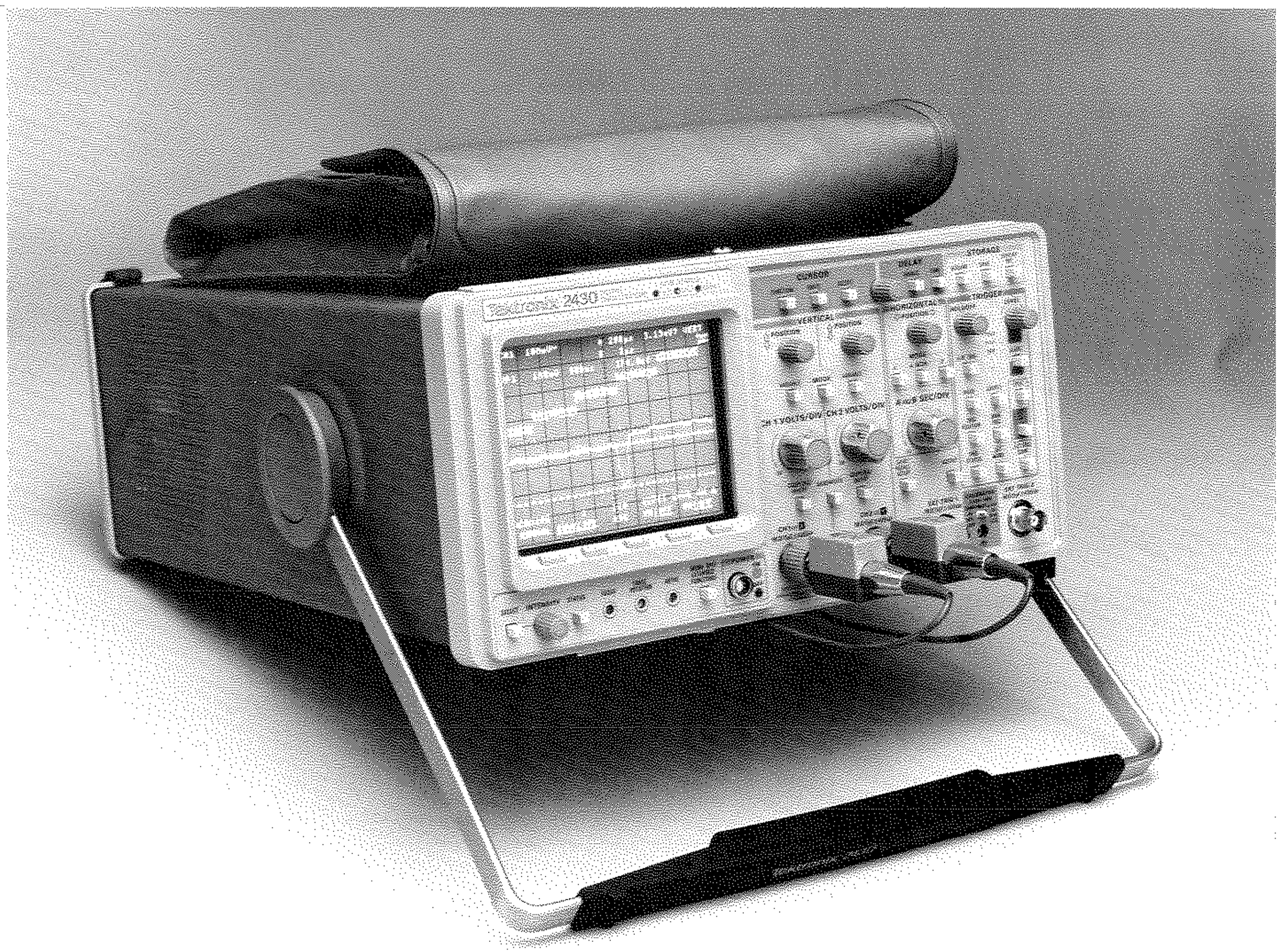
DIGITAL OSCILLOSCOPE CONCEPTS

- Calibration
- Effective Bits
- Averaging
- Save-on-Delta
- GPIB Fast Transmit



Tektronix
COMMITTED TO EXCELLENCE

CONTENTS

PREFACE

This document, made up of a series of five articles, is intended to promote greater understanding of several prominent features and design principles built into the 2430 Digital Oscilloscope. Each piece was written by a member of the engineering design team that developed the instrument and responds to an area where there have been requests for additional information.

CALIBRATION OF THE 2430 DIGITAL OSCILLOSCOPE

by Warren A. Finke

Calibration of the 2430 Digital Oscilloscope is as near to totally automatic as practical. This capability helps fulfill three major design objectives: (1) minimizing ownership costs for the end-user, (2) minimizing manufacturing costs for Tektronix, and (3) maximizing the instrument's "up time" at specified accuracy. The successful attainment of all these goals offers definite advantages to the user in terms of consistently high oscilloscope performance at significantly reduced life-cycle costs.

To accomplish this high degree of automatic calibration, the design team made wide use of digital calibration techniques. Instead of using a myriad of potentiometers and similar devices that depend on manual adjustment and, in many instances, require elaborate external test-signal references, the 2430 employs an extensive D-A converter subsystem. Together with built-in computer firmware, the subsystem is responsible for calculating and adjusting more than 100 voltages in the instrument.

Two Calibration Levels

The 2430 provides two levels of internal calibration: Self Calibration and Extended Calibration. Both levels can be initiated either locally from the front panel or remotely over the GPIB. Access is through the EXTENDED FUNCTIONS —CAL/DIAG menus, via menu entries titled SELF CAL and EXT CAL (see Figure 1).

When the SELF CAL routines are run, calibration adjustments to the instrument are made automatically by the subsystem. However, when running the EXT CAL routines, technicians themselves manually make additional calibration adjustments while interacting with the CRT readout.

Self Calibration. When the SELF CAL routines are selected, the D-A converter subsystem automatically calibrates virtually all of the analog measurement parameters within the 2430. Included are every gain and offset parameter for both the vertical acquisition system and the internal triggers. No adjustments are required in the horizontal subsystem (time base).

The entire self-calibration process takes less than 10 seconds to complete, even though it comprises a major portion of the instrument's total calibration requirements. No external equipment or stimuli are needed. The SELF CAL routines can be initiated at any time, thus guaranteeing accurate measurements in the current environment.

A user can ensure optimum instrument accuracy by performing a SELF CAL routine at three important times: (1) immediately before making critical measurements, (2) whenever the ambient temperature changes by more than 5°C since the last self calibration was completed, and (3) after the instrument warm-up period.

Figure 1. The CAL/DIAG menu showing PASS indications. These indicate that the SELF CAL and EXT CAL routines passed and parameters updated the last time they were run.

If all the parameters are within their specified tolerances at the end of the SELF CAL routines, a PASS message is displayed. However, if any parameter could not be properly calibrated, the subsystem automatically invokes the EXTENDED-DIAGNOSTICS menu. This menu in turn displays a FAIL indication opposite the label of each out-of-tolerance area (see Figure 2). At this point, the instrument operator can choose whether to make a measurement or not, depending on which parameter failed and how it would affect the measurement.

