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HANDSHAKE™

NEWSLETTER OF INSTRUMENTATION AND INSTRUMENT SYSTEMS

HIGH-PRECISION PICOSECOND MEASUREMENTS

Tektronix®
COMMITTED TO EXCELLENCE

Welcome to a new world of sampling

Sampling has been a feature of the Tektronix product line for almost thirty years. Now, by combining the very high-speed acquisition capabilities of sampling with the measurement power of the Tektronix 11000 family, the 11800-Series Digital Sampling Oscilloscopes extend measurement ease and accuracy into the 20 gigahertz range and beyond. This new series has been designed to provide solutions for the high-speed digital market place. This includes such applications as high-speed digital components, high-speed computers, and high-speed digital communications testing.

One of the key breakthroughs in this family of products is the combination of high-speed multi-channel acquisition and multi-channel time domain reflectometry (TDR). Never before have you been able to acquire more than sixty channels of repetitive multi-gigahertz signals in parallel. Nor has the capability to have a TDR pulse on all of these same channels been available before!

The 11800 Series moves TDR from the position of an occasional tool to an integrated part of your measurement strategy. With a simple command, you can switch from signal acquisition to TDR measurements — no disconnecting and reconnecting of cabling or probes before you start acquiring data!

The 11800 Series can even make differential TDR measurements — measurements previously not possible. Differential TDR reveals the true characteristics of differential transmission lines and systems, such as twisted-pair cable. With the rapid push to higher speed logic and data communication, differential transmission lines are becoming much more common. In addition, multi-channel TDR allows crosstalk testing on ribbon cables and circuit boards, as well as high-thruput single-ended TDR for traditional cable and connector applications. The 11800 Series provides unmatched performance for single-ended, multi-channel, and differential TDR.

Look for an article in a future issue of **HANDSHAKE** discussing this exciting application. But in this issue, we invite you to find out more about the features, design, and application of this exciting new product. Welcome to a new world of sampling as provided by the Tektronix 11800 Series!

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A look inside

Sampling is not a new test and measurement technique — it's been used for over three decades. But, in general, technicians and engineers have considered sampling systems difficult to use and, as a result, often relegated them to those special situations where nothing else would work.

Now, Tektronix changes all that with the introduction of the 11800-Series Digital Sampling Oscilloscope. The new 11800 family makes sampling measurements as easy as those made with conventional scopes. You can read all about these new instruments in the article **Introducing the 11800 family of digital sampling oscilloscopes** starting on page 4. Then, to see the 11800 Series in action, read the TDR application article **Removing fixturing delays from propagation delay measurements.** And to help you better understand sampling measurements, we've included the article **Basic sampling concepts**.

If you're interested in optical measurements, you'll want to read the article **A practical approach to optical waveform measurements.** This application provides answers to some of the common measurements encountered in optical systems.

In addition, you'll find some interesting new products described in this issue that will make your measurements easier, quicker, and more convenient.

For help in solving any of your measurement problems, please contact your local Tektronix Field Office or sales representative — they're willing and able to help. And be sure to tell them **HANDSHAKE** sent you!

A. Dale Aufrecht
HANDSHAKE Editor

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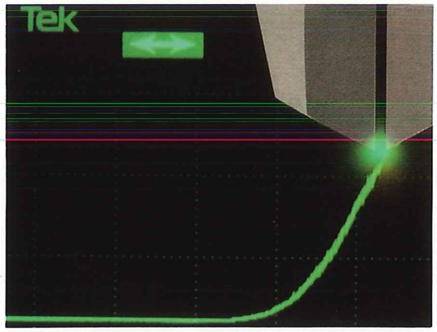

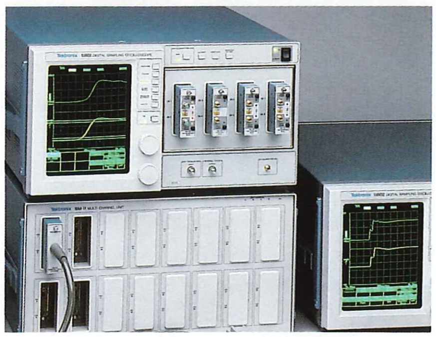

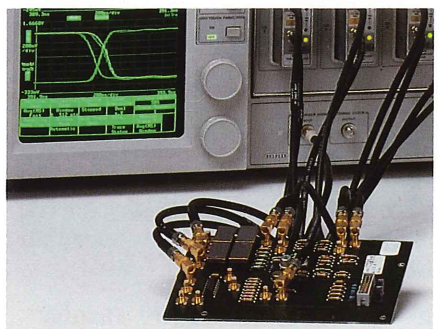

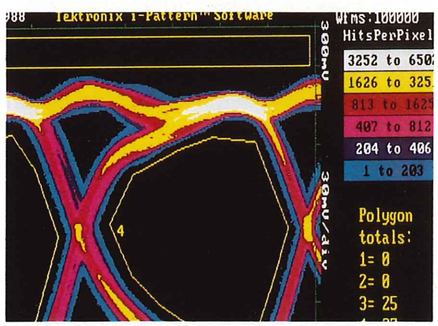

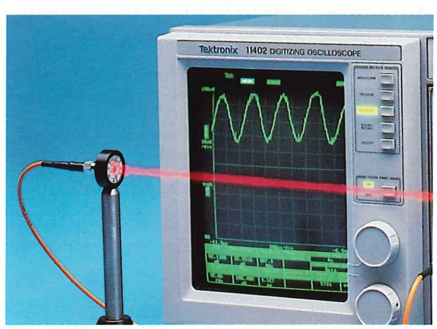

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Introducing the 11800 family of digital sampling oscilloscopes

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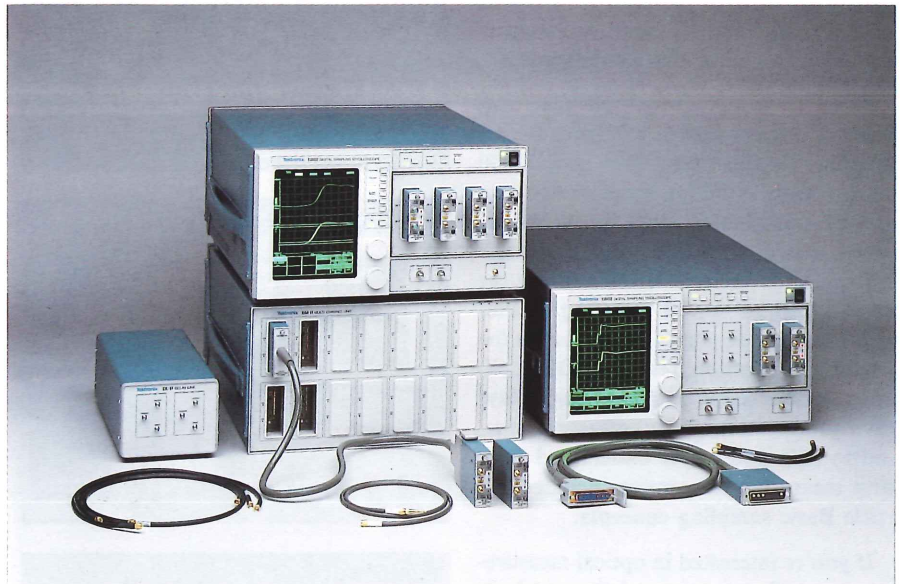


The 11800 family includes the 11801 Digital Sampling Oscilloscope, 11802 Digital Sampling Oscilloscope, SD24 TDR Sampling Head, SD26 Sampling Head, SD51 Trigger Head (not shown), and SM11 Multi-Channel Unit. Also shown are the DL11 Delay Line, P6150 9-GHz passive probe, sampling-head extender cables, and miscellaneous high-frequency signal cables.

Retired U.S. Navy Admiral Grace Hopper, a pioneer in early computer development, was known for using creative illustrations to help communicate new concepts to others. One of her best known illustrations was designed to help people visualize the small increments of time involved in electrical circuits and computers. She held up a piece of cable about a foot long and said "this is a nanosecond." She went on to explain that it took about one nanosecond for a signal to travel the length of the cable.

At that time, there weren't many circuits that operated with switching speeds less than a nanosecond. Today, many high-speed computers and devices operate at switching speeds measured in picoseconds. So, if Admiral Hopper's nanosecond of cable is one foot long, how long is a picosecond? How about 10 femtoseconds? A picosecond is about 0.012 inches — about the thickness of a dime! Ten femtoseconds? That's about 1.2 E − 4 inches! Try holding those cables up for an illustration!

Until recently, measuring a time interval with one picosecond repeatability was difficult, if not impossible. The new 11800 family of digital sampling oscilloscopes from Tektronix offers unprecedented timing resolution, repeatability, and accuracy. In combination with the SD24 and SD26 Sampling Heads, the 11800 family offers acquisition risetime of 17.5 picoseconds or less (20 GHz equivalent bandwidth) with sweep rates down to one picosecond per division. The minimum sampling interval is 10 femtoseconds at one picosecond per division with 1K waveform points!

Introducing the 11800 family

Two mainframes are currently available in the 11800 family. The 11801 Digital Sampling Oscilloscope has up to eight acquisition channels in the mainframe and expansion capability for up to 136 channels using four SM11 Multi-Channel Units. This large number of channels allows parallel acquisition for very fast AC testing of high-speed integrated circuits or for supplementing a functional test system.

For applications where four channels are sufficient, the 11802 Digital Sampling Oscilloscope offers a built-in dual compensated delay line with trigger pick-off. The delay line allows you to pick off a trigger from the input signal and provides up to five nanoseconds of pre-trigger view. This is especially useful in applications involving low repetition rate signals, where it may be impractical to trigger on one event and look at the next repetition of that event.

Both instruments are fully programmable over the built-in GPIB and RS-232C interfaces and both use the same patented digital time base to provide fast, precise waveform acquisition and measurement.

Modularity lets your system grow

In the Tektronix tradition, the 11800 family has a modular architecture to meet your expanding needs. A new series of plug-in sampling heads for the 11800 family contains all of the high-speed sampling circuitry that determines the bandwidth of the system. As higher bandwidth heads become available, you can easily upgrade system performance since the mainframe doesn't limit the bandwidth of the system. The mainframe is designed to support a variety of head types including acquisition, TDR, trigger countdown, and other types.

The first two acquisition heads in the new SD Series are the SD24 Sampling/TDR Head and the SD26 Sampling Head. Both heads offer two acquisition channels with 17.5 picosecond rise time (20 GHz equivalent bandwidth) and 1-volt peak-to-peak dynamic range. The SD24 also has two polarity-switchable TDR step generators with 35 picosecond or less reflected risetime. With the SD24, you can configure a system of up to 136 channels of TDR and acquisition (using the 11801 and SM11). Because the polarity of the pulse generators is selectable, you can also operate them in a differential (push-pull) mode to make differential TDR measurements. We'll discuss differential TDR in more detail later.

The SD51 Trigger Head extends the stable triggering range of the 11800 Series to 20 GHz. A front-panel sync control allows the internal oscillator frequency to be synchronized to a subharmonic of the input signal.

It's all in the timing

Most applications for sampling oscilloscopes involve timing measurements. Propagation delay, risetime, pulse width, etc., are key measurements for high-speed logic designers and manufacturers. Testing and characterizing Gallium Arsenide, ECL, and even some fast TTL and CMOS logic families require timing measurements with very high resolution and accuracy. In addition, time resolution and stability are key to resolving small, closely-spaced details common in TDR measurements.

The 11800 Series provides very high resolution and high stability with a patented digital time base (see sidebar **Digital time base provides unmatched time resolution**). In addition, software in the instrument allows the single time base to operate as two separate time bases. One time base acquires the "main" waveforms. The other time base, referred to as the "window" time base, allows you to expand portions of a main trace for higher time resolution. (The window time base is similar to the delayed time base in earlier Tektronix oscilloscopes.)

The 11801 and 11802 are the first sampling oscilloscopes to offer a window time base. With windows, you can see a complete waveform or group of waveforms in their proper time relationship using a slow time/division setting. Then, you can expand any section of the waveforms by creating one or more windows on the main waveforms with sweep speeds up to one picosecond per division. Figure 1 shows an example where windows are particularly important.

Windows make high-resolution propagation delay easy

If you want to measure the propagation delay through a device, there is often a trade-off between getting the best time resolution for the measurement and getting both the input and output waveforms on the screen. At slow time/division settings, you can get both waveforms on the screen, but you don't have enough samples on the input and output edges to get good timing resolution for the measurement. On the other hand, if you use fast time/division settings, you get more samples on the edges, but you can't get both waveforms on the screen to make a measurement.

If your instrument only has one time base, it can be difficult and cumbersome to make accurate, repeatable measurements. However, with the 11800 windows you can make this measurement easily and accurately. Simply display the two main waveforms choosing any time/division setting that conveniently gets both waveforms on the screen. Then create a window on each of the two waveforms, centering the window around the transition of interest.

The instrument puts an intensified zone on each main waveform that indicates where the window is located in the main record. You can move the window anywhere in the main record. When both windows are properly located on the transitions of interest, you're ready to make a propagation delay measurement between the two windows. Even though the window waveforms are aligned on the screen, the instrument keeps track of the time relationship between them. The propagation delay measurement provides accurate results regardless of where the windows are positioned on screen.

Automatic windows speed ATE measurements

Windows are a powerful feature for high-resolution measurements. However, using windows in an ATE environment can be difficult since you don't want to require an operator to position the windows on the main trace. To solve this problem, the 11800 family introduces another first in digital oscilloscopes — automatic windows.

Automatic windows allow you to specify a transition number from 1 to 15 on the main waveform, a slope (positive or negative-going transition), and a level in either relative terms (e.g., 50%) or absolute terms (i.e., millivolts). Then, the instrument automatically finds that transition and centers a window around it at any resolution you choose, up to one picosecond per division. You can select tracking mode, in which the instrument continuously checks the position of the transition you select and re-centers the window. Or, you can turn tracking off and use automatic positioning to locate the window once.

Live measurements

The 11800 Series, like their predecessors, the 11400 Series Digitizing Oscilloscopes, offer a "live" measurement system. You can select up to six measurements out of a list of sixteen possible measurements to be made at one time. The measurements you select are made continuously with the most recent results displayed in the measurement menu. With live measurements, you can see the results of a change in the waveform immediately. You can even change the parameters for a measurement, such as the mesial and proximal levels for risetime, and see the results change as you vary the parameters.

Figure 2 shows a typical measurement display on the 11800. If you want more detail or wish to change one of the measurement parameters for a particular measurement, just touch the measurement selector in the menu area at the bottom of the screen. A pop-up menu appears (Figure 3) that shows all the current measurement parameters and allows you to select and adjust those parameters.

Evaluate results with measurement statistics

The live measurement system also offers

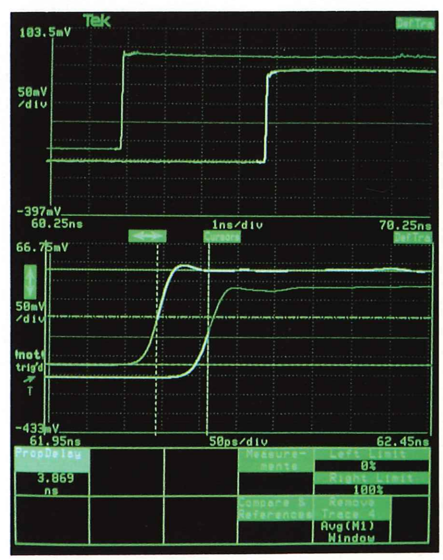


Figure 1. *Windowed display showing how windows can be used for propagation delay measurements.*

Digital time base provides unmatched time resolution

One key part of the performance provided by the 11800 family is the patented digital time base architecture. This time base provides sweep speeds to 1 picosecond/division, and sampling intervals as small as 10 femtoseconds (1 picosecond/division with 1K points). In addition, the closed-loop architecture and on-line time base calibration provide excellent long-term stability.

The sequential sampling time base used in the 11800 family is essentially a programmable slewing delay generator. Each time a trigger is recognized, the time base generates a precise delay from the trigger and outputs a strobe which tells the sampling head and A/D (analog-to-digital) converters to capture a sample. The delay is increased slightly with each trigger, so that each sample is taken slightly later on the input waveform than the previous sample (see figure A). This process is repeated until a full record of samples (from 512 to 5120 samples) have been captured.

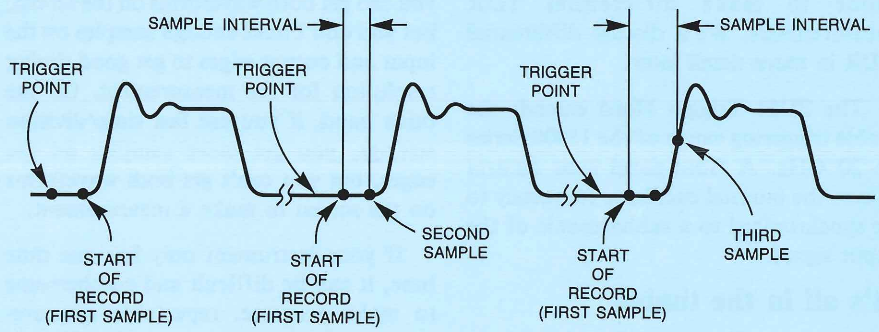


Figure A. *The sampling process. One sample is acquired on each trigger. Each successive sample is delayed slightly longer from the trigger point. This incremental delay is called equivalent time sample interval.*

Figure B shows a block diagram of the 11800 time base. When a valid trigger occurs, the trigger recognizer sends a pulse to the holdoff generator and to the Triggered Voltage Controlled Oscillator (TVCO). The holdoff generator inhibits further triggers until the time base has generated the strobe output and is ready for another trigger.

