Digital Waveform Processing in a High-Performance 7000-Series Oscilloscope

100-MHz Portable Oscilloscope Packs Digital Storage Power

Automatic Distortion Analyzer Speeds Distortion Measurements

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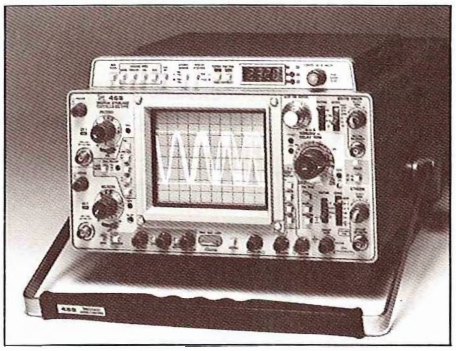
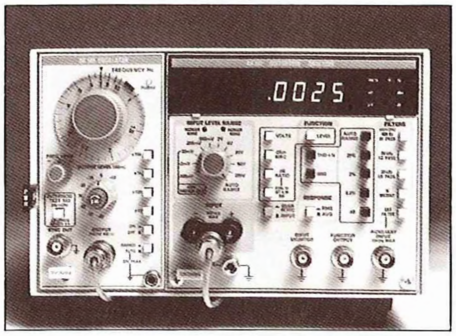
CONTENTS





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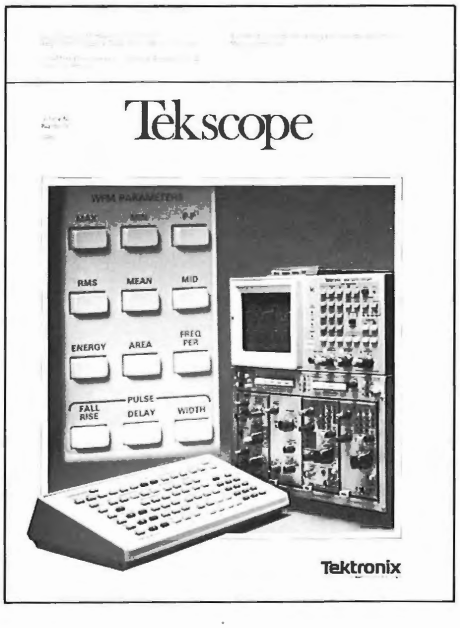
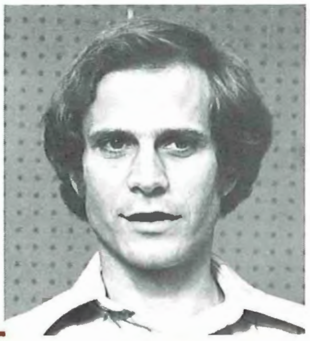
Tekscope is a quarterly publication of Tektronix, Inc. In it you will find articles covering the entire scope of Tektronix' products. Technical articles discuss what's new in circuit and component design, measurement capability, and measurement technique.

Cover: The 7854 with its Waveform Calculator keyboard reduces complex waveform measurements to a few simple push-button operations. Most common measurements are performed by pressing a single push button. The WFM PARAMETERS keys are present on both the scope and waveform calculator.

Cover photo by Jason Kinch



Digital Waveform Processing in a High-Performance 7000-Series Oscilloscope



Tom Rousseau, project manager for the 7854 Oscilloscope, joined Tektronix in 1968 following his graduation from Washington State University in Pullman, Wash., with a bachelor's degree in physics.

Tom first worked with 7000-Series product evaluation. He later designed 7000-Series plug-ins, including a series of vertical amplifiers, before moving to mainframe design and leading the 7854 engineering team.

In his spare time, Tom enjoys hiking, backpacking and what he describes as "ski mountaineering," a combination of downhill and cross-country skiing and mountain climbing. Ski mountaineering has taken Tom –on skis –to and from the summits of several mountains in the Cascade Range.

A graduate of Rice University, Houston, Texas, with bachelor's (1976) and master's (1977) degrees in electrical engineering, Bill Cox developed the diagnostics and test system for the 7854 Oscilloscope.

Joining Tektronix in 1977, Bill first worked with the Microcomputer Development Products group before moving to 7000-Series engineering. Currently he's leading a design team that's working on test diagnostics and ease of manufacture for laboratory oscilloscopes.

Bill enjoys woodworking and rose gardening, a hobby he shares with his wife Debbie, also a Tektronix employee. The Coxes are recent first-place winners in the miniature-rose category of the Tek 1980 Rose Show.

The new Tektronix 7854 Oscilloscope gives engineers and scientists a waveform-measuring and processing tool that significantly simplifies scope measurements. By combining the features of a high-performance plug-in oscilloscope with a microprocessor-based waveform processing computer, this bench-top unit not only acquires and displays signal information, it provides digital storage and quick, convenient push-button solutions to complex measurements. The 7854 thus improves measurement time, accuracy, and repeatability by reducing or eliminating operator involvement in many aspects of the measurement process (figure 1).

Begin with a versatile scope

The four-plug-in 7000-Series format was selected as the foundation for the 7854 because it provides maximum flexibility in meeting diverse user needs. Four-hundred megahertz bandwidth and 500 picosecond/division timing provide a mainframe with minimal speed restrictions. Availability of more than 30 plug-ins enables users to configure the instrument to meet specific needs. Compatible plug-ins include amplifiers with 10 microvolt sensitivities or real-time bandwidths up to 400 MHz (sampling units extend the bandwidth to 14 gigahertz). Spectrum analyzers and TDR plug-ins are also available.

Digital storage

The first level of enhancement to the conventional oscilloscope is the addition of digital storage. The 7854 can store 2048 waveform data points, which are user-configurable for storing up to 16 waveforms (options extend storage capability to 5120 points and up to 40 waveforms).

By depressing a single acquisition key, real-time waveforms are stored exactly as displayed. Once stored, waveforms are presented as bright, clean, nonfading displays. As many as eight stored waveforms can be displayed simultaneously and compared with real-time waveforms.

A key feature of the 7854 is the ability to perform signal averaging. By using a simple push-button sequence, the scope automatically performs multiple acquisitions, averaging each one sequentially with the accumulating results, on a point-by-point basis. The display is continuously updated with the most recent results, enabling users to actually see waveforms shed noise during the averaging process (figure 2).

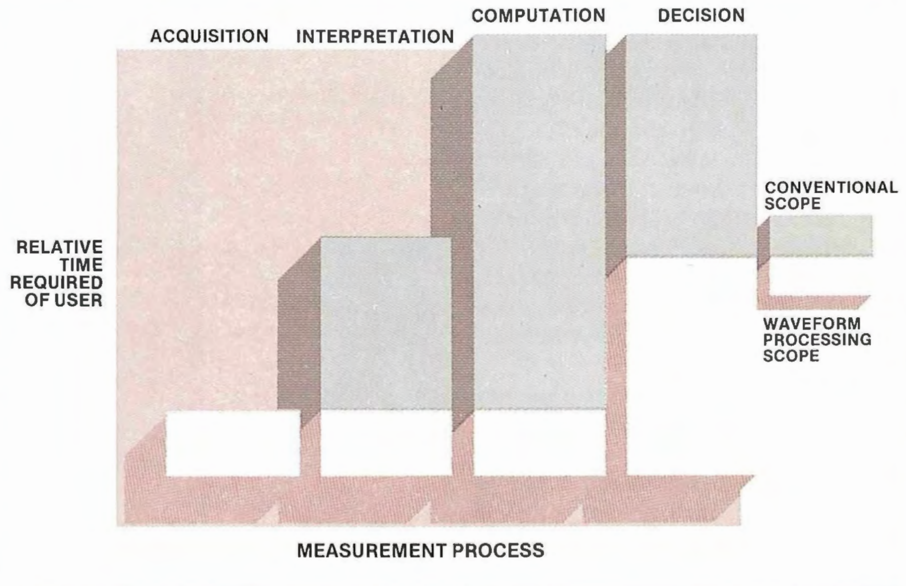


Fig. 1. The 7854 greatly reduces the time required of the user for the measurement process.

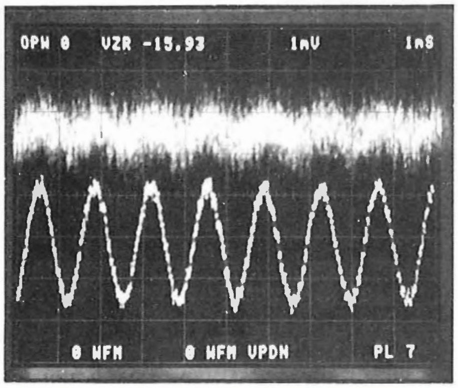


Fig. 2. The effects of signal averaging are shown in this photo. The upper trace shows a noise-contaminated real-time waveform. The lower trace shows the same waveform signal averaged and expanded to 1 mV/division.

Using a 7B87 Time Base plug-in, the 7854 can perform single-shot signal acquisitions as well as store pretrigger events. The maximum single-sweep conversion rate is 2.5 microseconds per point.

Simplified parameter measurements

Once waveforms are stored, common parameters are easy to measure using WFM PARAMETER commands. Single push-button operations automatically determine pertinent waveform amplitude and time-related information including maximum, peak-to-peak, and RMS values, or rise time, frequency, and pulse width. Even area-under-the-curve type measurements such as area and energy are easily determined, with answers clearly displayed on the CRT.

Cursors (displayed as controllable bright spots on the waveform trace) are another measurement aid. Cursors are used to point at, search for, or delimit portions of a waveform for specific measurements, with their status being continuously updated and displayed on the CRT (see figure 3).

Automated parameter measurements of digital waveforms are more reliable and accurate than those visually determined, because human interpretation of the display is eliminated.

Extended waveform processing

To compute results, most scope users frequently need more information than just a few waveform parameters. In the 7854, particularly useful and powerful WFM functions (figure 4) enable simple push-button operations to process data within a fraction of a second, performing tasks which previously required hours of manual computation. In addition, arithmetic commands applicable to waveforms and numeric constants, such as add, multiply, square root, log, and absolute value — are provided. These commands allow users to process waveforms and constants individually, or in combination, with the same ease as operating a pocket calculator.

