COMPUTER CONTROLLED INTEGRATED CIRCUIT TEST SYSTEMS

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Testing is a subject which is of major concern to all manufacturers and users of integrated circuits, whether they are low complexity gates and flip-flops, or more complex MSI and LSI devices. There seems to be general agreement in the industry that low complexity devices can be tested adequately on the test systems, generally computer controlled, that are available from several manufacturers. However, there is very little agreement about how the more complex MSI and LSI devices should be tested. Some commentators have even stated that LSI devices cannot be tested adequately at a reasonable cost.

This paper reviews the requirements that an integrated circuit test system must fulfill and shows why a computer controlled system usually, but not necessarily always, is the best choice. Various possible configurations of test systems are discussed and reasons for their applicability to certain test situations are suggested. In the latter part of the paper particular attention is given to testing more complex MSI and LSI devices. Finally, a short description of one manufacturer's approach to testing complex devices is given.

It is impossible to separate the philosophy of testing from the design and selection of test equipment. Some agreement on the philosophy of testing is essential before a product of the complexity of an integrated circuit can become a reality. Testing is basic in the vendor/customer relationship. A satisfactory definition of test methods and test equipment is essential if there is to be a satisfactory working relationship between the manufacturer and user. This applies as much when the manufacturer and user are separate departments within the same company as when they are completely different companies. The industry has established reasonable solutions to most of the testing problems related to low complexity integrated circuits. At this time, however, there is very little agreement about testing the more complex MSI and LSI devices.

It is the author's intention that some of the material in this paper will contribute to establishing some agreement on the basic philosophies of testing complex integrated circuits. In response to those who suggest that it is impossible to test these devices adequately and economically, it is relevant to point out that there are many similarities between testing LSI and testing complex digital functions in the form of printed circuit boards and sub-systems. These devices have been tested for many years with varying degrees of success. Workable, if not ideal, solutions to the problems of testing complex digital functions have been developed and used. It is reasonable, therefore, to start considering the subject of testing LSI from the basis that it can be done.

TEST ENVIRONMENTS

Integrated circuits test systems are used by manufacturers and users and also by independent test laboratories (Figure 1). Each of these types of organization use test systems for many different purposes and, for these purposes, require a variety of capabilities. For many purposes it is a requirement that one test system can satisfy all the requirements although, sometimes, it is more convenient to have separate test systems for the different purposes. This mainly depends on the size of the organization. Whereas a large organization can afford to have many test systems, each designed to satisfy a certain requirement, the smaller organization cannot afford to do this and must, therefore, have a versatile test system.

Integrated circuit manufacturers primarily use test systems to test devices at the wafer probe and final test stages. For them high throughput is a prime requirement. They are primarily interested in how much it costs to test a device. Initial cost of the equipment is less important than such factors as test rate, reliability, down-time, (which includes the time that the system is not testing while it is being reprogrammed as well as the time that it is not operational) and accuracy. These are the factors that determine the cost of testing and the cost of errors in testing.

At the wafer probe stage it is usually economic to perform a functional test first on each device as this allows a rapid decision to be made as to whether or not the device is worth further testing. In the case of complex devices, functional testing becomes much more important. Following functional testing it is usual to perform a number of static parameter tests (often referred to as dc tests) to verify that the device meets its specification. These tests are generally performed on a go/no-go basis. It is advantageous for process control purposes to accumulate parameter distribution information at this stage. To satisfy this requirement it is necessary that the test system has the capability of making measurements at high speed as well as making go/no-go decisions.

Until quite recently, there has been little need to attempt to make dynamic tests or measurements at the wafer probe stage of manufacture. However, some manufacturers are beginning to make this type of measurement. There will, no doubt, be a growing tendency to do this, particularly in the case of integrated circuits which are to be assembled into hybrid assemblies. When dynamic testing is performed at the wafer stage it is necessary that a test system is used that can make both static and dynamic tests at the same test head. This is because a wafer can only be probed once, otherwise unacceptable scratches on the metallization are likely to occur.

At the final test stage the manufacturer makes tests on packaged devices to ensure that they meet their published specifications and to verify that the lead bonding within the package is good. The degree of testing that is performed at this stage depends on the application for which the device is sold. It is usual at least to perform static and functional tests at room temperature. In addition the static parameters may be tested at the extremes of temperature for which the device is specified. Where the dynamic parameters of the device are critical these will also be tested. Environmental

