Automatic Test Equipment

Keith Brindley

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Preface

First, an explanation of terms. Often, writers use terms such as *system under test* (SUT), *board under test* (BUT), *device under test* (DUT) or *unit under test* (UUT) to describe both appliances being tested and measurements taken. This is rather indiscriminate and ambiguous. As it is a specific function of an appliance which is always measured by test equipment – and not the appliance itself (you can find its height, width, depth and so on in the appliance specification!), I refer to the quantity being measured as the **measurand**: a term regularly used in the field of study of electronic instrumentation. I refer to tested systems, printed circuit boards or devices individually.

Electronic test equipment has come a long way since the days of meters and basic oscilloscopes. It used to be that testing of appliances was just a case of measuring a few independent analog measurand parameters such as voltage and current amplitude, frequency and time relationships and so on, at a small number of points. Generally, parameters could be measured one at a time, without problems.

Typical modern appliances, on the other hand, are of a microprocessor-based system nature and demand testing of a large number of digital and analog parameters at a correspondingly large number of points. Additionally, parameters are often so interdependent their values only have significance when monitored in relation with each other. Thus, measurements must be taken simultaneously and in real-time.

Trends in electronic test equipment naturally reflect this change and Figure 1 illustrates the general move from single-time, single-measured test instruments to multi-time, multi-measurand instruments. Simple analog and digital meters represent basic equipment, capable of performing a single measurement at a single time. Oscilloscopes extend measurements by performing them over a period of time. Dual- and four-trace oscilloscopes allow a small number of measurements to be made over this period. Logic analysers take this facility two stages further: first, by