Programmability

In addition to offering simple keystroke solutions to measurements, the 7854 has commands that the user can program to perform very specific measurement operations. Any of the commands (except program control and edit) can be listed in a particular order, to construct a program which automatically executes each command. Programs can contain up to 920 commands. Figure 5 illustrates how to use this capability to compute the area of an X-Y display.

General-purpose interface

An IEEE-488 standard digital interface for programmable instrumentation rounds out the expanded oscilloscope features offered by the 7854. With the 7854, the user can send digitized waveform data, processed results, and internally-stored programs over the bus. In a systems environment, this capability is very useful for mass storage of data and programs.

The 7854 also reads waveforms from the bus. Once in the 7854's memory they are treated exactly as any other waveform. This feature allows users to easily establish limits for comparative waveform tests. Finally, the 7854 can read programs and even commands from the bus and execute them as if they originated from the 7854's keyboard. This capability is particularly useful for manufacturing situations where general text can be entered remotely and displayed for operators at a production line location (figure 6). In essence, GPIB capability enables the 7854 to work in harmony with stimuli instruments to provide benchtop ATE performance.

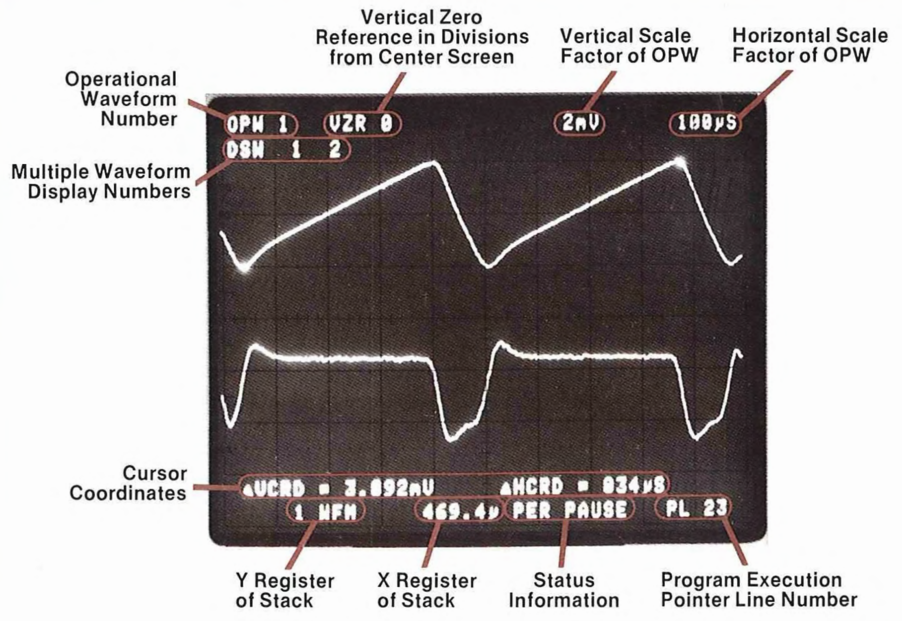


Fig. 3. The 7854 display contains a wealth of information. Included in this display are operands, results, and cursor coordinates.

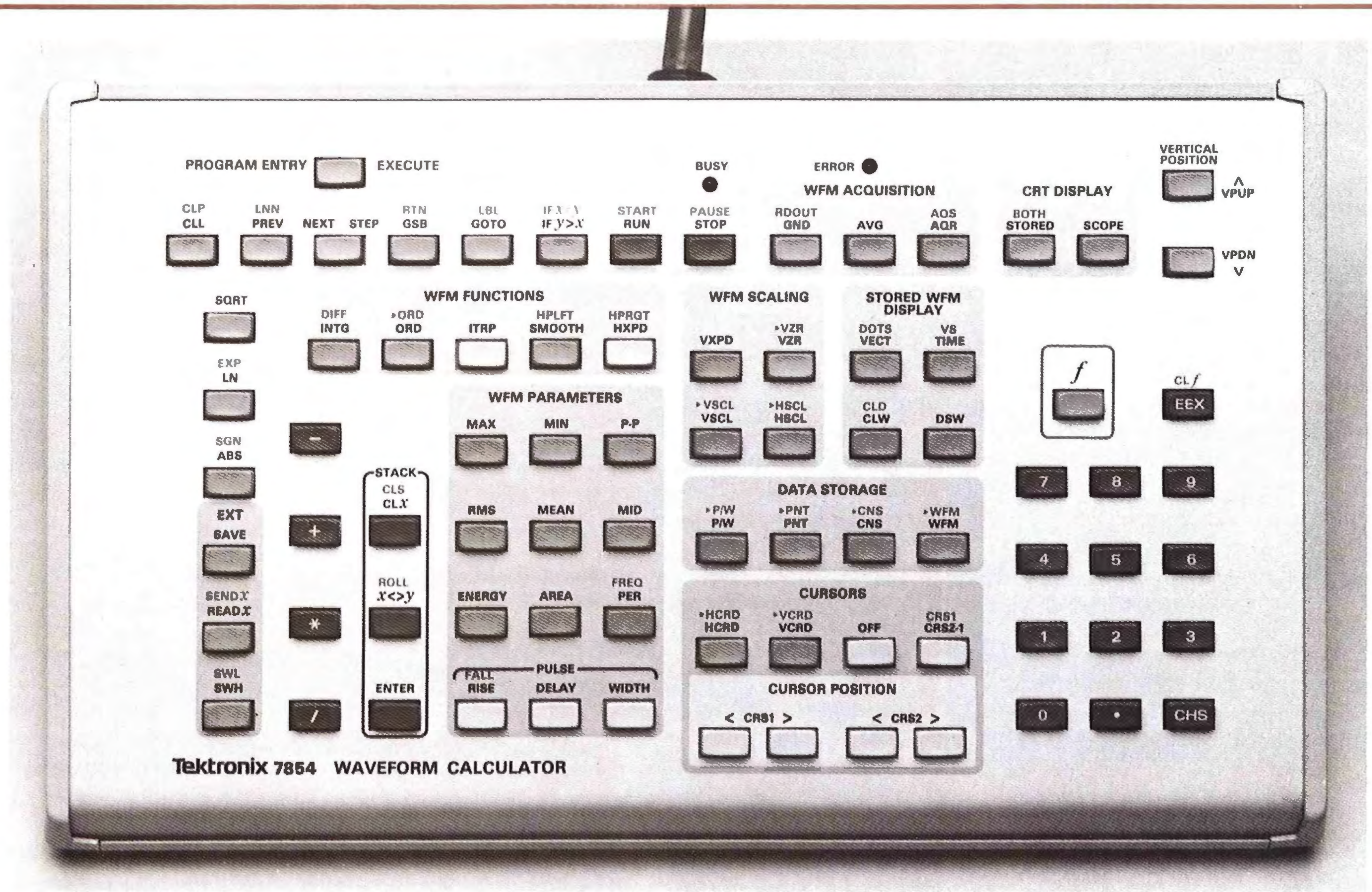


Fig. 4. The calculator keyboard shows convenient RPN operand-operator format. Panel and key shading differences, plus three-letter mnemonics help the user select commands and functions.

Operational architecture

The 7854 is a "friendly" instrument. Conceived as an oscilloscope, it provides all the familiar scope functions. What makes it special however, is that it's aided by a microprocessor-based, onboard computer which greatly simplifies measurements.

The 7854's operating controls enable the user to take maximum advantage of the added processing power. The basic oscilloscope controls are familiar to any laboratory scope user. Digital storage and measurement keys are grouped together in the upper right-hand section of the front panel, clearly separated from the analog controls.

A detachable Waveform Calculator keyboard duplicates the front-panel measurement keys and provides additional waveform functions, calculations, storage, keystroke programming, and GPIB I/O commands.

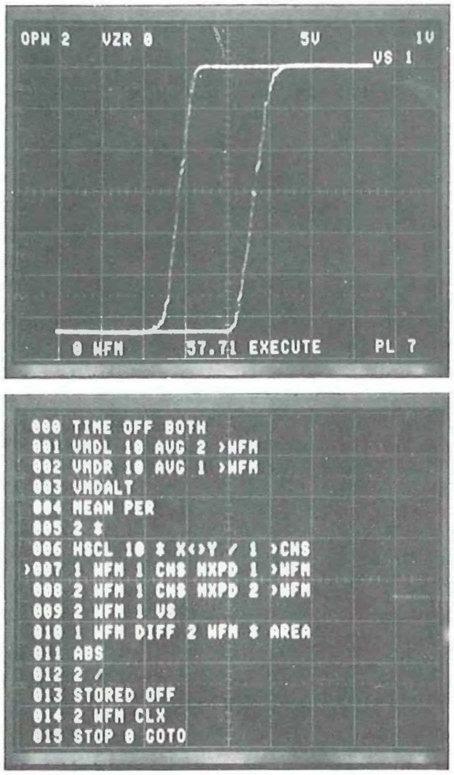
The Waveform Calculator keyboard uses the familiar Reverse Polish Notation (RPN) fixed-function format. Operation is similar to that of pocket calculators, except that the "numbers" are replaced by "waveforms" during computations.

The push-button arrangement on the Waveform Calculator keyboard minimizes hand motions and reversals in direction. Panel shading and color differences functionally group commands, and keys are labeled with three-character mnemonics for quick recognition.

The backbone of the RPN calculator is its data register structure. In addition to waveform registers, familiar stack and constant registers are provided (figure 7).

