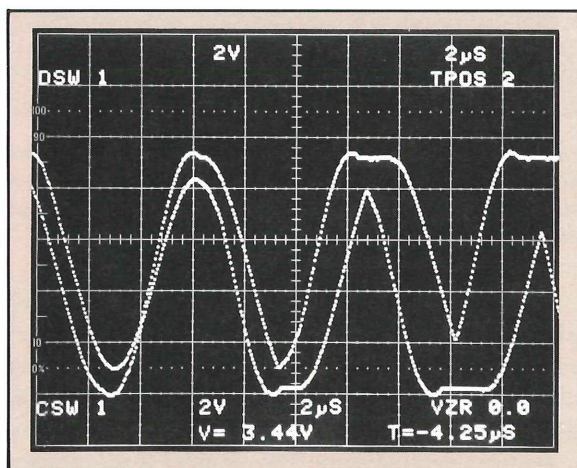


Fig. 5. Enveloping of many acquisitions of a sinusoid reveals both amplitude and frequency drift in the waveform.

Other possible acquisition and display features include roll-mode display, pre- and post-trigger modes, and sample rate switching.

Roll-mode display is essentially an untriggered continuous digitizing mode. The most recently acquired waveform point occurs on the right side of the display and is shifted left as soon as a new point is available. The result is a continuous shifting or rolling of the waveform to the left across the display. The effect is similar to a chart recorder. And, at any time a glitch or other item of interest appears, a HOLD button allows you to freeze the display for further study or analysis.

Pre- and post-trigger operations are illustrated in Fig. 6. A trigger level is set for triggering on some expected event. Then the amount of pre-or post-trigger shift is entered. The amount of pre- or post-triggering selected determines the amount of signal captured before or after the triggering event.

There are a variety of applications for pre- and post-triggering. For pre-triggering, perhaps the most common application is ensuring full

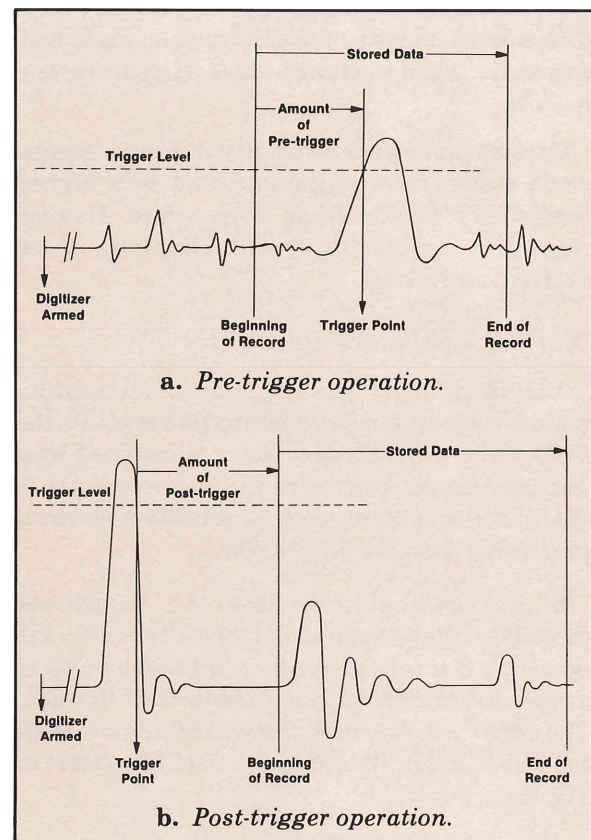


Fig. 6. Pre- and post-trigger operation let you select just the segment of data you want.

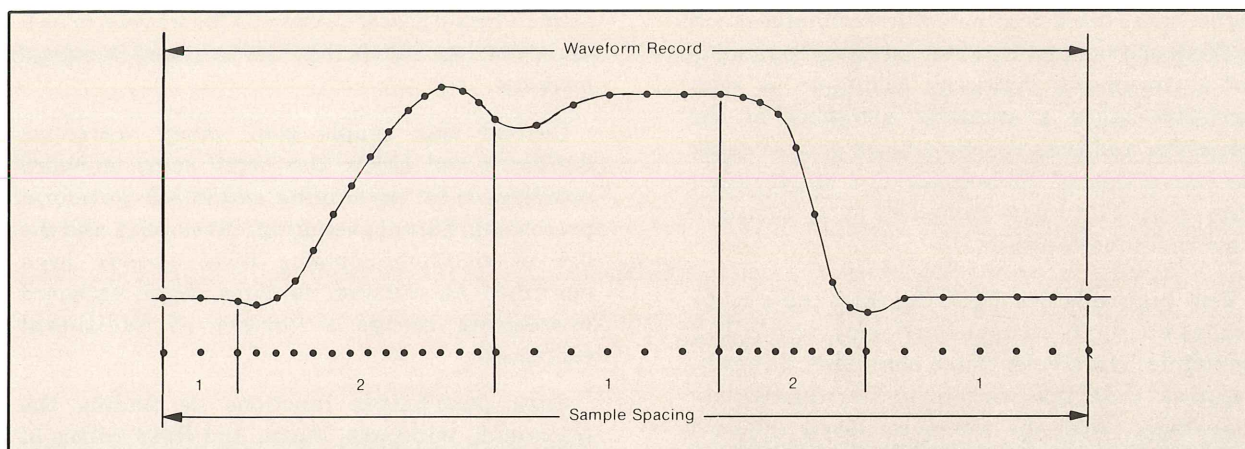


Fig. 7. Sample rate switching during the waveform record can be used to increase time resolution on transitions. The above example shows switching between rates 1 and 2 with four rate changes during the record.

capture of transient pulse leading edge. The trigger level can be set high enough to avoid triggering on spurious noise, and the pre-trigger operation captures data before the triggering point. In general, pre- and post-triggering finds application whenever you wish to study signal conditions leading up to or following any transient event.

Switchable digitizing rate is another innovation found in some modern digitizers. This feature is illustrated in Fig. 7. One typical application is acquiring waveforms with fast transitions followed by long durations of little change. For the fast transition areas, the digitizing rate can be increased for high resolution; then, in slowly changing areas requiring less resolution, the digitizing rate can be decreased. You don't waste digitizer memory on a long string of unchanging waveform samples.

Digitizing determined by waveform type

Waveform type—repetitive or nonrepetitive—is an important consideration in digitizer choice. To a large degree, waveform type determines the digitizing method that must be used.

There are two basic digitizer sampling methods you can choose from—equivalent-time and real-time sampling. Of these, real-time sampling is the easiest to understand. When digitizing starts or is triggered, the first sample of the waveform is taken and digitized. Then, after a short period of time called the sampling interval, the next sample is taken. This goes on, each sample taken in

sequence, until the waveform record is filled (see Fig. 8).

The advantage of real-time sampling and digitizing is that it takes the waveform as it comes. Thus, it can be applied to any type of waveform, repetitive or nonrepetitive. And, because all samples are taken in a continuous sequence, most all acquisition and display features (roll mode, pre- and post-trigger, etc.) can be easily implemented.

The speed-resolution trade-off is the major disadvantage of continuous real-time digitizers. In sequential operation, sampling, digitizing, and storage of each point must all be completed in a time span less than the sampling interval. For high time resolutions—sample intervals of hundreds or even tens of nanoseconds—there isn't much time for conversion of each point.

The exception in real-time digitizing is the scan conversion technique. Scan converters offer much

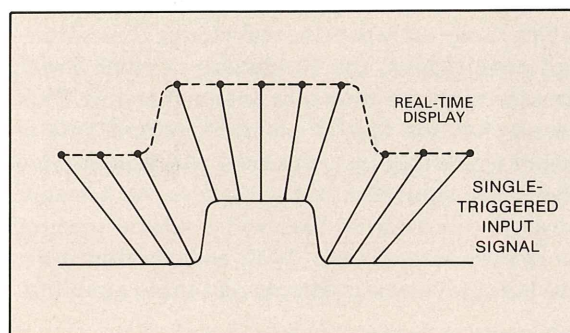


Fig. 8. In real-time sampling, samples are taken one after the other, in order, from the beginning of the signal acquisition to its end.

Basics of choosing ...

higher speed digitizing than other techniques such as flash conversion. However, scan conversion is not a continuous digitizing technique. A scan converter takes a snapshot sampling of the waveform and then spends a block of time doing the conversion of all samples as a batch rather than on the continuous sample-by-sample basis of other real-time digitizers.

Very high effective digitizing rates can also be achieved with equivalent-time sampling techniques. Equivalent-time sampling, however, requires that the waveform be repetitively triggerable. With the waveform being acquired repetitively, samples can be taken at a slow rate, a few samples per acquisition in either a random or sequential order. This allows a composite waveform of denser sampling to be built up over many repetitions. The process is illustrated further in Fig. 9.

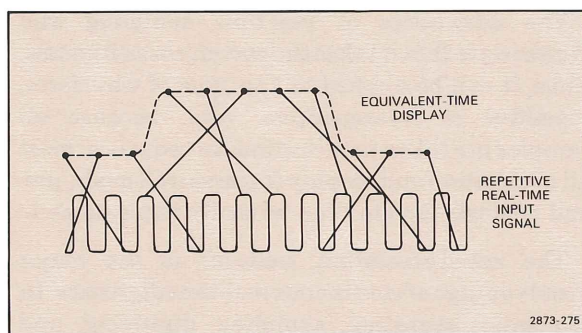


Fig. 9. *Equivalent-time sampling (random order shown) takes a few samples from each of numerous acquisitions of a repeated waveform and then assembles the samples into a representation of one acquisition (dotted line).*

Equivalent-time digitizing is often used in DSOs because of its high effective bandwidth. The limitation, however, is that it can only be used to its full range on repetitive waveforms. For single-shot acquisitions, the bandwidth is much lower since the digitizer must take data in real time. This means that the fastest real-time sample rate is simply the actual (not effective) real-time sample rate of the equivalent-time digitizer. As a result, the single-shot digital bandwidth will be one-half the actual sample rate. With today's digitizers, that still provides a moderate real-time capability.

More answers and faster

Whatever the method of sampling and digitizing, the desired end result is always the

same. The purpose is to express the waveform as a set of discrete values that can be stored in digital memory.

Beyond this simple goal, many waveform digitizers and DSOs also carry some on-board intelligence for performing additional waveform processing. Signal averaging, enveloping, and the use of electronic cursors have already been described as common features. More on-board processing brings a variety of additional functions.

