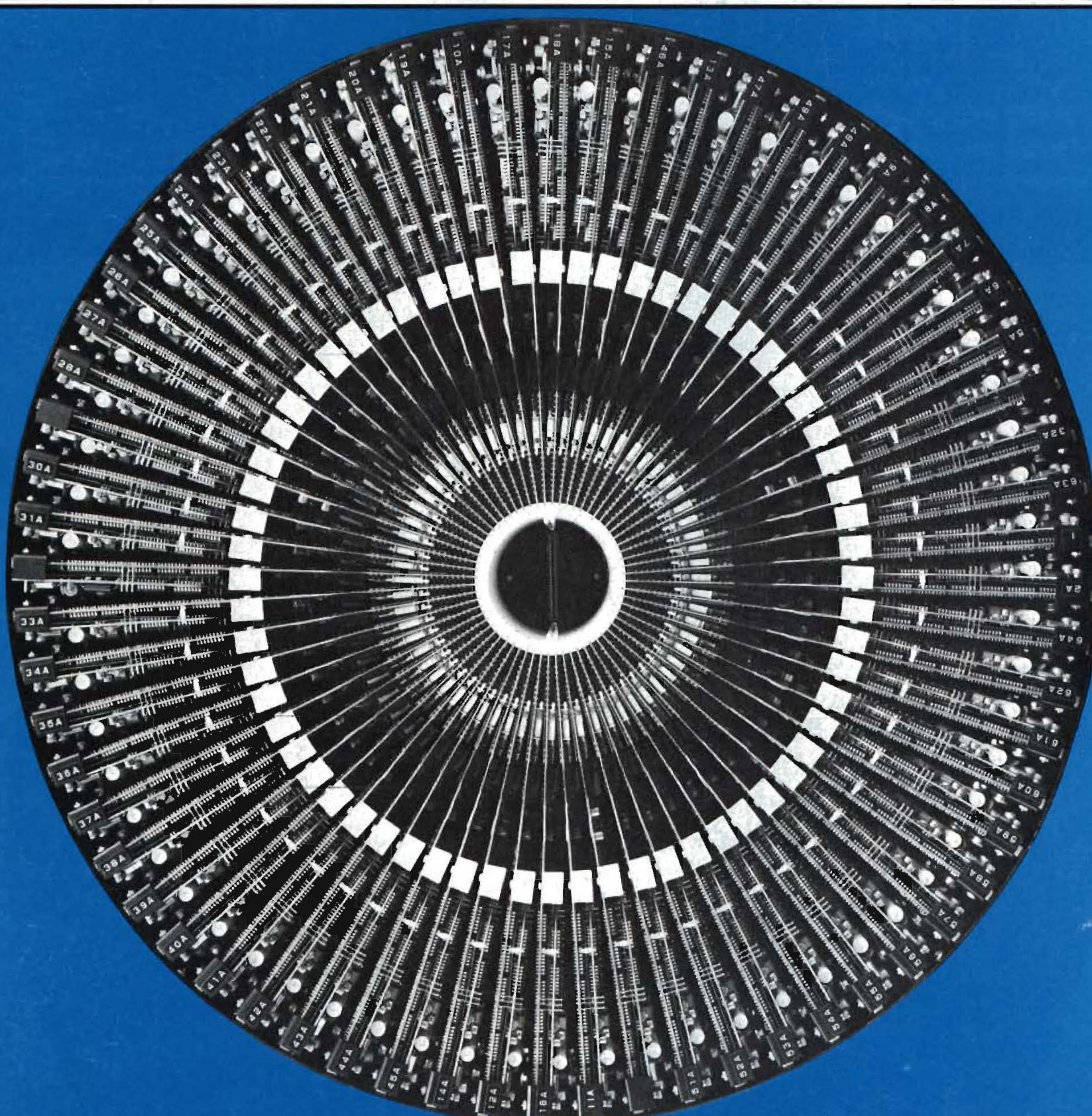
TEKTRONIX

TEKSCOPE

JAN/FEB 1973



TESTS AND MEASUREMENTS WITH TEKTEST III

DIFFERENTIAL AMPLIFIERS AND MEASUREMENTS

REPAIRING OSCILLOSCOPE PROBES

TEKTEST™ III

AUTOMATED TEST SYSTEM CONTROL THROUGH SOFTWARE

by W. E. Kehret Automated Systems Engineering

TEKTRONIX AND AUTOMATED TEST SYSTEMS

A FAMILY HERITAGE: The S-3260 Automated Test System is the most recent addition to the TEKTRONIX family of test systems which began in 1964. The first system, and much of the later development was based on programmable sampling oscilloscopes and digital readouts. In contrast, the S-3260 is a real-time test system which uses single-shot measurement techniques to replace the sequential sampling techniques of the earlier systems. System operations are performed under software control of a dedicated computer. A graphic computer terminal handles communication with the system.

As is true of most technologies, automated test systems have made rather sweeping changes since their inception a little more than a decade ago. Although these early systems used all of the technologies available to them, their performance appears very limited as we look back from the vantage point of more than ten years of technological advancement. However limited they may appear in hindsight, these early systems adequately made the measurements required of them, and only development of more sophisticated devices to be tested placed the capabilities of these systems in question. Most tests were fixed by the original system design; if test parameters could be changed, it was usually through internal wiring changes or by front-panel switching.

As test systems advanced to include stored program control and the capability to test more complex components such as integrated circuits, the major criterion of system performance was still the hardware—what instruments were used and how they were physically connected together. Major changes in test characteristics often required reconfiguration of the system.

Implementation of large-scale-integration techniques by semiconductor manufacturers brought about the need for a much more flexible test system. The vast number of checks required on each device made testing with existing systems unfeasible, both in view of limitations of the equipment and limitations in the ability to physically program all of these tests. For relief the systems designers looked to the computer's ability to control many operations in real time (as they occur) and to ease the burden of programming.

Cover: Sixty-four Input/Output sector cards form the heart of the S-3260 Automated Test System. The Device Under Test mounts on a test board in the center of this array, placing it very close to the measurement subsystems.

Addition of the computer to the test system shifted the focal point of system flexibility from the hardware configuration to the software operating system. In order to achieve a flexible system, the test language or software must also be flexible. Designers of the new TEKTRONIX S-3260 Automated Test System sought a test language which could be easily understood by engineers relatively untrained in computer programming methods, yet was powerful enough to control the full range of hardware capability in the system.

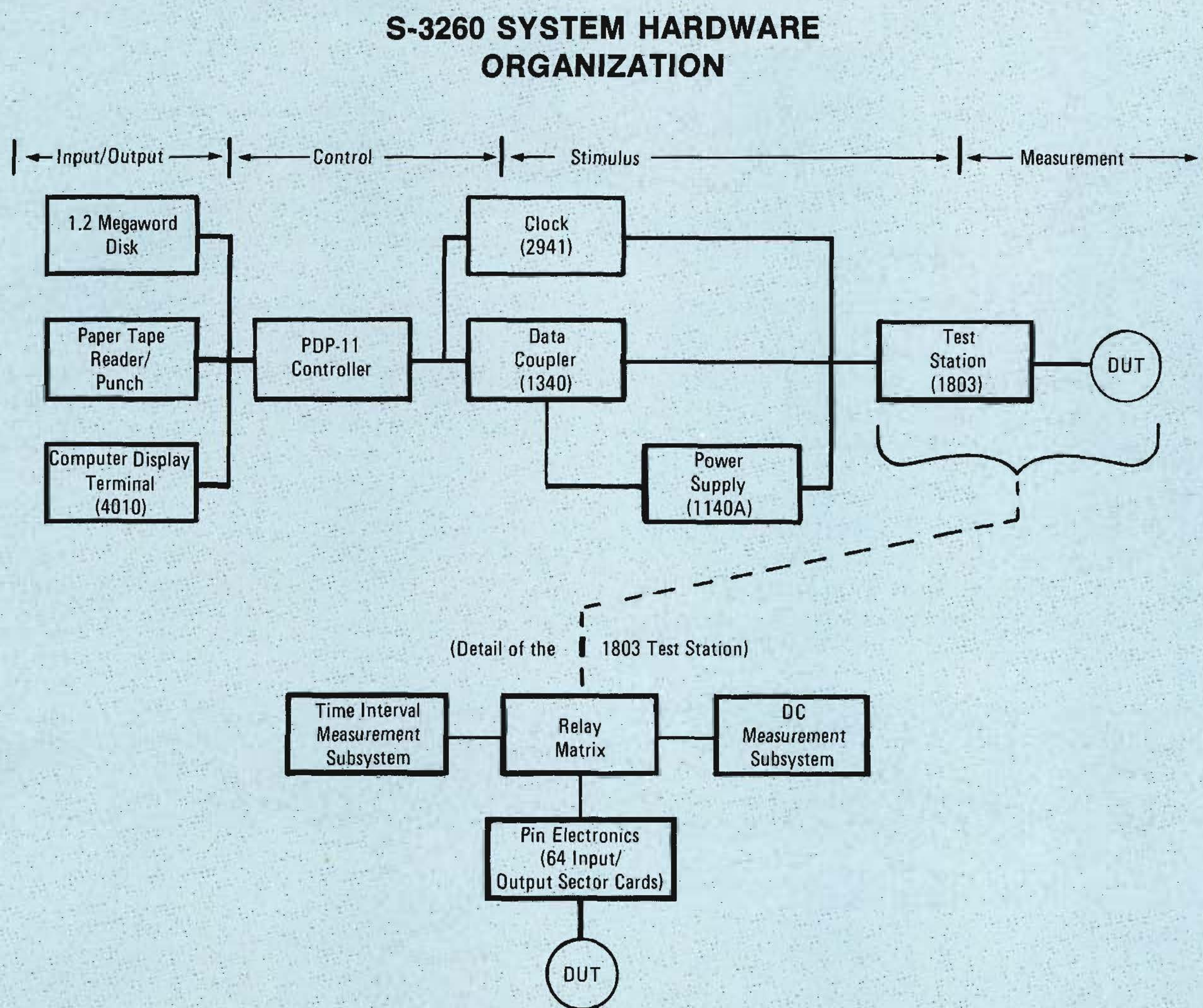
A New Language

Existing test languages proved inadequate to meet the goals set forth for the S-3260 System. As a result, a totally new test language called TEKTEST III was developed.