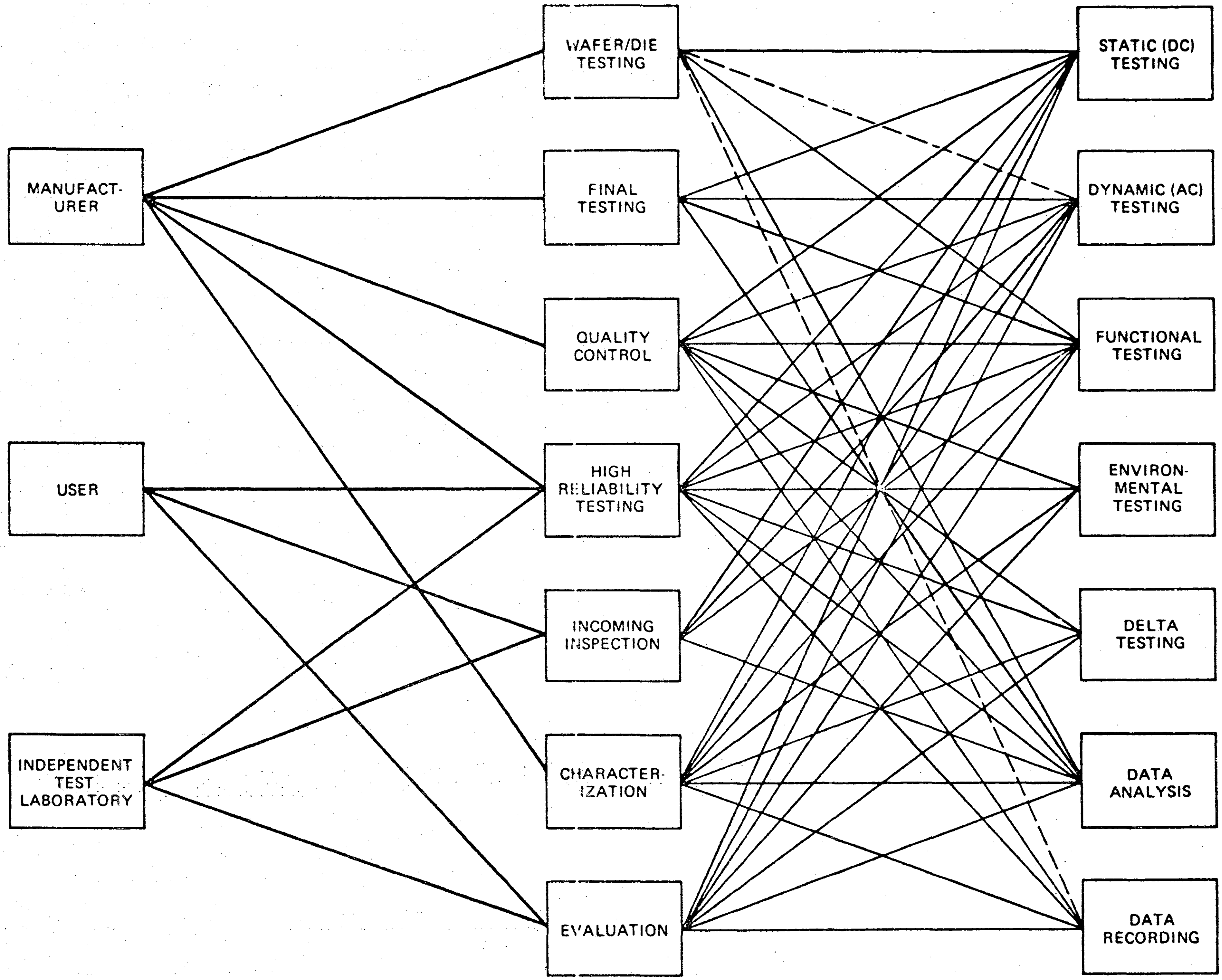


FIGURE 1 INTEGRATED CIRCUIT TEST SYSTEM REQUIREMENTS

testing and dynamic parameter testing may be performed on a sample of devices or they may be performed on every device.

The test system requirements for final device testing are similar to those for wafer testing. High throughput rates, good reliability, and accuracy are all important. One difference between wafer testing and final testing is that at the latter stage it is often possible, and sometimes even desirable, to perform different types of tests at separate test stations.

Quality control testing is performed on samples of devices at various stages in the manufacturing process. For this type of testing accuracy is of great importance. During a working day the quality control department typically performs tests on a small number of each of many different types of devices. It is important, therefore, that the test system can rapidly change from testing one type of device to testing another. Also quality control testing often involves recording parameter values. The ability to data log without significantly reducing the test rate is, therefore, important.

Delta testing is the measurement of parameter change due to stressing. The most common form of delta testing is to record parameter values before and after operating devices for a defined period, and comparing the change in parameter values against predetermined limits. The allowable parameter changes are sometimes stated in absolute values, sometimes in percentages, and sometimes both an absolute and a percentage delta limit are specified. Clearly, for this type of testing it is very desirable to have the test system connected to an on-line computer so that the delta results can be automatically calculated as the testing proceeds.

High reliability testing is very similar to quality control testing except that it involves testing all devices and recording their parameter values. In addition to recording parameter values it may be necessary to provide statistical summaries of the parameters and to give delta information. When testing devices for use in high reliability applications very stringent requirements are placed on the accuracy and reliability of the test system. It can be very expensive if, due to a test system error, a large batch of devices has to be retested or, even worse, is rejected.

Most large quantity users of integrated circuits make some electrical incoming inspection tests. These range from simple functional tests to very sophisticated and complete parameter measurement similar to that performed by manufacturers on high reliability devices. Typically the incoming inspection department has similar requirements for test systems to the manufacturers' final test department. It is important that the test methods used by the incoming inspection department should be very similar to those used by the integrated circuit manufacturer. If this is not so, many difficulties will arise due to discrepancies in measurements at the two locations. Just to give one example of how these difficulties arise, it is well-known that most semiconductor parameters are temperature dependent. Due to the internal dissipation of a device, its temperature will rise to some extent during testing. The actual temperature that will occur during testing depends on the time that power is applied prior to the time the temperature is measured. This can cause differences in test results at two locations to such factors as different test times used by two different test systems or by performing tests in a different order.

The two functions of characterization and evaluation are similar, the former being performed by the integrated circuit manufacturer as he seeks to gain sufficient knowledge about his devices to write a convincing data sheet and obtain a profitable yield from his production lines, and the latter being performed by the user as he tries to compare one manufacturer's device with another and gain some knowledge about the unspecified parameters of the device. In both cases a very versatile test system is required and one that has the capability to record and analyze test data.

The independent test laboratory performs a very useful function within the industry. It performs evaluation and incoming inspection functions for smaller users of integrated circuits and also acts as a back-up for the larger user when his testing requirements cannot be satisfied internally. Some independent test laboratories are also very active in the field of high reliability testing. The independent test laboratory requires very versatile equipment and places a high value on the ability to record and analyze test data.

TEST EQUIPMENT

A review of the preceeding paragraphs indicates that there are a wide range of applications of integrated circuit test equipment, each of which places a different emphasis on the importance of the various features of the system. It is important, therefore, that the designer of the equipment is completely cognizant of the use to which it will be put before he starts to design it. The potential purchaser must be equally sure that he understands his own needs before he decides which equipment to buy.

The following paragraphs suggest some of the considerations that should be borne in mind when defining integrated circuit test systems.

With the risk of appearing too elementary it is relevant to pay some attention to the purpose of integrated circuit test systems. Clearly, their function is to test integrated circuits. But why test integrated circuits? The reason, surely, is to ensure that, when they are soldered into an assembly, they will operate correctly and reliably. Integrated circuits are used in a very wide variety of equipment. It is reasonable, therefore, to suppose that the testing that must be done depends on the final use to which the integrated circuit is to be put.

There are four basic types of electrical tests that are commonly performed on integrated circuits, stress tests, functional tests, static parameter (dc) tests, and dynamic parameter (ac) tests. Much time and energy has been spent in arguments about which of these tests should and should not be performed. Most of this time and energy is wasted because it tends to assume that there is one answer that suits most, if not all, applications. All these types of tests are important and useful, but not all are necessary or desirable for all applications. Sufficient time and energy should be spent, prior to any attempt to define an integrated circuit test system, in understanding what each of these types of tests can achieve within the environment that they may be used. Unfortunately this is not always done.

Stress tests often take the form of applying voltages in excess of what will normally be experienced in use to the terminals of an integrated circuit. Correctly designed and interpreted these tests can be used to indicate the potential reliability of a device. They also give assurance that the device is unlikely to fail due to transient conditions in the equipment in which they are installed. Stress tests are frequently used to test the oxide integrity of MOS devices.

Functional tests, also referred to as truth table tests, are used to ensure that a digital device performs the correct logic function. Patterns of '1's and '0's are applied to the input pins of the device under test while the output pins are compared with the expected levels. At the wafer test stage functional tests are used to make a fast decision whether or not the device is basically good before it is committed to the more time-consuming static parameter tests. Functional tests become particularly important in the case of complex devices.

Static parameter tests are those in which measurements of voltages and currents are made at the terminals of the device under test at a speed which is sufficiently slow that the measurements are essentially independent of time. Typically static parameter tests are made in periods ranging from one to one hundred milliseconds. The voltages and currents that are measured ensure that the fan-in and fan-out, the power dissipation, and the threshold levels of the device under test are correct.

Dynamic parameter tests are those in which times or, sometimes, time dependent voltages, are measured. The most common of these are transition times and propagation delays. Less frequently instantaneous noise voltages are measured.

In addition to the four basic types of tests the decision also has to be made whether it is sufficient to measure the performance of integrated circuits at room temperature or whether measurements should be made over the temperature range at which the devices will be used.

