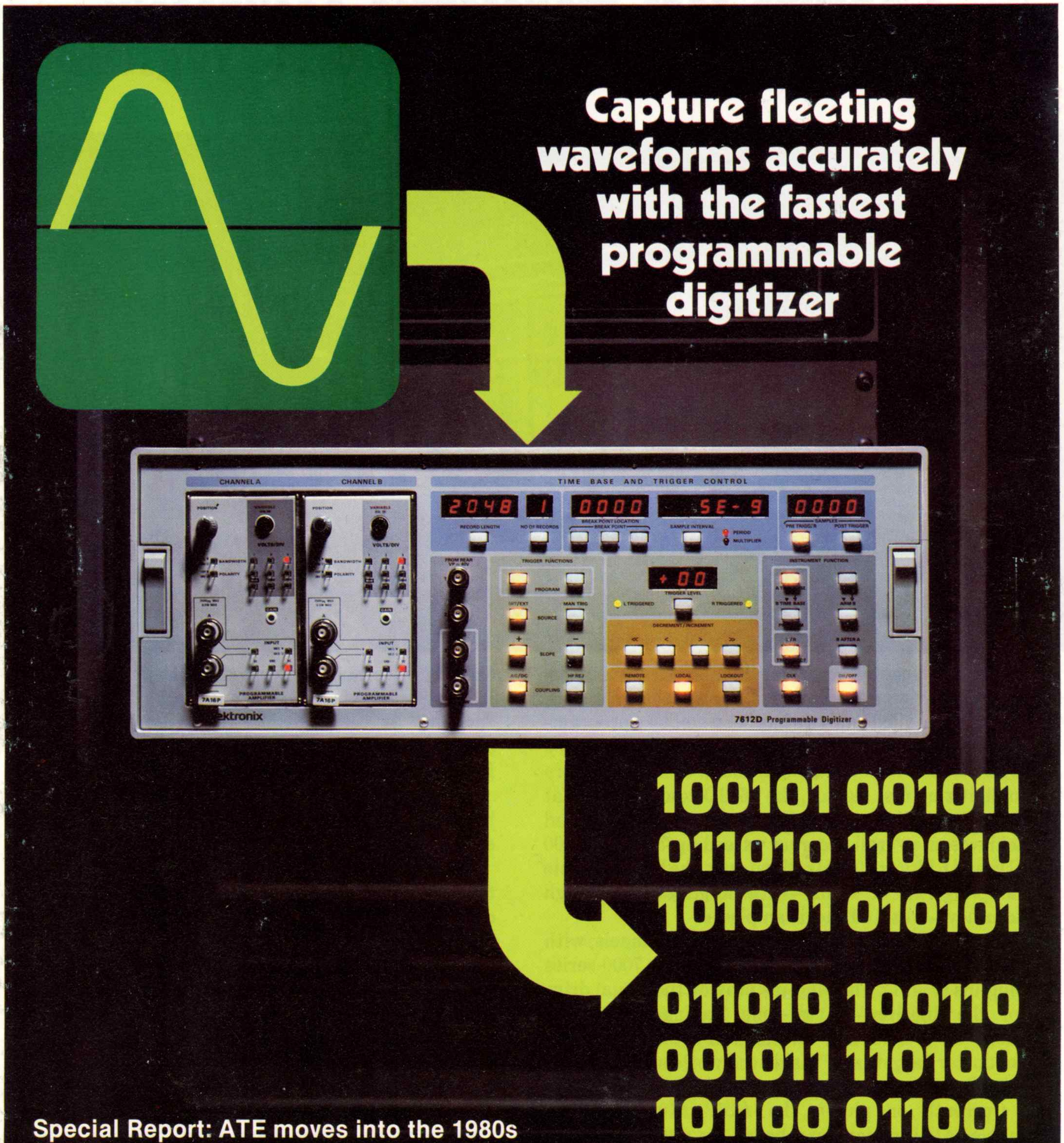
Electronic Design®

VOL. 28 NO. 3

FOR ENGINEERS AND ENGINEERING MANAGERS — WORLDWIDE

FEB. 1, 1980



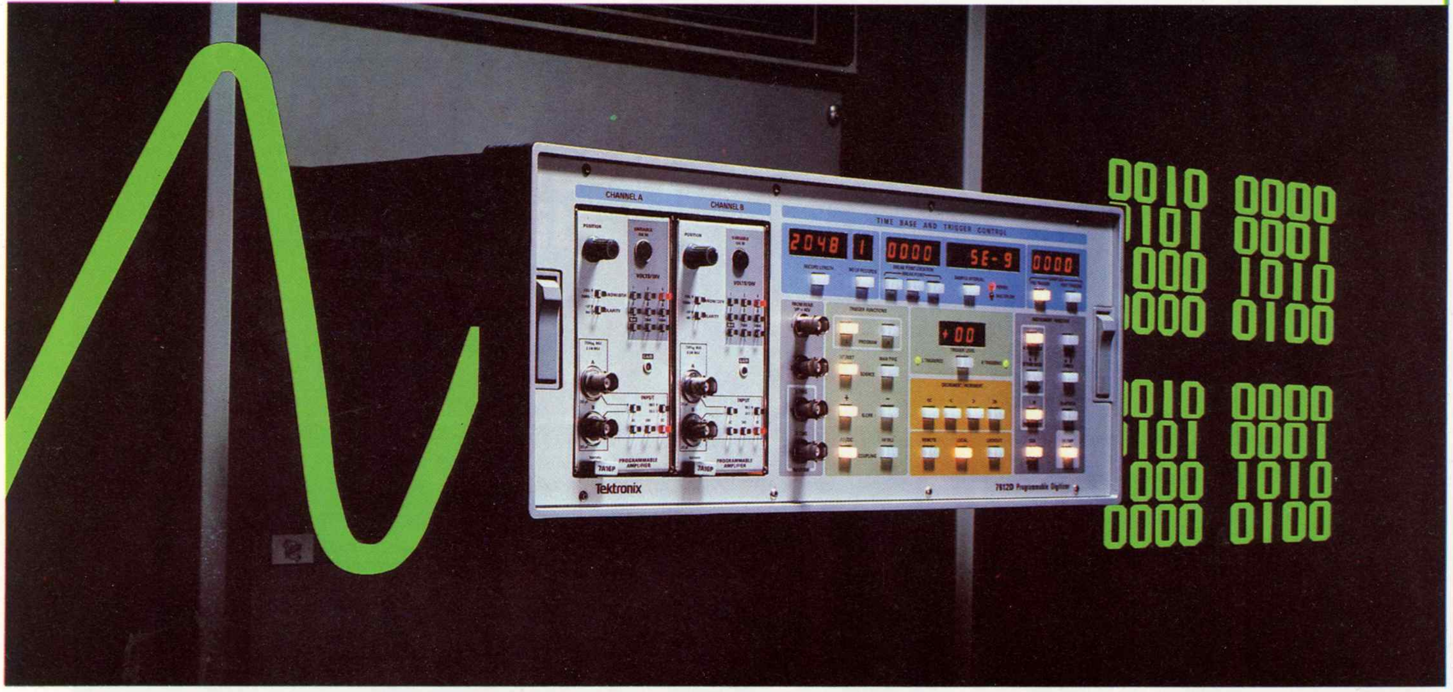
Special Report: ATE moves into the 1980s

Combating the problems of analog-circuit testing

Designing switching supplies above 100 kHz (Part 2)

Put single-chipper's eight operating modes to work

Capture fast waveforms accurately with a 2-channel programmable digitizer



The challenge of recording high-speed waveforms and providing the recorded information to a computer for detailed analysis has been met by a programmable instrument that looks like a 5-ns, 32-k memory (16 k per channel). Breaking through existing barriers to digitizing fast signals, the 7612D resolves 8-bits at a top sampling rate of 200 megasamples/s and achieves an overall accuracy exceeding 7.8 bits at 300 kHz and 6 bits at 20 MHz. Until now, the best available sampling rate at 8 bits—with no guarantee of high accuracy—was 100 megasamples/s.

The 7612D contains two independent channels, with input signals routed through standard 7000-series plug-ins (Fig. 1). The plug-ins provide the signal drive for the digitizer—a real-time leading-edge design based on a CRT and an electron-bombarded-semiconductor target (see "Inside the world's fastest 8-bit ADC").

Currently, one plug-in, the 7A16P, is fully programmable. All functions can be set up under computer control via a mainframe IEEE-488 connector.

Sampling rate is selectable from 5 ns to 1 s per sample, with many intermediate steps available, or it is selected via an external clock. Trigger-signal "arming" is very flexible; for example, one mode allows cross-channel arming that prevents channel B from arming until channel A has started.

In a fast digitizer, eight bits is a good compromise between speed and resolution. At full sampling rates, each channel can store 2048 8-bit words.

The all-digital time base in each channel provides the appropriate digitizer strobe signals and memory-clocking lines. Not only that, but each time base can change sampling rates without any ambiguity during the recording process, as well as enable the instrument to function as a time-interval counter (with appropriate software). In the first case, recording rate can change as many as 13 times during a recording period (Fig. 2).