For those familiar with computer operating systems, it is appropriate to distinguish TEKTEST III from existing compilers such as FORTRAN, ALGOL, or BASIC. While TEKTEST III is a higher level language with capabilities in some ways similar to the above mentioned compilers, this new software language for the S-3260 System is not equivalent to, or a subset of, any previously defined language. This is also true of other software components including the editors and the disk operating system. This totally new software system was developed to allow ease of operation for users other than systems specialists, and for speed of operation. Although it would appear that adaptation of existing software systems would be the easiest, this could not be done and still fully meet the objectives.

Software + Hardware = S-3260 System

While we will be dealing mainly with the Software Operating System, a basic understanding of the hardware used in the S-3260 Automated Test System is helpful. Please refer to the S-3260 System Hardware Organization discussion and Fig. 1 which accompanies this article.



The hardware which makes up the S-3260 System is shown in the block diagram of Fig. 1. Although a variety of options are available for this system, we will only look at those items which are a standard part of the system.

Input and output for the system is shown at the left side of the block diagram. The 1.2 Megaword Disk provides storage for the test program library, system programs, test results, files, etc. The disk system provides fast retrieval of stored material when addressed by the computer. Program material can be entered into the system through either the Paper Tape Reader Punch or the Computer Display Terminal. These devices can also be used for output. The computer display terminal is of particular importance when used to generate test programs in conjunction with the interactive programming capabilities of the Software Operating System. Since the terminal has both alphanumeric and graphic output capabilities, it can provide output in either form.

The entire system is under control of a dedicated computer referred to as the Controller. The Data Coupler interfaces between the Controller and other instruments in the system. Timing relationships for system operations are established by the Clock. Reference voltage levels are provided by the programmable Power Supply.

Interfacing for input or output to as many as 64 pins of the device under test (DUT) is provided by the Test Station. The Test Station contains 64 Input/Output Sector Cards which can be connected to the pins of the DUT through software control. Each card contains the forcing and sensing circuitry required for Functional measurements. Timing for these measurements is controlled by the Clock. The Sector Cards also contain a 1032-bit high-speed buffer memory. During functional tests, data is available from this buffer at Clock rates up to 20 MHz. Errors may also be stored in buffer memory at Clock rates.

In addition to measurements using the Sector Cards, the Relay Matrix allows each pin of the DUT to be connected to the parametric measurement subsystem. This subsystem consists of two separate measurement systems: the Time Interval Measurement Subsystem for timing measurements and the DC Measurement Subsystem for current or voltage measurements.

Fig. 1. *Basic block diagram showing hardware organization of the S-3260 System.*

Putting It All Together

To complement the very effective hardware organization, the S-3260 has an equally effective Software Operating System (see Fig. 2). This system can be broken down into three levels: Editor Level, Translator Level, and Machine Level. The Editor Level provides three separate editors to aid in the preparation of the test program (see The Editors for further information). This test program is not in the language most readily understood by the machine environment of the test system. The process of converting the source language to a machine language is called "translation" and is handled at the Translator Level. The translated code consists of macro-instructions which are processed under software control of a Digital Equipment Corporation PDP-11/40 and its floating-point hardware and software service routines. These macro-instructions relate to the S-3260 hardware functions at the Machine Level. These include clock generator instructions, power supply instructions, data coupler instructions, and parametric subsystem instructions.

System operations are classified by priority: background operations and foreground operations. Fig. 2 shows this breakdown. Foreground operations deal with the actual running of the test program. These operations occur at the Machine Level and are given priority by the Controller. Normally, pauses occur in the foreground operations as they are being run. These pauses are caused by reed switch settling time (normally 1 to 2 milliseconds), power supply slewing, etc. Rather than remaining idle during these pauses, the computer processes background operations if they have been scheduled by the operator. Background operations can consist of test program editing, data logging, graphing, etc. This relationship between foreground and background operations allows a form of time-sharing of the computers capabilities for more effective use of the total system. For example, a new program can be generated from the input terminal at the same time that devices are being tested. Even though the test receives priority scheduling, the programmer will probably not realize that he is not receiving the full attention of the computer.

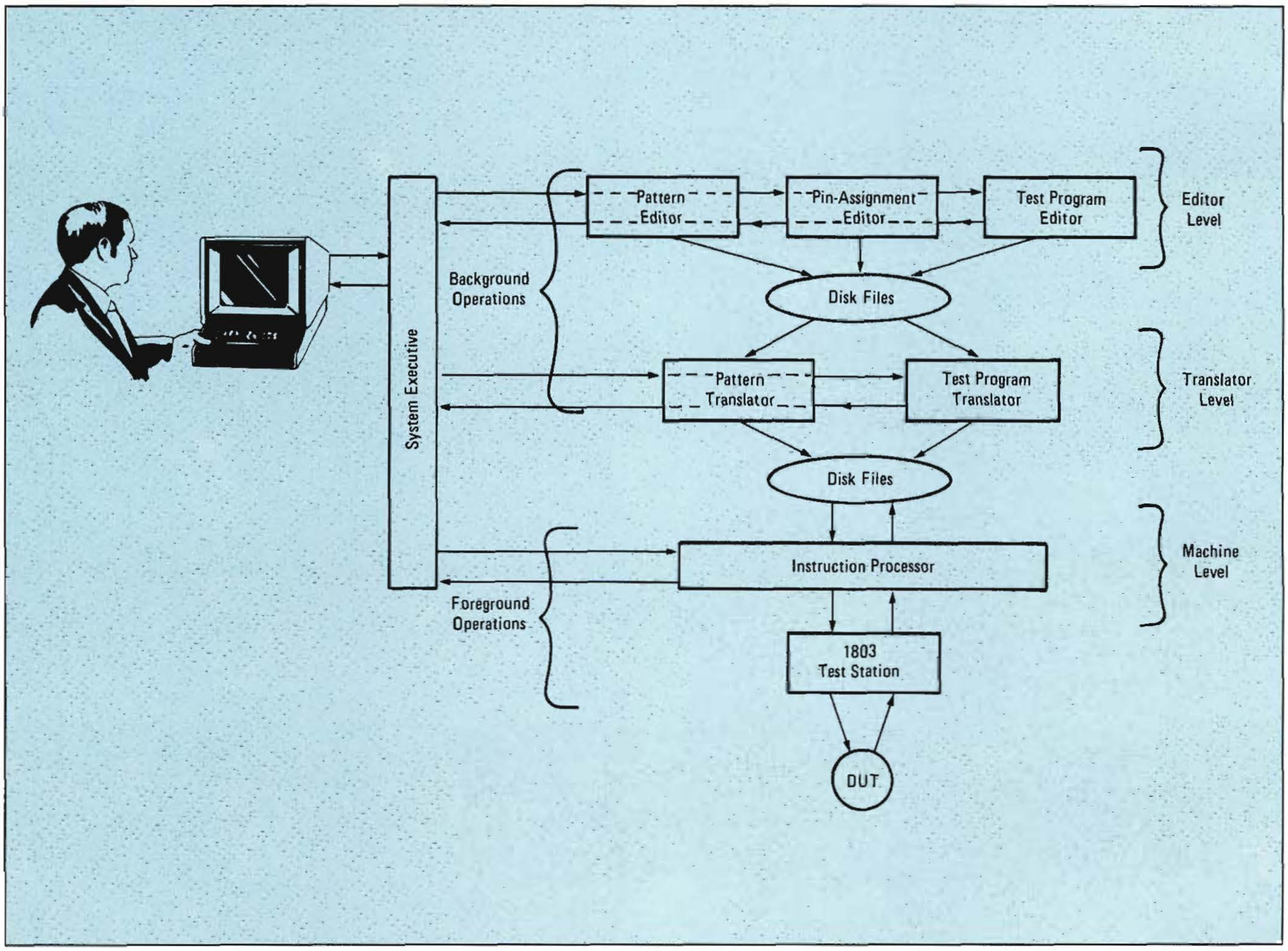
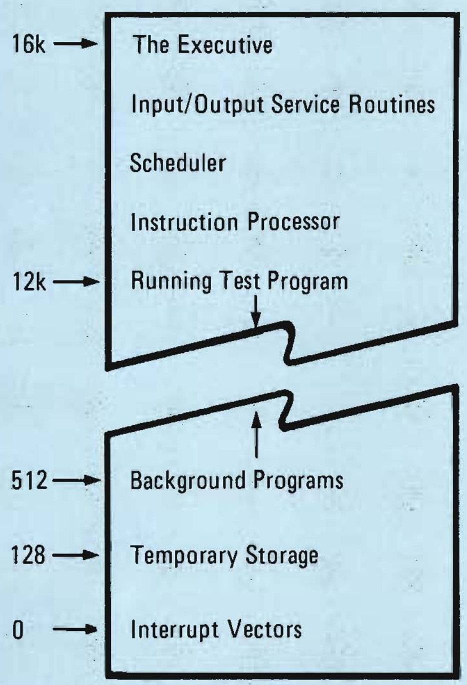


