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Tektronix®
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HANDSHAKE

Newsletter of Signal Processing and Instrument Control

Image Processing Simulations
Data Channel Monitoring
Pulse-Echo Capture

Tektronix
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HANDSHAKE
Newsletter of Signal Processing and Instrument Control

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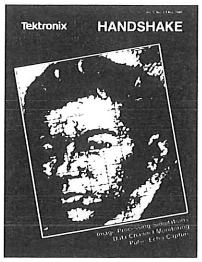
Why should we care about digital filters?

The question of the title is also a subtitle in the introductory chapter of R.W. Hamming's book, **Digital Filters**, 1977, Prentice-Hall, Englewood Cliffs, NJ 07632. And Hamming goes on to say, in part, "...we may think of blood pressure, a brain wave, the height of a wave on a beach, or a stock market price as a continuous signal that we have sampled (and quantized) at unit times in order to obtain our sequence of data x_n...Given such a signal, we may want to differentiate, integrate, sum, difference, smooth, extrapolate, analyze for periodicity, or possibly remove the noise; all these and many others, are linear operations. Therefore, in the digital form, the operations are digital filters."

In short, anyone digitally processing data is also going to be involved—knowingly or unknowingly—in digital filtering of some sort.

The point of Hamming's book is to make the involvement one based on knowledge. To do that, he covers the fundamentals of such topics as the Fourier series, nonrecursive filters, recursive filters, smoothing, missing data and interpolation, least-squares fitting, Butterworth filters, and Chebyshev filters. The coverage is from a nonspecialized viewpoint and relatively free of jargon. So no matter what your field of study, **Digital Filters** is an excellent learning tool and reference for applying digital analysis techniques.



Using a Digital Processing Oscilloscope in image processing simulations

Editor's Note: Tektronix, Inc., and HANDSHAKE extend their appreciation to **M.C. Cavenor**, **J.F. Arnold**, and **G.A. Moyle**, Department of Electrical Engineering, Royal Military College, Canberra, Australia for providing the following article on image processing simulations.

The application discussed in this article does require some minor circuit modifications to the Digital Processing Oscilloscope. These modifications, for safety reasons, should be carried out by qualified service personnel. Also, before carrying out any modification, consider its effect on your instrument warranty. If your instrument is still under warranty, we recommend you contact your local Tektronix Field Office or representative before making any modification.

With the continuing trend towards predominantly digital communications networks, many laboratories are currently evaluating efficient digital coding schemes for transmitting both voice and image signals. Initial studies of signal transmission schemes almost invariably take the form of a computer simulation which provides, among other things, an assessment of the fidelity of the proposed scheme. In the case of image transmission, an obvious and frequently used measure of the quality of the "received" image is the mean square error calculated on a pixel-by-pixel basis over an entire frame or series of frames [1].

While a vanishingly small mean square error is a sure sign of a non-degraded image, this easily calculated, objective measure of system performance is rather less useful when a small degree of degradation can be tolerated or when transmission errors become significant. At either stage it becomes necessary to view the image and subjectively assess the effect of such imperfections. Thus an immediate requirement for any computer study of image processing schemes is the ability to digitize a typical image and then, after processing, reconstruct the image for subjective evaluation.

The cost of existing video equipment designed to perform these tasks—while providing good linearity, fine resolution, and high quality images—is by no means insignificant. A low-cost alternative solution is, however, readily available to laboratories currently using, or proposing to use, what is rapidly becoming a general purpose laboratory instrument, namely the Digital Processing Oscilloscope (DPO).

The images reproduced in this paper, while not of studio quality, are adequate for many of the subjective evaluations that characterize the initial stages of image processing investigations. For example, it is possible to identify inadvertent errors that give rise to large mean square errors through no fault of the signal processing algorithm (Fig. 1b and 1c) and some feeling can be obtained for the way in which transmission errors manifest themselves with differing processing schemes (Fig. 1d and 1e).

With only minor modifications, fully described in this paper, the versatile DPO provides a useful facility for both image coding and restoration.

Image coding

Images are encoded by using the DPO as a flying spot scanner. A photographic negative of approximately 100x80 mm of the scene to be digitized is attached to the face of the cathode ray tube (CRT) and, under program control, a sequence of constant intensity spots appear on the CRT screen in a 256x256 matrix. A photomultiplier is mounted in front of the DPO screen, as shown in Fig. 2, for measuring the intensity of light transmitted by the negative in the immediate vicinity of the spot.

The voltage developed across the anode load resistor of the photomultiplier is applied to the Acquisition Unit of the DPO for sampling at a time corresponding to peak intensity. Analog-to-digital conversion by the DPO results in a matrix of picture transmittances corresponding to the area of the negative scanned by the spot. This matrix of data is then passed to the computer (a Digital Equipment Corporation PDP 11/10) for storage and processing.

a. Original image.

b. Inverted video signal.

c. Lack of line synchronism.

d. Transmission errors restricted to pixel in which they occur.

e. Errors averaged over a block of pixels.

Fig. 1. *Examples of images reproduced by the Digital Processing Oscilloscope showing large, readily identified errors.*

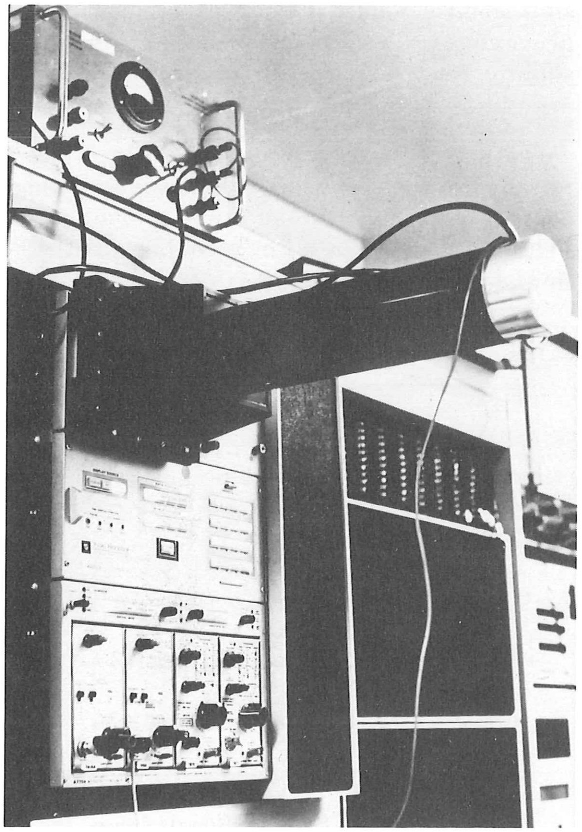


Fig. 2. *Tektronix WP1000 Digital Processing Oscilloscope and photomultiplier housing.*

Virtually any photomultiplier with good spectral responsivity in the region of 500-550 nm can satisfy the far from stringent requirements of detecting the light transmitted through a photographic negative by a bright, well-focussed spot on the DPO cathode ray tube. The relatively large and sensitive area of an end window photocathode was restricted by attaching a 1-mm diameter iris to the end of the tube before mounting it in front of the CRT. This reduces the solid angle for collection of light and therefore improves the resolution of the simple optical system.

Some modifications to the DPO

The Tektronix WP1000 normally samples and digitizes signals on a pseudorandom basis with a new sample being taken every 6.5 microseconds [2]. Thus, except for very slow waveforms, the input signal has to be repetitive. The DPO stores the information in the correct position within the 512-word storage array by digitizing both the vertical (i.e., voltage) and horizontal (i.e., time) positional information and using the latter as an address in the DPO memory at which the vertical information is to be stored.

In this application, however, only one point on the input signal waveform is of interest, namely the peak. Therefore, it becomes necessary to disable the normally free running Sample and Hold and then generate a signal to instruct the DPO to sample the input when it reaches its peak value. The hardware modifications needed to achieve this result are shown in Fig. 3. The lower printed circuit board is the A-D Controller board on which a link needs to be repositioned so that the Sample and Hold circuit will accept an EXTERNAL START pulse applied to pin A36 on socket J7. A connection already exists from this pin on the edge connector to the plug P207 which thereby provides a convenient means of access.