Such push-button functions as finding the maximum, minimum, mean, and RMS values of waveform arrays are becoming common on DSOs. Even such operations as waveform integration and differentiation can be accomplished from front-panel push buttons. Also, more advanced DSOs allow entry and storage of push-button sequences to create waveform processing programs within the instrument itself.

The ability to obtain waveform measurements at a push of a button is a significant step toward greater measurement productivity. No more counting screen divisions and multiplying by scale factors. And, no matter who pushes a button for a measurement, the measurement is done the same way every time by the instrument. This means greater measurement repeatability.

Automating with programmability

Yet another stage of sophistication is added by making the instrument's controls programmable. When this is done, instrument setups for various measurement configurations can be stored, then called up as needed. Again, productivity and repeatability are increased since the system can execute standard setups faster than a human operator.

Some instruments have settings storage provided internally. Pressing a few buttons causes the current settings to be stored by the instrument. Another button sequence allows the settings to be recalled and implemented by the instrument. When such settings programmability is provided, some means of interfacing to an outside controller is also invariably provided. Usually, this is via an IEEE Standard 488 instrument interfacing bus, or GPIB as it is more commonly called.

Instrument control and waveform data transfer over the GPIB opens another realm of measurement possibilities. Highly complex

measurement sequences can be reduced to programs that automatically set up the instruments, gather the data, and process it into results. The amount of data storage and processing that can be done now is essentially limited only to the computer and peripheral power you can bring to bear.

It's also at this stage of computerized waveform acquisition and analysis that the DSO begins to change. For fully automated measurements, there's really no longer a need for the oscilloscope display part of the DSO. A separate and simpler waveform monitor can be used on the few occasions where a quick look at the waveform is needed. So the DSO becomes, in many automated applications, simply a waveform digitizer.

Often, a waveform digitizer has controls similar to an oscilloscope for sample rate setting and input attenuation or amplification. But this is not always the case. A simple analog-to-digital converter board with some signal preconditioning and a sample clock added can function as a waveform digitizer. A programmable DMM with clocked measurement capability can even be used to effect waveform digitizing on a limited basis.

So, with all the possibilities, the choice of an instrument or device for waveform digitizing becomes complex. What should it be? A simple DSO, a programmable waveform digitizer, or something configurable from the board level?

Making the digitizer choice

While there is a tremendous variety of digitizer features available on the market, most are secondary in choosing a digitizer. An adequate job of waveform capture must be done before any other digitizer feature can be used. As a result, digitizing capability becomes the primary consideration in waveform digitizer selection.

Know your waveforms. Choosing the right digitizer for your needs hinges on, first and foremost, recognizing the types of waveforms you'll be dealing with. This will tend to steer you to one type of digitizing method or another, depending on the following general rules—

- For transients or nonrepetitive waveforms, real-time digitizing is required.
- For repetitive waveforms, either real-time or equivalent-time digitizing can be used.
- For repetitive waveforms above about 50 MHz, equivalent-time digitizing is usually more economical than real-time methods.

Of the above rules, the first one is hard and fast. With transient or nonrepetitive events, there's no chance for a second look. Digitizing has to be done as the event occurs. This makes real-time digitizing the only choice for transient digitizing.

Real-time digitizing can also be used on repetitive waveforms. But there are limits. Real-time digitizing of a high-frequency waveform requires very fast sampling and conversion rates along with very fast memory for storing the data. For example, to capture just two samples per cycle on a 100 MHz sine wave requires a sampling interval of 5 nanoseconds. Each sample must be taken, digitized, and stored in under 5 nanoseconds! That means leading-edge, state-of-the-art digitizing and memory technology. A typically lower cost approach for repetitive waveforms is to use equivalent-time methods. And you can achieve higher effective sampling rates, as high as 10 gigahertz or more in some cases.

Look at resolution and record length.

Digitizer resolution is the distance between sample points in either an X or Y direction, where the Y axis is amplitude and X is time. There is also a subtle relationship between record length (the number of samples taken) and frequency resolution. This latter relationship is generally observable only when digital Fourier analysis is done. However, some general guidelines can be obtained by applying the Nyquist criterion and the record length.

First, however, let's touch on amplitude resolution. Amplitude resolution for digitally stored waveforms is determined by the number of bits used in digitizing. An 8-bit digitizer, for example, resolves amplitude to 1 in 256 distinct levels. So, if the vertical or voltage range of the digitizer is one volt, 3.9 millivolts (1 volt/2¹⁸) can be resolved. For more resolution, more bits are required, and a 10-bit (1 out of 1024) or 12-bit (1 out of 4096) digitizer might be specified.

As always, however, there are trade offs. And vertical resolution is no exception. Generally, the higher the digitizing rate, the fewer bits that can be used. This is simply a limit of currently available high-speed device technology. As a result, real-time digitizing at a 200-MHz rate is limited to 6- or 8-bits. But more bits and higher effective rates can be achieved with equivalent-time sampling; this is because the actual sample rate can be held low while sample density is built up over successive acquisitions of the repetitive waveform.

Basics of choosing ...

Horizontal or time resolution is the time interval between samples on the acquired waveform. This is given by the inverse of the sample rate and can also be computed by dividing record duration by the number of samples in the record

When specifying a digitizer for time and amplitude measurements, it's important to specify vertical and horizontal resolutions adequate for definition of waveform detail. To make rise-time measurements, for example, the sample rate has to be fast enough to place more than just a few samples on the pulse's transition. The more samples on the rise, the better it's defined and the greater the measurement resolution. But this depends on adequate vertical resolution too. Defining rise time depends as much on being able to find the 10% and 90% amplitudes of the pulse with the desired resolution.

The range of choice for vertical resolution is somewhat limited. Typically, 6-, 8-, 10-, and 12-bit digitizers are available. This is narrowed to 6 or 8 bits for high-speed real-time digitizing. However, with a 6-bit digitizer, vertical resolution is still one part in 64.

Also, range of vertical input sensitivity plays an important part in waveform resolution. Digitizers usually have a fixed full-scale input value, for example 1 volt full scale. This means that, for a wide range of signal amplitudes, some input signal conditioning is needed to scale signals as close as possible to the digitizer's full scale. Acquiring waveforms at or near full scale ensures best amplitude definition on the waveform.

For time resolution, there are two things to consider—record length and sampling rate. Record length is the number of waveform points or samples acquired and is usually a power-of-two number—128, 256, 512, 1024, or 4096 points. Some digitizers have a fixed record length and sample rate is varied, especially in the case of DSOs, by the horizontal time-base setting. For example, for a digitizer with a 512-point record length and a time-base setting of 50 microseconds/division for 10 horizontal divisions, the sample interval or time resolution is $(10 \cdot 50\text{E-}6)/511$, or 0.978 microseconds. In other digitizers, both record length and sample rate are directly selectable, giving you a little more acquisition flexibility.

It is important to match record length, sample rate, and record duration capabilities to your acquisition needs. A transient having a fast rise

and slow exponential decay requires more record length than short duration pulses and most types of repetitive waveforms. You need a fast sample rate for resolution on the fast rise and a long record length in order to contain the slower portion in the record as well.

Meeting Nyquist and bandwidth criteria.

Bandwidth is a familiar specification for analog instruments and applies to waveform digitizers as well. A digitizer's analog input circuitry has a bandwidth which has the same implication as bandwidth in any other instrument.

The digitizer's sample rate relationship to waveform frequency content is also important. The critical frequency is called the Nyquist frequency, and it is equal to half the sampling rate. This Nyquist frequency is, essentially, the digital counterpart of bandwidth.

Basically, the Nyquist frequency is the highest frequency component definable by sampling. If you acquire a waveform having frequency components above the Nyquist frequency, those higher components will be aliased to appear below the Nyquist frequency as low-frequency components. This has minimal impact as long as the major frequency components of the waveform already exist below the Nyquist frequency. However, in extreme cases, loss of significant high-frequency content through aliasing can cause stretching of transitions and rounding of waveform corners. The result is similar to exceeding the bandwidth specification of an analog instrument, except high frequencies reappear as low frequencies instead of being attenuated.

In making a digitizer choice, several issues must be taken into account regarding Nyquist frequency. First of all, the Nyquist criterion states that it takes only two samples per cycle to define a sinusoid in terms of frequency, magnitude, and phase. In other words, sampling can define waveforms of multiple frequency content—pulses, square waves, etc.—up to a frequency limit corresponding to two samples per cycle (the Nyquist frequency).

As an example of applying the Nyquist criterion, consider acquiring a square wave. A square wave is made up of odd harmonics with amplitudes descending according to the reciprocal of the harmonic number. So the ninth harmonic is 9 times the frequency of the square wave and 1/9th

the amplitude of the fundamental component. Preserving the square wave up through the ninth harmonic requires a Nyquist frequency at least 9 times greater than the fundamental. That means a sampling rate 18 times greater than the square wave's frequency. If the fifteenth harmonic is desired, then the sampling rate must be 30 times greater.

For the square wave example, it's also important to remember that the digitizer input bandwidth must also be sufficient to pass all harmonics up through the last desired harmonic. The information has to get to the digitizer in order to be digitized. And, to ensure proper digitizing, the Nyquist frequency should at least equal the bandwidth if not be higher than the bandwidth. This is generally sufficient for capturing nonsinusoidal waveforms and single-shot events with high-frequency content that must be kept within the instrument bandwidth anyway.

But now think about what happens if you wish to acquire a sinusoid at or near the bandwidth of the digitizer. If the Nyquist frequency is the same as the bandwidth, you'll only get two samples per cycle on the sinusoid. While that may be sufficient to define it in the frequency-domain, two samples per cycle is woefully short of providing usable time-domain resolution. With a DSO this becomes graphically clear when the sampled waveform is displayed. It looks like a jagged mess instead of a sinusoid.

What is needed for sinusoids, and especially for waveforms that are just going to be digitally stored

and displayed, is substantial oversampling. To achieve this, the Nyquist frequency needs to be considerably higher than the bandwidth of the instrument. This leads to many samples per cycle for any sinusoid captured within the bandwidth of the digitizer.