Ideally testing should ensure that every integrated circuit operates correctly when it is first installed and that it will continue to operate correctly over the required life of the equipment. No amount of testing can absolutely guarantee this. So the facts of probability intrude into the test decisions. The more money that is spent on testing, providing it is wisely spent, the more confidence can there be that the testing is effective. A comparison has to be made between the cost of testing and the cost of not testing. A defective integrated circuit costs money to locate and replace whether this is done during the manufacture of the equipment or in the field. This cost depends on many factors some of which are the accessibility of the defective device (the cost of replacing a defective component in an unmanned satellite is the cost of that satellite plus the cost of putting it in orbit), the size and complexity of the module (eg printed circuit board) of which it is part, and the cost of not having the equipment operational while the defective part is being located and replaced. Clearly these costs vary enormously from one application to another. Equally, therefore, the amount that it is economic to spend on testing and on the test equipment varies greatly according to the application.

The very varied requirements for integrated circuit test equipment leads to a very clear choice. Either specific equipment must be designed for particular applications or the equipment must be sufficiently modular that it can easily and economically be tailored to suit many specific applications. It is rarely economic to design equipment specifically to suit a particular need. Even if the usage of the equipment is large enough to justify a special design, it is likely that the needs that are identified at any one time will change periodically making it necessary to redesign the equipment. This approach is unlikely to result in efficient and reliable test equipment. Usually, therefore, integrated circuit test systems are designed on a modular basis.

A specific example of a modular test system is briefly described at the end of this paper. This shows how a modular approach to the design of an LSI test system may be accomplished.

It is necessary to have a deep understanding of the nature of a device before an adequate system to test it can be designed. This is particularly true in the case of integrated circuits. Two examples of this as it applies to integrated circuits are given below.

At first it might seem to be a simple matter to measure the leakage current at an input terminal of an integrated circuit. Suppose that it is required to measure the leakage current of an input to a gate which is part of a complex integrated circuit (Figure 2). While the input in question is connected to one of the pins of the device all the other inputs are connected to the outputs of flip-flops which are buried within the device. To measure the leakage current under worst case conditions it must be done with all the inputs to the gate except the one being measured connected to a low logic level (DTL or TTL logic is assumed). To ensure that this state is reached it may be necessary to exercise the inputs of the device through a large number of logic states. It is desirable that this is done rapidly in order to minimize test time. From this arises the need to perform rapid function

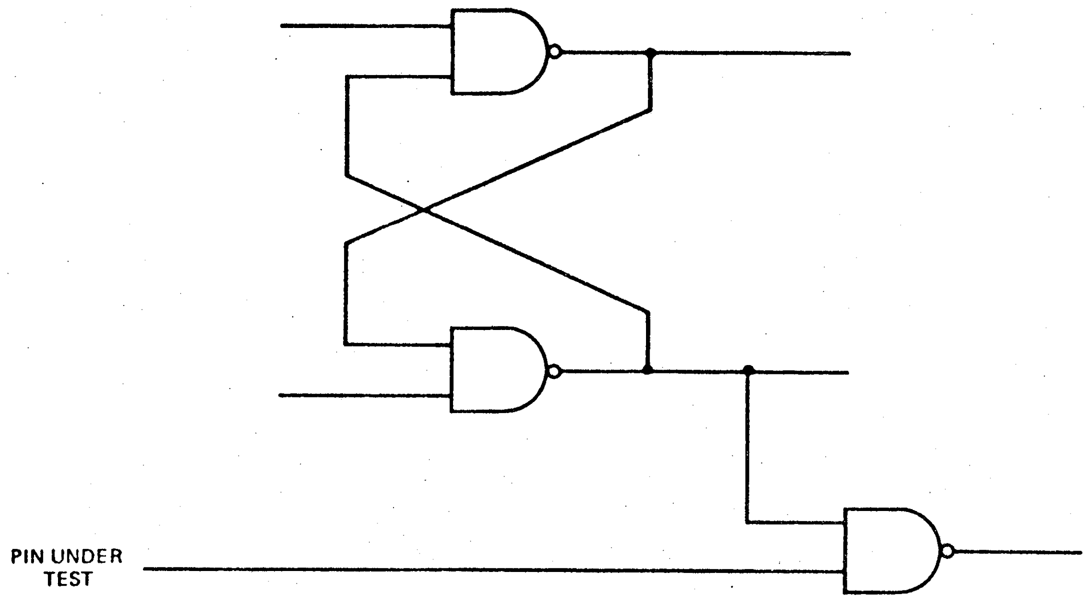


FIGURE 2 LEAKAGE CURRENT MEASUREMENT DEPENDS ON INTERNAL STATE

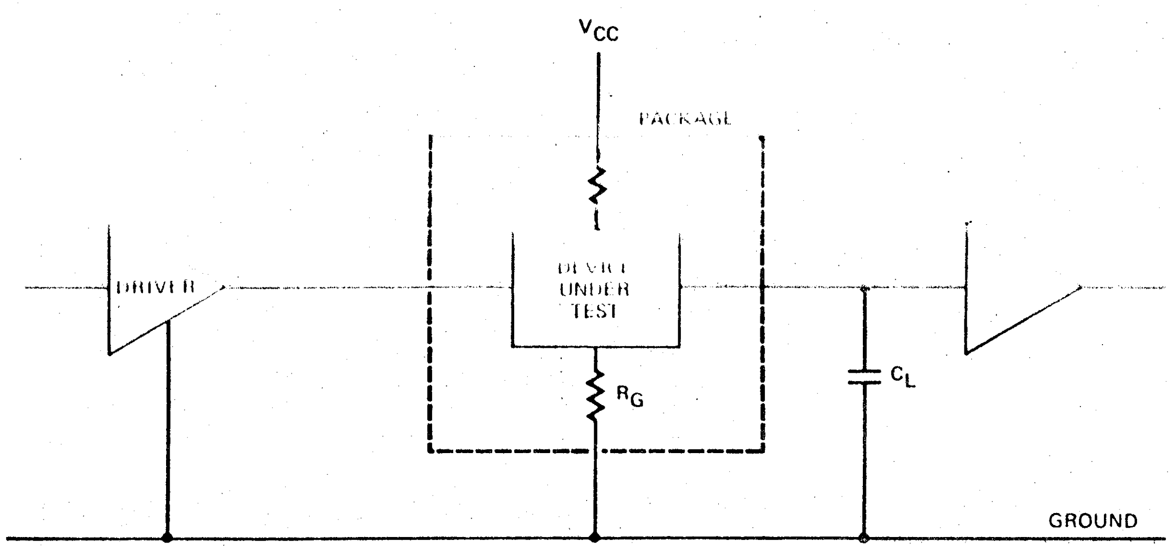


FIGURE 3 INFLUENCE OF CAPACITIVE LOAD

tests which are interrupted by static parameter tests at specific times. The test system, therefore, must be capable of switching from the high speed function test mode to the static parameter mode without producing tranients at the terminals of the device under test which might cause it to change state.