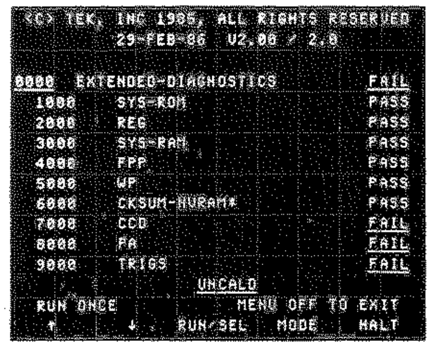


Figure 2. The EXTENDED-DIAGNOSTICS menu showing the 7000-, 8000-, and 9000-series tests are not within required limits.

Extended Calibration. The extended-calibration routines are for adjusting the remainder of the vertical acquisition and trigger system parameters. Four routines — accessed via the EXT CAL menu and labeled ATTEN, TRIGGER, REPET, and ADJUSTS — interactively guide the technician through the steps required for calibrating: (1) gain of the input thick-film attenuators, (2) gain and offset of the trigger amplifiers, (3) repetitive-mode ramps, and (4) the display system and Charge-coupled Device (CCD) amplifiers (see Figure 3).

All except the ADJUSTS routines can be accomplished without removing the instrument's cabinet; however, when these routines are run, external voltage references are needed.

During the EXT CAL routines, a FAIL display appears whenever there is an unsuccessful calibration attempt. When this occurs, the previous calibration constants are not overwritten and the instrument remains in its previously calibrated state. Also, when the EXTENDED-DIAGNOSTICS menu is invoked, an UNCALD message is displayed to warn the user that an attempted calibration has failed.

Two other conditions also can cause a FAIL message to be displayed: (1) a real hardware failure and (2) correct voltage levels are not connected as required.

Attenuator and external-trigger calibrations (ATTEN and TRIGGER) are recommended every 2000 hours, or once per year, if the instrument is used infrequently. On the other hand, repetitive-mode ramp and display calibrations (REPET and ADJUSTS) should only be performed whenever parts are replaced during instrument servicing. Unlike the SELF CAL routine, re-performing any portion of the EXT CAL procedure is not necessary to maintain maximum instrument accuracy over the ambient temperature range.

Manual Procedures. There are other manual adjustments in the 2430 for input capacitance, 50-MHz bandwidth limit, the CCD clock skew, the display system, and the CCD output amplifiers. Normally, these adjustments are made during the manufacturing process and should not require readjustment, unless parts are replaced during instrument servicing.

Dynamic Adjustments. During normal operation, the 2430 itself makes additional dynamic adjustments to the acquisition system and to the repetitive-mode ramps, which compensate for minor changes in offsets and repetitive-mode timing. These adjustments are both totally automatic and transparent to the user and require no service.

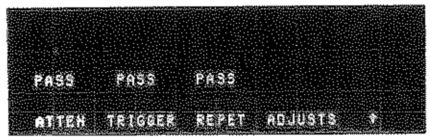


Figure 3. The EXT CAL menu showing that calibration routines for attenuator gain, trigger amplifier gain and offset, and repetitive mode ramps passed and parameters updated during the last time each routine was run.

NBS Traceability

Traceability to the National Bureau of Standards (NBS) means that an instrument's stated accuracy was established through calibration equipment whose own accuracies were fixed, either directly or indirectly, by NBS-certified references.

Before being packaged for shipment, the 2430 is calibrated with an external NBS-traceable source. Then, a jumper is installed inside the instrument to prevent an operator from accidentally running any extended calibration (EXT CAL) procedure that could void current calibration settings.

In the 2430, an external NBS-traceable voltage reference is used to calibrate the attenuators and external triggers via the EXT CAL menu (ATTEN and TRIGGER choices). When run, these calibrations not only make fine gain adjustments on the attenuators but also normalize the internal 10-V Calibration Reference to the external NBS-traceable source. This establishes the relative accuracy of the internal reference. The installed jumper disables the ATTEN and TRIGGER choices from the EXT CAL menu.

Once a complete sequence of the SELF CAL and the EXT CAL routines are performed successfully at the service center with an external NBS-traceable voltage reference, the 2430 and its internal 10-V Calibration Reference become traceable to NBS. Traceability is maintained, because subsequent SELF CAL routines use the internal (and unadjustable) 10-V Calibration Reference as the comparison source.

During a calibration attempt of the attenuators, should the external voltage reference and the internal 10-V Calibration Reference disagree by approximately two percent or more, a FAIL indication will appear. This indicates that one of the references is either faulty or incorrect. When a FAIL indication occurs, the previous attenuator calibration constants are retained and are not updated.

Failure Modes

If 2430 fails are detected that might affect instrument calibration, they are shown in the extended diagnostics (EXT DIAG) display. System, subsystem, and possibly device failures may be indicated, as well as the UNCALD calibration status. Failures can be of two types: (1) soft errors caused by drift in parameters (usually large operating temperature changes since the last self calibration) and (2) hard failures of 2430 components.

Potential soft errors are revealed to the user by: (1) failure of power-up diagnostic tests in the 7000 through 9000 range, (2) the word UNCALD displayed in the EXTENDED-DIAGNOSTICS menu, and (3) the word UNCALD displayed above the SELF CAL selection in the CAL/DIAG menu. These errors can be rectified by running SELF CAL and obtaining a PASS indication.

Hard failures are indicated by (1) a loss of the ability to run SELF CAL routines, (2) a FAIL indication when attempting to rerun SELF CAL, and (3) loss of EXT CAL (which points to a possible nonvolatile memory failure). In any of these cases calibration should be considered void, and the instrument serviced.

EFFECTIVE BITS—MEASURING DYNAMIC DIGITIZER ACCURACY

by Rolf Anderson

Specifications Determine Performance Limits

The desire of any test and measurement equipment user is to obtain an accurate picture of the signal under observation, with minimal distortion contributed by the test system. The user relies on specifications to determine what effect the test equipment will have on signal characteristics that are being measured.

In the analog oscilloscope realm, performance is stated in terms of widely known specifications such as bandwidth, rise time, aberrations, noise levels, linearity, and others. These limitations are also present in digital oscilloscopes, since they require analog front-end signal conditioning similar to analog scopes. In addition, digital scopes have performance considerations in the sampling circuit, and there is little industry consensus on testing methods or significance of the many popular digitizer specifications.

Common digitizer specifications include the number of bits, sampling rate, monotonicity, linearity, and aperture uncertainty. Although each of these has significance to the digital scope user, none gives an overall picture of digitizer performance. Effective bits combines all the other digitizer performance factors into a single specification that describes digitizer accuracy with respect to frequency. In essence, effective bits describes many specs rolled into one.