Typically, digitizers used for capturing transients are real-time digitizers and exhibit sampling rates that result in Nyquist frequencies near or somewhat above the rated bandwidth of the instrument. General purpose digitizers for repetitive waveform acquisition are usually equivalent-time digitizers and have very high effective sampling rates that place the Nyquist frequency well above the instrument bandwidth. In either case, you need to take into consideration the impact of both bandwidth and sampling rate on your particular waveform acquisition needs.

The final comparison. Vertical and horizontal resolution, record length, bandwidth, Nyquist criterion, equivalent-time or sequential digitizing—all are crucial to adequate waveform capture. They determine requirements that must be met before other special features—such as enveloping and pre- or post-triggering—can become useful.


In order to select a waveform digitizer with a feature set adequate to your needs, it's important to set an upper limit on the types of waveforms you are going to acquire. Then convert that upper limit to a table of necessary digitizer attributes—resolution, record length, Nyquist frequency, etc. That table will define your basic, indispensable

Characterizing electromagnetic transients discussed

In his 1980 Master's Thesis, William C. Goers, Jr., details work done in analyzing electromagnetic transients. The work was supported under contract by the Electric Power Research Institute and done by Texas A&M University. The goal was to characterize and quantify electromagnetic transients in the power substation environment. The resulting data would then provide information for designing EMP hardened digital control equipment for the power station environment.

Mr. Goers, Jr., discusses several aspects of the project in his thesis. However, the major thrust is data reduction and analysis. In this area, such

topics as data record time tying, deconvolution, filtering, transfer function correction, and extracting the measurement system transfer function from the data are covered. The discussion is detailed and supported with numerous examples of raw and processed data.

A copy of this thesis, **Characterization of Electromagnetic Transients in Power Substations**, by William Chester Goers, Jr., is available through interlibrary loan services. For information on availability, contact Inter-Library Services, Sterling C. Evans Library, Texas A&M University, College Station, Texas, 77843. 

Basics of choosing ...

digitizer needs. A final digitizer choice can then be made based on other optional features.

To help you get started on making a waveform digitizer selection, fill in Table 1 provided with this article. Special care should be taken on the MINIMUM BANDWIDTH and SENSITIVITY entries. Too often, these are underspecified, resulting in a system that fails to convey adequate signal fidelity.

Once Table 1 is completed, you can compare your requirements to the digitizer specifications in Table 2. Undoubtedly several digitizers listed there will meet your basic requirements. But, before making a final selection, there are several other issues that need to be considered. These tend to be issues that cannot be neatly specified or are specified in various manners depending on digitizing method or application. One issue is accuracy, often referred to as effective bits in

TABLE 1
DIGITIZER SELECTION CRITERIA

WAVEFORM ACQUISITION NEED	REQUIRED WAVEFORM DIGITIZER ATTRIBUTES
<ul style="list-style-type: none">• Transient or nonrepetitive waveforms, enter REAL TIME or Repetitive (periodic) waveforms, enter REAL TIME or EQUIVALENT TIME.• Enter highest significant frequency component.• Multiply bandwidth by 2 (by more for strictly display uses) and enter result.• Required vertical resolution (1 part in 2^n, where n is number of bits), enter number of bits. e.g., 6-, 8-, 10-bit.• Sensitivity (volts full scale), enter highest and lowest signal amplitudes to be captured.• Record length, enter number of waveform samples (usually 128, 256, 512, or 1024) that, when multiplied by 1/sample rate, provides sufficient time duration to capture the waveform.• Instrument control and data I/O, enter interface type (e.g., GPIB).	<p>TYPE: _____</p> <p>MINIMUM BANDWIDTH: _____</p> <p>SAMPLE RATE: _____</p> <p>NUMBER OF BITS: _____</p> <p>SENSITIVITY: HI: _____ LO: _____</p> <p>RECORD LENGTH: _____</p> <p>CONTROL and I/O: _____</p>
OPTIONAL FEATURES	CHECK FEATURES DESIRED
<ul style="list-style-type: none">• Multiple waveform storage• Oscilloscope display• Cursor measurements• Settings storage• Programmable settings• Built-in signal processing• Envelope mode• Pre- and post-triggering• Sample rate switching• Roll mode	_____ _____ _____ _____ _____ _____ _____ _____ _____


TABLE 2
DIGITIZER COMPARISON CHART

DIGITIZER FEATURE	DIGITIZER MODEL								
	336	390AD	468	5D10	5223	7D20,7D20T	7612D	7854	7912AD
Digitizing Technique	Successive Approx.	Dual-Stage Flash	Flash	Successive Approx.	Successive Approx.	CCD/Successive Approx.	EBS	Successive Approx.	Scan Conversion
Sampling Method	Equivalent Time (0.1ms/div and faster)/ Real Time (below 0.1ms/div)	Real Time	Real Time	Real Time	Equivalent Time (50 μ s/div and faster)/ Real Time (below 50 μ s/div)	Equivalent Time (1 μ s/div or faster)/ Real Time (2 μ s/div or slower)	Real Time	Equivalent Time/ Real Time with 7B87 Plug-in	Real Time
Analog BW	50 MHz	15 MHz	100 MHz	100 kHz	10 MHz	70 MHz	80 MHz*	400 MHz*	500 MHz*
Maximum Real-time Sample Rate	1 Ms/sec	60 Ms/sec	25 Ms/sec	1 Ms/sec	1 Ms/sec	40 Ms/sec	200 Ms/sec	500 ks/sec	100 Gs/sec
Maximum Equivalent-Time Sample Rate	2 Gs/sec	-	-	-	5 Gs/sec	2 Gs/sec	-	100 Gs/sec (5000 Gs/sec with 7S12)	-
Vertical Resolution (Number of bits)	8 bits	10 bits	8 bits	8 bits	10 bits	8 bits	8 bits	10 bits	9 bits
Vertical Sensitivity	Hi: ± 5 mV/div Lo: ± 10 V/div	Hi: ± 100 mV Lo: ± 50 V	Hi: 0.5mV/div Lo: 5V/div	Hi: 1mV/div Lo: 20V/div	Hi: 10 μ V/div* Lo: 20V/div	Hi: 5mV/div Lo: 5V/div	Hi: 10 μ V/div* Lo: 20V/div	Hi: 10 μ V/div* Lo: 20V/div	Hi: 10 μ V/div* Lo: 20V/div
Record Duration	2 sec to 500 ns	820 sec to 68 μ s	50 sec to 20 ns	500 sec to 1 ms	50 sec to 200 ns	200 sec to 500 ns	2048 sec to 10.24 μ s	50 sec to 10 ns	10 ms to 5 ns
Record Length (Number of points)	1024	2048 to 4096	256 to 512	256 to 1024	254 to 1016	1024	256 to 2048	128 to 1024	512
Number of Input Channels	2	2	2/1	2	4/2/1*	2	2	4/2/1*	1
Number of waveform Storage Locations	2 to 18	2	2 to 4	1 to 6	2 to 4	6	2 to 16	10 to 40	1
Display	Oscilloscope	External Monitor	Oscilloscope	Plugs into Oscilloscope	Oscilloscope	Plugs into Oscilloscope	External Monitor	Oscilloscope	External Monitor
Cursor Measurements	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Settings Storage	No	No	No	No	No	Yes	No	No	No
Programmable Settings	No	Yes	No	No	No	Yes	Yes*	Mainframe Settings	Yes*
GPIB Available	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Built-in Signal Processing Functions	Yes	No	Yes	No	No	Yes	No	Yes	Yes
Envelope Mode	Yes	No	Yes	No	No	Yes	No	No	No
Pre- and Post-trigger	Yes	Yes	Pre-trigger	Yes	Pre-trigger	Yes	Yes	Pre-trigger (7B87 Plug-in)	Post-trigger (7B92A Plug-in)
Sample-Rate Switching	No	Yes	No	No	No	No	Yes	No	No
Roll Mode	Yes	Yes	No	Yes	Yes	Yes	No	No	No

* Depends on plug-ins used.

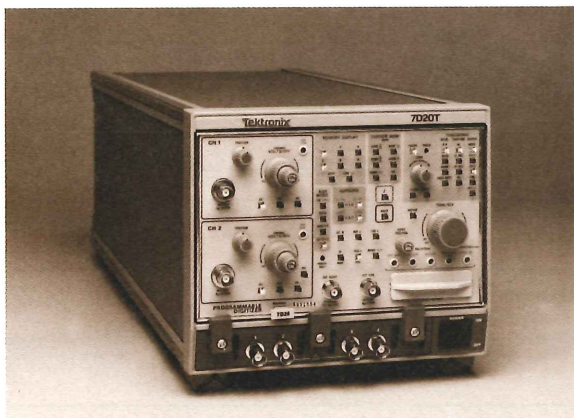
transient digitizers. Other issues to consider as well are ease of interfacing to a computer, availability of control and processing software for waveform acquisition and processing, and availability of application information, training, and service.

Referring to the numerous articles reviewed in this issue of **HANDSHAKE** will provide some

application information. Also, data sheets for specific digitizers can be requested via the reply card in this issue of **HANDSHAKE**. However, for the fastest response to your questions, contact the Sales Engineer at your local Tektronix Field Office. 

By Bob Ramirez,
HANDSHAKE Staff.

7D20 offered in new monolithic digitizer configuration




The 7D20 Programmable Digitizer plug-in unit was originally offered as a means of turning any 7000-Series oscilloscope into a waveform digitizer. Now, this same plug-in is being offered by itself as a standalone, dual-channel programmable digitizer.

The 7D20T consists of the standard 7D20 Programmable Digitizer unit plugged into a newly designed power supply/interface module. There's no need to plug it into an oscilloscope. The 7D20T

can be used as either a bench top or rack mounted programmable waveform digitizer and provides single-shot capture of signals up to 10 MHz or repetitive waveform acquisition for signals up to 70 MHz. Other digitizing features include pre- and post-trigger capabilities, signal averaging, and enveloping.

7D20T connection to an IEEE-488 bus can be via either the front-panel or rear-panel GPIB connector. There are also three rear-panel BNC connectors that provide X, Y, and Z outputs for use with an X-Y display monitor. BNC connectors are also provided for Hold Next Reset input and Hold Next Enable output. Four additional BNC connectors are wired through from the rear panel to the front panel for routing input and output signals to the front panel in rack mounted installations.


For a data sheet on the 7D20T, check the appropriate square on the reply card in this issue of **HANDSHAKE**. Price and ordering information can be obtained by contacting your local Tektronix Sales Engineer or the Tektronix Sales Representative for your country. 

