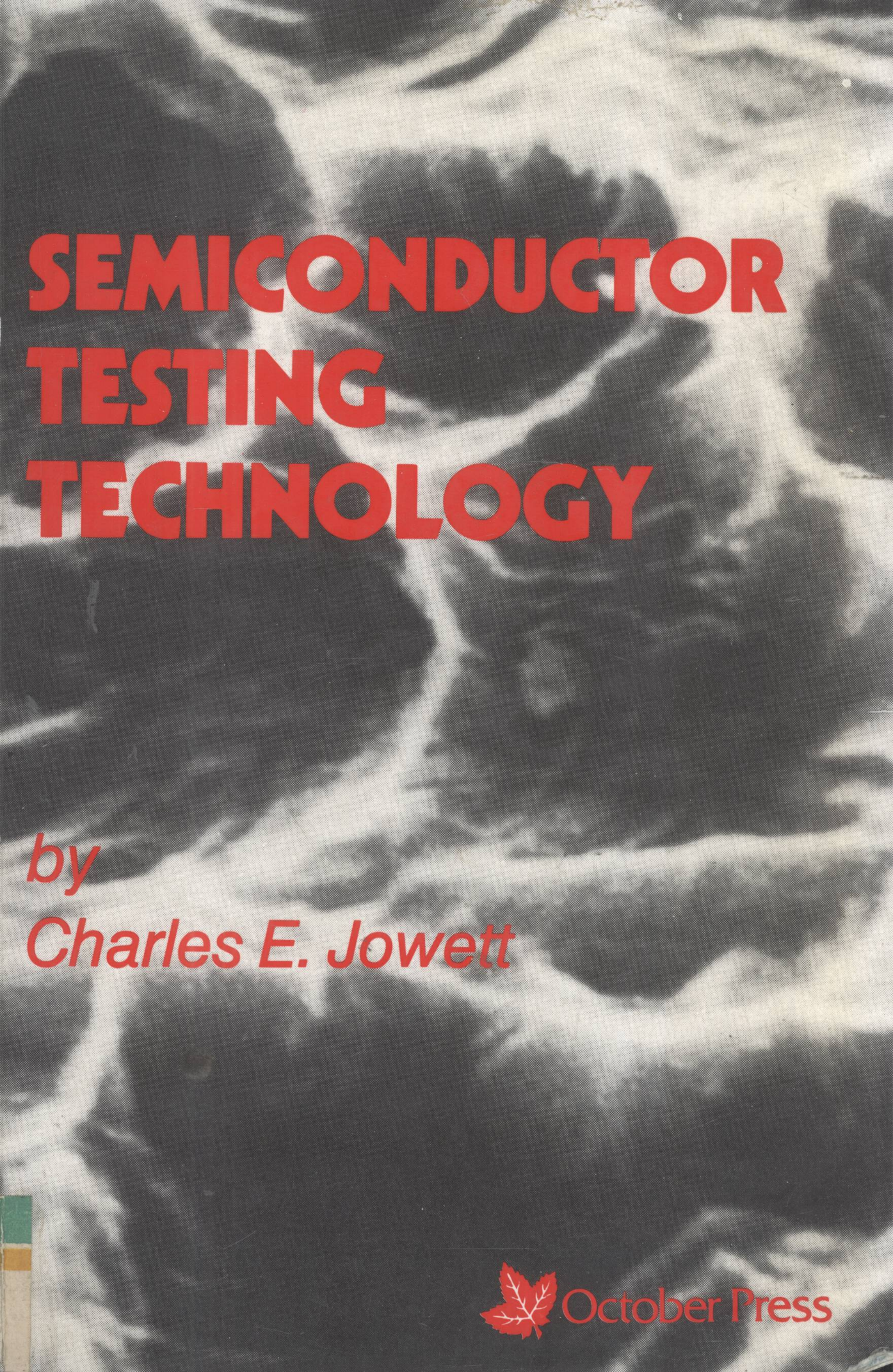
SEMICONDUCTOR TESTING TECHNOLOGY

by

Charles E. Jowett



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Preface

Semiconductor Testing Technology

This book is intended to present uniform methods of testing semiconductor devices also the dynamic testing of materials which have now become an increasing part of current electronic engineering.

For the purpose of this book, the term device includes such items as integrated circuits, transistors, diodes, voltage regulators, rectifiers and tunnel diodes.

The test methods have been prepared to serve several purposes, to specify suitable conditions obtainable in the laboratory which give test results equivalent to conditions in use in an equipment and to obtain reproducibility of the results of the tests.

Rapid advances in device manufacture have led to comprehensive test requirements being used in research and production, in a constant attempt to reduce failure rates to the minimum so that future device yield and lifetime may be determined by basic material properties alone.