Fig. 2. *Organization of the Software Operating System for the S-3260 System.*

By this time you may be concerned about getting it all together: editors, translators, background, foreground, and who knows what else? Fortunately, there's help built into the Software Operating System. This comes from the Executive. The Executive is a disk operating system which does file handling, program loading, background scheduling, and accepts data logging directives at test-program run time (see special description on Core Memory Utilization and Fig. 3).

CORE MEMORY UTILIZATION



Although the user does not need to be concerned about core-memory utilization when operating this system, an understanding of how the software operating system and the core memory inter-relate is helpful in understanding the overall system.

Fig. 3 is a graphic representation of how the 16K (16,000) words of core memory are used in running a program. The top 4000 words of memory between memory location 16K and 12K are occupied by the Executive, input/output service routines, the scheduler, and the instruction processor, in that order. The running test program is loaded downward from the instruction processor.

From the bottom of core, the first 128 words are occupied by interrupt vectors. The temporary storage occupies the area between the 128th and 512th words. Background programs are loaded upwards from the 512th word. The point at which the downward loaded test program meets the upward loaded background programs is controlled by the scheduler and the loader.

Fig. 3. *Graphic representation of core memory utilization by the computer.*

The Editors

The Editors consist of three separate editors to aid in test program preparation.

Test Program Editor. The Test Program Editor aids in the preparation of the test statements. This editor is line number oriented. To enter a statement, type a line number and the test command. For example:

```
 99.00 WHEN  ERROR      110
100.00 MOVE  REGISTER  (1,16) TO SECTOR
       ON    PINLIST
```

Additional statements can be added between two sequential statements as follows:

```
 99.00 WHEN  ERROR      110
100.00 MOVE  REGISTER  (1,16) TO SECTOR
       ON    PINLIST
 99.01 LOOP  100    IND=1,60
 99.02 HIDRIVE=5.0 V—50mV* IND ON DPINS
```

Statements 99.01 and 99.02 would appear in the program between 99.00 and 100.00. If the Editor was asked to list the program, it would appear in the correct line number sequence.

The Test Program Editor also allows statements to be erased either singly or in blocks, and replacement of individual lines by typing the original line number and the new command statement.

Certain programming errors are detected and may be corrected at the time the program is entered. Other program errors are not detected until the program is actually translated or run. An example of the latter would be a command to transfer program control to a non-existent line location in the test program. When this is encountered in translation, an error statement is printed along with the line number of the command statement where the error occurred. Then the programmer can enter the correct information from the terminal.

Another feature of the Test Program Editor is to list either the entire program or individual lines within the program. This allows the programmer to inspect or modify the program.

Pattern Editor. Patterns refer to the sequence of addresses and/or control data applied for functional testing of a device. A variety of patterns are in common usage, each one best suited to test particular types of devices.[1] The purpose of the Pattern Editor is to format the test pattern data into a two-dimensional matrix or table. A pattern-table row corresponds to data sent to the DUT; one row for each cycle of a clock sequence. A pattern-table column corresponds to the sequence of data at a particular pin of the DUT; one column for each active pin.

[1] For further information on patterns, refer to TEKTRONIX Automated Systems Application Note No. 2, "Test Patterns and Their Use In LSI Memory Diagnostics."

For simple devices, the test pattern can be developed manually. However, as the device becomes more complex, the difficulties in generation of the test pattern increase similarly. Through the use of the Pattern Editor and the interactive programming features of TEKTEST III, the Controller can be used to help develop the pattern according to a given algorithm or established logic sequence. If a pattern can be described by a closed algorithm, the test pattern can be generated under software control with the Algorithmic Program Generator.

Pin Assignment Editor. The pins of the device under test are referred to by a reference pin name and coordinated with an Input/Output Sector Card of the tester by program statements. The Pin Assignment Editor assists the programmer in preparing this list. Basic operation of this editor is similar to the Test Program Editor.

The Man/Machine Interface

The S-3260 System includes a Graphic Display Terminal both for input of programs or test data and for output of test results. The Executive portion of the software operating system serves as a coordinator between the input from the terminal and the rest of the system. Since the Executive is a disk-file based system, its operation is very fast. This speed becomes important in the interactive program preparation capability of the Software Operating System.

A major feature of interactive program preparation is on-line editing. Through the Executive, the operator communicates with the software system and receives quick feedback in the form of prompts and error messages. Several interactive loops are provided in the system for on-line editing (see Fig. 4). For example, assume that the programmer enters a program statement. If this statement contains certain errors, an error message is printed on the terminal (Loop I) even before the programmer can move his fingers to type the next part of the program. This quick feedback allows the operator to make the correction immediately rather than repeating this same error throughout a program. As a result, considerable time is saved in test program preparation compared to off-line program preparation.

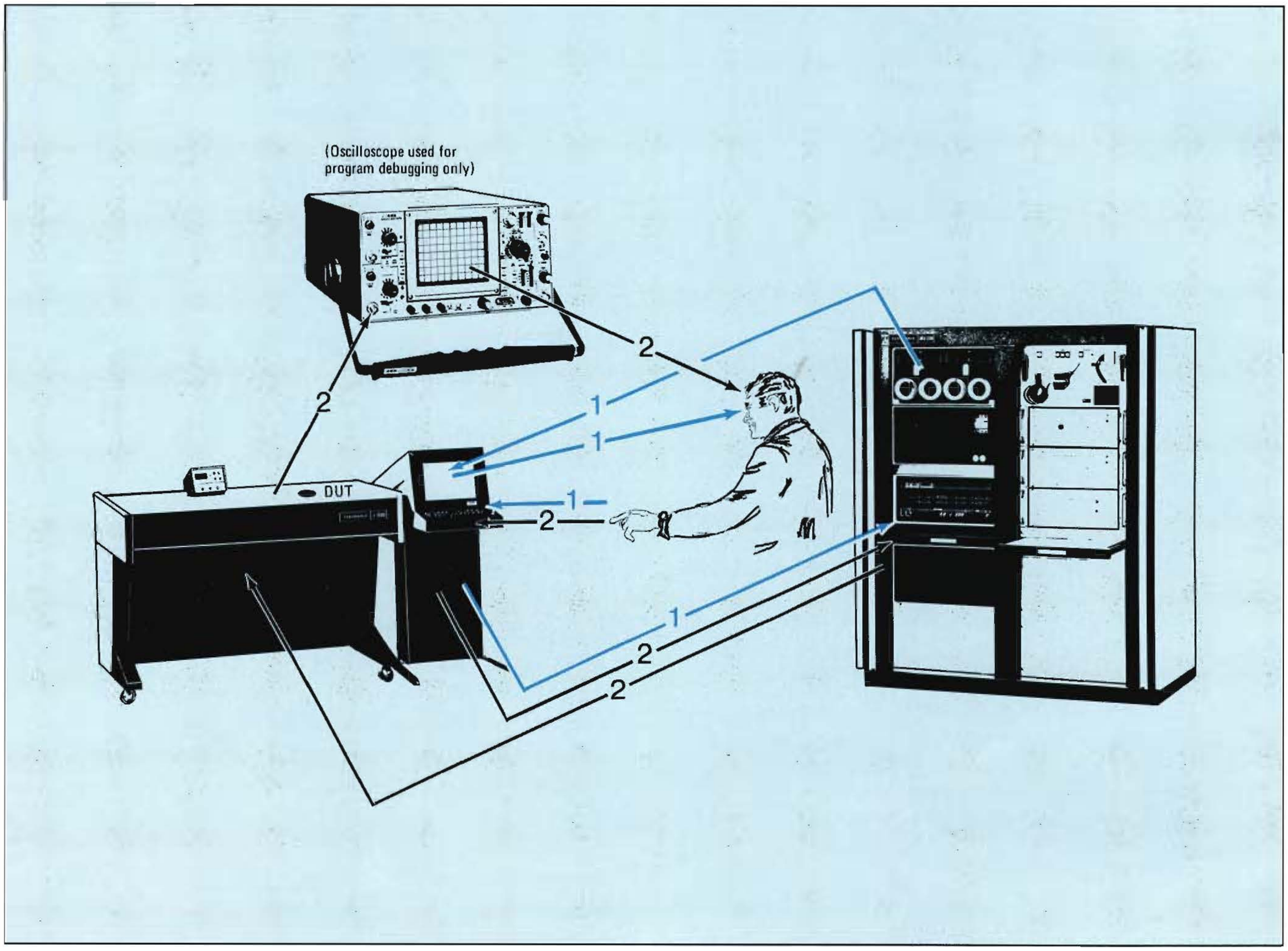


Fig. 4. The Man/Machine interface provided by the interactive program capabilities of TEKTEST III.