The second example concerns the capacitive loading that the test system places on the output terminals of the device under test. It is generally well known that some integrated circuits are unable to drive more than a certain capacitance. What is not understood is that, even though the device under test can drive a certain capacitance, this capacitance may cause significant errors in the tests that are made and may even make it impossible to test certain kinds of devices. In the drawing (Figure 3) an integrated circuit is shown driving a function test comparator that places a capacitive load C_L on the output terminal. The resistor R_G represents the resistance between the ground connection of the gates on the die and the external ground of the device package. This resistance is partly due to the resistance of the aluminum conductors on the surface of the die, partly due to the bonds between the die and the pins of the package, and partly due to the package leads. Suppose that the output of the integrated circuit is at a high logic level and that changes at the input terminal cause the output voltage to change to the low state. While this is happening the charge stored on the capacitor C_L discharges through the integrated circuit and through the resistor R_G. This current causes a temporary change in the internal ground level of the die which will not occur when the device is used in a system, unless the capacitive load happens to be the same. This temporary change of internal ground voltage can cause a number of problems. If the input voltage change is slow compared with the switching speed of the gates on the die it can cause multiple triggering of flip-flops. Even if the input edges are fast enough to avoid this problem there may be other inputs that are held close to the threshold levels which will pass through the threshold levels as the ground level changes. If this happens the device will not make the required changes in state. For these reasons it is important that the test system places a minimum capacitive load on the output pins of the device under test.

The above examples are just two of the many practical points that must be borne in mind when designing or selecting integrated circuit test systems. There are, of course, many other equally critical points.

WHY USE A COMPUTER?

In the earlier parts of this paper considerable attention has been given to what an integrated circuit test system must do, both in terms of the testing environment and in terms of the device to be tested. Very little has been said about the configuration of a test system or how it operates. It is not the intention of this paper to describe the hardware of a test system in any detail. Reference should be made to other papers for this information. In the simplest terms, every test system consists of a number of modules that are capable of applying defined conditions to specific terminals of the device under test and others that are capable of measuring the results of applying these conditions. From test to test the forcing conditions, the measurement conditions, and the connections to the terminals of the device under test are changed. This implies the necessity of a control function within the test system. A different sequence of test conditions is required for each device to be tested. Therefore the system controller must be programmable.

In the case of very simple integrated circuit testers a printed circuit board is used to provide control. Soldered connections on the board determine the connections to the device under test. Resistor networks provide the correct voltage and current forcing levels and also comparison levels. This type of tester can provide adequate testing under some conditions but is clearly very restricted in its flexibility. Somewhat greater flexibility is provided in more expensive test systems by providing the test program on punched paper tape. The test conditions are controlled directly from the paper tape as it passes through a reader. Again, this type of test system can satisfy some needs, but it has a number of disadvantages including slow speed, inflexibility and inconvenience.

Most automatic test systems have a means of storing test programs within an internal memory which takes the form of either a core memory or a magnetic disk. In these systems the stored program is converted into instructions for the modules of the system either by special purpose logic or by a general purpose digital computer. In older systems special purpose logic was used whereas, today, general purpose digital computers are used almost exclusively.

There are many reasons why it is advantageous to control an integrated circuit test system by means of a general purpose digital computer. Some of these reasons are explored in detail below. Before going into these details, however, it may help to clarify the use of a computer in this type of application if some general comments are made about general purpose digital computers.

The word 'computer' can be mis-leading. When computers were first developed they were designed to perform scientific calculations. The use of computers in this application enabled calculations to be made which were previously impossible due to the time that would be required by a human being operating a desk calculator and due to the inevitability of errors that arise whenever a human is involved in long and tedious operations. Later computers were developed for business applications where, again, calculation was their basic function. In this case the advantage of an automatic digital computer was that it could perform a very large number of simple calculations very rapidly. In both these types of use the main purpose of the computer was to perform computations. It was very reasonable, therefore, that it should be known as a computer.

More recently computers have come to be used for applications where their function is primarily that of control, rather than computation. In these applications the decision making capability of a computer is of great importance.

Both as a calculator and as a controller a computer operates on binary numbers. Binary numbers are stored in its memory, manipulated in its central processing unit, and written back into the memory. As a calculator these binary numbers are coded representations of decimal numbers. As a controller the binary numbers are coded representations of control information. In both cases binary numbers are also used within the computer as coded instructions for the computer itself.

To act as a system controller, where the system may be an integrated circuit test system for example, coded instructions for the various parts of the system are stored within the memory. These instructions are delivered to the appropriate parts of the test system either in the sequence in which they are stored or in a sequence which is determined by other information such as, for example, the results of previously made tests.

One of the principal reasons why general purpose digital computers have come to be used to control integrated circuit test systems is that of economics. Small general purpose computers are available today from many manufacturers. They are used in many applications both for computational and for control purposes. Due to the large number of these computers that are built and the competitive nature of the market they are available at quite low prices. It is possible to buy a small general purpose digital computer suitable for controlling an integrated circuit test system for considerably less than the special purpose logic to do the same task could be built. If the computer had no other advantages over special purpose logic it would be preferred from a cost point of view. However, as will be shown in the following paragraphs, the computer has a number of other important advantages.

Figure 4 represents a computer controlled integrated circuit test system. Notice that the test system main frame is a peripheral to the computer. The diagram shows a large number of input/output peripheral devices. It is unlikely that any particular installation would have all the peripherals shown. However, to suit particular requirements any combination of them may be desirable.

Most computer controlled systems use a teletypewriter, or similar device, as the basic method of communicating with the system. The system operating modes are selected by typing in instructions at the keyboard. Test programs may be read into the computer memory either by typing them directly in at the keyboard or by reading them in from a prepared punched paper tape. Test results may be typed out by the computer using the teletypewriter or may be punched onto paper tape.

Other input/output devices such as high speed paper tape readers and punches, card readers and punches, and magnetic tape drives are used to provide more convenient methods of reading information into the memory of the computer and recording test data. The principal advantage of these devices is high operating speed.

Magnetic tape drives and magnetic disks provide a very convenient way of having a large number of test programs readily available to the computer. Each has advantages and disadvantages. For many purposes the disk is preferred. Magnetic disks have a very short access time. It is possible to store a very large test program, such as might be used for testing an LSI device, on a disk and transfer it in sections into the computer memory as the testing proceeds. This enables very long test programs to be performed without the need for a very large and expensive core memory.

Where a large amount of data is to be printed two approaches are possible. One is to record the data on some high speed medium such as magnetic tape or disk and to translate it into typed copy off-line using a separate computer. The other approach is to use a line printer operating directly from the test system computer. The latter method is preferred as it gives the test system operator the opportunity to monitor the tests as they are being performed. Without the use of one of these methods the test system is used very inefficiently due to the slow speed of printing on a teletypewriter. The need for printing large amounts of data arises in high reliability testing where a permanent record of the test results is often required.

A cathode-ray-tube display of test results can be useful in testing LSI devices or printed circuit boards. Particularly at the time test programs are being debugged and when devices are being evaluated the CRT gives the operator the ability to have an immediate display of test results. Used with a versatile editing software package the CRT display can be an important and useful testing aid.