The tests have been divided into five classes:
environmental, mechanical, transistor, diode, electrical tests and dynamic testing.

The author has been associated for many years with several branches of the subject and has had to straddle, mentally, the fences between the divisions of research, materials, equipment design and testing. Knowledge of all these helps to give an understanding of the observed facts.

I am indebted to many correspondents at home and abroad for their kindness in writing to me about points discussed in this book.

Grateful acknowledgement for invaluable help is given to the author's many associates, to authors and publishers who permitted the inclusion of important parts of the text and to manufacturers who so generously furnished details and suggestions; also to Stephen Pugsley for his helpful advice and as publisher of this work.

CHARLES E. JOWETT

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Chapter 1

Introduction

General requirements

Test conditions

All measurements and tests should be made at thermal equilibrium at an ambient temperature of 25°C and at ambient atmospheric pressure and relative humidity unless otherwise specified. Wherever these conditions are to be closely controlled in order to obtain reproducible results, the reference conditions should be as follows: temperature 25°C, relative humidity 50%, atmospheric pressure from 650 to 800 mmHg.

Permissible temperature variation in environmental chambers

When chambers are used, specimens under test should be located only within the working area. The chamber should be controlled and be capable of maintaining the temperature of any single reference point within the working area within ±2 degC. The chamber should be so constructed so that, at any given time, the temperature of any point within the working area will not deviate more than ±3degC or ±3%, whichever is the greater, from the reference point, except in the immediate vicinity of specimens generating heat.

Electrical test frequency

The electrical test frequency should be 1 kHz±25% except for power diodes where a frequency of 40-70 Hz should be used unless otherwise specified.

Accuracy

The absolute (true) values of the device parameters should be within the limits specified. Wherever possible, measurements and equipment calibration should be traceable to British standards.

Accuracy of meters

Accuracies of not less than 2% for d.c. measurements and 5% for a.c. measurements should be maintained on all ammeters and voltmeters.

Orientations

X is the orientation of a device with the main axis of the device normal to the direction of the accelerating force, and the major cross-section parallel to the direction of the accelerating force.

Y is the orientation of a device with the main axis of the device parallel to the direction of the accelerating force and the principal base toward (Y_1) or away from (Y_2), the point of application of the accelerating force.

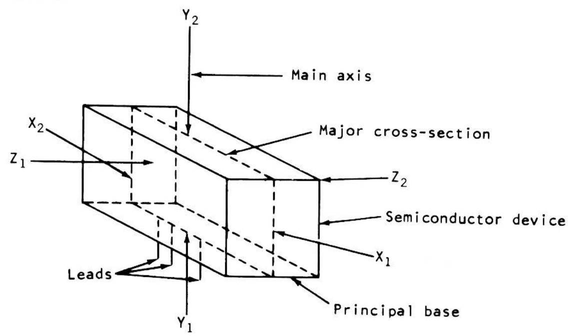

Figure 1: Orientation of a non-cylindrical semiconductor device to direction of accelerating force

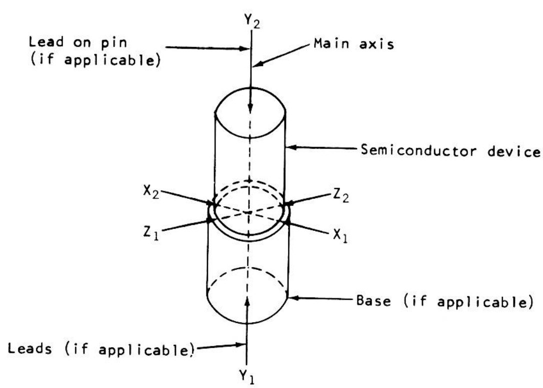

Figure 2: Orientation of cylindrical semiconductor device to direction of accelerating force

Z is the orientation of a device with the main and the major cross-sections of the device normal to the direction of the acceleration force.
For the case of configurations other than shown in Figs 1 and 2 the orientation of the device should be as specified.

General precautions
The following should be observed in the testing of devices.

Transients
Devices must not be subjected to conditions in which transients cause a rating to be exceeded.

Test conditions for electrical measurements
Test conditions for all electrical measurements should be such that the maximum ratings are not exceeded. These precautions should include limits on maximum instantaneous currents and voltages. High series resistances (constant current supplies) and low capacitances are usually required. If low cut-off or reverse current devices are to be measured, for example, nanoampere units, care should be taken to ensure that parasitic circuit currents or external leakage currents are small, compared with the cut-off or reverse current of the device to be measured.

Pulse measurements
When the static or dynamic parameters of a device are measured under 'pulsed' conditions, in order to avoid measurement errors introduced by device heating during the measurement period the following should be covered in the detail specification:

1 Pulsed test should be placed by the test specified.
2 Unless otherwise stated, the pulse time (t_p) should be 250 to 350 μsec and the duty cycle should be 1-2%.