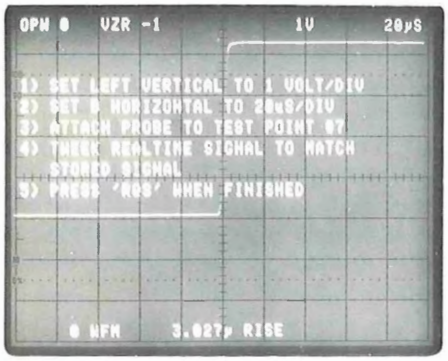
Waveforms are recorded in terms of vertical scale factor (VSCL), vertical zero with respect to ground (VZR), horizontal scale factor (HSCL), and digitized curve points. The number of digitized points per waveform is selectable (128, 256, 512 or 1,024) so users can trade-off resolution for the number of waveforms stored. Cursor coordinates are stored in a separate pair of registers.

As in other calculators, operation results go into the stack; however, as an entire waveform would take up more room than the stack could efficiently accommodate, only the waveform number is put in the stack, as a pointer. Individual points are then fetched from waveform memory as required. For user convenience, new waveform data always goes into waveform memory position 0 (and 1, when two waveforms are digitized simultaneously). In this way,



```
000 TIME OFF BOTH
001 VMDL 10 AVG 2 >WFM
002 VMDR 10 AVG 1 >WFM
003 VMDALT
004 MEAN PER
005 2 *
006 HSCL 10 * X<>Y / 1 >CNS
>007 1 WFM 1 CNS MXPD 1 >WFM
008 2 WFM 1 CNS MXPD 2 >WFM
009 2 WFM 1 VS
010 1 WFM DIFF 2 WFM * AREA
011 ABS
012 2 /
013 STORED OFF
014 2 WFM CLX
015 STOP 0 GOTO
```

Fig. 5. Top photo shows the computation of the area of an X-Y display of two time-related waveforms. The bottom photo is a display of the program used to achieve the computation.



```
1) SET LEFT VERTICAL TO 1 VOLT/DIV
2) SET B HORIZONTAL TO 20uS/DIV
3) ATTACH PROBE TO TEST POINT 07
4) TWEEK REALTIME SIGNAL TO MATCH
   STORED SIGNAL
5) PRESS 'RQS' WHEN FINISHED
```

Fig. 6. A display of typical general text information used to aid the operator during calibration.

users always know where newly-acquired waveforms are. Once an operation or acquisition is complete, the user can transfer the resultant digitized waveform to another memory for permanent storage.

Because calculations often require several operations to be performed in sequence on the same waveform operand, the 7854's designers developed an operational waveform' (OPW) concept to minimize button-pushing. The OPW waveform is the waveform whose number has appeared most recently in the X-register. It is displayed on-screen to prevent having a blank screen during computations. The operational waveform also is the only waveform on which the cursors are operational.

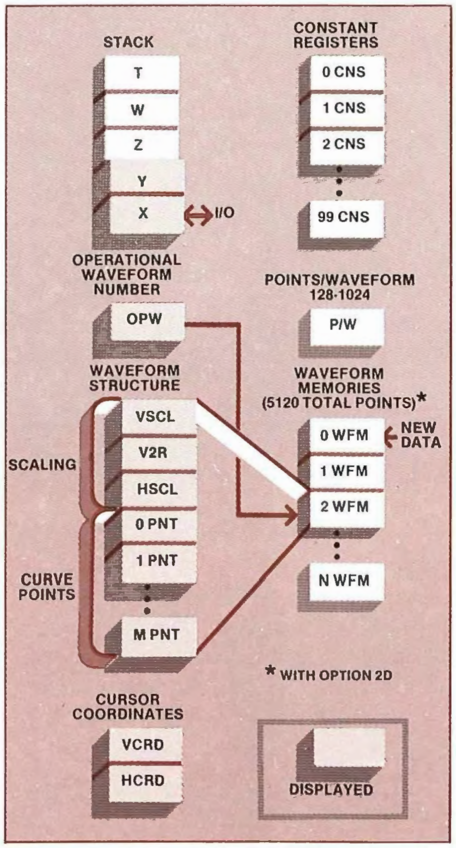


Fig. 7. The 7854's data register structure is similar to a scientific calculator's, with stack registers for operations and storage registers for constants and waveform data. Functions and commands indicated by shaded areas are displayed.

Hardware description

The 7854 hardware consists of two functional blocks: real-time oscilloscope and waveform processor (figure 8). The waveform processor includes the storage and display circuitry and the kernel, or microcomputer.

The scope section, builds upon the proven technologies and capabilities of the 7834 and 7904 oscilloscopes. Several changes were required to interface the analog scope with the 'computer,' including a larger power supply, additional inputs and signal switching in the vertical and horizontal amplifiers, and new control circuits. A new vertical channel switch provides a full-bandwidth, high-fidelity signal source for the digitizer. This hybrid IC utilizes gigahertz technology to make a channel switch having two identical high-speed differential output signals.

The storage and display section consists of equivalent-time samplers, a 10-bit digitizer, and logic circuits which control the flow and sequence of data through memory and display. Track-and-hold samplers are buffered prior to the digitizer switch, which directs either the vertical or horizontal sample to the digitizer. A 10-bit successive-approximation digitizer, based on a Tektronix-developed D/A converter IC, delivers vertical binary information to memory, using the horizontal binary code as the address. During signal acquisition, plug-in scale factors are also stored in ASCII format as 'leaders' to the waveform in memory (see "7854 Uses Display-Oriented Random Sampling Digitizing Technique").

The display circuits include vertical and horizontal D/A converters buffered to drive their respective real-time amplifiers in the scope. The user can select buffers for a dot display (actual data points from memory) or vectors consisting of linearly-connected dots. ASCII-formatted text information is decoded into a 5 x 8 dot matrix format for display.

The heart of the kernel is a TMS9900 microprocessor, which performs all data processing and controls the 7854. A 32 kilobyte ROM contains the operating system firmware, with an additional 6 kilobytes available for patches and other enhancements. The operational memory consists of an 8-kilobyte RAM partitioned as shown in figure 7. The keyboard and GPIB interface are executed through the kernel.

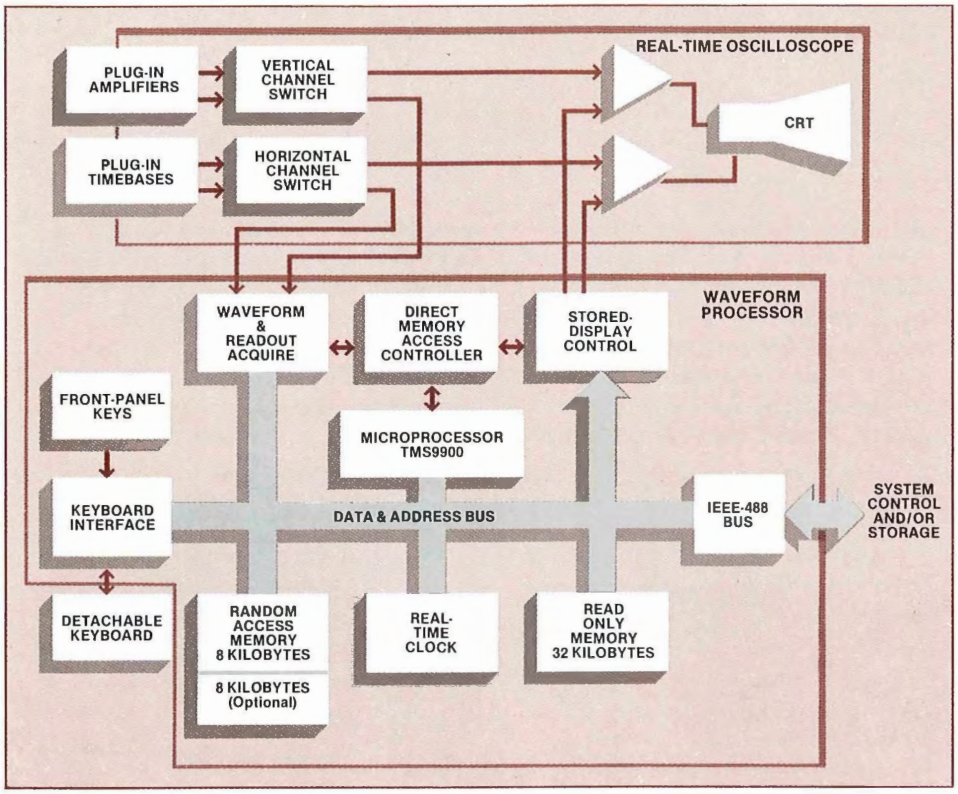


Fig. 8. Simplified block diagram of the 7854. Digitizing and stored-display control circuits capture and display waveforms acquired by the real-time scope; the processor computes waveform parameters as commanded by the keyboard.

Designed for reliability

In a high-productivity instrument like the 7854, reliability is an important factor. Equally important is testability (ease of repair). Both help minimize downtime, thereby increasing 7854 availability.

The original instrument specification set a high MTBF (mean-time-between-failure) goal for the 7854. Reaching the MTBF goal was a major accomplishment as the 7854 has twice as many parts as the 7904. Steps taken included the use of standard components with a known reliability history and burn-in of active components before assembly. Circuit power dissipation and internal instrument temperatures were minimized by using a high-efficiency power supply and, wherever possible, low-power Schottky logic circuits. Computer modeling and thermal profiling of prototypes identified problem areas and hot spots early in the development cycle.

Soldering-in most discrete components further increased reliability. Because soldering-in components conflicted with testability concerns, the final 7854 design required a trade-off. Most socketing for individual components is eliminated, but card-cage construction using plug-in, single-function circuit boards maintains, and even enhances, testability.

As a final step, each finished instrument receives a 200-hour active burn-in to weed out infant mortality failures and ensure users the most reliable product.

Designed for testability

The 7854's firmware includes a self-test that's automatically invoked upon power-up. If the test detects a failure, front panel indicators provide general information about the failure.

As mentioned previously, the 7854 has separate analog and digital subsystems, allowing easy problem isolation and troubleshooting access (figure 9). By using such aids as an analog test card, which simulates key functions of the digital section, the analog portion of the 7854 (except readout) is fully operational, even with all of the digital boards removed.