Some testing facilities have advanced to the stage where each test system is operated by a local (dedicated) computer and all are connected to a central computer. The central computer provides overall control of the test complex. Where a number of test systems are to be operated in the same location the cost of the installation can be minimized by this approach. For example instead of each test system having a disk file to store all the test programs a single disk file can be part of the central computer and access provided to each local computer. Similarly if computation on the test results is required, instead of each test system having a computer with facilities for the required computations, this task can be performed by the central computer. In some instances, this type of installation is used where the test systems are separated by many hundreds of miles.

The diagram (Figure 4) also shows a modem as a peripheral to the test system. This allows data to be sent to and from the test system over telephone lines.

As stated above, it is unlikely that any test system installation will have all the peripherals mentioned. However to be generally useful the test system needs to have the capability of having a selection of most of them. If the test system is designed using a general purpose digital computer it is likely that the computer has the capability, both from a hardware and a software point of view, of being interfaced to a versatile range of input/output devices. If the test system is designed to be controlled by special purpose logic the addition of each input/output device makes necessary the design of interface hardware to suit that device. This can be expensive and tends to produce reliability problems. It is usually less expensive and leads to greater reliability to have an established and proven unit.

The use of a digital computer to control a test system provides the opportunity to simplify the programming language. Programming languages tend to be a subjective matter to a certain extent, what is simple to one user may be complex to another. The users' view of the programming language depends to a large extent on his background. This is where the computer provides assistance. The same computer that controls the test system can be used to compile a test program written in a 'language' that is simple for the user to understand into the code that operates the system. The same computer can also translate a program written in a language designed for one test system into a language which can be understood by another.

In some applications of integrated circuit test systems it is very desirable to have a method of reducing or analyzing the test data. For example, in the case of wafer testing, distribution data based on test results is very useful information on which to base control of the fabrication processes. Data

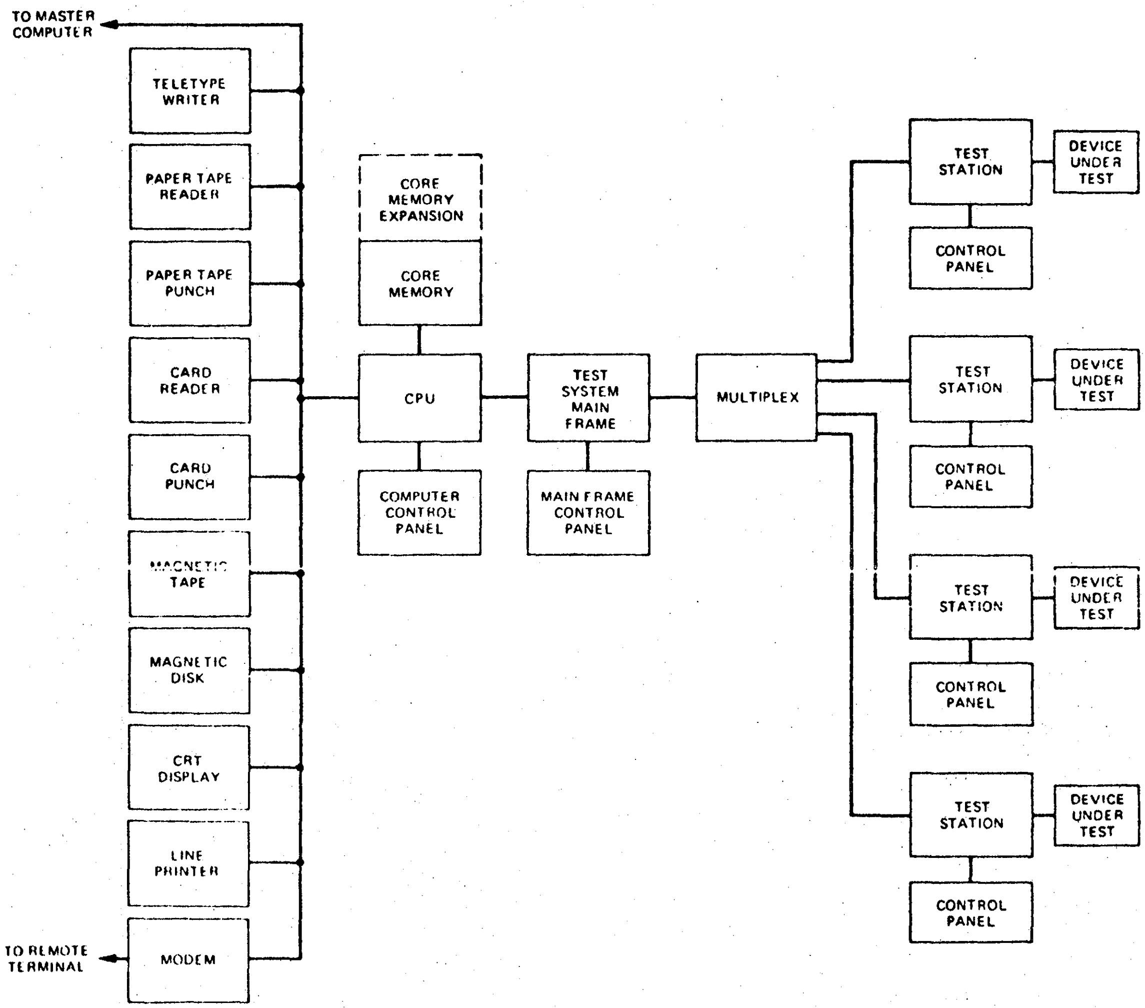


FIGURE 4 COMPUTER CONTROLLED TEST SYSTEM

reduction can either be performed off-line by recording the test results and using a separate computer or by using the computer that controls the test system to process the data while testing takes place. The latter approach is greatly to be preferred. One reason for this is that it allows the operator to monitor the test results while they are being produced. Another is that it makes the reduced data available immediately after a batch of devices have been tested. The computer controlled test system has the advantage over the non computer controlled system that it can do this.

Another example of where the computing ability of the computer controlled test system has an advantage is the case where go/no-go decisions are made as a result of calculated results rather than as a result of direct measurements. In high reliability testing delta measurements are often made. Devices are tested and all the measurement results are recorded. The devices are then subjected to some stress, such as being operated at a certain temperature for a defined time. They are then retested. Go/no-go decisions are made on the basis of the absolute or percentage change in parameter values between the two measurements. In some cases go/no-go decisions are made on the basis of limiting values of both absolute and percentage changes. A computer controlled test system can make this type of test readily. Without a computer it is necessary to store both sets of test results and to compute the changes off-line in order to pass or fail the devices. This is inconvenient, time-consuming, and expensive. It is also subject to errors due to the amount of manual handling both of the devices and the test data that is involved.

Yet another example of where the computing ability of the computer controlled test system is valuable is in the case of tests on devices where the specified parameter is obtained by calculation from two or more test results. This happens in the case of linear devices.