The upper PCB shown in Fig. 3 is the Display Controller board to which three additional wires need to be added. A signal appearing at the Q output of the STATUS flip-flop signifies that the display controller is in the X-Y mode while the voltage at the collector of transistor Q243 or Q245 rises upon receipt of the command to display a spot.

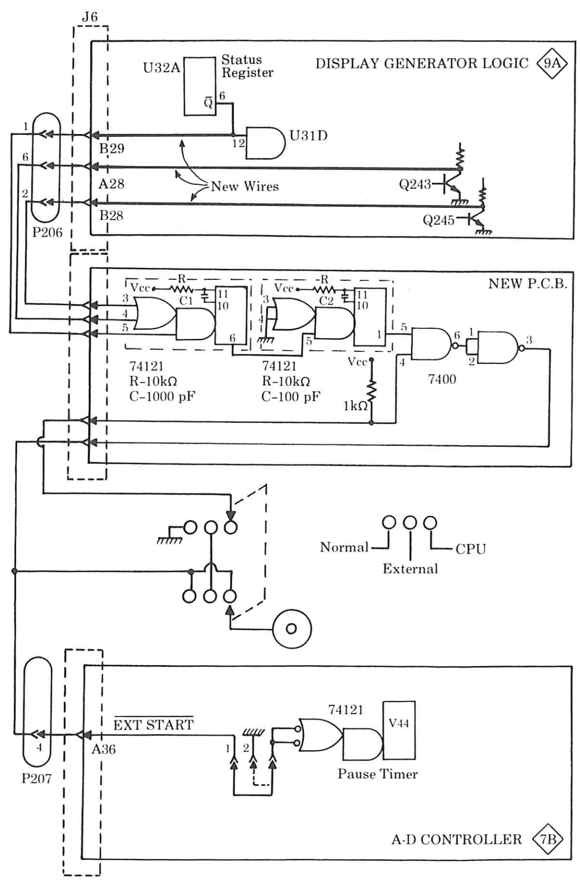


Fig. 3. *Modifications to existing circuitry and additional components needed to achieve image coding.*

Following a delay of approximately ten microseconds, the output from the photomultiplier attains its maximum value, at which time a one-microsecond pulse is generated to initiate the sample and hold. Two 74121 monostable flip-flops are used to generate this delayed pulse and in fact constitute the only additional circuitry required to perform image coding. A small circuit board holding these components was attached alongside the DPO/CP Bus Interface board and a three-position switch and BNC connector were mounted on the bus interface cover plate at the rear of the P7001 processor. The switch allows the DPO to be returned to its normal free-running mode of operation or, alternatively, allows the sample and hold to be initiated by the computer, as described above, or via an external input applied to the connector. In addition, the delayed external start pulse can be monitored via the connector to ensure that it occurs at the peak of the photomultiplier output signal.

Setting up for image coding

In addition to transmittance of the photographic negative, several other factors influence the signal amplitude from the photomultiplier tube and hence the numbers provided by the ADC (analog-to-digital converter) when it samples the waveform. These include—

a) The spot intensity, which although under program control is still adjustable by the display brightness control.

b) The gain of the photomultiplier, as determined by the operating voltage across the resistor chain.

c) The gain and shift controls on the DPO plug-in amplifiers.

The output from the ADC is such that a signal appearing at or below the bottom of the screen returns the number zero, whereas a signal at or above the top of the screen returns the number 1023. It is therefore necessary to ensure that the photomultiplier output signal is properly scaled and positioned on the DPO screen prior to any image digitizing. This was accomplished by placing a set-up negative in front of the DPO screen, the set-up negative having minimum transmittance in all regions except for a small area of maximum transmittance. Two spots were then displayed repetitively, giving rise to photomultiplier signals of minimum and maximum amplitude. The output numbers from the ADC were continually displayed on the computer terminal and the amplifier gain and shift control adjusted to give outputs slightly above zero for the dark region of the negative and slightly below 1023 for the bright region of the negative.

The set-up negative was then replaced by a negative of the scene to be digitized, and image coding proceeded under the control of a FORTRAN program [3] in accordance with the flow chart shown in Fig. 4.

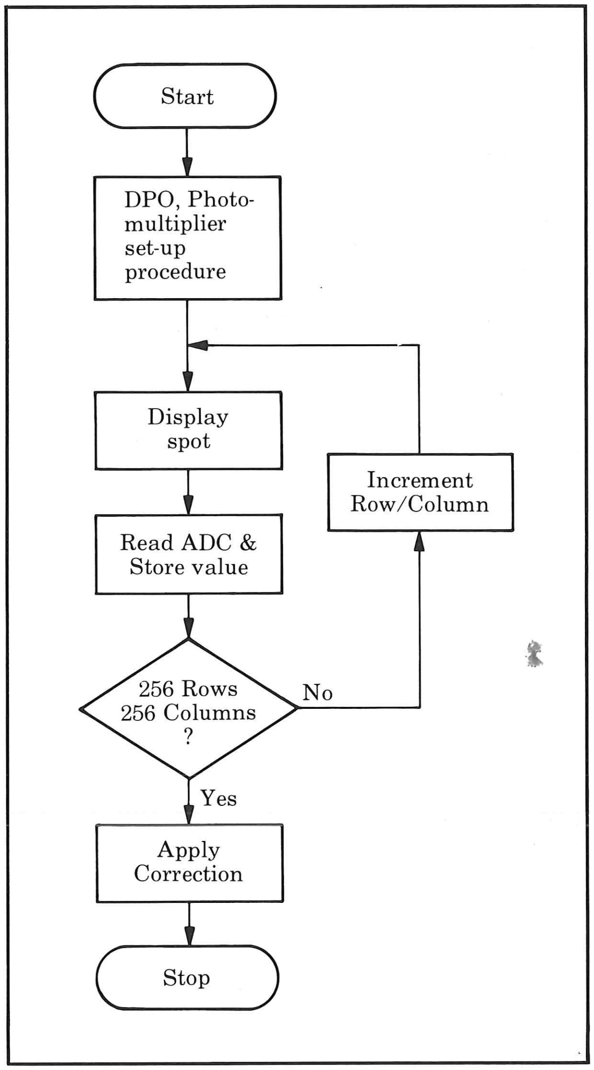


Fig. 4. *Image coding flow chart.*

Encoder performance

The performance of the encoding system, as measured by spatial resolution, was determined by encoding a resolution chart consisting of equally spaced light and dark bars. A DPO reproduction of the chart is shown in Fig. 5. The transmitted light intensity is shown as a function of distance across the chart in Fig. 6.

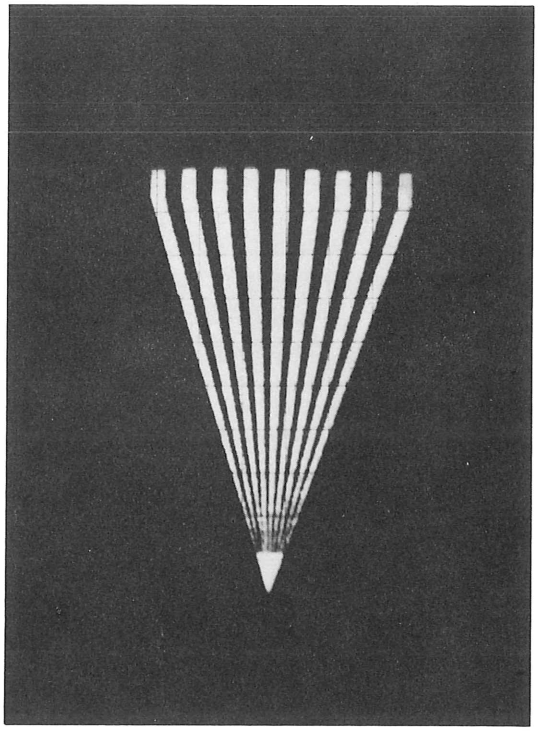


Fig. 5. *Resolution chart coded and reproduced by the Digital Processing Oscilloscope.*

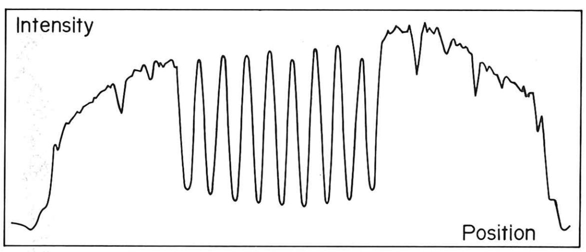


Fig. 6. *Maximum output from the photomultiplier along a line passing through the center of the resolution chart.*

In addition to the obvious features of light and dark bars, it is apparent that there is—

a) an overall decrease in the efficiency of light collection as the spot moves away from the center of the screen, and

b) a decrease in intensity as the spot passes behind a graticule line.