The output of the trigger recognizer

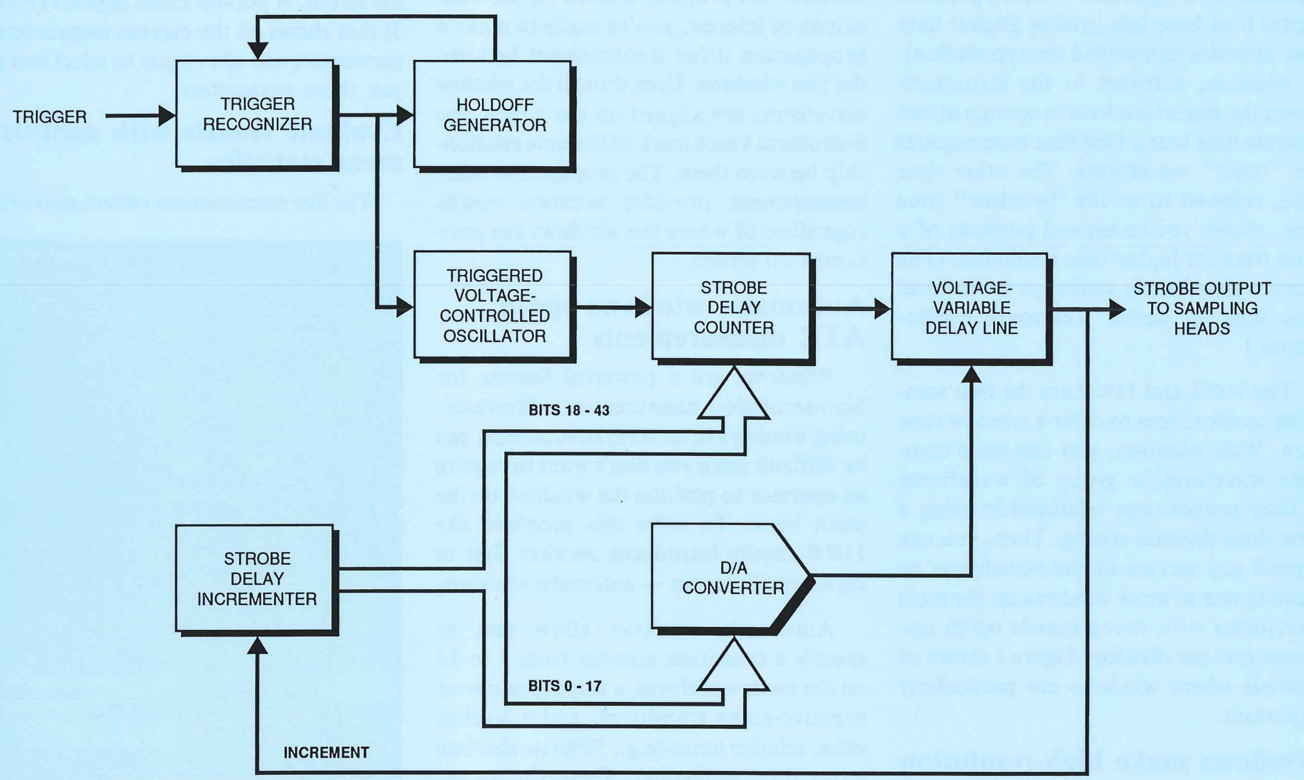


Figure B. *Simplified block diagram of the 11800 digital time base.*

starts the TVCO, whose output drives the strobe delay counter. This counter generates the coarse part of the delay for the time base by counting output periods of the TVCO. The period of the TVCO is about 2.6 nanoseconds, so one LSB (least significant bit) of the counter generates approximately 2.6 nanoseconds of delay.

The voltage-variable delay line is actually a custom integrated circuit that interpolates between the 2.6 nanosecond delay increments generated by the strobe delay counter. The propagation delay through this delay line is adjusted by the control voltage from the digital-to-analog converter (DAC). The composite delay through the strobe delay counter and the variable delay line is the sum of the two delays. This composite delay controls the delay from the trigger to the strobe output.

The strobe incrementer provides a 44-bit digital word that is incremented after each strobe by an amount set by the selected time/division setting. The lower 18 bits of the 44-bit word control the DAC that sets the control voltage for the variable delay line, while the upper 26 bits control the strobe delay counter. After each strobe, the 44-bit word is incremented to increase the trigger-to-strobe delay. The incremental change in delay is the equivalent time sampling interval (i.e., the time/division divided by the number of samples per division).

Calibration of the time base is performed continuously in a time-sliced fashion. The 80186 microprocessor tunes the TVCO so that its period exactly matches the adjustment range of the variable delay line. This match insures that when the delay line reaches its maximum value, incrementing the delay counter and resetting the delay line will result in a linearly increasing delay. The voltage/delay transfer characteristics of the variable delay line are also monitored by the 80186 microprocessor. The microprocessor builds a look-up table which corrects for nonlinearities in the delay line by loading a corrected value into the control DAC.

a new capability never before available in an oscilloscope — measurement statistics. Now you can see not only the result of the most recent measurement, but the mean and standard deviation of a selected group of measurements.

With a static measurement system, you don't know how stable the results are unless you collect many measurement results and compute statistics on paper or use a statistics program on an external computer. The 11800 Series provides a direct readout of the mean and standard deviation of the most recent set of measurements. Statistics are available for any measurement the instrument can make. Of course, the statistics are also available over the GPIB or RS-232C interfaces.

Measurements on 136 channels

The 11801, when combined with four SM11 Multi-Channel Units, can support up to 136 channels of acquisition. Up to half of the channels (i.e., 68) can be acquired and measured simultaneously — in a single acquisition cycle. This incredible measurement power is made possible, in part, by the distributed processing architecture used in the 11800 family (see Figure 4). Behind each pair of sampling heads, whether in the mainframe or in an SM11, is an acquisition subsystem which contains two acquisition channels. Each acquisition channel includes an amplifier, A/D converter, and special time-measurement hardware.

An acquisition channel can be connected to any of the four sampling-head channels in the pair of sampling heads it supports. For example, an acquisition channel in the 11801 can be connected to channels 1, 2, 3, or 4. Since there are two acquisition channels for each pair of heads (four channels), it is possible to acquire half the installed channels simultaneously. If, for example, all eight channels in an 11801 are acquired as main waveforms, the instrument acquires half of the channels in one acquisition and the other half in a second acquisition.

If the 11801 mainframe or SM11 are only half filled with sampling heads (i.e., a sampling head installed in every other compartment), it is possible to acquire all the installed channels simultaneously, since there are as many acquisition channels as there are sampling head inputs in this configuration.

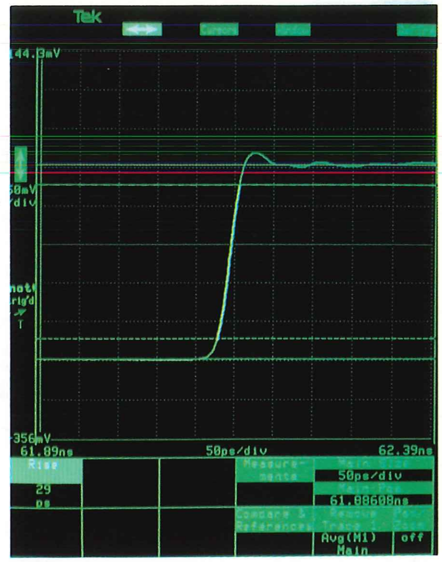


Figure 2. *Typical measurement display menu for measuring risetime.*

This highly parallel acquisition and measurement architecture not only eliminates the need for relay multiplexers, which degrade signal quality and system reliability, but it also makes acquisition and measurement of many channels practical in a production ATE environment.

Hardware measurements provide answers *FAST!*

Another important key to the measurement power of the 11800 family is the time-measurement hardware in each acquisition system. Timing measurements, such as rise, fall, delay, period, etc., can be made in software or hardware. In software mode, the instrument calculates measurements like

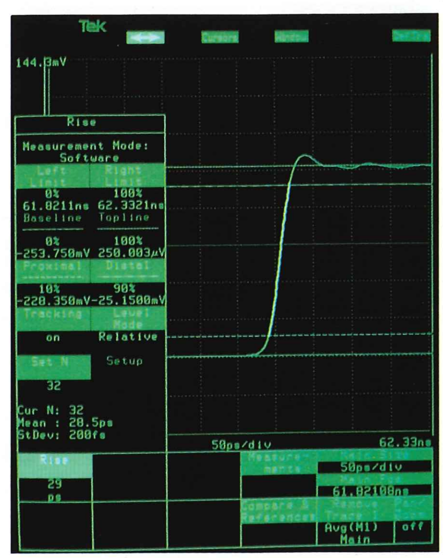


Figure 3. *Pop-up menu on 11800 screen.*

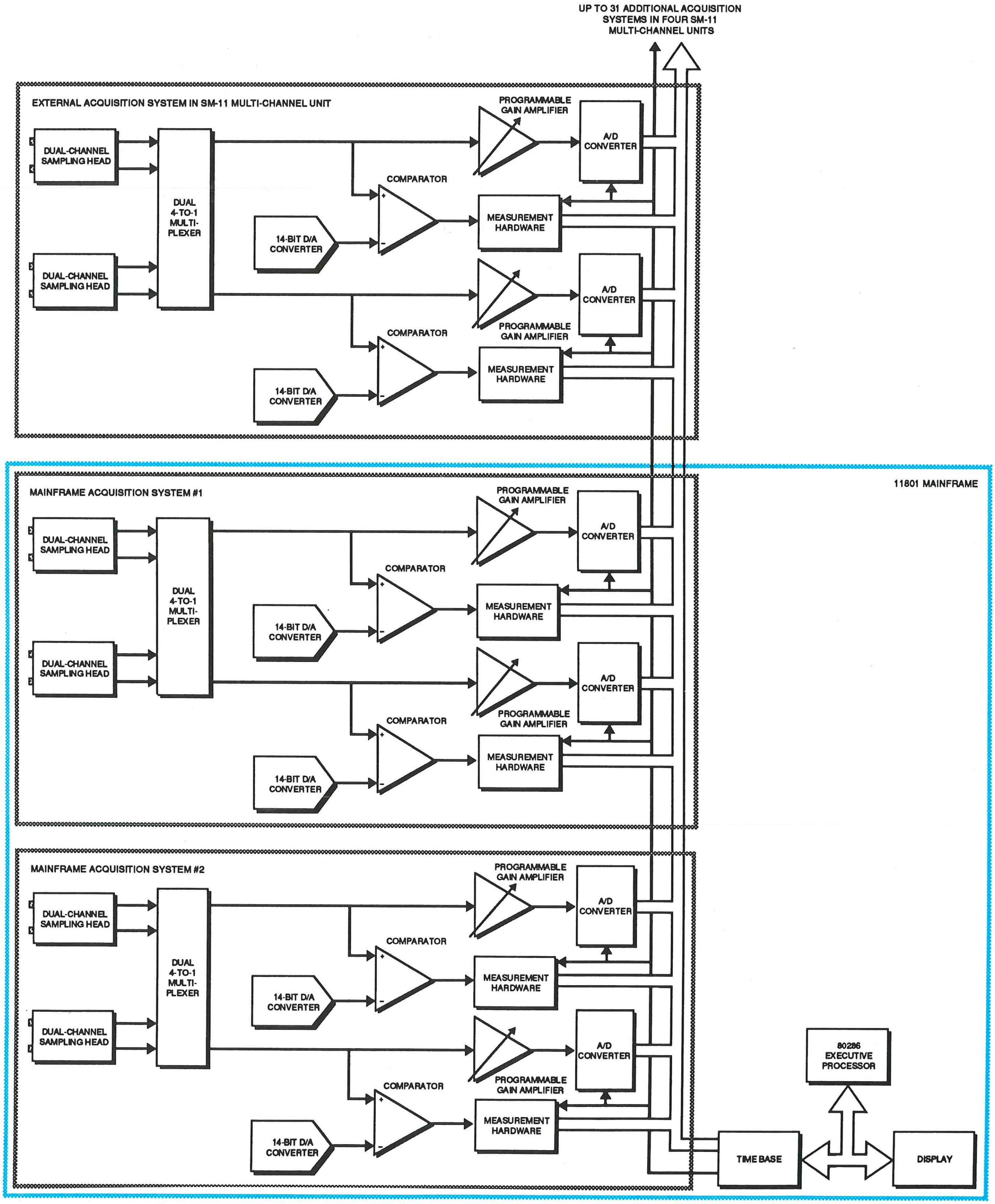


Figure 4. *Distributed acquisition and processing architecture of the 11800 provides up to 136 channels with simultaneous acquisition of up to 68 channels.*

most other digitizing oscilloscopes by acquiring data and processing the acquired points with an internal microprocessor.

In hardware mode, the 11800 Series make timing measurements by programming the precision voltage comparators in the measurement hardware for the appropriate measurement level. The hardware then counts the number of samples that occur between the switching points of the two comparators.

So why make timing measurements in hardware? Simply put, for speed. Hardware measurements are significantly faster, especially where a large number of channels are involved. Since the measurements are made in hardware with very little processor interaction and since they can be made in parallel, there is no penalty for making measurements on a large number of channels. You can make up to six measurements on each of 136 channels in an 11801/SM11 system and read all the results with one GPIB or RS-232C command!

For more detail on hardware mode measurements, see the sidebar titled **Hardware makes timing measurements faster** in the accompanying application article titled **Removing fixturing delays from propagation delay measurements.**

High-resolution TDR measurements

The 11800 family with the SD24 sampling head also provides unmatched TDR (Time Domain Reflectometry) performance. TDR is a powerful tool for evaluating cables, circuit boards, interconnect systems, or most other transmission systems. TDR allows you to measure reflection coefficient (a measure of how much energy is returned from a transmission system), impedance, and distance.

In addition, TDT (Time Domain Transmission) allows you to make propagation delay and gain measurements by transmitting a pulse into a system from one channel and measuring the output of the system on another channel. You can make TDR or TDT measurements with any channel or group of channels in the 11800 Series — up to 136 total channels with the 11801 and SM11.

Spatial resolution in TDR (the ability to resolve small closely-spaced discontinuities) is limited by the risetime of the TDR step generator, the characteristics of the TDR pulse (e.g., flatness, "foot", etc.) and the resolution and stability of the time base. The 11800 Series and SD24 combination provide very high-resolution TDR by combining a very fast, very well-behaved pulse from the SD24 step generators with a very stable, high-resolution time base in the mainframe. With the SD24 and 11800 Series you can resolve discontinuities of less than one millimeter (depending upon the size, type, and spacing of the discontinuities).

The many powerful features of the 11800 family, such as automatic windows and alternate scales (rho, feet, meters), allow fully automated, reliable TDR measurements. When you use alternate scales, such as meters on the horizontal axis, all measurement results, cursors, etc., are provided in those units — for example, propagation delay results would be reported in meters.

For an example of a TDR measurement, see the accompanying application article **Removing fixturing delays from propagation delay measurements.**

TDR in the differential world

Differential circuits and transmission systems are rapidly becoming the rule in high-speed computers and systems. Differential transmission systems offer better noise immunity and more stable transmission characteristics. However, they have also been difficult to characterize with TDR techniques — until now. The 11800 Series with the dual-channel SD24 Sampling Head allow you to make true differential TDR measurements.

Figure 5 illustrates a differential system that would be difficult to characterize using currently available TDR equipment. One way of estimating system performance is to make a separate TDR measurement on each side of the transmission system while grounding the opposite side. The sum of the two impedances might approximate the differential impedance. For some well isolated conductor pairs, this technique produces reasonably accurate results.

However, when the coupling between the two conductors is relatively high, as in twisted pair cables or closely spaced runs on circuit boards, single-ended TDR produces significant errors. Making this measurement accurately requires stimulating both sides of the differential system with complementary pulses and measuring response across both conductors.

With the polarity-switchable pulse generators in the SD24, you can do exactly that. Simply turn on both TDR step generators. Then set one for negative-going and one for positive-going output polarity. You can look at the individual reflections coming back to each channel or you can have the oscilloscope subtract the two traces and produce a differential display (see Figure 6).

Since the two acquisition channels in the SD24 are extremely well matched, and since the TDR step generators can be aligned at your reference plane, the differential TDR measurement results are an accurate measure of differential impedance.

Power that's easy to use

Sampling oscilloscopes have often been regarded as the "last resort" — use them

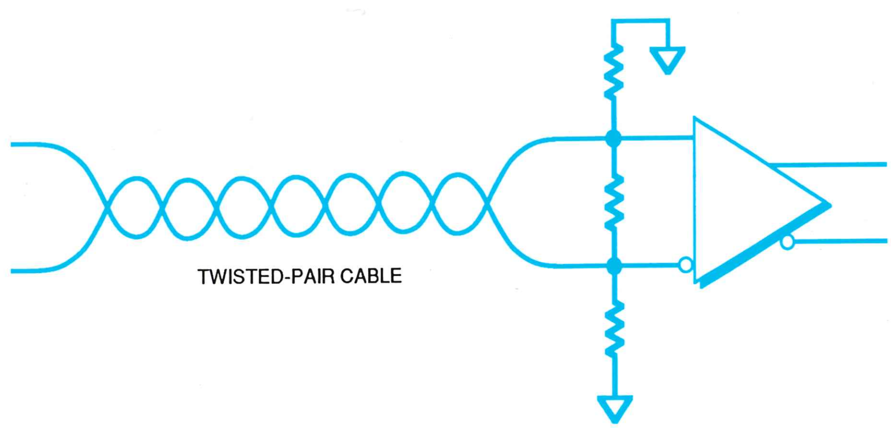


Figure 5. *A typical twisted-pair differential system like this one is difficult to accurately characterize with a single-ended TDR system since the two conductors are closely coupled.*

What is an LSB?