Computer controlled test systems are often faster than those that are not controlled by computers. There are several reasons for this. Usually test systems that are not controlled by a computer do not have a core memory. Instead they use a magnetic disk as the internal storage medium. The access time of a magnetic disk is usually in excess of ten milliseconds, whereas the access time of a core memory is only a few microseconds. The computer controlled system has virtually immediate access to information from the memory whenever it is required, whereas the disk controlled system often has to wait for information. Usually the computer controlled system can be programmed to minimize test times by making use of its capability for sophisticated branching. The use of subroutines in test programs can also reduce testing time and simplify programming.

One of the most important features of a computer controlled test system is its self-diagnostic capability. Diagnostic programs can be prepared which will check that the entire system is working correctly and, if a fault is found, will localize the fault so that it can be corrected rapidly. This can be an important contribution to minimizing the system down-time.

It has often been said that an advantage of the computer controlled test system is that it is less likely to become obsolete than a non computer controlled system. The reason for this is that the functioning of the system is controlled by software. System changes can, therefore be made without changing the hardware. There is a great deal of truth in this philosophy. However, there is need for some caution in interpreting it. It is an important and obvious fact that the software can only instruct the hardware to operate within its capabilities. Software cannot increase the voltage range of the system or the number of pins that it can service. Software cannot increase the bandwidth of a time measuring device significantly. Also it must be remembered that software can be expensive to produce. It may be less expensive to implement an improvement in the system capability with hardware than with software. Understanding that there are limitations on the changes that can be made with software, it is still valid to claim that the computer controlled system has an in-built flexibility that helps to prevent it becoming obsolete.

No discussion of a computer controlled system can be complete without a reference to the software. The computer is useless unless it has good and proven software to control it. Software development for any computer controlled system is a major development task.

In the case of commercially available computer controlled integrated circuit test systems the executive operating software is supplied by the system manufacturer. The test programs that enable the system to test specific devices are the responsibility of the system user.

Testing LSI with Sentry 600

The Sentry 600 provides the versatile hardware and data analysis capability required for in-depth LSI and dynamic MOS device characterization for critical device design, yield improvement, and pilot production program and quality assurance requirements.

The Sentry 600 delivers up to 10 MHz data rate. In addition, multiple timing generators provide a conservative clock rate of 20 MHz.

Under complete software control, the device is powered, functional and DC parametric tests are performed automatically, then repeated for all variations required by the test specification. All device data can be recorded for further processing by the Sentry 600.

Special attention has been given to optimization of the electrical testing environment A unique high performance test head of compact design provides specialized pin electronics in close proximity to the device under test. Each DUT pin has its own dedicated pin electronics circuit. Capacitance is minimized. Waveform characteristics are optimized. Testing of dual function (I/O buss) pins is a standard feature. Each pin electronics section contains all the hardware required to provide device bias, input drive pulses, input clock pulses, detect output pulses, and access to the DC measurement unit.

RAMS and other devices with dual function pins are easily tested. Input/output definitions are defined as part of the test procedure in local memory. The pin electronics card rapidly switches as necessary from input mode to output sensor. This is accomplished at real time rates not practical on other systems. No special wiring changes or other adjustments are necessary.

Long test sequences are handled with ease by the Sentry 600. First, the powerful 24-bit computer word controlled by FACTOR software allows addressing large memories in short length instruction. Secondly, the computer is backed up by an 18 million bit disc memory for fast access to additional patterns. Thirdly, since most long test sequences are highly repetitive, only minor variations are usually required. A unique high speed controller can be programmed to "loop" blocks of instruction. This allows reuse of instructions without duplication time or waste of memory. Standard microprogramming and the disc file make the number of tests per pin theoretically infinite.

The versatile test center

Sentry 600, a high speed computer-controller system, tests, measures, characterizes, and analyzes all electrical parameters of complex large scale digital circuits—bipolar and MOS, logic and memories, single chips and assemblies.

Application

Performing the widest range of semiconductor parameter measurements for the widest range of components, the Sentry 600 manipulates and arithmetically computes data, datalogs every selected test parameter, and reports statistical distributions and all types of data analysis. The system provides for in-depth study before and after environmental stresses—temperature, vibration, shock, and electrical.

The Sentry 600 tests at all stages of development—from wafer to packaged component

- ☐ wafer probing
- ☐ final test
- ☐ pilot runs
- ☐ production
- ☐ trend analysis
- ☐ evaluation engineering
- ☐ quality assurance
- ☐ incoming inspection
- ☐ research and development

Special capabilities

High speed testing

The Sentry 600 performs functional tests at up to 10 MHz data rate, and greater than 20 MHz four phase clock rate. It makes go-no go limit comparisons at 2,000 per second; DC parametric measurements for datalogging and data analysis at 1,000 per second.

Ability to test complex circuits

Accurate MOS testing is made possible through independent and precise control of data and clock input timing and output comparator strobe.

RAMS and other devices with dual-function pins are quickly tested because any pin of the tester can serve as data input driver or output detector. Pins are switched from input to output at real time rates under software control.

Complex logic arrays and memories require long function patterns. In the Sentry 600, long pre-determined function patterns are immediately available through direct access of deep pattern storage. Behind each DUT pin, the memory module provides a 256 bit pattern depth, expandable to 512 or 1024 bits per pin. Chaining provides a pattern 4096 bits deep. Additional pattern depth is available within software and mass memory storage.

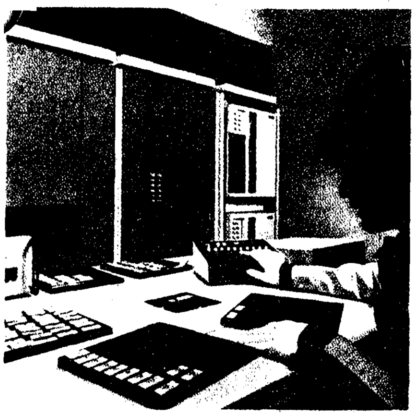
Powerful, easy-to-use software

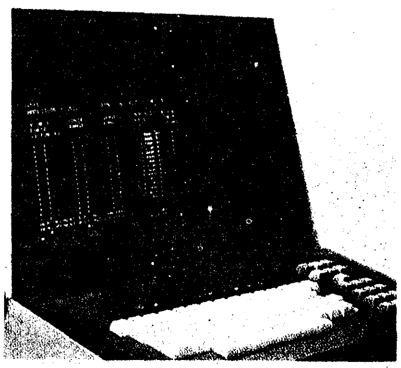
All testing hardware is under complete software control. This software is compatible among all Sentry systems. Data recorded on magnetic tape is compatible with IBM 360 and other large computers. English language FACTOR is easy to write, modify, and understand, not only by programmers, but also by supervisors and other departments. Software produces true understandable reports, not just formatted data.

Versatile

More test stations can be added to increase throughput. Station functions are modular and can be modified or expanded to accommodate advances in the state-of-the-art.

