TEK APPLICATION INFORMATION

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FALL 1987

HANDSHAKE

NEWSLETTER OF INSTRUMENTATION AND INSTRUMENT SYSTEMS

A NEW HORIZON IN WAVEFORM GENERATION

Tektronix
COMMITTED TO EXCELLENCE

A word about our mail list

Occasionally we receive comments from our readers that they've tried several times to get on the **HANDSHAKE** mail list without success. We won't attempt an explanation of all of the reasons for these problems, but just a few thoughts.

Often, we receive **HANDSHAKE** reply cards with insufficient address information or even blank addresses. For example, a card was received last February requesting a subscription to **HANDSHAKE** plus 20 sets of product information. The only problem with filling this request was that there was absolutely nothing in the address block to go from — a total blank! I'm sure someone out there was very disappointed with what they viewed as Tektronix' poor response to their request, but there was nothing we could do.

Another problem is cards damaged in the mail. And then there's partial or illegible information. Or information that is unreadable because of an overly zealous cancellation stamp. In all of these situations, our mail list staff goes out of their way to do everything possible to fill in the gaps — and with good success. But some cards just can't be deciphered and, as a result, a few of you are disappointed.

Let me assure you of one thing. We do not qualify our mail list in any way other than interest in receiving information on instrumentation and instrument systems from Tektronix. If you ask for a subscription to **HANDSHAKE** or for literature, we process it without question and provide the requested information whenever it is available. Our goal is to provide the information you need to make better measurements.

Correction

Some of you may have noticed a distinct similarity between Figures 1 and 4 in the article **Network and impedance analysis with the 2430** which started on page 11 in the Summer 1987 HANDSHAKE. While these figures were intended to be similar, they weren't intended to be identical as in the printed copy.

The correct version of Figure 4 is shown below. You will note that the only difference is that the signal for input to Channel 2 now comes from a current probe which is monitoring the current applied to the device under test — a minor change in the figure but a major change as regards operation. Text describing the connection was correct.

We apologize for any inconvenience this may have caused.

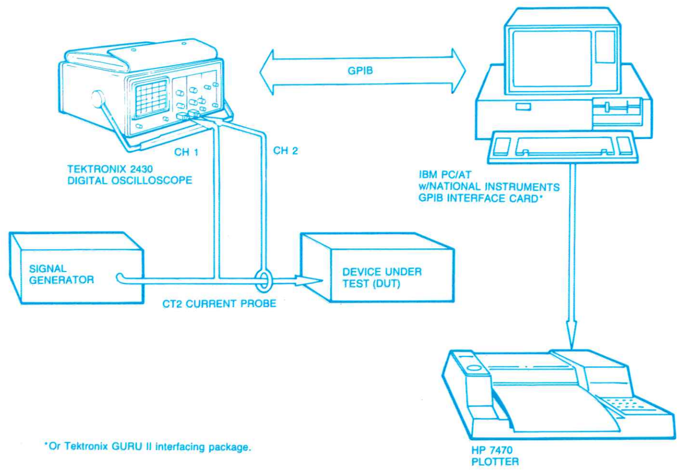

Figure 4. *The 2430-based system reconfigured for measuring complex impedances (voltage/current versus frequency).*

Manager and Editor: A. Dale Aufrecht
Production Editor: Anita Hicks
Graphic Design: Phil Malyon
Typesetting: Interface Typesetting
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Doerenkampgasse 7
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Austria
Phone: 43 (222) 68-66-02
Telex: (847) 111481 TEK A

Central and South America, Canada, Asia, Australia
Tektronix, Inc.
Americas Pacific U.S. Export Sales
P.O. Box 500, MS 73-393
Beaverton, OR 97077
U.S.A.
Phone: (503) 627-1915/6332
Telex: 4742110 TEKEXP

A look inside

In this issue of HANDSHAKE we discover that it's OK to be arbitrary — arbitrary, that is, if you're generating waveforms. The feature article beginning on page 4 describes the new AFG 5101 Programmable Arbitrary/Function Generator. This article titled **The AFG 5101 — Full performance in an arbitrary waveform function generator** describes this new product from the Instrument Systems Integration Division that combines the features of both a function generator and an arbitrary waveform generator in one compact unit. A companion article **A gallery of AFG 5101 applications** provides a brief overview of only a few of the many possible applications for the AFG 5101.

Digital storage is not new. But to get full digital storage features in a low-cost instrument is news. The article **Digital storage at an affordable price** describes the 2200-Series Digital Storage Oscilloscopes with emphasis on the new 2221 from the Portable Test Instruments Division.

The Spring '87 issue featured the RTD 710 Digitizer. The article **New systems extend the capabilities of the RTD 710** describes two new measurement systems based upon this digitizer which will make your instrumentation task easier.

An exciting new product, optical probes, is described in the article **One easy step to an optical oscilloscope**. This article describes how you can easily equip your 11000-Series Oscilloscope for optical measurements.

The focus on applications describes how to make those difficult measurements on low-speed phenomena. **Capturing slow-speed events with 2200-Series Digital Storage Oscilloscopes** describes this process using recorded calls of the humpback whale for illustration.

For our technology update this issue, we look at the latest innovation on the measurement interfacing scene — the RS-232-C interface. The article **Using the RS-232-C as an instrument interface** provides the background information necessary for applying this interface to your measurements.

And there you have another issue full of measurement information. To find out more about any of the products described in this issue, or for help with your other signal measurement needs, contact your local Tektronix Field Office or sales representative. And be sure to tell them you saw it in **HANDSHAKE**.

A. Dale Aufrecht
HANDSHAKE Editor

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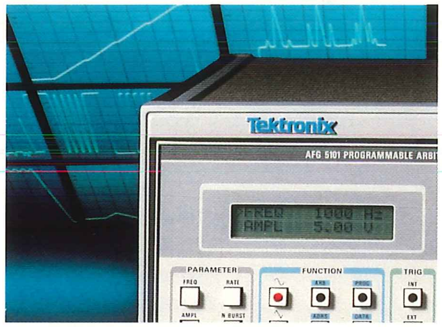

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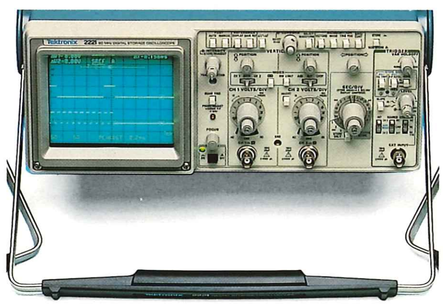
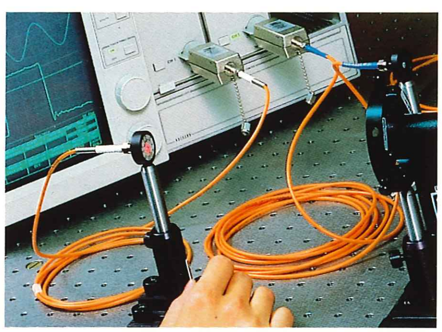
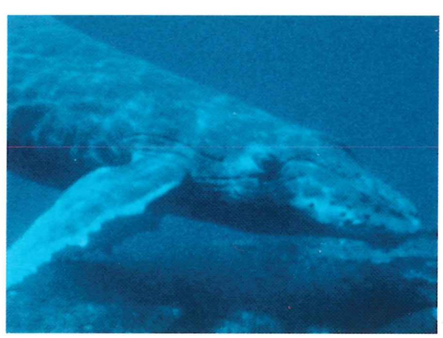






PRODUCT FEATURE

The AFG 5101 — Full performance in an arbitrary waveform/function generator

Waveform generation from 1 microhertz to 12 megahertz

Barbara Malin
Modular Instruments Product Marketing Manager
Instrument Systems Integration Division
Tektronix, Inc.

William Rich
Application Engineer
Instrument Systems Integration Division
Tektronix, Inc.

Full function arbitrary waveform generation capabilities are combined with conventional analog functions in the AFG 5101 Programmable Arbitrary/Function Generator. Other features include arbitrary sweep capability with frequency markers and arbitrary waveform generation from internal memory with 12-bit resolution and 100-nanosecond point rate. Complete setup is available from the front panel or setup can be controlled over the GPIB.

Sine, square, and triangular waveforms are generally available from most standard function generators. These serve a variety of basic test stimulus needs.

But what happens when you need a different type of waveform that doesn't fall within the repetoire of these standard function generators?

Maybe a frequency-modulated signal is needed for precision tests on a discriminator. Or a better simulation than a haversine function might be needed for neuro stimulus-response research. Perhaps the application calls for an ultra-low-frequency sensor output simulation to verify a preamplifier's design for robotics, geophysics, biophysics, or a myriad of other possibilities. Or maybe production testing can be simplified with some special waveshape or signal combination — something not available from the usual function generator.

Two function generators in one

These and a wide variety of other waveform generation and control needs are covered by the new AFG 5101 Programmable Arbitrary/Function Generator from Tektronix. The standard analog generated functions are DC and sine, square, and triangular waveforms with frequencies from 0.012 Hz to 12 MHz and amplitudes from 10 millivolts to 9.99 volts peak-to-peak.

These waveforms can be used in their standard form in a continuous mode, or they can be modified using triggered, gated, burst, AM or FM modulated, or the arbitrary sweep modes. For example, the sine function can be frequency-swept with a linear sweep or it can be frequency-shifted using a pulsed arbitrary sweep (see Figure 1).

But that's only the beginning. For highest flexibility and diversity in waveform generation, you can use the arbitrary waveform memory in the AFG 5101 to create your own waveforms or use one of the five predefined, mathematically derived waveshapes (sine, triangle, square, ramp up, or ramp down). There are two 8192-point memories for waveform building. These provide 12-bit amplitude resolution with point rates from 999.9 seconds to 100 nanoseconds (10 MHz clock) for waveform synthesis from 1 microhertz (μHz) to 5 megahertz (MHz).

Virtually any waveshape that can be drawn, mathematically generated, transferred from computer graphics or simulations, or captured by a waveform digitizer can be regenerated from waveform memory by the AFG 5101. Moreover, the waveforms can be edited or modified in instrument memory, and their generation can be controlled by the triggering, gating, bursting, modulation, or arbitrary sweeping modes.

This new function/arbitrary waveform generator is part of the Tektronix TM 5000 Family of modular instruments. It occupies three slots in any of the TM 5000 programmable power module mainframes. And since it conforms to Tektronix Standard Codes and Formats, it can be mixed with any of the TM 5000 modular instruments to form a fully programmable stimulus and measurement system.

Building upon basic waveforms

The AFG 5101 can be used in several manners to generate hybrid functions by modifying the standard functions using sweep, trigger, gated, burst, and modulation operations. All functions and oper-

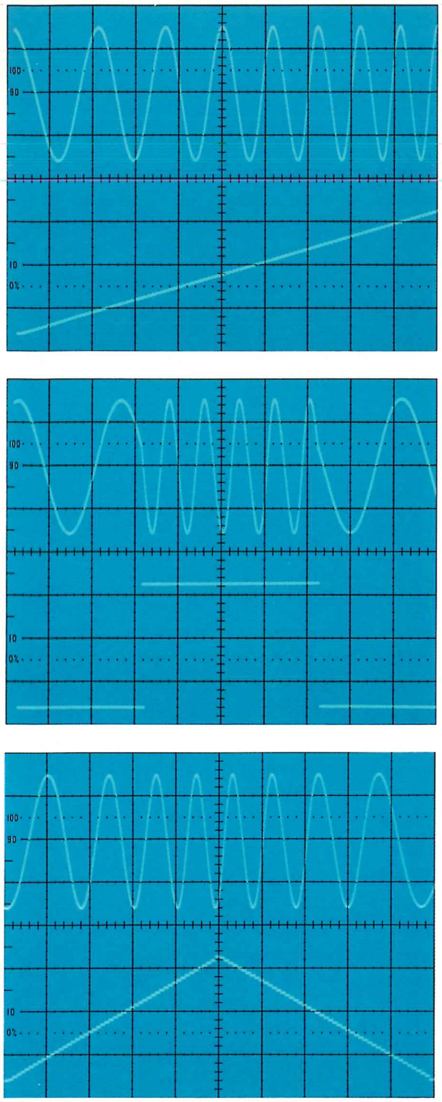


Figure 1. *Some examples of simple sweep shapes (bottom waveforms) and their effect on sine wave generation (top waveforms).*

ating modes can be selected and controlled either manually from the front panel or from computer programs via the GPIB. GPIB programmability and external archiving of function control, arbitrary sweeps, and waveforms holds enormous potential for automated testing based on calibration or stimulus waveform libraries.

But first, the waveshapes must be derived. In many instances, complex waveshapes needed for advanced testing can be derived from the standard waveform functions using one of the AFG 5101 operating modes to control how the standard waveform is output. These modes are described here along with some possible applications. More detailed applications using these control modes and arbitrary waveform generation are shown in the accompanying article entitled **A gallery of AFG 5101 applications.**

Continuous mode. This mode is the basic function generator mode. It provides continuous output of the selected waveshape at the selected amplitude and frequency. Both frequency and amplitude are read out simultaneously on the AFG 5101 front panel, and both can be set or accessed from the front panel or via the GPIB interface. This same readout and access capability is also provided in all other operating modes.

Modulation mode. The generated functions can be amplitude or frequency modulated by an externally applied signal. This is useful, for example, in testing detectors, discriminators, sideband filters, IF strips, or other transmission elements as isolated subassemblies.

Triggered mode. In this mode, there is no waveform output until the AFG 5101 is triggered. Triggering can be selected from an internal trigger, an external signal, a manual trigger, or a GPIB trigger. When triggered, the AFG 5101 outputs a single cycle of the programmed waveform at the specified frequency.

This mode can be used to generate specialized timing marks, event flags, strobes, or any other type of application requiring a waveshape occurrence based upon a triggering event.

Gated mode. Here the output waveform is gated on for the duration of the gating signal and continues through completion of the waveform cycle that is in process at the end of the gating signal. The gating mode is useful in creating signal bursts for testing tone control systems, simulating sonar returns, or providing controlled-duration stimulus by any waveshape.

Burst mode. Functions can be output as bursts with the burst length programmable in function cycles from 2 to 9999 cycles. This has similar applications to the gated mode, but provides a different means of specifying signal duration. Burst mode output is initiated by a trigger event as in the triggered mode.

Sweep mode. Frequency of the function can be controlled by any of a variety of sweep shapes. A linear sweep can be selected to provide a swept-frequency sine wave for filter response testing. Or a logarithmic sweep can be selected to create a log-scale frequency sweep. You can also define your own sweep shape in arbitrary memory. For example, a pulsed sweep can be defined to simulate an FSK waveform (frequency shift keying), or sweeps can be designed to emphasize or de-emphasize certain frequencies when testing or simulating transmission units.

In addition to the unique opportunity to design your own frequency sweeping functions, you can also set frequency markers on the arbitrary sweep. This is shown in Figure 2, where the markers appear as intensified regions on the oscilloscope display of a swept frequency response. Any number of markers can be placed on an arbitrary sweep to provide indicators of frequencies of interest. These markers can be viewed as fixed reference indicators.

For log or linear sweeps, a single marker can be dynamically positioned (similar to a cursor) to provide frequency readout of breakpoints, notches, or response anomalies. In this mode, a TTL compatible marker output signal drives the oscilloscope Z-axis and is also available to trigger other instrumentation coincident with the marked frequency occurrences.