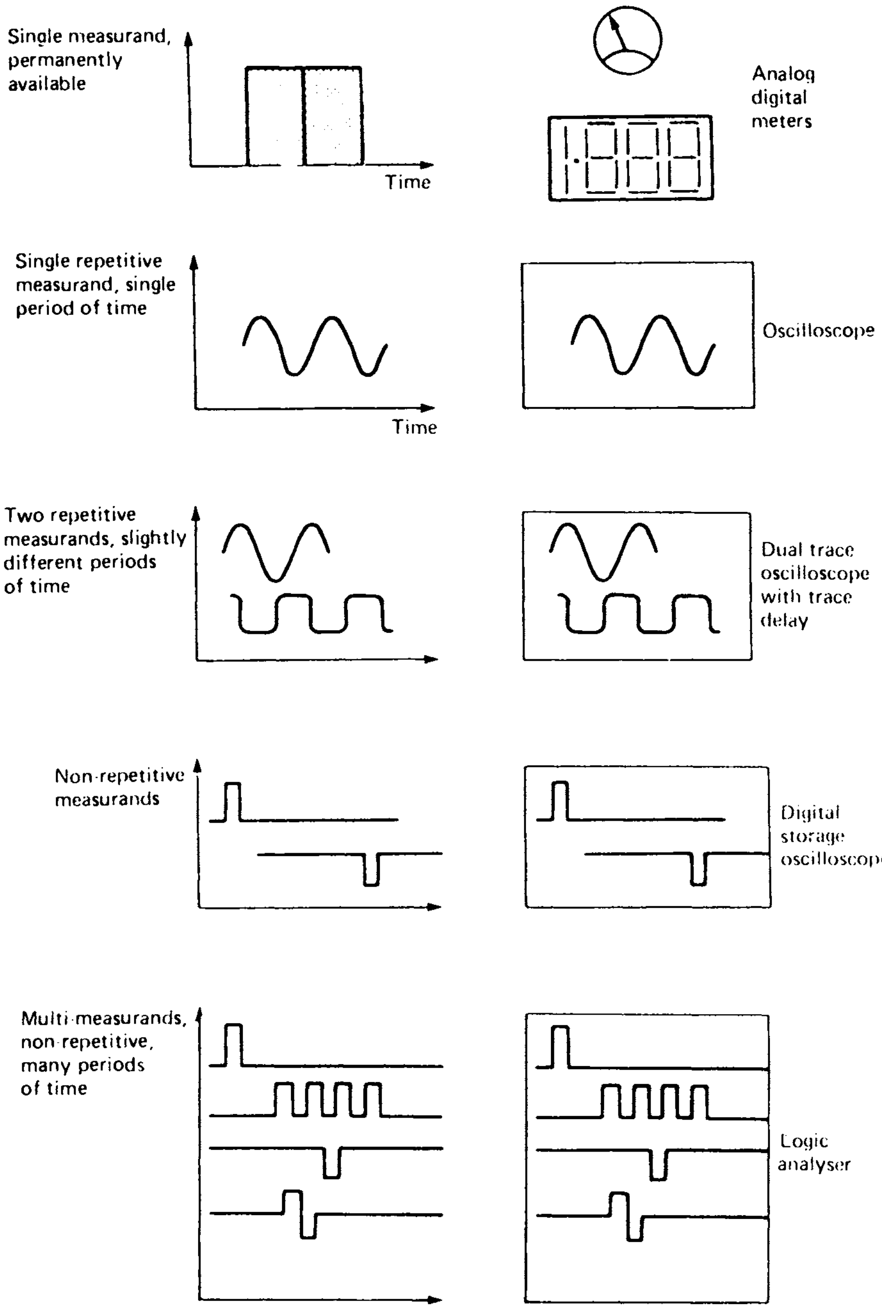

Figure 1 *Trends in modern electronic test equipment correspond to a general move from single-time, single-measured instruments to multi-time, multi-measured instruments*

allowing a large number of measurements to be made over the period; and second, with recent developments in logic analysis, by allowing a large number of measurements to be made over a number of time periods.

In all these instances, however, a user effectively controls test equipment functions. Consequently, limits suggested here are not, in fact, test equipment limitations but human limitations. It simply becomes increasingly difficult to correlate all the information regarding the many measurements modern test equipment is capable of taking and, in many instances, is even impossible. Where test functions still remain humanly possible test procedures often take so long as to be uneconomic.

Which brings us to automatic test equipment (ATE); capable of doing all the measurements and tests we require, then presenting test results in a requested format – quickly and economically.

My main purpose in writing this book is to demystify automatic test equipment. Existing literature on automatic test equipment is not often written in a clear manner. There are reasons for this – the people who write about automatic test equipment must be the people who understand the topic; and these are usually engineers who look at automatic test equipment from inside-out. However, engineers are not renowned for high qualities of authorship. Other main sources of literature are worldwide standards. These, though, do not *explain* automatic test equipment; instead they merely formalize its component parts. From any existing literature therefore it is impossible to ask the question, '*What is automatic test equipment?*' and find a satisfactory answer. Automatic test equipment is a mystery simply because of this.

Tackling the situation from outside-in, on the other hand, as a writer (with engineering qualifications) trained as a technical author and journalist, I hope I have been able to explain concepts and standards in a much clearer way, passing on my understanding of the topic more successfully. This I hope I have been able to do without shirking technical considerations.

This book is for anyone who has an interest in automatic test equipment. Anyone in the industry who needs to know what types of equipment are available; what each type is capable of doing, what tests are performed, what computer buses are used, what the buses are capable of, and so on will find answers here. Managers, engineers, technicians, scientists, students, teachers, graduates, those in purchasing positions will benefit. It is a general-purpose book, which explains concepts: but is a reference book too, which defines specifications.

I have attempted to organize the book in a reasonably logical manner. My intention in this respect is to allow readers of whatever technical ability and specific knowledge to be able to use it. Chapters describe in successively greater details aspects covered, more generally, in earlier chapters. Consequently, it's a good idea to read from the beginning through to the end. However, that's not to say specific details cannot be accessed immediately, by turning straight to whichever chapter is required. Further, a glossary of important terms and considerations of automatic test equipment systems is included. This is, of necessity, a fairly involved glossary. After all, automatic test equipment is quite involved, itself. Names and addresses of important organizations in automatic test equipment are included, as is a list of books, articles and papers for suggested further reading.

Keith Brindley

1 What is automatic test equipment?

Automatic test equipment comes in many forms. Indeed, it is difficult to define *precisely* what the term automatic test equipment means. Lowest common denominator suggests automatic test equipment to be any item of test equipment controlled by a computer. Yet this, in itself, is not totally complete because some items of test equipment have an internal computer (in microprocessor form) to monitor and control certain functions automatically, making the equipment easier to use.

Thus, an instrument such as a spectrum analyser could feature automatic control of functions such as frequency scan, centre frequency and resolution bandwidth: it is an example of an **automatic test instrument**. It is not necessarily, however, what we class as automatic test equipment.