Soldering
Adequate precautions should be taken to avoid damage to the device during soldering required for test.

Order of connection of leads
Care should be taken when connecting a semiconductor device to a power supply. The common terminal should be connected first.

Reliability of testing

The reliability of an electronic product depends equally on the soundness of its design and on the use of reliable components and manufacturing methods. The evidence confirming that each of these factors has received sufficient attention in evolving the final product is obtained mainly from test results. The production departments regard the successful completion of over-all tests on the final equipment as a reasonable check that assembly has been correctly carried out and that devices used are within specification. The electronic designer satisfies himself that mean values and deviations of the test figures are within the limits expected from design calculations. So much depends on the correctness of these results that specially designed test equipments are usually provided even for small production batches, to guarantee as far as possible the proper execution of final tests.

Some aspects of performance, having a profound effect on reliability, are unfortunately difficult to check during production. This may be due to the following factors:

1 Inaccessibility of a part of the completed equipment, where long connecting leads would upset circuit operation.
2 The appropriate tests may require expensive test equipment only suitable for a research laboratory or only operable by a highly skilled engineer.
3 For tests at elevated or reduced temperatures, the testing time may be too long and expensive to consider carrying out on every piece of final equipment.

The solution invariably adopted is to perform these searching tests on a 'breadboard' or prototype model, before full production is commenced. These tests are supervised by the designer and generally include sufficient informative tests to reveal any shortcomings of his design. Satisfactory performance of the prototype under worst-case conditions of such variables as ambient temperature and supply variations is taken as evidence of correct design.

It is then assumed that, since the basic design is thus proved correct, the relatively simple final testing indicates correct manufacture. This assumption is not necessarily justified particularly in terms of performance at elevated temperatures. There are two unfavourable possibilities:

1 A circuit component has poor performance at high temperatures only; this will be undetected in final tests at room temperature and even though the electronic design was correct the tested unit will fail in service at high temperature.

2 The design has not allowed for the expected deterioration of a component at high temperature — the component used in the very thorough prototype tests may be better than its specification, so that many apparently satisfactory production units will fail in service.

The second possibility is alarming and indicates the need for careful design and thorough checking of at least two prototypes to reduce the probability of missing a design error of that type.

It is clear that the reliability of the final product depends greatly on correct design and that designers rely on the results of prototype tests to indicate unforeseen design errors. In spite of this, designers often take little interest in ensuring that these tests are properly conducted. Inexperienced engineers or technicians are expected to produce the results without falling into the traps avoided by the designer only after years of sad experience.

Although these are simple measurements in principle, there are several ways in which misleading results can occur.

Loading effects — multimeters

A typical multimeter has a resistance of 20 kΩ/V f.s.d. and is often used on a 10-V full-scale deflection range giving 200 kΩ of voltmeter loading. The obvious consequence is that the circuit is disturbed by this load and displays the lower voltage that results.

This principle is elementary, but wrong measurements often go unnoticed because the degree of error is generally not enough to cause alarm. Mistakes of this kind are increasingly common because transistors and FET's can operate successfully at low currents and can use load resistors of the same order as the multimeter.

For instance, the T_1 collector-earth potential in Fig. 3 is nominally +8 V, but would be measured 4.8 V on the 10 V range; the emitter should and does read about +5.3 V, because loading of 200 kΩ on the emitter has little effect owing to the low output resistance at the emitter. The base seems to be more negative than the emitter yet the emitter circuit must be passing current to reach any potential above earth! The use of a second multimeter and measuring both quantities simultaneously would show up the error but would still give the wrong base voltage.

Using multimeters, the following should be routine: after each voltage measurement, the instrument should be switched to the next higher range and the measurement repeated. Any difference, other than reasonable reading errors, indicates that the loading is affecting the circuit.

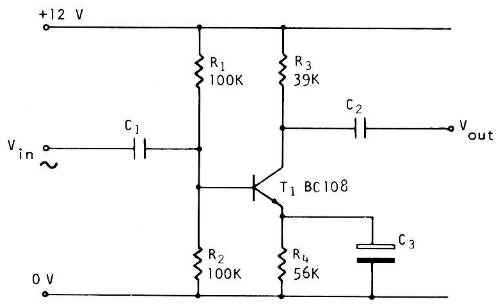

Figure 3:

Another problem in using a multimeter is the injection of mains or radio frequencies into the circuit under test or the provoking of self-oscillation in the circuit. Such signals can become rectified and thus change the d.c. levels being monitored.

The magnitude of this kind of signal and its effect are incalculable and the only safeguard is to monitor a suitable point in the circuit with an oscilloscope throughout the tests.

Current measurement is rarely attempted owing to the need for breaking connections to insert the meter. A common error when this is done is to forget the 0.5-V drop absorbed by most multimeters.