A key specification for digital oscilloscopes is vertical resolution. Vertical resolution is typically specified in terms of the number of bits in the digitizer's A/D (analog-to-digital) converter. For example, eight-bit resolution means that the A/D converter has 8 bits, or 256 levels ($2^8 = 256$). However, the number of bits doesn't tell the whole story. The architecture of the vertical system also affects the useable resolution.

Figures A and B show block diagrams of two vertical system architectures. Figure A shows an architecture where the A/D converter is connected directly to the output of the sampling gate. No amplifier or offset is used between the sampling gate and A/D converter. Generally, a high-resolution converter (10-12 bits) is required in this configuration, since there is no gain switching. Display sensitivity (volts/division) is accomplished by "zooming" the display in on the digital data. In this architecture, the size of the least significant bit (LSB) of the waveform data is fixed, independent of the volts/division setting.

Figure B shows the architecture used in the 11800 family. Here, an amplifier and offset circuit are added between the sampling gate and the A/D converter. This amplifier provides gain and offset control that significantly improves resolution at high sensitivities. When the volts/division is set to a small setting, such as 2 millivolts/division, the amplifier makes the acquired signal larger to take advantage of the full dynamic range of the A/D converter. Lower resolution converters can be used because their full dynamic range is always available.

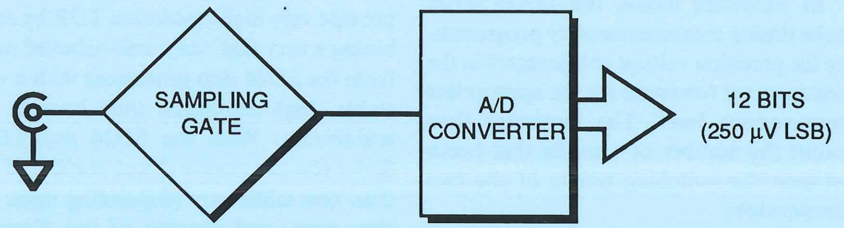


Figure A. *Vertical system without amplifier uses a high-resolution converter but may actually have poorer resolution than the 8-bit system shown below. Sensitivity changes are implemented only on the display in this architecture.*

The 11800 family provides fully calibrated volts/division settings in 1 millivolt/division steps from 2 to 255 millivolts/division. It also provides an offset range of ±2 volts. Vertical resolution is eight bits independent of the volts/division setting, so you get full eight bit resolution even at 2 millivolts/division. Even with a 12-bit converter, the resolution offered by the first architecture at high sensitivities will be significantly poorer, since only a small part of the A/D converter's range is used.

Thus, the size (in millivolts) of the LSB is often a better indicator of resolution than the number of bits in the A/D. In particular, note the LSB size at high sensitivities, since resolution is often most critical when viewing small signals. The 11800 has a 78 microvolt LSB at 2 millivolts/division (without averaging). Averaging can improve useable resolution even further.

In addition, with averaging the 11800 offers display magnification well beyond the basic 2 millivolts/division sensitivity.

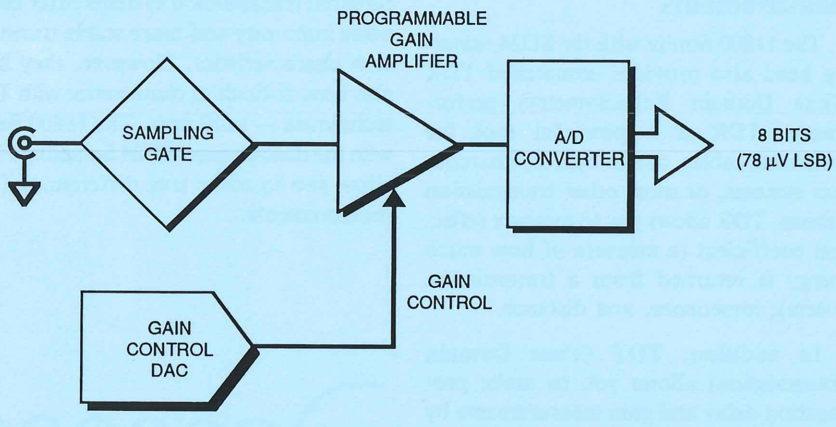


Figure B. *Vertical system with amplifier uses only an 8-bit A/D converter but offers much better resolution at high sensitivities because the amplifier provides gain for small signals.*

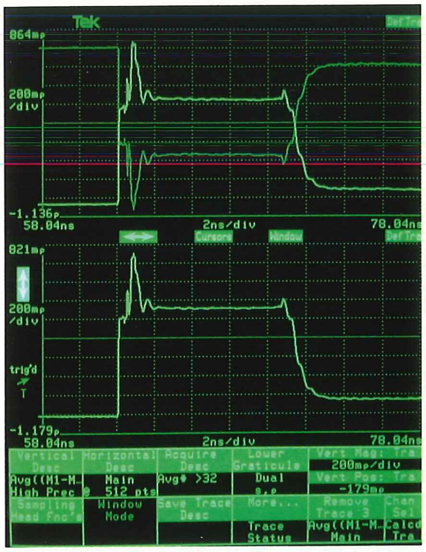


Figure 6. *Differential TDR display.*

only when nothing else will do the job. They were often difficult to set-up and confusing to operate. The 11800 family puts an end to the notion that sampling is hard to use. Even with all their measurement power, the 11801 and 11802 are still very easy to operate — either from the front-panel or via the GPIB or RS-232C interfaces.

A fast, flexible autoset feature helps you get started quickly. The simple menu-based human interface helps you take advantage of the built-in power without being overwhelmed by knobs and buttons. The high sampling rate provides a live display with smooth "real-time" feel when making adjustments. Unique features, such as automatic windows and measurement statistics let you make measurements quickly and give you confidence in the results.

In short, sampling oscilloscopes have never been as powerful or as easy to use as the new Tektronix 11800 family.

For more information

If you'd like to know more about the 11800 family of Digital Sampling Oscilloscopes, contact your local Tektronix field office or representative. U.S. readers can call the Tektronix National Marketing Center toll free for prices, additional information, or to order — 1-800-426-2200. And be sure to tell them you saw it in **HANDSHAKE.**

Q&A

Q The literature (catalog, data sheets, etc.) describes the PEP301 memory as 1 Mbyte. However, when I turn on my PEP301, it displays a message that says "892 Kbytes of RAM." Where's the missing memory? Is there anything that will get it back?

A The message you see when you start the PEP301 shows how much user-accessible memory has been found and determined to be working. User-available memory means memory available for applications software. The 892 Kbytes comes from two pieces of RAM. The first and largest is the maximum memory that MS-DOS can use — 640 Kbytes. The next portion is the memory beyond the 1M address point — 256 Kbytes in a standard PEP301. The missing piece — 128 Kbytes — is "shadowing" the BIOS area. It can be loaded with the BIOS code to improve performance. Its location is fixed and cannot be changed to make it available for other use.

Dave Barnard
Measurement Systems Division Marketing

Q Our company has standardized on Apple Macintosh computers. Can I interface my Tektronix 11402 easily to a Mac computer?

A Good News! You can now get virtual instrument panels for the 11400 Series Digitizing Oscilloscopes that work with LabVIEW Scientific Software.

During the past few months, Tektronix has been working closely with selected suppliers of test and measurement software to develop instrument drivers and macros for our digitizing oscilloscopes. Tektronix is already a dealer for ASYST from ASYST Software Technologies and we have worked closely with National Instruments and DSP Development Corporation in developing support for LabWindows, LabVIEW, and DADiSP.

For further information, contact National Instruments (512)250-9119 on LabWindows and LabVIEW, DSP Development Corporation (617)577-1133 on DADiSP, or the LID Support Center (503)627-3086.

Paul Kristof
Laboratory Instruments Division Marketing

Q What are the specification limits of the PTS101 dynamic A/D converter characterization system?

A The PTS101 will make the following tests: Effective Bits, FFT, Spectral Average, Signal-to-noise Ratio, Histogram, and Differential Nonlinearity. It will make all these tests to a maximum sample rate of 20 MSamples/second and a resolution of 12 bits. Note: The resolution specification has just been upgraded to 12 bits from 10 bits. Higher speed options are available as specially quoted options. Contact your Tektronix sales representative for details.

Q Can the PTS101 Software and Instrumentation cards be purchased without the PEP301 controller for use with an existing PC?

A Yes, the PTS101 can be purchased as an upgrade kit (PTSFO1) and will work with 286/386 IBM compatibles. A 287 or 387, respectively, coprocessor is required.

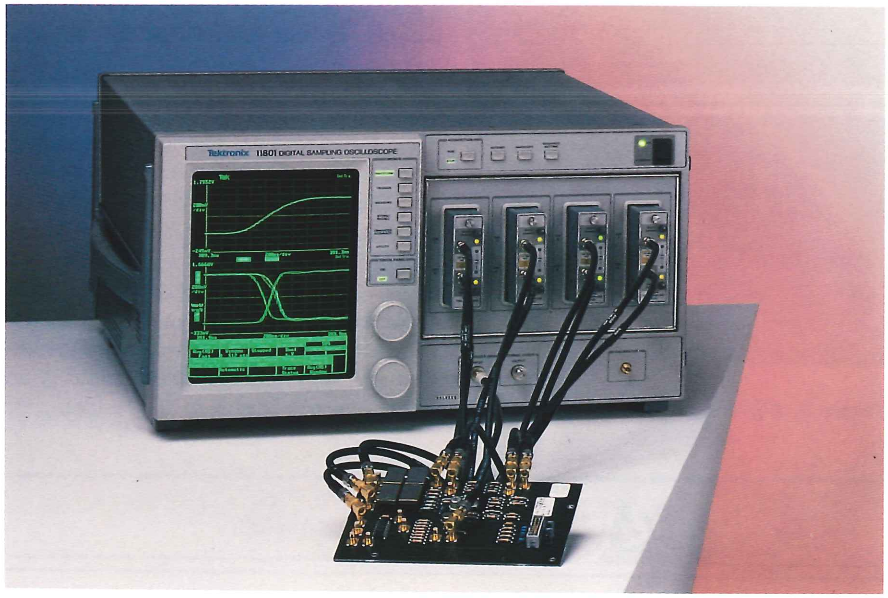
Chris Bednarek
Personal Test Systems Program Manager

Questions?

Do you have a question on signal measurements? Send it to **HANDSHAKE** Q&A, M/S 94-150, P.O. Box 4600, Beaverton, OR 97076, or use the Comments section of the reply card to send in your question. We'll get a personal answer to you as soon as possible and print questions of general interest in future Q&A columns. Your name and name of your company will be used with the printed question unless you specifically request that it be withheld.

Removing fixturing delays from propagation delay measurements

Mark D. Tilden
Product Design Engineer
Laboratory Instruments Division
Tektronix, Inc.



The 11800 Series provides an easy and convenient way to make propagation delay measurements using TDR techniques.

Making AC measurements on modern logic devices is an increasingly difficult task. As switching speeds rise and propagation delays fall, the demands on measurement equipment become enormous. Worse yet, test fixtures (i.e., the cables, sockets, test boards, etc. that hold and connect the device under test) introduce errors that are often difficult to remove from the measurement results.

Figure 1 shows a block diagram of a typical measurement test set-up for testing a GaAs (gallium arsenide) or ECL logic circuit. This system can be used to measure a variety of AC parameters including output rise and fall times, propagation delay, and output skew. The same system could also be used to measure a variety of other device parameters — e.g., input and output impedances, DC parameters, and set-up and hold times.

For a typical GaAs logic device, propagation delays will probably be several hundred picoseconds, with 100 to 300 picosecond rise and fall times. However, propagation delay measurements will be clouded by the delays introduced by the cables and test fixture. A typical two-foot cable, for example, will add about three nanoseconds to the propagation delay. A three-foot cable on the input and output of the device will add about six nanoseconds to the propagation delay measurement. There may also be a few hundred picoseconds or more of delay in the test fixture itself.

If the actual propagation delay of the device is 500 picoseconds, for example, and the measured delay is 6.5 nanoseconds, the device under test only contributes about 8% of the measurement result — the rest is fixturing delays!

Measuring fixture delays

How do you separate text fixture delays from the device under test?

There are two common approaches. The first involves connecting a shorting device between the input and output paths where the device under test (DUT) would normally connect. By measuring the propagation delay with a shorting device installed, you can find the delay through the fixture without the device under test. For devices with propagation delays of several nanoseconds or more, the small delay through the shorting device can be ignored. However, for faster devices, the delay through the shorting device becomes a significant part of the measurement. For even a small package, the shorting device will probably be close to an inch long — or roughly 100 picoseconds of delay.

Another approach for measuring fixture delay uses TDR (Time Domain Reflectometry) techniques to measure the lengths of the cables. By removing the DUT, the test fixture has an open circuit at the point where the DUT connects. If a TDR step is transmitted into the cable, most of the transmitted energy will be reflected when it reaches the open end of the text fixture (see sidebar **A TDR refresher**). The time between the transmitted step and the reflected step represents twice the propagation delay through the cable, since the transmitted step traveled the length of the cable to reach the open and the reflection again traveled the full length back to the TDR instrument.

TDR is a very accurate method of characterizing the fixture because it can measure the delay introduced by the cables and fixture, right to the point of the DUT connection. There are no extra delays introduced by shorting devices. In addition, the measurement resolution is excellent with modern TDR equipment. The Tektronix 11801 Digital Sampling Oscilloscope with SD-24 TDR/Sampling Heads have a 28 picosecond transmitted pulse risetime (35 picosecond reflected risetime), and can resolve the delay introduced by the cable to less than one picosecond.

TDR refresher

TDR (Time Domain Reflectometry) is a technique for measuring distance and impedance in transmission lines and electronic systems. TDR measurements are made by transmitting a pulse into a device under test (DUT) and observing the reflections that come back from the DUT. Reflections (i.e., energy that returns back to the transmitting point) are caused by changes in electrical impedance, much like a wave in a water tank is reflected when it strikes an object that obstructs its path.

The time between the transmitted (incident) pulse and the reflections represents the distance between the transmitting device (in this case the TDR/Sampling head) and the impedance discontinuity that caused the reflection. The amplitude of the reflection represents the difference in the impedance prior to the discontinuity and the impedance after the discontinuity.

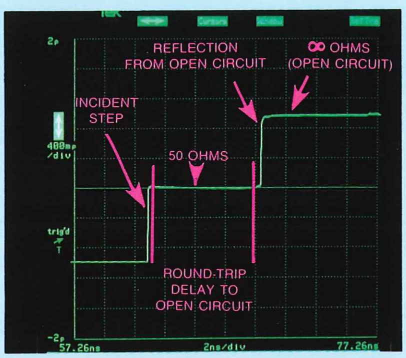


Figure A. *Typical TDR waveform for a 50-ohm cable with an open circuit at the end of the cable.*

For example, a 50-ohm transmission line, such as a coaxial cable, connected to the SD-24 TDR / Sampling head at one end and open at the other end produces a waveform like Figure A. The rising edge on the waveform is the incident step being transmitted into the cable. When the incident step reaches the open circuit at the end of the cable, virtually all of the energy is reflected in phase with the incident step, so the reflection adds to the incident step. The result is a second step in the same direction (positive-going) as the incident step and about the same amplitude as the incident step. The time between the two steps represents the round-trip distance between the sampling head and the open end of the cable.

If the same cable is terminated with a short circuit, the energy is reflected as in the open circuit case, but this time the reflection is out of phase with the incident step so it subtracts from the incident step and the waveform returns to the baseline value prior to the incident step (Figure B). Notice that the distance between the incident and reflected steps is still the same, regardless of whether the cable is open or shorted.

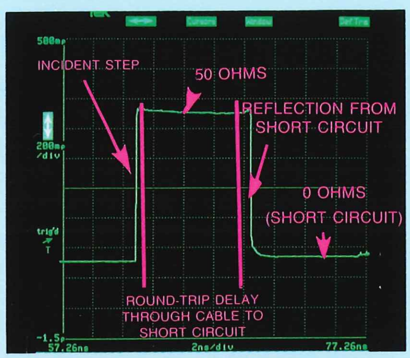


Figure B. *Typical TDR waveform for a 50-ohm cable with a short circuit at the end of the cable.*

Any terminating impedance at the end of the cable other than 50 ohms (the characteristic impedance of the cable) will result in some reflection. If the termination is lower impedance than the characteristic impedance of the cable, the reflection will subtract from the incident step, producing a negative-going reflection for a positive-going incident step. If the terminating impedance is higher, the reflection will add to the incident step in the same direction as the incident step.

Thus, the distance to an impedance discontinuity and the nature of that discontinuity can be determined from the TDR waveform. With fast risetime step generators, as in the SD-24 TDR/Sampling head, the propagation time (and therefore distance), can be measured with very high resolution (less than one millimeter for large discontinuities). In addition, the powerful scaling and measurement features of the 11801 allow simple measurement of distance and reflection coefficient.

Unfortunately, this technique is difficult to implement on instruments with a single TDR channel or separate TDR and acquisition channels because the measurements can't be made "in place." The cables must be disconnected from their normal acquisition channels, measured, the result logged, and the cables re-connected. For a large test system, this involves significant time and effort, as well as introducing a potential source of error. If the cables are not disconnected, measured, and re-connected in the proper order, length corrections may be applied to the wrong paths.

This problem is solved in the 11801 and SD-24 by providing TDR on every channel — up to 136 channels. With the 11801/SD-24, you can measure fixture delays with the device testing system connected in its normal configuration. Once fixture delays are measured, the system can begin to make measurements without re-cabling or reconfiguring the system.