Note in Fig. 2 that the "real-time" signal has a pair of very fast responses separated by relatively large time windows. Since high-speed memory usually comes at a premium, it makes sense to record only the data of value and to concentrate the available memory capacity in the highest-resolution modes. Note also that the time-base frequency has been altered several times (under program control) to expand those areas of interest. Information as to

---

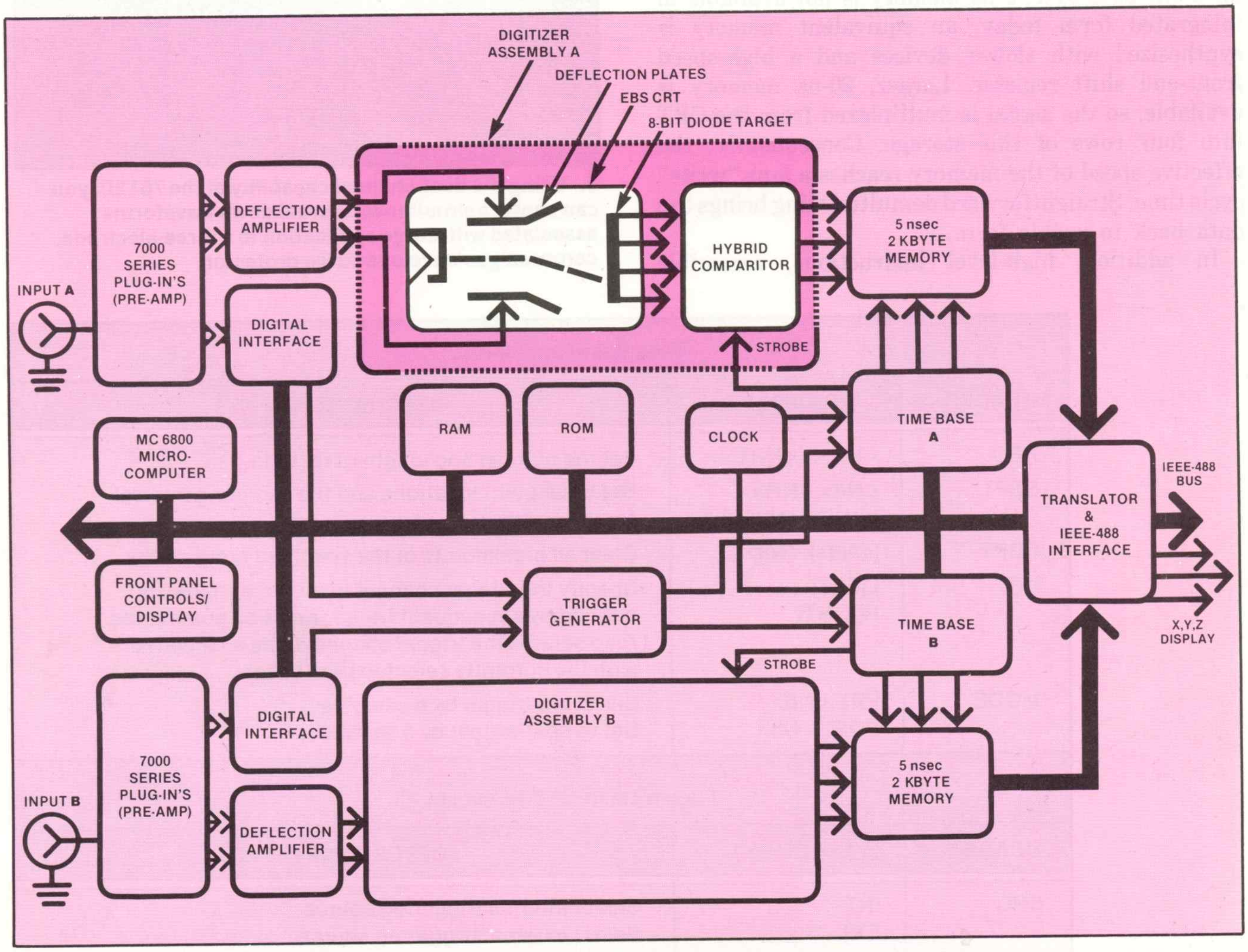
Neil A. Robin, Engineering Manager, Signal Processing Systems, **Bob Ramirez,**
Applications, Tektronix, Inc., P.O. Box 500,
Beaverton, OR 97077.

which waveform was recorded at what speed is relayed to the computer for reconstruction.

