The design and application of a data logging system to monitor discrete electronic components

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THE DESIGN AND APPLICATION OF A DATA LOGGING SYSTEM TO MONITOR DISCRETE ELECTRONIC COMPONENTS

by

Michael Daniel Hugh Prince

A Master's Thesis

Submitted in Partial Fulfilment of the Requirements for the award of Master of Philosophy of the Loughborough University of Technology

August 1987

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"... when you have reached the mountain top, then you shall begin to climb.

And when the earth shall claim your limbs, then you truly dance."

Kahlil Gibran
ACKNOWLEDGEMENTS

Along the way many people have helped me to produce this thesis. I would particularly like to thank Professor David Campbell, who has been my supervisor, for his help and guidance. Joe Hayes, Jeff Jones and Ajith Amerasekera who have given their advice and help so freely on various subjects. Susan Dart for her typing.

Moral support, inspiration and the occasional twist of the arm were provided by my parents, my brother, sisters and Alison. Between them they have given a great deal.

Finally, there are many people too numerous to mention who have been helpful on various occasions. Their assistance has also played its part.
ABSTRACT

A Data Logger has been designed and developed by the author. The Data Logger is used to take measurements on electronic components.

The Data Logger is outlined. It is described in terms of the hardware from which it was built. It is also described in terms of the software through which it is controlled using an Apple micro-computer.

An experiment on multilayer ceramic capacitors is detailed. A further experiment on optocouplers is outlined. Both experiments make full use of the Data Logger.

In concluding, the Data Logger is found to work best with two and three terminal components. Some changes are discussed, enabling the Data Logger to be compatible with the IBM PC format.
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<td>A</td>
<td>amps</td>
</tr>
<tr>
<td>ADC</td>
<td>analogue to digital converter</td>
</tr>
<tr>
<td>CTR</td>
<td>current transfer ratio</td>
</tr>
<tr>
<td>Ea</td>
<td>activation energy</td>
</tr>
<tr>
<td>eV</td>
<td>electron volt (≈ 1.602 x 10^{-19} coulomb)</td>
</tr>
<tr>
<td>F</td>
<td>farads</td>
</tr>
<tr>
<td>F(t)</td>
<td>cumulative distribution function (c.d.f.)</td>
</tr>
<tr>
<td>GPIB</td>
<td>general purpose interface bus</td>
</tr>
<tr>
<td>Hz</td>
<td>hertz</td>
</tr>
<tr>
<td>Ic</td>
<td>collector current</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electronic and Electrical Engineers</td>
</tr>
<tr>
<td>I/O</td>
<td>input/output</td>
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<tr>
<td>k</td>
<td>Boltzmann's constant (8.623 x 10^{-5} eV/K)</td>
</tr>
<tr>
<td>K</td>
<td>kelvin</td>
</tr>
<tr>
<td>L</td>
<td>inductance</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>mA</td>
<td>milliamp</td>
</tr>
<tr>
<td>MLC</td>
<td>multilayer ceramic capacitor</td>
</tr>
<tr>
<td>MTBF</td>
<td>mean time between failure</td>
</tr>
<tr>
<td>MTTF</td>
<td>mean time to failure</td>
</tr>
<tr>
<td>t</td>
<td>time</td>
</tr>
<tr>
<td>T</td>
<td>temperature</td>
</tr>
<tr>
<td>V</td>
<td>volts</td>
</tr>
<tr>
<td>V_{CE}</td>
<td>collector emitter voltage</td>
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$V_F$  
forward voltage

$V_{\text{SAT}}$  
saturation voltage

$\eta$  
characteristic lifetime

$\Omega$  
ohms
1. INTRODUCTION

1.1 OUTLINE OF THESIS

This thesis aims to give the reader a detailed account of the design and application of a Data Logging System to Monitor Discrete Electronic Components.

It first introduces the reader to the background behind this Data Logger. The background of reliability and reliability analysis. It then provides a brief look at data logging to give an idea of the scope of data logging, then finally a summary of different generic component types and an idea of what kinds of failures may be associated with them.

Next the Data Logger built at Loughborough University of Technology is introduced and its design features, the hardware that it uses and the software that runs it are described in detail. The construction of the Data Logger is described.

Chapter three is about the Data Logger applications. It discusses the general applicability of the system, defining what it can and can not be used for. Following this an account is given of the specific work that it has been used for, mainly on optocouplers and on ceramic capacitors. Then a brief account of some of the smaller applications that it has been used for is given.
Finally, in the conclusions the design, software and component application are assessed. This is followed by suggestions for improvements, some of which have already been put into use. A summary concludes the thesis.

1.2 RELIABILITY ANALYSIS

1.2.1 Introduction

Reliability can be described as the probability that a system will operate to an agreed level of performance for a specified period, subject to specified environmental conditions.

Reliability engineering has two sides to it, in practical terms. They are:

(i) Designing for Reliability

This means that when an equipment or component is manufactured, it is built in such a way that it will be intrinsically reliable. For instance, the materials used will operate over a specific temperature range so this equipment or component is designed to run at temperatures within the temperature ranges of all materials used. Alternatively, a piece of equipment is designed so that if one component fails, then the equipment still works because another component, or set of components, will also cover that need e.g. in a power supply a diode may be needed to rectify the input. If two diodes are used in parallel then if one fails, rectification will still take place.
(ii) Reliability Analysis

This means studying systems to assess their reliability. It involves both experimental and mathematical techniques. The experimental techniques usually take the form of stressing or overstressing the system using temperature, electrical, humidity and mechanical stresses (particularly the first three in dealing with electrical systems). Information is taken from these experiments and used to assess reliabilities and how they may be improved. Studying systems in the field is also an established method of obtaining reliability information.

1.2.2 Reliability Theory

In order to understand Reliability Analysis it is necessary to know something of the Reliability Theories that are commonly used.

Going back to our original definition we see that reliability is a probability and that a failure distribution can be plotted against time which will look typically like Figure 1.1.