A second kind of interaction involves the operator more directly in test program debugging (Loop 2). As part of the system hardware, a buffer channel is provided so that any pin of the device under test (DUT) can be monitored with a test oscilloscope. A trigger output is also provided by the clock generator. This trigger can be programmed to allow examination of an individual data pattern within a functional sequence by the oscilloscope. In this way, the operator is actively involved in the process of program development and debugging.

Command Statements

Command statements consist of three elements; line no., command name, and command argument. A typical example is:

39.00	COMPARE	PINLST WITH TABL99
Line No.	*Command name*	*Command argument*

The line no. identifies the correct sequence of a command statement in the program.

The command name defines the type of operation to be performed.

The command argument can consist of symbols of up to six characters, constants, or arithmetic expressions. The type of command used determines the format of the command argument.

For other examples of typical command statements, see the discussion on the Test Program Editor.

Functional Testing

The concept of functional testing with an automated test system is similar to testing with discrete instrumentation (see Fig. 5). The functional test system consists of three parts: the generator or stimulus, the unit or device under test, and an observing or measuring instrument.

It should be noted that for functional testing with the S-3260 System, the device under test is measured each time the stimulus is changed. This form of testing is often called real-time testing or single-shot testing and should be distinguished from repetitive stimulation required by sampling oscilloscope based systems. Let's examine the three parts of the functional test system for the S-3260 as they relate to the software operating system.

Parameters of the Stimulus. The stimulus source must be characterized by the software in time and amplitude. When sequential or memory devices are tested, the time/amplitude must also be specified relative to a clock cycle. When the device under test contains memory, the input patterns must be applied in specific order to carry the device from one state to another. If memoryless, the input patterns can be applied in any order.

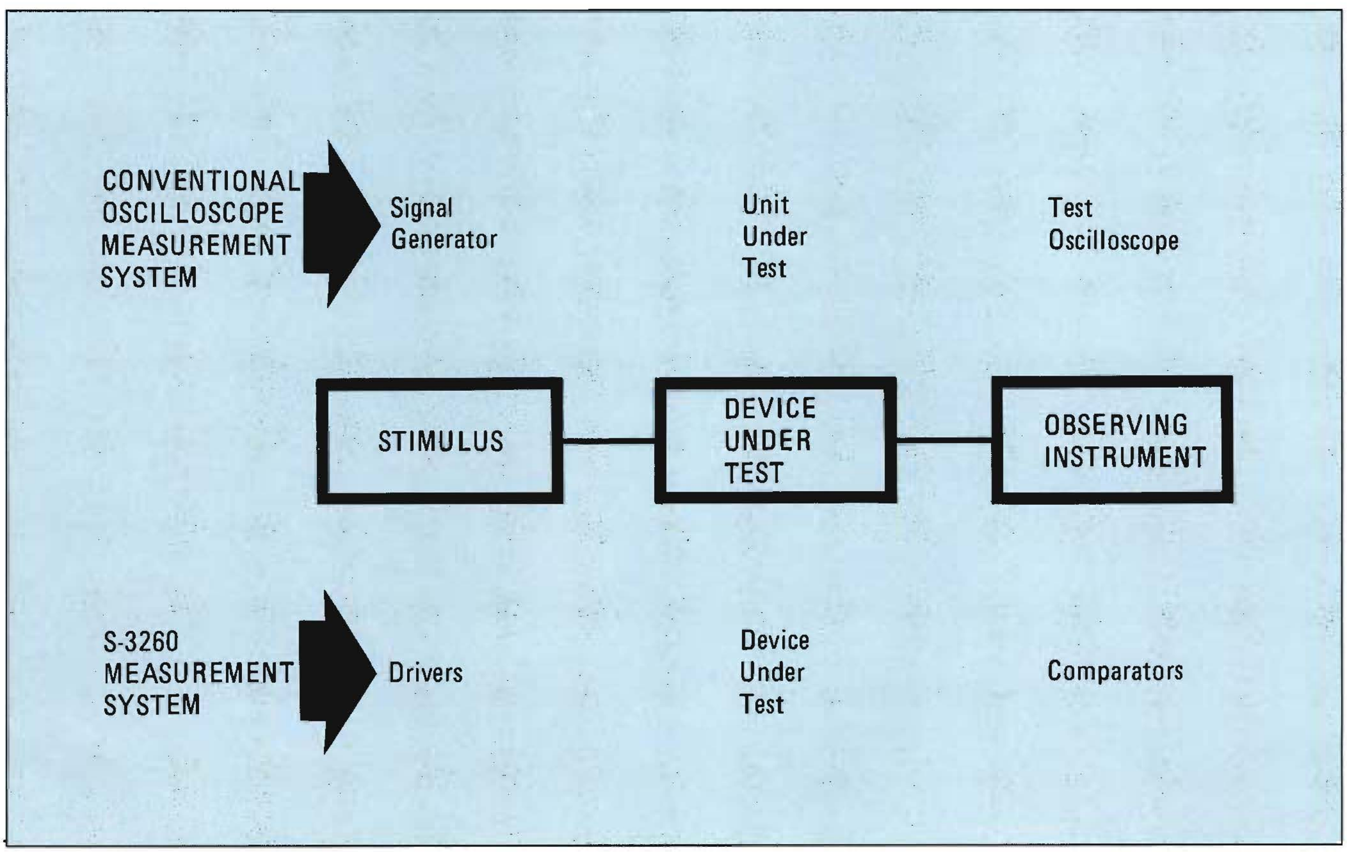


***Fig. 5.** Comparison between S-3260 functional testing system and a conventional oscilloscope measurement system.*

For logic devices the purpose of functional testing is to determine that all meaningful logic states can be reached according to the specified transition rules and that all meaningful inputs produce the desired results.

Environment of the Device Under Test. Interface to the device under test (DUT), can be conveniently broken down into two categories: input and output. The input functions can all be operated through the drivers located in the test station in close proximity to the DUT. This includes input data, address, control, and supply pins.

For functional tests, the output pins are connected to the comparators.

Nature of the Measurement Instrument. The measurement instruments for functional testing are comparators at each Sector Card which make a decision on the basis of expected data and time and amplitude references. The result of the functional test is a binary decision. This decision is communicated to the system Controller which determines the resultant action to be taken in the test program.

Parametric Testing

In parametric testing, current or voltage values or a time interval are measured. Current and voltage measurements can be made separately or while forcing, respectively, a voltage or a current.

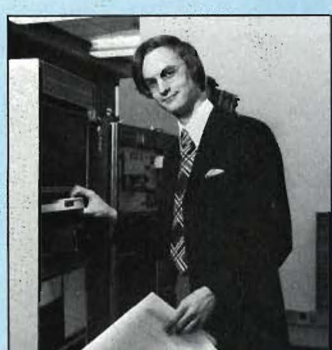
The program for a voltage measurement must specify two pins of the device under test, one of which may be ground. Current measurements must specify the pin of the DUT and the voltage supply between which the current is measured.

Time intervals are measured with the aid of the comparators. When the voltage at a designated start pin passes through a specified reference level, the time-interval measurement begins. It is stopped by a specified transition through a reference level at the stop comparator pin.

The result of a parametric measurement does not have a direct binary decision value. The result of the measurement is an analog quantity which must be compared against specified limits of the test program to diagnose the condition of the DUT. Measured values may be used as arguments in other commands, entered into arithmetic expressions, and be printed or logged as specified by the program.

SUMMARY

In this article, we have seen only a brief over-view of TEKTEST III—the Software Operating System for the TEKTRONIX S-3260 Automated Test System. The real power and flexibility of this new Software Operating System and automated test system cannot be presented within the context of these few pages.[2] What we have seen is that TEKTEST III is a new programming language, powerful enough to control the full range of hardware capability in the S-3260 System, yet easily understood by the systems engineer who may be relatively untrained in computer programming methods. As such, TEKTEST III can become a useful, flexible tool for your automated testing applications.


W. E. Kehret

OUR AUTHOR

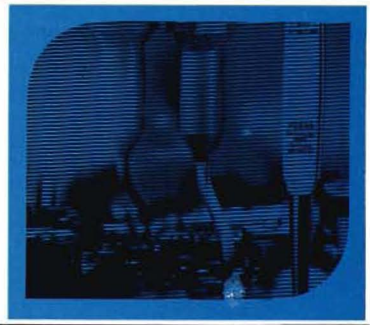
Bill joined TEK in 1966 after receiving a B.A. in Physics from The College of Wooster. He has continued his education with graduate study in Electrical Engineering at Oregon State University and is currently participating in a Systems Science Ph. D. program at Portland State University. Prior to his present work in the Automated Systems Group, Bill worked as design engineer in the Sampling and Digital Instruments group and Advanced Product Development.