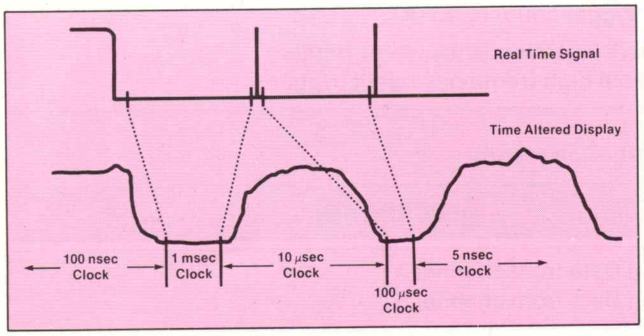
Combine the various time-base possibilities and the ability to examine an arbitrary signal-crossing point on the vertical axis, and the result is relatively high-precision time-interval counting (Fig. 3). Overall time-base accuracy is ±35 parts per million. When combined with pre-triggering, these techniques are particularly useful for calibrating waveforms in computers and avionics equipment.

In addition, the time base can reduce record size to less than 2048 words. This helps, say, with recording at high speed several events that occur much too quickly for normal recycling and data transfer. With the 7612D, simply record as few as 256 samples, then get ready to accept the next trigger pulse for further recordings. As a result, data transfer is postponed—very beneficial in burst transmissions and other rapidly occurring events.

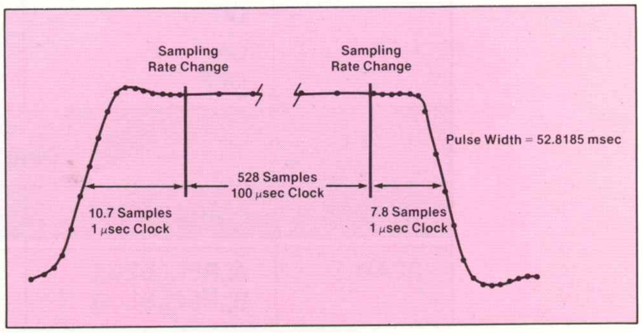
Moreover, the digitizer can align the trigger point



1. A two-channel digitizer aimed at system applications samples at 200 megasamples per second and offers a total memory capacity of 4096 8-bit words. Because no commercial 8-bit a/d converter was fast enough, the digitizer uses a novel technique to convert signals—a CRT combined with a special monolithic target.



2. Time-base breakpoints expand selected sections of an incoming signal. Up to 13 breakpoints can be called on to maximize use of internal memory capacity.

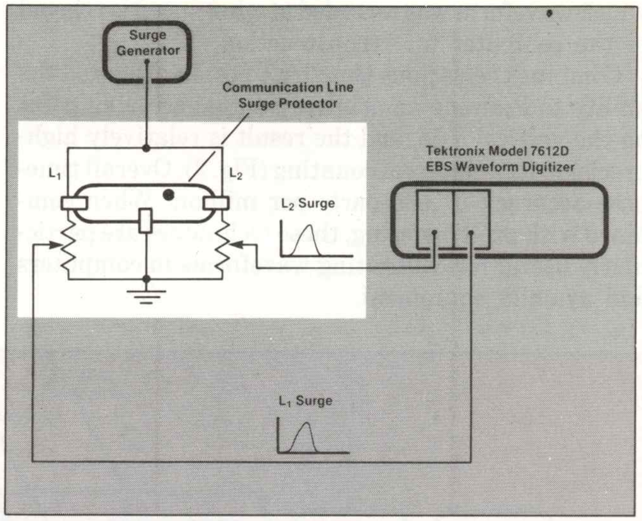


3. With breakpoints and a small software routine to detect an arbitrary trigger point, it is possible to obtain timing measurements that approach digital counter accuracy.

on any integer, in an eight-sample block anywhere from the beginning to the end of the record. This allows full pretrigger waveform viewing, full post-trigger viewing, or intermediate steps. Trigger signals require 20 least-significant bits (LSB) when the internal mode is used, with the unit triggering on signals up to 100 MHz. In addition, many trigger signal-coupling options are available, thanks to the 7000-series plug-ins.

The instrument's memory design is unique. Since an 8-bit, 2048-byte, 5-ns memory is not available in integrated form today, an equivalent memory is synthesized with slower devices and a high-speed front-end shift register. Larger, 20-ns memory is available, so the signal is multiplexed from the CRT into four rows of this storage. Consequently, the effective speed of the memory reaches a 5-ns "write" cycle time. Straightforward demultiplexing brings the data back to usable form.

In addition, high-level instructions, accessible



5. Using the dual-channel capability of the 7612D, you can capture simultaneous breakdown waveforms associated with surge application to a three-electrode, common-gas-envelope surge protector.