This gives the probability of a failure after a time \( t \) of \( F(t) \), and will clearly start at or near 0 and increase to 1 with time (when all components will have failed).

There are many different reliability distributions used to assess and model reliability, but some of the more commonly used
Figure 1.1. A typical cumulative distribution function.
ones are the Normal, the Log Normal, the Exponential and the Weibull which may be found described in any text on reliability engineering [1]. Other commonly used distributions include Poisson and Binomial.

There are two influences on the reliability of a system:

(i) Manufacture

(ii) Use

The way a system is manufactured will put limits on its lifetime. For instance, if there are contaminants in chemical processes, this can affect performance and reliability. Physical defects incurred during manufacture can also have the same effect.

There are two different ways in which a system may fail.

(i) Catastrophic failure - the system becomes totally unusable.
(ii) Parametric failure - the system no longer performs within its original tolerances but still works.

The usual way to put a time on failures is to use Mean Time To Failure (MTTF), or for repairable systems, where repair is being considered Mean Time Between Failure (MTBF). These are detailed in Appendix 3. These ideas are based on samples of systems as opposed to the behaviour of an individual system. The inverse of MTTF gives the failure rate \( \lambda \) or \( f(t) \). This is usually very small and so is defined as number of failures per \( 10^6 \) component hours.
The accepted model of failure rates for any system against time is the "bathtub curve", see Figure 1.2.

Any sample of components will have three defined periods of its lifetime:

(i) Infant mortality - this represents failures from badly manufactured components which will rapidly fail.

(ii) The 'useful life' - during this time there are few failures and the failure rate is constant. Those failures that do occur are random and attributed to longer failure mechanisms than in the infant mortality region, and the operating environment of the system.

(iii) Wear out - the systems are coming to the end of their natural life and consequently failure rate once again increases.

In accelerated life testing temperature is often used in order to speed up natural processes. The rate of a chemical reaction is governed by the Arrhenius Equation [2] which states:

\[ r = A \exp \left( - \frac{E_a}{kT} \right) \]

Equation (1)

\( r \) = reaction rate
\( A \) = constant
\( E_a \) = activation energy (specific to process)
\( k \) = Boltzmann's constant \( (8.623 \times 10^{-5} \text{ eV/k}) \)
\( T \) = absolute temperature
Figure 1.2. The bath tub curve.
This equation needs to be used with discrimination because the assumption must be made that the same conditions and reactions occur at $T_1$ as at $T_2$ in order to compare $r_1$ and $r_2$. It is, however, often very useful and in common use.

Rearranging Equation (1) we can get

$$\ln(r) = \ln(A) - \frac{E_a}{kT}$$

Equation (2)

which we can then plot as a \"y = mx + c\" line for two or more higher temperatures, see Figure 1.3. This allows us to extrapolate failure rate down from accelerated conditions to normal usage conditions. It is also possible to calculate $A$, $E_a$ and the rate of reaction for a given temperature.

It is possible to use an Arrhenius Plot to determine whether different failure mechanisms are dominant under different conditions. This can be illustrated using the following theoretical situation.

Any failure mechanism has an activation energy $E_a$ associated with it. Different failure mechanisms will have different activation energies. The gradient of an Arrhenius Plot equals $E_a/k$. Hence if a plot shows a change of gradient, see Figure 1.4, or if a plot has a different gradient compared to a plot from similar conditions but with a different stress factor changed (e.g. voltage), see Figure 1.5, then the activation energies are different. This implies different dominant failure mechanisms.
Figure 1.3 An Arrhenius Plot.

\[ \text{In } [F(t)] \]

\[ \text{Gradient} = \frac{E_a}{R} \]

\[ \frac{1}{\text{Temperature}} \]
Fig. 1.4 An Arrhenius Plot indicating different dominant failure mechanisms at different temperatures.
Fig. 1.5 Two Arrhenius Plots showing different dominant failure mechanisms at different stresses (other than temperature).
This is a very useful technique in accelerated life testing [3].

The Weibull function [4] is used extensively in accelerated life testing. This is a statistical distribution which is popular because it can be fitted to a wide variety of circumstances. A detailed description of its use is given in Appendix 4.

1.2.3 The Historical and Industrial Importance of Reliability

It is within the last forty years that Reliability has become a field within its own right. Before 1940 most related work concentrated on quality control or maintenance problems, and reliability in itself was not considered. With the advent of the Second World War and increasing complexity of electronic equipment, reliability came into its own. By the 1950's several formal studies had begun on reliability which set specification standards for the reliability of electronic equipment. One of the best known of these is AGREE [5] (Advisory Group on the Reliability of Electronic Equipment) formed by the U.S. Department of Defence in 1952. Today there are similar standards widely used like MIL-217 [6], BS9000 [7] and by British Telecom.

In industry today reliability engineering is used to increase the reliability of products and to improve production. For any product there is an optimum expenditure on reliability in relation to subsequent benefit, see Figure 1.6 [8].
Fig. 1.6 The cost effectiveness of a reliability program.
It is far more economic to implement an effective reliability scheme than to need corrective action at a later production stage. Discovering and correcting a potential weakness at an early design stage may cost many times less than if it were found during testing of the production standard hardware.

1.2.4 Common Methods of Reliability Analysis

Reliability analysis can take many forms, however like most forms of experimentation it usually means applying one or more tests to the system and taking measurements. These measurements are then analysed to give information on the reliability of the system. Typically this might include some temperature stressing, raising the system to a given temperature for prolonged periods of time, temperature cycling or humidity and temperature stressing.

Measurements of these systems can be taken either continuously or at pre-specified time intervals. These are then analysed and such aspects as parametric drift, or catastrophic failures or whatever may be picked out, either by hand or using a computer statistics program such as SPSS/PC+ which is available at Loughborough.

A great deal of reliability experimentation involves simulation of conditions using various different test chambers (usually able to simulate one or more of temperature, humidity, vibration and pressure requirements). These chambers are commercially available in the U.K. The other significant part of this experimentation involves
taking the measurements when and where needed either to be analysed on the spot, or later. Measurements may be taken by hand if small amounts of information are being gathered.