The TDR measurement process

Characterizing output delays. The first step in making TDR fixture measurements is to simply remove the device under test (DUT), leaving the fixture input and outputs open. Next, turn the TDR step generators on for each of the channels connected to fixture outputs. Since the DUT is removed, these outputs are an open circuit. Figure 2 shows the resulting waveform.

A time measurement from the incident pulse (the first rising edge) to the reflection from the open (the second step) represents twice the propagation delay of the cable. The actual propagation delay is half this time because the TDR pulse must pro-

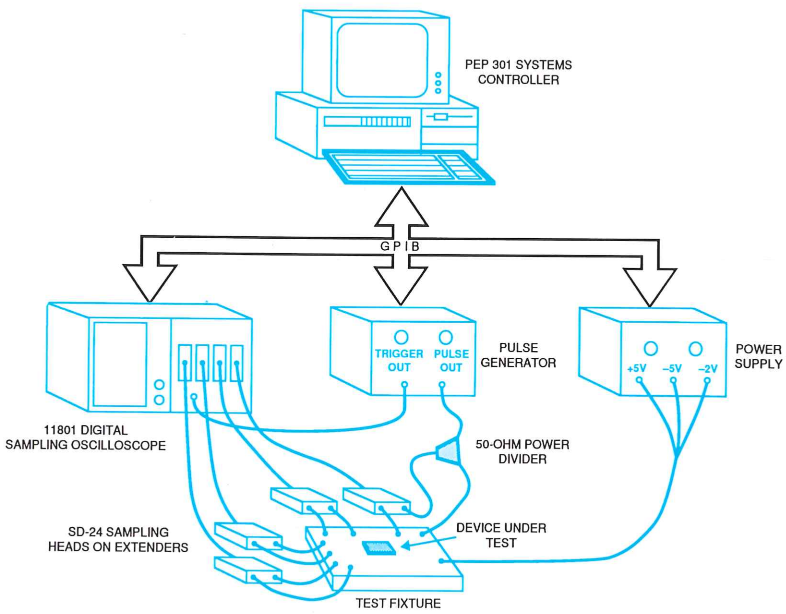


Figure 1. *Typical automated AC test system for ECL or GaAs devices.*

pagate down the cable to the open on the test fixture and then the reflection resulting from the open must travel the same path back to the sampling head input.

Measuring this delay in an automated environment is reliable and simple using the Autoset, automatic windows, and propagation delay measurement features of the 11801. The steps are outlined below (these steps describe the process from the front-panel operator's view; equivalent GPIB or RS-232C commands are available for operation under programmable control):

1. **Set the 11801 Autoset mode to "Edge" and invoke autoset (press the front-panel button send).** In edge mode, the 11801 adjusts the signal so the first rising edge covers two to five divisions of the screen horizontally and three to five divisions vertically. This results in a waveform similar to Figure 2.
2. **Create two windows on the TDR waveform.** Windows allow you to re-acquire a selected portion of the main waveform with as much resolution as you wish, much like the delayed sweep on analog oscilloscopes. See **Introducing the 11800 family** in this issue for a more in-depth discussion of windows.
3. **Set the window mode to automatic.** Automatic mode allows you to specify a transition number, slope, and level in the main record and have the instrument automatically position a window around that transition. Automatic mode is perfect for ATE applications, since it doesn't require a user to watch the screen and manipulate the position of the window.
4. **Set the window transition level for the first window to 25%. Set level for the other window to 75%.** Since the output of the channel is open, virtually all of the transmitted step will be reflected back from the short, so 25% of the total signal amplitude (including the incident step plus the reflection) will fall on the 50% point of the incident step. The 75% level falls on the 50% point of the reflected step.
5. **Select a propagation delay measurement and measure from the first window (the 50% point on the transmitted step) to the second window (the 50% point on the reflected step).** The propagation delay measurement begins with the "selected" (brighter) waveform on the screen and ends with a waveform you select from the propagation delay pop-up menu.

The measurement can be made without using windows, if you desire. You can directly measure the main waveform from the 25% point to the 75% point. However, windows give you better resolution by re-acquiring the transition regions with higher resolution.

This process can be done serially — one channel at a time. Or, you can set up the measurements on all the output channels and make the measurements in parallel. A single MEAS? command from the GPIB or RS-232C interfaces will return all the measurement results at once.

This measurement yields the delay from each of the DUT outputs to its corresponding sampling head input. The delays can be subtracted (either by an external computer or using the Compare mode on the 11801) from all measurements to compensate for the output cable lengths.

A look at input delays. To completely characterize the fixture, a measurement of the input delay is also required. The required measurement is actually the difference between the delay from the pulse generator to the sampling head (T3 + T1 in Figure 3) and the delay from the pulse generator to the DUT (T3 + T2). If these delays are identical, the output pulse from the pulse generator will arrive at the DUT and at the sampling head input at exactly the same time and no measurement compensation is required.

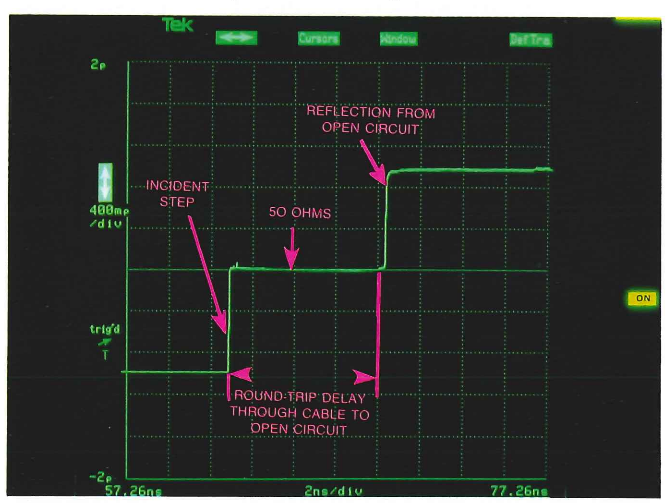


Figure 2. *Typical TDR waveform resulting from an open circuit at the DUT interface.*

If, however, the cable to the sampling head is longer than the cable to the DUT, the pulse will arrive at the sampling head later than at the DUT. This makes the measured propagation delay shorter than it actually is, since the sampling head sees the input pulse going into the chip later than it actually does. If the cables were mismatched in the opposite direction, the mismatch would make the propagation delay measurement longer than it actually is.

Measuring the length of these two cables with TDR requires that the ends be open (or at least have some relatively large impedance change from the 50-ohm cables). The pulse generator output must be switched off (opened) or disconnected.

If the test fixture does not contain a fixed termination resistor for the device input, simply removing the DUT will cause the input path to be open. If the fixture contains a fixed termination resistor for the DUT input, the termination resistor may inhibit finding the open if it is close to the DUT interconnect point. If a fixed termination resistor obscures the open circuit, a simple shorting device can be made using an empty package similar to the DUT package (i.e., a package with no die installed). The shorting device should short the input to AC ground as close to the interconnect point as possible. This presents a short circuit to the TDR pulse and generates a large reflection that can be easily located and measured.

Figure 4 shows a TDR waveform that results when the pulse generator output is open and the DUT input is shorted. The time from the incident TDR step to the first negative-going reflection represents the round-trip delay from the sampling head, through the power divider to the shorted DUT input and back (2*(T1 + T2)). When the incident pulse arrives at the open pulse generator output, the waveform goes back up to the incident level. Reflections from the shorted and open cables also propagate into the opposite cable (i.e., the reflection from the shorted cable propagates into the open cable and vice versa). These reflections reflect again off the shorted and open cable ends and meet at the sampling head to form the last large negative-going reflection. The width of the pulse formed by these last two reflections represents the round-trip delay from the power divider to the shorted DUT input and back (2*T2).

A little algebraic manipulation with the two measured values yields the difference between T1 and T2. Notice that T3 is insignificant, since T3 is common to both the DUT and sampling head paths. If T1 is larger than T2, the total fixture delay is smaller, since the pulse arrives at the sampling head later than the DUT and therefore, the measured propagation delay is too small. If T2 is larger than T1, the opposite is true.

The value of T1 – T2 is added to each of the output fixture delays to produce a composite delay for each input-to-output path. The resulting fixture delay corrections are subtracted from each propagation delay measurement result to yield the actual propagation delay through the device.

Making the measurements

With the fixture delays measured and stored, you're ready to begin making propagation delay and risetime measurements on the actual device. Several of the features used to make the fixture delay measurements also help make the DUT measurements easy and fast.

In this simple example, the measurements can be made by creating a waveform on the input and output channels and selecting a propagation delay and risetime measurement from the 11801 measurement menu for each of the output channels. All the measurement results can be requested simultaneously with a single GPIB or RS-232C command.

For better measurement resolution, windows can be used to expand the section of the main waveform that contains the transition of interest. In fact, window waveforms can be created and the main waveform can be entirely removed (the GPIB or RS-232C interfaces can create window waveforms directly without a main waveform). Automatic windows can be used to locate the transition of interest without operator interaction.

The results returned from the propagation delay measurements will reflect the total delay through the DUT, cables, and test fixture. The previously measured cable and fixture delay can be subtracted by an external computer. However, the 11801 can automatically remove these delays from each propagation delay measurement using the Compare and References feature. Sub-

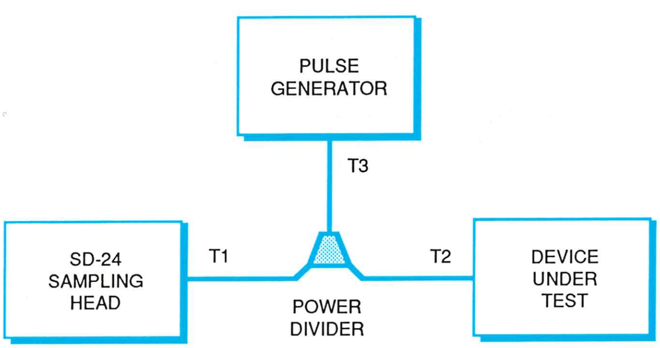


Figure 3. *Input fixture delay is the difference between the delay from the pulse generator to the sampling head (T1 + T3) and the delay from the pulse generator to the DUT (T2 + T3).*

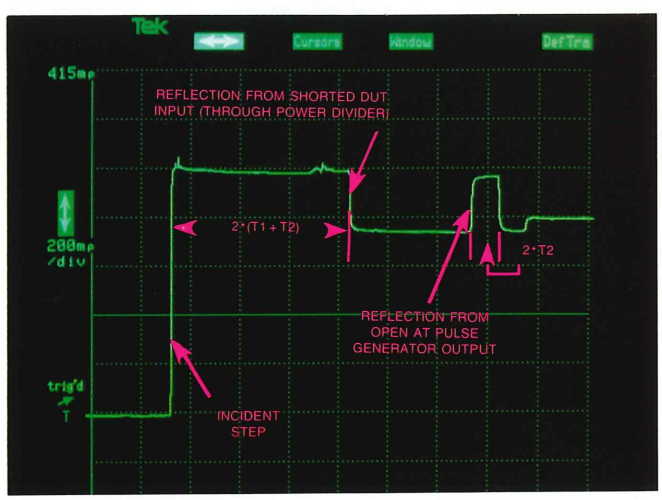


Figure 4. *Typical TDR waveform resulting from an open at the pulse generator output and a short at the DUT input.*

Hardware makes timing measurements faster

Most modern digitizing oscilloscopes provide some type of on-board timing measurement capability. These measurements are usually made by a microprocessor searching digitized waveform data for crossings through threshold levels. The microprocessor calculates results, such as risetime from these crossing points. The Tektronix 11801 Digital Sampling Oscilloscope offers this type of measurement in its software measurement mode.

For a large system with many channels, this technique becomes prohibitively slow since a single microprocessor can only make one measurement at a time. Multi-processor architectures can improve throughput but a parallel system of high-speed processors is quite expensive. The hardware measurement system in the 11801 provides a fast, accurate means of making timing measurements on a large number of channels.

Hardware measurements are made using precision voltage comparators at the output of the sampling heads (see Figure A). These comparators compare the output voltage from the sampling head with a reference voltage from a 14-bit DAC (digital-to-analog converter). The DAC is programmed with the threshold level for the measurement, such as the 10% level for a risetime measurement. Another comparator is programmed with the 90% level. When the instrument makes a measurement, the comparators monitor the sampling head output voltage. When the sampling head output voltage crosses through the reference voltage level, the comparator output switches from one state to the other (high-to-low or low-to-high).

Noise on the sampling head output or the comprarator reference may cause false transitions in the comparator output. To eliminate the effects of this noise, the output of the comparator is fed to a hardware transition filter which qualifies transitions in the comparator output. The filter only passes transitions which remain stable for a user-selectable number of successive samples. For example, if the filter is set for three samples, the comparator output must remain the same for a minimum of three samples after a transition to qualify that transition. Shorter transitions are ignored by the filter.

The transition filter drives a transition counter, which allows the user to specify a transition number from 1 to 15 to be measured. The hardware counts qualified transitions and produces an output when the specified transition of the specified slope (positive- or negative-going) is found.

The measurement hardware counts the number of samples that occur between two transitions. This number of samples is multiplied by the sample interval to produce a time measurement.

The 11801 and SM-11 have two comparators for each pair of sampling heads, allowing the instrument to make time measurements in parallel on many channels. A risetime measurement uses two comparators connected to the output of one sampling head channel. One comparator locates the 10% level while the other locates the 90% level on the selected transition.

Hardware measurement mode on the 11801 allows you to make timing measurements (but not amplitude measurements such as Peak-Peak) on any number of channels. Hardware mode measurements can be saved with Saved Trace Descriptions, to allow measurements on all 136 channels in an 11801/SM-11 system. In addition, hardware measurements are significantly faster than their software counterparts for a large number of channels.

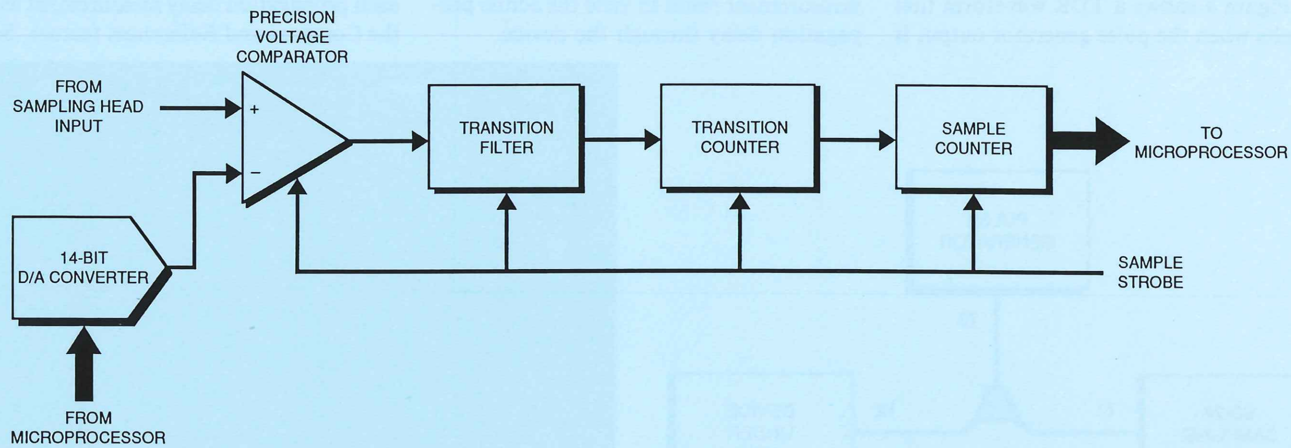


Figure A. *Simplified block diagram of the 11800 hardware measurement system.*

tracting the fixture delay in the 11801 reduces the processing load on the external computer. It also allows an operator to view corrected measurement results on the display.

Fixture delay corrections can be measured at the start of a run of parts or when the test set-up is changed. The results can be stored on computer disk for later recall. The computer can load the fixture delay corrections into the 11801 Compare and References function using the REFSET command from the GPIB or RS-232C interfaces. After the correction values are loaded, sending the COMPARE ON command tells the 11801 to subtract the reference values from all measurements. The corrected results are displayed on screen with a Δ preceding the measurement name to indicate that Compare mode is on. The corrected results are also returned in response to GPIB or RS-232C measurement result queries.

For measurements that need no correction (such as risetime) simply set the reference value to zero. Compare mode has no effect on the result with a reference value of zero.

Extending the concept...

This measurement system can be expanded to handle up to 136 channels for large multi-pin IC testing applications. Using the SM-11 Multi-Channel Unit, one 11801 mainframe can support 68 dual-channel heads for a total of 136 channels! Half of the channels can be acquired simultaneously (i.e., in the same acquisition) using main (not window) waveforms. This allows you to acquire data and make measurements very quickly and accurately. All channels in the mainframe and SM-11 have the same performance and there are no relay switching systems to degrade signal integrity or reliability.

However, it's obviously not practical to display 136 channels on the 11801 display, and making measurements on 136 channels, even with the fast 80286/80287 processor in the 11801, would be quite time consuming. For these large system applications, the 11801 has two special features that make multi-channel measurements fast and easy.

The first of these features, called "Saved Trace Descriptions" allows you to acquire waveforms and make measurements on waveforms that are not displayed. Using Saved Trace Descriptions (STDs) you can set up measurements on all 136 channels and request the waveform data or measurement results from the STDs without displaying the waveform or measurements. You can also recall an STD to the display to check measurement parameters, or other settings or to see the waveforms or measurement results on the display. Displayed traces, with their selected measurements, can be saved as an STD, so you can use the display to set-up measurements and then remove the waveform and measurements from the display. All STDs are stored in non-volatile RAM.