As leisure-time activities, Bill and his wife Bonnie enjoy sailing, skiing, and tennis.

[2]For a complete discussion of TEKTEST III, request a copy of "S-3260 Automated Test System Control Through TEKTEST III Software" from Automated Systems, Tektronix, Inc., Beaverton, OR.

TEKNIQUE

Fred Beckett – Engineer



A PRACTICAL APPROACH TO

DIFFERENTIAL AMPLIFIERS AND MEASUREMENTS

In Part I of this series we examined the basic concepts of the differential amplifier and the common-mode rejection ratio (CMRR). Part II dealt with making the differential measurement. The relative merits of the ADDED mode technique and the true differential amplifier were discussed. The use of the differential comparator and DC offset were also covered. In this final article of the series we will discuss the problem of overdriving the amplifier inputs and some seldom used techniques such as the "guarded" input.

PART III

INPUT LIMITATIONS AND GUARDED MEASUREMENTS

Maximum Common-Mode Voltage

The question often arises, "what is the maximum common-mode voltage that can be applied to a differential input?" There is no set answer to this question. This will vary from instrument to instrument. However, we can get a better understanding of this question if we understand the problems involved.

There are two major problems caused by large common-mode signals:

(1) The amplifier stages may be caused to operate in the nonlinear region resulting in degradation of CMR capability.

(2) Component failure may occur in the input circuitry.

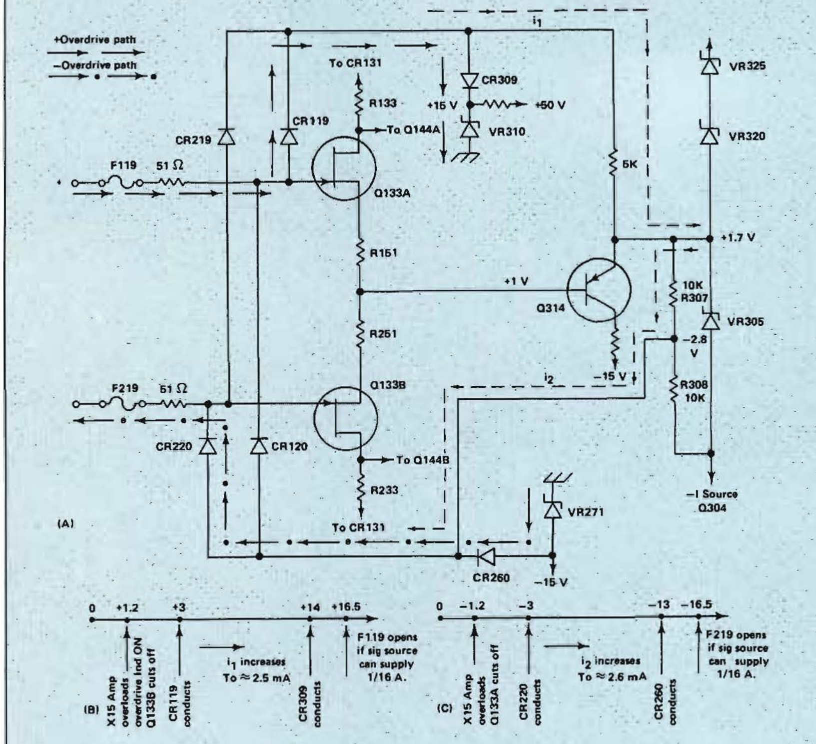
You will recall in Part I of this series there were two methods by which CMR was achieved in a differential amplifier—by the use of an active longtail, or by using a floating power supply for the input amplifier. The longtail method assumed that both the desired signal and the common-mode signal generated separate currents which were operating within the linear design limits of the active device. It stands to reason that large common-mode voltages will drive the input amplifiers into saturation invalidating the CMRR specifications. The same argument can be applied to amplifiers using the floating power supply technique. The mechanism is different but the results are the same.

Most differential comparators and amplifiers provide the operator with some indication of this condition with an overdrive lamp located on the front panel. The lamp indicates an overdrive condition from either signal and/or common-mode voltage.

Common-mode voltage normally takes two forms—a DC voltage common to both inputs, and an induced voltage, either through ground loops or EMI.

It is plain to see that this combination may damage input components, especially in those amplifiers such as the Type 7A22 that do not use attenuators in the most sensitive positions. With this fact in mind, the inputs are normally protected with the use of diode clamps and fuses (NOTE: resistor limiting is not used since component tolerance may upset symmetry). An example of this type of protection is shown in Fig. 1.

It is wise to check that the DC voltages at the point of measurement do not exceed those specified in the manual for common-mode signal conditions. If you must use probes, and invariably you will have to, use only the recommended probes for the instrument and make sure the probes are properly compensated.



There are two different kinds of overdrive associated with the Type 7A22, (a) single-ended overdrive, with one input grounded, and (b) common-mode overdrive, with approximately equal input voltages.

(a) Assume the −input grounded and a steadily increasing voltage on the +input. The chart in Fig. 1(B) indicates the sequence of events: F119 will open if the + signal source can supply 1/16 amp of current. If this much current is not present, the +input remains at +16.5 V, with the overdrive current flowing to ground as shown in Fig. 1(A).

Now assume the +input grounded and a steadily increasing −voltage on the −input. The sequence of events is shown in Fig. 1(C).

(b) For common-mode overdrives the clamping sequence is essentially similar, except the X15 amplifier does not overload, and the current i_2 does not flow until the input reaches approximately −13 V. The fuse opening current paths are shown in Fig. 1(A).

For differential overdrive the action is a combination of the + and − single-ended sequences, with the −input supplying i_2. (In effect the 5 kΩ resistor is connected across the inputs when the differential voltage reaches 3 V). The fuses will not open until one or both inputs reach +16.5 V or −16.5 V.

Fig. 1. (A) Simplified schematic showing input protection for the Type 7A22. (B) and (C) show sequence of events leading to excessive overdrive.

Input Impedance Limitations

In Part I of this series we dealt with the CMR problem where the two source impedances were different. The solution was to remove the 1 MΩ input resistors thereby creating a very high input impedance.

It becomes clear that the higher the input impedance, the better the apparent CMR will be, concluding that if

$$Z_{in(C\text{-}M)} = \frac{\Delta E_{in(C\text{-}M)}}{\Delta I_{in(C\text{-}M)}}$$

then if $\Delta I_{in(C\text{-}M)} \rightarrow 0$, $Z_{in(C\text{-}M)} \rightarrow \infty$.

Clearly if $Z_{in(C\text{-}M)} \rightarrow \infty$, no common mode signal can appear differentially due to an unbalanced source impedance. [Note that ΔI_{in} should be independent of temperature. Removing the 1 MΩ input resistors defines ΔI_{in} in terms of gate current (assuming FET input devices) which will vary with temperature, introducing an offset condition.]

Fig. 2 shows the problem as it exists. Here common-mode currents flow through R_1, Z_1 and R_2, Z_2 together with the desired signal. Imbalance in any of these components will lower the apparent CMR. There are several design techniques that help us approach the desired result of $Z_{in(C\text{-}M)} \rightarrow \infty$. We will examine three solutions: the floating amplifier, the guard, and a technique to increase the apparent input resistance.

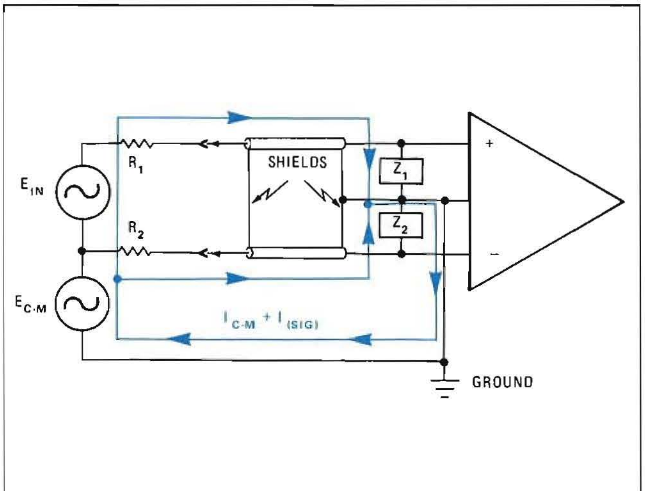


Fig. 2. Diagram showing the influence of the common-mode signal. R_1 and R_2 are the source impedance; Z_1, Z_2 the effective input impedances which include the input RC time constants plus cable and stray capacitances.

The first solution is to isolate the amplifier, thereby removing the common-mode path. This certainly meets our immediate goal (refer Fig. 3). Notice that both input terminals and the floating ground of the amplifier move together both in amplitude and phase with the common-mode signal. This meets our requirement that $\Delta I_{(C\text{-}M)} \rightarrow 0$ since no current will flow through an impedance if there is no potential difference across that impedance.