Loading effects — digital voltmeters

Owing to their very high input resistance and high accuracy, digital voltmeters are often used for critical d.c. measurements. The continuous monitoring of circuit behaviour by an oscilloscope is then particularly important because many digital voltmeters present a highly variable impedance, often being intermittently almost short-circuit. Some drive pulse trains into the circuit under test, while others have an extremely high parallel input capacitance (0.25 μF) on certain ranges, which could affect the normal operation of many circuits.

Loading effects — oscilloscopes

The oscilloscope is frequently used for d.c. measurements because it offers high input resistance and simultaneously monitors a.c. components, thus indicating unwanted pick-up and oscillation.

It is easy to overlook that the usual 1 MΩ input resistance can still load some circuits, e.g. that shown in Fig. 3, noticeably and even with the commonly attached 10:1 probe, the loading cannot always be ignored.

The input capacitance of a direct screened lead combined with that of the oscilloscope will often exceed 100 pF and oscillation of the circuit under test is more likely than with a multimeter using separated leads.

The use of an attenuator probe having less than 10 pF capacitance at the cost of 10:1 loss of signal, is therefore, essential for many measurements.

In cases where the 7 pF of a typical probe still causes oscillation, a resistor of a few kilohms should be clipped to the probe and the remote end of the resistor used for connection to the circuits, as if it were the probe tip.

Loading effects — reduction by provision of monitor points

It is evident that loading effects can lead to wrong readings which are revealed as erroneous. Much can be done to avoid these errors by the provision of monitor points during the initial design. These are designed to minimise loading by the measuring equipment used during testing, and generally they provide the bonus that inadvertent short-circuiting of the measuring point to ground causes less damage to active devices. Figure 4 illustrates an audio circuit provided with perhaps an excess of monitor points.

Power supply problems

In the testing of new circuit designs, bench power supplies are commonly used and the circuits are tested using their built-in supplies only at a later stage. The reason is clear — until the whole equipment is fully designed, the power supply load cannot be estimated and so its design is not begun until late in the development period. There are dangers in using bench supplies for the initial tests and some precautions are advisable.

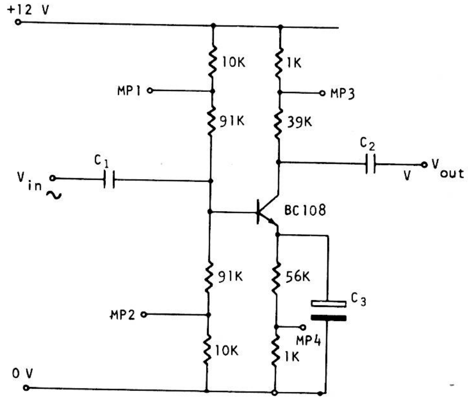

Figure 4:

Most d.c. supplies can be used for supplying current in one direction only. This applies to an unregulated supply derived from a.c. by diode rectification and also to a conventional stabilised d.c. supply using a series regulator, unless provided with a permanent 'bleed' load. If the circuit being driven uses two supplies of this type of the same polarity and part of the circuit uses the voltage between supplies, stability of one supply can fail. Figure 5 illustrates a possible configuration of this kind, where T_1 and T_2 form a multivibrator driving T_3. The current in the 10 V supply is reversed and a normal stabilised supply could lose stability. Note that when the same supplies are driving the whole equipment rather than the small part of it under test, it will function correctly provided the load has been correctly distributed. A cyclicly varying load current in the above situation may cause reverse current only at the peaks of each cycle. This often passes unnoticed since the mean supply voltage is scarcely affected, but may cause either oscillation or low gain because of the feedback thus introduced. The remedy for test purposes is to add bleed resistors to the supplies to ensure that the supply current does not reverse.

Supply arrangements

It is advisable when testing small parts of a large equipment to use individually variable supplies for each required voltage, rather than a specially made multiple supply as will be used in the final equipment. This enables the effect of variation of each line to be examined. Even if the test specification for the equipment does not require such a test to be carried out, it is useful to note the effect of, say, ±10% line variations. Naturally the circuit may fail to achieve its normal performance under these conditions, but complete failure to operate is usually a sign that the design is over-critical and warrants further investigation.

Some design based on critical d.c. levels may have every right to fail, but the designer would be aware of this and accept this particular result. When a circuit requires several power supplies it is useful to add a master switch between the circuit and the supplies. This greatly increases the probability that the technician will take the trouble to switch off supplies before circuit modifications are made. It also ensures that variable controls on the supplies are not accidentally moved, in switching on or off. There is, however, a danger associated with the use of a master switch. In badly designed circuits that will fail catastrophically when some supplies appear before others, the master switch may approximate to simultaneous connections well enough not