The second important feature is hardware timing measurements. The 11801 can make timing measurements (e.g., risetime, width, prop delay, etc.) in two modes. The normal (default) mode is software mode. In software mode, measurements are made by searching acquired waveform points for crossings through specified levels and computing results in the 80286 processor. The 11801 can also make timing measurements using time measurement hardware. This measurement hardware consists of precision strobed voltage comparators with 14-bit digital-to-analog converters providing the reference voltages for the crossing levels. The measurement hardware simply counts samples between the level crossings, returning measurement results with very little processor interaction. See sidebar **Hardware makes timing measurements faster** for additional information.

Hardware measurements are significantly faster than their software counterparts. Since the time measurement hardware is duplicated behind every sampling head in the 11801 and SM-11, hardware measurements can be made on many channels in parallel. Only hardware mode timing measurements can be used in a Saved Trace Description.

Putting it all together

With TDR capability on every channel to facilitate fixture delay measurements, powerful automatic windows, hardware measurement capability, and Saved Trace Descriptions, the 11801/SD-24 combination provides unmatched performance for making high-resolution automated timing measurements. For more information on the 11800 family and the SD-series sampling heads, contact your local Tektronix representative or check the box on the reply card.

Basic sampling concepts

Lisa Herring
Marketing Product Line Manager
Lab Instruments Division
Tektronix, Inc.

Sampling oscilloscopes have often been regarded as difficult to understand and hard to use. This discouraged many people from using sampling instruments except as a last resort — when nothing else would do the job. However, sampling oscilloscopes have a great deal to offer in terms of bandwidth, time resolution, etc. Modern sampling instruments are also much easier to use than their predecessors.

What is sampling?

Sampling is the process of characterizing a waveform by breaking it into a series of discrete values at defined points in time. In general, input signals are continuous with amplitude that varies over time. After sampling, the waveform representing the input signal is an array of values (samples) taken at discrete intervals on the continuous waveform (see Figure 1). The magnitude of any individual sample is equal to the amplitude on the continuous input waveform at the instant in time when the sample was taken. If the samples are graphed on a screen with the measured amplitude on the vertical axis and time on the horizontal axis, the result will be a dotted-line representation of the input waveform.

Perhaps the best illustration of the sampling concept is a strobe light. You've probably seen demonstrations using a strobe light to make fast-moving machinery or a fan blade appear to stand still or move very slowly. The strobe light takes "samples" of the fast moving machine at discrete points in time. By varying when those samples are taken relative to the movement of the machinery, the motion can be made to appear stationary or to move slowly.

Sampling oscilloscopes do the same thing to an electrical signal. They sample the input waveform at precise times and display an image of the input waveform. The output of the sampler is a replica of the input waveform, but at a much lower speed. Since it is slower, it's easier to process with conventional amplifiers and A/D converters.

Since the oscilloscope "knows" how it sampled the input waveform, it can display the sampled signal with the original time scale, even though the sampled signal has been slowed down for processing and display.

Considerations for measuring high frequency signals

The oscilloscope is one of the most important tools used by electrical engineers and technicians to design, troubleshoot, and calibrate electronic devices. It provides a lot of answers about electronic performance by providing a window into the electrical world.

The type of oscilloscope used depends upon the application. There are oscilloscopes for general use and those for special purpose use. The general-purpose oscilloscope is used for a wide range of measurements including voltage amplitude, current amplitude, and signal timing. Special-purpose oscilloscopes, make similar kinds of measurements but they usually have other characteristics that make them better suited for specific measurement applications. Sampling oscilloscopes, for example, offer extremely high bandwidth at the expense of much smaller maximum input voltage. Other special-purpose instruments might offer very fast sampling rates for transient events, differential inputs for high sensitivity measurements, or TDR (Time Domain Reflectometry) capability.

There's a direct relationship between the maximum signal risetime you can display, the risetime of the input signal, and the risetime of the scope you're using to make the measurement. This is expressed by the formula:

$$\text{Displayed } T_R = \sqrt{(\text{Signal } T_R)^2 + (\text{Scope } T_R)^2}$$

For best measurement results, the risetime of the scope should exceed the risetime of the measured signal by a factor of at least three. The measurement technology used in most conventional (non-sampling) analog or digital scopes today results in a maximum of about 350 picoseconds risetime (equivalent bandwidth of about 1 gigahertz) although some special-purpose instruments provide higher performance.

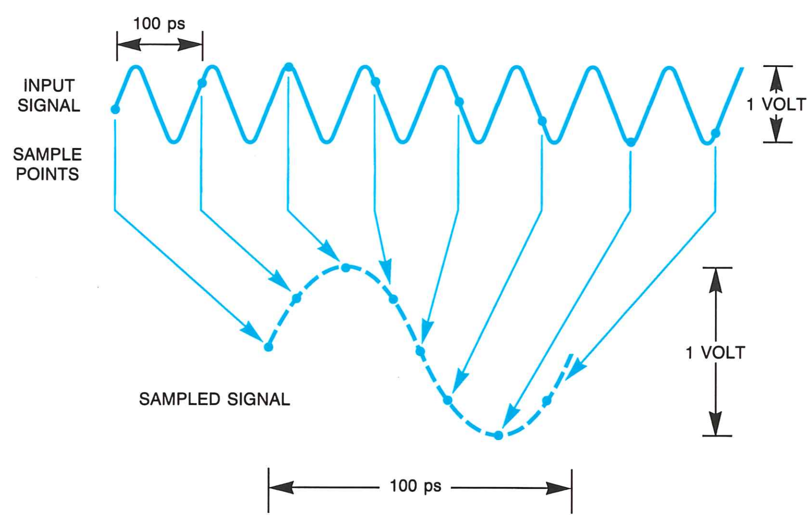


Figure 1. *Basic sampling concepts.*

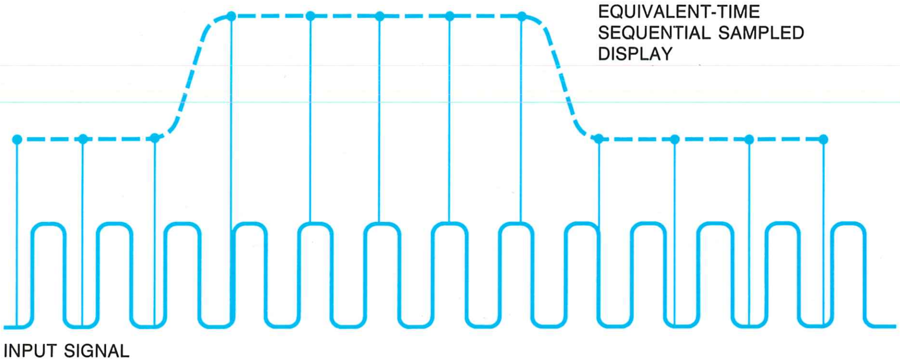


Figure 2. *Sequential sampling process.*

Sampling oscilloscopes overcome this limitation by taking a sample of the input signal as close to the signal input connection as possible (see the topic "A comparison between sampling and digital storage" for further information. Today's sampling oscilloscopes provide bandwidths in excess of 20 gigahertz (17.5 picosecond risetime). Again, some special-purpose instruments provide even higher performance.

Sampling techniques

There are three general sampling techniques used in sampling oscilloscopes: Sequential, random, and real-time sampling. Each sampling technique has unique features and advantages. Choosing the right technique depends upon the requirements of your application. This section describes each technique and outlines advantages and applications of each.

Sequential sampling. The sequential sampling technique takes a single sample following each qualified triggering event. The trigger-to-sample time is increased slightly on each subsequent sample by an amount which can be called the equivalent-time-sample-interval. Figure 2 illustrates this process. The equivalent-time sequentially sampled display results from the display of these samples obtained over a longer time in which triggering and sampling have been repeated for each successive dot of this display.

Note that in sequential sampling there is a required minimum delay between the trigger event and the start of the acquisition. As a result, an event that occurs less than this minimum delay from the trigger cannot be acquired. To capture the triggering event (when no pretrigger is available), some sampling oscilloscopes provide delay lines to overcome this minimum delay time. When used, these delay lines usually limit the overall bandwidth of the system.

In most cases the equivalent time intervals would be much shorter than shown in Figure 2 so that the reconstructed waveform consists of many more closely spaced dots. This gives the appearance of an almost continuous trace. The sampler may not acquire a sample for every repetition of the signal due to limitations of the maximum sample rate. However, if all of the repetitions are identical, it doesn't matter which repetition is used. The trigger circuit will ignore triggers until the sampler is ready to take another sample, and then only one sample is taken for each qualified triggering event.

Sequential samplers are most often used because they offer several benefits, including very high time resolution and low jitter. They are also less sensitive to trigger frequency changes.

Random sampling. Some sampling oscilloscopes have a random sampling mode available to overcome the need for pretrigger with sequential sampling. This method operates by looking at the repetition rate of the qualified triggers, predicting when the next trigger event will occur, and taking a sample prior to that time. It also carefully measures the actual time between the sample instant and the actual qualified trigger instant in order to place the waveform data point properly in the waveform record. Because the data points in the final record are not obtained in exact sequential order, this mode is called "random sampling." Figure 3 illustrates the random sampling process.

Under ideal conditions when the trigger frequency is very stable, samples will be taken on successive cycles at progressively later points on the signal, just like in the sequential sampling system. If the trigger frequency or the circuit that predicts the next trigger point has jitter, samples will be taken randomly. The result is a display where the dot spacing can vary in a random manner and the dots are not in sequence — thus the name "random sampling." However, each dot still represents the signal amplitude at the time the sample was taken and its horizontal position represents the exact time when the sample was taken.

Random sampling doesn't mean that the system is trying to take samples in a truly random manner or that it can measure random signals. The system requires repetitive signals. Also, signals must be more stable than those measured by the sequential sampler.

Real-time sampling. Sequential and random sampling systems use an equivalent-

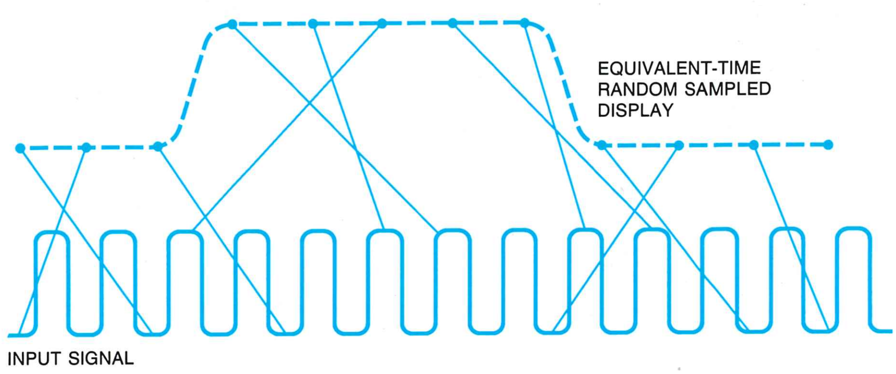


Figure 3. *Random sampling process.*

Glossary of sampling terms

Following are some words and terms often used when discussing sampling techniques.

Balanced sampling gate — A type of sampling gate arranged so that strobe currents are balanced to minimize kick-out (see kick-out).

Base-line drift — Vertical movement of the entire trace under constant signal conditions and control settings.

Blow-by — A display aberration caused by signal-induced current through the sampling-gate shunt capacitance. The nature of the aberration depends on the circuit time constants.

Coherent display — A display where the time sequence of signal events is preserved. A coherent display may be produced by either random or sequential sampling.

Countdown — The process of dividing an input frequency by "n" to produce a lower frequency output. Countdown is usually used in sampling oscilloscopes to generate a lower-frequency trigger signal by responding to every nth signal transition. N is an integer divisor that may or may not be constant.

Differential time domain reflectometry — A technique for determining the impedance of coupled transmission lines (such as twisted pairs) in which complementary steps are applied to the two sides of the line to be tested, and the timing and the amplitude of the reflected signals are to be measured.

Display window — The time window represented within the horizontal limits of the graticule (see time window).

Equivalent time — The time scale represented in the display of a sampling oscilloscope operating in the equivalent-time sampling mode.

Equivalent-time sampling — A sampling process that requires a multiple repetitive signal event to build up one acquired waveform. Thus, building the display takes longer than the time represented in the display.

False display — A sampling display that allows faulty or ambiguous interpretation, usually caused by insufficient sample density or improper triggering (also known as alias).

Kick-out — A signal from internal circuitry that comes out an input connector.

Loop gain — The product of sampling efficiency, forward gain, and feedback attenuation in a sampling loop. Loop gain in a calibrated system is normally unity (one), but can go to values more or less than unity.

Offset null — An adjustment to remove any unwanted DC offset that may be present in the sampling head. Effectively zeroes the sampling head so that an input signal with zero volts of amplitude delivers a zero volt output.

Pretrigger — A trigger signal that occurs before a related signal event.

Reflection coefficient (rho) — In time domain reflectometry, the ratio of peak amplitude of a reflection to the incident step amplitude. The observed reflection coefficient may depend upon system risetime, losses in the transmission medium, and the nature of the discontinuity that produced the reflection.

Sampling — A process of sensing and storing one or more instantaneous values of a signal for further processing or display.

Sampling efficiency — The percentage of signal voltage transferred across the sampling gate when the gate conducts.

Sampling gate — An electronic switch that conducts briefly on command to collect and store the instantaneous value of a signal (sometimes called sampling bridge).

Sampling loop — The circuits that provide the main signal path through the input sampling gate, amplifiers, forward gain attenuator, memory gate, memory, feedback attenuator, and back to the sampling gate (also called feedback loop).

Sampling oscilloscope — An oscilloscope using sampling along with the means for building a coherent display of the samples taken.

Sequential sampling — A sampling process where samples are taken at successively later times relative to the trigger recognition point.

Slewing — The causing of successive samples to be taken at different times than the trigger recognition point.

Smoothing — A process which reduces displayed noise by reducing the gain of the sampling loop. By oversampling the input signal, the sampling loop can maintain an apparent unity gain while reducing noise.

Strobe — A short duration pulse that operates the sampling gate.

Strobe kick-out — A fraction of the strobe signal coming out the input connector.

Time domain reflectometry — The technique of sending a pulse or step signal into a transmission line and analyzing any reflections produced.

Time position — The equivalent time relationship between the start of the time window and the trigger recognition point. Also a control to vary this relationship.

Time position range — The equivalent time interval over which the start of the time window may be positioned by the time position control. The time position range normally starts before the trigger recognition point in a random sampling oscilloscope and shortly after the trigger recognition point in a sequential sampling oscilloscope (assuming no signal delay lines).

Time window — The equivalent time interval over which signal events can be described by usable samples. May be greater than the display window.

Trigger kick-out — A signal from a trigger circuit that comes out of the trigger input connector.

Trigger pick-off — A circuit used to extract a portion of the input signal to trigger the time base.

Trigger recognition — The process of responding to a suitable triggering signal.

Trigger recognition point — The time when trigger recognition occurs. Also, the point on a displayed waveform representing the instant of trigger recognition.

Window — In general, the period of time acquired in a waveform is called a "window." In instruments with dual time base architecture, a window refers to the magnified section of a lower resolution (main) waveform. The window waveform is acquired with a smaller equivalent time sample interval than the main waveform.

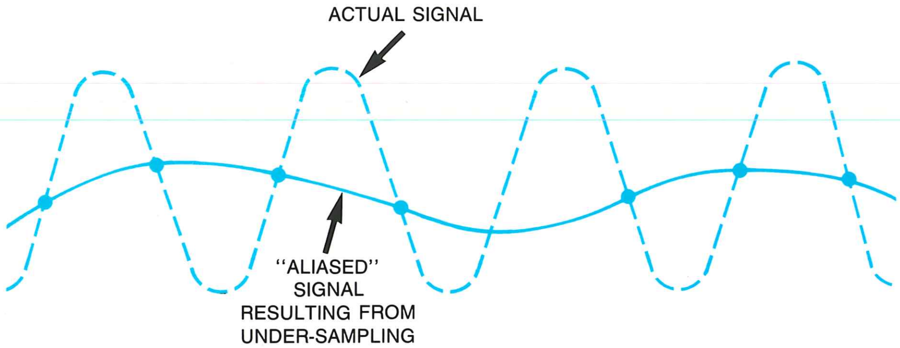


Figure 4. *To accurately reproduce an input waveform, the signal must be sampled at least twice as fast as the highest frequency component in the signal. This figure illustrates the aliasing that results when a sine wave is under-sampled.*

time sampling technique. For fast repetition rate signals, these systems do not sample on every cycle of the input signal since their maximum sampling rate prevents using every cycle. However, if the signal repetition rate falls below the sampling rate of the system, one sample will be taken every cycle and the sampling rate becomes the same as the signal repetition rate. For very low repetition rate signals, this leads to a very slow build-up of the complete display.

Real-time sampling acquires all of the waveform sample points on a single pass and therefore doesn't depend upon a repetitive signal. For this reason, it is important when using real-time sampling techniques that the frequency of the acquired signal is less than one-half of the real-time sampling rate to avoid aliasing. Aliasing occurs when a signal is sampled at less than twice the frequency of the highest frequency component in the acquired signal. When aliasing occurs, the sampled data does not accurately represent the input signal. Figure 4 shows an example of aliasing.

Real-time sampling is needed when the signal is not repetitive, or when repetition rates are low and the sequential sampling acquisition time becomes unsatisfactorily long. Figure 5 illustrates real-time sampling.