In addition to the card-cage, single-function circuit-board concept which allows isolation of specific functional modules for test, other design characteristics enhance testability. These include the capability of enabling or disabling hardware elements (such as interrupt request generators or DMA channels) through both hardware jumpers and firmware control; generation of dedicated control signals for signature-analysis-based troubleshooting; and easy access to numerous test points while circuit boards remain in the card cage.

A test connector on the microprocessor board gives the optional 7854 Diagnostic Test System access to all digital bus signal lines. Part of 7854 memory space and some of the highest-priority processor interrupt request lines are reserved for test system use.

Diagnostic test system

The 7854 Diagnostic Test System operates in conjunction with a diagnostic memory board which replaces the standard 7854 ROM board. An RS-232 terminal allows user interaction during testing.

Test system firmware consists of twenty-two commands, including automatic diagnostics for digital boards, and various utilities to control and monitor 7854 operation. The diagnostic system is easy to use. Flexible command entry and a "HELP" command aid users unfamiliar with system operation (figure 10). The system accepts free-form input for both commands and parameters, as well as understanding their two-letter abbreviations.

Diagnostic commands invoke a series of functional module tests organized along digital board boundaries. The system prints out the names of the function under test and makes a pass/fail decision wherever possible, isolating the fault to the failing component or components

The 7854 Uses Display-Oriented Random Sampling Digitizing Technique

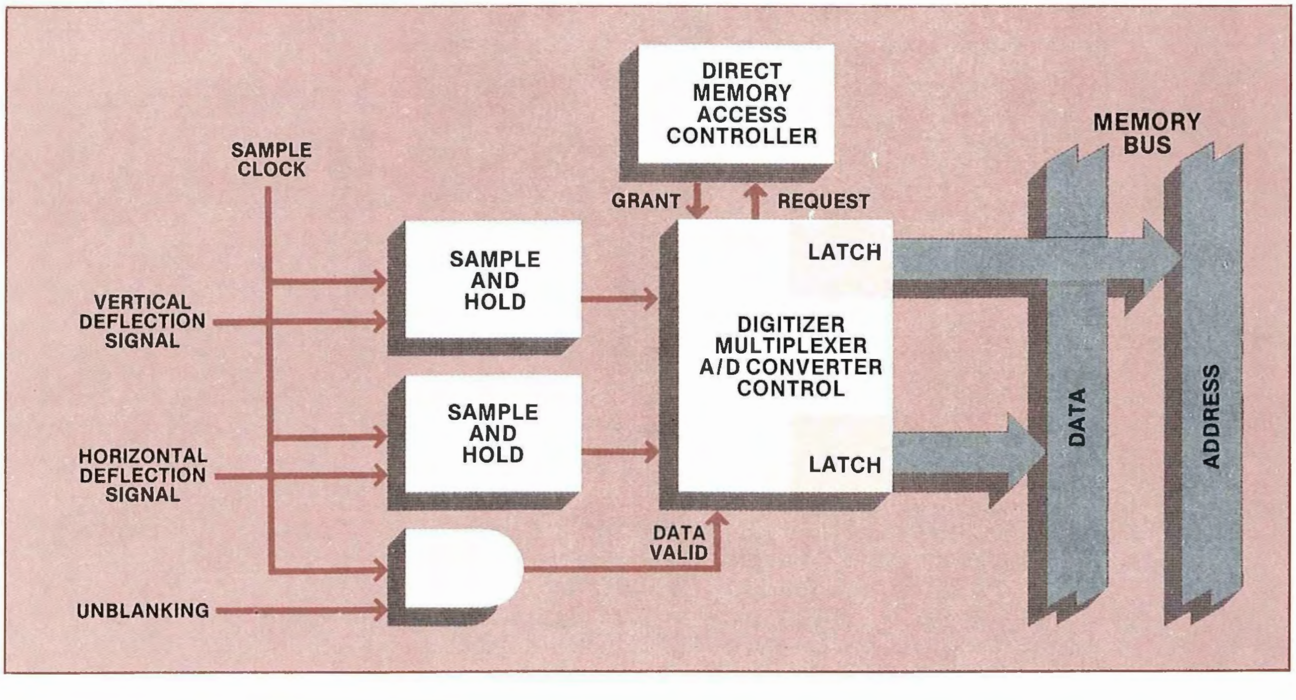
A major design criterion for the 7854 was compatibility with the existing line of 7000-Series plug-ins for both analog and digital storage operations. This means the 7854 can digitize signal input from any 7000-Series plug-in.

The system developed for the 7854 uses a display-oriented random sampling digitizing technique. In a digitally stored waveform, each storage location corresponds to a horizontal display coordinate, with the stored value being the vertical trace position at that point. The trace on the display screen is written by a single electron beam, thus the deflection voltages at any instant in time represent a horizontal/vertical coordinate pair. In the 7854, the display screen is regarded as having 1024 vertical coordinates, with a choice of 128, 256, 512, or 1024 horizontal coordinates.

When storage mode is selected, vertical (Y) and horizontal (X) analog signals are routed to respective sample-and-hold circuits. A free-running clock controls the sampling operation. Schottky diode bridges gate the X and Y values to the sampler hold capacitors, with both X and Y values sampled simultaneously. The unblanking signal from the time base is sampled at the same time as the X and Y signals. If the beam is on at sample time, a data-valid pulse is generated initiating a DMA request.

X and Y outputs of the sample-and-hold circuits are multiplexed to a single successive-approximation 10-bit digitizer, where they are digitized and latched. When DMA-grant is received, the Y value is written to the memory address represented by the X value, along with a flag marking the position filled. This continues until 99 percent of all real-time displayed points are stored. Remaining unfilled points are then interpolated by the processor. Digitizing time for each value of X and Y requires one microsecond, or a total of two microseconds per X-Y coordinate. Transferring this data to memory takes another 1.5 microseconds for an overall digitizing and storing time of 3.5 microseconds per point.

For dual-trace acquisition, the status of channel-switch control signals at sample time determines the proper memory location for storage of the digitized sample.



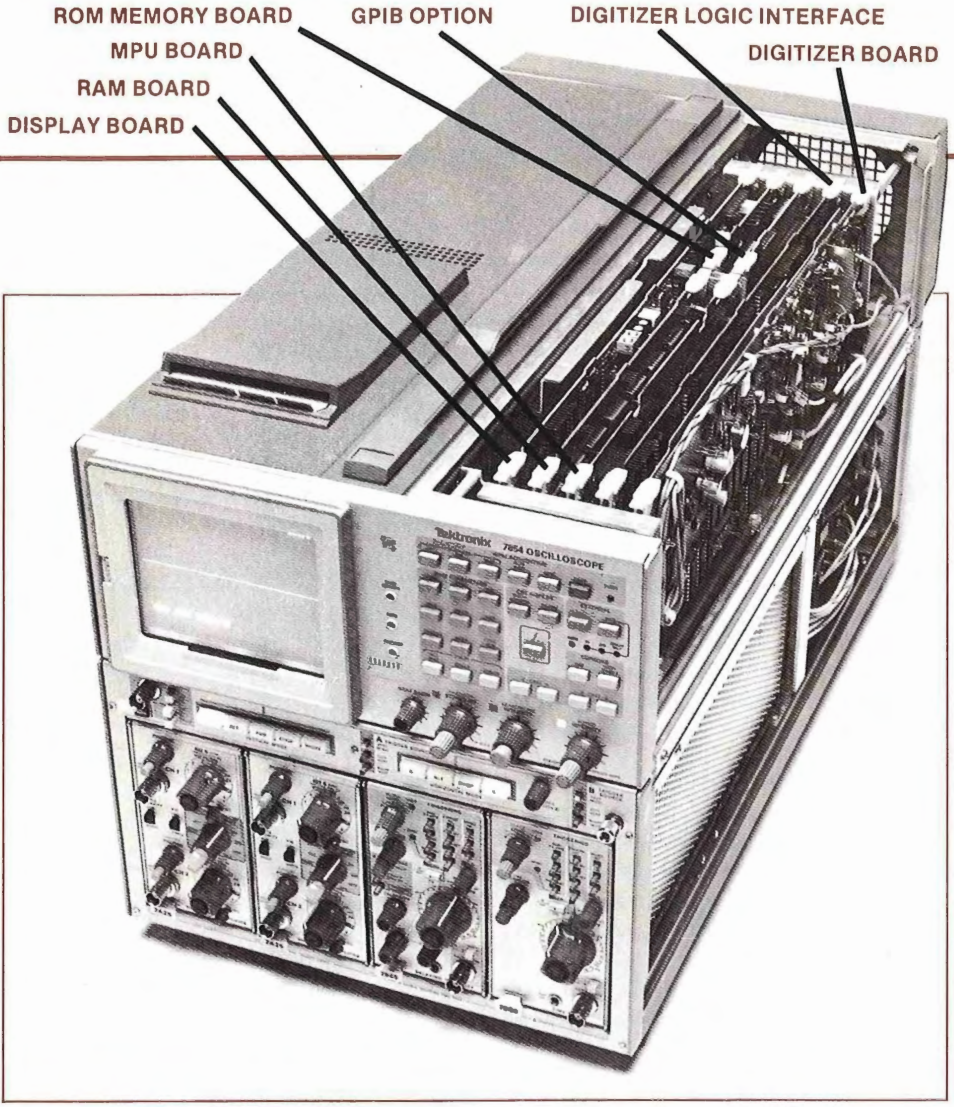


Fig. 9. The 7854's digital section. With the unit powered up, extender boards allow easy access for test purposes.

```
>HELP

7854 DIAGNOSTIC SYSTEM
   COMMAND LIST:

 BK [BREAKPOINT]
 CB [CLEAR BREAKPOINT]
 EX [EXAMINE MEMORY]
 DU [DUMP MEMORY]
 GO [GO]
 HE [HELP(COMMAND MENU)]
 LB [LIST BKPT. STATUS]
 RE [REGISTERS]
 RO [ROM CHECKSUM]
 RS [ROM S/A]
 ST [SELF TEST]

 067-0961-XX COMMANDS:

 BB [RAM BATTERY BACKUP]
 CA [CALIBRATE]
 CL [CONTROL LOGIC]
 CR [CRU UTILITY]
 DG [DIGITIZER]
 DS [DISPLAY]
 GP [GPIB]
 MP [MPU SIG. ANAL.]
 RA [RAM TEST]
 SE [SET PARAMETERS]
 TI [REAL TIME CLOCK]
```

Fig. 10. The command menu for the optional 7854 Diagnostic Test System.