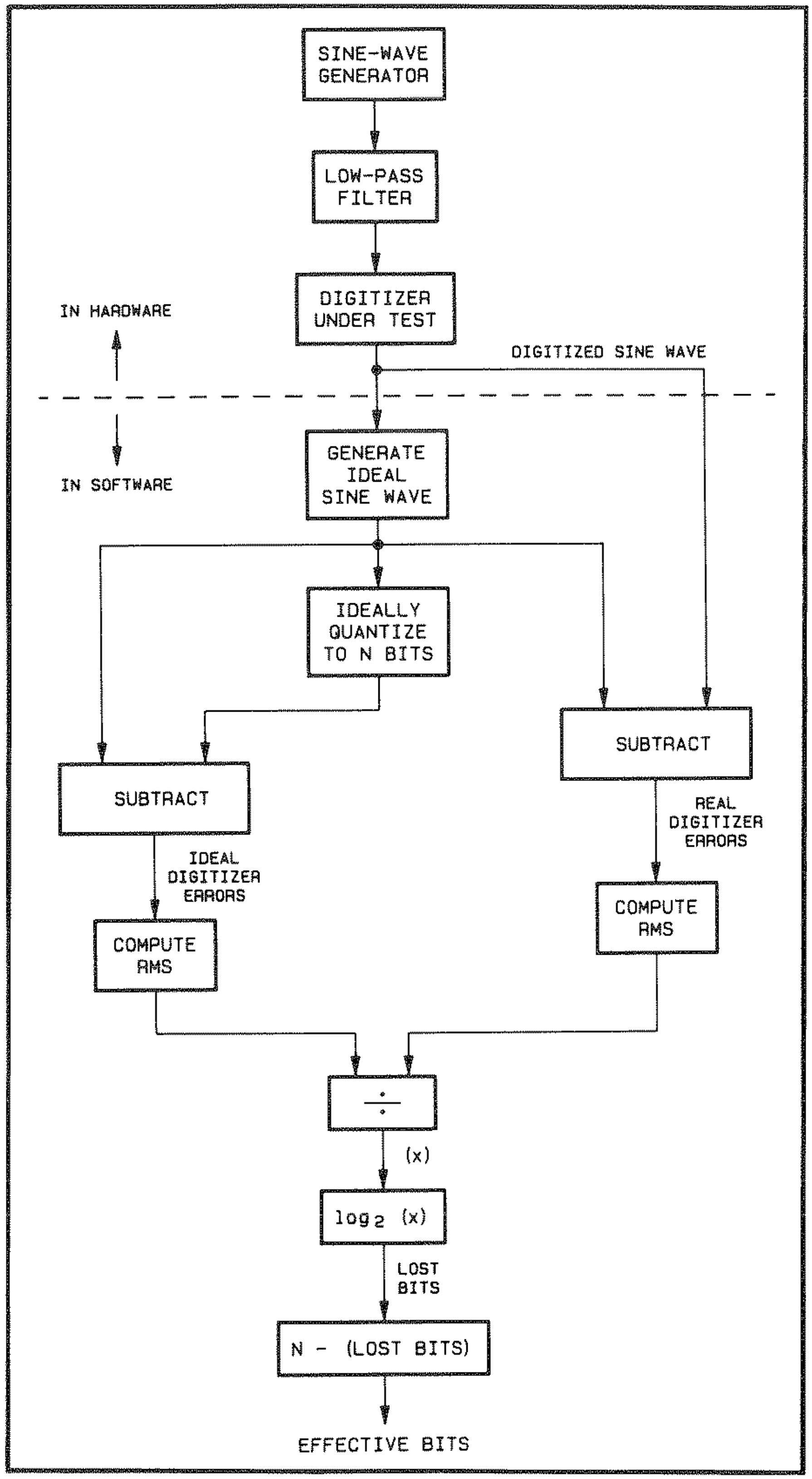


Figure 4. Procedure for measuring dynamic accuracy of an N-bit digitizer.

How Do We Measure Effective Bits?

The effective bits of a real digitizer are determined by comparing its output signal to the output of a theoretically perfect digitizer. An arbitrary input signal cannot be used, since obtaining a perfectly digitized version of the input signal would be impossible. Instead, sine waves are used, since high-frequency, high-quality sine waves are relatively easy to generate as the inputs to the real digitizer being tested. Also they are easily generated numerically as inputs to the perfect digitizer.

To perform the effective-bits test, a pure sine wave is fed into the real digitizer. Pure in this case means a sine wave whose harmonics are below the sensitivity of the digitizer. Harmonic distortion of the test waveform must be minimized, since it adversely affects the measurement of effective-bits. Typical leveled sine-wave generators are usable, provided their outputs are passed through an appropriate low-pass filter.

The sine wave is digitized, and the numerical data fed to a computer for analysis. During the analysis, numerical curve-fitting techniques are used to determine frequency, phase, amplitude, and dc offset parameters—which then are used to reconstruct the assumed-pure sine wave coming from the imperfect (real) digitizer output. Errors in these waveform parameters (frequency, phase, amplitude, and dc offset) that result from real digitization are not determined by the effective-bits analysis. The reconstructed sine wave is then numerically sampled in the computer—as though it were processed by a theoretically perfect digitizer.

The real digitizer's ouput is subtracted, sample by sample, from the computer-generated sine wave, leaving behind the digitizer errors. These real digitizer errors are then compared to the errors of an ideal digitizer with identical resolution. Using the error values, effective bits are determined by first computing the number of lost bits:

$$\text{Lost Bits} = \log_2\left(\frac{\text{Real Digitizer RMS Errors}}{\text{Ideal Digitizer RMS Errors}}\right)$$

Then subtract the lost bits from the available digitizer bits:

$$\text{Effective Bits} = (\text{Digitizer Bits Available}) - (\text{Lost Bits})$$

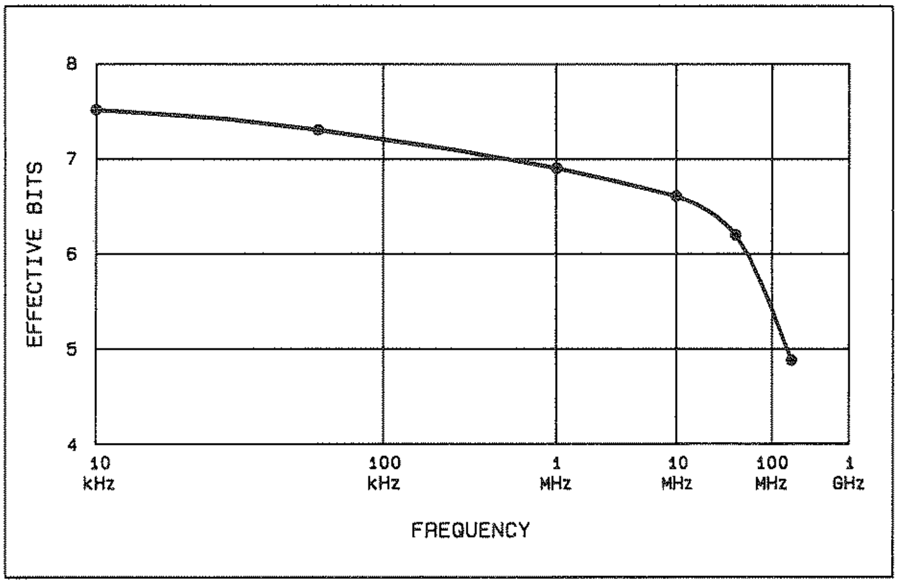


Figure 5. Dynamic performance of the 2430 Digital Oscilloscope. Measured with a five-division input signal and 50-ohm input coupling.