The first effect is due to the reduced sensitivity of the photomultiplier tube for rays of nonperpendicular incidence. The second is unavoidable due to the fact that the graticule lines are engraved on the inside of the 7704A display unit CRT. Both effects, however, can be significantly reduced by applying a spatially dependant correction factor. This is obtained by removing the negative and recording the amplitude of the output signal for each point on the 256x256 raster. The correction factor is then simply

$$\frac{\text{Maximum Value}}{\text{Actual value for each pixel}}$$

computed from the data obtained with no negative, and this multiplies the corresponding pixel for the data gathered with the negative in position.

Using the criterion that the chart has been resolved when the ratio of bright intensity to dark intenstity falls to $1/\sqrt{2}$—i.e., when the signal obtained with the spot directly behind a dark line is 70% of the signal when the spot is between lines—then the encoding system has a resolution of ten line pairs per cm.

For reasons that have not been fully investigated, two problems were encountered in maintaining a constant spot intensity during image coding. It was found that, if the scanning raster is generated at a rate restricted only by the inherent delays in the FORTRAN program, then the small additional delay occurring at the end of each line causes the spot intensity to vary systematically for the initial section of the following line. This may be due to inadequate power supply regulation for this application; however, it was readily overcome by adding between calls to generate the spot a delay sufficient for the effect to disappear. A further improvement may be effected by repeating each line several times and averaging. This reduces what appear to be small random fluctuations in either the spot intensity or photomultiplier gain.

Restoring the image

Since the cathode ray tube of the DPO was not designed to display images, the brightness control of the instrument beam is limited.

The DPO display generator status word provides four levels of spot intensity, namely bright, off, and two intermediate levels. The spot, however, may be positioned on the CRT with finer resolution (512x768) than required for the construction of a 256x256 image. By generating four spots in a 2x2 array with an overall intensity proportional to the intensity of a single picture element, an extended grey scale can be achieved without loss of spatial resolution.

Not all of the 64 possible combinations of spot position and intensity in the 2x2 array result in detectable changes in overall intensity, so a 13-level grey scale was chosen using the thresholds and permutations shown in Fig. 7. This proved adequate for reproducing the majority of images; however, the program controlling the DPO in its display mode also contains provisions for altering the threshold values in order to vary the contrast of the displayed scene.

Percentage of Full Intensity	Spot Position and Intensity
0 - 7.7%	0 0 0 0
7.7 - 15.4%	1 0 0 0
15.4 - 23.1%	1 0 0 1
23.1 - 30.8%	1 1 0 1
30.8 - 38.5%	1 1 1 1
38.5 - 46.2%	2 1 1 1
46.2 - 53.8%	2 1 1 2
53.8 - 61.5%	2 2 1 2
61.5 - 69.2%	2 2 2 2
69.2 - 76.9%	3 2 2 2
76.9 - 84.6%	3 2 2 3
84.6 - 92.3%	3 3 2 3
92.3 - 100%	3 3 3 3

Fig. 7. *Position and intensity of the four spots that comprise a single pixel in the 13-level grey scale.*

Additional facilities built into the image display program [3] include control over aspect ratio, selection of either a positive or negative display mode, and scaling to allow a segment of the image to be expanded to fill the entire display area. For situations in which the selected scaling factor requires a non-integer line of the stored image to be displayed on the DPO, intensity is derived by linear interpolation between adjacent lines.

The processing delays inherent in the image display program result in the completed image being generated over a period of approximately 60 seconds, thus necessitating photographic recording. The photographs reproduced in this paper were recorded on 3000 ASA Polaroid* film while slides and photographic negatives have been produced using a standard 35-mm camera. Prior to photographic recording, a computer generated grey scale was displayed in order to establish optimum spot brightness and camera aperture settings.

With only limited spatial resolution and grey scale, the DPO cannot match the performance of specialized video equipment in providing an image coding and restoration facility. The DPO does, however, allow simulations of image processing schemes to be initiated with, what is for several laboratories, an existing instrument. Furthermore, its performance is more than adequate for many of the subjective evaluations that characterize the early stages of image processing investigations.

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References

[1] Huang, T.S., Bandwidth Compression of Optical Images, Progress in Optics, Vol. 10 (North-Holland Publishing Co., Amsterdam, 1972) pp. 1-4.

[2] Tektronix WP1000 Digital Processing Oscilloscope Operation and Applications Manual.

[3] Listing of the programs used for image coding and restoration may be obtained by writing to Dr. M.C. Cavenor.

**Polaroid is a registered trademark of Polaroid Corporation.*

ONERR and STATUS SCHED ferret out program trouble spots

Your program is running smoothly. Then all of a sudden a message flashes on the terminal screen:

FATAL S-22 AT LINE 1020 IN TASK 0

The program stops dead, and you start tracing the problem only to find that it occurred in a subroutine that can be called from any number of places in the main program, or even by another subroutine. At this point, most people resign themselves to inserting PRINT statements before each subroutine call in order to trace the problem to its origin.

TEK SPS BASIC V02 software offers a more convenient way of tracing such call-dependent program bugs. It's a routine using the ONERR and STATUS commands. It's quite simple, and the routine can be left in the program as a permanent debugging feature. Here's how it works.

Normally, the STATUS command prints system information such as currently loaded nonresident commands and the amount of free memory. But when you add the keyword SCHED, the command is modified to look at the current contents of the program scheduler queue and stack. The scheduler queue and stack keep track of tasks created by instrument and clock interrupts, tasks interrupted by higher priority tasks, and the return points for subroutine calls. For each task, STATUS SCHED prints out the task's number and priority, the line number that created the task, and the line number the task will return to. That's just what you need for backtracking out of a nest of subroutine calls.

There is a minor problem, though. When a fatal error occurs in program execution, the scheduler queue and stack are cleared of all tasks having the same number as the task that committed the error. This means that by the time an error message is printed on the terminal, the information needed for tracing the error is gone. But this can be prevented by using the ONERR command.

With ONERR in effect, program control is passed to a designated line number whenever an error occurs. This leaves the scheduler queue and stack undisturbed, still holding the condition that existed at the time of the error. Therefore, with ONERR and a five-line routine using STATUS SCHED, you can trap the error and print out the scheduler information for tracing its origin. To see how it is done, let's look at an example.

First, consider the example program in Fig. 1. This program was contrived to generate difficult to trace errors. It contains a subroutine (lines 1000-1050) which cause a warning error about 2% of the time and a fatal error about 1% of the time. The subroutine is called at ten different points in the main program (lines 100-999).

```
100 X=RND(0)
110 GOSUB 1000
200 X=RND(0)
210 GOSUB 1000
300 X=RND(0)
310 GOSUB 1000
400 X=RND(0)
410 GOSUB 1000
500 X=RND(0)
510 GOSUB 1000
600 X=RND(0)
610 GOSUB 1000
700 X=RND(0)
710 GOSUB 1000
800 X=RND(0)
810 GOSUB 1000
900 X=RND(0)
910 GOSUB 1000
990 GOTO 100
1000 REM ROUTINE TO GENERATE ERROR 1% OF TIME
1010 IF X>=.01 THEN 1030
1020 GARBAGE
1030 IF X>=.03 THEN 1050
1040 X=LOG(-X)
1050 RETURN

READY
*RUN
WARNING  E- 11  AT LINE   1040  IN TASK   0
FATAL  P- 9  AT LINE   1020  IN TASK   0

READY
*
```

Fig. 1. *A debugging problem: Can you tell which subroutine calls were responsible for the warning and fatal errors?*

As the output of the program in Fig. 1 shows, the standard error messages are not very helpful in tracing call-dependent errors. Although the line number where the error caused termination is given, there's no hint of what routine actually originated the error.