7912AD used in semiconductor pulsed-laser annealing studies

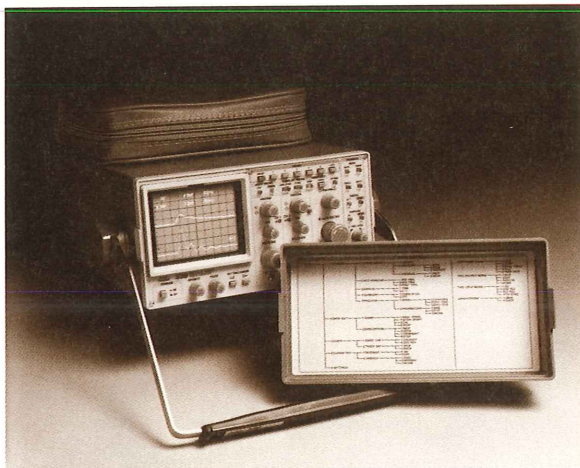
Annealing plays an important role in semiconductor production, and the prediction and control of the annealing process continues to be a subject of considerable study. In particular, the dynamics of annealing, and especially the velocity of material resolidification, are of high interest and importance. In fact, resolidification velocity is a primary parameter in segregation, trapping, and phase separation of impurities in semiconductors as well as being an influence on the defect structure of the annealed material.

A recent American Physical Society paper takes a close look at capturing and analyzing data describing pulsed-laser annealing dynamics. A Tektronix 7912AD Programmable Digitizer is

used to capture transient electrical conductance data during annealing melt and resolidification. Captured data is fed directly to a minicomputer for immediate analysis after each laser shot to determine melt depth and resolidification velocity.

The authors—G.J. Galvin, M.O. Thompson, J.W. Mayer of Cornell University; P.S. Peercy of Sandia National Laboratory; and R.B. Hammond and N. Paulter of Los Alamos National Laboratory—discuss the details of these annealing experiments in "Time-resolved conductance and reflectance measurements of silicon during pulsed-laser annealing," **PHYSICAL REVIEW B**, 15 Jan. 1983, p.1079. 

Sony/Tektronix 336 Digital Storage Oscilloscope



Sony/Tektronix has a new portable digital oscilloscope. Here are some of its vital statistics:

- 50-MHz Dual Channel, Delayed Sweep
- 50-MHz Equivalent Time Storage Bandwidth
- 1 Megasample/second
- Two 1Kbyte Waveform Memories
- CRT Readout
- Pre-, Mid-, and Post-Trigger
- Menu Driven Operation
- Cursor Measurements
- Waveform Processing:
 - CH 1 + CH 2 Averaging Peak-to-Peak
 - CH 1 - CH 2 RMS Envelope Mode
 - CH 1 * CH 2 Mean Roll Mode
- Outputs for XY Chart Recorder
- 11 Pounds of Portability

Portable data acquisition

With the optional GPIB talker-only interface, and at only 11 pounds, the 336 is well suited for portable data acquisition and analysis. Many of its functions are menu driven, making the 336 easy to use. You can display analog or digitized waveforms, separately or together. Up to 18 waveforms can be stored if you have the GPIB option. In addition, the GPIB option includes a backup battery that saves stored waveforms and front-panel settings for a minimum of three days.

Self-contained waveform analysis


With its waveform processing capabilities, the 336 is a self-contained waveform analysis

instrument. Add the GPIB option, and it functions as a smart waveform acquisition machine. The 336 can upload its digitized waveforms to a GPIB controller, such as the Tektronix 4052A or the Tektronix 4041, or it can transmit its waveform data to a data storage device in a controllerless GPIB system. The 336 can also drive a standard x-y plotter or it can operate in roll mode as an electronic strip chart.

Practically runs itself

In addition to the easy, menu-driven operation, the 336 has both vertical and horizontal autoranging.

Two buttons on the front panel control the cursors, and their vertical and horizontal positions are displayed in real units of time and voltage. The same display contains readouts of the vertical and horizontal scale factors.

To find out more about this powerful, easy-to-use, portable data analysis instrument, contact your local Tektronix Sales Engineer. 

Putting waveform digitizers to work in R&D

If you were to look at a brochure on waveform digitizers and measurement systems, you'd probably find a few introductory paragraphs reading something like this:

"Digital Storage Oscilloscopes, or DSOs, offer many enhancements over standard oscilloscopes. Multiple waveform storage and redisplay, special acquisition modes, cursor measurements, and even some onboard waveform processing are all combined to extend your day-to-day measurement capabilities. However, for DSOs and waveform digitizers in general, full measurement and analysis potential is not realized in the instrument alone.

"Full potential is realized in a systems environment. This is a potential for both general-purpose and special capabilities far beyond anything ever provided before in scientific instrumentation. And, especially for R&D applications, the speed and quantity of data analysis possible mean far more avenues of exploration in much shorter time. The measurement and analysis process is streamlined."

Sound like smooth sales talk? Or is there really something to it?

In reality, there's a lot to it. The potential for streamlining R&D efforts becomes more apparent as you consider what a measurement system is and what its implications are. Numerous case histories, some reviewed elsewhere in this issue of **HANDSHAKE** and one detailed later in this article, further attest to the power of waveform digitizing and processing. While these applications differ markedly, from retinal pattern analysis to power station transient recording, they all depend on the same basic measurement system functions.

The basic measurement system

Any measurement system, simple or complex, can be reduced to three primary functions. These functions appear at the apexes of the measurement triangle shown in Fig. 1.

Looking at a traditional system, a standard oscilloscope plays the acquisition part in Fig. 1. All else is provided by the operator. The operator controls the instrument or communicates with it by adjusting settings. The instrument in turn

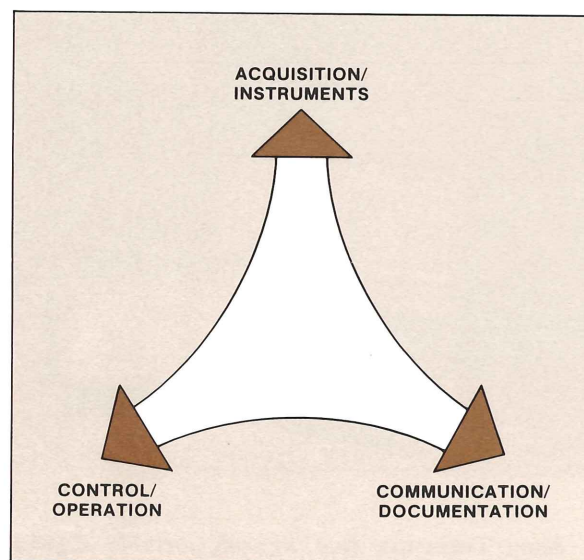


Fig. 1. The fundamental measurement system.

communicates with the operator via CRT readout and waveform display. The operator and the oscilloscope work in combination as a system. But, in general, the results rest solely on the operator's skills and waveform analysis capabilities.

The same basic system functions of Fig. 1 apply when a DSO or waveform digitizer is used as the acquisition instrument. However, the tasks of operation, control, communication, and documentation can be automated to a large degree. Tasks demanding high skill or specialization can often be reduced to push-button or menu-selection operations.

Operating digitally is the key factor, and the waveform digitizer is the starting point. It converts analog signals to digital representations. Not only is the digitized waveform easier to store, but it's also in a form that can be transferred or communicated to a computer. And, with appropriate signal processing software, digitized waveforms can be added, subtracted, multiplied, divided, integrated, differentiated, convolved, correlated, and further analyzed in depth.

While some analysis may be done in the digitizer itself, most advanced or involved analysis is done with an interfaced computer and its software. This same computer and software can also provide the

control and operation functions indicated in Fig. 1. This is most often done via an IEEE-488 instrument interface. In the simplest cases, the control goes no further than transferring measurement data from the instrument to the computer. However, if the measurement instrument is programmable, full instrument operation and control can be exercised from the computer.

The computer and peripherals can also provide communication and documentation of measurement results. With a graphic terminal and hard copy unit or plotter, waveform data and the results of waveform calculations can be plotted. This is typically more efficient and convenient than previous recording methods such as CRT photography. Also, large blocks of data can be either stored in memory for later reference or output to a printer or other hard copy device. Again, this is certainly a more efficient approach than requiring an operator to laboriously hand copy data into a project notebook.

In short, through digital means, the entire measurement system triangle of Fig. 1 can be

automated. The measurement functions themselves—acquisition, control, documentation—don't change. They're just done more efficiently.

More data, faster for research

For research, the impact of going digital means more power. Waveform digitizing allows full waveform capture in a format ideal for numerical analysis of parameters. Programmable instruments and signal switchers offer the capability of multiple measurements and rapid data collection with a high degree of repeatability from experiment to experiment. And digital memory provides quick storage and retrieval for massive amounts of data. More data can be collected at far greater resolution than possible with traditional standalone instruments and manual recording methods. More avenues can be explored in a much shorter time.

Consider simple voltmeter measurements as an example. The operator must interpret and scale the readings, then write each reading down. This takes a minute or more for each reading. The same operations done under software control take only a few seconds, in some cases only a few milliseconds.

High-speed waveform capture and logging


How quickly waveforms can be captured and logged out to a peripheral storage device depends on a number of things. There's the actual speed of the instrument used in capture—how quickly it can convert the waveform, prepare it for output, and do the actual transfer over an interface. Also, logging speed depends on the software and computer used and the speed of the storage system. How rapidly can the system read data from a bus, convert or format it, and store it?

Typically, systems that deal in binary data offer the fastest data transfer rates. This is because numbers expressed in binary require fewer bytes than numbers expressed in ASCII format. This means fewer bytes of data to transfer. And, if the system software has provisions for directly reading and storing binary data, the transfer rate is maintained. On the other hand, system software that handles only ASCII data requires additional time for converting binary to ASCII.

The Tektronix 7912AD Programmable Digitizer operating in a system with TEK SPS BASIC software, offers a good example of a waveform acquisition system using binary data transfer.

Waveform data from the 7912AD is in binary, and TEK SPS BASIC includes commands for directly reading binary data from instruments.

In cases where you want to log waveforms as quickly as possible to storage, the ADLOG command can be used to directly log raw 7912AD waveform data to a disk. High throughput is achieved by using the 7912AD REPEAT mode and the DMA (Direct Memory Access) capabilities of the GPIB interface. The waveform transfer rate will vary with controller type, instrument settings, and transfer mode. Depending on 7912AD writing beam intensity, from 6 to 20 waveforms per second can be transferred with ADLOG.