Sweep start, stop, and rate are all programmable via the front panel or over the GPIB. Any of the defined or arbitrary sweeps can also be used in a continuous, triggered, gated, or burst mode. This adds

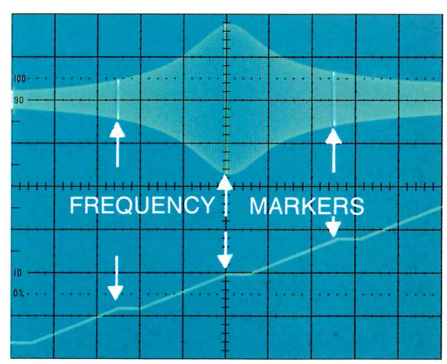


Figure 2. *A sine wave with varying frequencies (top) programmed by the arbitrary sweep function on the bottom. Note the frequency markers on the top waveform that have been programmed to indicate key frequency locations.*

Why arbitrary waveform generation?

Why Arbitrary Waveform Generation? Understanding the answer to this question will help to understand how the AFG 5101 can be put to use.

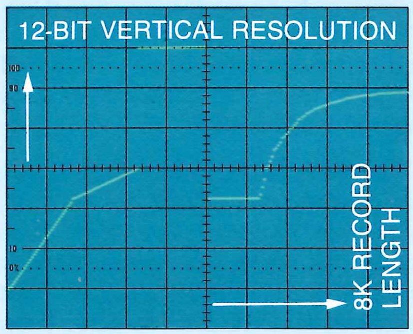
Natural phenomena do not express themselves as ones and zeros. The real world is analog, and for the bulk of test and measurement history, instrumentation has been analog.

Then, less then two decades ago, dramatic changes in instrumentation began to take place. Analog-to-digital conversion for broadband waveform digitizing became commercially viable. By converting analog waveforms to a digital format, far more measurements and analysis could be done in less time. Moreover, the depths of waveform analysis could be extended through digital waveform processing. Suddenly, a large body of theoretical analysis techniques began to move out of the textbooks and into practical application.

But waveform digitizing and processing tell only half of the story. How do you move the digitally generated products of theoretical analysis and simulation back to the reality of the analog world?

Arbitrary waveform generation completes that loop with digital-to-analog conversion. Test and simulation waveshapes no longer have to be limited to the few front-panel selections of conventional analog signal generators. With arbitrary waveform generation, any imaginable waveshape that can be described as a series of points can be generated as an analog waveform. The accompanying figure shows how an arbitrary waveform memory works.

An arbitrary waveform memory can be represented by two axes. The vertical axis is amplitude expressed by discrete digital levels, for example 4096 levels for a 12-bit system. The horizontal axis represents discrete memory addresses corresponding to arbitrary time intervals. With 8192 addresses, for example, and 4096 possible levels for each address, you have an array of over 33-million points for describing a waveshape. With that many points, the shape of the waveform can be arbitrary — basically without restriction.



An arbitrary memory representation of a waveform. A DAC connects the dots to generate an analog signal with the waveshape of the data points in memory.

Any address can have any of the 4096 values or levels. It makes no difference to the digital-to-analog converter (DAC). It's arbitrary. The DAC simply connects the points, whatever their values, by ramping an analog voltage from point to point. When it reaches the last point, it returns to the first point for another memory cycle of analog waveform generation.

Not only does the DAC "draw" a continuous analog equivalent of what is in arbitrary memory, but it can be programmed to do it at different amplitudes or rates. For example, the 0 to 4096 levels can depict peak-to-peak signal amplitudes in ranges from millivolts to volts, and the DAC can draw voltages between points at rates from 100 nanoseconds/point to 999.9 seconds/point. So, not only is waveshape arbitrary, but there's a wide range of arbitrary selection of amplitude and frequency.

Just draw, capture, compute, or modify the points to create whatever waveshape you want. The arbitrary function generator outputs it as an analog signal. There are millions of signal generation possibilities for electronics, robotics, mechanics, biophysics, geophysics, any application — all from a single instrument.

still other dimensions of sweep control capability as indicated in Figure 3.

Any waveform from memory

All of the operating output control modes discussed thus far, with the exception of sweep mode, can also be applied to waveforms generated from the AFG 5101 arbitrary waveform memory. Waveforms generated from memory are synthesized from the point-by-point amplitude information for the waveform. Amplitude points expressed at 12-bit resolution (1 part in 4096) are clocked through digital-to-analog conversion at selectable rates from 999.9 seconds to 100 nanoseconds per point. This corresponds to a 1 microhertz to 5 megahertz frequency range for arbitrary waveform generation.

The key point, however, is that any waveshape that can be represented within a 4096 vertical × 8192 horizontal array of points can be generated as an analog waveform by the AFG 5101. The points can be individually set by manual input, or the manual editing tools can be used to create or change waveforms with "auto-line" line draws between specified points. Arbitrary waveforms can also be created in a computer by mathematical formulation or simulation and transferred to the AFG 5101. They can be manually drawn with a computer mouse or graphics tablet. Or they can be captured by a waveform digitizer and transferred via computer to the AFG 5101 (see Figure 4).

Virtually any method of digitally capturing, generating, combining, or drawing a series of points representing theoretical calculations is fair game for creating arbitrary waveform data. And, once the arbitrary waveform points are transferred to AFG 5101 memory, they can be further modified by changing individual point values or with the "auto-line" function.

Beyond the ability to create any waveshape desired and generate it as an analog waveform, there are several other key advantages to arbitrary waveform generation. For example, any waveshape can be regenerated at any desired frequency within the bandwidth limits of the generator. This regeneration frequency is governed by the following general rule:

$$F = 1/T = 1/(N*RATE)$$

where,

F = frequency of the waveshape

T = period

N = number of points being used per waveshape

RATE = the selected point-to-point rate of generation

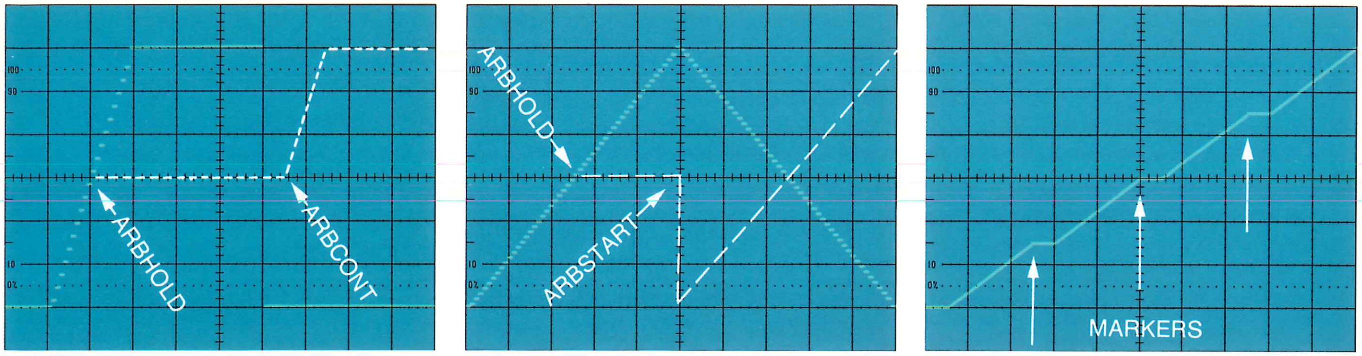


Figure 3. *A few examples of sweep generation using the various programming commands of the AFG 5101. Dotted lines show effect of the command. Left, Triggered sweep, ARBHOLD and ARBCONT (continue); Center, Triggered sweep, ARBHOLD and ARBSTART (reset); Right, Triggered sweep with added markers.*

Depending upon the number of points used and the rate selected, waveforms can be regenerated at extremely low frequencies — even as low as 1 microhertz. This ultra-low-frequency generation is extremely difficult with analog techniques, but it can be done as a matter of course with the arbitrary waveform function of the AFG 5101.

Another benefit is the ability to generate highly linear ramp waveforms. This is due to the high-accuracy, high-resolution point-by-point control offered by AFG 5101 arbitrary waveform generation. Any point can be described to 12-bit resolution and generated with 0.01% point accuracy. These highly linear ramps are ideal as standards for linearity testing of any kind of device or material.

A synthesizer option (Option 2) is available for the analog functions. This allows sine, square, and triangle analog waveform functions to be automatically generated with 5-digit resolution and 50 parts-per-million (0.005%) timing accuracy.

Full front-panel access

All of the operating modes of the AFG 5101 are front-panel accessible. In addition, the AFG 5101 provides non-volatile memory for storing up to 99 complete front-panel setups. A wide range of AM or FM modulated or sweep-modified waveforms can be created from existing waveforms in the analog generator. The setup for each waveform can then be stored and recalled as needed, or any of the two arbitrary waveform memories can be called up for arbitrary waveform generation. This offers, within a standalone instrument, the capability of generating extensive sets of waveforms for test or calibration sequences simply by recalling waveforms or setups with a few push buttons. The result is faster change-over from one test or calibration waveform to another. It also means more repeatable testing since the waveforms are regenerated from memory the same way, every time.

Arbitrary waveform generation also reduces test equipment expense and pool logistics. Being able to generate any desired waveshape from a single instrument eliminates the need for purchasing and maintaining a wide variety of specialty function generators. In an R&D environment, arbitrary generation capabilities reduces the expense and delays associated with creating custom signal sources. You have a single arbitrary waveform source, and waveshape modifications are done in digital memory rather than by custom design changes.

A systematic approach to waveform generation

For more extensive needs, the AFG 5101 is fully programmable over the GPIB interface. This allows complete control of modes, operation, and waveform points via a program running on a GPIB-interfaced computer, instrument controller, or production system host.

Fully automatic operation under computer control is a prerequisite for most automatic test systems and production applications. For example, in functional trimming of hybrid circuits with laser systems, the laser system host computer must have complete control of all stimulus and measurement systems. This is necessary for continuous control and feedback of the hybrid circuit's operating parameters as the laser trims circuit elements to achieve final output parameters or operating ranges.

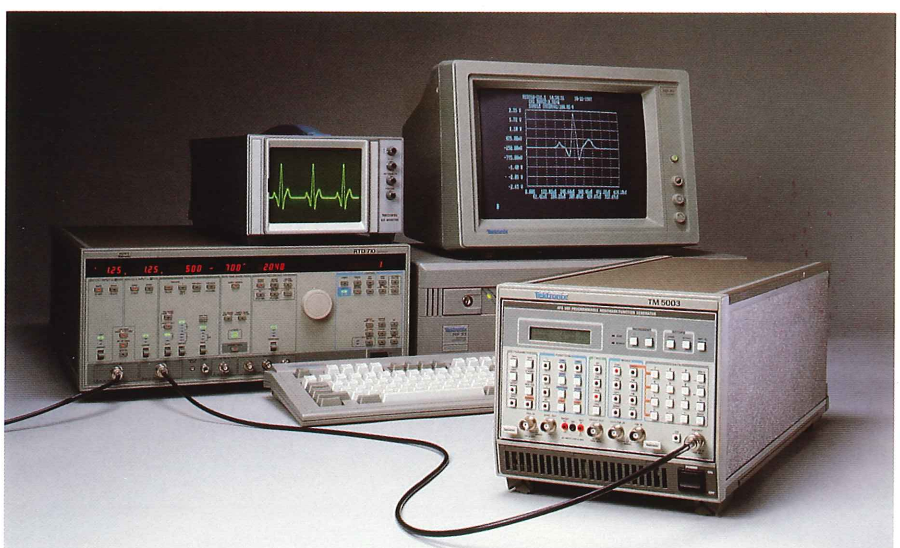


Figure 4. *The AFG 5101 can regenerate waveforms captured with a digitizer such as the Tektronix RTD 710 Waveform Digitizer as part of a programmable measurement system.*

Additionally, the system needs full automatic control for fast setup of the next trim or to change trim stimulus and measurement procedures for different circuits. The same requirements apply to any automated production or testing environment where a variety of stimulus signals are required because of either test complexity or the diversity of devices being tested.

However, automated testing is not the only area to benefit from GPIB control of the AFG 5101. As waveforms are created in the arbitrary memory, they can be uploaded to a computer for disk storage in waveform and setup libraries. Then any time a set of waveforms is needed for a particular test, calibration, or experimental procedure, the waveforms and control modes can be downloaded from archive files to the AFG 5101. The AFG 5101 can still be operated as a standalone bench tool. Downloading of waveforms and setups from disk files simply expedites instrument operation to using a few setup recall buttons.

GPIB interfacing can also simplify waveform creation. Standard waveforms from known good devices or systems can be captured with a waveform digitizer or digital storage oscilloscope (Figure 4). These digitized waveforms can then be transferred to the AFG 5101 via an interfaced GPIB controller. Or idealized waveforms can be simulated in the computer or even drawn by using a mouse or a digitizing tablet. These arbitrary waveforms can then be transferred to AFG 5101 memory for regeneration or modification by any of the operating modes to obtain variant waveforms.

Consider the possibilities

The possibilities are endless when you can arbitrarily define waveforms in digital memory and convert them to analog output. We've only given a brief introduction to these possibilities. For more information on the application possibilities or detailed specifications on the Tektronix AFG 5101 Programmable Arbitrary/Function Generator, use the reply card in this issue or contact your local Tektronix Field Office or representative.

With appreciation to Robert W. Ramirez, Technical Writer and Signal Processing Consultant, North Plains, OR.

A gallery of AFG 5101 applications

Applications for the AFG 5101 Programmable Arbitrary/Function Generator are numerous and limited only by your imagination and creativity. Here, to give you some ideas of how this unique new instrument might be put to work are only a few of literally thousands of ways the AFG 5101 can be used.

Biomedical

The arbitrary waveform generator can be used to create precisely controlled heartbeat patterns for pacemaker testing. Haver waveform generation allows highly controlled nerve and muscle stimulus for response testing in drug research and prosthetic developments, for example. In the zoological sciences, variants of digitized animal calls can be created in arbitrary waveform memory. A speaker system can then be driven with the original and modified calls to study reactions of the animal's mate or offspring.

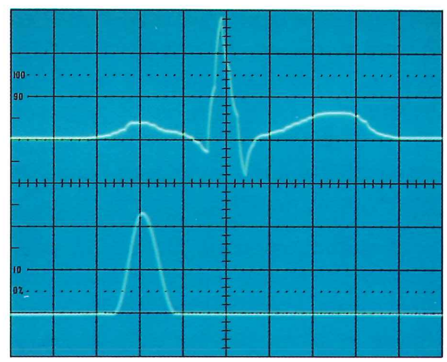


Figure A. *Heartbeat pattern (top); Haver waveform (bottom).*

Materials sciences

Using special sweep shapes under control of the Hold and Resume functions, waveforms can be generated for highly controlled drive signals on materials testing equipment. For example, the AFG 5101 output signal can be designed to raise a piece of metal to maximum strain and then subject it to any number of fatigue cycles.

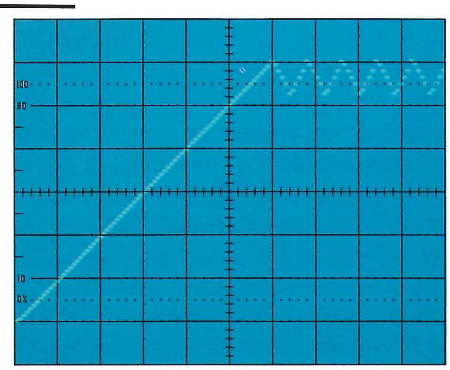


Figure B. *Control signal for stressing material to maximum strain and applying fatigue cycles.*

Physics

Simulations of oscillatory movement (pendulum or mass on a spring) can be created using generated waveforms. The basic equations can then be modified to inject damping factors from various friction sources. Formula generation of waveforms can be done on a small computer. Waveshapes can be checked with computer graphics, or the generated waveform data can be downloaded to the AFG 5101 and modified in arbitrary waveform memory while monitoring waveform output with an oscilloscope. The simulated waveforms can then be used to drive sensors, timers, or other laboratory equipment. Or they can be used as sources in developing and testing energy pumping and control systems for sustaining oscillations.