To trace the origin of the error, the program can be modified as shown in Fig. 2. This is done by adding the ONERR command at line 1 and an error tracing routine starting at line 9000. Lines 9000 and 9010 print the error message. Line 9020 prints the trace by executing a STATUS SCHED command. And lines 9030 and 9040 determine whether the error is a warning error or fatal error and whether the routine should return or stop.

ONERR and STATUS SCHED...

```
1 ONERR ER GOTO 9000
100 X=RND(0)
110 GOSUB 1000
200 X=RND(0)
210 GOSUB 1000
300 X=RND(0)
310 GOSUB 1000
400 X=RND(0)
410 GOSUB 1000
500 X=RND(0)
510 GOSUB 1000
600 X=RND(0)
610 GOSUB 1000
700 X=RND(0)
710 GOSUB 1000
800 X=RND(0)
810 GOSUB 1000
900 X=RND(0)
910 GOSUB 1000
990 GOTO 100
1000 REM ROUTINE TO GENERATE ERROR 1% OF TIME
1010 IF X>=.01 THEN 1030
1020 GARBAGE
1030 IF X>=.03 THEN 1050
1040 X=LOG(-X)
1050 RETURN
9000 PRINT "ERROR ";CHR(ER(1));"-";STR(ER(2));" AT LINE";
9010 PRINT ER(0);" IN TASK";TSK(0);" CODE ";ER(3)
9020 STATUS SCHED
9030 IF ER(3)<>2 THEN STOP
9040 ONERR RETURN

READY
*RUN
ERROR E-11 AT LINE 1040 IN TASK 0 CODE  2
               TASK      PRI     FROM     LINE
QUEUE...         -1       -1        0        0
CURRENT.          0      127     9020     9020
STACK...          0       50      210      300
                 -1       -1        0        0

ERROR P-9 AT LINE 1020 IN TASK 0 CODE  0
               TASK      PRI     FROM     LINE
QUEUE...         -1       -1        0        0
CURRENT.          0      127     9020     9020
STACK...          0       50      810      900
                 -1       -1        0        0

STOP  AT LINE   9030
READY
*
```

Fig. 2. *By adding an ONERR command (line 1) and a STATUS SCHED routine (9000-9040) errors can be traced to the originating calls.*

When the program is run with this modification, it is easy to trace down the cause of errors. As the example run shows, the first warning error occurred when the subroutine was called from line 210; and the fatal error occurred later, when the subroutine was called from line 810.

This error tracing technique is a tremendous help when developing complex programs. And, as mentioned before, it can be left in place as a debugging feature. It tells you what is happening when something goes wrong, and it stays out of the way when everything is going okay.

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Tektronix, Inc.

New instrument captures difficult pulse-echo data

Aiming a pulse at a target and studying the reflection is an analysis technique that is gaining popularity as measurement tools become more capable. Not only can the distance to the target be accurately determined, by measuring the time from pulse transmission to echo reception, but analysis of the return can reveal many characteristics of the target. And the technique has widespread application, with pulses ranging from acoustical to laser being used to characterize various types of targets.

In acoustics, for example, information of interest includes the propagation characteristics of the acoustic wave, its reflection characteristics, and consequently the characteristics of the material causing the reflection—its composition, shape, the absence or presence of flaws in the material, and the material's distance from the pulse source. Sonar applications duplicate acoustics with a lower and sometimes similar frequency content. Ultrasonic applications in research and quality control use nearly identical signal shapes but with higher frequency content. Radar is also similar but uses still higher frequencies. And lidar, the use of laser pulses to detect characteristics of distant objects, follows the pattern at still higher frequencies.

Transmitted and reflected pulses, such as those associated with acoustics, sonar, ultrasonics, radar, and lidar, have traditionally posed some challenging measurement situations. A look at a typical pulse-echo pair (Fig. 1) reveals some basic problems cutting across a variety of applications.

Problems with pulse-echo pairs

In nearly all cases, the pulse-echo pair comprises two pulses which are short durationed relative to the "dead time" between them. The basic challenge is to capture both pulses with resolution adequate to reveal their individual characteristics while also maintaining sufficient time resolution for accurate measurement of echo return time. Also, there are some variations on the basic challenge that provide added interest—there may be a rapid series of pulse-echo pairs, the echo may be much lower in amplitude than the transmitted pulse, and often pulse-echo pairs are single-shot occurrences.

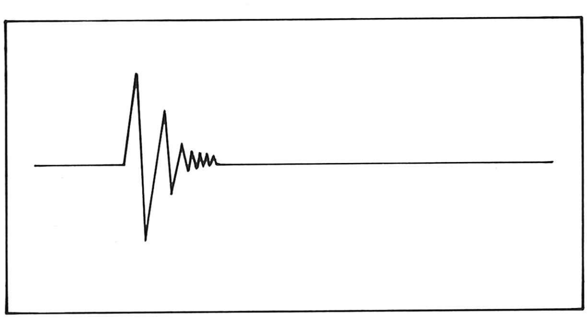


Fig. 1. *Typical pulse-echo pair.*

These conditions, singly or combined, can make pulse-echo observations with traditional instruments difficult at best and sometimes next to impossible. For example, direct-view oscilloscopes, even when fitted with high persistence display tubes, are not entirely satisfactory for observing low repetition rate signals. Oscilloscopes with storage tubes solve some display problems. But there is still the difficulty of capturing both the transmitted and reflected pulses at adequate resolution when both are separated by long dead times (see Fig. 2). Nor do storage oscilloscopes or scope cameras lend themselves well to capturing a train of rapid pulses. This latter limitation is due to finite rearm times as well as the number of pulses that can be satisfactorily displayed simultaneously on the storage screen.

Other traditional instruments also have their problems in dealing with pulse-echo measurements. Spectrum analyzers, because of

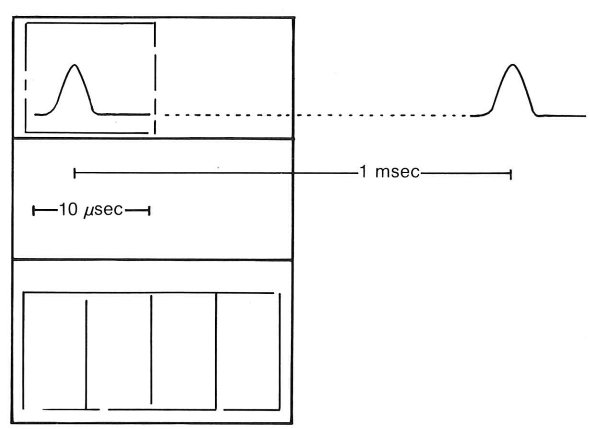


Fig. 2. *Because of the long dead times between pulses, pulse-echo capture is an "either or" situation for most instruments: Either you capture the entire pulse pair with low resolution, or you capture one pulse with high resolution and miss the other because it's beyond the time duration of the capture window.*

swept filter front ends, cannot deal with single-shot pulses. Even for repetitive events, they cannot provide phase information or pulse-to-pulse variance statistics. Real-time analyzers are limited generally to low bandwidths. And counters and sampling voltmeters provide only limited parametric information.

A state-of-the-art solution

All of these shortcomings in traditional instruments can, however, be swept aside by a new state-of-the-art waveform digitizer. This new instrument, the 7612D Programmable Digitizer, provides dual-channel high-speed digitizing, partitionable memory, variable sampling rates, and pre- and post-triggering to ensure capture of the most difficult pulse-echo combinations. And it captures them so that you always have sufficient data for complete amplitude, time, frequency, and phase analyses.

High-speed digitizing. The 7612D is an extremely fast eight-bit analog-to-digital converter using a unique sequential digitizer known as an Electron Bombarded Semiconductor (EBS) tube. With its sequential sampling rate variable from a maximum of 200 megasamples per second to 1 sample per second, the 7612D is able to cover the full spectrum of pulse-echo signals. And this dual-channel device has a long record length—2048 data points per channel—to allow high-resolution sampling while also being able to digitize relatively long time windows.