System operation





Typical system operation begins with the translation of a test specification into the Sentry programming language FACTOR. FACTOR statements are transferred to punched cards, and are entered into the system via the card reader. The program is digested by the computer and then stored on the 18-megabit disc file for use by any test station. The disc can carry an entire library of test programs. It stores operating software system diagnostics, device test programs and any temporary work. Any test station can call up any program, facilitating broad system usage. The magnetic tape transport adds virtually infinite bulk storage.

The Video Keyboard Terminal, VKT, is the primary man/machine interface. It controls the operating modes of the Sentry 600, displays test programs, provides for program alterations directly from the keyboard, and displays test data. A simple keyboard command assigns the desired test program to the appropriate test station.

The operators' involvement is limited to inserting the device, pressing the test start button and observing Pass/Fail lamp and/or binning lamps. All testing and decision making is performed by the Sentry 600. For testing operations involving wafer probing, device handlers or temperature chambers, the inking or binning is accomplished under system control.

When the test station requests service, either manually (when the operator presses the start test button)—or automatically (by wafer prober or device handler), the assigned test program is transferred from disc to computer memory.

Acting under that test program, the computer automatically translates and directs individual test commands to required hardware elements. Bias voltages and "O" and "I" reference voltages are generated in the mainframe and directed through the test station controller to the device under test at the test station.

Specialized high speed electronics are triggered and the preprogrammed truth table flows into the device under test. Simultaneously, the function pattern flowing out of the DUT is compared against the expected pattern. Any error in the DUT output is automatically detected and recorded for further processing per test program instructions stored in the computer.

In addition to the function test described above, the computer automatically controls and directs the measurement of all DC electrical parameters of the device under test. These results are also detected and recorded for further processing as requested by the test program.

During any testing sequence, the measured and function fail data may be collected in the computer memory for further processing. Test results are formatted and, at user option:

- ☐ displayed on the Video Keyboard Terminal (VKT)
- ☐ printed at high speed on a line printer
- ☐ recorded on IBM compatible magnetic tape for later processing by the 600 computer or larger off-line computer
- ☐ or recorded on the magnetic disc for later retrieval.

Software

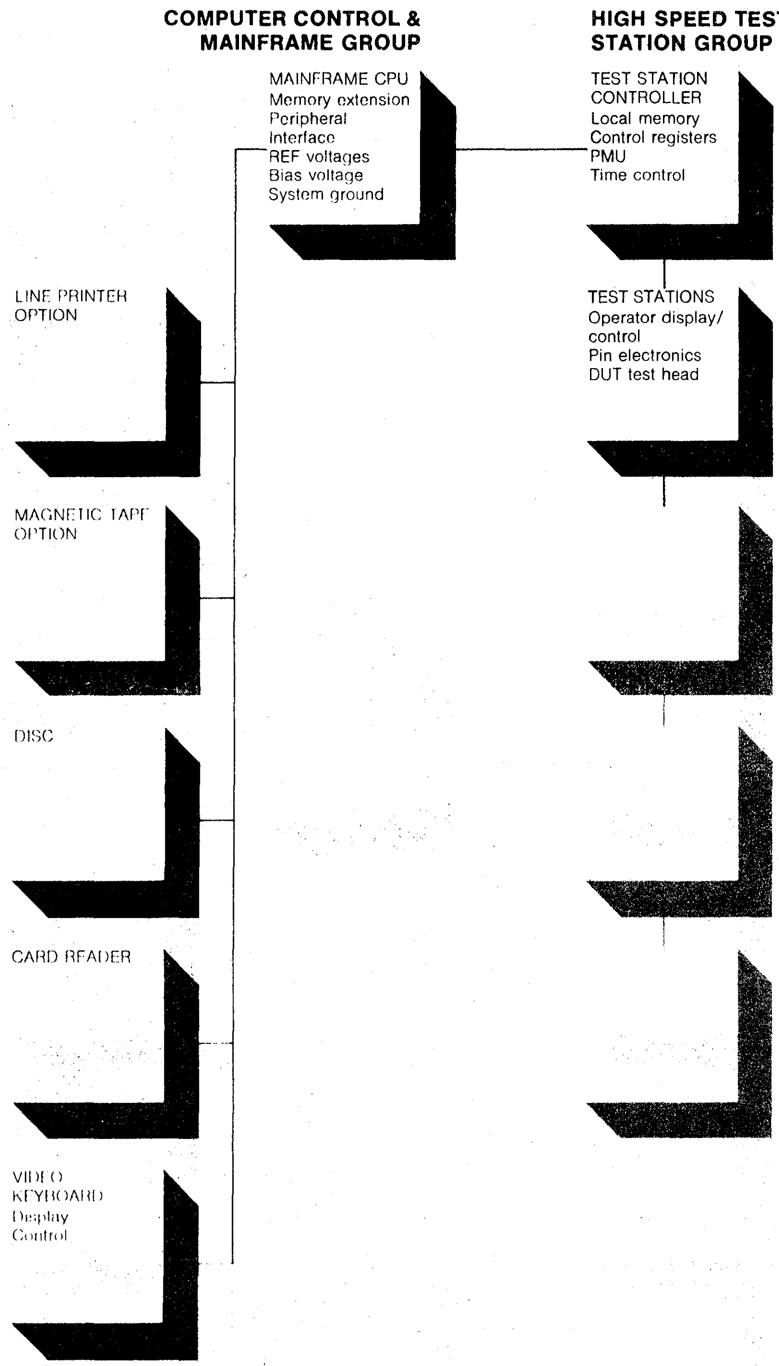
The FACTOR language, used for *all* programming, allows the user to add many levels of decision-making into the test program. This allows exhaustive testing of any device-type of any complexity. A monitor mode allows the user to modify and experiment with test conditions at any test station. He can verify programmed voltage and current levels, modify them while observing the element being tested, check out power supply levels, run strobe signals through an oscilloscope, etc.

Device characterization requires more than thorough testing. The test results must be analyzed. Lot data must be analyzed for parameter distribution, mean value, percentages within Sigma limits, and Delta comparisons. The same FACTOR language employed for test programming is used to analyze the data in any manner required.

FACTOR power provides the testing and data analysis tool to:

- ☐ characterize the device
- ☐ analyze the device
- ☐ analyze lot data
- ☐ provide device and yield improvement data
- ☐ monitor process control
- ☐ monitor vendor shipments
- ☐ provide device engineering data and controls

System description



The entire 600 is focused on the testing and data analysis requirements of the LSI device. The system is organized to perform that task. This description summarizes the integrated system elements that focus on the Device Under Test.

The Sentry 600 includes two hardware groups

The *mainframe* provides all central functions: computer, its control functions, peripherals, digital to analog converters for reference voltage and bias supplies, and multiplex control.

The *high speed test station group* provides all specialized hardware necessary to perform high speed functional and DC parametric tests of wafers, packaged devices, or higher level assemblies.

The mainframe group
System Computer

Fairchild's FST-1 process computer controls the total system. Using FACTOR, an English test program language, and powerful 24-bit words, the computer transmits control data and receives subsystem status reports, interrupt requests and test data. The computer uses 16K of memory to control *high speed test stations*. Operating in a *direct memory access* mode, the computer minimizes test execution time by direct loading of local memory.