When to use sampling

Sampling overcomes the bandwidth and risetime limitations of conventional analog or digital oscilloscopes. With a sampling scope, you can measure signals with frequencies far above one gigahertz. However, you must operate within the following guidelines:

1. **Repetitive signals.** A sampling scope collects samples during many cycles of the input signal. Because of this, the sampling technique works when the shape of the signal cycles remain the same over the sampling time period. In other words, the signal must be repetitive.

2. **Lead time.** Trigger circuits cannot respond instantly to a changing signal level, and the sweep circuit cannot start instantly when the trigger occurs. Therefore, if you try to trigger on a fast signal slope, that transition may end before the sweep or sampling process starts.

   There are at least four ways to get around the minimum delay from the trigger to the first sample:

   - Adjust the delay of the time base so that a later repetition of the input signal is on screen. For relatively high repetition rate signals, this technique is usually quite satisfactory. However, jitter accumulates as the delay setting increases. So, the larger the delay required to view the signal, the more jitter will affect the displayed waveform.
   - Provide a pretrigger signal that occurs enough prior to the signal of interest to satisfy the minimum trigger-to-first-sample delay. Many pulse generators offer trigger outputs that can be set to occur prior to the output pulse. Remember that the delay from the trigger to the output pulse must have low jitter since any jitter in this delay will be directly reflected in the acquired waveform.
   - Insert a delay line in series with the input signal and pick off the trigger prior to the delay line. This way, the trigger signal occurs when the signal enters the delay line. The delay line inserts enough delay to satisfy the minimum trigger delay so the sampling unit is ready to acquire the signal when it arrives at the input. Unfortunately, the delay line limits the input signal bandwidth. Some instruments offer built-in delay lines that are compensated for best frequency response and also have built-in trigger pick-off circuits.
   - Use a random sampling instrument which doesn't require delay from the trigger to the first sample. These instruments, however, usually don't offer the excellent resolution and low jitter of the sequential time base instrument.

3. **Input amplitude.** Most sampling oscilloscopes couple the input signal directly to

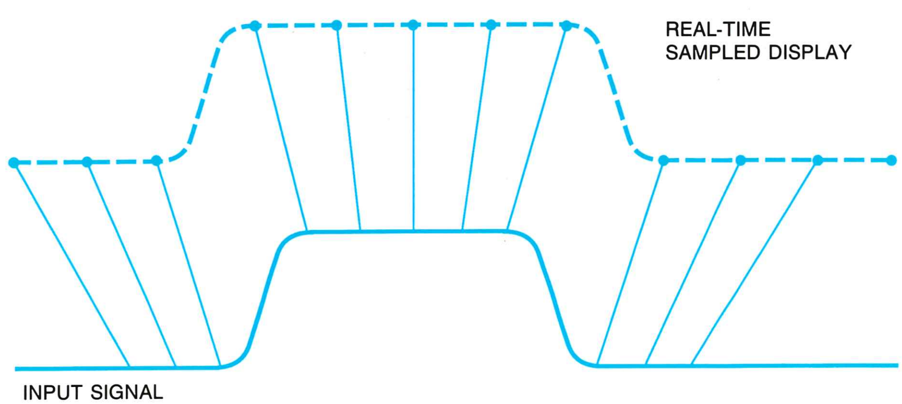


Figure 5. *Real-time sampling process.*

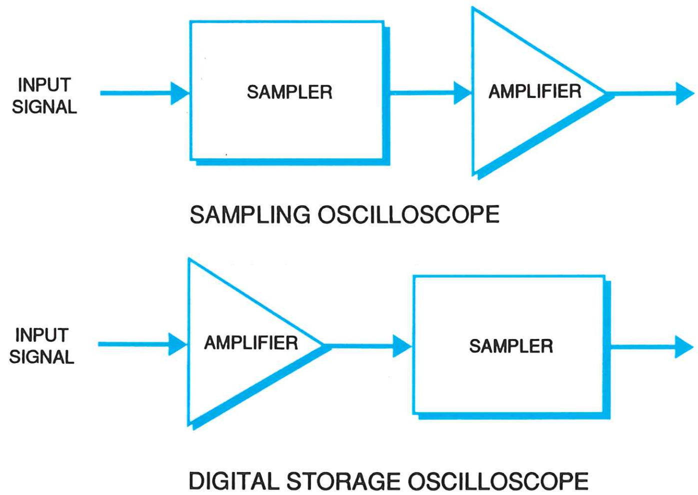


Figure 6. *Block diagrams comparing the order that sampling occurs in a sampling oscilloscope and a digital storage oscilloscope.*

the sampling bridge or gate diodes. Sampling input circuits are susceptible to excess AC or DC levels. Tek sampling oscilloscopes are calibrated for maximum input signals of one volt peak-to-peak. Signals that exceed this operating voltage will not permit a valid display. Voltages above ±3 volts can cause permanent damage or degrade performance of sampling heads. Also, sampling bridges are very static sensitive due to the small size of the diodes which are required for good high frequency performance.

4. **Input impedance.** Sampling scopes allow you to measure higher frequency, faster risetime signals than conventional scopes. This is the major reason for their use. To achieve this performance, the signal is coupled directly to the sampling bridge or gate diodes which usually have an input impedance of 50 ohms.

   To keep the sampling heads from loading the circuit-under-test for some applications, a higher input impedance is needed. This higher impedance can be achieved, with bandwidth and risetime limitations, by using high-impedance probes at the sampling-head input.

A comparison between sampling and digital storage

Sampling scopes and digital storage or digitizing scopes share a similar technique. They both take samples of the input signal and display the slower speed "sampled" signal as dots or vectors. As a result, all digitizing oscilloscopes could be called "sampling oscilloscopes."

The major distinction between a digital storage oscilloscope (DSO) and a digital sampling oscilloscope is at what point the input signal is sampled (see Figure 6).

In a digital storage scope, the amplifier/attenuator is located ahead of the sampler. The amplifier provides a uniform size signal to the sampling gate by amplifying or attenuating input signals. This allows much larger signals to be applied to the input and protects the sampling gate from excessive voltages. However, this larger input range comes at the cost of bandwidth.

In a sampling scope, the signal is connected directly to the sampling diodes. Bandwidth of the signal available to the sampling diodes is higher since it is not limited by the amplifier. However, amplitude of the input signals are limited to the dynamic range of the sampling diodes and excessive voltage inputs can damage the sampling diodes.

So, even though both digital storage oscilloscopes and sampling scopes sample the input signal in a similar fashion, the term sampling oscilloscope has generally come to mean instruments which sample the input signals before any amplifier or attenuator.

Summary

Sampling oscilloscopes perform where conventional methods fail. To view very high frequency signals and very fast rise pulses, they are often the only choice.

Sampling methods vary. Equivalent time sampling allows you to view fast, repetitive signals and pulses by reproducing the display over a period of time. Equivalent time sampling can be either sequential or random. Sequential sampling, which is most often used, builds a display sample after sample until the signal is reproduced. Random sampling provides a means of looking at leading edges at high frequencies when delay lines cannot be used or if a pretrigger signal is not available. Real-time sampling can be used to view single-event or low repetition rate signals.

Sampling is more than just another scope system. It's often the only solution to a tough measurement need. Modern sampling oscilloscopes are much easier to use than their predecessors, offering many of the same features as general-purpose DSOs. If you have a question that may be answered with sampling techniques, contact your local Tektronix Field Office or sales representative.

This article is based upon a technique primer by the author entitled **Sampling Oscilloscope Techniques,** *Tektronix Literature Number 47W-7209. This primer includes additional information on sampling circuits and sampling applications. Contact your local Tektronix Field Office or representative for a copy.*

Making the most of available space

One of the most important considerations, next to choosing the right instrument or system for the job, is choosing the right location for that instrument. If your workbench or lab is typical, there's already too many items demanding their share of too little space. Or maybe you want to share instruments or systems between work locations, or need a convenient way to move the instrument or system to the measurement site. Tektronix SCOPE-MOBILE carts and the new Tek-Tilt pedestal provide a convenient way to mount or move your instruments.

The K501 Tek-Tilt Pedestal is a compact, swivel base designed for convenient mounting and viewing of portable instruments on the bench top. The swivel base allows the instrument to be rotated 360 degrees and tilted 30 degrees for the desired viewing height and angle. Designed specifically for Tek portable instruments, the K501 can hold instruments up to 50 pounds (23 kilograms).

K501 Tek-Tilt Pedestal with 2432 Oscilloscope.

The K212 Portable Instrument Cart provides a stable measurement platform for all Tek portable instruments. The instrument tray can hold instruments up to 80 pounds (36 kilograms) and can be tilted for convenient viewing. The bottom tray can hold additional instruments or accessories. An optional tray can be attached to the main pedestal for peripheral instruments such as printers or plotters. Large rear wheels and lockable front casters provide stability on the move and when making measurements.

The K213 Lab Instrument Cart (not shown) provides a mobile platform for a

K212 Option 22 Portable Instrument Cart with 2440 Digital Oscilloscope and HC100 Color Plotter.

variety of instruments. The K213 features a tiltable top tray that can hold instruments up to 75 pounds (34 kilograms) with a width up to 13.7 inches (34.8 centimeters). An additional 25 pounds (11 kilograms) can be carried on the bottom shelf. A four-outlet power strip, a lockable accessory drawer in the bottom shelf, and an adjustable, tilting middle shelf with 40 pound (18 kilogram) capacity are standard. A sliding keyboard shelf and a plug-in storage compartment are also available as options. Large, lockable casters are provided for easy mobility and measurement stability.

The K217 and K217S Rack Instrument Carts are similar to the K213 except they are specifically designed for rack-width instruments. The tiltable top shelf has a capacity of 100 pounds (45 kilograms) and can hold instruments up to 17.6 inches (47.7 centimeters) wide. The bottom shelf will hold an additional 100 pounds and an adjustable, tilting middle tray (K217S only) can hold 40 pounds (18 kilograms). An accessory drawer is mounted under the top instrument shelf.

K217S Rack Instrument Cart with 11401 Digitizing Oscilloscope.

The Model 206 and K318 Utility Carts can be used as a convenient operating platform for instruments or to move or store instruments. The Model 206 (not shown) provides two fixed shelves with a capacity of 100 pounds (45 kilograms) each. Large, lockable casters make it easy to move the cart or keep it stable during measurements. The K318 is similar to the Model 206 except that it adds a front drawer for storage of cables, probes, and other accessories. This drawer also provides a convenient shelf for a PC keyboard. A slide-out shelf on the side provides additional work area. The K318 has a four-outlet power strip on the back.

More information

U.S. customers can get information, prices, or place an order for any of these products by calling the Tektronix National Marketing Center — 1-800-426-2200. Or contact your local Tektronix Field Office or representative. And tell them you saw it in **HANDSHAKE.**

K318 Utility Cart with PEP 301 Systems Controller and HC100 Color Plotter.

A new method of viewing and extracting information from digital signals

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Dennis Kucera
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Laboratory Instruments Division
Tektronix, Inc.

In digital design and verification, it's necessary to understand, measure, and document variations in signals over time. This often involves measuring timing jitter or signal noise for digital logic circuits, or visualizing and measuring "eye" patterns for digital communications circuits. By combining the data acquisition power of a Tektronix digital oscilloscope with a personal computer, you now have a quick, easy, quantifiable method of statistically measuring and documenting the performance of your digital circuits.

The i-Pattern™ software from Tektronix enables you to use computer enhanced two- and three-dimensional graphics displays as well as three statistical measurement applications to extract more information from waveforms than is possible with an oscilloscope alone. The dynamic memory of the Tektronix PEP 301 controller (or other IBM PC-compatible controller) is used to store real-time waveform data in a three-dimensional histogram — Time vs Voltage vs Number of Hits. This 3-D histogram is stored in a 512 by 256 by 2 byte data array. A region of the composite of many waveforms can then be selected with cursors, analyzed, and compared to a normal distribution. User definable masks (closed polygons) can also be defined. The number of "hits" falling within these mask regions are automatically computed.

Data acquisition

Data acquisition occurs over the GPIB interface bus. The program supports all Tektronix 11000-Series and 2400-Series digitizing oscilloscopes, the Tek 2230 portable DSO, plus the Tektronix 7D20 and Sony/Tektronix RTD 710/A programmable waveform digitizers. You can select the digital scope that has the necessary performance to match your present application. Then, if future measurements require higher performance, you can upgrade the hardware when necessary without losing capability or having to learn another software system.

Each instrument's fast transmit mode is supported to insure maximum waveform transfer rate. Waveform transfer rates are up to 55 waveforms a second, depending upon the digitizing scope used. 512-point waveforms are transferred repetitively and stored in the PEP 301. The waveform data is placed in a 20 Kbyte rotating buffer to produce a live display in a variable persistence mode. Vertical resolution is 8 bits. At the same time, data is added to the 3-D histogram buffer (256K) which supplies the information for the color histogram display.

Data display

The i-Pattern Software supports Hercules graphics, CGA, and EGA video display adapters (VGA systems are supported in EGA mode). Data can be displayed in a standard 2-D plot with color used to indicate histogram level (see Figure 1). Histogram color mappings are selectable. Two types of 3-D displays also pro-

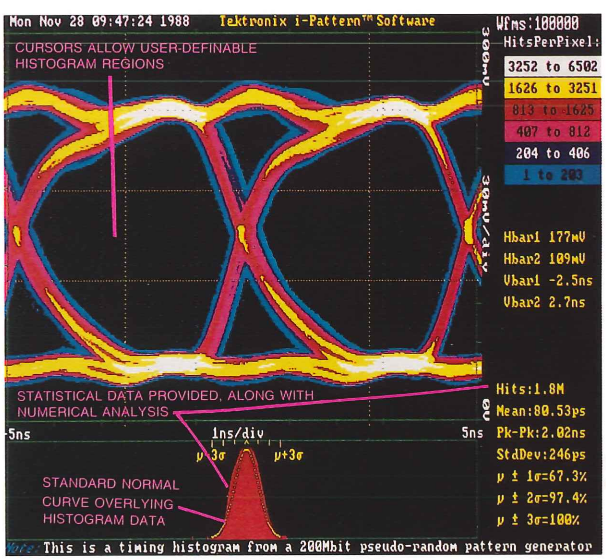

Figure 1. *A timing histogram (above) can quantify timing jitter; a voltage histogram (Figure 2) can measure voltage level fluctuations.*

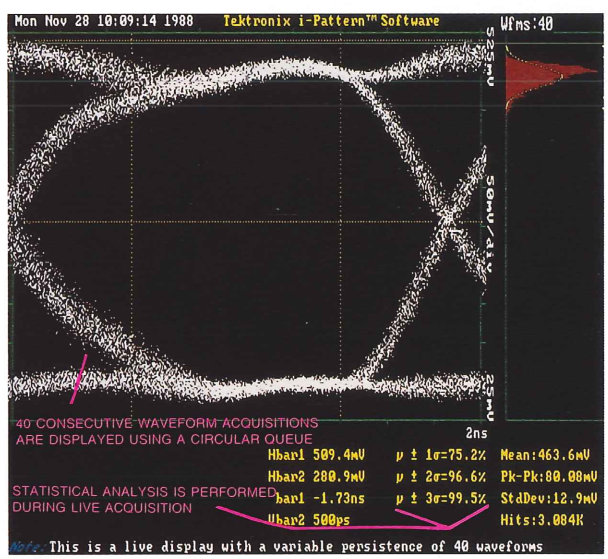

Figure 2. *The live display provides a variable-persistence mode to monitor adjustments, troubleshooting, and verification (voltage histogram shown).*

vide a new means of visualizing waveform data. A waterfall display (an X-Y-Z histogram) and a type of solid-fill waterfall are also provided. A live waveform display lets you show a sequence of acquired waveforms (up to 40) in a "variable" persistence mode (see Figure 2). This mode is of particular value in the digital communications field.

Hardcopy output is available for each of the display screens. Black and white copy is available through an Epson dot-matrix graphic printer or equivalent. A gray-scale version of the i-Pattern color display can be obtained using Pizazz or Pizazz Plus from Application Techniques, Inc. Pizazz Plus can output to over 140 printers, including the HP LaserJet.

For color printouts, a Tektronix 4696 Color Ink-Jet Printer or Tektronix 4693D Color Image Printer can be used in conjunction with Pizazz Plus. The original color hardcopies for this article were produced on a 4693D Color Image Printer. The 4693D also makes high quality color transparencies.

Measurements

In addition to dual time and voltage cursor readouts, the following data are available: the number of waveforms acquired, number of "hits" in the region bounded by the dual cursors, as well as mean value, standard deviation, and peak-to-peak value. The percentage of "hits" falling within 1, 2, and 3 sigma (standard deviations) of the mean value is also displayed. A normal distribution curve is superimposed on the actual slice histogram allowing you to compare performance of your circuit to a randomized system. Either timing or voltage histogram measurements can be made.

Quantifiable "eye" pattern measurements can be made using the mask feature of the i-Pattern software (see Figure 3). Closed polygons, or masks, can be defined and edited. Each polygon can contain up to 50 corner points and up to 10 independent polygons can be defined for use at one time. In mask testing mode, the number of "hits" per polygon and the total number of "hits" is available. This mask feature greatly simplifies pass/fail testing and troubleshooting circuits in manufacturing test, incoming inspection, and calibration.

Easy operation

All i-Pattern functions are selected from drop-down menus contained in a main menu (see Figure 4). Menus and functions are selected by pressing the first letter of the menu or function name, or by highlighting a selection with the directional arrow keys and pressing <Enter>. In addition, several "hot" keys are activated during live waveform acquisition to speed making changes in the waveform display. Extensive HELP information is available throughout the program.

The software lets you store and retrieve waveforms, front-panel settings, and mask files; specify the drive or directory where the files are stored; and change GPIB controller and scope addresses.