Sample rate switching. Until now, oscilloscopes and digitizers have not been capable of high-speed capture over very long durations. This is because data acquisition or digitizing has traditionally been done at a constant rate with only a finite amount of display area or digital memory for waveform storage. With the 7612D, however, the sampling rate can be varied during waveform capture. This is an extremely valuable capability when dealing with pulses and their echoes.

As an example of the power of variable sampling rates, consider sampling a waveform at a constant rate of ten nanoseconds per point. Given a 2048-word memory, you can look at time windows up to 20 microseconds (Fig. 3). If an echo follows a pulse later than 20 microseconds, you either have to compromise with a slower sample rate (Fig. 4a) to increase the time window or miss the echo pulse. With the 7612D, you can avoid this by varying the sampling rate to capture the transmitted pulse at a high sampling rate for best resolution, switching to something slower during the dead time to avoid wasting valuable samples, and speeding back up to capture the echo at high resolution (Fig. 4b). The 7612D allows such sample rate switching up to 13 times in a record or 26 times if both channels are used in a concatenated mode. And the sample rate switching is coherent. So timing information between switching is preserved.

Longer records. In the concatenation mode, you can actually turn the dual-channel 7612D into a single-channel device with twice the record length. To do this, simply feed the same signal to both channels. Then delay the start of digitizing for the second channel until the first channel finishes its 2048th sample. The result is a continuous 4096-point record of the waveform.

Greater trigger flexibility. The 7612D pre-triggering and post-triggering features are particularly useful in capturing noise degraded signals. Pulse-echo or "pitch-catch" type signals often exist in noisy environments. As a result,

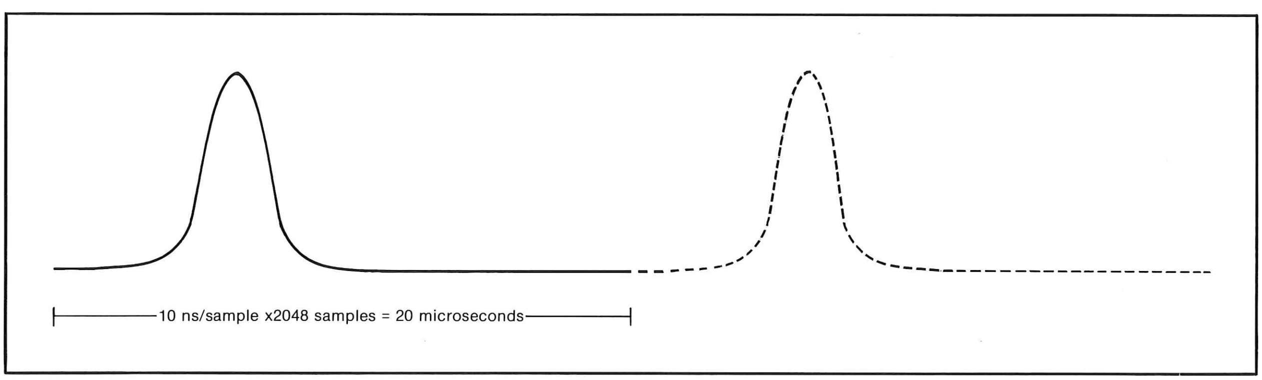
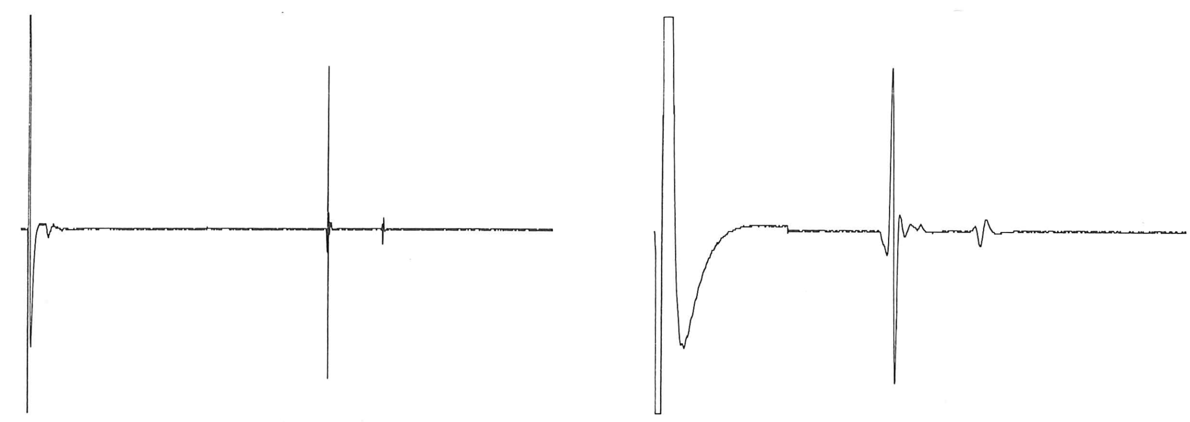


Fig. 3. *With a constant sample rate, important pulse-echo data can be missed. For example, the 20-microsecond window shown here isn't long enough to capture the second pulse. Sampling slower, at 20 nanoseconds per sample, doubles window duration, but at the expense of time resolution. Sample rate switching, demonstrated in Fig. 4, can give you both resolution and window duration.*



a. Pulse pair captured at constant sample rate.

b. Same pulse pair captured with sample rate increased during pulses and decreased between pulses.

Fig. 4. *Using sample rate switching to improve data acquisition.*

spikes and other variations can occur on signal baselines. This makes it difficult to get solid triggering with most instruments while still capturing the entire leading edge of the pulse. With the 7612D, pre-triggering allows solid triggering on some relatively high amplitude portion of the pulse while retaining signal data occurring before the trigger point (Fig. 5). Post-triggering, on the other hand, is useful when you are interested only in the reflection pulse but would like stable triggering from the transmitted pulse. This is often the case when measuring arrival times or time jitter of returns (Fig. 6).

Dual-channel capability. Wide amplitude variations present another difficulty in measuring pulse-echo signals. The typical situation (Fig. 7a) is a high amplitude transmitted pulse and a much lower amplitude reflection. Transmit-return ratios can be from 10 to 1 to 10,000 to 1. Nominally, however, the ratios are from 1000 to 1 to 5000 to 1, but even these conditions require substantial measurement resolution.

To meet these resolution requirements, the 7612D can be configured for two channels of data capture at two different sensitivity settings (Fig. 7b). For example, Channel A can be set at ten volts per division to capture a transmitted pulse, and Channel B can be set to ten millivolts per division