Time Base Commands

HEADER	ARGUMENT	DESCRIPTION
REC	<NR1>,<NR1>	Set the number and length of records.
SBPT	<N8>,<NR3> [,<N8>,<NR3>]...	Set breakpoint locations and the sampling interval for the segment.
CBPT	[<N8>[,<N8>]]...	Clear all breakpoints or the specified breakpoints.
LTC	L[EFT] R[IGHT]	Specify the trigger channel to be programmed or queried by subsequent trigger function commands (Also selects the trigger channel to be associated with the currently selected time base).
MODE	PRE,<N8> POST,<N8>	Set to pre-trigger by n samples. Set to post-trigger by n samples.

Trigger Channel Commands

HEADER	ARGUMENT	DESCRIPTION
SRC	INT EXT	Select internal triggering source. Select external triggering source.
SLO	POS NEG	Set trigger slope to positive. Set trigger slope to negative.
LEV	<NR1>	Set trigger level.
CPL	AC DC	Set trigger coupling to AC. Set trigger coupling to DC.
HFR	ON OFF	Enable high-frequency reject trigger. Disable high-frequency reject trigger.

Data Transfer Commands

HEADER	ARGUMENT	DESCRIPTION
READ	A[,REC[,SEG]] B[,REC[,SEG]]	Read Data from channel A Read Data from channel B

4. Rigid adherency to the latest IEEE-488 standards has been followed in the instrument commands, along with new soon-to-be-approved standards for codes and formats. The IEEE-488 interface has been widely accepted as a hardware standard, but it still lacks software formats and protocol standards.

Inside the world's fastest 8-bit ADC

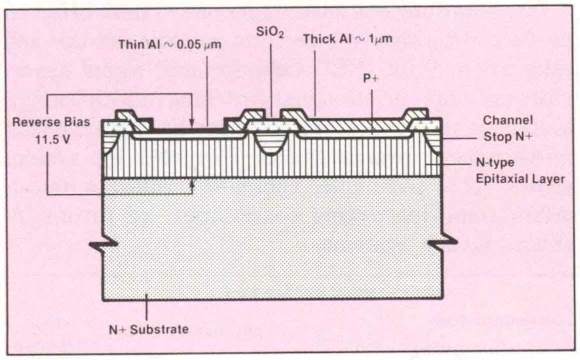
By performing high-speed real-time digitization, the 7612D offers an advantage not to be attained by the two other usual digitizing approaches, scan conversion and equivalent-time sampling—single-shot, full-pretrigger data recording. This proves a big help when events are unpredictable, as in failure analysis.

A real-time instrument continually digitizes the analog signal and stores the results in memory, usually solid-state. As memory fills with data, new data are systematically written over the old. At any given instant, the memory contains all previously recorded data—it has historical or pretrigger information.

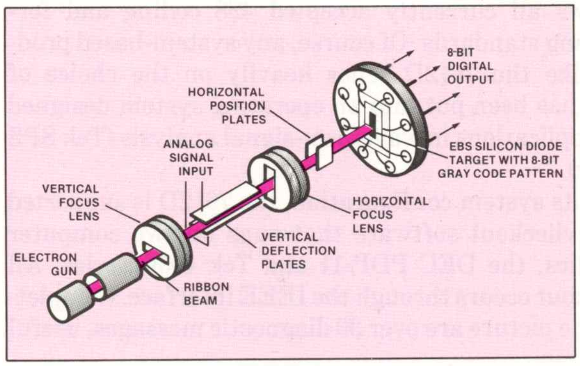
Anyone who has had a piece of equipment fail intermittently knows the value of pretriggering. For one thing, time-related signal data can be stored as an identified failure condition approaches. The trigger (failure) can be totally unpredictable. Of course, most digitizers in this class also provide for more conventional post or mid-screen triggering, useful for observing events surrounding the trigger point.

One of the main problems in implementing a high-speed real-time digitizer is to realize high sampling rates along with good resolution. The 7612D's solution: Combine a CRT with an electron-bombarded semiconductor (EBS) target.

Why get so exotic?



In any parallel digitizer, the frequency components of the least-significant bit (LSB) can build up very rapidly to tremendous values. For example, in digitizing a 10-MHz sine wave to 8 bits with a half-scale amplitude signal, the frequency of the LSB at the waveform's zero crossing will be about 1 GHz. To reach that speed with high resolution is extremely difficult with solid-state technology. The EBS technique can provide the gain necessary to sense extremely fast signals.



The above figure shows the internal construction of the CRT and the Gray-code target. Any discerned similarity to a conventional CRT fades very quickly with the discovery that there is no phosphor screen. Notice that the electron beam is focused into a ribbon (not the conventional small dot or point) approximately 0.040 in. wide by 0.0013 in. thick at the target end of the tube. Beam profile is altered by aperture slots on the focusing lenses. The input signal (23.5 V pk-pk) is applied to the vertical-deflection plates; the horizontal plates carry a static voltage, primarily for beam positioning.