Frequency	Effective Bits
50 kHz	7.3
1 MHz	6.9
10 MHz	6.6
40 MHz	6.2
150 MHz	4.9[a]

[a]With 16 averages.

Effects of Input-signal Amplitude and Slew Rate

In terms of slew rate, a large input-signal amplitude places greater demands on both the front-end analog circuitry and the sampling circuits. Because of these greater demands, the effective bits are reduced as input-signal amplitude increases.

Well then, how should the input amplitude for an effective-bits test be determined? Most measurements are usually made with about five divisions amplitude, and specifications such as rise time and bandwidth also use a five-division input. Since a five-division input represents a typical measurement parameter, that is what was used for the 2430 effective-bits test.

The direct implication of effective bits for the user is that, for a given sine-wave measurement at a given frequency, the digitizer may be viewed as if it were an ideal digitizer whose dynamic vertical accuracy is specified by the effective bits at that frequency. Figure 5 and the accompanying table summarize effective-bits performance for the 2430 Digital Oscilloscope.

Vertical accuracy, when measuring other types of signals—for example, step functions—is not certain. This is due to the dependence of effective bits upon slew rate. It does mean, however, that signals with lesser slew rate—for example, a smaller-amplitude sine wave—will have greater vertical accuracy. And those with greater slew rate—such as a step input—will probably have less.

Additional References

DeWitt, Laurie, "Dynamic testing reveals overall digitizer performance," *HANDSHAKE*, Vol 10 No. 1 (Spring 1985): 8-11.

"Dynamic Performance Testing of A-to-D Converters," Hewlett-Packard Product Note 5180A-2.

IMPROVING MEASUREMENT SIGNAL-TO-NOISE RATIO AND RESOLUTION THROUGH AVERAGING

by Rolf Anderson

Why Averaging?

Noise pervades every electrical system, whether it's a piece of test equipment or a circuit under test. When viewed on a digitizing oscilloscope, a signal often can be completely obscured by noise and will sometimes appear to contain no useful information.

Because of its random nature, noise can be partially eliminated from the oscilloscope display. More importantly, its random qualities also can be used as the means to increase digitizer resolution. Recent developments in fast-waveform processing spurred the evolution of averaging techniques for efficiently reducing the noise seen on a display and improving the scope's measurement resolution.

The averaging process in a typical digital-storage oscilloscope uses the differences between signals of interest and random additive noise sources. Because of the time-locked positioning of samples relative to the trigger point in successive acquisitions, any given sample amplitude consists of two parts: a fixed signal component and a random-noise component.

The desired incoming signal contributes a fixed amplitude component to each given sample position in each triggered acquisition. Random noise, however, does not have a fixed time relationship to the trigger point. Because of this, noise may be viewed as numerous signals added together, with each noise signal being different in frequency from the desired signal. Noise signals move in time relative to the triggered signal, contributing positive and negative amplitudes equally to each sample in the acquisition record.

The amount of noise reduction increases with the number of acquisitions averaged, as the average of the noise amplitudes approaches zero.

The 2430 Combines Two Averaging Methods

The usual definition of averaging means that N numbers are added together, then their sum is divided by N. If only this algorithm were implemented in a digital storage oscilloscope, it would create an inconvenience for the user. Since the display would not be updated after each acquisition, the scope user would have to wait until the N acquisitions had taken place before seeing the averaged signal.

Another factor that the scope designer must consider when implementing an averaging function is that some signals may vary in amplitude, frequency, and phase over time. Normal averaging techniques would eventually "average away" most of these types of signals. For these reasons, the 2430 blends togeher two methods of averaging: stable and exponential.

Stable averaging is a variation on the usual meaning. It adds a correction term to the current acquisition value, which is based upon previous averages. This produces a display that not only is updated with each acquisition but also becomes less noisy after each update.

The stable averaging algorithm is:

$$A_n = A_{n-1} + \frac{x_n - A_{n-1}}{2^j},$$

for

$$2^{n-1} < j \leq 2^{n+1};$$

where

A_n is the new data-point estimate,
A_{n-1} is the previous data-point estimate,
x_n is the current-acquisition value, and
j is an integer value such that the resulting divisor, 2^j, is the first power of two greater than or equal to the current acquisition number (see Table 1).

Table 1
Relationship of Current Acquisition Number to the Divisor 2^j

Acquisition Number	j	2^j
1	0	1
2	1	2
3	2	4
4	2	4
5	3	8
6	3	8
7	3	8
8	3	8
↓	↓	↓
253	8	256
254	8	256
255	8	256
256	8	256

Stable averaging produces slightly less improvement—that is, a smaller signal-to-noise improvement ratio (SNIR) —than conventional averaging (see Table 2). In the 2430, stable averaging occurs on the first T acquisitions, where T is the number of user-selected averages. After T acquisitions are made, averaging automatically switches to the exponential method.

Table 2
Stable Averaging SNIR

Selected Averages (T)	Signal-to-Noise Improvement Ratio: Numeric	Signal-to-Noise Improvement Ratio: dB	% of Conventional
2	1.41	3.0	100
4	1.98	5.9	98.9
8	2.75	8.8	97.2
16	3.84	11.7	96.1
32	5.34	14.6	94.4
64	7.51	17.5	93.9
128	10.60	20.5	93.3
256	14.90	23.4	92.8

Exponential averaging gets its name from the fact that the averaging is exponentially weighted toward the newest samples. Its algorithm is identical to the stable-averaging algorithm, except that the divisor, 2^j, is replaced by T, the number of user-selected averages. Because the divisor now is a constant, the algorithm never ends. This means that each averaged update of the display tracks the incoming waveform with a time constant equal to T divided by the acquisition rate.

Table 3 lists, at each value of T, the expected time constant for 8-bit accuracy and 11.3-bit accuracy, which is needed when the waveform is expanded by a factor of 10. The effects of exponential averaging are most noticeably demonstrated on a slowly changing waveform.