Most modern automatic test instruments are **programmable**; they feature an interface allowing their internal microprocessor (and hence their measurement functions) to be controlled by another computer or microprocessor. Usually most, if not all, measurement facilities of an automatic test instrument may be set by a computer via this interface, and measurements taken are similarly relayed back to the computer for correlation and display. When a computer is used to control one or more programmable automatic test instruments the resultant system is what we know as **automatic test equipment** (ATE). This difference is important: automatic test instruments are devices capable of performing and displaying measurements autonomously or in a system; automatic test equipment is a complete measurement system, consisting of one or more automatic test instruments and a computer controller.

Automatic test equipment requires computer control to ensure correct operation, record measurements, correlate vast amounts of measurement data, and present data in a form understandable by human users. In effect, users no longer *directly* control automatic test equipment (although users must still program the computer which *does* control it) and most, if not all, functions are automatic.

Measurements are not limited by users: any number of measurements can be performed in any number of time periods. For example, the user of an analog voltmeter has great difficulty in taking and recording even one measurement a second. Programmed automatic test equipment may take, record and display as many as, say, one thousand measurements in the same time. Alternatively, automatic test equipment may take and record one measurement every second for the next thousand days – non-stop and accurately (without food, drink or sleep!).

Types of automatic test equipment

There is a large number of types of automatic test equipment. These types are defined, basically, by the way they set about testing products. Is power applied to the product? Are external inputs applied, as if the product were in its real-life application? Can individual components within the product be tested, in isolation from all other components? It doesn't take many questions like these to show there are almost as many pure types of automatic test equipment systems as there are manufacturers of automatic test equipment systems. After all, each manufacturer likes to include at least a few features which define its automatic test equipment system as being different, better, cheaper, than the rest.

Fortunately, this large number of types can be generalized into only a handful of categories. These are described in Chapter 2.

Fixtures

Any automatic test equipment system must be connected to the product it is to test. How this connection comes about is usually a matter of electromechanical interfacing; via connectors, probes and so on. Those parts of an automatic test equipment system used to interface to products are given the name fixtures and some basic types exist. These basic fixture types, and some possible future types, are discussed in Chapter 3.

Test strategies

Obviously, the earlier definition of automatic test equipment: a programmable, computer-controlled system, is a basic one. It leads you to reason that such a system is all-encompassing and may, simply by changing the program, be used to perform any measurement task. This is not, of course, the case; you would not use top-of-the-range automatic test equipment costing, perhaps, £1 million to measure resistance of a resistor. That is the test equipment equivalent of using a sledgehammer to crack a nut.

In the other extreme you would not expect a cable harness checker to be able to tell you what is wrong with the mother-board of a malfunctioning nuclear-tipped missile guidance system. Although in the story David won, it would take an even greater fluke to beat Goliath, here.

These two examples serve to illustrate the need for an effective **test strategy**, which carefully plans and defines an organization's requirements for automatic test equipment. A test strategy can not only help an organization to choose the correct type of automatic test equipment for its technical purposes, but also shows the most economically suited solution. This may be a considerable advantage, where equipment can be as cheap as just a few thousands of £s up to a few millions. Test strategies, costs and, indeed, even the reasons for need of automatic test equipment are discussed in Chapter 4.

Test methods and processes

Part of this test strategy an organization must have, is a definition of individual tests which must be performed on products, and a consequent understanding of processes which those tests must follow. Definition of required tests depends almost totally on the products to be tested. Products should be assessed in quality terms: likelihood of failures; where failures are likely to occur; abilities of personnel involved in design to make products easier to test, and so on. Factors such as these have direct relevance to the test processes and, hence, test strategy used. Test methods and processes are discussed in Chapter 5.

Basic methods of creating automatic test equipment

There are three basic methods of creating automatic test equipment. First, a unique system may be designed and made, specifically for the purpose. Figure 1.1 shows an example, capable of taking a number of measurements of voltage and current, while counting events, measuring frequency, distortion and frequency response, and monitoring signals on a data bus. Output from the device to the appliance being measured is a swept sine-wave signal. Control of the various measuring facilities is provided by the microprocessor-controlled heart of the device, which in turn is controlled by programmed instructions from the user. This type of automatic test equipment is, in fact, a computer system complete with the necessary input and output units to allow measurements of the various measurand parameters of the appliance tested. Recording of the values of these measurand parameters and the format of the correlated information again depends on the user's programmed instructions, and is displayed either on a monitor or hard-copied onto paper with a printer.