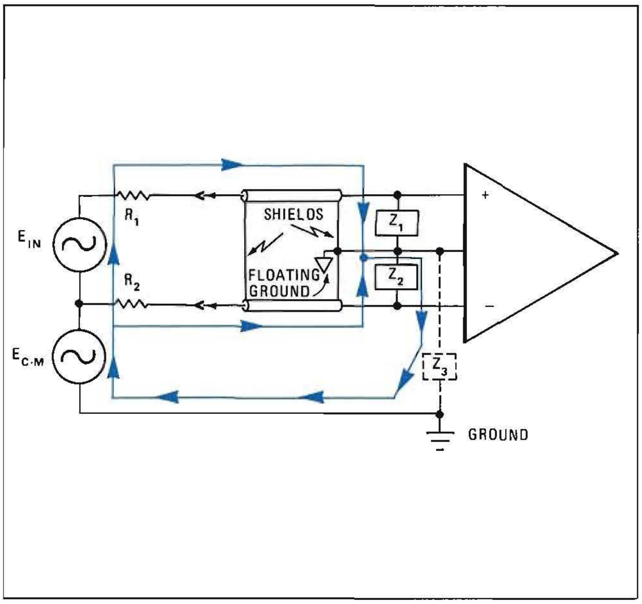


Fig. 3. Diagram depicting the floating amplifier technique. The amplifier effectively floats above ground. R_1, R_2, Z_1, Z_2 are the same components described in Fig. 2. Z_3 is the isolating impedance between the floating amplifier ground and the actual ground. Z_3 which is predominantly capacitive reactance in parallel with leakage reactances, is very large at low frequencies thus inhibiting $I_{C\text{-}M}$.

This is an acceptable method of improving the apparent CMR and is widely used by instrument manufacturers. However, it is not the final answer since stray capacitance still can exist between the isolated amplifier and ground. This stray capacitance can be all but eliminated by placing an electrically isolated shield between the floating amplifier circuit and ground. This shield is referred to as the "guard shield." The guard shield is connected to a front panel terminal called the "guard terminal." The method of connection is important, refer to Fig. 4. If your instrument has a guard terminal provided, do not leave the terminal disconnected.

The second solution is the use of the "driven guard". The isolated amplifier method described above relied on the fact that the whole amplifier and its input circuit floated above ground. While this is satisfactory for many applications, in some cases, especially medical equipment, such a technique could be hazardous to the patient's health. Safety requires that the measuring instrument and its environment be referenced to ground.

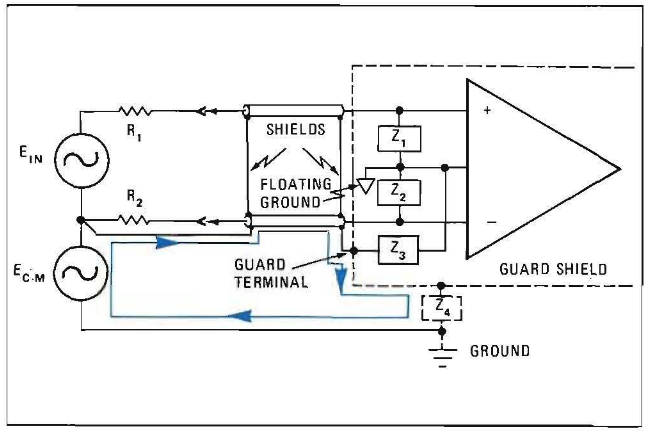


Fig. 4. Diagram showing guarded amplifier technique. Here, the floating amplifier shown in Fig. 3 is isolated by a shield, all but eliminating the impedance Z_3 described in Fig. 3. The net result is that $E_{C\text{-}M}$ is confined to the path shown through Z_4, the effective impedance between the guard shield and ground. Z_3 is the effective impedance between the floating ground and the guard shield. Note the method of connection. The cable shield is connected to the guard terminal and the source as shown. The cable shields must be covered with an insulating material.

If the measuring instrument has a differential input, the "driven guard" is a possible solution to common-mode problems. An example of this technique is seen in the TEKTRONIX 410 Physiological monitor, refer Fig. 5. Here the common-mode signal appearing at the FET inputs is coupled through Q111 to the input cables shield. The net result is that both the input circuit and the shield move together in amplitude and phase with the common-mode signal. This meets our initial requirement that $\Delta I_{in(C\text{-}M)} \rightarrow 0$. Q111 acts to isolate the input amplifier from the shield. The emitter circuit of Q111 may be thought of as a guard terminal "driven" by Q111.

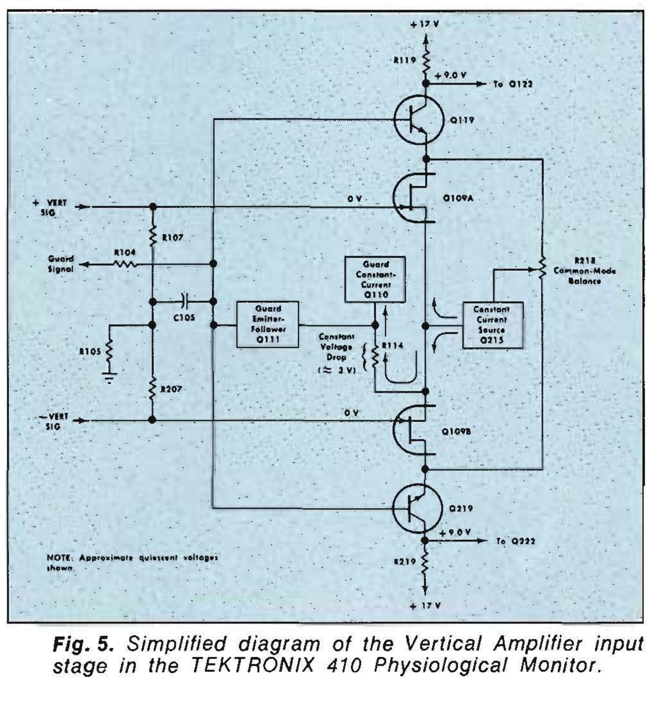
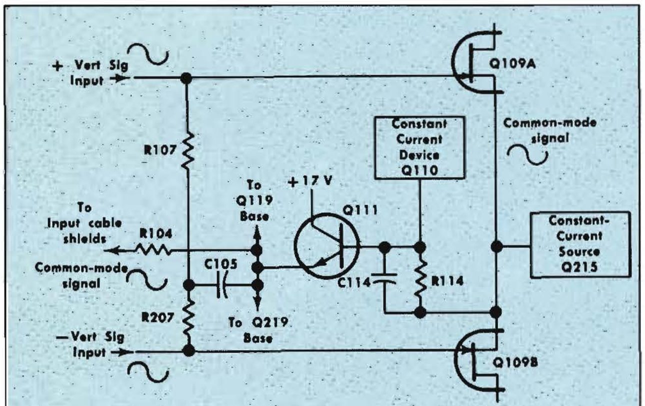


Fig. 5. Simplified diagram of the Vertical Amplifier input stage in the TEKTRONIX 410 Physiological Monitor.

The third solution is to increase the "apparent input resistance." Recall that one method to increase the input impedance is to remove the 1 MΩ input resistors as shown earlier. However this defines I_{in} in terms of the gate current which is temperature dependent. An alternative to this is shown in Fig. 6. Here the common-mode signal is returned to the "lower" end of the input resistors resulting in a theoretical increase in apparent input resistance of 2000 times.

Before leaving the subject of differential amplifiers there is one other technique for improving CMR that we should discuss.



Assume that 99.95% of a 60 Hz common-mode signal applied to the input FET gates is passed through the guard circuit to the R107-R207 juncture. Thus, a 1-volt common-mode signal applied to the inputs produces a 999.5 mV in-phase signal at R107-R207 juncture. With only a 0.5 mV change across R107 and R207 the effect is an apparent multiplication of R107 and R207 values, as shown by:

$$(1)\quad R_{in} = \frac{\Delta E_{in}}{\Delta I_{in}},\ \text{where } \Delta E_{in} = 1 \text{ Volt and}$$

$$\Delta I_{in} = \frac{E_{in} - E_{guard}}{R107},$$

$$= \frac{1\ \text{Volt} - 999.5\ \text{mV}}{R107},$$

$$= \frac{0.5\ \text{mV}}{R107}$$

$$(2)\quad R_{in} = \frac{1\ \text{Volt}}{\frac{0.5\ \text{mV}}{R107}}$$

$$(3)\quad = \frac{1\ \text{Volt} \times R107}{0.5 \times 10^{-3}\text{Volt}}$$

$$(4)\quad = R107 \times 2 \times 10^{3}$$

For example, applying a value of 10 MΩ to R107 and R207 results in an apparent input impedance of 20,000 MΩ for each side. The value realized in practice is substantially lower, because R107 and R207 are paralleled by many resistive and capacitive leakage paths which cannot be guarded.

Fig. 6. Calculating the apparent input impedance to common-mode signal.