The EBS target (above) is a monolithic IC, about 250 × 40 mils (20 × 230-mil active area), processed with a metalized mask to provide a diode array in the form of an eight-column Gray-code pattern. Each position of the electron beam corresponds to a unique code on the target. The beam is wide enough so all eight columns are addressed at any reasonable position of the vertical-deflection system.

Why Gray code, instead of binary? Because only one bit changes state for each incremental change in quantizing level, thereby avoiding coding ambiguity and nonmonotonicity. Once information is recorded in memory, it can be converted back to binary at a leisurely pace by slower logic.

Use of Gray code does not cause any penalty in the number of needed bits. All the diodes in each column are tied together by metalization, providing eight signal lines that exit the CRT, but with 256 quantizing levels represented.

Two-thickness metalization forms the windows on the EBS target. As shown in the figure, a very thin layer, about 0.05 μm, provides a return path for current flow and access to the pn junction by the electron beam. When electrons with about 10 kV of accelerating potential strike the thin metal, they pass through it and head towards the junction area. The resulting diode current totals about 2000 times that of the electron flow, because secondary hole/electron pairs are released by bombardment of the reversed-biased target.

The output level of the target diode is a very impressive 250 mV into a 50-Ω load. Since the LSB has an extremely high-frequency component—often exceeding 2 GHz—producing large-amplitude wideband signals at these frequencies is no small feat. The output is so broadbanded that very short leads are a must to transfer the eight signal lines to proprietary hybrid comparator circuits—in fact, the comparators are integrally fastened to the outside of the CRT. Only digitally latched data, updated at a "modest" 5-ns rate, come out of the CRT assembly.

Signal coupling occurs after the digitization process, so no front-end sampler is needed. It is far easier to design a high-speed digital comparator than an analog one with a refresh rate of 200 megasamples per second.

through the IEEE-488 interface, make the unit easy to use (Fig. 4). To ensure GPIB compatibility, the unit follows all currently accepted 488 coding and formatting standards. Of course, any system-based product like the 7612D relies heavily on the choice of fore, has been put into an operating system designed for applications in waveform-signal analysis (Tek SPS Basic).

In its system configuration, the 7612D is supported with checkout software that runs on two computer families, the DEC PDP-11 and Tek 4050 Series. All checkout occurs through the IEEE interface. Completing the picture are over 30 diagnostic messages, useful in system integration.

Many applications demonstrate the power of the 7612D programmable digitizer, but one—testing three-electrode, common-gas-envelope surge protectors—illuminates its capabilities. These devices, often found on balanced-pair communications lines, protect equipment and personnel from overvoltages, be they from equipment malfunctions, power-line crosses, or lightning-induced transients.

Fig. 5 shows a test setup for a three-electrode protector, in which a capacitive-discharge surge generator applies a high-voltage transient to each line connection of the protector. The dual-channel capability of the 7612D proves an advantage because it allows

Measuring ADC performance

A/d converters have always suffered from specsmanship, with almost as many ways to measure performance as there are vendors. But the principal problem in measuring performance is the reference signal: How precisely can it be predicted? Is the test truly dynamic in nature?

In the 7612D, performance tests keep several key considerations in mind:

- Computerize whenever possible to speed up results—provide unattended measurements.
- Use commonly available test equipment and fixtures.
- Minimize human interpretation—strive for go/no-go decisions from the computer.
- Log the results for future reference.

One simple technique meets all these criteria in principle: providing a high-quality analog sine wave to the digitizer input at various test frequencies (see Fig.). Narrow-band filters ensure that harmonic and noise components are reduced to an insignificant level before signal application.

Digitized results from the unit under test go to the computer via the IEEE-488 bus. Software, taking over at this point:

- Finds the best nonlinear, least-squares sine wave fit to the incoming digitized data. Trials are taken with changes in frequency, amplitude, dc offset and phase.
- Quantizes the input signal in the computer, simulating perfect digitizer response.
- Compares the actual digitized data from the unit under test with the digitized "best-fit" response.