(figure 11). The system also prints whatever data it has about a failure (example: "06 CHARACTERS DISPLAY CYCLE FAILED — ETX NOT RECOGNIZED") and, whenever possible, the identity of the failed component.

At this point, to isolate the fault within the failing module or function indicated by the diagnostics, the user may invoke a backup stimulation routine, such as signature analysis or a scope troubleshooting loop. This scheme cuts service time by using the comparatively slow manual procedures of signature analysis or scope loop troubleshooting only when necessary and then only on the small portion of circuitry indicated by the diagnostics.

To make the calibration of both digital and analog sections easier, the diagnostic test system includes a Calibration Aids package consisting of several standard waveforms and specialized routines.

```
>SET CLEAR

>DS 01

DISPLAY V 2.0
01 RT CLOCK FAILED--CLOCK MISSING
02 RO ACQ DMA PASSED
03 Y-T:AWRD INTERACTION PASSED
04 X-Y:AWRD/BWRD INTERACTION
   A-WORD REGISTER ADDRESSES PASSED
   B-WORD REGISTER ADDRESSES PASSED
05 CURSORS DSY CYCLE PASSED
06 CHARACTERS DSY CYCLE
   BURST MODE: PASSED
   8 KHZ MODE: PASSED
07 Y-T DISPLAY

>SET LE

>DS

DISPLAY V 2.0
01 RT CLOCK FAILED--CLOCK MISSING
      SCOPE LOOP #1
   PRESS [GO] KEY TO EXIT
>
```

Fig. 11. Display board diagnostic test showing real-time clock failure and activation of scope loop for troubleshooting.

Acknowledgements

While the 7854 project involved the efforts of dozens of people, the following deserve special recognition for their significant contributions. Val Garuts conceived and developed the instrument concept. The design team included: Les Larson, digitizer; Jack Collins, sampler; Jim Schlegel, Ellen Delaganes and Burt Johnson, firmware; Wes Kosta, interface and CRT circuits; Tim Holte, high speed analog circuits; Kirk Wimmer, power supplies and memories; Gary Fladstol, display and MPU circuits; Jim Tallman, system architecture, testability and training; and Mark Anderson and Ed Wolf, mechanical design. The 7854 was thoroughly evaluated by Greg Rogers, Ray Blohm, Mike Mraz, Roy Kaufman and Jim Peterson. Norm Church helped develop the service diagnostics, and Clark Foley contributed many valuable applications. Bettie Turnbull coordinated prototype and pilot builds and Ernie Johnson and Bob Simpson provided invaluable manufacturing support.

100 MHz Portable Oscilloscope Packs Digital Storage Power

Bruce Blair received his degree in mathematics from the University of Nebraska in 1969, spent four years in the Air Force as a computer operator, and returned to Nebraska for his M.S.E.E. (1975). Joining Tek upon graduation, Bruce contributed to the 7612D Transient Digitizer design, then transferred to the portable scope design group. His leisure-time activities include gardening and radio-controlled airplanes. He has a pilot's license.

Storage oscilloscopes, in which storage takes place in the cathode ray tube (CRT), are used in many applications. Now, with low-cost semiconductor memory available, it is possible to store waveforms digitally and fulfill many of these applications more efficiently.

With digital storage, displays are crisp and bright, viewing time is unlimited, and the stored display can be expanded and positioned vertically and horizontally. Multiple stored waveforms and realtime waveforms can be displayed together, and events occurring prior to the trigger signal can be stored and displayed. Further, the use of cursors, averaging techniques, and an accurate time base clock improves resolution and accuracy.

Storage with a familiar face

The new Tektronix 468 Digital Storage Oscilloscope is designed for applications best served by an instrument that combines wide-bandwidth analog performance with digital storage, in a portable format.

The widely used Tektronix 465B serves as the basis for the 468 design. In the nonstore mode, the 468 is a 100-MHz conventional oscilloscope that has the characteristics of, and operates just like, the 465B.

The storage controls, labeled in terms familiar to scope users, are located on a small front panel extending across the top of the instrument (figure 1). A digital readout displays calibrated cursor measurements or the number of sweeps selected in the average and envelope storage modes.

Some new capabilities

Most digital storage scopes have a bandwidth in the hundreds of kilohertz, which limits their range of application. The 468 combines a 25-megahertz digitizer and sine-wave interpolator to achieve a useful storage bandwidth of 10 megahertz. A linear, or pulse, interpolator is available for fast-rise signals.

Digital storage scopes designed prior to the 468 have an inherent display problem with horizontal jitter that occurs during multiple acquisitions of a signal. Jitter of up to ± ½ sample interval occurs because of the asynchronous relationship between the trigger signal and sampling clock. In the 468, an anti-jitter circuit overcomes this problem. The time interval between the occurrence of signal trigger and the next sample clock is measured, and a horizontal offset equivalent to this time interval is developed and applied to the horizontal amplifier. The result allows the user to view displays magnified up to 100 times without excessive jitter.

Aliasing, the perception of a false waveform, sometimes occurs in a digital storage display when there aren't enough dots to delineate the waveform. The 468 permits two means of detecting aliasing. Users can switch to the nonstore mode to see if the input signal is higher in frequency then the apparent stored display signal, or they can switch to the envelope storage mode. In the envelope storage mode the 468 acquires, the maximum and minimum amplitude levels reached during each sample period and presents them in a cumulative display (see figure 2).

The envelope mode is also useful for detecting glitches. In the normal storage

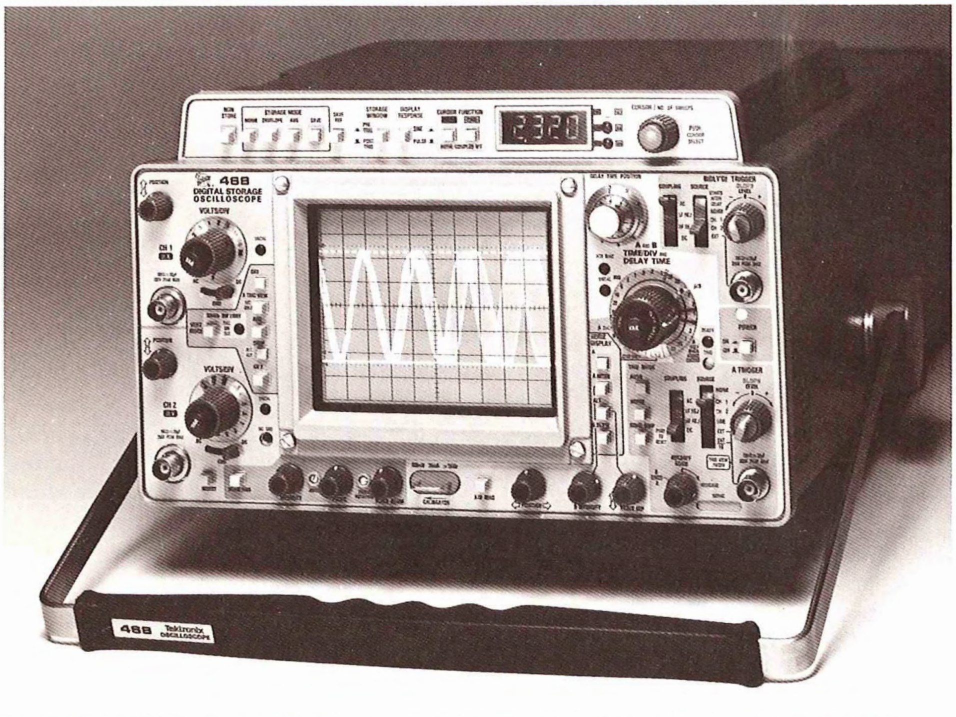


Fig. 1. The 468 Digital Storage Oscilloscope. Analog operation is just like the 465B. Digital storage controls are in the panel at the top of the instrument.

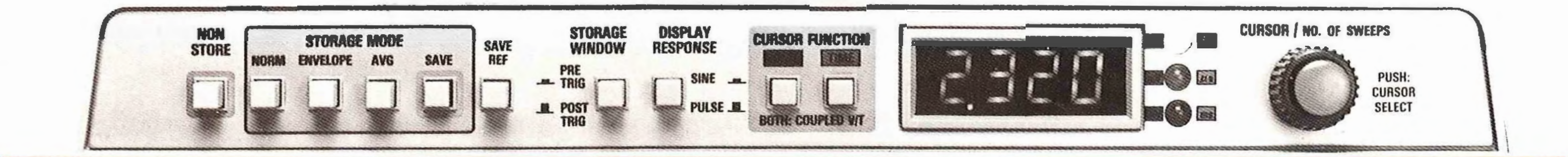


Fig. 3. The digital storage controls are clearly separated from the analog controls and are labeled in terms easy to understand.

mode, sampling frequency is set by the TIME/DIV control to maintain 50 samples per division (for sweeps slower than 2 μs/division). At the slower sweep speeds, the longer periods between samples limit the likelihood of acquiring a glitch. In the envelope storage mode, however, a 5 megahertz sample frequency is used for sweep speeds slower than 20 μs/division. The user can select the number of sweeps over which the maximum and minimum points of the waveform will be acquired. With these conditions, the probability of acquiring the glitch increases considerably. The stored display shows only the time position and amplitude of the glitch. Knowing when the glitch occurs, the user can use display and expansion to examine the glitch in detail.