For additional transfer speed, ADLOG also has a fast option. This provides about a 20% increase in logging rate. To achieve this increase, the FAST option instructs the internal disk driver to begin writing to the disk without the additional step of checking disk head positioning. Because of this, the FAST option should be used only when logging data to a disk reserved only for waveform storage. 

Putting waveform digitizers ...

The same orders of speed can also be achieved in acquiring entire waveforms. This is covered in "High-speed waveform capture and logging" accompanying this article.

But collecting more data in a shorter time is only the beginning.

Where an operator once had to stare at a display, interpolating data and trying to draw inferences from it, the process now can be carried out by computer program. Complete waveform capture and analysis sequences can be done in seconds.

Pulse analysis, for example, can be fully automated as indicated in Fig. 2. The pulse is captured under program control, transferred to the computer, and an analysis program run to compute the various parameters—rise time, fall time, width, etc. The whole process takes far less than a minute, including outputting a hard copy of the waveform data and results shown in Fig. 2. Or, instead of making a hard copy, the results can be stored on a disk or tape as part of a larger data base.

Greater flexibility for development

Eventually, research yields a product idea or a method for improving on current products. It is at

this stage that measurement needs move across a line from research to product development.

The same type of measurement system with signal processing software is a boon to development as well. The flexibility of general-purpose instrumentation, such as a DSO, allows precise definition of the data acquisition or sensing requirements needed for the planned product. And general-purpose software allows zeroing in on the processing algorithms needed to reach final results. Once the specifics are determined, they can be converted to hardware and firmware optimized for the product.

Perhaps the best way to demonstrate the process is by an actual case history.

The Eyedentify case

In 1974 Mr. Robert "Buzz" Hill was assisting his father, Dr. R.V. Hill, in ophthalmological research. Dr. Hill needed a method of precisely positioning the human eye for serial photography of the retina, choroid, and optic nerve. Buzz Hill's role was to provide the electronics and instrumentation skill for position detection.

The proposed approach was to use the distinctive vascular structure of the retina as a

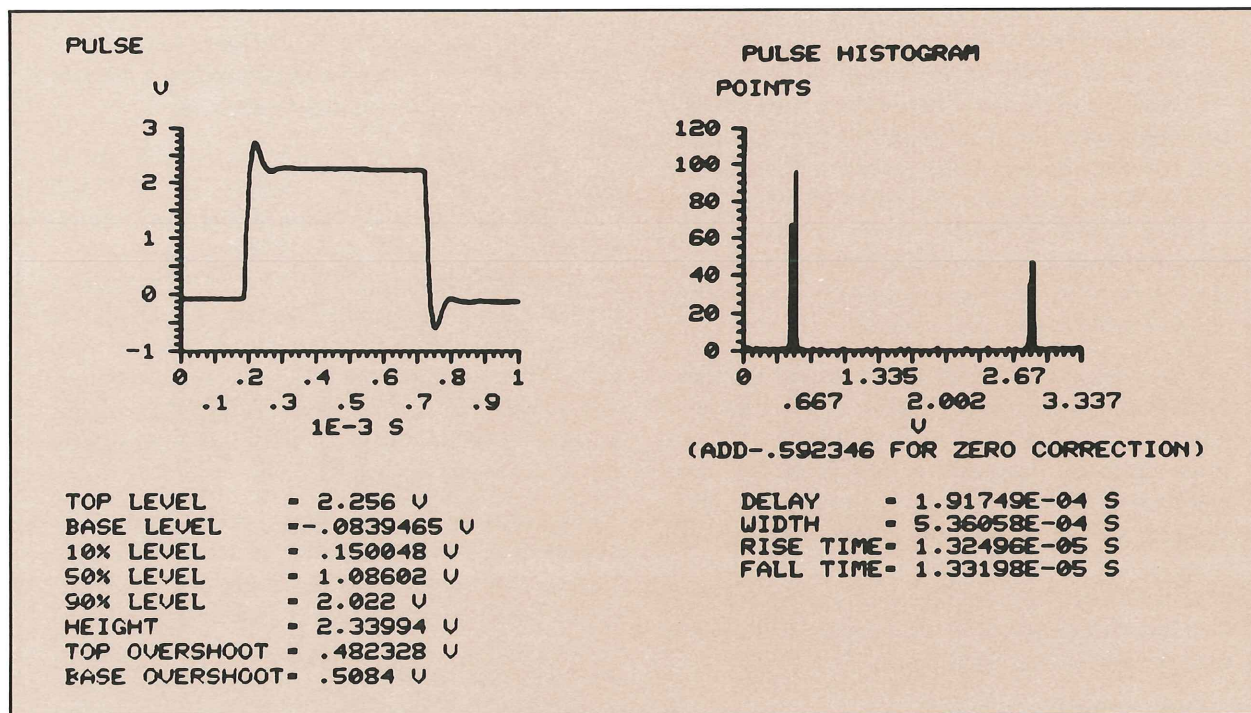


Fig. 2. Example of pulse analysis results obtained in far less than a minute with a waveform digitizer and signal processing software. Not only is the speed greater than with traditional manually operated instruments, but notice the higher resolution of the results. And repeatability is high as well.

positioning reference. A light beam was scanned around the retina and the reflection from the retina detected (see Fig. 3). The amplitude of the reflection varies according to the vascular pattern. Thus, the waveform from the detector is a linear plot of vessel structure and location around the retina of the subject's eye.

The trick at the time was to capture the retinal scan waveform and somehow analyze it for matching and comparison to previous scans. An oscilloscope and an operator skilled in analyzing retinal scan waveforms would have been the standard approach in 1974. However, a new approach was available. Tektronix had recently introduced the first commercially available digitizing oscilloscope. This instrument, along with a desktop computer and signal processing software, promised a number of new and exciting possibilities—scans could be captured quickly, they could be stored easily on convenient magnetic tapes, and best of all, analysis of the retinal scans could be done automatically in the computer. In fact, the now easy application of advanced techniques, like Fourier analysis, held further promise of analysis and diagnostic techniques never tried before.

Buzz Hill went to work with this new capability. In his words, "I was very fortunate to have a

system available with friendly software. That made it easy to begin experimenting and learning very quickly."

Fourier analysis offered a new way of looking at retinal scan data. But more importantly, it made correlation an easily applied approach for quickly matching retinal scans.

Before long, retinal scans from a number of study subjects had been collected and analyzed. Buzz Hill noticed, among other things, that each subject's retinal scan differed from all others. Even the right and left eye scans for an individual differed.

An idea for a product was being born. Could it be that each person's retinal vascular pattern, like a fingerprint, was unique from all others in the world? If so, there existed the possibility for a new type of automatic identification system.

A literature search was done. Sure enough, work had been published several decades earlier on retinal patterns. Thousands of retinal photographs had been painstakingly analyzed by hand. The conclusions: your retinal pattern does not change with age, and each pattern is unique to an individual, even among identical twins.

What remained now was to develop a product prototype. The general purpose digitizing

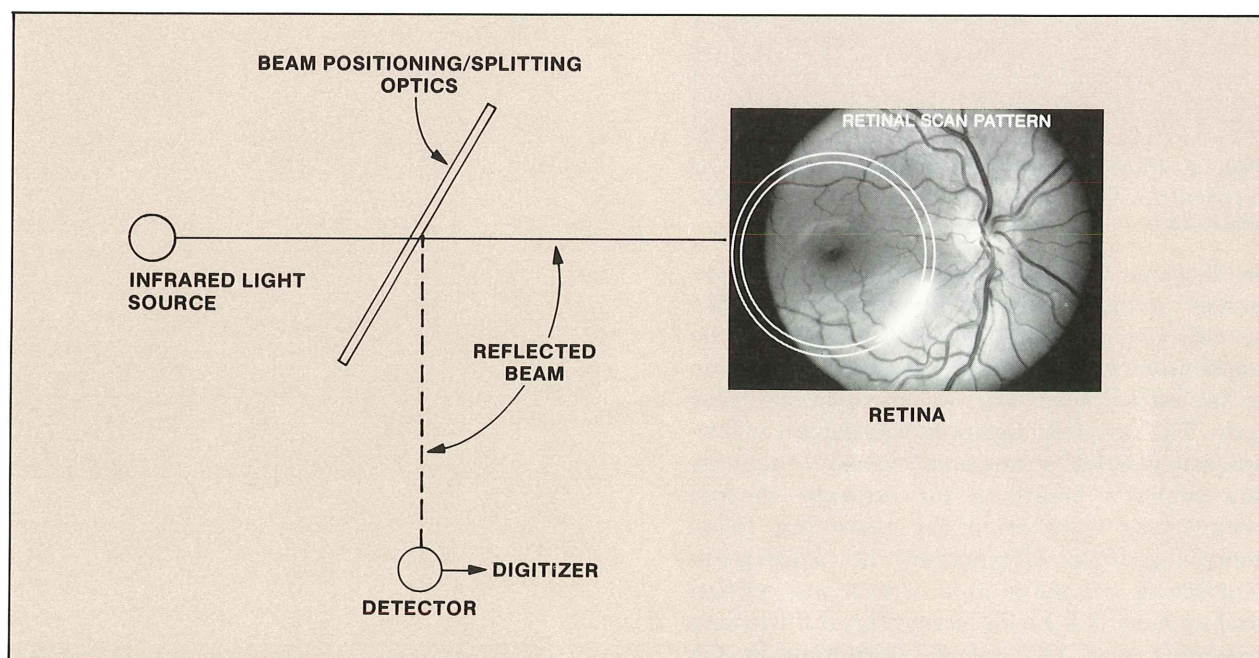


Fig. 3. Basic concept of collecting retinal scan data entails focusing the eye on a target while an infrared beam is scanned 360 degrees around the retina. The reflected beam is detected and digitized for software processing. (Retinal scan photo courtesy of Eyedentify, Inc., 1225 N.W. Murray Rd., Portland, OR 97229.)