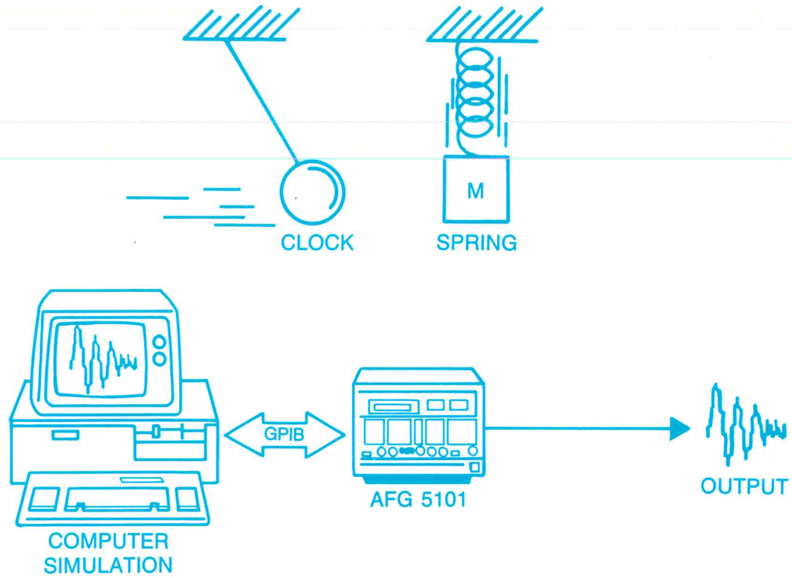


Figure C. *Pendulum/Mass simulation setup.*

Mechanical engineering

Real-life vibration waveforms can be captured with a waveform digitizer. These can be stored in a controller or disk library of test waveforms. The stored waveforms can then be downloaded to an AFG 5101, which regenerates the waveforms in a laboratory environment for study or simulations. For example, the regenerated waveforms could be used to drive a vibration table for laboratory testing of shock absorbers.

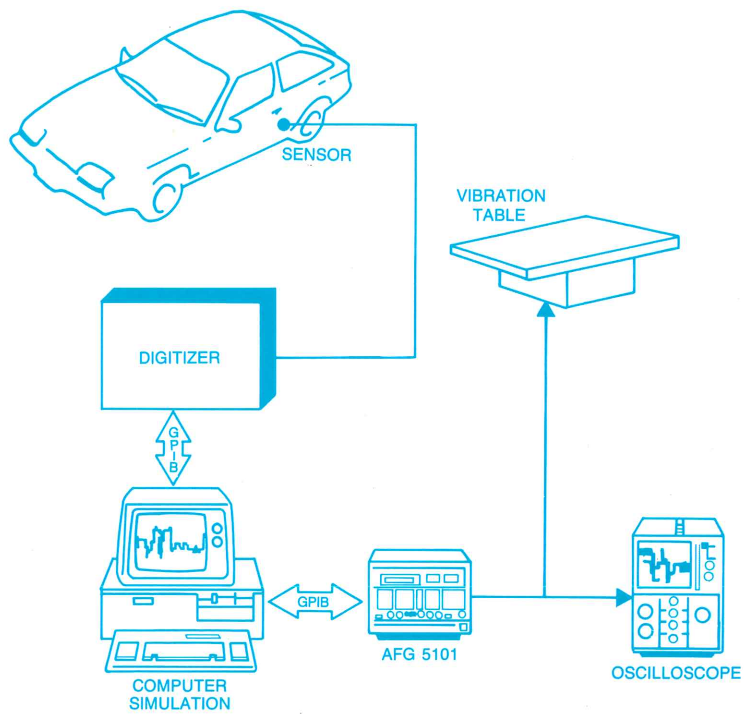


Figure D. *Vibration capture/regeneration system.*

Electronics design and test

Standard sine, square, triangular, ramp up, and ramp down waveforms can be generated at frequencies from as low as one microhertz to 5 megahertz (12 megahertz for analog function.) Such low frequencies are particularly useful for simulating sensor outputs when designing detectors and amplifiers for environmental monitoring applications. Moreover, the ramps generated by the synthesizer option have extraordinarily good linearity. This allows them to serve as reference signals for testing device and circuit linearity. Arbitrary waveform generation can be used to create a variety of synchronization and servomechanism drive waveforms. This is particularly useful in disk drive testing, where specialized test generators are often custom built to provide proprietary test waveforms. An arbitrary waveform generator can eliminate the custom generator expense and provide faster entry into production test.

Following are some examples of how the AFG 5101 can be used in electronics design and test.

A gallery ...

Noise testing

A wide range of precision noise testing can be done using the arbitrary waveform function. For example, noise spikes can be added to standard waveforms for precise testing of glitch suppression networks. Noise and ringing can be added to pulses to test the noise margin of digital circuits. Or amplitude-limited noise can be used as the arbitrary sweep to cause controlled amounts of pulse jitter for testing timing margins.

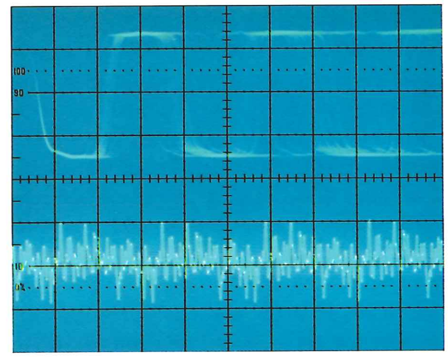


Figure E. *Pulse jitter (top) resulting from using noise (bottom) as an arbitrary sweep.*

Waveform acquisition and regeneration

Transient capture and regeneration can be done with a digitizer/computer/AFG 5101 combination. The transient waveform is captured with the waveform digitizer and transferred through the computer to the arbitrary waveform memory of the AFG 5101. Once in the AFG 5101, the transient can be regenerated at any desired level, at reduced or increased speed, or by continuous, triggered, gated, or burst modes. The transient can also be further refined in the AFG 5101 by manually altering specific points, or selected segments of the transient can be regenerated.

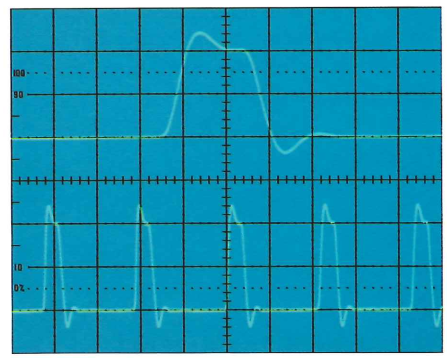


Figure F. *Signal acquired by a waveform digitizer (top) and regenerated as a stimulus signal (bottom).*

Filter testing

Production testing of filters can be expedited in several manners. Log/linear/log sweeping can be used for wideband audio testing. The linear portion of the sweep can be positioned to provide detailed views of specific frequency bands — for example, around roll offs or notches. Additionally, markers can be employed for quick visual location of key frequencies. Filter testing can also be done with semi-linear (or semi-log) sweeps while using variable step values to jump to specific frequencies of interest. Or sampled filter testing can be done by simply using frequency stepping with step sizes set to correspond to the desired frequency intervals.

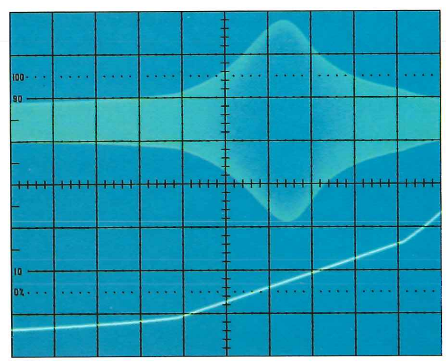


Figure G. *Log/linear/log swept response (top). Arbitrary sweep for log/linear/log sweeping (bottom).* ▷

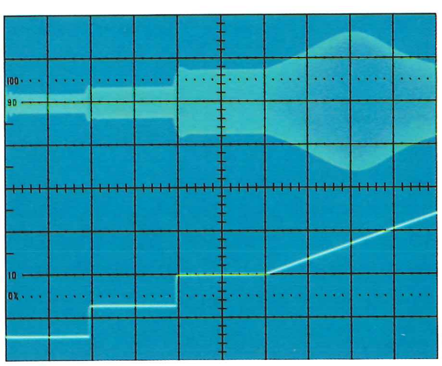


Figure H. *Response testing with combined frequency sweeping and stepping (top); Sweep for swept/stepped frequency response testing (bottom).* ◁

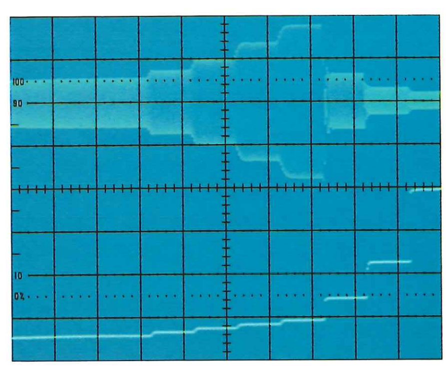
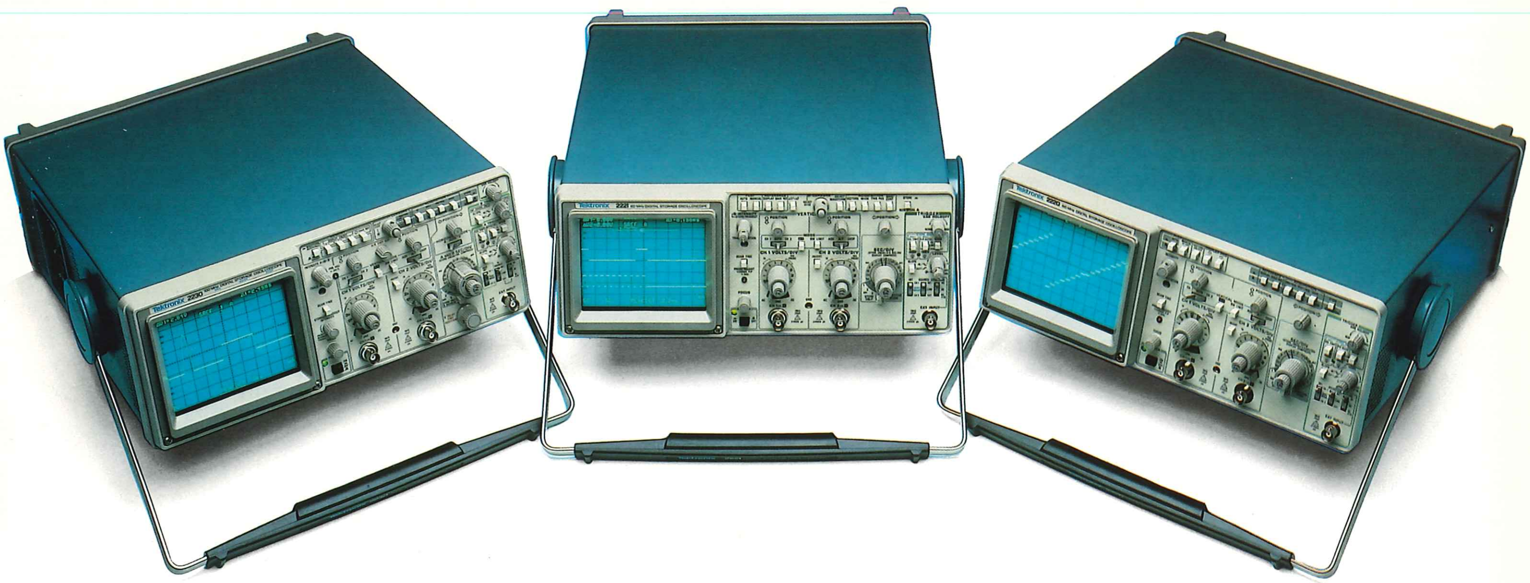


Figure I. *Sampled response testing.* ▷

NEW PRODUCTS

Digital storage at an affordable price



The 2200-Series Digital Storage Oscilloscopes provide digital storage capability at an affordable price. Left, 100 MHz 2230; Right, 60 MHz 2220; Center, the new 60 MHz 2221.

Have you been thinking of moving up to digital storage but delayed because of the "entry cost" for this move? This entry cost includes purchase of the new equipment as well as the re-training required to learn how to effectively make digital measurements.

Now there's an answer to this dilemma. The Tektronix 2200-Series of Digital Storage Oscilloscopes (DSOs) offers an affordable answer to digital storage measurements.

All in the family

The 2200 DSO Family consists of the 2220 60 MHz Digital Storage Oscilloscope, the 2221 60 MHz Digital Storage Oscilloscope, and the 2230 100 MHz Digital Storage Oscilloscope. Together they provide a choice so you can pick the performance to best fit your digital storage needs.

At $2995 (U.S. Dollars), the 2220 DSO provides an affordable entry into digital storage scopes. Even at this low cost, it offers advanced digital storage features. For example, you can store 4096-point records — not just 1024 points as provided by many other digital storage scopes. Analog bandwidth is 60 MHz with a digitizing rate of 20 megasamples/second at 8-bit vertical resolution. A complete 4096-point record can be stored in the internal Save/Reference memory for later recall. Couple this with a unique Peak Detect feature, pre- and post-trigger capability, flexible X-Y display, plotter output, and an optional GPIB or RS-232-C interface and you have the most versatile, low-cost digital storage oscilloscope available.

The 2221 is the newest member of the 2200 DSO Family. It provides all of the features of the 2220 plus additional signal-processing capabilities such as averaging to display a signal lost in noise and accumulated peak detect which builds an envelope waveform showing the extremes of signal variations. On-screen readout displays front-panel control settings and waveform measurement results. Waveform cursors allow easy voltage and timing measurements — even delta changes in time and voltage can be measured directly from the display. Price of the 2221 is $3995 (U.S. Dollars).

The high-performance 2230 contains the largest complement of digital storage features in the 2200 DSO Family. In addition to all of the features of the 2220 and 2221, the 2230 includes a dual-time base for delayed-sweep measurements, menu selection of signal processing and waveform manipulation functions, point-selectable triggering to any point on the total 4K record, and a bandwidth of 100 MHz. Record length is selectable to allow storage of one 4K record or 3 1K records. An optional battery-backed memory allows saving up to 26 waveforms for as long as three years. The 2230 is priced at $4995 (U.S. Dollars).

Buying into the 2200 Digital Storage Oscilloscope Family has many advantages. First, it offers you a choice at the time of purchase — match the instrument to the requirements of the application. Second, it offers a low-cost entry into digital-storage measurements while allowing room for later growth as your measurement needs change without the need for re-training or learning how to use a new instrument. Third, it allows you to mix different 2200-Series DSOs in a multiple-instrument facility with less cross-training of operators. Lastly, it offers the promise of product upgrades to meet your future measurement needs as new members of the family are introduced.

Easy to learn

Maybe you've been afraid to join the digital revolution because of all the unfamiliar measurement terms and extra training required. The 2200 DSO Family has a non-store (analog) mode which operates just like the analog oscilloscope you've been using for years. The front-panel controls are logically organized and function in a conventional manner. If you're familiar with analog scope operation, you'll be up and running in minutes.