High Frequency Common-Mode Rejection

We normally associate common-mode signals to the low frequencies such as 60 Hz ground loops. However, by definition common-mode signals can occur at any frequency. Common-mode often is seen in signal lines and systems as noise spike, clock pulse and the like. Suppression of these interfering signals often becomes a problem especially when interfacing subassemblies or racks of equipment.

A partial solution to this problem is found by using a balun (balanced transmission line to unbalanced transmission line device).

A balun can take the form of a bifilar wound transformer which can be made to have broadband characteristics. As a result of being bifilar wound, equal and opposite currents due to differential signals generate no net flux, hence encounter no inductance; these signals will pass through the device unattenuated. For common-mode currents the opposite is true, the device acts as an inductance inhibiting these currents. This type of balun often takes the form of a toroid core on which two or three bifilar wound turns are placed. These devices are frequently used in high-speed circuitry (see Fig. 7).

Summary

The differential amplifier can be used to solve many difficult measurement problems. Some are solved most easily using a differential comparator; others require full differential capability with DC offset. Whatever the measurement, satisfactory results depend on the user's knowledge of differential techniques and the limitations of his equipment.

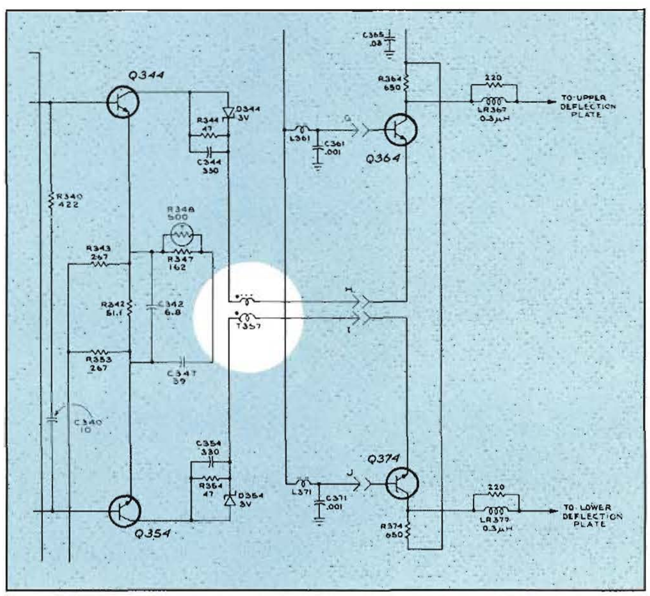


Fig. 7. Partial diagram of the TEKTRONIX 453 Vertical Output Amplifier showing use of a balun device to suppress H.F. interfering signals when coupling between subassemblies.

SERVICE SCOPE

REPAIRING OSCILLOSCOPE PROBES

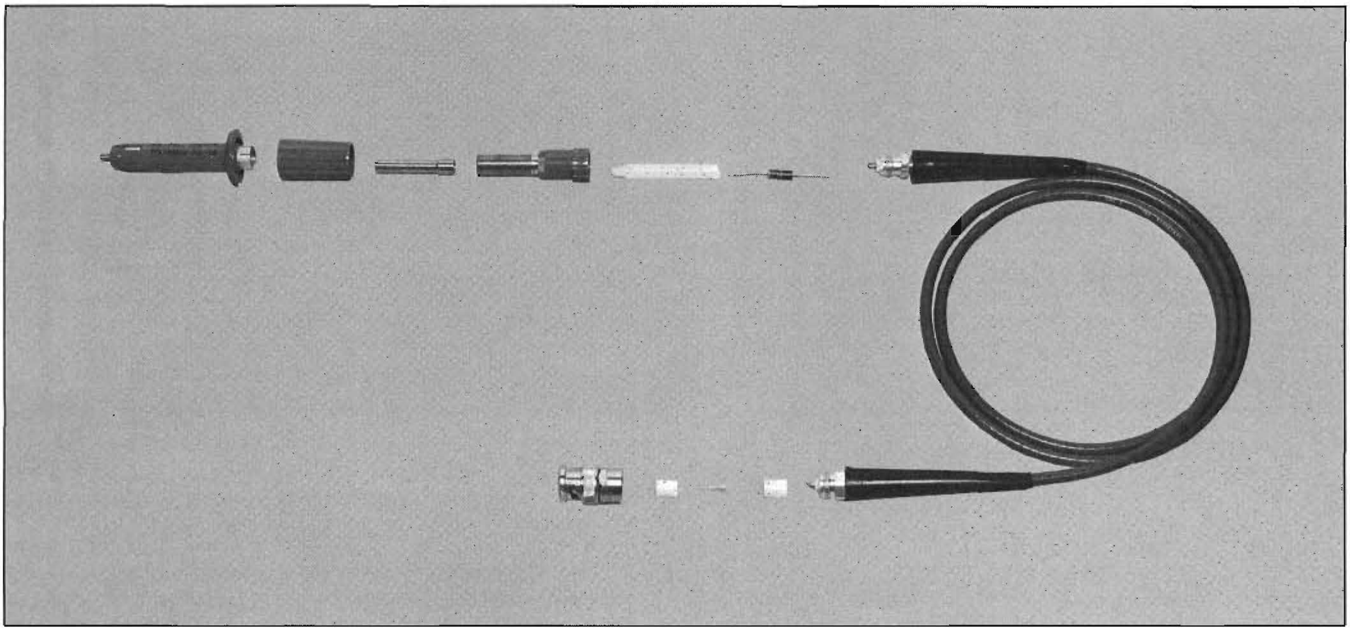


Fig. 1. The P6006 Probe disassembled to show the individual parts making up the probe.

Are there any dusty twenty dollar bills hanging on your test lead rack or laying in the work bench drawer? There probably are but you don't recognize them since they're in the form of oscilloscope probes with open cables, broken probe tips, etc. With just a little time and a few parts you can put those dusty twenty dollar bills back to work for your company.

About this time someone says, "Oh yeah? I've tried repairing those probe cables and you can't solder to the center conductor. It's resistance wire and solder rolls off it like water off a duck's back". He's right, it does so let's try a different approach—let's replace the entire probe cable. TEKTRONIX supplies replacement cables complete with boots and bushings to connect to the probe body and the connector. And you don't have to solder to the resistance wire; a solderable lead or terminal is provided at both ends of the cable. You can usually replace the probe cable in just a few minutes. Sound interesting? Then let's take a more thorough look at probe repair.

There are basically three types of probes to consider: passive voltage attenuator probes, current probes and probes using active devices such as FET's. Passive attenuator probes are by far the most numerous and the easiest to repair so let's discuss these first.

Passive Attenuator Probes

Passive probes are usually designed to provide optimum performance when used with a particular instrument. This results in minor variations in the construction of the different probe types. For example, you've probably noticed the differences in the approach to low-frequency compensation. With some probes you loosen the locking sleeve and rotate the probe body. In others, it's a screwdriver adjustment in the compensating box. Some probes also contain high-frequency adjustments. These are calibrated at the factory for a specific oscilloscope input capacitance. While it's not necessary to check these adjustments as often as the low-frequency compensation, it would be well to check them after performing probe repairs.

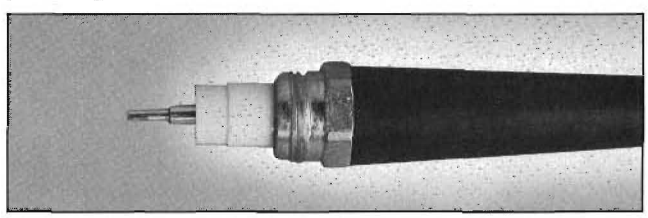


Fig. 2. The probe contact pin and insulating bushing on the BNC connector end of the probe cable. Some pins are crimped on, others are soldered.

The passive probes are easy to disassemble for changing the probe cable. The instructions and exploded view of the probe in the manual are helpful in describing how the probe comes apart. You may have a little difficulty in removing the probe contact pin and insulator bushing from the BNC connector end of the probe cable, especially on some of the P6006's. The usual procedure in assembly is to solder a short piece (about 5/16") of #20 wire to the copper stud on the end of the probe cable. The insulating bushing is slipped in place over the wire, and the probe contact pin is then soldered to the wire extending from the bushing. On some probes the contact pin is crimped on rather than soldered. It is not feasible to salvage these. When you order the replacement probe cable it would be well to order some spare probe contact pins and insulating bushings.

The Needed Items

The first item you'll need for each type of probe to be repaired is a manual. This contains a complete breakdown of the probe assembly, part numbers, schematic, maintenance and calibration details and probe characteristics. Some parts are also made available as part of a subassembly as it is sometimes easier to replace the subassembly than the individual part. The manual usually lists the part number for the subassembly. If you don't have the necessary manuals, contact your nearest Tektronix Field Office.

The only special tools you will need in addition to those normally found on the workbench are a few thin open end wrenches. If not available locally, these can be manufactured by grinding down standard thickness wrenches. The manual will tell you the wrenches needed for the probe being repaired.

The test equipment needed to check high frequency compensation is dependent upon the bandwidth of the probe to be checked. If you don't have the equipment called for in the manual, contact your Field Engineer for alternatives.