Comparison is made on the basis of the following equation:

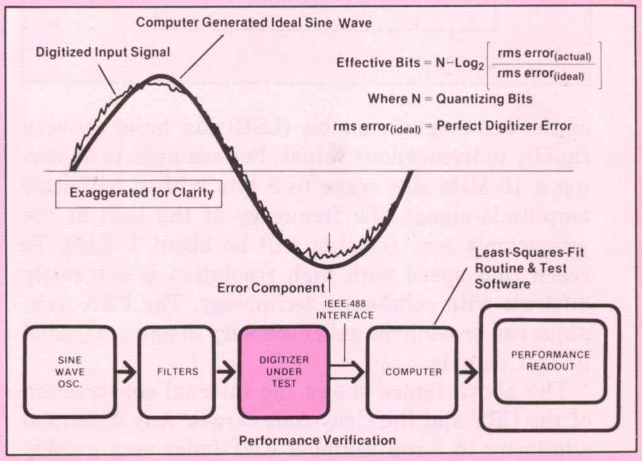
$$\text{Effective bits} = N - \log_2 \frac{\text{rms error (actual)}}{\text{rms error (ideal)}}.$$

The 7612D accuracy specification, six bits at 20 MHz with a half-scale signal amplitude, is based upon this test. Those who rarely measure sine waves may wonder if the test is valid for them. It is. To classify instrument performance, tests must be reliably reproducible. Although pulse-parameter measurements form the more important class, sine waves are relatively easy to create, have a very predictable dv/dt and are bidirectional.

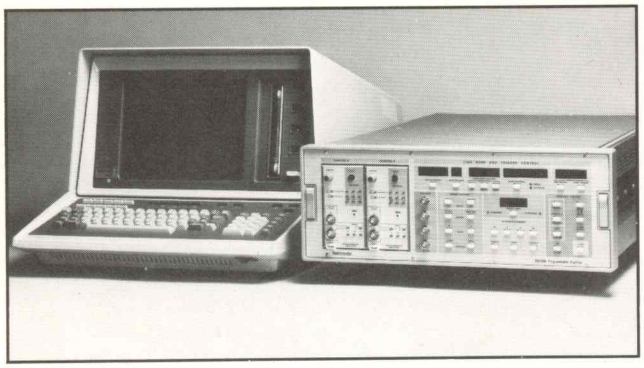
With a "standardized" pulse for performance measurement, there's always the nagging question: How predictable is that pulse? High-precision pulses are very difficult to guarantee. But today's digitizers need that precision—they often have accuracies that equal or exceed those of an oscilloscope. Eyeballing a waveform on the scope simply doesn't take the place of reproducible testing techniques.

Another way of expressing performance, based on the outlined test, is by signal-to-noise ratio. An ideal digitizer with a full-scale signal will have an s/n of (6N + 1.8) dB, where N = resolution in number of bits. Note that this test does not consider the dc offset drift of the system, which can be measured by comparing a known dc input voltage with the output.

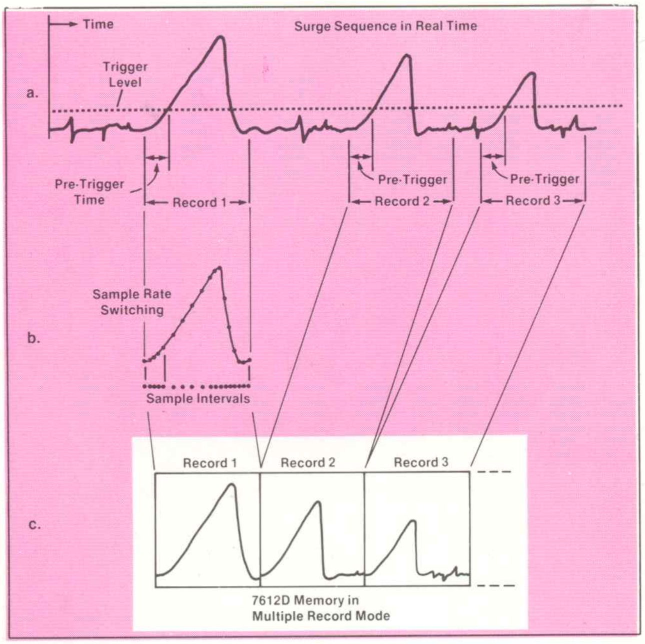
One of the obvious advantages of a system-oriented product is the ability to perform periodic self-test and calibration. With IEEE-488-interfaced signal generators and appropriate signal switching (multiplexing), system-calibration information can be logged so that measurement results can be corrected for system errors. This technique, commonly called auto-cal, offers some interesting possibilities for future instrumentation systems.



Measure digitizer performance with a nonlinear, sine-wave, least-squares-fit routine. This method requires relatively straightforward test equipment and minimum-skill operators, which is good since the setup must be very repeatable and trustworthy. What's more, very little interpretation is needed since the final result is displayed in numerical form.



Because the 7612D is GPIB controllable, digitized data can be analyzed as desired by an external computer.