But when you switch to the store mode, powerful new capabilities are at your command. Digital memory provides waveform storage, processing, and manipulation functions. Plus, you can always view a signal in the analog mode with just the push of a button — this allows you to confirm that your digitized display is correct. You get the best of both worlds — the power of digital storage along with familiar analog scope operation.

To help you get the most out of your 2200 Series DSOs, Tektronix provides a complete line of instruction manuals, training programs, and application assistance (see Figure 1). Training workshops are also available at selected locations (see **Classes and Seminars** listing in this issue).

Figure 1. *Documentation and support material available to get the most out of your 2200-Series DSOs includes training programs, application notes, video taped seminars, and more.*

The clear advantage of digital storage

With digital storage, virtually any signal you need to examine closely can be frozen on-screen for detailed measurement and analysis. This stored display is clear, crisp, and complete. Fast transients that appear as just a blink on a conventional oscilloscope can become a lasting record with the power of digital storage. And with low-repetition rate signals, digital storage shines again. Digital storage eliminates the annoying blink and flicker normally associated with these signals.

Another advantage of a digital storage display is that you can view it for as long as required with no degradation in signal. In addition, you can store the waveform in internal memory and bring it back to the screen when needed for comparison or reference to other waveforms. With an optional GPIB or RS-232-C interface, waveforms can be saved or retrieved from external storage devices.

Capture elusive transients

The Tektronix patented Peak Detect mode allows you to capture signals that many digitizing scopes miss — as narrow as 100 nanoseconds at any sweep speed (see Figure 2). Even when the event falls between sample points, a sample is stored — an event that would be missed on most digital storage scopes. This feature allows you to view normal signal activity, even at slow sweep speeds, and still catch unexpected fast events.

See more with long record lengths

Standard record length for the 2200 DSO Family is 4K — that's equivalent to four 1024-point screens of information displayed end-to-end (see Figure 3). Any 1K portion of the total 4K record can be displayed on screen. A unique bar graph on the display shows the 1K portion of the total record length that is shown on each screen.

The 2230 offers a choice between 1K and 4K record lengths — you can save up to three 1K waveforms or one 4K waveform in Save/Reference memory, allowing a choice between record length and number of records to best fit your specific application.

Now you can see what caused an event

Sometimes the activity just preceding an event is just as important as the event itself. With pre-trigger capability available on the 2200 DSO Family, you can store and display up to seven-eighths of the total record length before the trigger event. You can also select mid- (one-half of record) or post- (one-eighth of record) triggering. With the 2230, the trigger point is adjustable over the entire record length.

Need a baby-sitter?

Problem signals don't always occur at convenient times. Sometimes you have to wait for hours, or even days for a random signal to appear. But when it happens, you have to be ready. You can leave the 2200-Series DSOs digital scopes running unattended in a "baby-sitting" mode to capture single-shot events when they happen — even if you're miles away. Scan and Roll modes (sweeps slower than 0.1 second/division only) further enhance unattended signal capture. In these modes, the display is continuously updated until a trigger occurs; then, the display is frozen in memory along with pre-trigger information if desired.

Average out unwanted signals

When you're making measurements in the real world, there's often interfering noise that prevents you from clearly seeing the signal of interest. The 2221 and 2230 DSOs contain an averaging mode that allows you to effectively eliminate random noise without distorting the signal (see Figure 4). This is of particular interest when making low-level signal measurements.

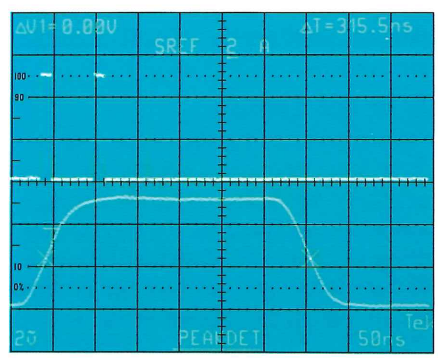


Figure 2. *Even fast transients that would be missed on many digital scopes can be captured using the 2200-Series Peak Detect mode. Bottom trace is an expanded view of the pulse using Delayed Sweep mode (2230 only).*

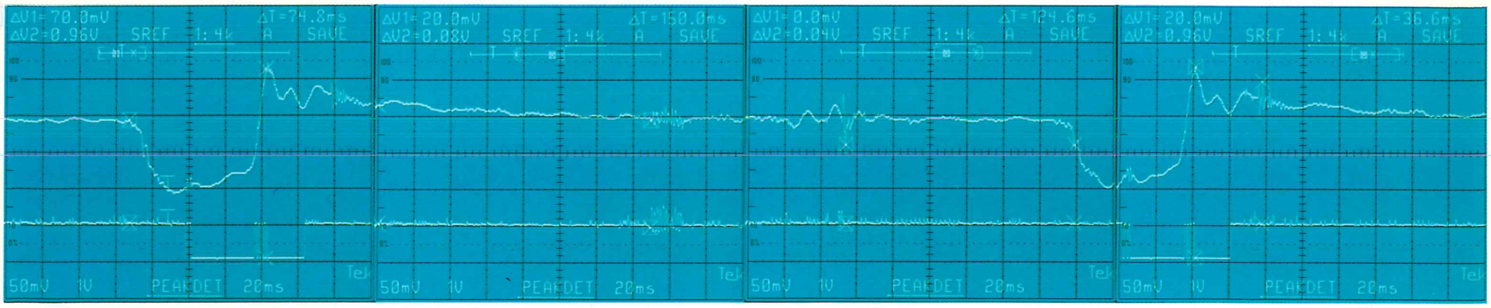


Figure 3. *Four screen photos spliced end-to-end show the amount of waveform data stored in a 4K record. Note the bar at the top of each 1K segment; the brackets on this bar indicate the portion displayed on this screen; the T indicates the trigger point.*

It can also be used to eliminate the effect of offending EMI from surrounding equipment so that what you get is the real measurement, undistorted by outside signals. Averaging weight is fixed at 1/16 for the 2221 and is selectable on the 2230 from 1/1 up to 1/256.

Easy waveform documentation

Connectors for an X-Y plotter, including pen-lift control, are standard. This allows the display to be plotted along with the graticule and readout (no readout on the 2220).

When equipped with an IEEE-488 or RS-232-C interface, the display can be sent to an attached printer or plotter that converts waveforms to HPGL, Epson, or ThinkJet format.

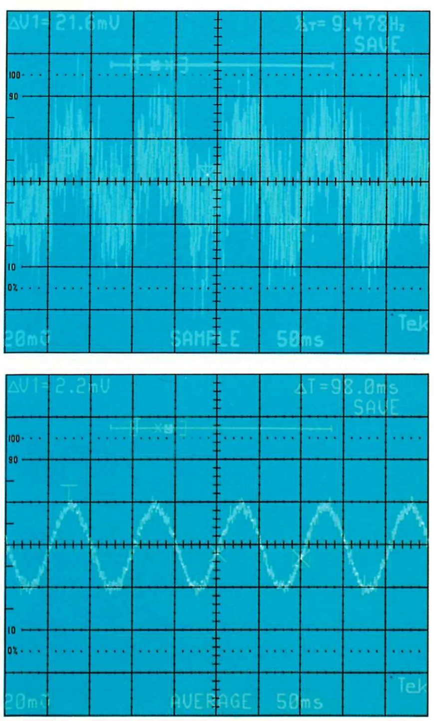


Figure 4. *Average mode allows random noise to be eliminated from the displayed signal so you can view the signal of interest.*

And interfacing too!

With the optional IEEE-488 (GPIB) or RS-232-C interface, you can send and receive digitized waveforms to and from external devices such as controllers, computers, external storage devices, plotters, and printers. With either interface option, your scope is transformed into a component that is easily integrated into a measurement system.

A variety of software packages are available from Tektronix to help with this system integration. Here's a short summary of available software:

S49Z201 — RS-232-C Utility Software for 2220/2221/2230 with IBM PC or compatibles.

S49Z202 — GPIB Utility Software for 2220/2221/2230 with IBM PC or compatibles.

S49Z203 — GPIB Utility Software for 2220/2221/2230 with IBM PC or compatibles (written in Basic A).

S10Z210 — Signal Processing and Display software (SPD) for 2220/2221/2230 with GPIB and IBM PC or compatibles (written in Turbo Pascal). Requires GPIB card such as Tek GURU II.

GURU II — GPIB control software plus a PC-to-GPIB interface for IBM PC or compatibles.

ASYST — Data acquisition and analysis routines for IBM PC or compatibles.

S49Z121 — GPIB Utility Software for 2220/2221/2230 with Tek 4041.

S49Z122 — GPIB Waveform Analysis Software for 2220/2221/2230 with Tek 4041.

For more information on any of this software, contact the Tektronix National Marketing Center (800-426-2200), your local Tektronix Field Office or representative, or check the appropriate box on the reply card in this issue.

A warranty to match

To match the excellent performance and reliability of the 2200 Series, Tektronix provides a three-year warranty on labor and parts including the CRT. A variety of optional service plans can economically extend this coverage to a total of five years in most countries. You can even select plans that include periodic calibration. Warranty and service are available at Tektronix Service Centers located around the world.

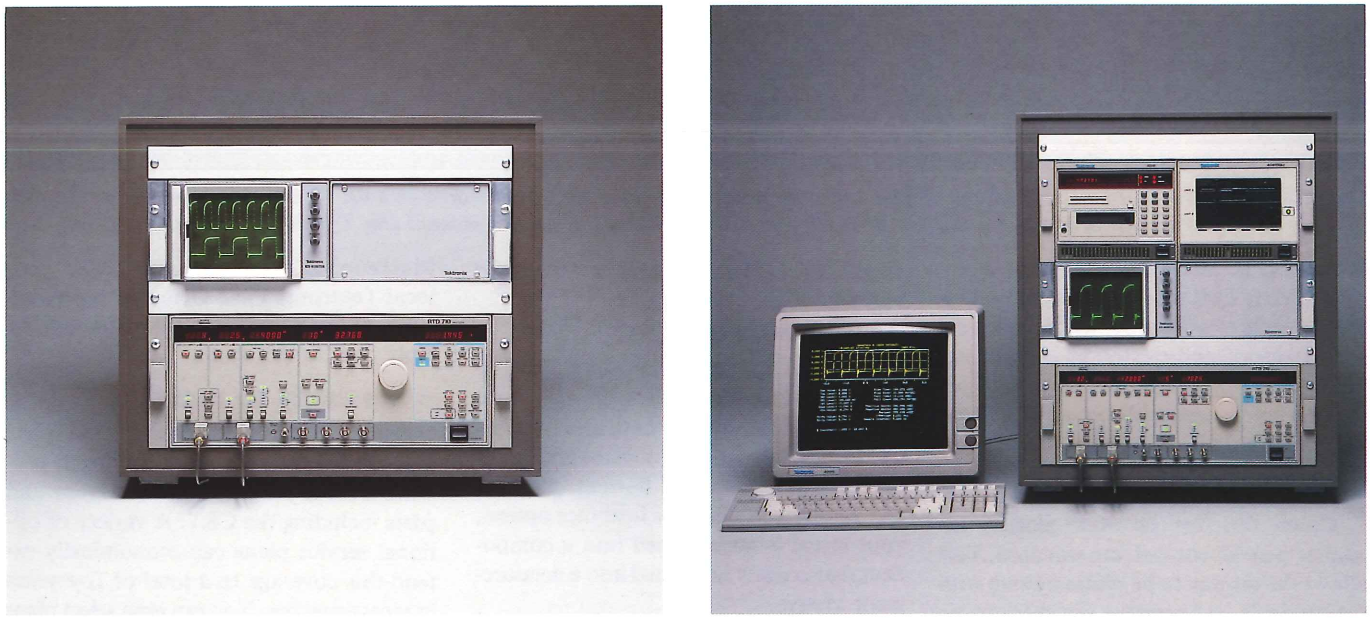
Want to know more?

Now that you've found out about all the capabilities of the 2200-Series Digital Storage Oscilloscopes, you can read about a typical application in the article **Capturing slow-speed events with 2200-Series Digital Storage Oscilloscopes** in this issue.

A free demonstration video tape is available to show the 2200-Series DSOs in action. It summarizes the features and performance of these scopes to show how they will work in your application.

For a copy of the available literature or free video tape on the 2200-Series, check the appropriate box on the reply card in this issue. To find out which of these digital storage oscilloscopes — the 2220, 2221, or 2230 — best fits your measurement application, U.S. customers can call the Tektronix National Marketing Center toll free — 800-426-2200. Or contact your local Tektronix Field Office or representative. And tell them you saw it in **HANDSHAKE.**

New systems extend the capabilities of the RTD 710



Two new measurement systems based upon the RTD 710 Digitizer. Left, MP 1701 Viewing Package; Right, MP2701 Acquisition/ Processing Package.

Two new systems extend the waveform acquisition capabilities of the RTD 710 Digitizer. These systems enhance the performance of the RTD 710 and provide a convenient and useful package.

The RTD 710 is a transient digitizer providing simultaneous dual acquisition, 10-bit vertical resolution, 0.4% vertical accuracy, 100 MHz bandwidth, acquisition rates to 5 nanoseconds/point (200 megasamples/ second), and 64K words of waveform memory. Memory can be used to store a single long record or segmented for multiple records. Sample-rate switching is also provided. For additional details on the RTD 710, see the Spring 1987 **HANDSHAKE**.

The MP 1701 adds an X-Y-Z monitor to the standard RTD 710. The system is assembled in a sturdy enclosure for placement on your bench or near your measurements. The MP 1701 system is ideal for applications where the signals are acquired and viewed without additional waveform processing. It is also the ideal addition to an existing instrument controller or host computer system.

The MP 2701 builds upon the MP 1701 configuration and provides everything required for a complete, self-contained waveform measurement system — display, instrument controller, graphics terminal, and software. Processing power is provided by the Tektronix 4041 Instrument Controller with the 4041DDU disk drive unit. The Tektronix 4205 Graphics Terminal provides an easy interface to the 4041 as well as graphic display of measurement results.

As with any system, a very important part is the system software. The MP 2701 system software is designed to extend the performance of the RTD 710 in six areas — Acquisition, Signal Processing, Storage and Recall, Processing, Display, and Utility.

Each of these six areas are further refined by means of user-defined "environments" that allow program operation to be structured in a manner that is most useful for a specific application. Environment editing is on an individual parameter basis and any editing changes remain in effect until changed. Environments can be saved to media files and then recalled later to set up predetermined measurement requirements for a specific application.

Details of each of the six areas:

Acquisition — Data from either channel, any of 64 records, or any RTD 710 connected to the system can be stored in one of six memory locations. Data can also be acquired from processed waveforms or waveforms from media files.

Signal Processing — Includes 20 pulse analysis parameters, 17 time and amplitude measurement parameters, gain and phase measurements between two waveforms, time delay measurements, time A to B measurement on a single waveform or between waveforms, and spectral analysis.

Storage and Recall — Save and recall RTD 710 settings, waveform data, MP 2701 operating environments, and "learned" system sequences.

Processing — Provides the ability to manipulate waveform data. Functions include add, subtract, multiply, divide, and correlation of waveforms. Single waveform manipulation includes integration, differentiation, smoothing as a low-pass filter, correlation, and graphically segmenting a waveform to allow study of the area of interest.

Display — Display choices include one or two waveforms on one graph, two waveforms on two graphs, two waveforms on one graph with two sets of vertical axes, X versus Y waveform plots, and the choice of not having waveform data graphically displayed. Graphs can also be annotated with user text that can be positioned on the display for maximum effect.

Utility — Includes a general-purpose talk/listen routine for communication with any instrument connected to the IEEE-488 bus, file utilities for managing data, and support for various hardcopy devices to allow capturing the data and graphics on the terminal display.