CURRENT PROBES

There are three general types of current probes manufactured by TEKTRONIX: high-frequency current probes which use a current transformer permanently wired into the circuitry as a test point, clip-on AC current probes and clip-on DC current probes. We will concern ourself with only the latter two. Let's look first at AC current probes.

AC Current Probes

The two clip-on AC current probes which we will discuss are the P6021 and P6022. They are similar in construction but differ in bandwidth capability and physical size.

The most common problem encountered with these probes is dirt or some other foreign substance on the pole faces, causing poor low-frequency response or noise. The probe should be taken apart and cleaned if you have these symptoms.

The manual describes how to disassemble the probe. However, there are a few techniques which will simplify the task. The probes contain some small parts so it would be well to work with a clean cloth or piece of felt on the workbench to avoid losing parts. You will note that the thumb-controlled slider which opens and closes the transformer core, is spring loaded. As with most spring loaded devices you can experience some surprises when taking the probes apart unless you exercise care.

The first step is to remove the rubber boot at the end of the probe body. With the probe body held in the left hand, firmly grasp the boot with the thumb and forefinger of the right hand on the sides of the boot and working the boot from side to side slide it to the rear. It's a firm fit and will take a little effort.

Next, carefully lift the upper half of the probe body slightly at the rear and slide it off the front of the probe. Here's where the surprises come in. You will need to keep firm pressure down on the thumb cam of the slider or the slider spring will pop the slider out. This is especially true of the P6022. The next thing to watch for is the small metal ball setting in a detent on top of the slider. It's easy to lose this unless you're working over a surface where the ball won't roll. Remove the ball if it hasn't already fallen out.

You may have difficulty getting the top cover over the probe nose on the P6021. This is due to the insulating sleeve in the lower transformer core. Squeezing the top and bottom of the front portion of the top cover will help in removing the cover. Remember this also when you reassemble the probe.

To remove the slider it's best to turn the probe so that the slider portion is on the bottom. This prevents the components in the slider from falling out. With the P6022, you will probably want to remove the spring and spring retainer before turning the probe over to remove the slider.

It is a simple matter to remove the printed circuit board and current transformer in the P6021. After removing the two Phillips-head screws securing the plastic spring retainer, just pull up gently on the cable at the rear of the probe. Lift the circuit board, transformer, and cable straight up out of the probe body as a unit. A scribe can be used to work the header free at the front of the circuit board if necessary. When replacing the Phillips-head screws, tighten them so they are just snug; excessive torque will strip the plastic threads.

It's a little more of a chore to remove the board and transformer in the P6022. There are two points you will need to unsolder before lifting out the cable, board, and transformer as a unit. You should use a small iron to avoid applying excessive heat to the cable and printed circuit board.

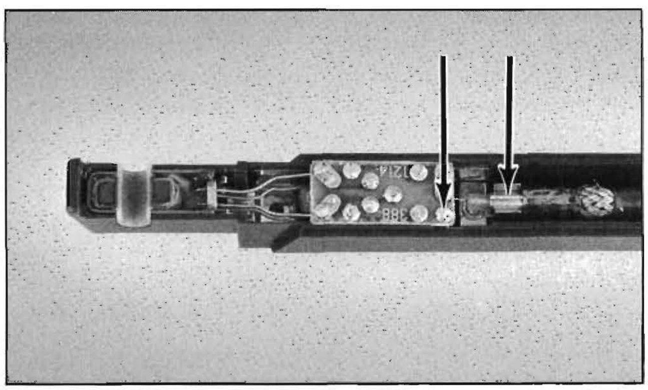


Fig. 3. *Arrows point to the two points to be unsoldered in the P6022 when removing the cable, circuit board and transformer.*

Cleaning The Transformer

The transformer pole faces and the surrounding mu-metal shield should be clean and free from scratches. There are a number of methods you can use to clean them. A soft bristle toothbrush with a rubber gum-massage tip works well. The rubber tip is used to clean the pole faces and the brush to remove the residue and dust. Another technique used to clean the pole face is to use a hard-surfaced piece of paper such as coated stock. Lay the paper on a flat surface and rub the pole piece back and forth in a polishing motion. Brush away any loose particles. Sometimes a bright spot of metal will adhere to the pole face. This can be removed by a sharp tool such as a scalpel or X-acto knife, being careful not to scratch or gouge the pole face. Once you have the surfaces clean, avoid touching them with the fingers.

Before reassembling the probe, place a minute amount of Lubriplate or similar lubricant to the contact area of the grounding tabs on the slider. This assures smooth operation and eliminates squeaking of the slider. If you have replaced any components, or the probe cable, the high-frequency response should be checked using the procedure in the manual. You will find the short-pulse technique described in the January, 1971 issue of TEKSCOPE helpful in adjusting the pulse response.

The DC Current Probe

Now let's take a look at the P6042 DC Current Probe. The construction of the DC current probe is similar to that of the AC probes with the exception of two small screws on the bottom of the probe body that must be removed to disassemble the probe. You should use care in removing the printed circuit board and transformer as the wires in the multi-conductor cable are small and easily broken.

The probe is permanently attached to a unit containing the power supply, amplifiers and degaussing circuitry. It also provides convenient storage for the probe. Since this unit houses all of the active devices except the Hall-effect device, it is the most likely place to suspect trouble if the probe malfunctions.

The Current Probe Amplifier

The amplifier consists of essentially two amplifiers—low frequency and high frequency. The output of the Hall device in the probe is fed into the low-frequency amplifier. The ouptut of this amplifier passes through the current transformer in the probe, which provides the high-frequency portion of the signal. The combined signals then pass through the high-frequency amplifier to the output connector.

The front panel DEGAUSS switch provides a convenient means of isolating the low-frequency and high-frequency amplifiers. Holding the DEGAUSS switch depressed, you can check the DC operation of the high-frequency amplifier by rotating the OUTPUT DC LEVEL knob and noting that you have control of the output DC level. The high-frequency operation can be checked by uncoupling the attenuator lead at J80 and feeding an external RF signal into J80. A cable with a female BNC on one end and a male Selectro Connector on the other is handy for this purpose (Tektronix Part No. 175-0419-00).

If the entire system is badly unbalanced DC-wise you may have a broken wire in the probe. Also check the probe wires where they terminate in the amplifier unit. Remember that the probe slider has to be completely closed to get a signal on-screen. If you find it necessary to pull the low-frequency amplifier stages Q44, Q45, or Q53, Q54 which are mounted in heat sinks, be sure and turn off the power first. They are easily damaged if removed with the power on.

The Degaussing Operation

It is necessary to degauss the probe frequently and it is important that the degaussing circuit work properly. The General Radio 50 Ω terminating loop called for in the list of calibration fixtures in the manual, provides a convenient means of feeding the degaussing signal into the test scope. Use a GR-to-BNC adapter to connect the current loop to the input of the scope; then clip the current probe around the loop and depress the DEGAUSS switch. (You will need to activate the interlock switch in the probe storage compartment.) You should see a damped sine-wave signal about 400 mV in amplitude and 200 ms in duration. In some units the amplitude is reduced to about 100 mV or less if the DEGAUSS switch is depressed slowly. This can be cured by adjusting the degaussing switch contact that is connected to the lead going to square pin H on the etched-circuit board.

To complete the discussion on the DC current probe we would like to note a change in the manual calibration procedure. Step 9 (e) under Adjust CURRENT/DIV BALANCE Range should be revised to read, "Adjust both R16 and R17 for a CURRENT/DIV BALANCE range of ±55 ma". Both R16 and R17 will be near mid-range when the adjustment is correct.

Repairing FET Probes

The new high-frequency FET probes available today pack outstanding performance in a very small space. Because of the sub-miniature parts and close physical tolerances needed to construct such a probe, extreme care is required during servicing. We recommend you return these probes to the factory for repair.

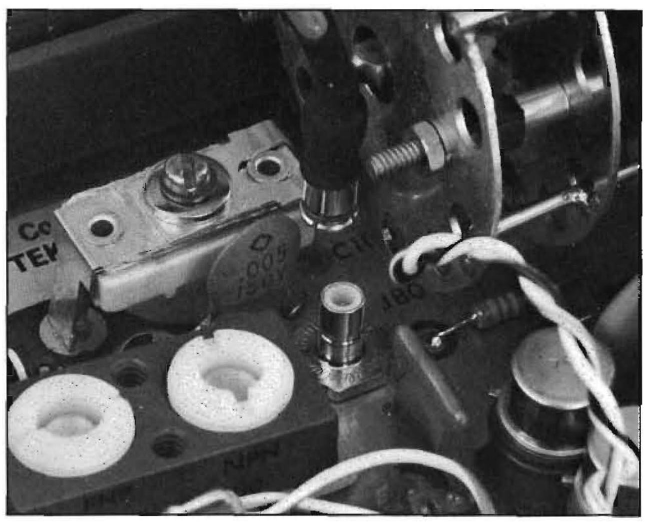


Fig. 4. Attenuator can be disconnected at J80 and signal inserted to check high-frequency amplifier of the P6042.

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