The i-Pattern software provides new insight and measurement capability beyond that available with a digital scope alone. Combined with a Tektronix digital oscilloscope and high performance IBM-PC compatible controller, it provides a state of the art analysis tool allowing you to better design and verify your digital circuitry.

See the software in action!

You can see the i-Pattern software in action on your IBM-PC compatible controller. Just check the appropriate box on the reply card for a free copy.

For more information or to order i-Pattern software, contact your local Tektronix Field Office or sales representative. U.S. customers can call the Tektronix National Marketing center toll free for information or to order — 1-800-426-2200. And tell them **HANDSHAKE** sent you!

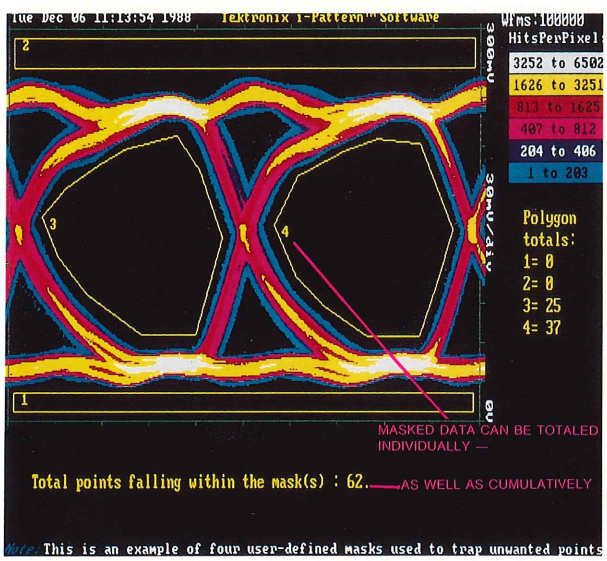

Figure 3. *User-definable masks allow an operator to make easy and objective pass/fail determinations.*

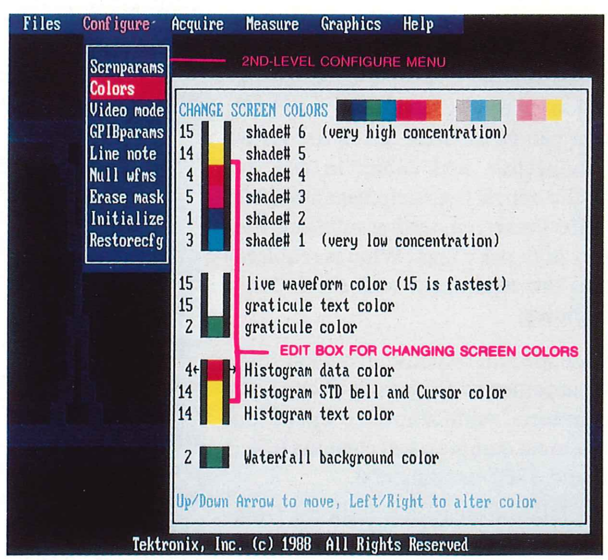

Figure 4. *Drop-down menus make the software quick to learn and easy to use. Program setup changes are automatically saved.*

A practical approach to optical waveform analysis

Brian Boso, Ph.D.
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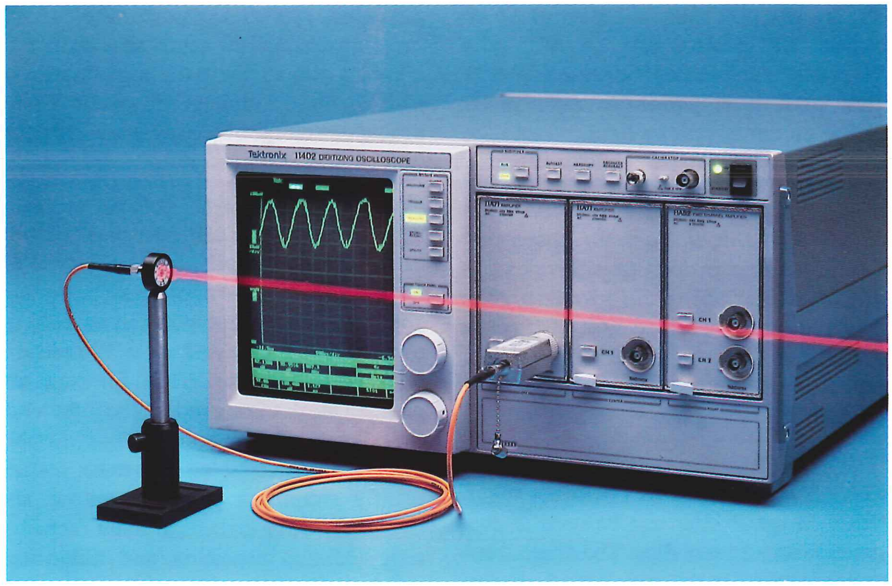
Tektronix, Inc.



The P6701 Optical-to-Electrical Converter Probe, the P6751 Spatial Input Head, and the 11402 Digitizing Oscilloscope provide an easy and accurate system for characterizing optical sources.

Optical waveform characterization has always been a difficult problem for photonics engineers because most available tools lack flexibility and accuracy. Accurate optical characterization requires the use of optical-to-electrical (O-E) converters that allow an oscilloscope to create an accurate representation of the optical waveform.

Although many types of optical-to-electrical converters are now on the market, engineers who survey the available test equipment discover performance limitations such as low bandwidth, poor accuracy, and lack of DC response that pose real barriers to adequate characterization. In addition, coupling the signal to an O-E converter can be difficult, given the variety of connectors and cables in use. In general, the optical test equipment available today offers marginal testing solutions but with very high price tags. What is required is optical test equipment with the following attributes:

1. A wide spectral response, from less than 500 nanometers to greater than 1700 nanometers, with calibrated operation at the most common wavelengths (e.g., 850 and 1300 nanometers).
2. A modulation frequency response from DC to as high as practical, allowing average power metering and pulse power metering, as well as high-speed analog measurement capability.
3. Compatibility with a wide variety of optical fibers up to 100/140 micrometer core size.
4. Low cost.

A problem in need of a solution

Until now, photonics engineers have learned to design around problems associated with the lack of adequate test gear, or have "lashed together" test benches out of existing components. Since the number of engineers working on photonics applications in the past has been relatively small, these engineers have been content with assembling a wide variety of detectors, sources, fixtures, and traditional electronics test equipment to solve their particular measurement problems. Yet even the best efforts to piece together test equipment often run into problems, given the poor and uncalibrated performance of available optical test equipment.

Optical fiber is rapidly moving from "long-haul" into "short-haul" applications with a resulting increase in demand for engineers, applications devices, and test equipment. As this market continues to grow and more electrical engineers begin to work with electro-optic components, it's clear that reliable, accurate, and easy to use integrated measurement solutions are needed.

Here are just a few of the problems that are becoming increasingly common as photonic applications grow:

- An engineer designing an optical transmitter circuit for a LAN (local area network) application needs to characterize variations in optical output versus input current for a specific LED (light-emitting diode). Knowledge of these variations allows the engineer to design drive circuitry that will maximize diode life while providing sufficient optical power for the LAN.
- An optical data link manufacturer is experiencing excessive bit error rates because of abnormal or intermittent laser or LED pulses or because of problems in the receiver circuit. The manufacturer needs high-speed O-E converters with flat frequency response and a way to display and analyze system performance.
- A laser researcher needs to characterize laser performance, including DC output drift, and measure pulse parameters. This is particularly difficult when the laser is not connected directly to an optical fiber. A high-fidelity O-E converter is needed, plus a means of feeding the laser pulses into the converter.

An integrated solution

An integrated solution is required to address these optical measurement needs. Part of the solution can be found in the

Tektronix 11402 Digitizing Oscilloscope which includes extensive waveform analysis and processing capability.

The Tektronix P6701 and P6702 Optical-Electrical Converters work closely with the 11402 to provide the rest of the solution for engineers working with optical waveforms. Table I shows the optical characteristics of the P6701 and P6702. These optical probes make characterizing optical waveforms as straightforward as characterizing analog voltage or current waveforms.

Table I
P6701/P6702 Converter Characteristics

	P6701	**P6702**
Wavelength Response	450 to 1050 nanometers	1000 to 1700 nanometers
Bandwidth	DC to 700 MHz	DC to 500 MHz
Risetime	0.7 nanoseconds	1.0 nanoseconds
Conversion Gain	1 volt/milliwatt at 850 nanometers	1 volt/milliwatt at 1300 nanometers
Calibrated Offset	0 - 1 milliwatt	0 - 1 milliwatt
Maximum Input Optical Power for Linear Output	2 milliwatts	2 milliwatts

Much of this ease of use is made possible by a communication interface which tightly integrates the optical probe and the oscilloscope. Seven pins surround the BNC input on all Tektronix 11000-Series plug-in amplifiers. These pins supply power to the O-E probes and allow the oscilloscope to poll a ROM in the converter to obtain information about the device. This provides information so the display is properly scaled (milliwatts/division) and sets the correct input termination (50 ohms). Displaying measurement units in milliwatts is very significant, given the 11000-Series on-board measurement and waveform processing capability. Direct measurement of optical waveform characteristics such as pulse power, peak power, RMS power, etc., can be made quickly without conversion on the part of the user.

Characterizing optical devices

Optical output versus input voltage or current. One of the first tasks facing an engineer designing an optical transmitter circuit for LAN applications is to characterize the optical output versus input voltage/current of the LED to be used. Figure 1 shows the test setup and Figure 2 shows the resultant measurement. Optical output of the LED is input to the P6701 via a two-meter 100/140 micrometer fiber optic cable and is displayed on the vertical (Y) axis at 5 microwatts/division.

Voltage drop across the LED is displayed on the horizontal (X) axis at 200 millivolts/division. The 11402 Digitizing Oscilloscope acquires and displays these two signals in the X-Y mode. Cursors can be used to make measurements directly from the curve. This particular LED has a threshold voltage of 1.38 volts and an output power of 81.33 microwatts (−10.9 dBm) at 1.64 volts.

Output power versus forward bias current. Figure 3 shows the test setup and the resultant display for measuring the output power versus forward bias current of the LED. Since we are measuring voltage drop across a precision one-ohm resistor, the horizontal axis can be read directly as milliamps rather than millivolts.

The curve displays the typical increasing saturation of the optical output as the forward bias current is increased. The cursor shows that at 99 milliamps forward current, the output is 52 microwatts (−12.8 dBm), which is well within the specification for this particular LED.

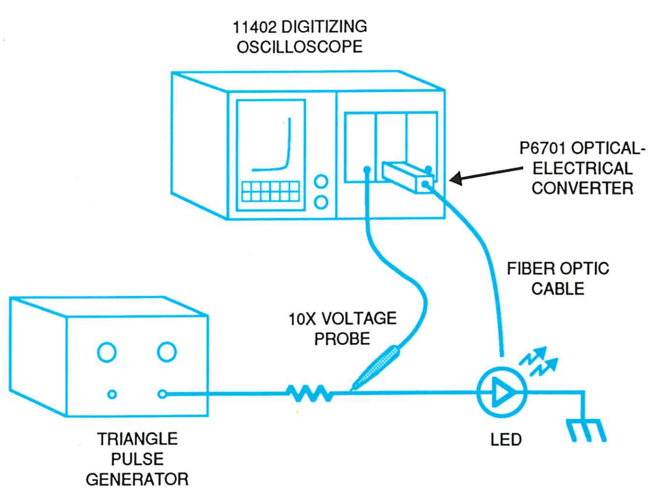


Figure 1. *Setup for measuring optical output versus the forward voltage characteristics of an LED.*

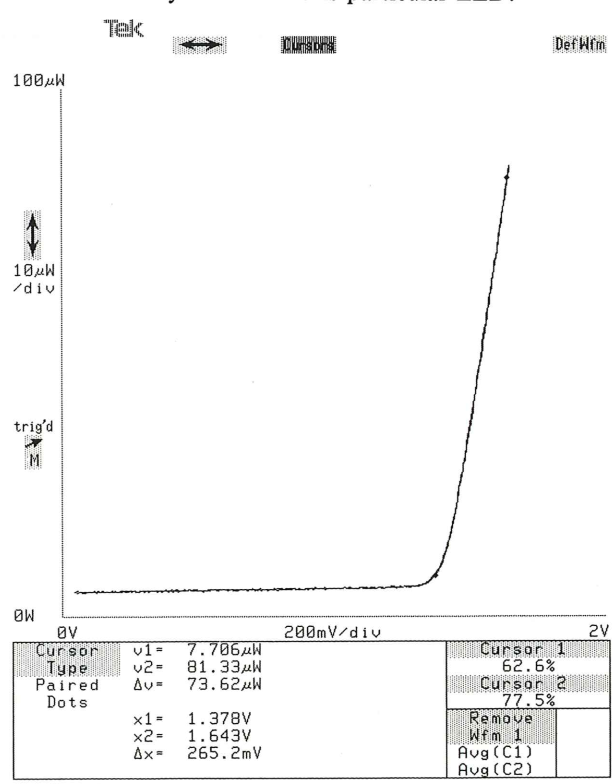


Figure 2. *Curve showing optical output versus forward voltage characteristic.*

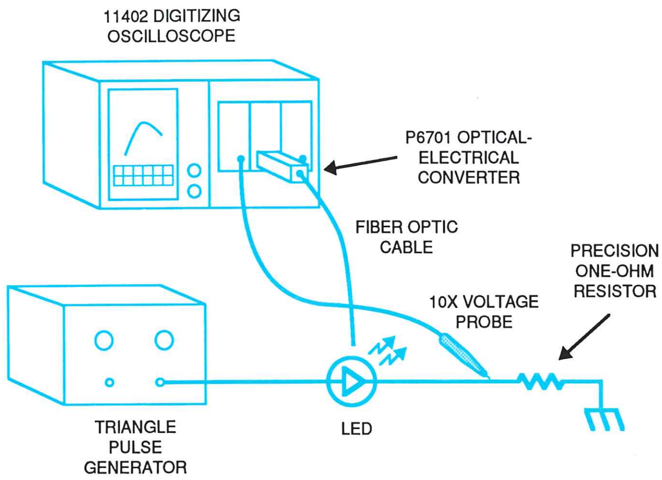


Figure 3. *Setup for measuring optical output versus bias current characteristics of an LED.*

This entire measurement takes only a few minutes to set up and requires no conversion from voltage to optical power. A hard copy of each measurement can be made for documenting the design by simply pushing a button. Thus, it is simple for the engineer to characterize a handful of LEDs and determine the necessary design parameters that the transmitter circuit must meet.

Comparing input and output waveforms. To locate the source of system bit error rates, you need to follow signals through the transmitter, cable, and receiver subsystems in order to isolate the source of errors. Figure 5 shows the optical output of the transmitter (bottom trace) compared to the electrical input (top trace). Since no aberrations or ringing are present on the output waveform, distortion in the output signal must be coming from other optical devices and can be located by "tracking" the optical signal through the system.

Electrical and optical characteristics such as risetime, pulse width, pulse levels, and aberrations can be measured and compared using the 11000-Series measurement menu. For more detail, you can zoom in on the pulse and examine it with more detail (see Figure 6).

Acquiring Laser Signals. Inexpensive HeNe lasers are used in electro-optic laboratories for a variety of purposes such as aligning optical components, testing optical switches, and producing holograms. Frequency of the light output of these lasers is controlled by the HeNe gain curve and the longitudinal mode spacing, which is a simple function of the laser cavity length. Several longitudinal modes usually fall within the Doppler-broadened gain curve; thus, most HeNe lasers simultaneously emit from two to four modes. As the laser heats and cools, undergoing thermal expansion, the modes shift under the gain curve, giving rise to unstable laser output power.

Acquiring and analyzing this instability can be simplified using the P6751 Spatial Input Head, with its graded index lens system that focuses the laser beam onto the core of the cable. Test setup is shown in the picture at the beginning of this article. Measured waveform is shown in Figure 7.