Another important feature of the MP 2701 software is a "learn" mode. A sequence of measurement steps can be "learned" and later executed as a single step. These measurement "macros" can be saved to media files and recalled as needed. More than one measurement "macro" can be resident at one time.

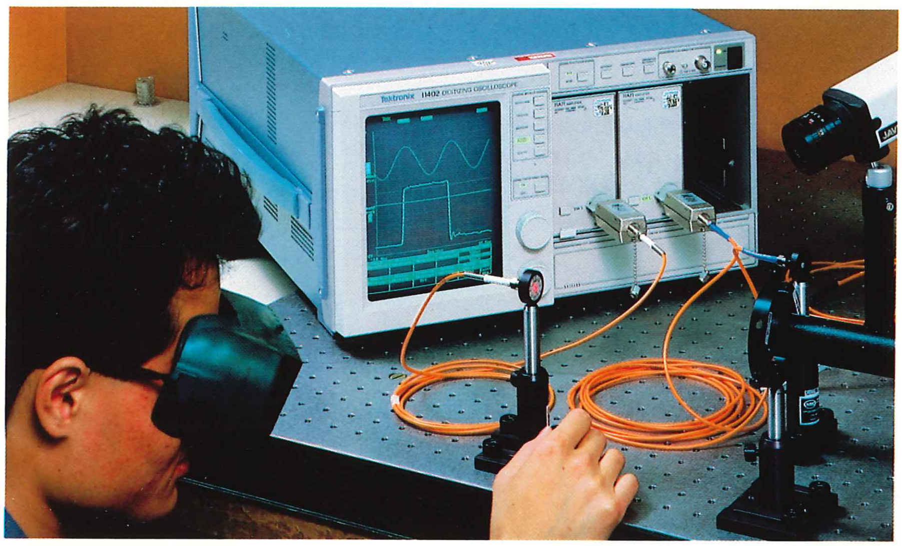
For those who already own a Tektronix 4041 Instrument Controller, the MP 2701 software can be purchased separately as S45F701 System Software. Other levels of software support are also available to use the RTD 710 with other computers or controllers. Contact your local Tektronix Field Office or representative for price and availability of RTD 710 system software.

For more information

Check the appropriate box on the **HANDSHAKE** reply card for more information on the MP 1701, MP 2701, RTD 710, or 4041. Or call your local Tektronix Field Office or representative. And be sure to tell them you saw it in **HANDSHAKE**.

NEW PRODUCTS

One easy step to an optical oscilloscope



The P6701 and P6702 Optical to Electrical Convertor probes convert an 11000-Series oscilloscope into an optical oscilloscope (shown with the P6751 Spatial Input Head).

The P6701 and P6702 Optical to Electrical Convertor probes turn the Tektronix 11000-Series oscilloscopes into high-bandwidth optical oscilloscopes in one easy step — simply attach one of these probes to the input connector of an 11000-Series plug-in, connect a fiber-based optical signal, and make measurements on the resultant display in the conventional manner.

These optical probes are compact units (Figure 1) which attach directly to the input connector and, as a result, require no bench space. Up to eight channels of optical data can be simultaneously acquired by an 11000-Series oscilloscope.

Applications for the P6701 and P6702 are numerous. They include, but are not limited to:

- Characterization of electro-optic devices (e.g., diode lasers, LEDs, electro-optic modulators, optical waveguides, etc.)
- Development and servicing of electro-optic systems (e.g., fiber-optic control networks, LANs, optical disk storage systems, etc.)
- Manufacturing of electro-optic components (e.g., quality control, device calibration, process troubleshooting, etc.)

Simple measurement of light

The P6701 and P6702 Optical to Electrical Convertor probes make characterizing optical waveforms as simple as characterizing voltage or current waveforms. They use the 11000-Series TEKPROBE interface to allow direct reading of measured values on the oscilloscope screen (see details on TEKPROBE interface below).

The powerful processing capabilities of the 11000-Series Oscilloscopes can then be used to measure waveform parameters such as RMS-power, frequency, peak-to-peak power variation, and energy (Figure 2).

These convertors allow waveform measurements on light signals having wavelengths between 450 and 1700 nanometers — 450 to 1050 nanometers for the P6701 and 1000 to 1700 nanometers for the P6702. A graph on the bottom of each convertor case shows the relative spectral response based on a calibrated reference wavelength (Figure 3). Bandwidth is DC to 700 MHz (−3 dB optical) for the P6701 and DC to 500 MHz (−3 dB optical) for the P6702.

Connection of fiber-based optical signals is easy. The P6701 and P6702 come standard with SMA fiber-optic input connectors. An FC input connector is available optionally. In addition, Tektronix offers a complete line of optical cables with a variety of connectors to serve as adapters to systems with differing output connectors.

Figure 1. *The P6701 and P6702 Optical to Electrical Convertors and the P6751 Spatial Input Head comprise a compact optical measurement system.*

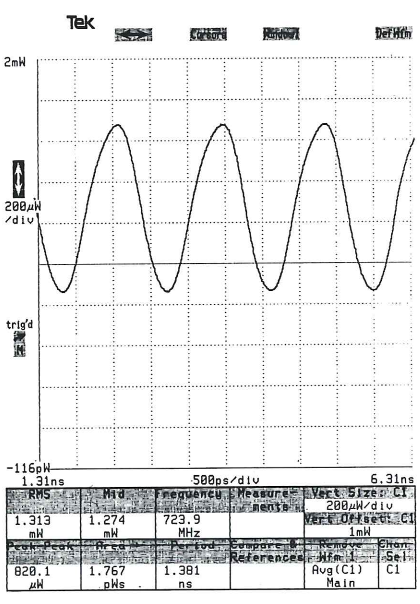


Figure 2. *Hardcopy output from an 11402 Oscilloscope with the P6701 measuring the modulation of the output power of a 630 nanometer HeNe laser due to the interference between adjacent modes. Note the modulation frequency is approximately 725 MHz.*

The perfect companion — the P6751 Spatial Input Head

The P6751 Spatial Input Head is a tunable lens system for sampling the optical energy from any free-space optical source. It serves as the perfect companion to the P6701 and P6702 for collecting optical energy from any source and delivering it to the optical convertors via a fiber-optic cable. The P6751 can be easily mounted using standard optical-bench fixtures. It is calibrated from 500 to 1500 nanometers and can be adjusted by the user to optimize the amount of optical energy collected and delivered into the fiber-optic cable.

The TEKPROBE interface

The P6701 and P6702 use the TEKPROBE interface connector which is a unique feature on the 11000-Series plug-ins. This connector consists of a standard BNC connector for signal connection surrounded by seven pins (Figure 4). These pins supply power to the Optical to Electrical Convertors and allow the 11000-Series mainframe to poll a ROM in the convertor for scale factor and input termination data. Based on this data, the proper scale factor is displayed in milliwatts/division. Also, any processing performed on the optical data reflects the correct units. This allows direct measurement of optical waveform characteristics such as pulse power, peak power, RMS power, etc., without the need for further conversion by the user.

Figure 3. *Graph on the P6701 and P6702 shows the relative spectral response for each convertor.*

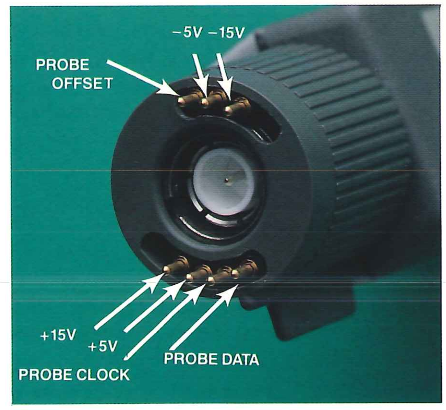


Figure 4. *The TEKPROBE interface connector on the P6701 and P6702 allow these optical probes to be an active part of an 11000-Series measurement system.*

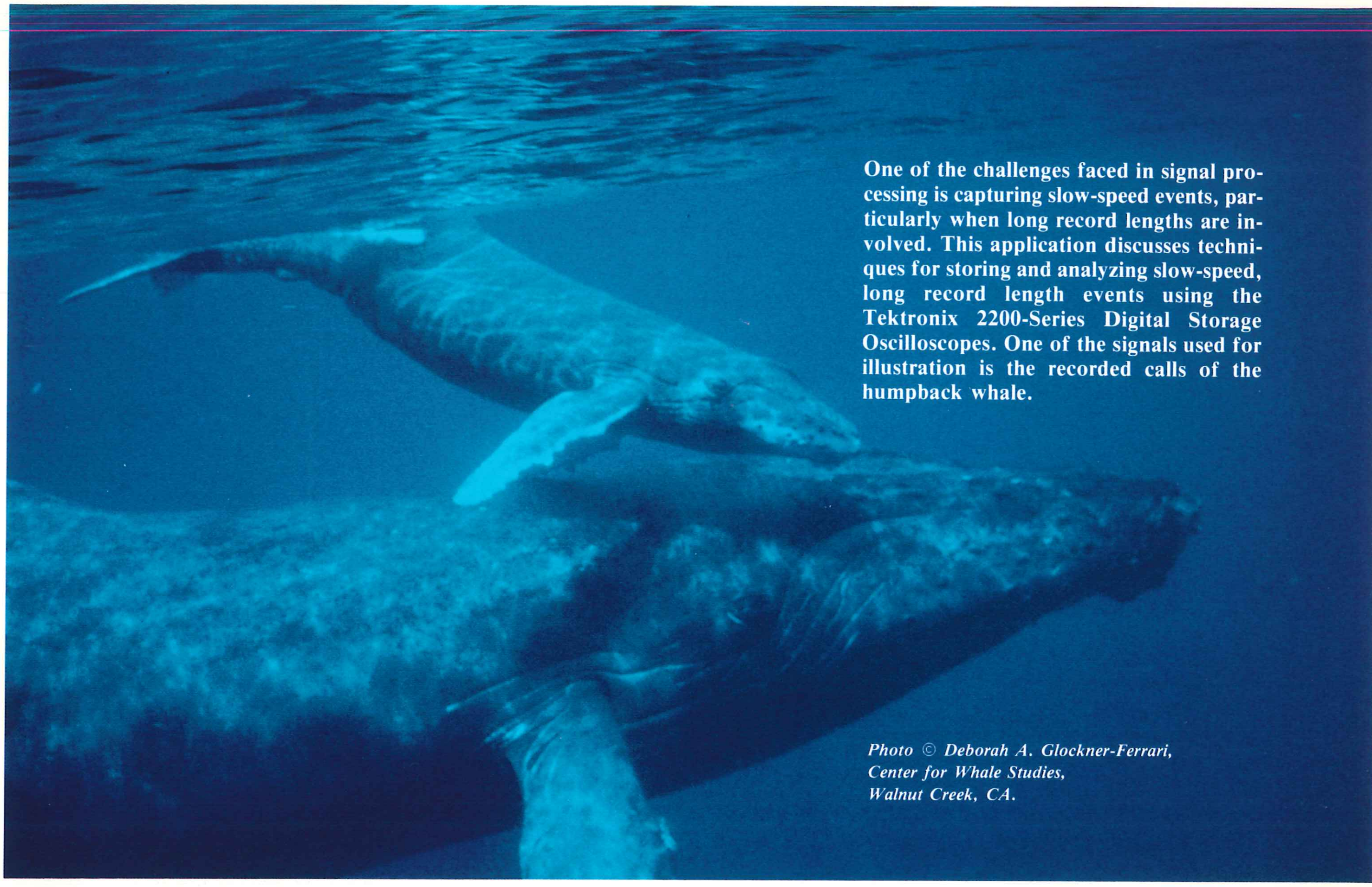
For information

To order the P6701, P6702, or P6751, U.S. customers can call the Tektronix National Marketing Center 1-800-426-2200. Or contact your local Tektronix Field Office or sales representative. And be sure to tell them you saw it in **HANDSHAKE**.

For a data sheet on the P6701, P6702, P6751, and 11000-Series, use the reply card in this issue of **HANDSHAKE**.

For further information on the 11000-Series, refer to the Winter 1986/87 **HANDSHAKE** or contact your local Tektronix Field Office or sales representative.

Capturing slow-speed events with 2200-Series Digital Storage Oscilloscopes



One of the challenges faced in signal processing is capturing slow-speed events, particularly when long record lengths are involved. This application discusses techniques for storing and analyzing slow-speed, long record length events using the Tektronix 2200-Series Digital Storage Oscilloscopes. One of the signals used for illustration is the recorded calls of the humpback whale.

Photo © Deborah A. Glockner-Ferrari, Center for Whale Studies, Walnut Creek, CA.

Waveform digitizing and storage capability is particularly advantageous for low-speed phenomena encountered in a wide range of scientific studies. Segments of continuously changing data — such as voice waveforms — can be frozen on-screen for viewing or detailed measurement and analysis. Low-repetition data — such as heart beats — can be scanned and anomalies such as arhythmias selectively captured. Long duration phenomena — such as tensile test data — can be captured from start to finish with high resolution. Or infrequent or unpredictable events — such as a mother humpback whale calling her pod — can be captured in a single-shot "baby-sitting" mode.

Unlike standard oscilloscopes which show low-speed waveforms only as a bright dot or a quickly fading trace, digital storage oscilloscopes (DSOs) such as the Tektronix 2200-Series Digital Storage Oscilloscopes maintain a complete display. You see a bright, clear, stable display of the entire waveform and you can view the waveform for as long as you like. The waveform can be stored in internal memory, then called back to the screen for comparison to other waveforms. Or you can send the waveform to a computer — such as a low-cost personal computer — for archiving or advanced software analysis.

For additional information on the 2200-Series DSOs, refer to the article **Digital storage at an affordable price** in this issue.

Key DSO features for low-speed phenomena

Taking full advantage of waveform digitizing and storage for low-speed phenomena requires using a DSO with the right feature set. For example, the DSO must have a time base with slow enough ranges to match your data needs. In the case of the Tektronix 2200-Series DSOs, the slowest time base setting is 5 seconds/division. For ten horizontal screen divisions, this translates to as much as 50-seconds of data which you can view at any given time.

But there is actually more than that. The 2200-Series DSOs have a selectable long-record storage feature — 4K points in length — corresponding to four screens of data. That's up to 200-seconds of continuous acquisition and storage, with any 50-second interval viewable on screen. In addition, acquisition and storage can be extended beyond 200 seconds with an external clock input. Also, time resolutions as high as 1 part in 4096 can be maintained throughout.

While record length and resolution are important data quality considerations, capturing the right segment of data is an equally important consideration. For example, how can you selectively pick whale calls out of ocean background noise and store individual calls? How do you select and store individual calls? How do you select and store aftershock following a seismic event? Capture a momentary arhythmia from a string of normal heart beats? Or catch both pre-fracture and fracture data in material fatigue testing?

To help zero in on just the data segment needed, the Tektronix 2200-Series DSOs provide several special capture modes. These are referred to as SCAN, ROLL, and SCAN-ROLL-SCAN (SGL SWP). These modes can be used for real-time capture directly from sensors. Or they can be used to display segments of interest from previously recorded data. This latter capability is particularly useful for dealing with data containing long quiescent periods — a common situation in seismic monitoring for example. It is also useful for converting taped histories to computer format in order to apply advanced analysis or statistical data base techniques.

Picking the right mode for your application depends upon the type of data you are dealing with and how you want to view that data. This in turn hinges on having a basic understanding of the SCAN, ROLL, and SCAN-ROLL-SCAN modes and how they display data. The following discussion concentrates on the major concepts involved. Once these concepts are understood, setup and operating details can be found in the Operators Manual for the specific 2200-Series DSO.