System peripherals

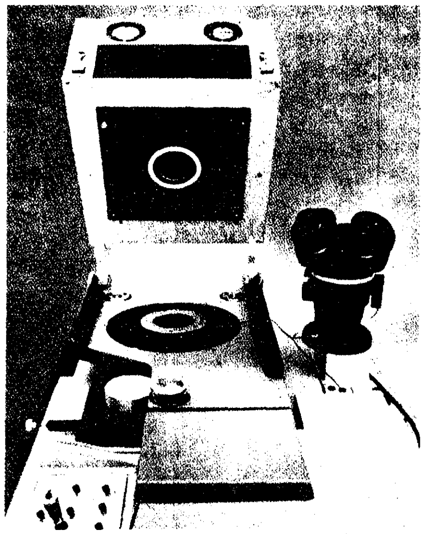
Supporting core memory is an 18-megabit *disc mass memory unit* with a fixed head per track. The disc provides fast access to any test program, operating software systems, and system diagnostic and self-check programs. About 350 test programs averaging 1,500 words each can be stored on disc along with the entire operating systems software.

A high speed *card reader* provides fast, convenient, and flexible test program entry for complex LSI circuits. It also frees *Video Keyboard Terminal* (VKT) for user/system communication. The VKT controls the system, displays test programs and test results. It provides rapid access to the system for quick switchover between device types.

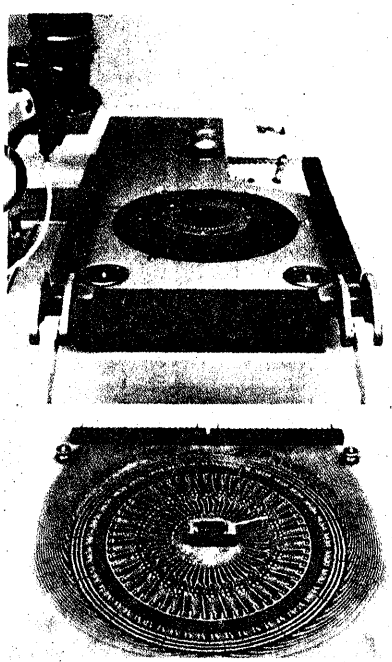
Two optional peripherals are IBM compatible read/write *magnetic tape transport* and *high speed line printer.* Tape adds virtually infinite program storage and extra datalogging capability. The high speed printer offers rapid print-outs:

- ☐ computer aided test programs for immediate use by the originator
- ☐ device data in report form for immediate use by supervisors and management.

O st head on wafer prober lowers your vestment requirements.



Test head used as wafer prober



Wafer probe used for manual testing

Controlled by the computer, the *mainframe* acts upon the assigned device test program. The mainframe multiplex allows several test stations to be controlled from one center.

The mainframe contains the D to A converters. These units provide programmable voltages and currents. They also provide all voltage references for the zero and one logic levels used for function testing at the individual test stations.

High speed test station group

This group includes the high speed test station *controller console* and up to four high speed *test stations.* Under control of main system, this sub-system provides all specialized hardware necessary for high speed functional and DC parametric tests.

The *controller console* contains high speed special purpose controller, timing generators, and digital pin electronics, reference voltage buffers and associated pin select logic, the precision measurement unit, and test station multiplexer.

Each *test station* contains test head assembly with test head pin electronics. The pin electronics is the final link between the 600 and the Device Under Test (DUT). Pin electronics provide pin drivers and detector functions to each pin of the DUT and access to DC testing and performance board.

The compact test head is designed for optimal device testing. Each pin electronics card is located in a "carrousel" configuration that provides minimum yet uniform lead length to each DUT pin. The assembly will accommodate up to 30 pin cards to service up to 60 DUT pins. Each pin electronics card can function as data input driver, clock driver, device power supply, and data output comparator. Inputs can be switched to outputs within one data period. No pin swap boards are needed.

Test heads function with manual test, wafer prober, or automatic device handler. This provides maximum device throughput with optimum data correlation between wafer test and final test.

High speed special purpose controller

The heart of the high speed test station controller console unit is the high speed special purpose controller, high speed registers, and timing generators that control function testing. The function test patterns are stored in the local memory of the special purpose controller.

The specialized controller consists of a bipolar random access local memory, control registers, and instruction set. One local memory channel is assigned to each DUT pin. The depth of the memory channels is expandable from 256 to 1024 bits. The channels can be "chained" under software program control in order to double or redouble the available function test pattern depth.

In addition, the local memory architecture and instruction set provides the following capability under complete software program control:

- ☐ Load function patterns into the local memory from the FST-1 in a Direct Memory Access (DMA) mode
- ☐ Store device input patterns and expected output patterns for up to 60 DUT pins to a depth of 1024 bits per pin
- ☐ Transfer the function patterns to the DUT at full rated speed
- ☐ Compartmentalize the local memory into major and minor "loops" with separate start and stop addresses
- ☐ Alter any portion of the local memory while testing continues at full rated speed
- ☐ Initialize the DUT (if required) then proceed to testing without interruption of the programmed test rate
- ☐ Branch to a new function pattern based on test results
- ☐ Repeat the stored pattern at various worst case voltage and timing conditions
- ☐ Remain in continuous recycle mode for program debug or other manual test requirements.

High performance pin electronics

High speed registers dedicated to each DUT pin provide additional function test capability under software program control *on a pin-by-pin basis:*

- ☐ Selection of the input data format: Return-to-Zero (RZ) or Non-return-to-Zero (NRZ)
- ☐ Set up of the DUT pin as an input only, output only or input/output (I/O Buss) pin
- ☐ Selection of one of two separate I/O definition registers
- ☐ Change the set up of I/O Buss pins from input to output on the fly at full rated speed
- ☐ Masking of the output comparator during any "don't care" condition of the output pin
- ☐ Selection of one of two separate mask registers so that function testing can proceed from DUT initialization (a *don't care* condition) to DUT testing (a *care* condition) without interruption of the testing rate

Timing generators

Up to eight timing generators provide function test synchronization and timing of input data and clock wave forms and comparator strobes for clocked and multiphase circuits. Any generator can be assigned to any pin or pins under software control. Each generator is completely and independently programmable for both delay and width. This independent control provides the capability to accurately program a narrow width pulse at the end of a long delay.

Precision measurement unit

Precision measurement unit (PMU) performs complete, full range DC parametric measurements on any DUT pin under software program control. This multimode unit may be used for stress, breakdown, leakage, and loading measurements for either go/no go testing, or subsequent datalogging/data analysis. It is also the primary instrument for system self check tests. It makes go-no go limit comparisons at 2,000 per second; DC parametric measurements for datalogging and data analysis at 1,000 per second.

The unit contains a digitally programmed voltage supply with programmable current limit, a digitally programmed current supply with programmable voltage clamp, and a programmable precision current or voltage detector for high speed go-no go testing. Either voltage-force/current-sense or current-force/voltage-sense measurements may be made. The results are digitized for formatting and analysis by the FST-1 computer or for transmittal to the magnetic tape option for off-line storage, and subsequent data analysis.