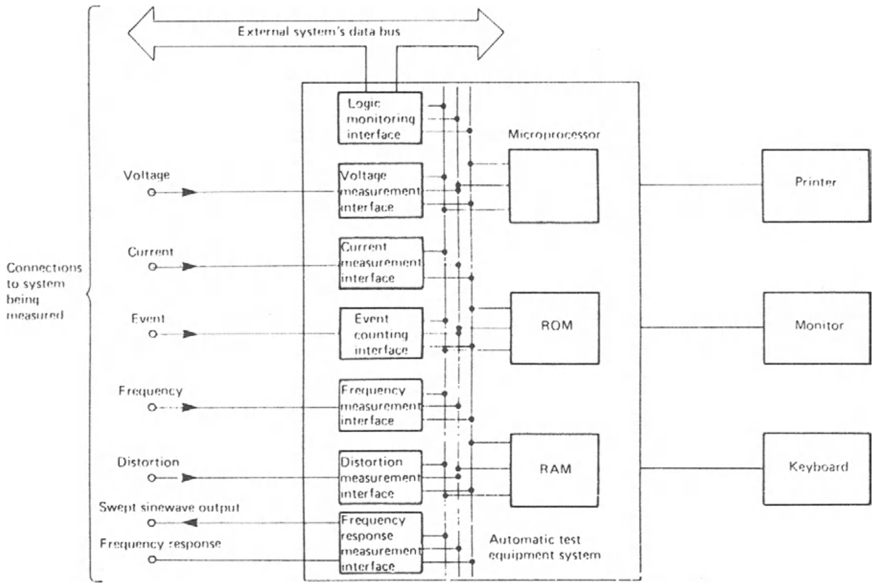

Figure 1.1 *Turnkey automatic test equipment system, in which equipment is a unique device, built for one application*

Such automatic test equipment is known as a **turnkey** system. It is a custom-built *device*, likely to be quite expensive in terms of initial capital outlay, can generally only be used to test one particular appliance and will probably be used to test electronic appliances (such as printed circuit assemblies) manufactured in vast quantities. In such a situation high capital outlay is justified against higher reliability it gives the manufactured appliances.

Second, microprocessor-based computers may be used to control general-purpose automatic test instruments such as meters, universal counter timers, logic analysers and signal generators, treating them as peripheral devices, as illustrated in Figure 1.2. In this method each peripheral test instrument performs measurements on the system being tested under central computer control, relaying readings to the computer which records and displays the correlated data onto a monitor or onto paper. As in the first method, the user controls overall system operation with programmed instructions.

This method gives a custom-built automatic test equipment *system*, still quite expensive but which can be adapted to allow its use in other test applications. Thus more than one particular appliance can be tested, so the system will most probably be used to test electronic appliances, say, manufactured in quite small quantities (with the knowledge that the system

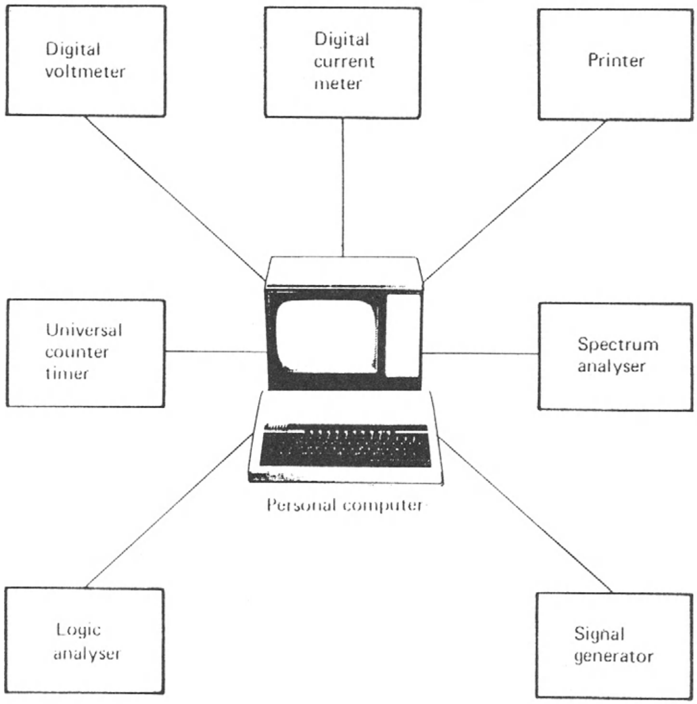

Figure 1.2 *Rack and stack automatic test equipment system, in which a personal computer or any other microprocessor-based computer is used to control programmable readily-available test instruments*

can be easily adapted to suit other applications as and when necessary). Often an automatic test equipment system along these lines is called a **rack and stack** system.