SCAN mode basics

SCAN mode digitizing and storage automatically goes into operation for time base settings from 0.1 second/division to 5 seconds/division (or external clocking) and when peak-to-peak (P-P AUTO) or normal (NORM) triggering is selected. When P-P AUTO triggering is used, SCAN writes a complete record from left to right across the screen. Then it begins updating the record by over-writing with new data, again from left to right. This process is illustrated in Figure 1.

Sampling, storage, and display of the waveform are continuous. You can see the newest waveform data scan left to right as it updates and over-writes the oldest waveform data. To freeze the display at any time so that no further updates occur, simply press the SAVE button. An example of a "SAVEd" display is shown in Figure 2. The digitized waveform data forming this display can be transferred to one of the reference memories for later recall to the screen if desired.

Note the time/division readout at the bottom of the screen in Figure 2. The audio transient from tape playback startup has been captured at 0.5 second/division. The total display, which is made up of 1K sample points, spans ten divisions or 5 seconds. Such slowly evolving events are best captured with SCAN mode since their evolution can be observed on screen and then saved by pressing the SAVE button.

Once saved, the event can be analyzed using the waveform cursors. This is also shown in Figure 2. The cursors — indicated by an X and boxed [X] — have been placed at the transient start and peak. The amplitude of the transient (vertical distance between cursors) is shown in the upper left readout. The time from start to peak (horizontal distance between cursors) is shown in the upper right readout.

There will be cases where you want just a single SCAN of the data — no updating. For such cases, use the SCAN mode with normal (NORM) triggering mode. A trigger level and slope can then be set according to the signal you want to capture, and SCAN will not start until the signal reaches the trigger level. Then, the new data is scanned onto the screen from left to right and held without updating until another signal triggers the next SCAN.

In normal triggering mode, the 4K-point record mode becomes useful for capturing longer durations of data. You get four screens of data without losing any sample resolution. Or you can go to a faster time base setting and increase the sample resolution on the event. This latter case is shown in Figure 3, which is another capture of tape-playback startup.

Notice in Figure 3 that a "T" designates the trigger point on the waveform. Also, note the bar graph above the waveforms which indicates the 1K segment which is

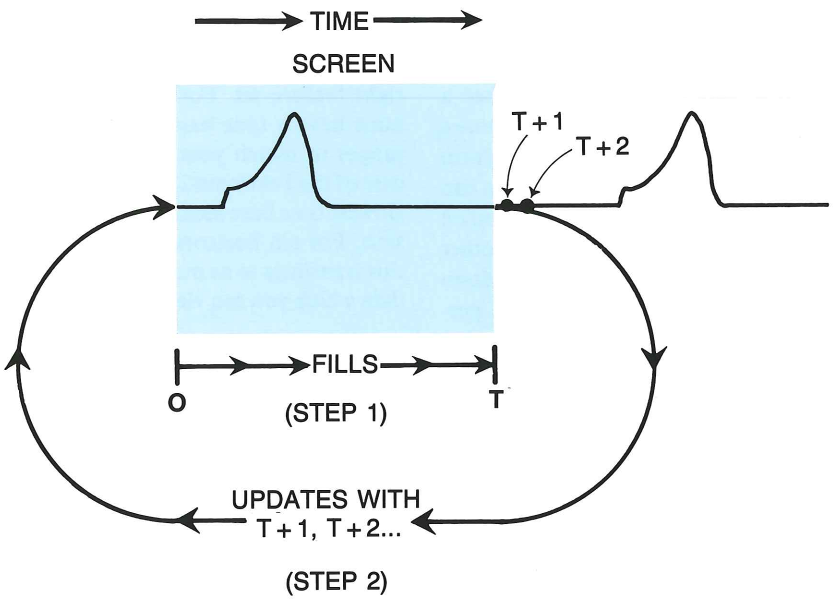


Figure 1. *In SCAN mode the screen fills from left to right with waveform samples (step 1). This display remains on-screen until updated from left to right by over-writing with new samples (step 2).*

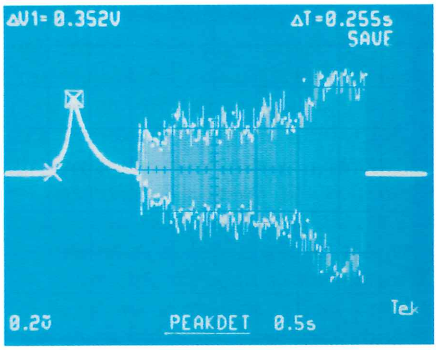


Figure 2. *SCAN mode capture of audio transient from tape-playback startup. The display was SAVEd (locked in memory) before the audio completed SCAN update on the right edge of the screen.*

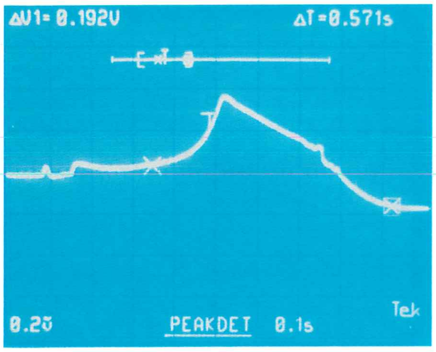


Figure 3. *SCAN mode used with NORMal triggering and a 4K record length to increase resolution of tape-playback start transient. Note the bar graph above the waveform showing the displayed 1K segment of the 4K record as well as the trigger point.*

displayed out of the total 4K record length. The entire 4K record is represented by the straight line, and the displayed portion is indicated by the square brackets. The location of the T on this graph indicates that nearly a full screen of data has been captured prior to the trigger point (pre-trigger data). This is followed by about three screens of data after the trigger point (post-trigger data). Any 1K segment of this data can be scrolled into view by using the cursor positioning knob.

ROLL mode basics

While SCAN mode is good for capturing single, slowly evolving events, other applications often involve a series of events or a continuum of events. Examples of these applications include capture of voice, respiration, or fluid turbulence data. Such continuous phenomena are better observed with the ROLL mode.

All triggers are disabled in ROLL mode, and the waveform data scrolls continuously across the screen from right to left — the newest data on the right and oldest on the left. The action is quite similar to a chart recorder and is illustrated in Figure 4.

Typically, the best way to use ROLL mode is in the 4K-record length mode with the cursors adjusted to the far right of the record. This allows you to immediately see data as it begins filling in from the right. If you were to view the left most edge of the record, you would have to wait through the three preceding screens of capture before data begins to ROLL onto the left most edge of the screen.

Figure 5 further illustrates the use of ROLL mode. The top photo shows the displayed segment set to the far right. This allows viewing of the newest data as it "rolls" onto the screen and into digital memory. Once the data of interest has rolled fully onto the screen, press SAVE to freeze the data on the display and in digital memory — as shown, SAVE was pressed as the call of a mother humpback whale tapers off into background ocean noise. In the center photo, the cursors have been moved backward in time through the 4K record to display a middle portion of the whale call. On the bottom, a portion of interest marked by the boxed [X] cursor has been expanded 10 times using the time base magnifier.

By using ROLL mode in the above manner, you can assure capture of the complete event. Then, as in Figure 5, you can move the cursors to specific areas of interest for detailed analysis.

SCAN-ROLL-SCAN mode basics

In some instances, it is desirable to ignore low-level signals and automatically trigger waveform capture on a higher level signal element. This might be the case, for example, in capturing whale calls from a continuous background of ocean noise. For this, or any other randomly occurring event of interest, the DSO needs to be operated in a "babysitting" mode. Such a mode allows the DSO to be set up for capture and left waiting for the event to occur. When the event occurs it is automatically captured, without anyone having to monitor the display or take any action.

For low-speed events, this "babysitting" capability is provided by the 2230 SCAN-ROLL-SCAN mode (2220 and 2221 have similar modes). To use SCAN-ROLL-SCAN, press SGL SWP. Then adjust the trigger level control to set triggering on the signal of interest. If triggering occurs on a lower than desired signal element (noise for example), set the trigger level slightly higher and press SGL SWP again to rearm the single sweep mode.

In single-sweep mode with time base settings of 0.1 second/division or slower, the 2230 automatically goes into SCAN-ROLL-SCAN mode. When the sweep is armed by pressing single sweep, the display is cleared for waveform capture and SCAN filled with pre-trigger data. This pre-trigger data is then continuously ROLL updated. The display remains in this condition until triggered by a signal that reaches the selected trigger level (as set with the LEVEL control).

When a trigger occurs, the pre-trigger data is frozen in place. This is immediately followed by SCAN filling of the post-trigger portion with the triggering waveform.

This SCAN-ROLL-SCAN cycle is illustrated in Figure 6. When it completes by SCAN filling the post-trigger portion, data acquisition stops and the waveform is frozen on screen. The waveform can then be stored in reference memory. Or a new SCAN-ROLL-SCAN cycle can be initiated

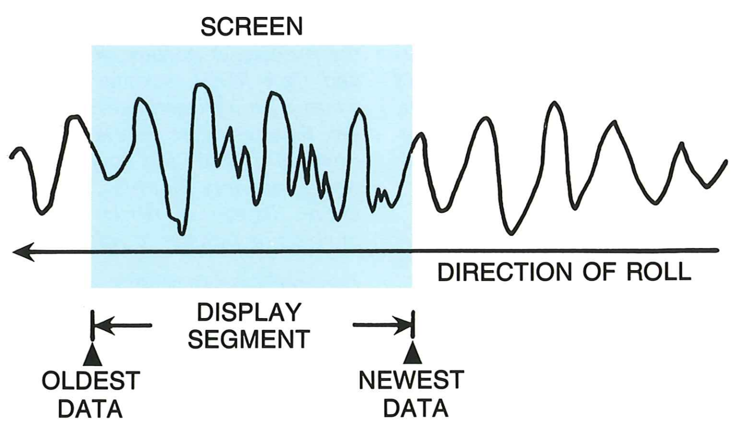


Figure 4. *In ROLL mode the waveform slides continuously across the display from left to right, resembling a chart recorder. The desired segment of data can be frozen in memory and on the screen for analysis by pressing SAVE.*

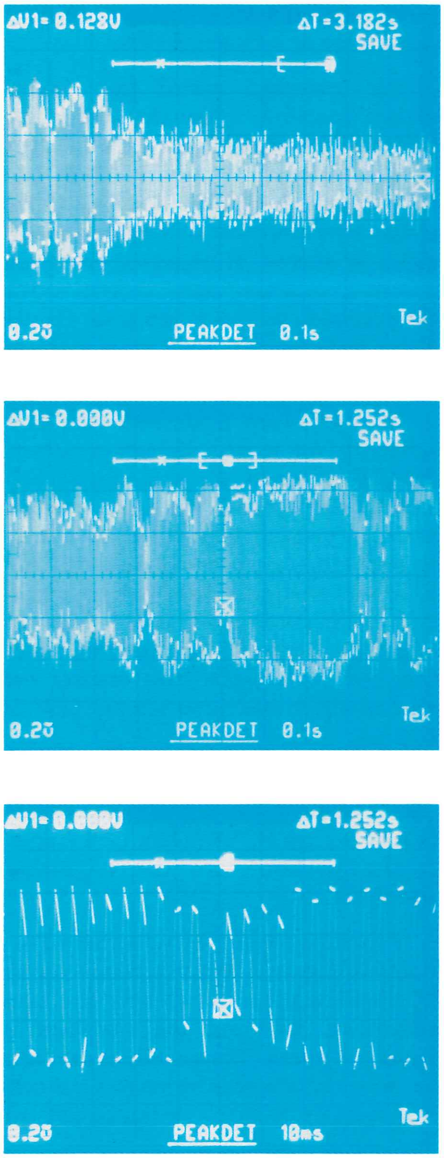


Figure 5. *Mother humpback whale calling her pod. Data was captured from a recording using ROLL mode. Top, Data stored by pressing SAVE as call finishes; Center, Display scrolled back into stored data; Bottom, Display expanded 10 times around cursor.*

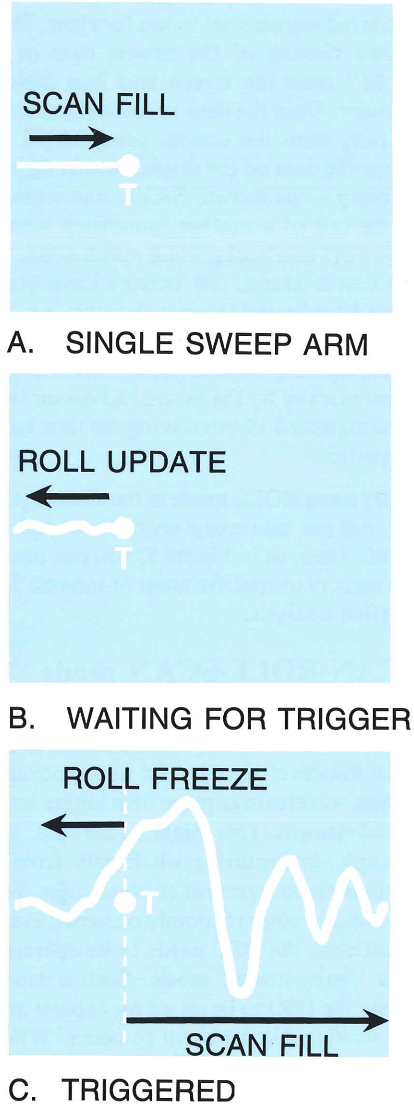


Figure 6. *In SCAN-ROLL-SCAN mode, the pre-trigger portion SCAN fills (top), and then ROLL updates (center), while waiting for a triggering event. On the trigger, the pre-trigger data is frozen, and the event data SCAN fills the post-trigger portion of memory (bottom), Once filled, the entire display is frozen on-screen for analysis or transfer to reference memory.*

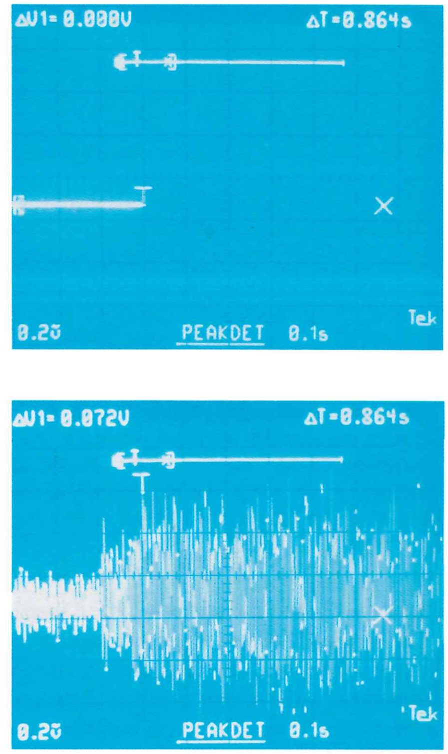


Figure 7. *An example of SCAN-ROLL-SCAN being used to capture the cannon roar in Tchaikovsky's 1812 Overture. Top, waiting for trigger; Bottom, trigger occurred on high-amplitude cannon shot.*

by pressing SGL SWP to rearm the single sweep. An example of using this mode is shown in Figure 7. Again note the bar graph above the waveform indicating the displayed portion and the trigger point.

Dealing with stimulus/ response data

In addition to the single-channel operation illustrated here, the SCAN, ROLL, and SCAN-ROLL-SCAN modes can also be used in dual-channel or X-Y modes. For example you can acquire stimulus data on one channel and response data on another channel. With the Vertical Mode switches set to BOTH and ALT or CHOP, two traces are rolled or scanned across the screen. The only difference is that half as many points per trace are stored in dual-channel operation. This is because sampling is shared between channels.