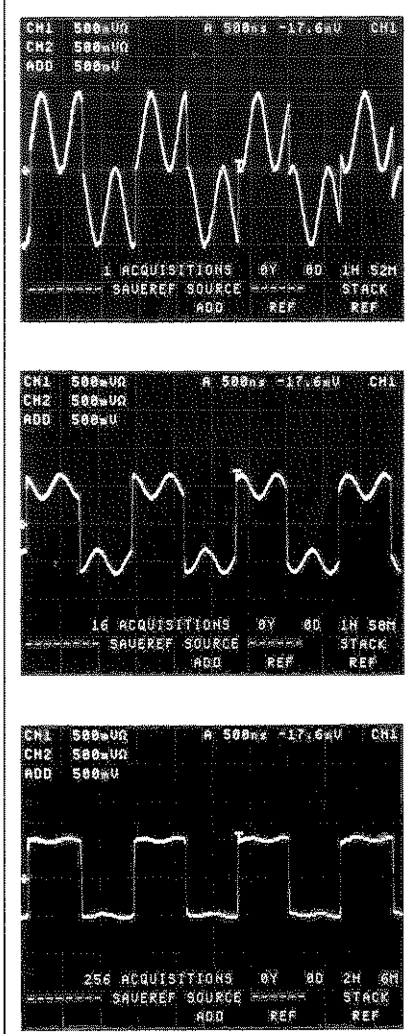


Figure 6. Averaging sequence of a square wave added to a slightly different frequency sine wave. Triggered on the square wave. Watch the sine wave average out.

Table 3
Time Constants to Achieve Accuracy

Selected Averages (T)	Time Constants: 8-bit Accuracy	Time Constants: 11.3-bit Accuracy
2	300 ms	410 ms
4	723 ms	988 ms
8	1.56 s	2.13 s
16	3.22 s	4.40 s
32	6.55 s	8.95 s
64	13.20 s	18.00 s
128	26.50 s	36.20 s
256	53.10 s	72.60 s

Obtainable Improvement is Not Unlimited

The achievable signal-to-noise ratio improvement is limited by other noise sources that are not random but are related in some way to the signal being digitized. For example, if a measurement has harmonics that are above the useful bandwidth of the digitizer at the selected sweep speed, the harmonics will be aliased onto the fundamental, thus producing errors.

Time jitter, when averaged, produces a low-pass filter characteristic. Also, within the oscilloscope, signals related to the sample rate by frequency produce errors that cannot be reduced through averaging. Another limitation on signal-to-noise ratio is the word length used in the averaging algorithm itself. As successive acquisitions are averaged, the least significant bits of the result must be rounded (because of finite word length used in the algorithm), thereby limiting resolution.

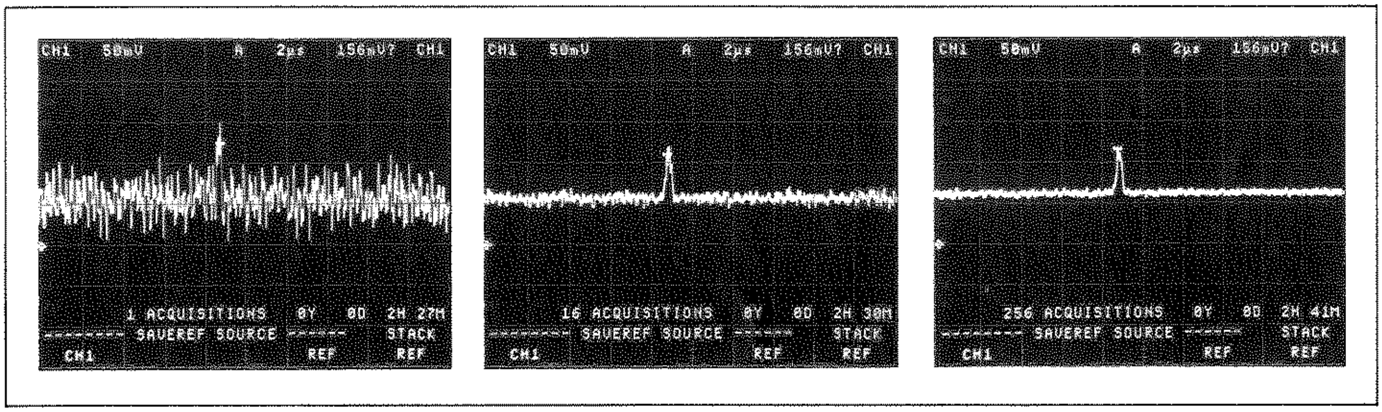


Figure 7. Averaging sequence of a very noisy signal.

Resolution is Increased

Averaging also increases the potential resolution of the digitizer. The increased resolution may be better understood by following the example of an eight-bit digitizer. The value of an eight-bit number ranges from 0 to 255. If you add two eight-bit numbers together, the range of values goes from 0 to 510. Thus the value of one count decreases from 1/255 to 1/510, giving increased resolution. This increased resolution will be obtained when dividing to obtain the average, provided the number of bits used in the calculation is sufficient to prevent round-off or truncation errors.

For example, the resolution for a sample of 128 and for a sample of 127 is 1. Their averaged value is 127.5, but now the resolution is 1/2. Resolution has doubled. In fact, the resolution increases by a factor of N, or $\log_2 N$ bits, when N acquisitions are averaged using stable averaging. Exponential averaging requires more acquisitions to obtain the same resolution improvement as stable averaging.

The presence of random noise in the digitizer is essential for producing this extra resolution. Assume for the moment that the system had no noise. Then, whenever an input signal is quantized to some number, say 10, at some sample point, every later acquisition would quantize that point to the same number (10), and the average would be 10, even though the signal may actually be 9.5. Now re-introduce the noise. The chosen sample point during one acquisition may now read 9, and at the next acquisition read 10, producing an average of 9.5. An extra digit of resolution has therefore been achieved.

Remember that resolution is not the same as accuracy. In spite of the fact that the extra resolution can be computed, the digitizer is still limited to the signal-to-noise limitations mentioned earlier.

Nonrepetitive Signals Can Be Made to Appear Repetitive

To be averageable, signals must be repetitive. Signals that are nonperiodic can sometimes be made to appear periodic to the scope for averaging purposes. For example, an infrequently occurring glitch may be made periodic by setting the scope to trigger on the glitch, then use averaging with NORM TRIGGER MODE selected.

Noise Reduction

A good portion of most measurements involve measuing repetitive signals. Thanks to the fast waveform processing of the 2430, the user may choose to constantly reduce noise through averaging, with no loss of display update rate.

Additional References

Oppenheim, Alan V., and Ronald W. Schafer. *Digital Signal Processing.* Englewood Cliffs: Prentice-Hall, 1975.

Trimble, Charles L. "What is Signal Averaging?" *Hewlett-Packard Journal* (1968).