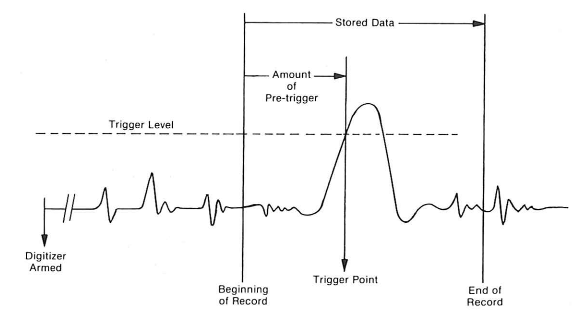


Fig. 5. *Using pre-trigger to get above the noise.*

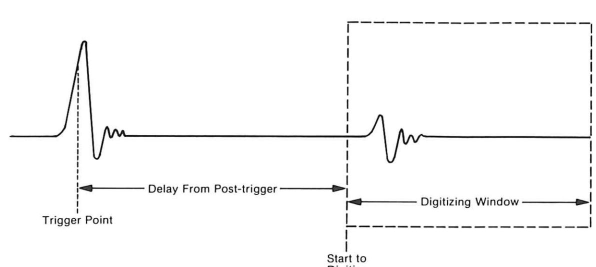


Fig. 6. *Using post-trigger to delay acquisition.*

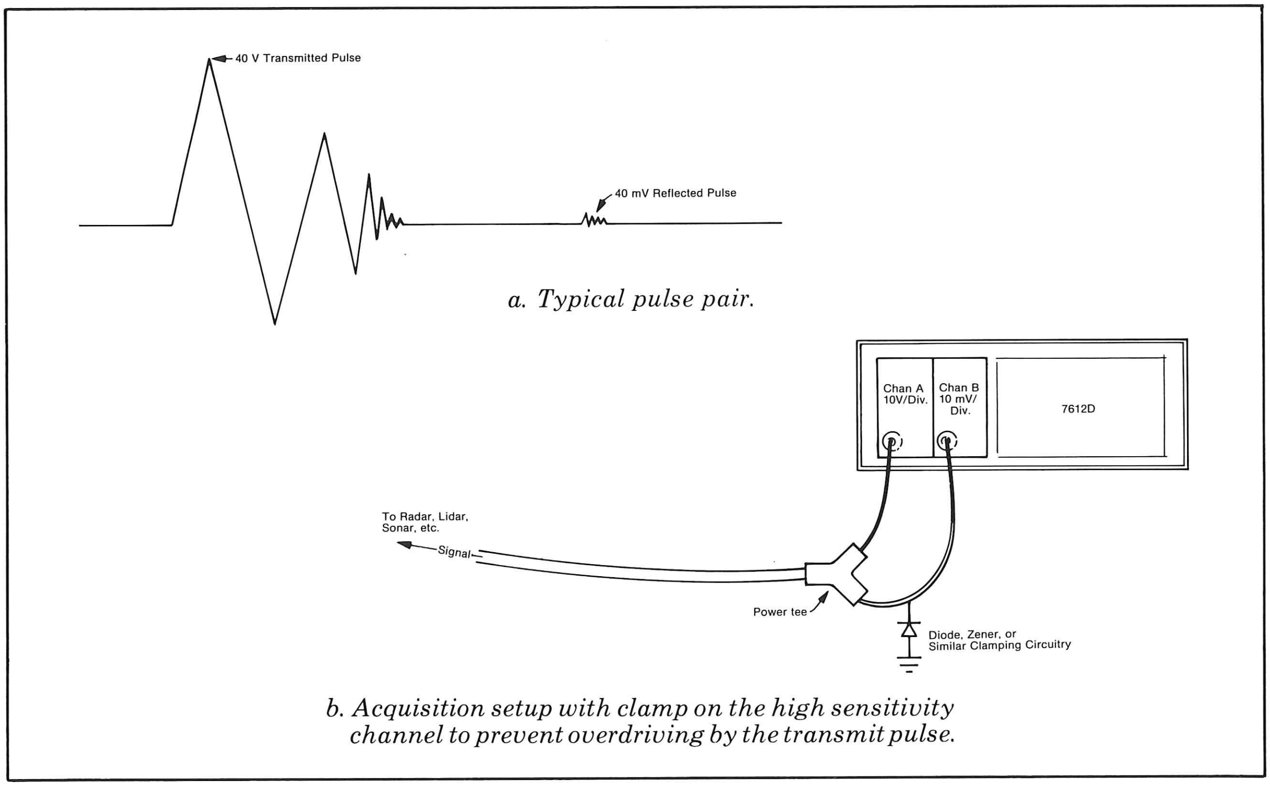


Fig. 7. *Using dual-channel capability to capture pulses of widely varying amplitude.*

for the reflection. With this setup, two pulses—one as high as 80 volts and the other as low as ten millivolts—can be resolved easily. That's a dynamic range of more than 78 dB, the equivalent of a single-channel digitizer with over 14 bits of vertical resolution.

Partitionable memory. Often there is also a need to test for pulse-to-pulse variations in a series of transmissions or returns. The results can be used to check either the generating circuitry, the receive circuitry, or characteristics of the reflecting object. The memory partitioning feature of the 7612D makes pulse train capture quite easy for such studies.

Memory partitioning allows you to divide available instrument memory into multiple records. The range of partitioning is from one record of 4096 points (two records concatenated) down to 16 records of 256 points per waveform (eight records per channel with two channels concatenated). Each specified record is individually triggered, just as if successive digitizers were set to trigger one right after the other sequentially. So, with a single 7612D, you can capture a series of up to 16 pulses. And as long as pretrigger delay conditions are not violated, those pulses can even be arriving randomly!

Putting it all to work

Characterizing antennas and other equipment associated with electronic countermeasures and radar systems offers an interesting application example of the 7612D. The same techniques also apply in some areas of lidar.

Electronic countermeasures, radar, and lidar all require measurements on a large number of pulses at a high repetition rate. Until the 7612D, these pulse series were virtually impossible to capture without highly specialized, highly sophisticated, and expensive signal processors using pipeline techniques. The 7612D provides a new and unique method of capturing parametric information from such pulse trains.

The pulses are fed into the vertical channel of the 7612D just like any other signal. But sampling is controlled by using the external clock input to gate 7612D digitizing. In a normal transmit-return pulse system, a pulse can easily be developed to coincide with each return pulse. This pulse, through the external clock input, then tells the 7612D when to sample the input waveform. The sampled and digitized result for a long train of pulses is a series of 2048 points per channel, each point representing the peak amplitude of a pulse in the train (see Fig. 8). This peak data can then be averaged, analyzed, and plotted in a radiated or received response pattern to characterize the sensitivity of a system (Fig. 9). Such pattern plots are useful aids in optimizing antenna systems.

The 7612D can also be configured to digitize into one channel while previously captured data is read from the other channel to a peripheral storage device. By alternating between channels, continuous digitizing can be done with only minor pauses for channel rearm and trigger times. And, operating in the mode of one clocked sample per pulse as in Fig. 8, alternate channel digitizing and data transfer can easily handle pulses returning at up to a 40-kilohertz rate. That's with a moderate-speed system. Faster rates are possible with faster software and controllers.

Acoustic emission, though different from radar or lidar, is still another area of application for 7612D features. Acoustic emission occurs when a material is mechanically stressed. Slowly bending a wooden pencil, for example, brings about an audible cracking noise before the pencil actually breaks or fails totally. The same thing occurs to some degree when many other types of materials are stressed, and these acoustic emissions are useful indicators in materials studies.

Using the pre-trigger mode of the 7612D, materials under stress can be monitored until the large acoustic emission of failure occurs. This emission triggers the 7612D. But, depending upon the amount of pre-trigger selected, portions of prefailure acoustic emission will be stored in memory (Fig. 10). Thus, data leading up to critical points is easily and surely captured for study. And, by using the dual-channel mode of the 7612D, strain gauge data can be taken simultaneously. All of this data can then be transferred from the 7612D to a calculator or minicomputer for extraction of simple time-domain parameters—such as time to peak and emission duration—or more sophisticated frequency-domain data, including phase relations of frequency components. Much of this kind of data is missed with standard analog instrumentation.