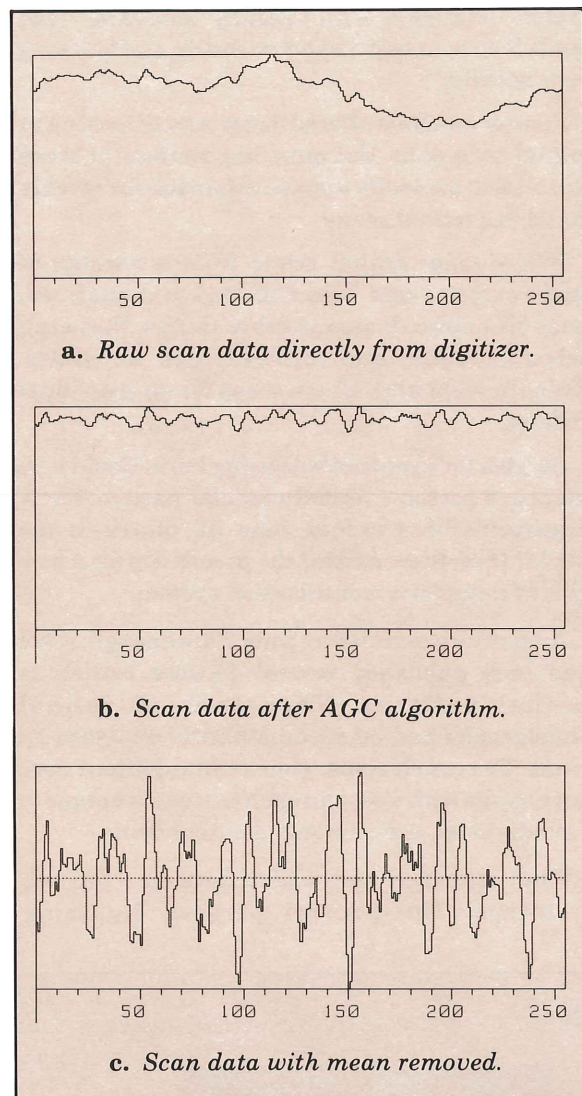



Fig. 4. Retinal scan data (supplied courtesy of Eyedentify, Inc., 1225 N.W. Murray Rd., Portland, OR 97229).

oscilloscope and waveform processing software proved invaluable for quickly zeroing in on the specific acquisition and processing needed for the application. It was found that acquiring 256 points of the retinal scan (Fig. 4a) provided sufficient data. The raw data, however, was subject to low-frequency perturbations from a variety of sources, the subject's breathing for example. Several techniques were tried for removing these perturbations. Ultimately an algorithm simulating automatic gain control was written and applied with good success (Fig. 4b). The next operation was DC removal, resulting in the reduced retinal scan data shown in Fig. 4c. Matching subsequent retinal scans is done with a correlation routine.

With the basic process developed via general-purpose waveform digitizing equipment and signal processing software, patents were applied for and received. Then a basic unit was built.

The identification process involves an enrollment scan. This is a retinal scan of one or both eyes that is processed and filed under a PIN (personal identification number). Actual identification occurs at any time later when the subject enters his or her PIN and looks into a binocular-like ICAM (eye camera). The ICAM does a retinal scan and passes the scan waveform through an analog-to-digital converter to a microprocessor. The scan waveform is correlated with the enrollment waveform filed under the entered PIN. A low degree of correlation results in rejection. A high degree of correlation (the scans match) results in identification, and the subject is granted entry or access.

While no part of the original digitizing oscilloscope system or its software appear in the final product, the concepts they uncovered are key to the product. And, just as importantly, they proved out the specialized processes needed for the product, thus minimizing false starts and speeding development time. 


By Bob Ramirez,
HANDSHAKE Staff.

Article explores digital storage in biomedical research

Almost since their inception, oscilloscopes have proved invaluable in biomedical research. When the first storage CRTs became available in the mid-1960s, biomedical researchers gained the additional capability of being able to capture single-shot or short-lived events for study.

Now, in this decade, the digital storage oscilloscope offers not only the advantage of being able to capture data and store it long term for study, but also the advantage of being able to manipulate the data digitally either in the oscilloscope or by transferring it to a micro- or minicomputer. With digital storage and processing, many things that could only be estimated with conventional scopes can now be directly measured. Plus digital storage scopes add many new waveform capture capabilities such as


roll mode, pre-trigger viewing, and bislope triggering.

These capabilities and their use in the biomedical field are discussed in an article which appeared in the December 1982 issue of **MEDICAL ELECTRONICS**. The article, by Les Hurlock of Tektronix and entitled "*Digital Storage Oscilloscopes in Biomedical Research*," also covered a specific example of using a digital scope's roll mode to retrieve data—such as ECG or EEG data—pre-recorded on an FM tape recorder. The roll mode allows scanning through the data and freezing on any portion of interest. For more details, you can obtain a reprint of the article by using the reply card in this issue of **HANDSHAKE**. 

Digitizers evaluated for recording high-voltage impulses

"Precise recording of nonrepetitive, microsecond duration impulses has always been a major problem in high-voltage impulse testing and digital techniques potentially offer a convenient solution." So begins a paper that recently appeared in **IEEE Transactions on Instrumentation and Measurement**, Vol. IM-32, No. 1, March 1983. The paper is entitled "*Measuring Properties of Fast Digitizers Employed for Recording HV Impulses*" and was authored by R.A. Malewski, Institut de Recherche d'Hydro-Quebec, Varennes, Que., and T.R. McComb and M.M.C. Collins, National Research Council, Ottawa, Ont.

The authors go on to point out that the convenience of transient digitizers is that they can be used directly with computer analysis and storage. The digitizer can be set to wait for an impulse, and when it occurs, the digitizer automatically converts it to digital words that can be processed, displayed, printed out, and stored. Also, digital correction techniques can be applied to improve the acquired data.

The authors note that the conveniences offered by digitizers are not directly available in the analog oscilloscopes traditionally used for high-voltage studies. At the same time, they also advise caution in specifying digitizers for high-voltage impulse applications. Primarily, digitizers tend to be specified on a repetitive waveform basis rather than on a transient waveform basis. The differences in methods of specification and some factors affecting digitizer performance in the arena of high-voltage insulation testing are detailed in the paper. Included in the data are evaluation results for the 8-bit 7612D Transient Digitizer from Tektronix. * 

* **HANDSHAKE** has learned that one of the authors, R.A. Malewski, has since acquired and evaluated a Tektronix 390AD Programmable Waveform Digitizer. He reports superior transient waveform vertical resolution from this 10-bit digitizer.

Getting the most out of TEK BASIC graphics—

High resolution contour plotting with TEK SPS BASIC

What's a contour plot?

Most of us are familiar with contour plots. Weather maps, hiking maps for wilderness areas, and aviation maps are just a few examples of contour plots that are used daily. The same kinds of maps can be used in science and engineering for such things as heat flow studies, ultrasonic measurements, circuit topology, etc. In general, contour plotting is a method for graphically representing three-dimensional data on a two-dimensional surface, like a piece of paper or the screen of a graphics terminal. CONT1.MAT is a program that simplifies the plotting process.

The array processing power and graphics flexibility of TEK SPS BASIC are used by the CONT1.MAT program to produce high resolution contour plots. The program reads data points $f(x,y)$ and some descriptive information about the data from a disk file and then draws its display on the terminal. Display resolution is a function of both the data acquisition method and the amount of memory available in the particular computer being used. A unique feature of this program is that it generates contour plots with equal vertical and horizontal resolution.

Setting up the data file

Before data can be plotted, it must be stored in a disk file. Whether the data is calculated by a TEK SPS BASIC program or acquired from instrumentation over the GPIB, the two following statements within a program will write a data file, on a disk opened to logical unit 1, that can be used by CONT1.MAT:

```
WRITE #1,DX,DY,X1,X2,Y1,Y2,X$,Y$  
WRITE #1,Z
```

where...

Z = An array of DIMension Z(DX,DY) that contains the values $f(x,y)$ to be plotted.
X1 = Lower x boundary for $f(x,y)$.
X2 = Upper x boundary for $f(x,y)$.
Y1 = Lower y boundary for $f(x,y)$.
Y2 = Upper y boundary for $f(x,y)$.
X\$ = X-axis labeling.
Y\$ = Y-axis labeling.

The CONDAT.GEN program listed in Fig. 1 illustrates a way you can prepare data for the contour plotting program. Lines 100 and 110 dimension the data array (F), which is 60 elements by 60 elements in this example. (Note that TEK SPS BASIC array indices start at 0.) After selection of a name for the data file, the boundaries for x and y input values to the function to be plotted are set at lines 120 and 124, respectively. The x and y sample intervals for the plot are calculated at lines 122 and 126, respectively. You may notice that the sample intervals are based on the array dimension and the boundary values set at lines 120 and 124. Next the horizontal and vertical labels for the plot are defined. Then function values are mapped into the data array at lines 140 to 200. Finally the data file is written at lines 220 to 250.

```
10 REM ** CONDAT.GEN V1.0 27-JUN-83 - GENERATE TEST DATA **  
20 REM ** FOR THE CONT1.MAT CONTOUR PLOTTING PROGRAM. **  
90 REM -- SET UP ARRAY BOUNDS. SIZE IS LIMITED BY AVAILABLE MEMORY --  
100 DX=59:DY=59  
110 DIM F(DX,DY)  
115 PRINT "OUTPUT DATA FILE NAME:";INPUT FNS  
118 REM -- MAP USER UNITS TO ARRAY ELEMENTS AND DETERMINE --  
119 REM -- INCREMENTAL VALUE BETWEEN ARRAY ELEMENTS. --  
120 XL=1:XH=2  
122 XI=(XH-XL)/DX  
124 YL=1:YH=5  
126 YI=(YH-YL)/DY  
128 REM -- SET UP HORIZONTAL AND VERTICAL AXIS LABELING --  
130 HLS="X [MM]" : VLS="Y [CM]"  
140 FOR I=0 TO DX  
143 REM -- TELL THE USER HOW DATA GENERATION IS PROGRESSING --  
145 PRINT "I=";I  
150 FOR J=0 TO DY  
160 X=XI+XL  
170 Y=YI+YL  
180 F(I,J)=LOG(X*Y)*((SIN(X)^2)/Y)  
190 NEXT J  
200 NEXT I  
210 REM -- WRITE DATA TO THE FILE IN THE FORM REQUIRED BY CONT1.MAT --  
220 OPEN #1 AS DX1:FNS FOR WRITE  
230 WRITE #1,DX,DY,XL,XH,YL,YH,HLS,VLS  
240 WRITE #1,F  
250 CLOSE #1  
300 END
```

Fig. 1. CONDAT.GEN is a TEK SPS BASIC program that prepares a data file for the contour plotting program. The function to be plotted is defined at line 180.