It may not be possible for measurements to be taken manually under the following circumstances.

(i) There is too much information to be measured.
(ii) The working environment does not permit direct human involvement (hazardous or inaccessible).
(iii) Measurements are to be taken at odd times or over very long or very short periods.

In these circumstances a form of automatic measurement and storage of results needs to be used, such as data logging.

1.3 DATA LOGGING

1.3.1 The Definition and the Uses of a Data Logging System

In its simplest form a Data Logger is a device for measuring and storing measurements. By such a definition Data Loggers have been around for a long time (e.g. a barometer with a pen chart recorder). Nowadays the picture has diversified greatly.

"The ubiquitous microprocessor makes nearly every data gathering product a candidate for data acquisition discussion" [9]
Broadly speaking, the modern Data Logger is controlled by a small computer or a microprocessor. This controls one or more instruments and switches. It is usual for a Data Logger to use switches to look at devices sequentially.

To get an idea of what might constitute a Data Logger, there are two examples. The first one is a simple Data Logger that could be constructed in any laboratory without much difficulty (see Figure 1.7), and is typical of the type of device that might be used in an educational or research project [10,11] for storage of information and control of instrumentation.

The instrument is continuously measuring a parameter, which it outputs as an analogue voltage. This in turn is converted into a binary word by the analogue to digital converter (ADC) which outputs this voltage as a binary word. This can then be read into the computer using a parallel port (such as the parallel interface adapter incorporated on a BBC B microcomputer). This information from the instrument is continuously being sent to the computer. At appropriate, preprogrammed moments, the computer can sample the information, write it on the screen, store it on the disc and compare it for any further action.

Such a system represents a very simple straightforward example of a dedicated machine which has been set up to perform one task. It will do this effectively, but it is not capable of much more without being programmed again virtually from scratch.
Fig 1.7  A simple data logger.
At the other end of the scale are the massive commercially available machines costing up to thousands of pounds. They will have been developed over a period of time by a design team and will feature many different abilities.

A top of the line Data Logger may have many input channels, interfaces, archiving ability and many other features. For instance it may be able to sample up to 30,000 [12] channels a second. This allows for practically continuous monitoring of a large number of inputs with one measuring device, (assuming it can measure at that speed). Appendix 1 gives details of some commercially available Data Loggers, showing their various features and costs. This is the alternative to building a Data Logger in house.

Typically, Data Loggers are used for gathering information. Two interesting examples have been taken from Automation magazine [13,14].

In the first example the stresses inside a ship were recorded. The ship carried bitumen at high temperature (165° Celsius), and this built up thermal stresses inside the ship's structure. The most efficient way of monitoring this was by the use of a Data Logger to be used over a journey. The results were used to help design new ships, armed with the knowledge of how thermal stresses developed.

The second example was using a Data Logger (Systematic Micro's CR7) on a train. In the British Rail experiments, which cover some
of their latest diesel locomotives as well as electrical multiple units and high speed trains, the logger was used to capture data onto its built in cassette tape recorder. The data was processed and analysed using an onboard Hewlett-Packard HP9845 desk top computer, which could produce graphs or tables of data very rapidly.

The term Data Logger represents a very wide range of equipments. However they all basically retrieve and archive information, usually measurements.

1.4 COMPONENTS (PASSIVE AND ACTIVE)

Electronic components form the basic structure of any electrical circuit, they consist of passive devices such as resistors which restrict current flow, capacitors which store charge inductors, and other similar devices. A passive component can be defined as a component where the output impedance equals that of the input. They are usually two terminal devices.

Active devices started with valves. Nowadays almost all of the silicon and gallium arsenide devices produced are active devices. Active devices have three terminals and their input and output impedance are different. Under this definition a silicon diode is not classed as active. The diode is by definition a passive device, performing the role of a variable resistor. However, since the silicon diode is a pn junction, the basis of transistors and many active devices, it is usually considered to be an active device.
For the purposes of this discussion, an electrical component will be defined to be a device for transmitting or modifying electrical signals whose constituent parts cannot readily function alone.

1.4.1 Component Reliability

As detailed in the Appendix 2, components are divided into separate categories, each of which has its own typical reliability problems associated with it. To give a broad overview we have the following:

1.4.1.1 Resistors

Resistors are probably the simplest case and have three basic ways that they can fail (failure modes). They are:

(i) open circuit
(ii) closed circuit
(iii) change of resistance

Of these (iii) is the most vague, since a change of resistance in one application may mean failure (ceases to do what is required of it) while in another application this change may not constitute a failure, hence this is specific to the use of the resistor.

The failure mechanisms that can precipitate these modes are:
Different types of resistors are susceptible to different ways of failing, but generally they can all be divided up into these headings or combinations of headings:-

(i) mechanical
(ii) chemical/biological
(iii) temperature
(iv) electrical
(v) manufacture
(vi) misuse

Mechanical failure is usually brought on by vibration or shock. This is usually only a problem in environmentally severe conditions.

Chemical/Biological failures can be brought on by fungal growths in high humidity conditions. During encapsulation organic compounds may be encapsulated which subsequently attack a component. There are many possibilities for component failure involved [15,16].

Temperature failure, operating in temperatures above or below rated temperatures may mean that the components either stop functioning or change their properties. Resistance will generally increase with temperature increase [17].

Electrical failures are usually fairly obvious, 240 V across a 1 Ω, 1 Watt resistor will cause it to drastically overheat and probably catch fire giving failure.
Manufacturing failures. These divide up into two parts. Firstly there are failures because the way it was made means there is an intrinsic weakness. Secondly failures of the 'Monday morning' variety can occur (e.g. perhaps someone was a bit careless mixing the ceramics for this batch, or this resistor did not mould correctly).

Misuse if a resistor is put into a position that it was not designed for, then there is a good chance that it may fail. This represents a failure in one of the previous categories, but nevertheless is because of misuse.