In practice even the first method can usually be adapted to test more than one appliance, as a modular design approach is often used which allows the user (or at least the automatic test equipment supplier) to change measurement modules and software to suit other applications. These two methods are merely simplified representations of extremes of automatic test equipment design philosophy. In the first method, the range of test instruments is built into a complete computer-controlled device; in the second method the range is simply a collection of individual but interconnected instruments, controlled by a central computer.

If a number of instruments are to be controlled by a single, central computer it makes sense if each instrument's two-way interface to and from the computer links to common data and control buses. Connections between individual instruments and computer are simplified enormously – often wiring is simply a matter of linking instruments with ribbon cable, as

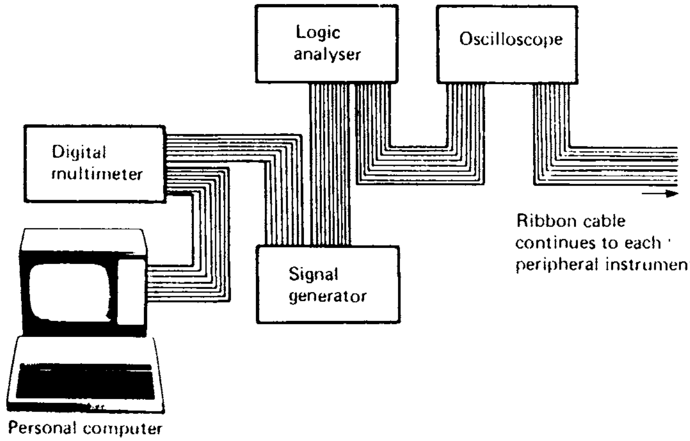

Figure 1.3 *Another method of creating a rack and stack automatic test equipment system, in which instruments and controller are connected with common data and control buses*

shown in Figure 1.3. Bus structures for automatic test equipment make corresponding systems very flexible as extra instruments may be added with little fuss, and changing system test requirements is simply a matter of changing instruments and reprogramming computer controllers. There are, needless to say, many bus standards in use, and main types are discussed in Chapter 6.

Rack and stack automatic test equipment systems' use of central computer controllers with peripheral instruments points the way to the third method of making automatic test equipment. Recently a trend has developed, building on the automatic test equipment bus principle, in which the bus is controlled not by a stand-alone computer but by a purpose-built, standard-sized computer controller. Further, peripheral instruments under computer control are also standard-sized and in modular form. A major benefit of this trend is that a single housing may then be used to hold all instrument modules. All functions and features of each peripheral instrument (including power supply) are controlled and adjusted by the computer via the buses.

Obviously system cost can be much lower (estimated at around one-third the price of an equivalent non-modular system) and overall size is considerably reduced (about one-tenth the equivalent non-modular system). A modular system ensures an automatic test equipment system is easily adaptable to future requirements: when a different system is needed, unwanted modules may be taken out of the housing and new modules simply slotted in.

Another important benefit is the extremely high data rates which may be allowed with a purpose-built bus, a factor important where a large automatic test equipment system, with many measurands and programmed steps, is required.

For want of a better generic name, such automatic test equipment systems may be called **modular** instrument bus systems.

On a broad outlook, the method used to make automatic test equipment is irrelevant. Although each has its advantage and disadvantages which guide prospective users to choose one particular method to suit a particular application, in the end each method of construction is there to do but one job – to test manufactured products. The method used to make the automatic test equipment needed to test the products a user manufactures is simply a means to that end.

A comparison of automatic test equipment system types

In reality, of course, all automatic test equipment systems constructed by whatever method are organized around computer-controlled instrument bus systems. Table 1.1 is a comparison of all three methods, giving details about each part of each system type.