How CONT1.MAT works

Once you've properly prepared a data file, you can use CONT1.MAT to generate a contour plot. Figure 2 shows interaction with the program, and Fig. 3 shows the resulting plot. Note that CONDAT.GEN was used to generate the file for this example.

Now let's see how the plot was generated. The program is listed in Fig. 4.

Setting up for plotting

First, the terminal screen is set up in lines 10 through 65 and you are asked for the data file name. The data file is then read and WAVEFORM WZ is set up in lines 80 through 130. The process of drawing and labeling the axes of the plot is made easier in TEK SPS BASIC through the use of a WAVEFORM construct.

```

CONT1.MAT - XM, U3-7.7.83-JB
FILENAME: ?PLOT1.DAT
MINIMUM Z VALUE: 0
MAXIMUM Z VALUE: .62891
# OF CONTOURS: ?13

CONTOUR VALUE 1 ?0
CONTOUR VALUE 2 ?0.05
CONTOUR VALUE 3 ?0.1
CONTOUR VALUE 4 ?0.15
CONTOUR VALUE 5 ?0.2
CONTOUR VALUE 6 ?0.25
CONTOUR VALUE 7 ?0.3
CONTOUR VALUE 8 ?0.35
CONTOUR VALUE 9 ?0.4
CONTOUR VALUE 10 ?0.45
CONTOUR VALUE 11 ?0.5
CONTOUR VALUE 12 ?0.55
CONTOUR VALUE 13 ?0.6

```

Fig. 2. Example of user interaction with CONT1.MAT. The program asks you to input the name of the file containing function data, the number of contour lines to draw, and the contour value of each line. File PLOT1.DAT was generated by the program in Fig. 1.

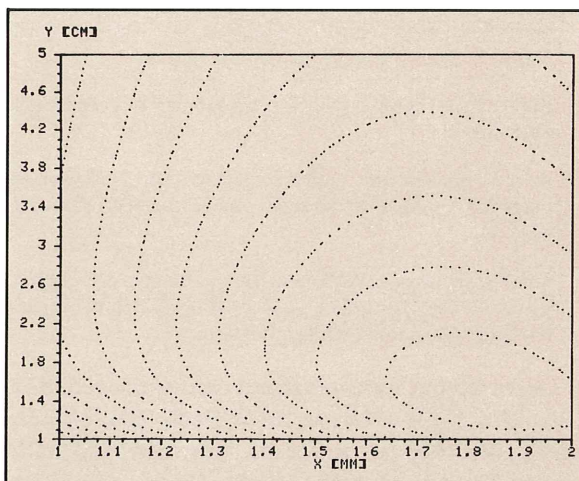


Fig. 3. Contour plots with equal horizontal and vertical resolution are produced by the CONT1.MAT program. This is a plot of $f(x,y) = \ln(xy)/(\sin^2(x)/y)$.

Lines 150 through 170 find the minimum and maximum function values in the data array. These values will help you decide on the contour values to plot. Of particular interest are lines 154 and 164. Often, function values will very nearly approach an integer value, yet the value will not be an integer. But when the value is printed by most BASICs, it will be printed as an integer! For

```

10 P$="CONT1.MAT - XM, V3-7.7.83-JB"
20 REM ** CONTOUR PLOT OF THE DATA IN A DATA FILE **
30 DATE D$;TIME T$
40 PAGE=1
50 PRINT P$,D$,T$;PRINT
60 PRINT "FILENAME: ";INPUT F$
65 TA=30
70 REM -- READ DATA FROM FILE --
80 OPEN #1 AS DX1:F$ FOR READ
90 READ #1,DX,DY,X1,X2,Y1,Y2,X$,Y$
100 DELETE Z=WAVEFORM WZ IS Z(DX,DY),XX,X$,Y$
110 XX=1
120 READ #1,Z
130 CLOSE #1
140 REM ---- SEARCH FOR MIN AND MAX VALUES OF Z ----
150 MI=MIN(Z);MA=MAX(Z)
152 ER$=""
154 IF VAL(STR(MI))<>MI THEN ER$=" +/- ROUND OFF."
160 PRINT;PRINT "MINIMUM Z VALUE: ";MI;TAB(TA);ER$
162 ER$=""
164 IF VAL(STR(MA))<>MA THEN ER$=" +/- ROUND OFF."
170 PRINT "MAXIMUM Z VALUE: ";MA;TAB(TA);ER$
180 REM ---- INPUT CONTOUR VALUES ----
185 PRINT
190 PRINT "# OF CONTOURS: ";INPUT NC
195 PRINT
200 DELETE CV=DIM CV(NC-1)
210 FOR I=1 TO NC
220 PRINT "CONTOUR VALUE";I;" ";INPUT CV(I-1)
230 IF CV(I-1)>=MI THEN IF CV(I-1)<=MA THEN 290
235 PRINT CHR(7)
240 PRINT "CONTOUR VALUE #";I;" ";CV(I-1);" IS OUTSIDE THE RANGE";
245 PRINT " OF DATA VALUES."
250 PRINT "PLEASE TRY AGAIN."
255 PRINT
260 GOTO 220
290 NEXT I
300 REM ----- DRAW GRATICULE -----
310 PAGE=1
320 VIEWPORT 100,900,100,750
330 WINDOW X1,X2,Y1,Y2
340 SETGR VIEW,WINDOW,GRAT 2,2,2,2,NOPL
350 GRAPH WZ
360 MOVE X2,Y1
370 DRAW X2,Y2,X1,Y2
380 WINDOW 0,DX,0,DY
390 REM ---- SEARCH FOR HORIZONTAL CROSSINGS ----
400 DELETE V=DIM V(DX)
410 FOR I=0 TO NC-1
420 FOR J=0 TO DY
430 V=Z(0:DX,J)
440 X0=0
450 X=CRS(V(X0:DX),CV(I))
460 IF X=-1 THEN 510
470 MOVE X,J;DRAW X,J
480 X0=ITP(X)+1
490 IF X0>DX THEN 510
500 GOTO 450
510 NEXT J
520 NEXT I
530 REM ---- SEARCH FOR VERTICAL CROSSINGS ----
540 DELETE V=DIM V(DY)
550 FOR I=0 TO NC-1
560 FOR J=0 TO DX
570 V=Z(J,0:DY)
580 Y0=0
590 Y=CRS(V(Y0:DY),CV(I))
600 IF Y=-1 THEN 650
610 MOVE J,Y;DRAW J,Y
620 Y0=ITP(Y)+1
630 IF Y0>DY THEN 650
640 GOTO 590
650 NEXT J
660 NEXT I
670 WAIT
680 END

```

Fig. 4. CONT1.MAT is a TEK SPS BASIC program that produces contour plots. Contour map resolution depends on the number of data points, computer memory, and display resolution.

Getting the most ...

example, if the maximum value of $f(x,y)$ is 0.9999995 it will likely be printed as 1. Lines 154 and 164 make sure you know if any rounding has occurred in printing the minimum and maximum function values.

The number of contours to plot and the value to be represented by each contour line is input at lines 185 through 290. Lines 220 through 260 check the desired contour values to make sure they are not outside the range of values for $f(x,y)$.

Drawing the axes

The graticule for the waveform plot is drawn by lines 310 through 370. First, the size of the display, in terms of the locations of points on the graphics terminal, is set in line 320. Next, line 330 maps the

function input values to points within the VIEWPORT set in line 320. Axes are then drawn and labeled according to the limits set by the preceding WINDOW and VIEWPORT commands in lines 340 and 350. Finally, lines 360 and 370 complete the drawing of the graticule.

Drawing contour lines...twice

Now the contours can be plotted. Plotting is done in two stages: First, points are plotted row-by-row, and then they are plotted column-by-column. Initially it's hard to understand why the contour lines need to be drawn twice, but the reason becomes apparent as we continue to examine the program.

New ROM speeds and enhances 4050-series graphics



Add a new Graphics Enhancement ROM Pack to your 4050-series controller, and you get 65 new high-level graphics commands. Not only that, you get increased drawing rates—


Drawing Rate Increase (ROM vs. BASIC MOVE/DRAW)

	Vector	Dots
4051	27X	138X
4052/ 4052A	6X	39X
4054/ 4054A	14X	16X

Graphic transformations are also provided by the ROM pack for scaling, translation, and rotation of graphic images. Scale factors can be separately varied for the X and Y directions, and mirror images can be generated by using negative scale values.

Other features include—

- High density storage for large drawings (18,000 vectors in 4052/4054 with full memory).
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- Refresh text makes positioning labels on screen easy and flexible.
- Audio generation routines allow the 4050-series internal speaker to be used for a variety of sound effects.
- Utility routines are provided for such tasks as reading graphic images from tape, locating individual points, finding maximums and minimums, etc.

Users of 4051 systems should order the 4051R12 Graphics Enhancement ROM Pack. 4052/4052A and 4054/4054A systems use the 4052R12 Graphics Enhancement ROM Pack. For more details on upgrading your 4050-series graphics capabilities, contact your local Tektronix Representative or Sales Engineer. 

Line 380 prepares for plotting by mapping array indices to locations on the graphics terminal. Then the row-by-row plot is done in lines 400 to 520.

Line 400 sets up a single-dimensioned array in memory that contains the same number of elements as there are columns in the data array. The loop from 410 to 520 steps through the contour values to be plotted. The row of the data array for which points on the desired contour line will be plotted is selected by the loop from lines 420 to 510. Once a contour value and a row of the data array have been selected, the program is ready to plot points on a contour line.

CRS function does the trick

Line 430 copies the selected row of the data array to the single-dimensioned array. The CRS statement at line 450 then scans the single-dimensioned array to find a point corresponding to the selected contour value. If such a point is found, then the desired contour line passes through the region on the map represented by the selected row. The point is plotted, and then the single-dimensioned array is checked for more crossings. If the contour line does not pass through the region corresponding to the selected row, or if all crossings have been plotted, control is passed to statement 510, which selects the next row of the data array to check.

The TEK SPS BASIC CRS function is a powerful tool that makes it easy to generate a high resolution plot using a minimum of memory. Here's how the function does its job: CRS scans the single-dimensioned array, looking for an element equal to the desired contour line value. If the function finds such an element, its index in the array is returned. If the CRS function finds that two adjacent array elements contain values that "surround" the desired contour line value, it will linearly interpolate to return the index of the crossing point to the nearest tenth of an array location. Otherwise, if the desired contour does not cross the selected row, CRS returns -1.