You can also set the Vertical Mode to ADD instead of ALT or CHOP. The ADD display is the sum of the two input channel waveforms. Or you can invert one channel by pressing INVERT to get a displayed difference (CH 1 – CH 2) of the two input channels.

As still another alternative, you can display both channels plotted against each other in an X-Y mode. This can be used with ROLL mode, for example, to produce a dynamic display of cylinder pressure-volume cycles.

For more information

For additional information or literature on the Tektronix 2200-Series Digital Storage Oscilloscopes, U.S. customers can call the Tektronix National Marketing Center toll free — 800-426-2200. Or contact your local Tektronix Field Office or representative. And be sure to tell them you read about it in **HANDSHAKE.**

For a brochure and data sheet on the 2200-Series DSOs, check the box on the reply card in this issue.

Using the RS-232-C as an instrument interface

Ray Kennedy
Applications Engineer
Portable Test Instruments Division
Tektronix, Inc.

The RS-232-C interface has long been used as a communications interface for such applications as terminals, modems, and printers. However, with the recent development of measurement instruments which use the RS-232-C interface, it has also found usage as an instrumentation interface. This article provides information to help you better understand and use this interface in your measurement applications.

What is the RS-232-C?

The acronym RS-232-C is used to describe communication interfaces on many types of equipment. But if you examine these interfaces closely, you'll notice that they vary in their implementation — sometimes quite widely. Why is this so?

The RS-232-C standard was established by the Electronic Industries Association (EIA) to provide a common basis of communication between instruments. However, the RS-232-C standard is a "recommended standard" which, unlike some other standards, may not be rigidly followed in all aspects in a particular implementation. Various instruments use subsets and variations of the standard because of differing interpretations, cost considerations, or available technology. Obviously, this can lead to some confusion when supposedly compatible instruments won't talk to each other. It also demands that the user have an understanding of the interface in order to successfully implement a system based upon the RS-232-C.

Basically, adherence to the RS-232-C standard ensures three things:

1. That control and signal levels will be compatible.

2. That interface connectors of the same type may be plugged together (mated) with identical pin wiring and corresponding connections.

3. That control information supplied by one device will be understood by the other device.

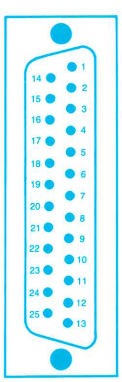
A standard connector — or is it?

The RS-232-C standard defines the pin assignments for use with a 25-pin connector. Though the specific type of connector is not defined, industry has settled on a 25-pin "D"-shell connector as shown in Figure 1.

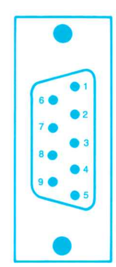
Some recent implementations of the RS-232-C interface use a 9-pin "D"-shell connector which is rapidly becoming a de facto standard. Reasons for this may vary, but one prime motivator is that only a few of the 25 pins are actually used in most implementations and the 9-pin connector is adequate. In addition, space is often a consideration in most equipment designs and the 9-pin connector obviously requires less mounting space. Since the 9-pin connector is found on many RS-232-C instruments, Figure 1 also identifies the pins and functions in a 9-pin connector.

Table 1 lists the commonly used RS-232-C signals and describes their function. This should simplify the basic problem of connecting two instruments together but, unfortunately, it's not that simple.

If you're trying to interface equipment that use differing physical connectors, your first task is to get the connectors mated with the signals properly routed. The information in Figure 1 and Table 1 should help in the construction of an adaptor cable. These cables are also available from electronic supply houses or computer supply stores for the most common combinations. In addition, adaptor cables are often available from the manufacturer of equipment that uses a non-standard connector.



25-PIN "D"-SHELL		9-PIN "D"-SHELL
1	CHASSIS GROUND	NC
2	TRANSMIT DATA (TxD)	3
3	RECEIVE DATA (RxD)	2
4	REQUEST TO SEND (RTS)	7
5	CLEAR TO SEND (CTS)	8
6	DATA SET READY (DSR)	6
7	SIGNAL GROUND	5
8	DATA CARRIER DETECTED (DCD)	1
20	DATA TERMINAL READY (DTR)	4
22	RING INDICATOR (RI)	9



NOTE: DATA TERMINAL EQUIPMENT (DTE) PLUG IS MALE;
DATA COMMUNICATIONS EQUIPMENT (DCE) PLUG IS FEMALE.

Figure 1. *Detail of the RS-232-C connector with commonly used lines identified. Left, 25-pin "D"-shell connector; Right, 9-pin "D"-shell connector.*

Table 1
Commonly Used RS-232-C Signals

Signal Name	Mnemonic	Pin Number for 25-Pin Connector	Pin Number for 9-Pin Connector	Usage
Protective Ground	None	1	NC	Connection to the metal chassis
Transmitted Data	TxD	2	3	Outgoing data path from the DTE point of view
Received Data	RxD	3	2	Incoming data path from the DTE point of view
Request To Send	RTS	4	7	Activated by the DTE to tell the DCE that it is ready to receive data
Clear To Send	CTS	5	8	Activated by the DCE to tell the DTE that it is ready to receive data
Data Set Ready	DSR	6	6	Activated by the DCE to tell the DTE that the DCE is operational
Signal Ground	None	7	5	Return path for all other signals on the bus
Data Carrier Detected	DCD	8	1	Activated by the DCE to tell the DTE that the modem has made contact with the modem on the far end and can sense the carrier
Data Terminal Ready	DTR	20	4	Activated by the DTE to tell the DCE that the DTE is operational
Ring Indicator	RI	22	9	Indicates that the modem detects a ring signal on the phone line

NOTE: DTE = Data Terminal Equipment; DCE = Data Communication Equipment.

Matching the signals

In its most basic form, the RS-232-C interface consists of three wires — two used for signals, and a ground wire. Since the RS-232-C interface is intended to pass data between two pieces of equipment, the designers of the interface chose to give each piece of equipment a data output line and a data input line.

By connecting the output line of the first instrument to the input line of the second, the first can talk to the second. Or, to say it differently, the second can listen to the first. By connecting the output of the second to the input of the first, we also have a path for communication in the other direction.

In addition, four other lines are used to control the flow of data. These are called "handshake" lines and, like the data lines, are used in complementary pairs.

There are two types of RS-232-C equipment: Data Terminal Equipment (DTE) — such as computers and terminals — and Data Communication Equipment (DCE) — such as modems. Both types of devices have the same basic functionality (i.e., talking, listening, and handshaking) — the difference being how the logical functions are matched up to the signal names. For example, the line called TxD is the Transmitted Data from the DTE device, which goes into the DCE device's (logical) receive data input (shown in Figure 3 and discussed in detail later). Though still called TxD at the DCE end, the logical function for the DCE device is that of receiving data. To say it another way, signal lines are named with respect to the DTE function, and DCE functions complement the signal name.

Since a typical usage of the RS-232-C interface is an instrument at a remote site (DTE) talking to an instrument controller (DTE) over phone lines via modems (DCE) (i.e., two DTE devices talking to each other via two DCE devices), the following discussion about handshaking revolves around what the two DTE devices see during the session. While we need to remember that the DCE devices (modems) are in the system, they can be thought of as simply knowing how to properly handshake with DTE devices and how to put the DTE data onto the phone lines and get it back off in a format that the DTE devices understand.

This modem-to-modem connection can be simulated on the test bench using what's called a "null-modem cable." This is where we'll start our handshaking discussion. Figure 2 illustrates the signal-line swapping that occurs inside the null-modem cable to allow the two DTE devices to be directly connected together. The end result is similar to having the DTE devices connected via modems with the handshaking lines thrown in (compare to the lines/connections shown in Figure 3).

For the rest of this article, we will be speaking in terms of the DTE function/signal-name assignments. The discussion that immediately follows describes the full handshaking that occurs when two DTE devices are connected together using a null-modem cable as shown in Figure 2. We'll describe what happens with modems in the system at a later point.

Full handshaking

The DTR (Data Terminal Ready) line is an output that, when asserted (i.e., pulled above + 3V), says the device is powered up and physically able to communicate. The DSR (Data Set Ready) line is the input for DTR from the opposite device and controls when the sending device is allowed to transmit data. Sounds confusing, but it's really not.

Here's what happens. Device #1 asserts DTR, telling Device #2 that it's ready to talk to it. (The DTR from Device #1 goes to the DSR of Device #2.) Device #2 also asserts its DTR, telling Device #1 that it's ready to communicate (Device #2 DTR goes to Device #1 DSR input). The order isn't important, just the fact that they both get ready to communicate.

Another signal line is used to inform the connected devices of the status of the communications channels. This is most useful when using modem interconnections, where it tells the receiver that the data it's seeing is coming from a properly modulated carrier tone. This line, DCD (Data Carrier Detected), sometimes called RLSD (Receive Line Signal Detected), is an output from the modem to the connected DTE device that is asserted when the modem detects a modem carrier (from the other modem) on the phone line. Essentially, this line says "I hear the other modem — connection is OK."

The same logical function is assumed in our test-bench setup. Figure 2 shows that any time one DTE device is ready to listen (RTS asserted — see following paragraphs), the DCD line for the opposite device will be asserted. How the modem uses this line will be further clarified in the discussion on "Communicating via modems" later in this article.

Since either instrument may have temporary periods of time when it can't receive more data, some way of telling the other instrument to stop sending must be provided. This is accomplished with a second pair of handshake lines called "Request To Send" (RTS) and "Clear To Send" (CTS).

It should be noted here that most current implementations of RS-232-C use RTS to mean "I can listen," instead of "I have something to send" as originally described in the EIA RS-232-C guidelines. The rest of this discussion uses the "I can listen" convention.

When either receiving device is able to listen, it asserts its RTS output. This output goes to the other device's CTS input and, when the other device sees CTS asserted, it knows that it can now send data.

When either device decides that it can't accept any more data right now (for example, maybe it's a personal computer and needs to write some of the data it's been receiving out to disk), it unasserts its RTS, saying "I'm not ready anymore." The other device sees this on its CTS input line and stops sending data. It will not send any more data until it sees its companion's RTS reasserted. When the other device catches up, it reasserts RTS, saying "I'm ready again," and data will again be sent. This scheme prevents the loss of data between devices when one of them has to take some time out to do other things.

The handshake (from the DTE perspective) can be summarized as follows.

Assert DTR — "I'm ready to communicate."

See DSR — "I see you're ready too."

See DCD — "The communication channel is OK."

When all of the above criterion are met, the actual handshake proceeds with RTS and CTS as follows.

Assert RTS — "I can listen now. You can send data until I tell you to stop."

See CTS — "I see you're ready to listen. I'll send data whenever I have it, as long as you remain ready to listen."

The protocol described above is typical of many RS-232-C implementations. Note that DTR and DSR are only used as hardware status lines, indicating only whether or not the equipment is powered up and physically capable of communicating. These lines may also be used as handshaking lines, but in most cases are not. Most implementations use only RTS and CTS for handshaking.

Flow control

Well, with all these handshake lines to turn transmissions on and off, we won't need anything else, right? Not necessarily.

If every available device that claimed to be RS-232-C compatible had implemented the full standard, this would be true. But, because we live in the real world with real problems to solve, many deviations from the full implementation have occurred.

Most of these deviations fall into two categories — handshake protocols and hardware minimization. While absolute adherence to the RS-232-C standard may be a goal well worth pursuing, the best solution to a specific problem rarely turns out to be fully standard. It usually has strings attached like "cheaper," "faster," or "almost like, but....."

Handshake-protocol deviations occur when a system has to do its task "faster," or in an "almost like, but..." fashion. By changing the way standard RS-232-C interface parts toggle their handshake lines, some specific applications can make data transfer speed improvements, or may be able to detect specific events in very specific situations. As long as both devices understand what the other is doing (the same firmware/software program at both ends), all will go well. But trying to connect one of these devices with a standard device will most often cause problems.

Hardware-minimization deviations usu-

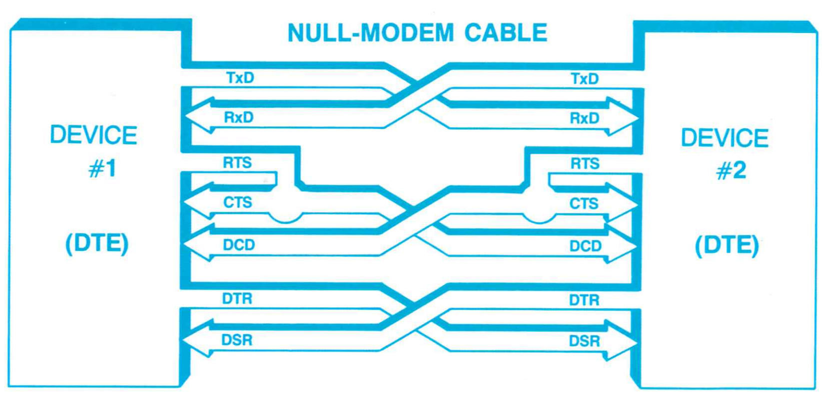


Figure 2. *Signal lines and line-swapping in a null-modem cable.*

ally occur for one reason only — cost savings. It is obviously cheaper to string 3-wire cables than 5- or 7-wire cables. In applications where cost considerations outweigh data-rate considerations, an obvious way to attack the problem is to eliminate one or both of the handshake-line pairs (and their associated support circuitry).

In fact, this is conceptually what's done with modems. The handshake lines go as far as the modems, but can't propagate over the phone lines. The only line that really relates to anything happening at the other end of the connection is DCD, which simply says that the receiver hears a proper carrier.

Using a data-transmission technique called "flow control," instruments with non-standard interfaces (i.e., those without the hardware handshake lines) can be made to talk to each other. Flow control emulates the function of the hardware handshake lines by placing special messages on the data channels to turn data transmission from the opposite device on and off. What's required is a program on each end that knows how to ignore the handshake lines and watch for these special ON/OFF commands instead.

The RS-232-C interface is based upon chopping up a data stream into small chunks that represent the individual bits in each character or number. These chunks of data are inserted (or "framed") between a start-bit and a stop-bit, and are then transmitted down the line to be decoded at the other end.

When you remove the handshake lines (or choose to ignore them), the interface hardware has no way of discriminating between valid data and invalid data except to watch for the presence of these framing pulses.

The flow control protocol can be used at each end of the interface to work around this handshaking (or lack of handshaking) problem by allowing the receiving device to tell the sender when it (the receiver) can or cannot accept more data. As the sender transmits its data, it is also watching its receive channel (RxD), interpreting every framed time-slice of information as a valid character, and checking for two specific characters to turn transmission of data on or off. These characters are called XON (transmission on) and XOFF (transmission off) and are usually assigned to be the <CTRL-Q> and <CTRL-S> characters respectively, though the specific characters chosen are a function of the program used.

What we have now is a situation where either instrument may send data to the other until it is told to stop (receives XOFF character). It keeps watching the RxD line, interpreting every time-slice (as defined by the framing pulses) as a character, checking to see if it is the defined XON character. When it sees the XON character, it knows that the other device is now ready for more data, so it starts sending again. This stop-start process continues throughout the duration of the transmission.

One other special character is commonly used to signal the end of transmission. This is the EOT (end of text) character and is usually defined to be <CTRL-D> or <CTRL-Z>, though once again, definition is entirely dependent upon the software/firmware programs being used. Most programs interpret the EOT character to mean "this is the end of this message or transmission."