1.4.1.2 Capacitors

Similarly to resistors, capacitors can suffer failure modes of:

(i) open circuit
(ii) closed circuit
(iii) parametric drift

Whether or not parametric drift constitutes a failure will again depend on the specific use of that component.

Again failure mechanisms are similar to the case of resistors, with perhaps the addition of humidity which can play an important part in capacitor reliability, particularly in wet capacitors such as the electrolytic type where, for instance, a very dry or hot
environment leads to failures due to the drying out of capacitors [18,19].

1.4.1.3 Other Passive Devices

Other passive devices include Inductors, (Passive Microwave), Connectors, Relays and Switches. These devices, especially the last three, all tend to be subject to failure of mechanical means. There is little literature on inductor reliability, but Jowett [15] gives a comprehensive list of conditions that may degrade inductors. These indicate that temperature, moisture and vibration factors need to be taken into account during design and manufacture.

Passive microwave devices will depend very much on the use these devices are going to be used for, as generally they are 'tailor made' for specific purposes.

1.4.1.4 Semiconductor Devices

For a complete discussion one can refer to "Failure Mechanisms in Semiconductor Devices" by E. A. Amerasekera and D. S. Campbell [20]. They state in the conclusions that:

"It is not possible to present a tabulated list of failure mechanisms in an order of importance because the frequency of each failure mechanism is dependent upon
(a) Operating and environmental conditions
(b) Device technology (e.g. Bipolar, MOS etc.)."
However they go on to say that the most commonly quoted failure mechanisms are:-

(1) Electrical Overstress
(2) Contamination
(3) Package Related Failure Mechanisms

As for failure modes, there are many ways that a semiconductor can fail, depending on its use, its nature and the cause of failure. A list of possible failures is as follows:-

(1) Open circuit
(2) Closed circuit
(3) Illogical logic
(4) Degraded logic levels
(5) Total breakdown of function
(6) Partial breakdown of function

1.4.2 Components in General

The numbers of new components, and their complexity (especially in semiconductors) are increasing, while technology is producing better and more stable versions of simpler components.

It is debatable whether a microprocessor is a component or not, since once assembled it is fairly indivisible. On the other
hand it contains a myriad of often sub-micron devices which themselves could be used to produce a different complex component, with a different use and function. It is for these devices that companies and research establishments will pay very large sums of money for automatic test equipment and highly complex Data Loggers.

1.5 SUMMARY

The reliability of a component is an important piece of information if that component is to be used successfully. It is therefore necessary to devise some means of collecting information to make that assessment.

To make this assessment there are two ways:

(i) collect field failure data
(ii) conduct experiments in a laboratory

In this chapter we have looked at reliability analysis, data logging and components to give a background for the second approach to assessing reliability, using the Data Logger that was developed by the author at Loughborough University of Technology.
1.6 REFERENCES


12. 'Data Loggers Survey'. Automation, pp. 36-43 (October 1984).


2. THE DATA LOGGER

2.1 INTRODUCTION

A small low budget Data Logger has been designed and built by the author at Loughborough University to help in the accelerated life testing of components. It is designed to enable accelerated life tests to take place involving large numbers of components in samples (typically around 100). This has enabled the Component Technology Group to produce work that is statistically very credible.

In 1983 the Component Technology Group at Loughborough purchased 10 Farnell Switching Boxes (IEEE-488 SWITCHING UNIT SWIB). These were to form the basis of a data logger that would be able to switch around from component to component using computer control, to measure the component and to log the results. This approach was decided on because the group had received a contract from the Ministry of Defence to work on Failure Studies in Electronic Components. This study had so far been using small samples, and it was felt that the use of a data logger provided an excellent opportunity to expand the work.

The Data Logger consists of:

10 Farnell Switching Boxes
1 Solatron 7065 Digital Voltmeter
1 Keithley 617 Electrometer
1 Wayne Kerr 4120 LCR Bridge
2 Farnell Resistively Programmable Power Supplies
1 IEEE-488 General Purpose Interface Bus
1 Apple IIe Microcomputer

The equipment is arranged as in Figure 2.1.

2.2 DESIGN FEATURES OF THE DATA LOGGER

The Data Logger is designed to measure a wide variety of active and passive components. It can assess simple d.c. and low frequency a.c. (up to 10 kHz) parameters that may be of use in accelerated life testing.

Measurements of several components and several parameters may be made in any order. For simplicity's sake, usually the Data Logger will switch around from one component to the next taking measurements of several parameters in the most natural logical sequence.

The equipment is housed on a trolley (see Figure 2.2). The trolley has shelves to carry all the equipment, a filtered power supply and rides on castors. This allows the Data Logger to be wheeled up to an experiment with ease, to be connected and the appropriate measurement and logging programs to be run.
Figure 2.1  Schematic diagram of the data logger.
All the separate instruments on the Data Logger were bought separately and may be commercially obtained, their total cost approaching £15,000 replacement value.

The beauty of buying separate instruments is that it makes the system very flexible. Any instrument which has IEEE-488 compatibility may be controlled by the Data Logger.

The main limitations on the system are:

(i) The Data Logger uses relays to connect to components. Any measurement will, by necessity, include measuring across a relay.
(ii) There is a limit to the speed the computer and IEEE interface can operate. For practical purposes a measurement will take about 1 second including any switching and processing. These considerations will be dealt with in Section 3.2.

Another aspect of the Data Logger that is worth briefly mentioning is the software (see Section 2.4). What can be done with the Data Logger is dependent to a large extent upon the software written. The software determines the switching sequences and all the measurements. This means that good software is important for the Data Logger to run effectively.

All software has been written in Basic because it is easy to change and alter on the spot, or to write new programs. It is also very easy to try ideas out using Basic as a command language and quickly develop them. However, compiled languages such as Pascal can be used.