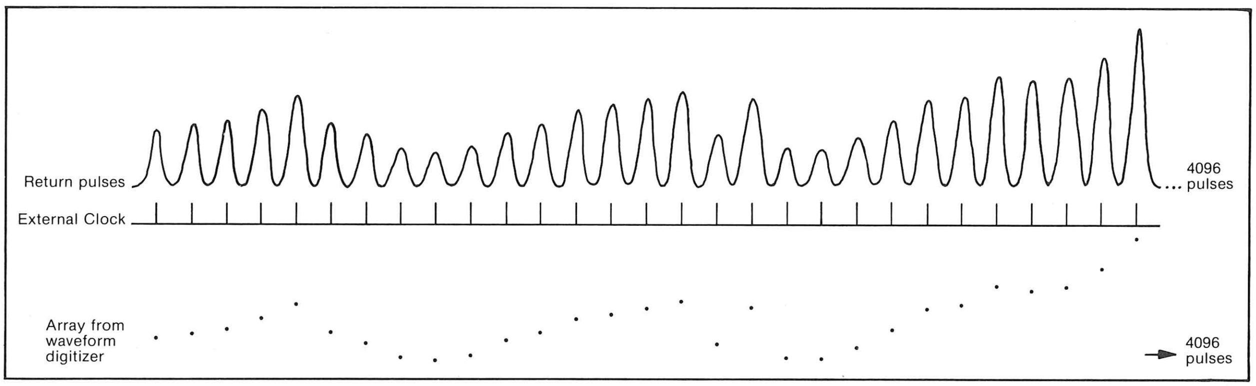


Fig. 8. *Capturing pulse train data for reponse pattern studies.*

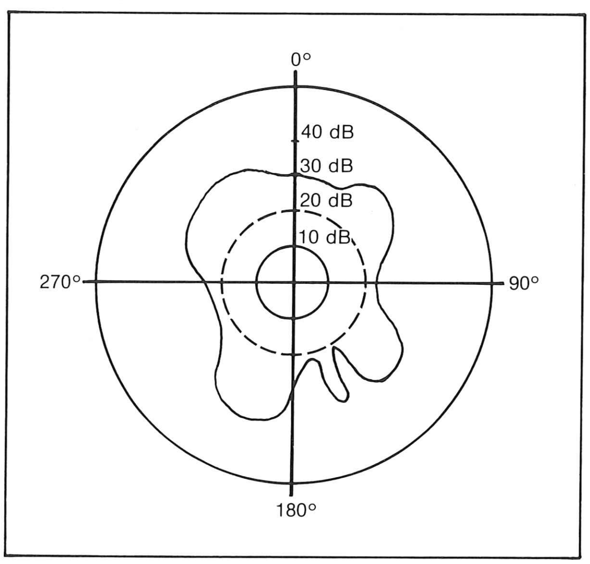


Fig. 9. *Response pattern plot.*

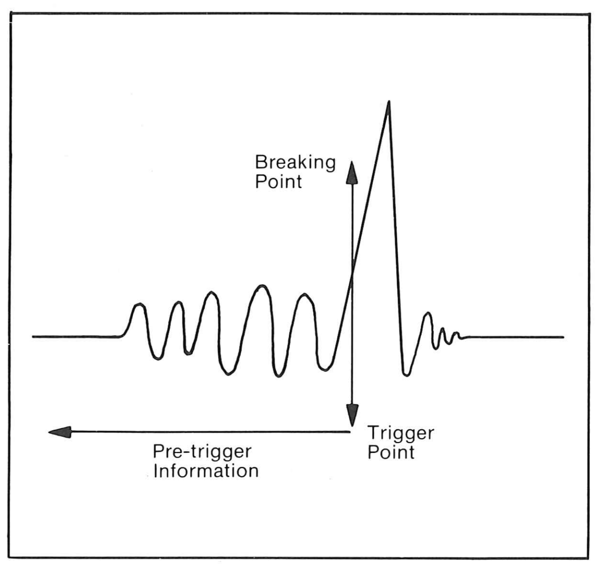


Fig. 10. *Pre-trigger captures data preceding critical points.*

Can you afford to miss that next burst of data?

You won't with the new TEKTRONIX 7612D Programmable Digitizer. From radar to acoustics, it has the flexibility and feature mix to capture the most elusive waveform. For more information on this versatile waveform digitizer, check the appropriate square on the HANDSHAKE reply card. Or contact your local Tektronix Field Office or the Tektronix sales representative in your country.

By Dean Turnbaugh,
Tektronix, Inc.
Rockville Field Office

Literature available from Tektronix

Copies of the following pieces of literature can be ordered via the reply card bound into the center of this issue of HANDSHAKE.

Capture fast waveforms accurately with a 2-channel programmable digitizer, Electronic Design reprint, AX-4401.

This reprint contains an in-depth discussion of the new 7612D Programmable Digitizer from Tektronix, Inc. The major features—dual-channel operation, variable record length, sample rate switching, pre- and post-triggering—are described in terms of both operation and use. A full application example, testing a three-electrode gas lightning arrestor, is also presented.

Digitizing-oscilloscope systems simplify transmission measurements, EDN reprint.

Approaches to measuring transmission parameters in both coaxial-cable and fiber-optic systems are discussed. Test setups and test methods are discussed and examples of measurement results are given.

TDR Difference Testing with TEKTRONIX Signal Processing Systems, Application Note AX-3482.

This application note discusses the basics of time-domain reflectometry (TDR) and then discusses techniques of digitally processing TDR waveforms for precise comparative measurements. Test setups are diagrammed and flow charts are provided for the programs.

Automating Swept RF Measurements, Application Note AX-3810.

Use of a signal processing system to automatically measure VSWR and insertion loss is demonstrated. Both bridge and slotted-line techniques for measuring VSWR are discussed. Also, a brief discussion of software compensation for detector variation from square law is included.

Measuring Transistor Switching Times with the DPO, Application Note AX-3481.

For those involved in designing or evaluating switching power supplies, multiplexers, or any device using switching transistors, this application note opens a new path for fast and accurate determination of switching parameters. Test setups using the Digital Processing Oscilloscope are given and a program for use with either DPO TEK BASIC or WDI TEK BASIC is listed.

Spectrum Analysis Systems, Application Note AX-4011.

The Spectrum Analyzer has long been recognized as the most accurate and versatile instrument for making a wide variety of RF component measurements. But what about documentation of the results? What about the computations involved? This concept note describes how a Digitizing Oscilloscope system can be used to provide automatic spectrum acquisition, analysis, and report generation.

An Overview of Disk System Testing, Technical Note TN-0005

Waveform processing systems offer greater speed and repeatability for evaluating and testing magnetic disk systems. This technical note provides an overview of the system and some of the tests that can be made with a waveform processing system.

HANDSHAKE Applications Library Catalog

The latest edition of the HANDSHAKE Applications Library Catalog is now available. Besides carrying a new name, this catalog lists ten new programs and includes a listing of Application Notes and Technical Notes that are applicable to signal processing and instrument control.

Monitoring data communication channels with the 7612D

Eye pattern monitoring with real-time oscilloscopes has been an essential of data channel evaluation for some years. It's a labor intensive operation. But, with faster sequential digitizers becoming available, much of the workload can now be automated.

The way it was

Eye patterns are X-Y plots of two channels of transmitted or received information. In QPSK satellite communications, for example, the pattern on the oscilloscope CRT is the I channel versus the Q channel in an X-Y mode with the system clock furnishing the unblanking (Z-axis) signal to the CRT (Fig. 1). The same approach is used in monitoring telephone lines for data communication quality.

Monitoring is usually done by a technician seated in front of the oscilloscope. Beyond being a boring job, there are some other disadvantages. For example, there is only a finite period of time, usually short, that a person can stare intensly at a screen without looking away. Glitches can be missed. Or a series of glitches may occur so rapidly that the technician cannot keep track of the number or characteristics of them. Added to these human factors, rising data rates are outpacing oscilloscope X-Y and Z-axis bandwidths, making reliable X-Y plotting even more difficult. And last, but certainly not least, there is the expense of keeping several people glued to oscilloscope CRTs for extended periods of time.

The way it can be

Modern sequential digitizing coupled with low-cost computing devices can solve most data channel monitoring problems. Additionally, by operating with programmable digitizers, unattended long-term monitoring can be done and statistical appraisals of data channel quality computed.

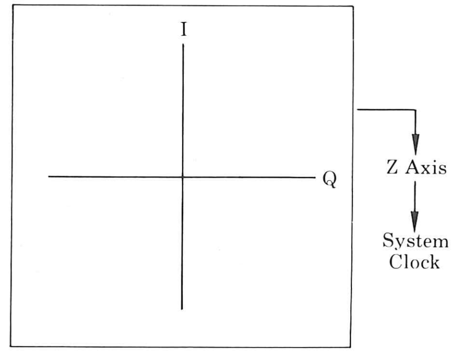


Fig. 1. *Oscilloscope setup for eye pattern monitoring: The I channel provides vertical drive, the Q channel horizontal drive, and the data system clock Z-axis drive.*

The TEKTRONIX 7612D Programmable Digitizer, because of its high digitizing speed (200 megahertz sample rate), programmability, and many other features, provides an excellent example of what can be done. For data channel monitoring, the 7612D can be configured essentially as an "analog logic analyzer" under external control of the system clock. One data channel is coupled to Channel A of the 7612D. The other channel is connected to Channel B of the 7612D. And, finally, the data system clock is fed into the external clock input of the 7612D. With this arrangement, the 7612D samples the data channels coincident with the system clock as shown in Fig. 2. The result is two banks of