Measuring mode interference. Figure 7 shows the roughly sinusoidal variation in the output power of a HeNe laser due to mode interference. This modulation results

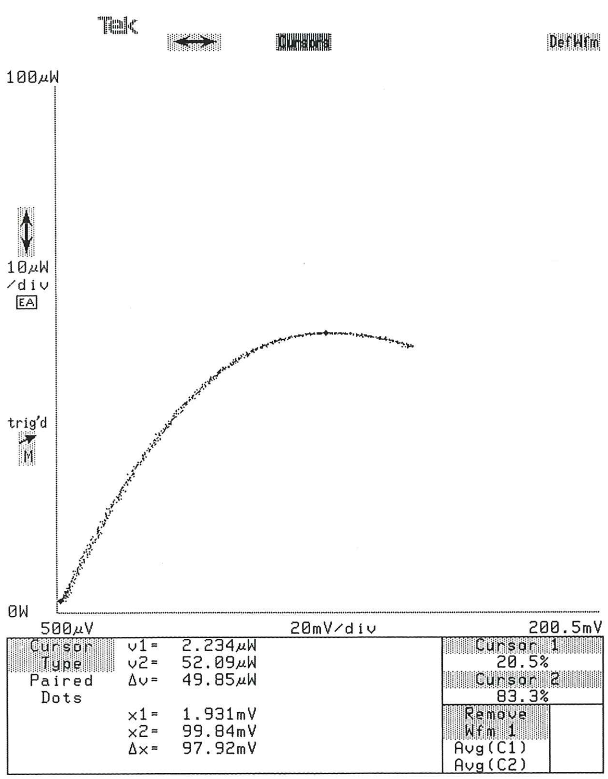


Figure 4. *Curve showing optical output versus bias current characteristic.*

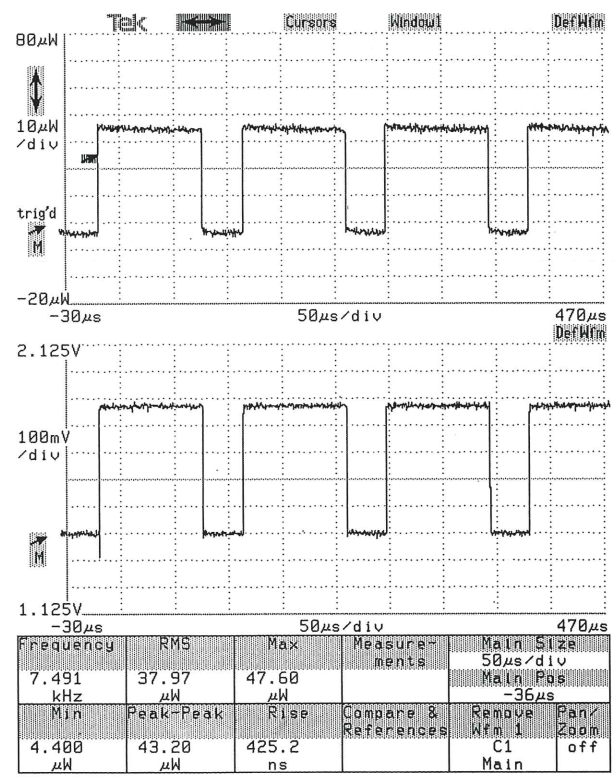


Figure 5. *Simultaneous measurement of the electrical drive signal (bottom) and the optical output waveform (top) of an optical transmitter.*

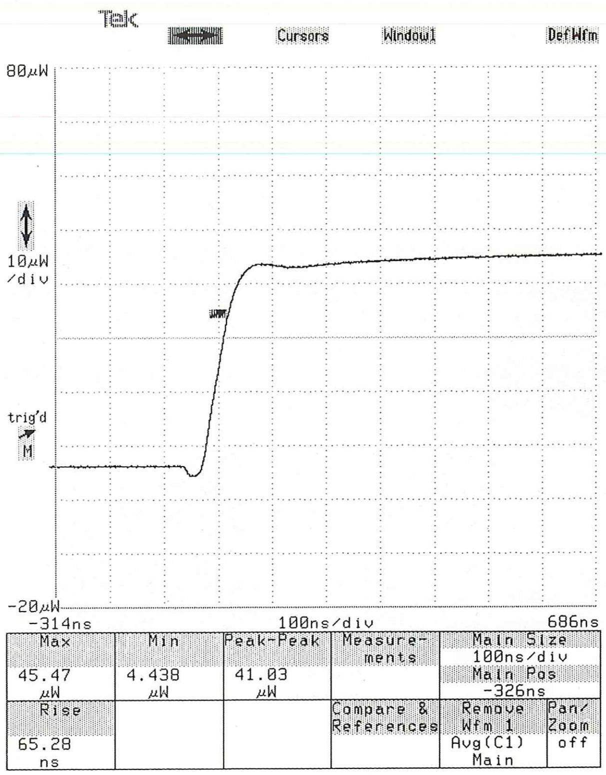


Figure 6. *Expanded view of pulse using zoom to allow measurement of risetime or closer examination of waveform.*

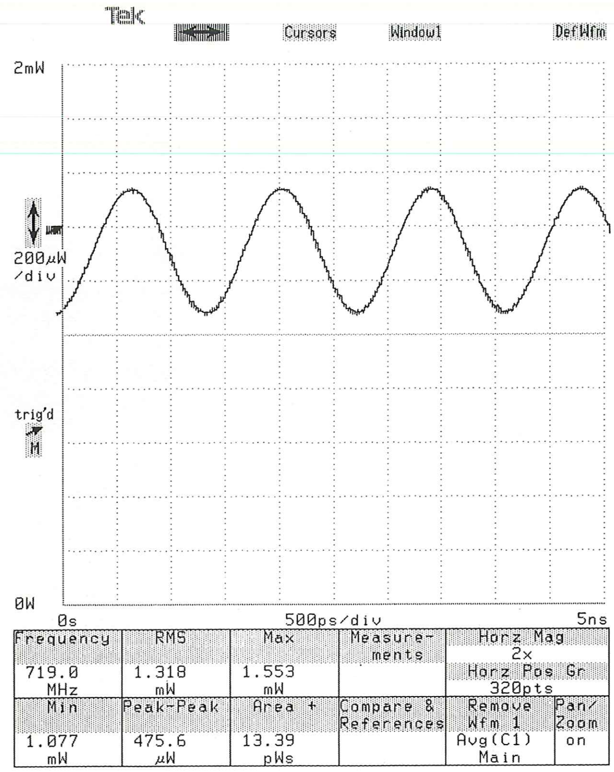


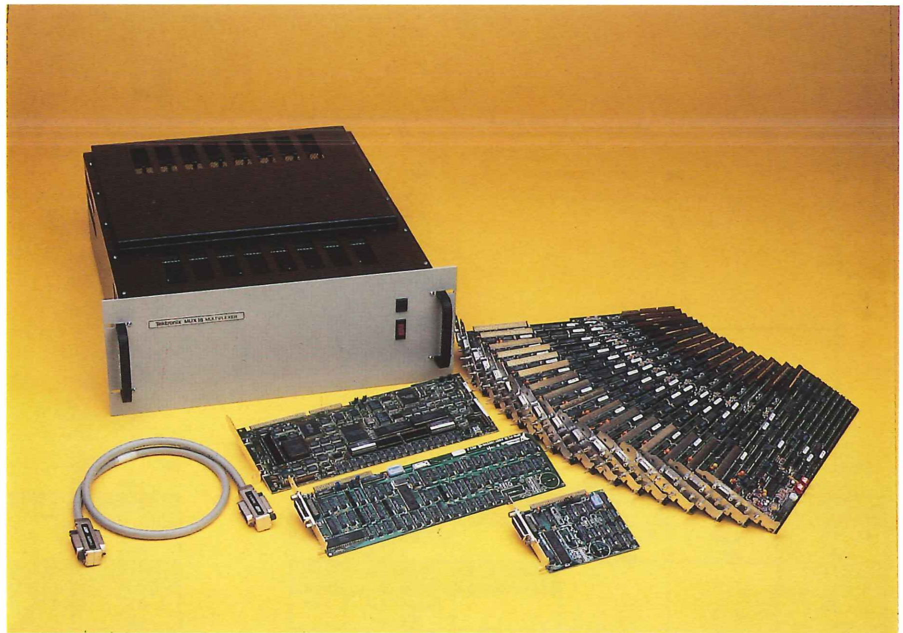
Figure 7. *Measuring laser output stability, modulation interference, and output power.*

from multiple modes being emitted simultaneously. The measurement menu at the bottom of the waveform shows that the frequency of this mode "beating" is 719 MHz, the RMS power of the beam is 1.31 milliwatts, and the modulation depth is 0.475 milliwatt. The ability to monitor any DC drift of self modulation due to thermal expansion of the laser can be critical to applications where bandwidth and power measurements are being made.

For more information

For more information on optical measurement instruments available from Tektronix, contact your local Tektronix Field Office or representative. U.S. customers can call the Tektronix National Marketing Center toll free for prices, availability, or information — 1-800-426-2200. And tell them you read about it in **HANDSHAKE.**

Multiplying your waveform acquisition options



The MUX16 can hold up to 16 optional cards including DX01 Frame Store Boards, an 80286 CPU Card, or a GPIB Interface Card.

Now you can store up to 256 channels of digitized waveform information from analog oscilloscopes. The Tektronix MUX04 and MUX16, along with the Tektronix Digital Camera System, can expand the capabilities of your present instrumentation system to include digital waveform storage and waveform processing with minimum additional cost and reconfiguration.

The MUX04 Multiplexer is designed for benchtop use and can hold up to four DCS Frame Store Boards. The MUX16 Multiplexer can hold up to 16 DCS Frame Store Boards. It is designed for mounting in a 19-inch rack or it can be used on a bench.

Operation

The MUX04 and MUX16 are designed to be used with a host controller and are not capable of standalone operation without additional user-supplied hardware and software. The host controller must have a compatible GPIB interface card capable of system-controller/controller-in-charge operation.

The MUX mainframe is a talker-listener to the host controller via a high-speed GPIB card. The host controller downloads the MUX operating software to the MUX. After the Frame Store Boards acquire the waveforms, the stored video images are processed by the MUX CPU to produce waveform files. The waveform files can then be uploaded to the host controller for additional processing and/or storage.

GPIB programmable oscilloscopes and other instruments can be controlled by the host via the MUX through the use of a PC-IIA GPIB card (optional). This allows automation of the measurement system to the extent allowed by the capabilities of the instruments in the system.

An optional 80386 CPU card can be installed in the MUX. This improves the local processing speed by about three times. Up to 16 MUX16 Multiplexers can be linked, permitting as many as 256 channels of waveform data to be captured.

Software

The heart of the MUX systems is the MUX/DCS software. This software allows the host controller to communicate with and control the MUX units connected to it. Each MUX software package is divided into two parts.

1. Software which is executed by the slave CPU inside the MUX. This controls the operation of the Frame Store Boards and can be used to process the captured images into waveform data.
2. Host controller software which controls the operation of the host.

The following MUX/DCS software packages are currently available:

MS-DOS MUX Remote Software for PCs. This software supports only one MUX unit (MUX04 or MUX16) so the maximum number of acquisition channels available is 16. It provides a graphical representation of captured data as well as data manipulation capabilities.

MS-DOS MUX Data Logging Software for PCs. This software provides only data gathering, logging, and system calibration. No graphical presentation of captured data or data manipulation is available. This software is intended for use with other measurement software which include extensive waveform manipulation capabilities such as Tektronix SPD or ASYST software. Up to 16 MUX16 Multiplexers can be controlled for a maximum of 256 acquisition channels.

MUX Data Logging Software for VAX or MicroVAX. This software provides data gathering, logging, and system calibration. No graphical presentation of captured data or data manipulation is available. Up to 16 MUX16 Multiplexers can be controlled for a maximum of 256 acquisition channels.

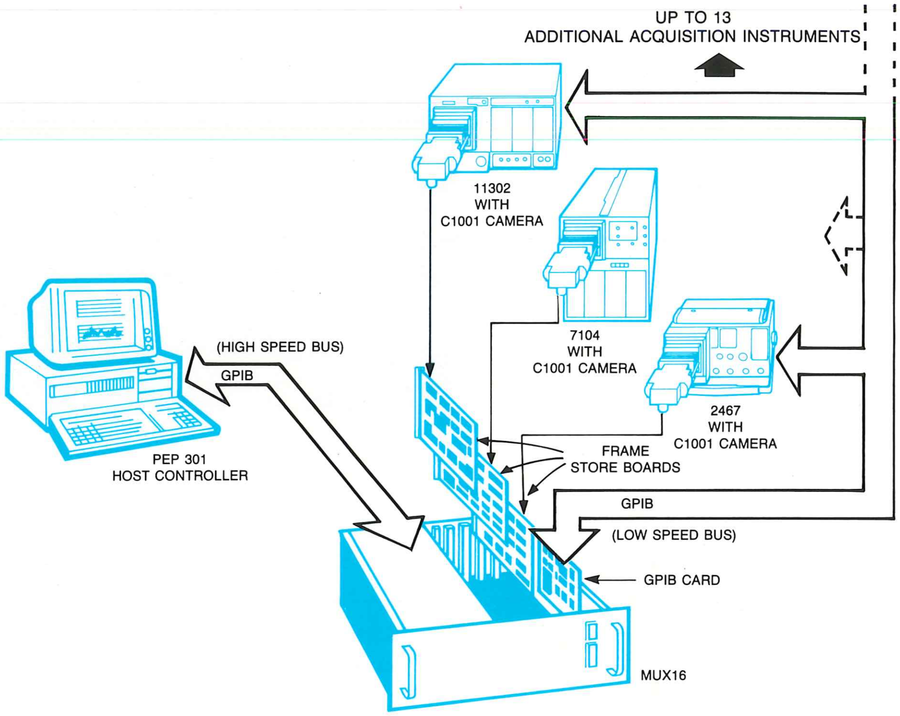
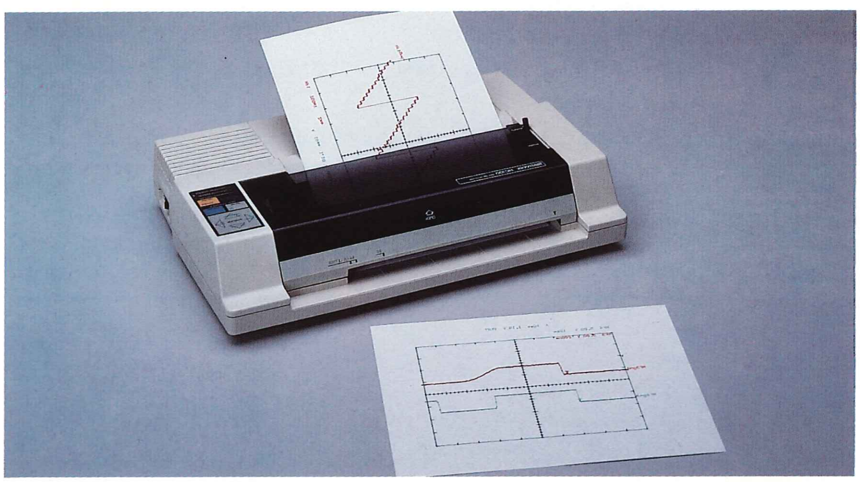


Figure 1. *Multiple-channel acquisition with a MUX16 Multiplexer. Up to 16 units can be connected to a host controller to acquire and digitize signals from up to 256 individual DCS/oscilloscope systems.*

Another way to output your data



The HC100 Color Plotter now has even greater capability. Originally introduced with GPIB and Centronics interfaces (see Winter 1987/88 **HANDSHAKE**), the HC100 can now be ordered with Option 03 — RS-232C and Centronics interfaces.

The HC100 Option 03 supports most common RS-232C implementations and includes a full complement of selection switches to allow easy set up and configuration. It can be used with most Tektronix instruments that support plotter output via the RS-232C interface. In addition, it can be used with many controllers or computers.

If you already have an HC100, RS-232C capability can be added in place of the GPIB interface. Contact your local Tektronix Field office or sales representative for details.

For additional information

If you would like additional information on the MUX04 or MUX16, the Digital Camera System, any of the waveform processing software available from Tektronix, or the HC100 Color Plotter, contact your local Tektronix Field office or sales representative. U.S. customers can call the Tektronix National Marketing Center toll free for information, prices, or to place an order — 1-800-426-2200. And tell them you read about it in **HANDSHAKE.**

CLASSES AND SEMINARS

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.

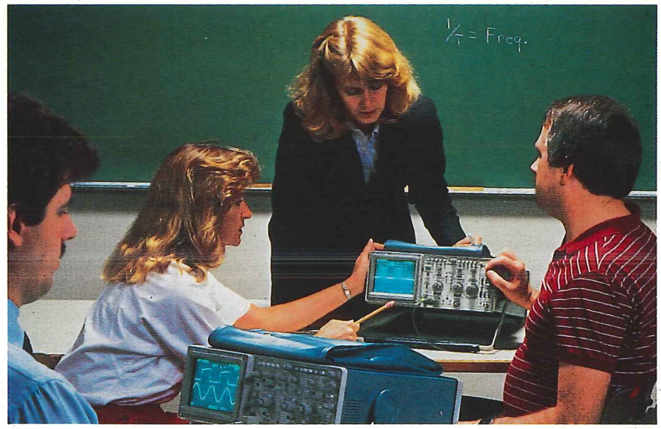
Product Service Training Classes

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

CLASS	LOCATION	DATES
465B/475A Portable Oscilloscope	Boston, MA Dallas, TX	Feb 13-17 May 15-19
2215/35/36 Portable Oscilloscopes	Boston, MA Dallas, TX	Feb 20-24 May 22-26
2230 Digital Storage Oscilloscopes	Boston, MA	May 8-12
2445/2246 Portable Oscilloscopes	Atlanta, GA	Mar 6-10
7904/7633 Laboratory Storage Oscilloscopes	Dallas, TX	Apr 24-May 5
TM 500 Calibration Package	Dallas, TX	Apr 10-14
TM 5000 Distortion Ana. (SG/AA)	Beaverton, OR	Feb 20-24
TM 5000 Function Gen. (FG)	Beaverton, OR	Feb 27-Mar 3
TM 5000 Calibration Gen.(CG5001)	Beaverton, OR	Mar 6-10
113XX Programmable Oscilloscopes	Beaverton, OR	Apr 24-28
114XX Programmable Oscilloscopes	Beaverton, OR	May 1-5
118XX Digitial Sampling Oscilloscopes	Beaverton, OR	Mar 20-24

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.

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.



Operation Training Workshops

Call Tektronix IG Customer Training, 1-800-835-9433, ext. 430 to register for the following workshops.

CLASS	LOCATION	DATES
2230 Digital Storage Measurements	Dallas, TX	Apr 5
2430/2440-Series Advanced Digital Storage Measurements	Dallas, TX	Apr 6-7
7854 Waveform Processing	Wash.DC	Mar 14-15
11200/11400-Series Waveform Measurements	Dallas, TX	Apr 11
11200/11400-Series Advanced Waveform Measurements	Dallas, TX	Apr 11-12
11300-Series Measurement and Analysis	Dallas, TX	Apr 14
Fundamentals of Digital Oscilloscopes	Dallas, TX	Apr 4
Instrumentation Control Using a PC Compatible	Dallas, TX	Apr 13

Most of the above workshops are available in a self-study format. On-site training is also available. For information call 1-800-835-9433, ext 430.

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

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