6. Numerous 7612D modes provide a variety of acquisition possibilities. In the surge sequence (a), the trigger level is set to ensure stable triggering; and pre-trigger time to capture the entire leading edge. Sample-rate switching (shown in b with far fewer samples than normal) can increase time resolution in selected areas; and memory division captures rapid sequences of events (c).

Calculating s/n and accuracy

It is well known that even an ideal a/d converter exhibits noise because of the quantization error inherent in the conversion process. This root-mean-square noise is found by

$$\text{rms error} = Q/\sqrt{12},$$

where Q is the quantum or value of the least significant-bit.

The signal-to-noise ratio of an ideal N-bit digitizer can be found from the ratio of the rms signal to the rms noise. For a full-scale sine wave,

$$\text{Ideal s/n} = \frac{\text{rms (signal)}}{\text{rms (error)}}$$

$$= \frac{2^N}{2} \cdot \frac{\sqrt{2Q}}{2} \Big/ \frac{Q}{\sqrt{12}}$$

$$= \frac{2^N\sqrt{6}}{2} \qquad (1)$$

Or, in dB,

$$\text{Ideal s/n} = 20 \log \frac{2^N\sqrt{6}}{2}$$

$$\approx 6N + 1.8.$$

If a real digitizer presents an actual signal-to-noise ratio of s/n, its performance can be expressed in terms of the performance of an ideal digitizer with N_1 effective bits of resolution. The value of N_1 is derived as follows:

$$\text{Actual s/n} = \frac{2^{N_1}\sqrt{6}}{2} \qquad (2)$$

Combining Eq. 1 and 2 gives the value of N_1:

$$N_1 = N - \log_2 \left(\frac{\text{rms error (actual)}}{\text{rms error (ideal)}} \right)$$

Consequently, an 8-bit digitizer with a measured s/n of 43.8 dB actually performs as an ideal 7-bit digitizer.

simultaneous capture of the clamping activity from each line terminal to the ground terminal.

This is crucial for several reasons, one being that the voltage at which breakdown occurs for each terminal is an important parameter. In addition, any differences between the waveforms from each terminal should be determined since major differences can give rise to major line-to-line overvoltages. Indeed, since heating can change surge-generator characteristics from shot to shot, and residual ionization can change protector reaction from shot to shot, simultaneous acquisition of each terminal's breakdown activity for each supplied surge becomes a virtual necessity.

Another 7612D feature, pre-triggering, enhances measurements further (Fig. 6) and ensures that the entire leading edge is captured without risking the instabilities of low-level triggering. Sample-rate switching is used to provide the greatest time resolution where needed. In addition, it is often useful to test protection capabilities for repeated surges that might arise, for example, from a quick succession of lightning strokes. The multiple-record-length capability of the 7612D allows acquisition of such rapid successions of events. Up to eight surges per channel can be captured before the digitized waveforms must be transferred out to either peripheral storage or to an external processing unit.

Since the 7612D is IEEE-488-compatible, interfacing to a variety of GPIB controllers or minicomputers is a standard operation. This makes it very appealing to transfer digitized waveforms to a minicomputer, where appropriate software routines can provide quick, accurate, in-depth analyses. For example, the surge waveforms from each protector terminal can be subtracted to get line-to-line voltage. In addition, the surges can be differentiated to provide wave-front rate of rise, and either integrated for contained energy or analyzed further by the software.■■

For the address of your nearest Tektronix Field Office, contact:

U.S.A.
Tektronix, Inc.
P.O. Box 1700
Beaverton, OR 97075
Phone: 503/644-0161
Telex: 910-467-8708
Cable: TEKTRONIX

Africa, Europe
Middle East
Tektronix Int'l, Inc.
European Marketing
Center
Postbox 827
1180 AV Amstelveen
The Netherlands
Telex: 18312

Asia, Australia, Canada, Central & South America, Japan
Tektronix, Inc.
America's/Pacific
P.O. Box 500
Beaverton, OR 97077
Telex: 910-467-8708
Cable: TEKTRONIX

Tektronix offices to serve you around the world:
Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Denmark, East Africa, Ecuador, Egypt, El Salvador, Federal Republic of Germany, Finland, France, Greece, Hong Kong, Iceland, India, Indonesia, Iraq, Israel, Italy, Ivory Coast, Japan, Jordan, Korea, Kuwait, Lebanon, Malaysia, Mexico, Morocco, The Netherlands, New Zealand, Norway, Pakistan, Panama, Peru, Philippines, Portugal, Republic of South Africa, Saudi Arabia, Singapore, Spain, Sri Lanka, Sudan, Surinam, Sweden, Switzerland, Syria, Taiwan, Thailand, Turkey, Tunisia, United Kingdom, Uruguay, Venezuela, Zambia.

Tektronix®
COMMITTED TO EXCELLENCE