Table 4
Display-Request List

Selected VERTICAL MODE	DELAY by TIME Δ TIME	Displayed Live Waveforms	Compared Against Selected DISPLAY REF		
			REF1	REF2	REF3
CH1	OFF	CH1	CH1	—	—
CH2	OFF	CH2	CH2	—	—
CH1 + CH2	OFF	CH1 + CH2	CH1	CH2	—
ADD	OFF	ADD	ADD	—	—
ADD + CH1	OFF	CH1 + ADD	CH1	ADD	—
ADD + CH2	OFF	ADD + CH2	ADD	CH2	—
ADD + CH1 + CH2	OFF	CH1 + CH2 + ADD	CH1	CH2	ADD
MULT	OFF	MULT	MULT	—	—
MULT + CH1	OFF	CH1 + MULT	CH1	MULT	—
MULT + CH2	OFF	MULT + CH2	MULT	CH2	—
MULT + CH1 + CH2	OFF	CH1 + CH2 + MULT	CH1	CH2	MULT
CH1	ON	CH1 + CH1/D2	CH1	CH1/D2	—
CH2	ON	CH2 + CH2/D2	CH2	CH2/D2	—
CH1 + CH2	ON	CH1 + CH2/D2	CH1	CH2/D2	—
ADD	ON	ADD + ADD/D2	ADD	ADD/D2	—
ADD + CH1	ON	ADD + ADD/D2 + CH1 + CH1/D2	ADD	ADD/D2	—
ADD + CH2	ON	ADD + ADD/D2 + CH2 + CH2/D2	ADD	ADD/D2	—
ADD + CH1 + CH2	ON	ADD + ADD/D2 + CH1 + CH2/D2	ADD	ADD/D2	—
MULT	ON	MULT + MULT/D2	MULT	MULT/D2	—
MULT + CH1	ON	MULT + MULT/D2 + CH1 + CH1/D2	MULT	MULT/D2	—
MULT + CH2	ON	MULT + MULT/D2 + CH2 + CH2/D2	MULT	MULT/D2	—
MULT + CH1 + CH2	ON	MULT + MULT/D2 + CH1 + CH1/D2	MULT	MULT/D2	—

SAVE-ON-DELTA OPERATION

by Fred Azinger

A powerful new capability was implemented in the 2430 Digital Oscilloscope —the ability for the instrument itself to make pass-fail measurement decisions for you! This feature, called Save-on-Delta, accords scope users an added dimension of efficiency in hunting and finding those infrequently occurring events. It offers them the freedom of unattended operation while tracking down circuit problems.

Essentially, the Save-on-Delta function compares incoming waveforms with a user-defined reference waveform or envelope, then automatically stores those incoming waveforms that exceed the limits set by the reference. Therefore, making the best use of this feature and correctly interpreting its results requires some knowledge about how Save-on-Delta comparisons are initially set up and how the instrument subsequently performs them.

From the user's standpoint, there are three basic steps involved in setting up the 2430 for Save-on-Delta operation: (1) establishing the waveform-comparison pairs, (2) establishing the comparison mode, and (3) generating the comparison waveform envelope. The first two are discussed in this note; the latter is the subject of a separate application note.

Setting Up the Comparison Pairs

When SAVE ON Δ is selected, the 2430 determines which reference waveforms—that is, those stored in the reference memories—can be compared against an incoming signal. It does this via an internally stored display-request list, which maintains a status of waveforms that have been selected for display. These include both incoming live waveforms and those saved in reference memories.

Updating the list occurs whenever any one of the following three parameters are changed using the front-panel controls and menus: VERTICAL MODE displays, DELAY (by) TIME Δ TIME status, and DISPLAY REF selections. Hence, the settings of these three parameters control which incoming live waveform will be compared against an appropriate stored reference waveform. In other words, they establish the waveform-comparison pairs.

It is important to note here that, although there can be more than six waveform-display requests active at any time, the inability of the display system to show more than six waveforms at a time does not affect the operation of the Save-on-Delta function.

The many waveforms available within the 2430 for display produce a great number of choices for Save-on-Delta comparison operations. To minimize the complexity of the human interface required for making all these choices and to avoid diminishing the host of useful capabilities in the Save-on-Delta function, we implemented a table-driven approach. It is similar to that used in the operation of the STACK REF feature.

When determining the particular live waveform that will be compared against a specific reference waveform, the oscilloscope looks at the selections made in the VERTICAL MODE menu. This information, along with the DELAY (by) TIME Δ TIME status, are used as indexes into the display-request list. It then looks at which DISPLAY REF memories are selected. If it sees that both the live waveform and the contents of a specific DISPLAY REF memory are both selected for display (refer to Table 4), then a Save-on-Delta comparison for this pair of waveforms is programmed-up for the waveform processor.

This method of deciding when to perform the comparisons gives a user the ability to "babysit" one node in a circuit while observing another node of interest. To determine which comparisons are considered, look at the line that corresponds to the selected VERTICAL MODE and DELAY by TIME Δ TIME status. Next, look into the table on that row to find the particular live waveforms that will be compared against specific references. Continue along the same row to find a matching waveform in the DISPLAY REF columns.

For example, suppose you have selected MULT and CH2 VERTICAL MODE, with DELAY (by) TIME Δ TIME toggled ON, and both REF 1 and REF 2 selected for display. In this instance, a Save-on-Delta comparison operation occurs between the incoming live multiplied waveform at the first delay (MULT) and the reference waveform stored in REF 1. A comparison also occurs between the live waveform display at the second delay (MULT/D2) and the waveform stored in REF 2.

Establishing the Comparison Mode

There are three comparison modes for the 2430 Save-on-Delta function — we'll call them Standard, Roll, and Repetitive. The criteria for differentiating between these three modes are: the SEC/DIV setting, the ACQUIRE REPET status, and the A TRIGGER MODE selection. Each mode (Standard, Roll, and Repetitive) causes the Save-on-Delta comparison operation to be performed in a different way. Collectively, they offer greater flexibility to the user in handling signals with a wide variety of characteristics. Table 5 summarizes the criteria for each comparison mode.

Table 5
Establishing Save-on-Delta Comparison Modes

Save-on-Delta Comparison Mode	If SEC/DIV Setting Is	Then Selected A TRIGGER MODE Should Be	And Selected ACQUIRE REPET Should Be
Standard	100 ms/div and slower	Any except ROLL	Either ON or OFF
	50 ms/div and faster	Any	OFF
Roll	100 ms/div and slower	ROLL	Either ON or OFF
Repetitive	200 ns/div and faster	Any	ON

Standard Mode. For the Standard Save-on-Delta comparison mode, any SEC/DIV setting can be used. If it is set at 50 ms/div or faster, the A TRIGGER MODE selection can be any of the four choices, but ACQUIRE REPET should be toggled OFF. When the SEC/DIV setting is slower than 50 ms/div, any A TRIGGER MODE except ROLL should be selected, and REPET acquisition can be either ON or OFF. Remember that if AUTO A TRIGGER MODE is active when the sweep speed is 50 ms/div or faster, it automatically changes to ROLL whenever the sweep speed is shifted to a setting slower than 50 ms/div.

In the Standard mode, the entire 1024-point live waveform record is compared against the reference record, which is assumed to be 512 maximum-minimum pairs. Each maximum-minimum pair of points on the incoming live waveform is compared with the corresponding pair of points on the reference waveform to determine whether either point exceeds its respective limit.

Roll Mode. In Roll mode, the SEC/DIV setting must be slower than 50 ms/div. The selected A TRIGGER MODE should be ROLL, and ACQUIRE REPET can be either ON or OFF.

If the Standard Save-on-Delta method of implementing comparisons were to be used also in the Roll mode, each incoming data point, given enough time, would be compared to every maximum-minimum pair in the reference waveform. This is due to the way data rolls through the record in Roll mode.