Such is the importance of the three methods of making automatic test equipment, however, now and in the foreseeable future, that the last three chapters in this book discuss specific ways these three methods are usually (not always!) organized – detailing important characteristics and attributes. The usual way rack-and-stack automatic test equipment systems are organized is with an interface bus known as the **general-purpose interface bus** (GPIB), which is discussed in Chapter 7. A common interface bus used to organize turnkey automatic test equipment systems is **VMEbus**, discussed in Chapter 8. Modular automatic test equipment systems are most often organized around the **VXIbus** interface bus, discussed in Chapter 9.

Advantages of automatic test equipment systems

In many instances, use of automatic test equipment systems is a foregone conclusion. Where manufactured appliances are complex, human testing ability is stretched beyond its possibilities. Here the advantages of automatic test equipment systems are taken as a matter of course:

- More measurements – all measurements in an automatic test equipment are performed automatically, with a consequent increase of speed, so it is possible to increase the number of measurements made.
- Greater accuracy – many errors may be introduced in manual test equipment systems, often because measurements are taken once, at a

Table 1.1 Comparing automatic test equipment systems of three main types

Automatic test equipment method	*Instruments*	*Bus*	*Controller*	*System*
Turnkey	Often purpose-built May be modular	Often specific to system May be a standard bus	Specific to system	Custom-built device
Rack and stack	Individual	Standard bus (e.g. GPIB) May be specific	Often a personal computer	Custom-built system, adapted devices
Modular	Modular May be purpose-built	Standard bus (e.g. VXIbus)	Often specific to system May be personal computer	Modular, off-the-shelf, integrated

single time. Automatic test equipment systems may offer a solution by taking multiple readings and averaging results; errors are reduced and may even be eliminated.

- Faster procedures – where measurements entail complicated setting up, triggering, result interrogation and evaluation procedures manual measurement systems are inevitably slow. Human involvement means these processes must be undertaken at human speed; automatic systems, on the other hand, can perform the same procedures much faster.
- Elimination of human involvement – automatic procedures avoid human interpolation of results, subjective result interrogation, subjective evaluation and erroneous recordings of measurements.

Often, high expense of automatic test equipment may be offset against greater reliability of appliances tested. An amortization time of less than two years is common. After that period the automatic test equipment system, far from being an expenditure actually makes money. Customer benefits of greater reliability and cheaper products are well documented.

There is no doubt: use of automatic test equipment, in itself, is an advantage – an advantage manufacturers must be careful not to miss out on (1) by not using automatic test equipment (2) by not choosing the right type for the application, in the first place.

2 Types of automatic test equipment

Automatic test equipment is available in many forms. Part of its nature is its chameleon-like ability to test whatever is testable. Automatic test equipment is, as we have seen in Chapter 1, computer-based equipment and as such is governed by the computer principle of deferred design – simply by giving the computer a suitable program and providing it with necessary input and output peripherals it will do just about anything. Thus, in one example, automatic test equipment is found doing the simplest of tasks such as measuring components' resistances while, in another, it is capable of testing the most complex printed circuit assemblies; pin-pointing defective components to make repair easier.

Complexity of automatic test equipment, on the other hand, compared with individual test instruments such as meters, oscilloscopes and logic analysers, is such that it is possible to itemize particular areas of involvement requiring specific equipment. Contrasted with individual test instruments, where an oscilloscope is an oscilloscope whether it's used on the bench or on the production line, automatic test equipment is more likely to be purpose-built for one application.

Generally, applications where automatic test equipment is used to test a product parallel the normal stages of that product's life. Thus, automatic test equipment systems may be used in a product's:

- Design and development.
- Production.
- Reliability and certification test.
- Service.

More often than not, different automatic test equipment systems are used at each stage, although it is possible to design a single system with the capability to test the product at every stage.

There is a number of types of automatic test equipment, broadly categorized into the main tests performed. There is, however, no reason why more than one type of test cannot be performed by a single system. Similarly, there is no reason why a single system cannot perform *all* tests required: indeed, the trend is towards this. Use of a computer-controlled bus with modular peripheral instruments, as discussed here and in later chapters, makes such an encompassing automatic test equipment system possible.

Main categories of automatic test equipment include:

- Component testers – to test individual parts prior to assembly within a product to ensure they fall within specified tolerances.
- Unpackaged assembly testers – to test assembled parts, say, printed circuits, prior to packaging. This is the main area of concern for this book.
- Packaged assembly testers – to test and ensure reliability of the complete and packaged product prior to use by a customer.
- Maintenance and service equipment – to repair and overhaul a used product.