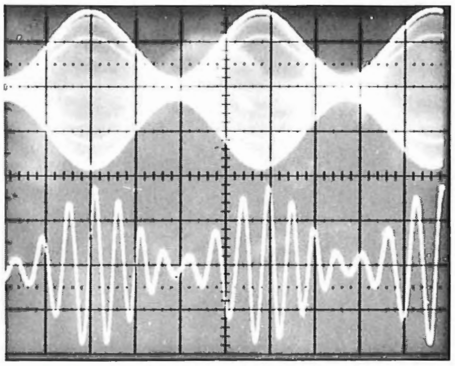


Fig. 2. Aliasing is quickly confirmed by switching to the ENVELOPE mode. Solid lines at the top and bottom indicate aliasing is occurring.

The cumulative nature of the envelope mode makes it useful for other applications, such as finding intermittent pulses in a pulse train, or viewing frequency drift and amplitude modulation in a signal.

The storage controls

An overview of the 468's storage functions can best be gained by a review of the storage controls (figure 3).

Two acquisition modes — NORM and ENVELOPE — are standard. A third mode — AVG — is available as an option. In the NORMal mode, the 468 continually updates the display with new waveforms being acquired and displayed each sweep. The ENVELOPE mode is a repetitive mode in which the signal is acquired over a selected number of sweeps. Each data point of the input waveform is compared to the maximum and minimum values of the same data point accumulated from previous sweeps. If the data point represents a new maximum or minimum value for that data point, it replaces the previously acquired value. Thus, the display is an envelope showing the extremes traversed by the waveform during the selected number of sweeps. The optional AVG mode is a repetitive mode also, with the display representing the average value for each data point over a selected number of sweeps (2 to 256 in a binary sequence). This mode is useful in extracting signals masked by noise.

Two other storage modes — SAVE and SAVE REF — provide for holding a display indefinitely to facilitate measurement and comparison. The SAVE mode stops acquisition immediately in the NORM or ENVELOPE (continuous sweep) modes; however, it allows completion of the selected number of sweeps in the AVG and selected-sweep ENVELOPE modes. The user can position the stored display and expand it up to 10 times vertically and 100 times horizontally using the vertical attenuator and time base controls.

In the SAVE REFerence mode, the 468 holds the display but continues acquisition in the selected storage mode. The reference waveform is displayed in the vertical position at which it was acquired, and will not be affected by any front-panel control change other than horizontal position.

The user may acquire waveform data before or after the trigger by selecting either the PRE TRIGger or POST TRIGger storage window. In the PRE TRIG mode, the 468 stores approximately 8.75 divisions of signal occurring before the trigger event. The B DLY'D horizontal display mode can be used to position the trigger point anywhere on-screen to view data points occurring after the trigger. In the POST TRIG mode, 1.25 divisions of pretrigger signal are stored and displayed, with the remainder of the display showing events occurring after the trigger.

In storage operation at sweep speeds of 1 μs per division and faster, the display is enhanced by the use of interpolators. When the user views sine-wave signals, a sine-wave interpolator inserts extra points to allow viewing of frequencies up to 10 MHz. The interpolator uses an optimized, windowed $\frac{\sin x}{x}$ transfer function implemented in software. For signals with step functions, such as square waves and pulses, the 468 achieves a more accurate reproduction with linear interpolation in which the data are connected by straight lines.

Two sets of digital cursors improve accuracy and repeatability when making digital storage measurements. A 10-bit digital-to-analog converter provides a resolution of 1000 bits, or 0.1 percent, both vertically and horizontally. The amplitude accuracy of ±3 percent is determined by the analog circuitry. However, the time base accuracy is equivalent to the resolution, 0.1 percent.

The VOLTS, or amplitude, cursors are displayed as two horizontal lines which can be positioned by the CURSOR/NO. OF SWEEPS control. The TIME cursor appears as two bright dots on the waveform trace, also positionable by the cursor control. A 4-digit LED readout displays the difference in time or amplitude between the respective cursors.

By depressing both the VOLTS and TIME cursor push buttons, the user can couple the cursors together — a convenience for some measurements. For example, to accurately measure the period of a sine wave, the time cursors can be accurately positioned on successive peaks of the waveform by noting when the LED readout (which is displaying amplitude) shows zero. Releasing the VOLTS push button causes the readout to display the time between dots which, in this instance, is the period of the sine wave. The coupled mode is also convenient for measuring rise time.

Besides displaying amplitude and time, the LED readout can display the number of sweeps selected in the envelope or average modes. It also displays an error message should the 468 fail the

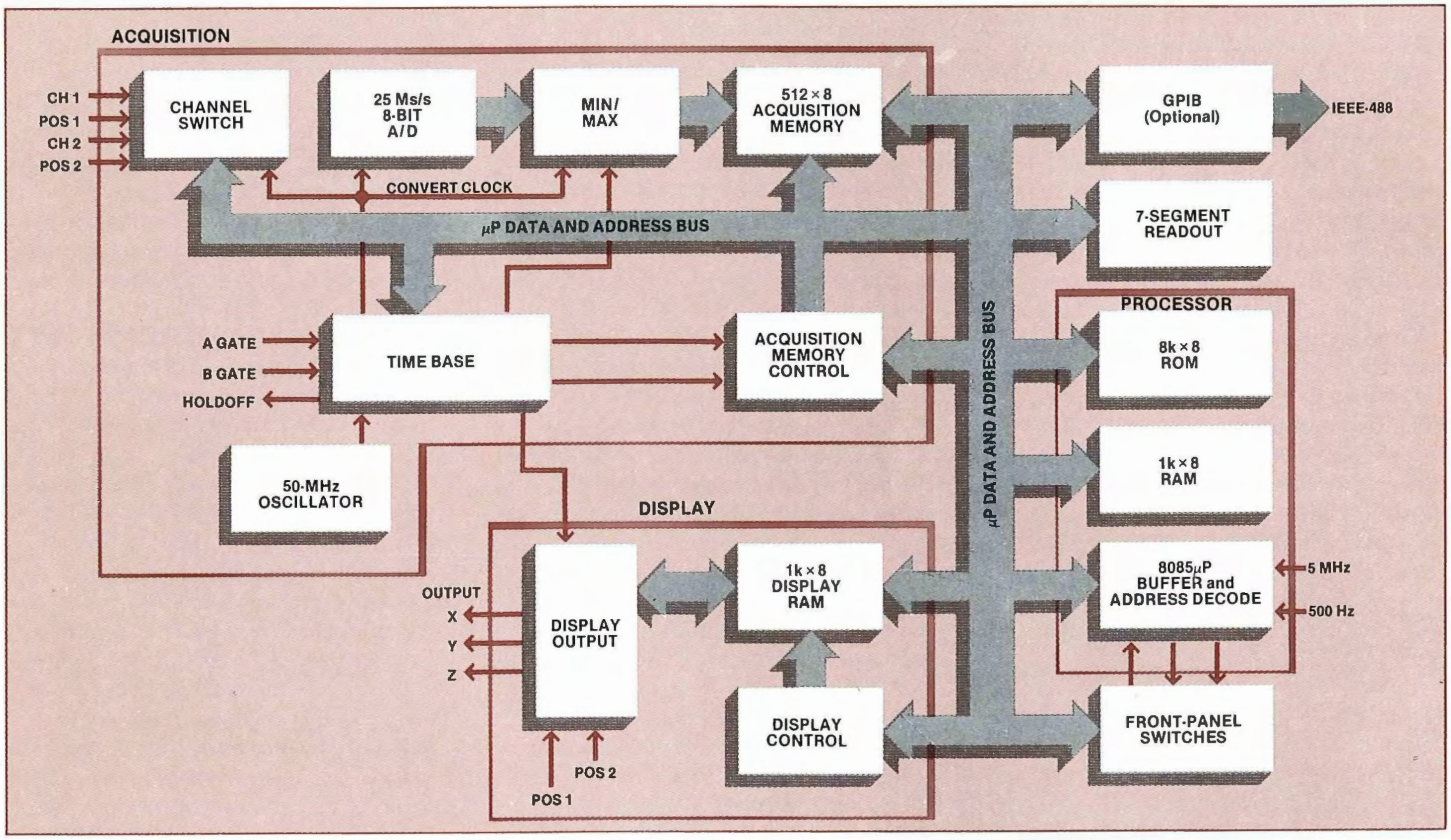


Fig. 4. A simplified block diagram of the 468's digital storage circuitry. Separate acquisition, processing, and display memories allow these activities to take place simultaneously, thereby speeding up the measurement process.

start-up diagnostic routine initiated when the instrument is turned on.

Adding digital storage

The analog circuitry in the 468 is basically the time-proven circuitry used in the 465B. Power supply capacity is increased to provide the power required for the digital circuitry, which resides on four printed-circuit boards: three at the rear of the instrument and one in back of the storage control panel.

The digital storage function, controlled by an 8085 microprocessor, consists of three major subsystems: acquisition, processor, and display (figure 4).

Analog signals picked off at the vertical preamplifiers, along with position information from the vertical position controls, are routed to a channel switch in the digital section. When the user selects the store mode, the channel switch passes the analog signal to the 25-megasamples-per-second, 8-bit analog-to-digital converter. The digitizing rate varies from 10 samples per second, at the 5 sec/division sweep speed, to 25 megasamples per second at sweep speeds of 2 µs/division and faster.

The digital signal passes through the envelope circuitry, which prefilters the data in the envelope mode of operation, and is stored in the acquisition memory. At the end of each sweep, the data is transferred to the scratch memory, where the processor performs interpolation, averaging, and envelope accumulation. Storing in scratch memory allows acquisition and display to proceed while processing takes place. Two 512-bit or four 256-bit waveforms can be stored in the 1-k RAM scratch memory. The processed waveform data are then transferred to the 1-k display RAM to await conversion to analog signals for display.

The digital time base, sweep-jitter-correction circuitry, and acquisition-memory control are also part of the acquisition system. The time base generates the sample clock and other clocks needed for the storage and display functions. The A and B GATE signals from the analog section serve as the trigger source for the digital section.

The display system

When the user selects the store mode, the analog portion of the 468 continues to function normally, with the exception that signals from the digital storage section now drive the X, Y, and Z amplifiers. The vertical amplifier switches to the trigger view mode, as the trigger view port serves as the stored waveform input during store operation. The analog sweep and Z-axis currents are shunted to ground, and their stored counterparts are inserted into the X and Z amplifiers.