As a result, the Save-on-Delta comparison in fact is a DC level comparison. Its maximum limit is equal to the minimum of all the maximums, and its minimum limit is equal to the maximum of all the minimums. Accordingly, the usefulness of the Roll Save-on-Delta function is confined to monitoring DC levels. Moreover, if the reference is a DC window only, then the first incoming sample to exceed the window causes the 2430 to enter SAVE, and the errant sample will be at the very end of the record — at essentially 100% pretrigger.

To broaden the usefulness of the Roll Save-on-Delta mode, it was decided to only make comparisons around the trigger position. When ROLL TRIGGER MODE is selected and SAVE ON Δ acquisition is OFF, the trigger position is usually irrelevant. However, when ROLL is selected and SAVE ON Δ is ON, trigger position becomes important for controlling the amount of pretrigger samples that are preserved when an excursion outside the reference envelope is detected.

Therefore in the Roll Save-on-Delta mode, comparisons happen only on those sample occurring from about 20 sample points ahead of the trigger position through the sample at the trigger position. In the ideal situation, only the sample at the trigger position needs to be checked. But due to the batched nature of the way the comparison operation is implemented in the 2430, this window was enlarged.

Repetitive Mode. In this Save-on-Delta mode, REPET acquisition must be toggled ON, and the SEC/DIV SETTING should be 200 ns/div or faster. The A TRIGGER MODE can be any selection.

Now, since the waveform is built up using many acquisitions, there must be yet another way for Save-on-Delta comparisons to take place. At the start, all waveform data points are intitialized to −128, which indicates that a data sample has yet to be acquired for the current position in time within the record. Because of these yet-to-be-acquired samples, a Standard-mode comparison, if implemented, would cause the scope to enter SAVE immediately. Therefore, only the points in the live waveform (that were updated during a particular acquisition) are compared with the reference envelope. Since REPET does not operate in ENVELOPE mode, both the maximum and the minimum points of the reference envelope (that correspond with the live points sample period) are compared.

Other Operational Considerations

One scope parameter that does not affect Save-on-Delta operation is Horizontal Position. This parameter is germane only to the display system. It determines what points are displayed but has no effect on how or where the Save-on-Delta comparison is done. However, here's an important tip to remember when using the Save-on-Delta function. Lock the Horizontal Positions so that all reference waveforms will track the horizontal position of the live waveforms. Then when the 2430 enters SAVE, the event that caused the Save-on-Delta to occur will be centered on the screen, with its reference envelope appropriately positioned also.

Another significant aspect of using the Save-on-Delta function is the rearm dead time. This is the period during which the 2430 is busy processing its last acquisition. Throughout this interval, the scope is not ready to start acquiring data for the next acquisition. And while the scope is not acquiring data, it cannot be performing a Save-on-Delta comparison. However, it is important to note that although the Roll Save-on-Delta mode is effective only for monitoring DC levels, the combination of ROLL TRIGGER MODE and ENVELOPE acquisition (with the peak detectors) yields 100% coverage for a ≥4-ns event.

USING THE GPIB-FAST-TRANSMIT MODE FOR WAVEFORM TRANSFER

by Steve Lyford

Transferring waveforms from a 2430 Digital Oscilloscope to another device in a GPIB-driven sytems environment can be speeded significantly by using the fast-transmit mode. This article describes the fast-transmit function, with several examples, and how it can be used to attain the highest waveform transfer rate available from the 2430 when it's used as part of a GPIB system.

Although the 2430 can send single waveforms at high rates, the real power of the fast-transmit mode (hereafter labeled FAStxmit to conform with its GPIB command header) becomes apparent in repetitive-transfer situations, where multiple waveforms must be acquired then sent to a controller.

Because of its high update rate, the 2430 can acquire a waveform, send it to the controller, and rearm itself for the next acquisition fast enough to capture and send up to 47 waveforms per second. In any measurement situation where the trigger rate is less than the transfer rate (for instance, video frame rate), FAStxmit delivers full coverage, with an acquisition and transfer occurring between every trigger.

In the 2430, the 9914A interface chip is still used for handshake control, but to speed things up, the system processor shuts down all unnecessary overhead and concentrates on sending bytes over the bus.

Memory Background

When data comes out of Acquisition memory, it goes into what is called the Save memory. If waveform expansion and positioning are selected, the waveform processor performs the required operations on the waveform in Save memory, then transfers it into Display memory. The ADD and the MULTIPLY waveforms also are created from waveforms in Save memory, then likewise placed into Display memory.

There are four slots available in Save memory—one each for the CH1 and CH2 main-sweep waveforms and one each for their respective delayed waveforms. Normally, when a waveform is requested using the CURVE? query (and not using FAStxmit), the requested waveform is built out of Save-memory contents, stored in another holding memory, then transmitted to the controller. Therefore, the waveform received at the controller is the same one displayed on screen.

But when FAStxmit is selected, a waveform transmitted to the controller comes directly from Save memory. In this transmission mode, there can be situations when the waveform received at the controller does not match the waveform being displayed on screen. This can happen when expansion or processing functions are selected (since the expanded, positioned, multiplied, and added waveforms are built from Save-memory contents, then placed into Display memory). Although the transmitted and displayed waveforms may not match, the waveform received at the controller is always the one that was acquired by the 2430.

How to Set Up FAStxmit

Let's see how we use the FAStxmit command to set up the 2430 for fast transfer of waveforms to a controller. First, the waveform of interest must be specified in the argument; the choices available are DELta and NORmal.

If DELAY by TIME Δ DELAY is OFF (use DLYTime? DELta), then NORmal is the selection you want. This will send to the controller the contents of the CH1 or the CH2 slot or BOTH slots in Save memory. Which waveforms are transmitted depends on the link argument selected to follow the NORmal argument.

If DELAY by TIME Δ DELAY is ON, and you are interested in the delay waveforms, then select the FAStxmit DELta argument. This will retrieve data from the delay slots in Save memory. Again, the chosen link argument (CH1, CH2, or BOTH) determines the waveforms that will be sent.

If the link argument BOTh is selected, then the specified number of waveforms from each channel are transmitted in the following sequence: CH1, CH2, CH1, CH2, CH1, . . ., CH2.

Examples:

FAStxmit NORmal:CH1	Sends Channel 1 main-sweep waveform(s).
FAStxmit DELta:CH2	Sends Channel 2 delay waveform(s).
FAStxmit NORmal:BOTh	Sends both Channel 1 and Channel 2 main-sweep waveform(s).

The next step is to specify the number of waveforms you want to send. This number can range from 1 to 65535, and it sets the quantity of acquire-send sequences that will be completed before the FAStxmit mode ends.

Examples:

FAStxmit 20000
FAStxmit 1
FAStxmit DELta:CH1,15

The last example sets up the 2430 to send 15 Channel 1 delay sweeps. If the 2430 were in an ACQUIRE mode, each waveform would be newly acquired before it's transmitted. And if a SAVE mode were selected, each transmitted waveform would be a copy of the one before it (since no new acquisitions would occur).