It should be noted here that flow control cannot be reliably used when doing binary data transfers since the values of the XON and XOFF characters also correspond to valid data values. Hex or ASCII encoding should be used with flow control. Even this encoding/protocol mix is not foolproof since noise on phone lines (line hits) can simulate the required framing pulses, as well as (more rarely) the flow-control characters themselves. This is why you can get bursts of bad characters (especially with flow-control off) when using modems on noisy telephone lines. Using flow-control greatly increases the probability that data will be transmitted and received properly. Any time hardware handshaking is not used to orchestrate the orderly flow of data, the flow control protocol (with Hex or ASCII encoding) should be used when the hardware devices support it.

Communicating via modems

Figure 3 illustrates a typical data transmission sequence for two DTE devices communicating over phone lines using modems (DCE Devices). Note that the handshake signal-name/function correspondence changes between DTE and DCE devices.

Note also, that the hardware handshake lines (and therefore their associated functions) do not propagate across the phone lines, so flow control must be used to ensure proper receipt of data.

The handshake sequence described illustrates how Device #2 can control the flow of data from Device #1. You need to remember that a data channel also exists in the opposite direction (from Device #2 to Device #1), so similar handshaking will be occurring in the opposite direction simultaneously.

Interface parameters

Now we know, in general conceptual terms, how data moves between instruments on the RS-232-C interface, as well as over phone lines using modems. But there are still a lot of "nitpicky" details to be attended to in order to ensure that proper communications can take place. RS-232-C devices know how to talk binary, but the "dialect" may vary. These details may be thought of as getting the devices to talk the same dialect.

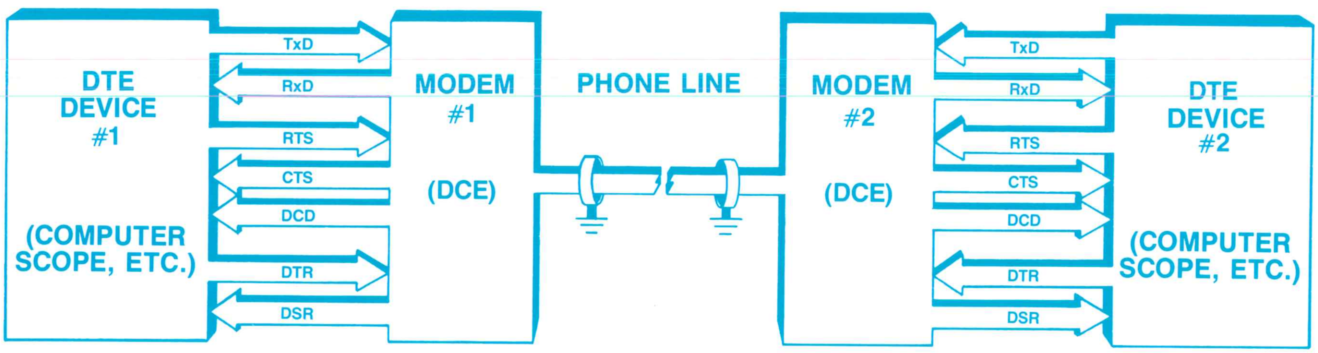
The data transmitted on an RS-232-C interface has very specific timing relationships that must be maintained. The most basic of these is what is called baud rate and is the rate at which the individual bits of the data stream are put onto the data lines. In order for the receiving device to be able to correctly interpret what is being sent, it must be set to receive the data stream at the same rate as it is being sent. In other words, the baud rates of both devices must match.

Other dialect "quirks" have to do with how many of the bits in the data stream are used to represent a data unit or character and how those bits are interpreted.

Notice that the polarity of the data channels (TxD/RxD) is reversed from that of the handshaking logic. For example, on a data channel, asserted means more negative than -3 volts while, for handshaking lines, asserted means more positive than +3 volts (as described earlier). You probably will only need to know this if you have to do low-level troubleshooting of your system, and is only mentioned here for the sake of completeness.

Depending on the type of data to be transmitted, the data stream may assume a variety of formats, each meant to optimize transfer of a certain type of data. The most common implementations of the RS-232-C standard use 10 or 11 bits per

RS-232-C HANDSHAKING PROTOCOL FOR MODEM COMMUNICATIONS



Receive Dialog as DTE Device #1 sees it	**Transmit Dialog as DTE device #2 sees it**
1. **DTR** — Assert DTR. Device #1 is powered up and ready. **DSR** — Modem #1 powered up (ready).	1. **DTR** — Assert DTR. Device #2 is powered up and ready. **DSR** — Modem #2 powered up (ready).
2. **DCD** — "Carrier detected" (receive channel OK).	2. **DCD** — "Carrier detected" (receive channel OK).
3. **RTS** — Assert RTS. "I can listen. Modem get ready to receive."	
4. **CTS** — Delay slightly from RTS, then assert. "Modem is ready now."	
	5. **TxD** — Transmit data to modem when ready. Modem modulates data onto phone line.
6. **RxD** — Modem demodulates phone data and sends to computer on RxD.	
7. **TxD** — Send XOFF character. "I can't accept any more data."	7. **RxD** — Receive XOFF character. "I will stop sending until I see XON."
8. **RTS** — Unassert RTS. "Modem, don't decode anymore until RTS is re-asserted."	
9. **RTS** — Assert RTS. "Modem, get ready to listen again."	
10. **CTS** — Delay slightly from RTS, then assert. "Modem is again ready."	
11. **TxD** — Send XON. "I can accept more data now."	
	12. **RxD** — XON character received. "I can again send data whenever I have it."
13. Loop back to 5 until connection terminated.	13. Loop back to 5 until connection is terminated.

Figure 3. *Typical transmission sequence for two DTE devices connected via modems.*

character, broken down as follows:

Start bit — 1 bit always set to "space" (unasserted). This is the first "framing" pulse.

Data Bits — 7 or 8 bits, depending upon the range of values or type of data to be represented, least-significant bit first.

Seven bits provides encoding of the entire ASCII character set or for numbers ranging between 0 and 127 inclusive. Flow-control characters (<CTRL-S>, <CTRL-Q>, <CTRL-D>) are used primarily for ASCII transfers and can be properly encoded with just seven bits.

Eight bits provides encoding for numbers between 0 and 255 inclusive (binary data), as well as the ASCII character set (eighth bit set to zero). Eight-bit data is used primarily for binary transfers.

Parity bit — Used for character-validity checks on 7-bit data. Not used for 8-bit data.

By setting both the transmitting and receiving devices to use parity, some degree of checking may be done on 7-bit data. Setting parity to "even" causes the transmitter to send a parity bit that makes the number of mark bits in the data (plus parity bit) come out to be even. Upon receiving the data, the receiving device adds up the mark bits (including the parity bit) and verifies that there were indeed an even number of mark bits received. If not, an error flag may be asserted to cause the hardware/software to modify its operation to handle the error.

"Odd" parity works in the same way, except that the number of mark bits is expected to be odd. Parity may also be set to mark or space, which causes the parity bit to always be sent (and checked) to be asserted or unasserted respectively.

Stop bit(s) — 1 or 2 bits always set to "mark" (asserted). The last stop bit is the second framing pulse.

1 bit is used almost exclusively; 2 bits is a carry-over from the days of mechanical teletypes (2 stop-bits allowed enough time for the carriage to return to left margin).

The transition from one character's stop bit(s) to the next character's start bit is used to synchronize the receiver to the transmitter. This ensures that the data bits for each character are read at the optimum times relative to the transition (start of character).

Errors occurring due to mis-matched baud rates, data bits, or stop-bits often show up as framing errors; i.e., the frame surrounding the data (start-bit and stop-bit) have the wrong timing relationship with respect to each other. Since they cannot be recognized properly, the data cannot be properly extracted from the bit stream.

Data encoding and communication protocols

The subject of data encoding and communication protocols deals with how a software (or firmware) program massages the data prior to transmission or after receipt.

The simplest scheme passes data straight through without changing anything on either transmission or receipt. This is called binary encoding and simply sends and receives 8-bit data exactly as presented to the RS-232-C interface circuits. This provides for compact transmission of numbers and characters, but has several drawbacks that limit how it may be used.

Remembering that 8-bit data has no provision for checking parity, an obvious drawback is that you have no way of checking the validity of characters as they are received. An occasional error may be acceptable if you're "shooting the breeze" with your buddy via a modem link, but could have drastic consequences if your computer is moving company assets around using tele-banking services.

Another scheme, called ASCII encoding allows numbers and characters to be encoded in 7-bit format, allowing the eighth bit to be used for parity. This allows parity checking of characters as they are received, but at a premium price in terms of transfer speed. What happens is this. All alpha character data is sent as 7-bit, parity-checked characters, but all numeric data values are converted to their ASCII character equivalents. For example, the number "243" in binary format, could be transmitted as a single 8-bit character, whereas using ASCII format would require three separate characters (a "2", a "4", and a "3") to represent it, plus a delimiter (",") to separate it from any numeric value that follows — four characters in all. For transfers involving mostly text, very little performance is lost, but for number-intensive transfers (like moving waveforms around), considerable degradation occurs.

Halfway between these two encoding methods is a 7-bit, parity-checked scheme called hex encoding. Hex encoding splits each 8-bit byte into two characters that can be sent as 7-bits with parity. The characters sent consist of the valid hexadecimal digits 0-9 and A-F. For human readers, the hex format numbers are quite cryptic, but arrive parity checked. In addition, this format almost always requires less space than for ASCII transfers.

Another transmission method commonly seen is called XMODEM protocol. This is a packetizing protocol that chops the data to be sent into 128-byte packets. These packets encode the data in 8-bit binary format for transfer efficiency, and add a calculated checksum to the end of the block in order to check the validity of the transfer. If received properly, the next packet is sent. Otherwise, the packet is resent until properly received. Most instruments do not support XMODEM protocol internally, so a software program is required at each end of the link to do the required data translations.

Choosing the right protocol

There are numerous variations on these basic protocols, but the concepts are basically the same. Table 2 provides a summary of these protocols and should be useful for determining which may best fit your application.

In many instances, the choice of protocol is limited by the protocols available on the instrument and the controller. Like everything else on the RS-232-C, the protocols must match at each end of the interface.

Where several choices are supported by the hardware devices, the following recommendations may help in choosing an appropriate protocol for your application. Remember that anytime the data is changed in any way at the transmitting end, a complimentary program must exist at the receiving end to decode it. This may mean writing a translator program if the application demands it.

Binary encoding is appropriate when the quality of the data path is very high — high enough to virtually assure proper transfer of data. These conditions will probably be met when two pieces of equipment are connected directly together over a single RS-232-C cable.

ASCII encoding is appropriate when the transmissions between devices consist primarily of alphanumeric characters, or when the received results should be in a human-readable form.

Hex encoding is appropriate when transfers are number-intensive over a signal path of questionable integrity. If noise is likely to creep into the transfer, the parity-check information can be used to selectively accept and reject received data.

XMODEM protocol goes beyond data encoding format and provides a way of doing fairly large transfers quickly and reliably, even over poor signal paths. It works with any of the encoding formats described above, but you may as well use binary encoding with XMODEM protocol (binary is the most time-efficient) since the checksumming provides about the same degree of confidence as parity checks.

Putting the RS-232-C interface to work

Now that we've learned about the interface, we're ready to put it to work. In an upcoming issue of **HANDSHAKE,** we will provide several applications which use the RS-232-C interface as the basis of instrument control.

Application note 41W-6748, **Making the Remote Connection,** includes the information in this article plus an application describing remote service using modems. For a copy of this application note, check the box on the reply card in this issue or call your local Tektronix Field Office or representative. U.S. customers can call the Tektronix National Marketing Center literature desk toll free — 1-800-426-2200. And tell them **HANDSHAKE** sent you.

Table 2

Data Transfer Formats/Protocols

Format/ Protocol	Data Word Width	Parity Check?	Advantages	Disadvantages	Comments
Binary Encoding	8-bit	NO	Compact format	No data verification provided, very cryptic	Do not use with flow control
ASCII Encoding	7-bit	YES	Human-readable data, simple parsing in user programs, parity checking to validate data	Numeric transfers require up to four times as many characters as binary format	
Hex Encoding	7-bit	YES	More compact than ASCII for numeric transfers, parity checking to validate data	Requires twice as many characters as a binary transfer, quite cryptic, requires filter programs to encode and decode the data	
Flow Control Protocol	8-bit	Can be used with ASCII or Hex data	Prevents buffer overflow when hardware handshaking	Cannot be used with binary (8-bit) data	Do not use with 8-bit data
XMODEM Protocol	8-bit	NO	Almost as compact as binary for long numeric transfers, checksums for transfer validation	Very cryptic, requires filter programs to encode and decode data	XMODEM protocol is supported by many telecommunications software packages

Customer training classes and workshops

Tektronix offers classes and workshops for the convenience of Tektronix customers with application, operational, or service training needs. Here's the schedule of classes and workshops to be offered in the near future.

Service Training Classes

Call Tektronix Service Training, 1-800-835-9433, ext WR1407 (in Oregon, call 629-1407) to register for the following classes.

CLASS	LOCATION	DATES
465B/475A Portable Oscilloscope	Irvine Boston	Feb 15-19 May 2-6
2215/35/36 Portable Oscilloscope	Irvine Wash. DC	Jan 25-29 May 23-27
2430 Digital Storage Oscilloscope	Dallas	Feb 22-Mar 4
2465A Portable Oscilloscope	Boston Dallas	Nov 9-20 Mar 21-Apr 1
7904/7633 Laboratory Storage Oscilloscopes	Atlanta Boston	Dec 7-18 Mar 21-Apr 1
7912HB Programmable Digitizer	Beaverton	Nov 2-13
7612D Programmable Digitizer	Beaverton	Feb 8-19
7854 Waveform Processing Oscilloscope	Beaverton	Jan 11-29
TM 500 Calibration Package	Irvine	Feb 1-5
113XX/114XX Programmable Oscilloscopes	Beaverton	Feb 29 Mar 11

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

IG Customer Training Workshops

Call Tektronix IG Customer Training, 1-800-835-9433, ext 430 (in Oregon, call 629-1017) to register for the following classes.

CLASS	LOCATION	DATES
Using a 4041 System Controller	Lexington Philadelphia	Dec 8-10 Jan 26-28
Using the PC as a Controller	Atlanta Raleigh	Dec 18 Apr 1
7912AD/7612D Advanced Waveform Processing with TEK SPS BASIC	Beaverton	Feb 16-19
2230 Digital Storage Measurements	Atlanta Raleigh	Dec 15 Mar 29
2430A Advanced Digital Measurements	Atlanta Raleigh	Dec 16-17 Mar 19-20
7854 Waveform Processing	Wash. DC	Feb 8-9
11301/11302 Measurement and Analysis	Orlando Woodbridge Detroit	Dec 11 Jan 14 Mar 30
11301/11302 Advanced Measurement and Analysis	Woodbridge Detroit	Jan 14-15 Mar 30-31
11401/11402 Waveform Measurements	Santa Clara Orlando Detroit Irvine	Dec 1 Dec 9 Mar 1 Mar 22
11401/11402 Advanced Waveform Measurements	Santa Clara Orlando Detroit Irvine	Dec 1-2 Dec 9-10 Mar 1-2 Mar 22-23

Workshop and class sizes are limited. We recommend that you enroll early. Other classes are planned beyond this schedule. For more information or to register, call the numbers listed above.

We retain the option to cancel or reschedule classes or workshops.

HANDSHAKE
Group 157 (02-382)
Tektronix, Inc.
P.O. Box 500
Beaverton, Oregon 97077
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