The Data Logger has been designed to be flexible and versatile to respond to different requirements, and it undergoes a program of constant improvement. Its main function is to make repetitive simple measurements, but with clever programming it can do more subtle measurements.
The hardware for the Data Logger consists of switching boxes, power supplies, an IEEE bus, an Apple IIe microcomputer, several different measuring instruments, which may all be used together or separately, and a trolley which was built specially to hold all the apparatus together. Generally speaking they can all be used as stand alone instruments (with the exception of the IEEE bus and the switching boxes). Each instrument will be detailed separately.

2.3.1 The Apple IIe Microcomputer

The Apple IIe is based on the Rockwell 6502 microprocessor working at a 1.023 MHz clock rate [1]. This has 64 kilobytes of range giving it plenty of memory space for the purposes of the measurement programs run for the Data Logger.

The Apple also has 48 K of random access memory where programs and other information are stored to run the various programs.

In addition to the basic computer, the Apple also has six I/O ports which host the disc drives, a printer, an IEEE port (detailed later) and a 'Mountain' clock card. These devices can all be accessed to receive and transmit information. Further ports could be added if necessary, (e.g. a serial port) and there are many devices commercially available for these purposes.
Many similar microcomputers could have been used to do the job of controlling the Data Logger. However, there is not a great deal to choose between them, the choice being a matter of personal preference as much as anything. The Apple microcomputer was readily available.

2.3.2 The IEEE Bus

The IEEE bus or IEEE-488 general purpose interface bus is a standardised input/output (I/O) interface which has been developed since 1972 in an effort to provide a universal I/O device. A peripheral card, the Apple II GPIB card is plugged into a slot in the Apple IIe microcomputer. This conforms to the IEEE standard-488. Standard 24 way cables then connect from the card to all devices under the control of the IEEE.

The IEEE-488 standard interface began as the General Purpose Interface Bus (GPIB), which was developed by the Hewlett-Packard Corporation. In 1975 the IEEE adopted this interface as its standard [2]. The main advantages of the IEEE-488 bus as opposed to an RS232 link or using analog-to-digital converters and a parallel or serial port are:

(i) An ability to work in electrically noisy environments without picking up interference.
(ii) It has a bus structure allowing many devices to be interfaced to the same controller.

The IEEE bus uses eight data lines [3] and eight control lines to transfer commands and data to and from devices on the bus. The devices on the bus can be described in terms of their primary functions, controller, talker or listener.

A device is called a "talker" when its primary function is the transmission of data, e.g. a DVM taking measurements and passing them over the bus to the computer.

A device is called a "listener" when its primary function is to execute commands. An example of this is a switching box which sets its relays in the configurations demanded by the computer.

A "controller" is the device that arbitrates all transfer of data on the bus. The controller can turn on a listener for the transmission of data. The controller can turn on a talker for the reception of data.

The IEEE bus can control up to 14 external devices, and they may be connected in a star configuration or in a daisy chain configuration (see Figure 2.3). It must also not exceed 20 metres in total length.
1. PIGGY BACK CONNECTORS.

Daisy chain configuration.

2. Daisy chain configuration.

3. Star connected configuration.

Fig. 2.3 Configurations of the IEEE bus.
2.3.3 The Switching Boxes [4]

The switching boxes are Farnell SWIB switching boxes (SWIBS).

Each SWIB contains 32 change over relays which can be addressed and activated using the IEEE-488 bus. When a relay is selected this is indicated by a red light on the front panel of the SWIB.

Connection to the 32 relays is made via two 50 way Amphenol plugs.

The relays are mechanical and are of the type P.O. approved type 23. They can settle within 20 ms of the last bus command and may be scanned at a rate of up to 25 Hz.

This means that, assuming everything else is able to perform at this rate we can measure up to 25 different components in one second.

The maximum electrical ratings for the relay contacts are:

\[
\begin{align*}
\text{DC} & : 110\text{V} \quad 1\text{A} \quad 30\text{ Watts} \\
\text{AC} & : 120\text{V} \quad 2.5\text{A} \quad 100\text{ VA}
\end{align*}
\]

These are important limitations on measurements. They may not be confidently exceeded. This must be considered when setting up a measurement program using the SWIBS.
2.3.4 Power Supplies [5]

It is possible to use any power supply with the Data Logger. However, the Data Logger does have two Farnell "S" series Stabilised Power Supply Units (PSUs).

These PSUs are mains driven d.c. stabilised output power supplies. They are capable of providing an output of between 0 and 45.00 volts in 0.01 volt increments.

These PSUs are resistively programmed, to produce the required output. A box of resistors plugs into a switching box and then by selecting relay combinations it is possible to determine the output voltage. This means that there are two power supplies which are capable of being controlled by the computer over the IEEE bus.

2.3.5 Solatron 7065 Digital Voltmeter [6]

This voltmeter is a high accuracy digital voltmeter with an IEEE interface. It is capable of measuring voltage, both a.c. and d.c., and resistance. The measurement facilities are:

- DC voltage from 1 μV to 1 kV
- AC voltage from 1 μV to 1 kV
- Resistance from 1 mΩ to 14 MΩ

In addition to these basic measurements the meter is capable
of filtering for a stabilised output. Filtering produces an averaged reading. It is possible to change the integration time of a measurement and the scale lengths. The integration time is the time that the meter uses to measure a signal. Integration times are chosen to be exact multiples of the mains supply frequency. This means that measurement remains unaffected by mains pick-up.

The voltmeter is highly accurate, generally to less than 0.01% over 24 hours.

2.3.6 Wayne Kerr 4210 LCR Bridge

The Automatic LCR Meter provides direct and accurate measurements on inductors, capacitors and resistors at any of three alternative frequencies (100 Hz, 1 kHz, 10 kHz). In addition to measuring the major term (inductance L, capacitance C, or resistance R), it can be switched to measure the resistive loss term of inductors and capacitors and any L or C term present with resistors. The bridge is also capable of measuring the dissipation factor D and Q factor of inductors. \( D = \omega R_s C_s \) and \( Q = \omega L_s / R_s \) where \( \omega = \) angular frequency, \( R_s = \) series resistance, \( L_s = \) series inductance and \( C_s = \) series capacitance [7]).