We're half way there


The row-by-row plot is complete when the loop from lines 410 to 520 has been exited, indicating that all rows in the data array have been checked for all contour line crossings.

At this point, all contour lines should be visible on the screen. However, horizontal resolution can be up to ten times greater than vertical resolution.

To equalize vertical and horizontal resolution, a column-by-column scan of the array is performed in lines 540 through 660. The technique used to plot contour lines is similar to the process used for the row-by-row plot.

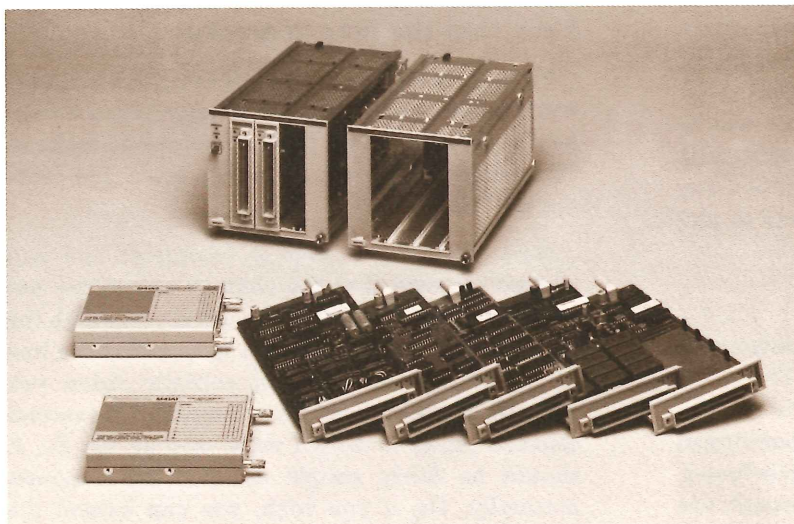
Now that the map is drawn...

Finally, after the map is drawn, the program waits for you to examine the display. If you want a hard copy of the plot, this is the time to make it. The program finishes execution when you press the RETURN key.

Now the contour plot is complete. You will probably notice that the contour values are not marked on the display. However, if you watch the graph being drawn, you will notice that the line corresponding to the first contour value you selected is drawn first, the contour for the second selected value is drawn next, and so on. So, it should be fairly simple to label the contours manually. Or, if you wish, you can extend the program to use TEK SPS BASIC Graphic Input with the terminal's crosshairs to label your map. 

*By Jerry Kryszek,
HANDSHAKE Staff, with
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CONT1.MAT Contour Plotting Program.*

New MI 5010 cards offer 12-bit digitizing, 16K memory



The MI 5010 Programmable Multifunction Interface is a GPIB-compatible card frame that accepts a variety of programmable special function cards. You can select various cards and custom configure your own programmable instrumentation with the MI 5010. Various cards are available—D/A converter, digital I/O, relay scanner, development card, etc. And now a programmable 12-Bit A/D card and a 16-Kbyte memory card are being added to the selection.

50M10 Analog-to-Digital Converter Card

The 50M10 is a 12-bit successive approximation A/D. Conversion time is 32 microseconds, giving the card a sample rate of 30 kilosamples/sec.

Analog input to the converter is through a front-panel connector. Three input amplifier ranges are provided plus a fourth 10X attenuated range. These ranges are as follows—

0.1 volt range	(-102.4 mV to +102.35 mV)
1.0 volt range	(-1.0240 V to +1.0235 V)
10 volt range	(-10.240 V to +10.235 V)
100 volt range	(-102.40 V to +102.35 V)

Resolution on any range is 1 part in 4096.

Converted data can be sent over the GPIB in volts or in decimal, binary, or hexadecimal format. A front-panel connector also allows transmission

of data from the 50M10 to other cards installed in the MI 5010. If the data is sent to a 50M50 Memory Card for buffering, the 50M10 A/D can be programmed in conjunction with the memory card as a waveform digitizer.

50M50 Memory Card


The 50M50 Memory Card contains 16 Kbytes of user accessible memory along with program configurable I/O ports and buffering. This allows the 50M50 to be configured over the GPIB for a variety of applications.

Four front-panel lines operate as the 50M50 data I/O pairs for transferring data between the 50M50 and other devices. These lines can be programmed to operate either as a single I/O pair for 16-bit words or as two different channels for 8-bit words. The I/O ports can be connected under program control to any of the 16 available data buffers. These buffers can be programmed to any length needed within the 16 Kbyte limit of total memory. Additionally, handshaking and external control lines are provided for interfacing the 50M50 in various input/output applications.

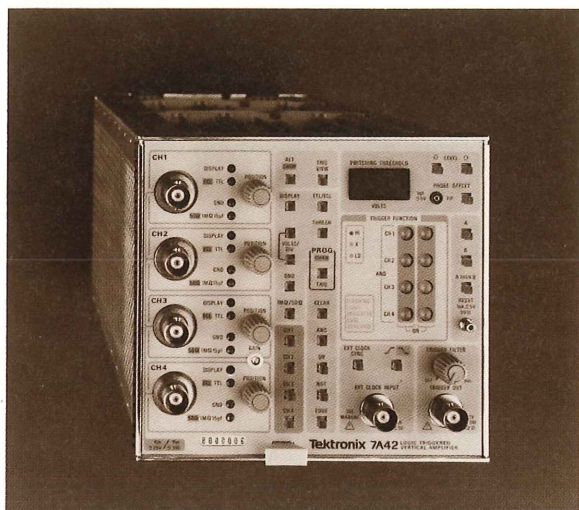
As a programmable digital buffer and memory, the 50M50 has broad applications in digital data acquisition and digital word generation. One typical application finds the 50M50 used to supply preloaded data to a 50M20 D/A Converter Card for

waveform synthesis. Another typical application pairs the 50M50 with the 50M10 A/D Converter Card to provide waveform digitizing capability.

For a data sheet on these and other special function cards for the MI 5010 Programmable Multifunction Interface, use the convenient reply

card in this issue of **HANDSHAKE**. Prices, ordering information, and further application information are available through your local Tektronix Sales Engineer or the Tektronix Sales Representative for your country. 

7A42 brings logic analyzer triggering to digitizers and oscilloscopes



The new 7A42 Logic Triggered Vertical Amplifier from Tektronix is a high-bandwidth, four-channel vertical amplifier for 7000-series oscilloscopes and digitizers. And it's also much more. The 7A42 offers a unique and powerful Boolean logic trigger capability that marries the high-resolution display of traditional oscilloscopes with the flexible triggering of a logic analyzer.


The 7A42 comprises four independent vertical amplifiers, each with a separate trigger channel. Switching thresholds for each channel can be independently set, and the trigger channels can be combined in any Boolean combination (e.g., NOT channel 1 AND channel 2 OR channel 3 AND channel 4).

There are also two independent trigger "functions" that can be separately programmed from the 7A42 front panel. Acquisitions can be triggered by either function or the two functions

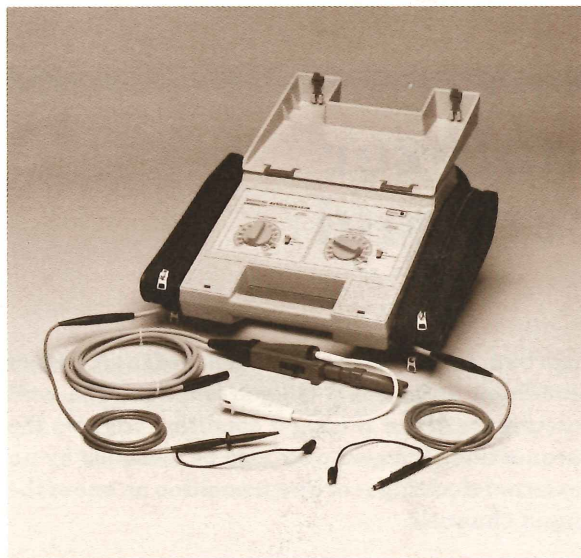
can be nested so that an occurrence of the A trigger condition arms the B trigger function. The next occurrence of the B trigger condition triggers the acquisition. Triggers may also be qualified by an external clock input or by a transition on one of the input channels.

All this triggering flexibility means that 7000-series oscilloscopes and digitizers can now capture signals that were previously too difficult or time-consuming to capture because of limited triggering facilities. For example, capturing transient faults in a digital system, such as a noise glitch or low-amplitude pulse, is just about impossible with most conventionally triggered digitizers. But the 7A42 makes this kind of task easy. Installed in a 7854 digitizer, for example, the 7A42 can monitor up to four channels of information and trigger simultaneous acquisitions on up to two channels.

The 7A42 bandwidth is 350 MHz with a one-nanosecond rise time. System bandwidth for a 7A42 installed in a 7854 is 275 MHz with a system rise time of 1.3 nanoseconds. The differential delay between any two channels is limited to 200 picoseconds—an order of magnitude better timing resolution than most logic analyzers. In addition, switchable input impedance (50 ohms or 1 Megohm) and a probe offset feature ensure good probe matching and minimum loading of the device under test. Battery backup preserves instrument settings and status when power is removed.

All this capability adds up to a powerful new tool for 7000-series oscilloscopes and digitizers. For more information on the 7A42, contact your local Tektronix Field Office. Or check the appropriate square on the reply card bound into this issue of **HANDSHAKE**. 


Floating measurement safety offered by A6902A Isolator



The new A6902A Isolator from Tektronix extends your waveform digitizing capability to high-voltage environments while maintaining safe instrument grounds. Two optically and transformer coupled channels allow data capture

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Typical applications for the A6902A include measurement of gate-to-cathode signals on silicon controlled rectifiers, emitter-base voltages on high-power semiconductor devices, bridge measurements, multiphase power system measurements, output noise on switching power supplies, and measurements wherever else high common-mode potentials prevent referencing a signal to ground. It is the only general-purpose instrument capable of making these kinds of measurements while fully complying with the latest worldwide safety standards, including UL 1244, IEC 348, VDE 0411, BS 4743, and CSA Electronics Bulletin 556B.

To find out more about the A6902A Isolator, use the reply card in this issue of **HANDSHAKE** or contact your local Tektronix Field Office or Sales Representative. 

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