The final step starts the fast-transmission process. Waveforms begin transmission when the 2430 is addressed to talk—or more specifically, when a transition occurs from the untalk condition to being addressed to talk. Only when the controller issues the talk address for the 2430 and the user has requested FAStxmit waveforms will the fast-transmission sequence begin.

Before sending the talk address, the programmer should allow enough time for the 2430 to interpret and turn on the FAStxmit command. A minimum delay of 50 ms is necessary between sending a FAStxmit NORmal:CH1 command and requesting input from the 2430 (by addressing it to talk). This is needed to ensure that the 2430 recognizes the fact that FAStxmit is now active.

Sample Program

The following program example is one way that the fast-transmit mode can be implemented. This example was done in 4041 basic, and the 4041's Direct Memory Access (DMA) mode is used to maximize transfer speed. Using the DMA mode requires that Option 01 be installed in the 4041.

```
10  !
20  ! Fast Transmit Example
30  !
40  Scope=1
50  Open#scope: "gpib1
    (pri=1,eom=<0>,
    tra=DMA,tim=2):"
60  !
70  Dim wave$ to 32000
80  !
90  Prin#scope: "fas 30 ,nor:ch1"
110 Wait .05
120 Inpu#scope:wave$
130 !
140 Prin#scope:"fas off"
150 End ! end of fast transmit
```

The program acquires 30 main-sweep waveforms from Channel 1 and stores them in a variable—wave$. Line 110 inserts the necessary delay to ensure that the 2430 knows it is in the fast-transmit mode before it is sent a transition command changing its condition from untalk to talk. The "print" statement in line 90 performs an untalk when it is finished, and the "input" statement in line 120 performs a talk when it begins. Line 140 is not executed until all of the fast-transmit waveforms have been sent. This example produced a transmittal rate of about 40 waveforms per second, with the A SEC/DIV set to 100 μs/div and the display turned off.

Potential Traps

Each succeeding FAStxmit waveform is transmitted right after the waveform processor finishes moving it from Acquisition memory to Save memory. The code for starting the FAStxmit sequence resides in the waveform-processor-done (wpdn) interrupt routine. It's important to realize that waveform acquisitions are what stimulate the wpdn interrupt—and subsequently cause the FAStxmit waveform transmissions. Because of this implemented sequence, there are two situations that should be avoided.

One exists if a user activates FAStxmit while the 2430 is acquiring in ROLL mode. In this case, since there is constant waveform acquisition during ROLL operation, no wpdn interrupts are generated; it takes a transition to SAVE mode to supply the necessary wpdn interrupt. The controller must be used to cause the 2430 to go into SAVE mode by sending it a RUN SAVE command before starting the FAStxmit sequence. If the programmer does not observe this step, bus operation will hang up.

The other situation occurs after a user requests FAStxmit DELta waveforms with the DELAY by TIME Δ DELAY mode OFF. In this case, the 2430 is prevented from ever acquiring a delay waveform, so the necessary wpdn interrupt will never be generated. Meanwhile, the FAStxmit sequence continues to wait for an interrupt—thus, it too suspends the GPIB.

In both of these situations, only the bus hangs up—the front-panel operation is not affected. The reason is that, when the 2430 recognizes it's been addressed as a talker, it turns off the interrupt coming out of the 9914A interface chip. This is done to reduce conflicts arising from polling information that possibly could be changed by the interrupt. Transfer of the waveform data is precluded by the handshake routine, which polls the interrupt bit and only looks to see whether the GPIB is ready for a new byte. At this point, the 2430 is in an output-only mode and will not pay attention to any bus command until all the requested waveforms have been sent.

To get out of this predicament, the operator can take one of two alternatives: (1) turn OFF the POWER switch to reset things, or (2) press the SAVE button on the front panel to stimulate the transition needed for generating the wpdn interrupt. Although both alternatives are extreme, the tradeoff is speed. And since FAStxmit is a special mode for users with a need for speed, it seems reasonable.

Speed is also a factor in the decision to ignore Device Clear, Interface Clear, and the Talk and Listen address changes until the FAStxmit sequence is complete. Because the interrupts are turned off, checks for these events would be made during the tight loop that is actually sending out new bytes. This increases the total loop time, as well as the time to send the entire waveform.

Speedy Transfer Rates

We've measured some waveform transfer rates for the FAStxmit mode (see Table 6). They were obtained using a very fast controller and a frequency counter attached to the RTRIG output on the rear panel to measure time between the occurrence of record triggers. The intervals measured include both the time to acquire the waveform and the time to send that waveform to the controller.

Because the waveform processor not only moves waveform data from Acquisition memory to Save memory but also from Save memory to the display, turning off all waveform displays (using the VMOde command) also speeds the transfer. Turning off the display eliminates the large data-moves going to it, which in turn accelerates the 2430's part in the transfer.

Table 6
Measured Waveform Transfer Rates

Sweep Speed or Mode	Transfer Rate
100 μs/div	47 wfm/s
50 μs/div to 500 ns/div	36 wfm/s
SAVE mode	65 wfm/s

The timing numbers were measured for sweep speeds of 100 μs and faster. At speeds slower than this, waveform baud rates are retarded, since data acquisition takes longer. And because sweep speeds faster than 500 ns require equivalent-time sampling to fill waveform points (which takes time), fast transmittal of waveform data becomes superfluous. But for sweep speeds from 50 μs to 500 ns, data is handled exactly the same way internally, so the transfer rates are the same.

User Tip: If a high transfer rate for one waveform is needed to reduce system overhead, then placing the 2430 into the SAVE mode (RUN SAVe) before initiating the FAStxmit sequence works well.

Command Timing

Tables 7 and 8 list various GPIB commands and queries available to the 2430 along with the respective times to execute them. These timing measurements were made with a Tektronix 4041 controller and an 8540 emulator station. Each measurement started when the header (for example, CH1 and HORizontal) was decoded. It stopped when the hardware was updated, with the 2430 ready to process the next command.

Table 7
Measured Command and Query Timing

Header	Arguments	Time
SET?	LONg ON OFF	0.93 s 0.79 s
SET	LONg ON OFF	4.94 s 4.60 s
LLSet?		0.14 s
LLSet		0.44 s
CURVe?	Binary Data ASCII Data	0.45 s 3.55 s
CURVE	Binary Data ASCII Data	1.19 s 7.33 s
CH1	VOLts:.2	0.11 s[a]
HORizontal	ASEcdiv:.001 .002	0.08 s 0.09 s
ACQuire	MODe:NORmal	0.07 s
ATRigger	LEVel:0 .1234	0.02 s 0.03 s

[a]Attenuators take time to change!

Table 8
Measured Query Timing

Query	Points Between STArt and STOp	Time
AVG?	128 1024	0.18 s 1.13 s
PCRoss?	128 1024	0.10 s 0.16 s
MINimum?	128 1024	0.10 s 0.17 s

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