The instrument selects its own ranges. The range can be fixed to speed up measurement times. It also has the capability of sorting measurements into what are termed 'bins'. These bins can be
selected either by % age deviation from a specific value or by absolute value. Ten bins are available.

The 4210 has an IEEE-488 bus. This allows total control by the Apple IIe on board the Data Logger.

The meter may read to an accuracy of 0.1%. At a speed of typically 650 ms. It can read:

- **Resistance (Ω < 0.1)** 0 to 990 MΩ resolving to 0.1 mΩ
- **Capacitance (D < 0.1)** 0 to 990 mF resolving to 0.001 pF
- **Inductance (Ω > 10)** 0 to 9900 H resolving to 1 nH

Dissipation and Q factor can be measured with similar accuracies from the ranges 0.0001 to 9900 [8].

2.3.7 **The Keithley 617 Programmable Electrometer [9]**

The Keithley Model 617 Programmable Electrometer is used occasionally as an alternative instrument for measuring voltage, current, charge and resistance. It can be controlled using the IEEE-488 bus. The electrometer has an especially high input resistance. This means that it is capable of detecting very small currents and very high resistances. Typically it can detect currents as low as 0.1 fA
(10^{-16} \text{ A}) \text{ and resistances up to } 200 \text{ G}\Omega. \text{ This makes the instrument especially suitable for measuring insulation resistances.}

2.4 \textbf{SOFTWARE}

2.4.1 \textbf{Purpose of Software}

The Data Logger is programmed to operate various tasks using the Apple II run under the Apple 3.3 operating system using the Basic language.

Basic is used because:

(i) it is simple to use
(ii) easy to write and alter
(iii) straightforward to edit while developing programs.

This makes programming very straightforward. The fact that it is an interpreted language means that it is easy to slow down parts of a program when waiting for measurements to settle. Errors are easy to trace and not needing excessive speed there is no great demand for compiled languages such as Forth or Pascal.

Typically a simple line of Basic takes about 1 or 2 milliseconds to be executed.
The software is used to direct the sequence of commands, to control and read instruments and then store this information in files in a readily accessible manner. The manner in which all this happens has been programmed. This is the flexible part of the Data Logger. What the instruments are capable of is fixed, but much can be achieved by imaginative software (see Figure 2.4).

We see that the software can allow us to communicate with every part of the system.

2.4.2 Programs Written for the Data Logger

A library of programs has been written, some for general use and some for specific uses. Listings of all programs are in Appendix 5.

2.4.2.1 General Programs

2.4.2.1.1 Subroutines

This contains all the subroutines needed to build a program for the Data Logger. It consists of a number of subroutines which may be called using the command GOSUB. It cannot operate by itself but forms the basis of the bigger measurement programs. It is useful because it helps reduce the time spent writing a new program.
Fig. 2.4  Software control of the Data Logger.
2.4.2.1.2 Relay Control

This is a simple program for controlling the relays a step at a time. It is used to check relay combinations, for instance the stray capacitance of a circuit can be measured. Any relay combination may be programmed, programming a box at a time.

2.4.2.1.3 Fileread

A program for reading a text file, which can then be read on the screen or output to a printer has been written. The file is opened and the file length is read. All entries are copied into a string and the file is closed. Finally the string is output to the screen or the printer.

2.4.2.1.4 Meansd

This program is based on FILEREAD. It reads the file into an array. The mean and standard deviation are calculated discounting any data values that lie outside specified ranges. Out of range values are displayed by the computer. This allows rogue values to be spotted and to look at shifts in distribution for good data, from reading to reading. It does not consider the shape of a distribution of data and so is only used for preliminary data analysis.

2.4.2.2 Specialised Programs

Specialist programs have been written for use with specific experiments (see Chapter 3 for details of the experiments).

45
2.4.2.2.1 For Volta, Ctra, Sat Volta

These three programs are used for an experiment on accelerated life testing of optocouplers. Each is used to measure a particular parameter and to record the parameter values of the optocouplers in a text file on a floppy disc. The programs all select one optocoupler in turn via the relay boxes, take a measurement, then switch to the next optocoupler.

(i) For Volta - measures forward voltage of the light emitting diode of the optocoupler. This is measured for a given constant current supplied by an external source.

(ii) Ctra - measures the current transfer ratio of an optocoupler - the ratio of current through the transistor for a given current through the light emitting diode (L.E.D.). This is achieved by measuring the voltage drop across a resistor in series with the transistor and calculating the current and hence the current transfer ratio using Ohm's Law.

(iii) Sat Volta - this estimates the saturation voltage of the optocoupler's transistor by measuring transistor currents for increasing values of $V_{CE}$. It considers a graph of $V_{CE}$ against $I_C$ and calculates the gradient between the last two consecutive readings. When the gradient falls below a certain value (5 if $I_C$ measured in mA, $V_{CE}$ in volts) it uses that calculated value.
gradient and the previous calculated gradient to estimate the value of $V_{CE}$ that gives an instantaneous gradient of 5, using the Newton-Ralphson method [10]. This value of $V_{CE}$ is called $V_{SAT}$, the saturation voltage.

2.4.2.2.2 Lookcer, Ceram*, Autoceram

As their names imply, these programs are concerned with the measurement of ceramic capacitors.

(i) Lookcer - this program, although used for ceramic capacitors, can be used more generally. It switches around from one capacitor to another measuring series resistance and displaying the results on the computer terminal. This is used in looking for devices that have catastrophically failed short circuit (characteristic of multilayer ceramic (MLC) capacitors in accelerated life tests [11]).