The microprocessor loads the display memory from the scratch memory. After setting up the display gain and position controls, a start signal, sent from the microprocessor to the display controller, begins the display function. The 250 kHz display clock is enabled and data is clocked from the display and dot memories to the vertical DAC, filter, and output circuits. The CRT beam is turned on and the horizontal display ramp is enabled. As discussed earlier, an offset current from the jitter-correction circuitry determines the starting point of the ramp. Horizontal cursor positions, displayed as two intensified dots on the trace, are derived from the dot memory. The microprocessor computes the time between cursors, and outputs appropriate drive signals to the 7-segment LED readout.

Several steps are involved in the vertical display activity. A 10-bit digital-to-analog converter (DAC) converts data from the display memory to an analog signal. The signal then passes through a series of stages which provide positioning for SAVE mode and magnify the vertical component. A sample-and-hold circuit and low-pass filter remove glitches generated by the conversion process and smooth the signal before it passes to the vertical channel switch for display. The vertical cursors reside in registers and, along with data from the display memory, are multiplexed into the DAC on alternate sweeps.

Much of the 468 design effort focused on minimizing the deviation from conventional scope operation. This involved limiting the number of "store only" controls. The methods used to magnify and position the display in the SAVE mode typify these efforts. An extra set of contacts on the vertical-attenuator switches and a programmable-gain amplifier allow the user to increase the amplitude of the displayed waveform without adding a new control.

Likewise, the vertical position controls used for nonstored signals can also position the saved waveform. Figure 5 shows a simplified block diagram of the circuitry that accomplishes this double function. In nonSAVE store operation, the 468 stores a position value during signal acquisition. A feedback signal, generated by the successive-approximation register and DAC, keep the input of the comparator at zero volts. This value is an element in the data stored in the display memory.

Selecting the SAVE mode stops the D/A conversions. The voltage at the input to the comparator, and hence vertical position, then tracks the position control setting.

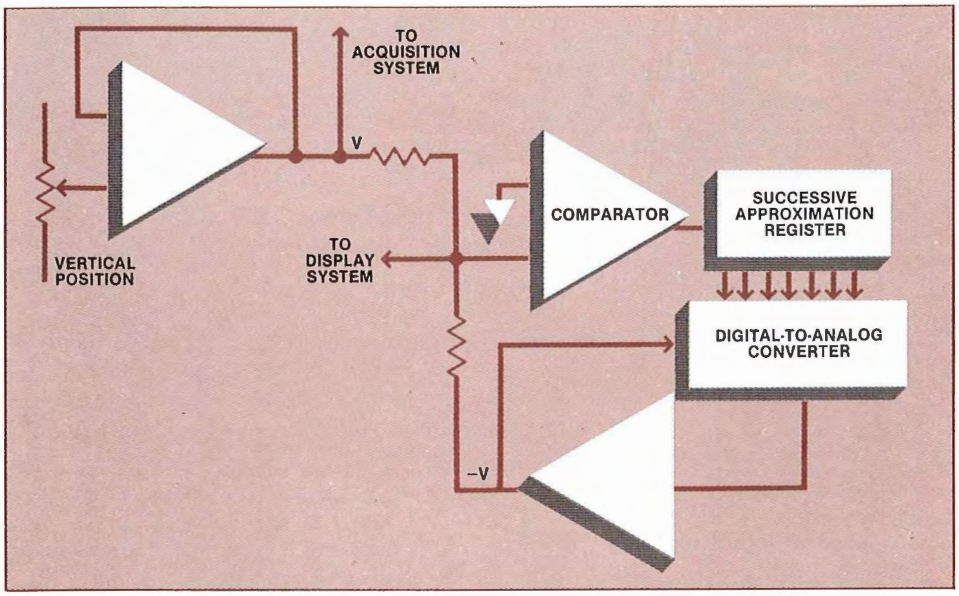


Fig. 5. A simplified block diagram of the stored-waveform positioning circuitry. During normal storage, the comparator input is kept at zero volts by feedback from the DAC. During SAVE storage, digital-to-analog conversions stop and the input to the comparator tracks the vertical position control setting.

Options expand capability

A number of options are available to enable users to configure the 468 to their particular application. For those working with low-level signals, the signal-averaging option improves measurement accuracy by reducing displayed noise. A GPIB option provides access to the digitized signal for data logging or further processing via the IEEE-488 interface bus. Another option provides sync-separator circuitry for triggering on a television signal.

Serviceability is enhanced by an optional service ROM that provides service and signature-analysis routines for verifying and troubleshooting the digital portion of the instrument.

Summary

The 468 provides the benefits of digital storage while maintaining the conventional measurement capability and operating ease of the industry-standard 465B. Many of the shortcomings of earlier digital storage instruments, such as limited bandwidth, trace jitter, and aliasing are overcome in the 468. New capabilities, such as viewing of pretrigger events, extracting signals from noise through signal averaging (optional), and logging of signal data via the GPIB (also optional) make the 468 one of the most versatile portable oscilloscopes available today.

Acknowledgements

The program manager for the 468 is Luis Navarro: Tom Dagnostino, project engineer up to design completion, designed the display system and scope interface. The author became project engineer after design completion and also had design responsibility for the acquisition system and GPIB. The microprocessor system is the work of Dave Olsen, firmware project leader; Karen Walker assisted in firmware design. Len McCracken did the mechanical design. Doug Strobergerwas our resident expert on the 465B. Mark Acuff, Doug Robbins, and Alan Dickerson provided technical support. Special thanks are due our prototype support and ECB-design groups for their valuable contributions.

Automatic Distortion Analyzer Speeds Distortion Measurements

Bruce Hofer was both project manager and a contributing engineer for the AA 501 Distortion Analyzer and SG 505 Oscillator. He first came to Tektronix in 1969 as a summer student prior to receiving his B.S.E.E. from Oregon State University. Bruce worked on the design of several 7000-Series time bases before joining the TM 500 group. He has three patents (with three more pending) and is author of a paper on oscillator design.

Bruce devotes most of his leisure time to his family (a wife and two daughters, ages one and three). He also enjoys playing the organ and listening to fine music.

Traditionally, distortion analysis required several minutes of a skilled operator's time, performing many steps, just to get a single measurement. Now, the new Tektronix AA 501, at the touch of a button, returns a valid distortion measurement in just five to seven seconds.

What is distortion?

Distortion is a measure of signal impurity. It is basically any undesirable element or change in a signal. There are many forms of distortion; however, the most common ones add components not contained in the original signal.

The human ear has the ability to detect very small levels of distortion. For example, under favorable conditions, distortion levels of 0.1 to 0.2 percent are detectable by most people. Some claim even greater acuity.

A typical electronically-processed audio signal must pass through many stages of amplification, detection, and filtering before reaching the ear. Because distortions from each stage are cumulative, it is not uncommon to require individual stage distortion levels of less than 0.01 percent to ensure overall quality.

The AA 501 Distortion Analyzer and SG 505 Signal Generator combination can measure signal impurity to less than 0.0025 percent, or one part in 40,000. This extremely small level of distortion is equivalent to the sound of gently rustling leaves on a quiet day compared to a loud rock band measured at the same distance. The SG 505 itself contains less than 0.0008 percent (eight parts per million) signal impurity and is the lowest-guaranteed-distortion continuously-tunable oscillator available commercially.

How is distortion measured?

The basic approach to measuring distortion is to filter out the desired components of a signal and measure the remainder expressed as a percentage of the original level. For example, when making a total-harmonic-distortion plus noise (THD + N) measurement (see figure 2), the operator uses a finely-tuned notch filter to null out the fundamental and then measures the remaining harmonics (caused by distortion and noise) with a wideband voltmeter.

Figure 3 shows the basic block diagram of the AA 501. A true differential front end, consisting of attentuators and

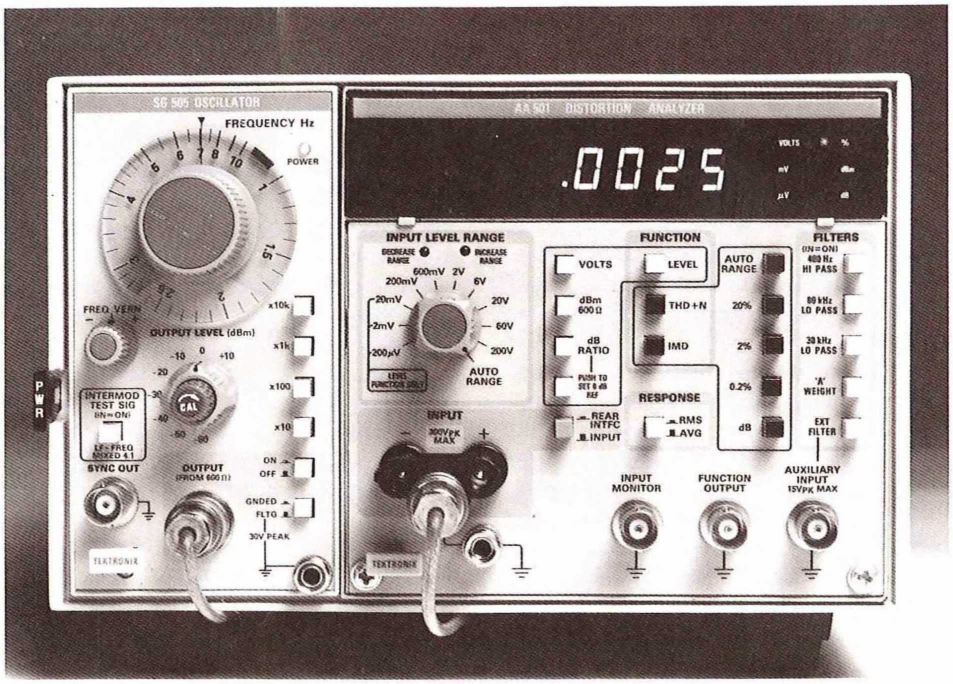


Fig. 1. The new TM 500 AA 501 Distortion Analyzer and SG 505 Oscillator make complex distortion measurements easy.