These are all very broad categories, though, and we must consider each in detail. One or more categories of test may be used in any particular application, and those categories used depend on an organization's overall test strategy (see Chapter 4).

Component parts test equipment

Testing of component parts is rarely performed in anything other than the manufacturing stages of a product. Nevertheless considerable test equipment is devoted to the testing of component parts and so must be considered.

Component parts testing is a fairly basic procedure. Generally, it is accomplished using simple procedures designed to determine measurands such as resistance, capacitance, semiconductor functions, dimensions, solderability and continuity. Testing is performed simply to ascertain the parts are of a specified quality. Tests inevitably depend on the parts.

Passive component parts are generally tested simply to measure their value and dimensions. Simple meter or bridge circuits can be used to perform such tests manually or semi-automatically. More complex, automatic measurements may be made using instruments which incorporate bridges, analog-to-digital conversion, function generators, voltage supplies, analog and digital stimuli and so on.

Active components are usually tested on a functional basis, that is, they are supplied with stimuli which simulate operating conditions, and resultant relationships are measured and compared with the ideal. Again, this may be a manual, semi-automatic or automatic test.

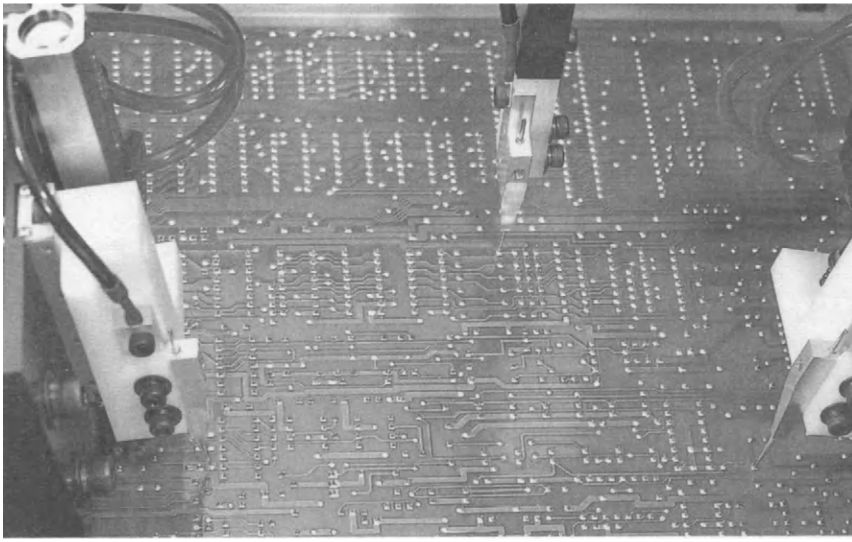

Photo 2.1 *Close-up of APT-2200N fixtureless tester, using moving probes to test unassembled printed circuit board (Contax)*

Printed circuit boards are often tested prior to assembly. Such **bare-boards** can be of a range of complexity; from simple single-sided boards which will hold only a handful of through-hole (that is, leaded) components, to extremely complex multi-layered boards (perhaps with over thirty internal track layers) designed to hold hundreds of surface mounted (that is, leadless) components. Consequently, test equipment used varies largely according to the circuit boards to be tested.

Simple boards may require just a straightforward visual check, perhaps with a magnifying aid. Visual checks are not reliable on more complex boards, though, and so test equipment which checks continuity of board track is common. A simultaneous check of insulation between tracks is recommended too. Automatic continuity and insulation test equipment – in which the bare-board is placed on a bed-of-nails fixture or, featuring a pair of moving probes programmed to position at large numbers of test points around the board – is available. With multi-layered boards it is often impossible, though, to check internal layers for continuity.

Automatic optical inspection (AOI) using cameras, scanning lasers, or sometimes X-rays is used to compare bare-board tracks with an ideal image (often called the **golden image**). Such systems, however sophisticated, cannot absolutely guarantee continuity or insulation.

Similar to the requirements of continuity and insulation testing in circuit boards, cable harnesses and backplanes of complex multi-board products need to be checked prior to assembly. Similar continuity and insulation checking test equipment is therefore available, too. It is becoming increasingly popular to use time domain reflectometers to provide a graphic signature of the harness or backplane, indicating presence and type of fault or similarity to a golden signature.