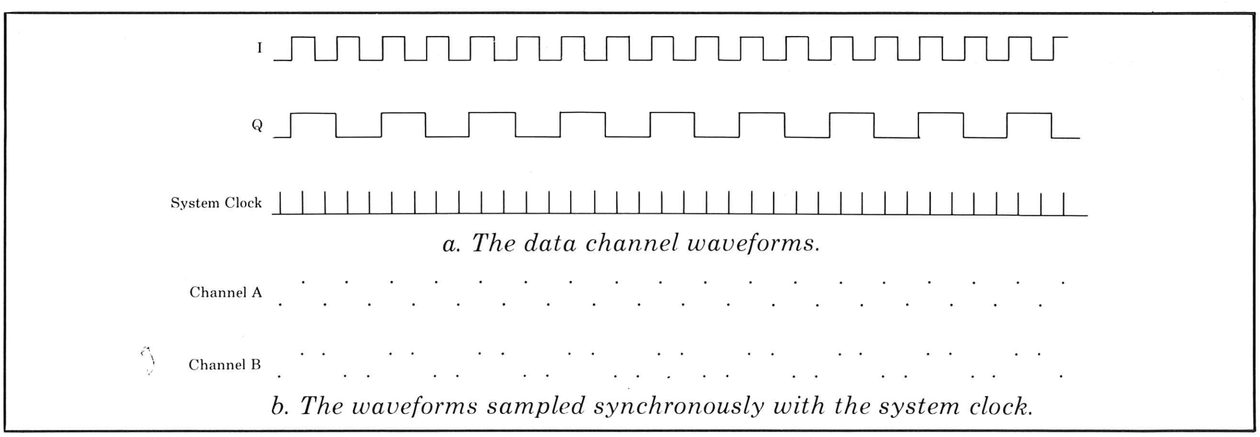


Fig. 2. *Data channel waveforms and how they are sampled by a TEKTRONIX 7612D Programmable Digitizer.*

instrument memory, one for each channel, containing stored information about channel quality. Pulse-to-pulse variances in each data channel, noise, dropped bits, dropped channels, phasing shifts, and amplitude levels can all be detected from this information. One way of doing this is by plotting the stored samples in X-Y form as shown in Fig. 3.

The X-Y plots will vary according to the quality of the channels under analysis. When channels become noisy, the noise shows as amplitude variations from pulse to pulse. An X-Y plot of this condition looks like Fig. 4. Phasing problems show up as a rotation in the plot as in Fig. 5. Extraneous noise and phase hits are shown in Fig. 6 as a scattering of some points. And a catastrophic loss of channel results in a plot like Fig. 7.

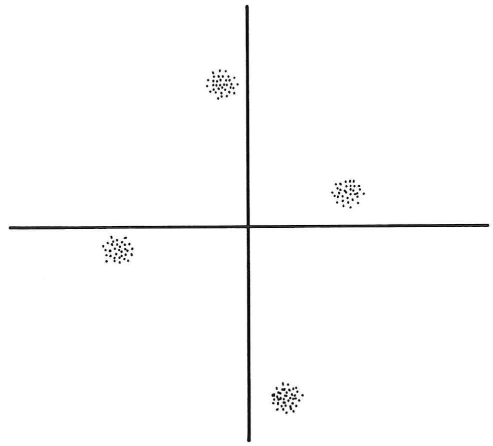


Fig. 5. *X-Y plot showing skewing from phase shifts.*

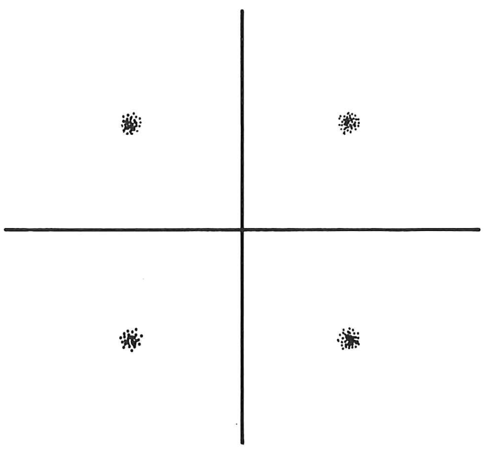


Fig. 3. *X-Y plot of good data from I and Q channels.*

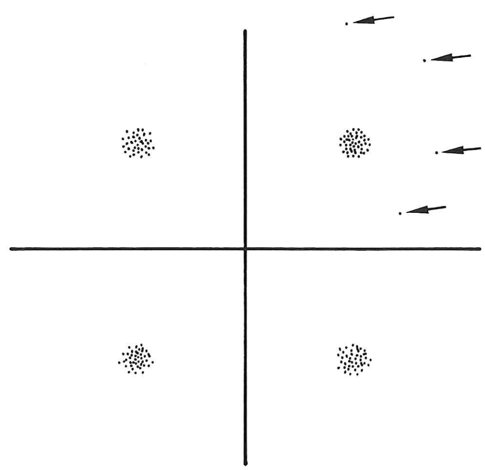


Fig. 6. *X-Y plot showing scattered points due to transient noise and phase hits.*

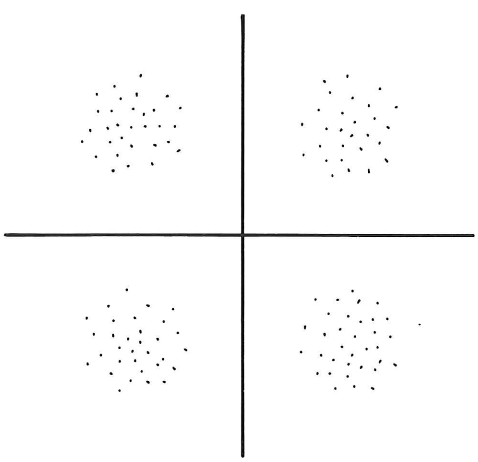


Fig. 4. *X-Y Plot showing effect of noisy data.*

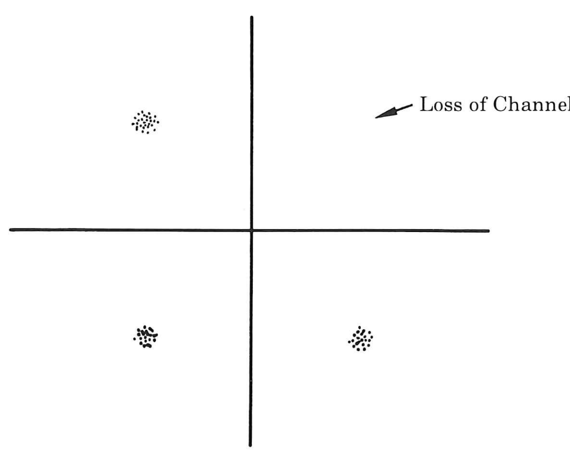


Fig. 7. *X-Y plot showing loss of a channel.*

These X-Y plots can be copied to paper and are certainly a step above staring at an everchanging CRT display. But greater steps can be taken through the software and controller used with the 7612D Programmable Digitizer. Instead of having to look at sequences of X-Y plots to find problems, you can use software to do it automatically. Limits of data acceptability can be set, and the incoming data can be analyzed for excesses. Should the noise level exceed specification, the phasing go out, a channel drop, or a transient hit occur, software routines can be automatically invoked to output pertinent data in the form of parameters or an X-Y plot of the problem area. Or the information can be logged to a peripheral storage device for later use in computing long-term statistics.

There are some limitations, however. Every system has at least a few. In this case, high data rates, which can be up to 50 megabits per second or more, preclude a real-time mode of operation for digitizing, transferring, storing, and analyzing channel waveforms. But, a solid statistical sampling of data channel integrity can be made. And it can be made over the long term, unerringly, all day, all night, without having people glued to CRT displays. If you'd like to have it that way, call your local Tektronix Field Office or sales representative for more information on the 7612D Programmable Digitizer and the Waveform Processing Systems designed around it. Or simply fill out and return the convenient reply card bound into the center of this issue of HANDSHAKE.

By Dean Turnbaugh,
Tektronix, Inc.
Rockville Field Office

Finding out more about Tektronix signal processing systems

Tektronix maintains Field Offices and Service Centers throughout the world. In the United States, the Field Offices listed below have Signal Processing Specialists ready to answer your questions and help you select the system that best suits your measurement needs. Outside of the United States, the Tektronix subsidiary or distributor in your country will be pleased to offer you the same services.

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