(ii) Ceram* - this program is a general program which uses the Wayne Kerr LCR bridge. It will measure up to ten different parameters and conditions, on up to 256 devices. The program asks the operator to type in the parameters and conditions for measurement. It then opens up a file for each different set of measurements and switches around from device to device, first measuring one parameter, writing the information to disc then the next parameter and so on until completion.
Autoceram - this program is built up from Ceram*. It makes use of a Mountain Clock Card, available for the Apple, enabling measurements to be made at any preprogrammed time. Autoceram consists of programs which call each other. The computer loads the information that normally an operator would type in from an information program. It then 'Watches the Clock' until the time it has to measure (as laid out in information). It then runs a program, also called Autoceram which executes the necessary commands, then returns to Watch the Clock. It can also change bias voltage at a given time, via the programmable power supplies.

The subprograms are self-explicitly called Hello, Information, Watch the Clock, Autoceram and Change Voltage.

This program will also reload itself in the event of a power failure and continue watching the clock until the next time for action.

The clockcard has a battery back up and so when the computer is switched off it continues to work.

2.4.2.3 Details of Subroutines, the Control Program

Subroutines is the program which contains all the essential subroutines used to control the Data Logger. As such this program will be discussed in some detail (see Appendix 5 for a complete listing).
These opening lines set up listening and talk addresses for the IEEE bus, it tells how many switching boxes are used on the bus, and it sets the string values that will determine whether a relay is on or off.

This will open a text file that is named by the operator. The text file can be used to store information retrieved by a program.

This sets relay J to the ON state by putting a 1 in the string R%(J) and calling another subroutine that actually sets the relay (GOSUB 9300).

This sets relay J to the OFF state by putting a 0 in the string R%(J) and calling another subroutine that actually sets the relay (GOSUB 9300).

This uses the same technique as the above two subroutines except it switches off all the relays (using GOSUB 9500 which sends
the string DFHLOO to all boxes causing all relays to go to the off state) before it switches relay J on.

9500 to 9590 Reset All Relays.

This sends the string DFHLOO to each box in turn causing the relays to be set to the off position.

9300 to 9370 Set Relay J

This converts the integer J, representing the Jth relay, into a string which can be sent to a particular box, altering that relay from on to off without affecting the other relays. The positions of all the relays are stored in a string R%(J) and so these strings for the boxes are calculated afresh each time a relay position needs to be changed.

9400 to 9427 Sets Up Electrometer to Measure Resistance.

This sends a string to the electrometer, at bus address 30, preparing it to measure resistance.

9430 to 9465 Measure with Electrometer

This takes a reading from the electrometer and places it into a string A%. It can then be stored in a file or used by the program.
9600 to 9640 Clear All Devices

This sends a message down the IEEE bus 'CA'. This literally will clear every device that is connected to the bus.

9700 to 9740 Write A$ to a File

This puts the string A$ and places it in the file F$ which was opened at the beginning of the program.

9750 to 9780 Initiate DVM and Set Ranges to Ohms

This clears the DVM and sets it to remote (i.e. controlled by the IEEE bus). It then sends a string to the meter, which in this case selects it to measure resistance.

9800 to 9880 Take a Reading into A$

This is similar to lines 9430 to 9465. It triggers the device at address 30 and takes a measurement. This is then sent over the bus to the controller and stored as a string A$.

9900 to 9960 Send A$ to Box Number BN

This is used for controlling the switching boxes. A string such as DnnFnnHnnLnn is sent to box number BN. The n's represent numbers which are interpreted as relay combinations similar to the way ASCII code represents binary combinations.
Additionally, there are subroutines which have been written to drive other instruments, the Wayne Kerr LCR bridge for instance. They are all very similar to the subroutines that are used to command the DVM or the electrometer, except that it will reside at a different address, and of course the command strings that the bridge needs are different, for instance in line 9770

```
9770 PRINT "WT";LA$;"MIR\1IT1"
```

this could be changed to

```
9770 PRINT "WT";LA$;"CA;PA;FU;ME;"
```

where

- **CA** Capacitance
- **PA** Parallel
- **FU** Frequency Upper (10 kHz)
- **ME** Measure

i.e. "measure parallel capacitance at 10 kHz"

2.5 **SUMMARY**

The Data Logger has been built using separately available commercial instruments and switching boxes. Most of these are able to be used on their own, but have been combined to work together using an Apple Iie as a controller on an IEEE-488 general purpose interface bus.
The logger has been designed to be flexible and to measure a variety of different electronic components, being able to make and store measurements of Voltage, Current, Resistance, Capacitance and other parameters.

A suite of programs has been developed for this purpose and for any specific need a program can be written, using Apple Basic, by writing the necessary software and calling upon the subroutines and protocols that are already in existence in subroutines.

Applications of this Data Logger will be discussed in the next chapter.
2.6 REFERENCES


4. 'Farnell Instruction Book for IEEE-488 Switching Unit SWIB'. Pub. Farnell.


3. APPLICATIONS OF THE DATA LOGGER

3.1 RELIABILITY SOURCE OF COMPONENTS

It is envisaged that in the future the Data Logger will be used to investigate the reliability of components using accelerated life techniques. It will obviously not be possible to investigate every single kind of component, so it is necessary to select those for study which are important.

In the Component Technology Group at Loughborough University a data base is being established [1] whose aim is to establish a set of dependable field failure data for components that have been shown to be the most likely causes of failure in equipments. The study will involve the collection of data from a wide range of sources. Using the information in this data base it will be possible to find out, using a Pareto Analysis [2] for instance, those components which are most troublesome. From that list it will be possible to choose those devices which are suitable for accelerated life testing and measure them using the Data Logger.

At present the Data Logger is being used to study two sets of components. Firstly, Multilayer Ceramic Capacitors are being studied. These were initially studied so that it would be possible to design and build the Data Logger using the capacitors as a case study. The capacitors were donated by STC. The results of the experiment were reported back to STC. This has been a valuable help in assessing the Data Logger.
The other component that the Data Logger is being used to study is the optocoupler. Studies at the Danish Academy of Engineering, under Professor J. Møltoft, have shown that the optocoupler is a 'troublemaker' [3] component and so 1,000 have been placed 'in the field' to be studied, and 1,000 are being studied under accelerated life test conditions at Loughborough University. The Data Logger is used for measuring.