There is a method which sidesteps requirement for testing component parts of a product – to use parts which are known and guaranteed to be of required quality. National, regional and international standards organizations have coordinated (and continue to do so) standards and procedures which ensure components manufactured by a supplier are of a defined quality. Standards and procedures effectively form complete specification systems, incorporating all types of components and manufacturers.

BS9000 is the British specification system, CECC system operates in the UK and Europe, while IECQ system operates in the UK, Europe and worldwide. Approved components are listed in frequently updated qualified products lists (QPLs) and it is a simple matter for the purchaser to identify the required components from these lists prior to purchasing.

This sort of self-assessment procedure, known commonly as **vendor assessment**, can aid product manufacture enormously and is all part of commonly accepted methods of improving quality. Accurate manufacturing times can be predicted and, overall, considerable wasted time may be eliminated. When component parts are purchased outside such a procedure, **purchaser assessment** remains the only viable method of assuring a finished product's quality. Fortunately, test equipment to carry this out is easily available and not too expensive.

Readers are referred to another of the author's books; *Newnes Electronics Assembly Handbook*, for a detailed discussion of the subject of quality, standardization and specifications systems.

Unpackaged assembly test equipment

Once assembled and soldered, but prior to packaging, it is usual to test printed circuit boards to ensure the complete assembly performs as expected. Test equipment to do this could be used in maintenance and service environments, too, but is usually restricted to manufacturing stages simply because of large size. As far as this book is concerned, it is this area of automatic test equipment which is most important.

Three main categories of test (although other relatively minor categories exist) may be undertaken on unpackaged assemblies: in-circuit; functional; combinational, each of which has sub-categories.

In-circuit test

Performed by accessing nodal points within an assembly, generally with the use of a bed-of-nails fixture, then testing individual parts of the circuit,

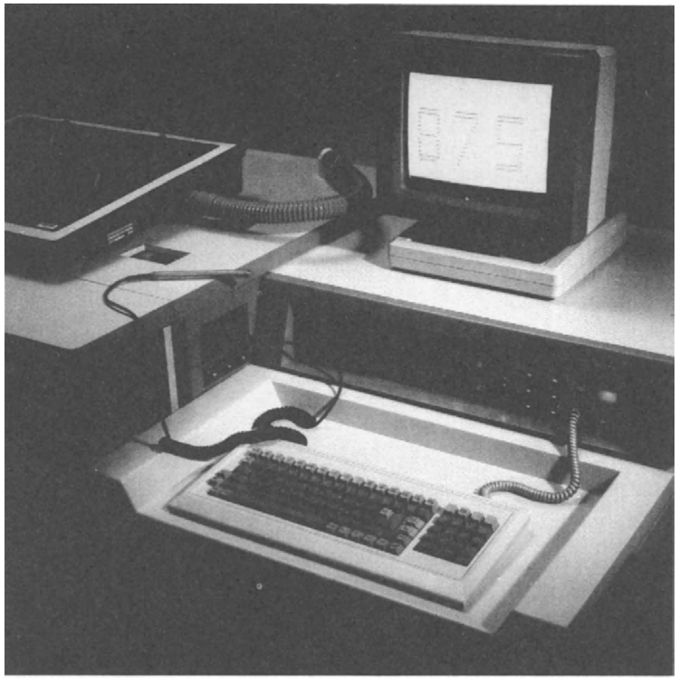

Photo 2.2 *Zehntel 875 in-circuit test system (Teradyne)*

often to a component level. Often, bed-of-nails fixtures have many hundreds, if not thousands, of test probes. By comparing the measured values with defined ideal values, faults such as short circuits, misplaced components, wrongly valued components, poor soldered joints and defective tracks can be isolated. Tests on components are performed sequentially so that, depending on circuit complexity and numbers of components, a complete procedure may take considerable time. Nevertheless, it has been reported that some 90% of manufacturing faults can be detected by in-circuit testing, so it can represent an extremely powerful procedure. However, it is not capable of testing overall performance, in a real-time dynamic situation.

Manufacturing defects analysis

Inherent in the use of in-circuit testing is the assumption that most problems occur in the manufacturing stage – in other words they are manufacturing defects. For this reason certain in-circuit testing techniques are known as **manufacturing defects analysis**, although this term strictly refers to in-circuit testing when no power is applied to assembly, testing the