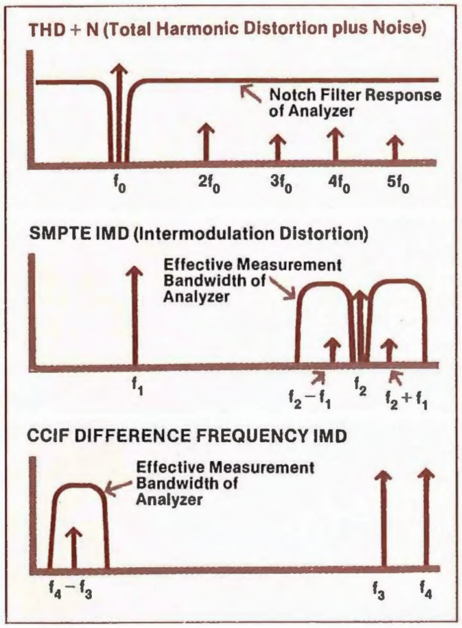


Fig. 2. Three types of distortion and the approach used to measure them are depicted in this drawing.

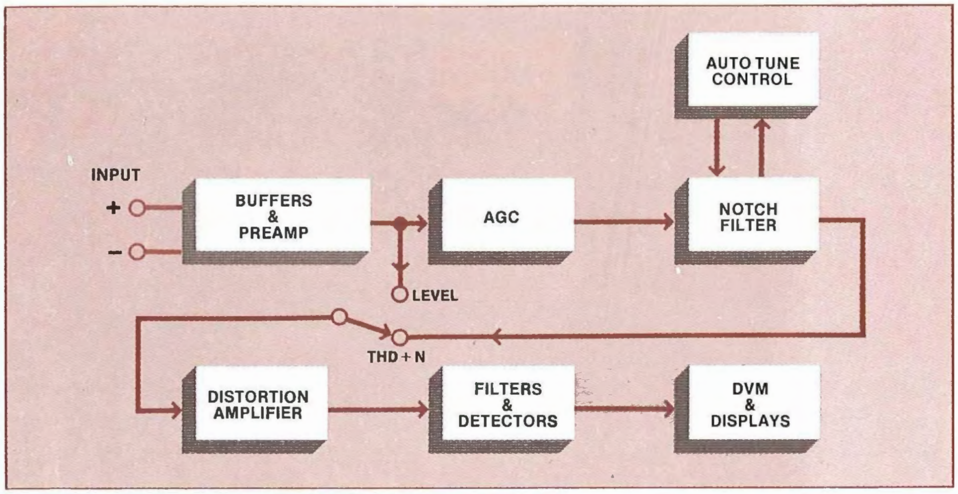


Fig. 3. Basic block diagram of the AA 501 Distortion Analyzer.

buffer amplifiers, minimizes the effects of ground loops and common-mode signals. The input circuitry accommodates signal amplitudes from less than 60 millivolts to 200 volts.

Automatic attenuator selection keeps the preamplifier signal output within a 10 dB-level window. The automatic gain control (ACG) circuitry subsequently processes this signal to a constant amplitude, which becomes the 100 percent distortion reference level or set level.

The signal then passes through an elaborate, automatic-tracking notch filter, which removes the fundamental component. Tuning is accomplished in bands, using light-dependent resistors (LDRs) as the variable elements, to minimize distortion and noise contribution. Few competitive distortion analyzers offer the degree of automatic tuning the AA 501 affords. Many units require the operator to tune the instrument's notch filter to within several percent of the signal frequency before automatic fine tuning takes over. In comparison, the AA 501 doesn't even have a tuning control.

From the notch filter, the resultant distortion signal is amplified, filtered to restrict the measurement bandwidth (if desired), and detected for measurement. The AA 501 provides both average and true RMS types of detection. Although true RMS is the more accurate of the two for the usually-nonsinusoidal distortion waveform, many applications require the more-traditional average response. Average response typically gives a one to two dB lower reading than true RMS.

The AA 501 is unique among distortion analyzers because it provides two forms of display. Accurate measurements are taken from a 3½-digit display with measurement units displayed separately. Analyzers which use meters as the display often confront the operator with several scales, introducing the possibility of errors. However, they offer an advantage over digital displays in their ability to convey rate or trend if the signal is unstable or changing. The AA 501 uses an analog bar graph display to convey rate of change information. The ten-segment display is energized logarithmically, with each fully-illuminated segment representing about2.5 dB. Intensity modulation of the segments creates the illusion of a moving indicator, making level changes of less than 0.5 dB readily detectable, The bar graph is extremely useful for nulling or peaking applications, such as amplifier-crossover-distortion adjustment or function-generator calibration.

IM distortion capability

The AA 501 features an optional intermodulation distortion (IMD) capability conforming to SMPTE(1), DIN(2), CCIF(3) standards. This option makes IMD measurements as automatic as harmonic distortion measurements.

SMPTE IMD is the degree of amplitude modulation of a relatively high frequency tone caused by the presence of a relatively low frequency tone. The DIN standard measurement is similar to SMPTE but uses slightly different frequencies. CCIF difference IMD is the generation of relatively low-frequency, even-order components caused by the presence of two closely-spaced, equal-amplitude, high-frequency tones.

The AA 501 senses the frequency components of the applied test signal, automatically determines which form of IMD is being measured, and selects the appropriate filter circuitry.

Figure 4 shows the simplified block diagram of the AA 501 operating in the IMD mode. For clarity, many of the blocks shown in figure 3 have been omitted. Measuring SMPTE IMD is basically a process of AM demodulation, to quantify the amount of sideband energy at sum and difference related frequencies (see figure 2). From the input buffers and

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[1] Society of Motion Picture and Television Engineers, Standard No. TH 22.51.

[2] Deutsches Institute for Normung e V, No. 45403 Blatt 3 and 4, January, 1975.

[3] International Telephone Consultative Committee.

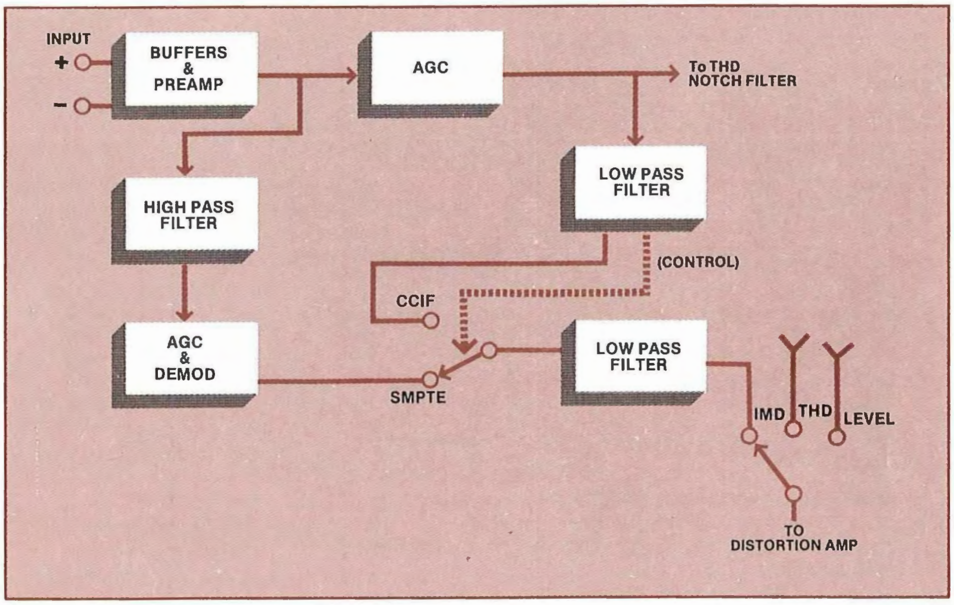

Fig. 4. Simplified block diagram of the AA 501 with the IMD option installed. Some of the basic blocks from figure 3 are omitted for clarity.

preamplifiers, the signal passes through a very sharp rolloff high-pass filter to remove the low-frequency-tone portion of the test signal. The resultant signal is then leveled to a known 100 percent reference voltage and demodulated for AM content. As the test signal amplitude ratio can vary from 1:1 to as much as 5:1, the IMD AGC circuit must have more range than the one used for THD analysis. The multiple high-frequency tones generated by the demodulation process are removed by the final low-pass filter stage.

Measuring CCIF difference frequency distortion is a very straightforward process. The input signal, after leveling by the same AGC circuit used for the THD measurements, passes through two very sharp rolloff low-pass filters. These filters remove the two closely-spaced high frequency tones of the test signal, allowing only the difference frequency components (which would be less than 11 Hz) to be measured.

A wide range voltmeter

Quite often a user needs to measure absolute signal level. In the LEVEL operating mode, the AA 501 functions as an autoranging voltmeter covering a range of 200 microvolts to 200 volts full scale. Signals as small as several microvolts (the input stage residual noise) can be measured on the 200 microvolts range, with 0.1 microvolt resolution (this is about 1000 times the sensitivity of a general purpose digital multimeter).

Additionally, the AA 501 can display the results in volts, dBm (600Ω), or dB ratio. The dB RATIO mode is useful for directly measuring gain, frequency response, or signal-to-noise ratios. Momentarily pressing the PUSH TO SET 0dB REF button forces the display to read 0.0dB, which becomes the reference level for all subsequent measurements. With this feature, it is possible to measure ratios greater than 150 dB, conveniently and accurately.

Summary

The AA 501 is a state-of-the-art, fully-automatic distortion analyzer. Reference level setting, meter range selecting, frequency range selecting, and nulling are all performed automatically, with no sacrifice to measurement accuracy. And the AA 501 reduces measurement time from minutes to seconds.

Acknowledgements

Many people contributed to the success of the AA 501 project. The design team included project leader Rush Hood and design engineers Rich Cabot and Fred Armentrout. Bob Metzler, Norb Luersen, and Warren Beals provided significant marketing input.

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