Both these components and the experiments being conducted are discussed fully in Section 3.3.

3.2 GENERAL APPLICABILITY

This section will define the limits within which the Data Logger will satisfactorily operate.

The Data Logger is designed to operate in a benign laboratory environment. It is not suitable for use out of doors or in extremes of temperatures. Components are taken to the Data Logger for measurement rather than the other way round.

The two main factors which affect the performance of the Data Logger are the Apple IIe computer and the switching boxes. The Apple IIe dictates the speed at which processes can run, by virtue of the speed it can implement software. The SWIBs have the greatest effect on the minimum and maximum voltages, currents etc. that can be measured by virtue of the relays inside them. They also limit
The complexity of a component that may be measured since there are a maximum of 256 switches available (admittedly this is usually not a problem).

The relays in the SWIBs have each a capacitance of 5 to 6 pF (series) when open and a dc resistance when closed which varies between 0.1 Ω and 0.2 Ω. This variation can be attributed to the fact that some relays will have been used more than others. The relay units are not sealed hermetically and therefore surface contamination and oxidisation of the contacts is to be expected, causing a temporary increase in resistance. The mechanical effect of the contacts closing together will help reverse this effect.

Therefore it is possible to measure capacitances to about 10 pF and to measure resistances to about 1 Ω with confidence. The voltage and frequency limitations are provided by the relays. The voltage and current across a relay should not exceed 110V, 1A dc, 30W or 120V 2.5A, 100VA a.c. Any applied voltages or currents should be below these values if they are likely to pass across the relays. Regarding frequency, the Data Logger is designed for low frequency and direct current measurements. It is not intended for high frequency measurements.

We can therefore formalise the limits to measurement of current, voltage, resistance and capacitance.
| **Current** | up to 1A dc  
|           | 2.5A ac  
| **Voltage** | up to 110V dc  
|           | 120V ac  
| **Resistance** | down to 1Ω  
| **Capacitance** | down to 10 pF, this lower limit may be decreased by considering the relay capacitance as a systematic error.  

The limits of measurements are otherwise limited by the instruments being used, and so it is possible to measure a resistance of Giga (10⁹) Ohms using the Electrometer, and this would prove no problem for the Data Logger. Generally speaking the Data Logger is to be used for electrical measurements which would not be considered extreme in value.

### 3.3 **SPECIFIC COMPONENTS**

The Data Logger was developed and tested using an experiment with multilayer ceramic capacitors. This experiment is dealt with in Section 3.3.2. Since this experiment, which was used to develop the Data Logger, it is now being used for an optocoupler experiment, for measurements upon thick films and for surface mounted ceramic capacitors. These represent typical uses for the Data Logger.
The optocoupler experiment is described in depth in Section 3.3.2, and Section 3.3.3 describes experiments other than optocoupler and multilayer ceramic capacitor experiments which have used the Data Logger.

3.3.1 Multilayer Ceramic Capacitors

Multilayer Ceramic Capacitors (MLCs) were investigated using the Data Logger. The capacitors were provided free of charge by STC in return for which STC would be privy to our results. The capacitors were used for an accelerated life style experiment which was used as a test bed upon which to help develop the Data Logger and generally to uncover any weaknesses.

Screen printed multilayer ceramic capacitors (100 nF, 50 & 100V X7R type) were subjected to accelerated life tests. The tests used voltage and temperature overstress to investigate their effects upon lifetimes. The experiment also investigated the possibility of different failure mechanisms at different stress conditions. The Data Logger was used to take parametric measurements and to locate failures.

3.3.1.1 Outline of the Experiment

The experiment consisted of two different parts: (a) a series of step stress tests; (b) biasing capacitors at different fixed voltages and temperatures.
The step stress tests followed a regime of increasing stresses and looks for parametric drift and failures. One hundred and twenty capacitors were placed on test at maximum rated voltage and temperature (50 volts, 125°C) for 1,040 hours. Voltage was increased in steps for times given (see Figure 3.1) until approximately 20 capacitors had failed. Half the capacitors were then held at this voltage and temperature was stepped up in 10°C steps to 205°C for a time constant to the next voltage step time. The remaining half were all continued on the original test plan. The Data Logger was used to take regular measurements of parallel capacitance and resistance (at 1 kHz) and the dissipation factor, and hence to log all times to failure, using the program CERAM*.

In addition to this step stress, a series of tests were conducted at fixed combinations of temperature and voltage. These conditions are shown in Figure 3.2. These tests were conducted logging times to failure more accurately. This was achieved by monitoring leakage current and switching off the voltage bias when it exceeded 5 milliamps. A clock counted the number of hours voltage bias and this was also stopped when the voltage bias was switched off. A diagram of the circuit for this can be seen in Figure 3.3. In Figure 3.4 this circuit can be seen incorporated into the whole experiment.

When a failure occurs the clock and voltage bias are switched off, and it is necessary to remove or disconnect the faulty component. The Data Logger is connected to the batch of capacitors with the
<table>
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<th>Time (Hours)</th>
<th>Accn</th>
<th>Factor</th>
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</tr>
<tr>
<td>229</td>
<td>13</td>
<td>10.8</td>
<td>96</td>
<td>4.58</td>
</tr>
<tr>
<td>235</td>
<td>14</td>
<td>10</td>
<td>104</td>
<td>4.70</td>
</tr>
</tbody>
</table>

**Fig. 3.1** Table of Voltages and Times for Accelerated Life Tests of Multilayer Ceramic Capacitors

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>125°C</td>
</tr>
<tr>
<td>100 volts</td>
<td>128 capacitors</td>
</tr>
<tr>
<td>400 volts</td>
<td>128 capacitors</td>
</tr>
</tbody>
</table>

**Fig. 3.2** Conditions for Accelerated Life Tests at Fixed Conditions
Fig. 3.3 Diagram of current leakage detection circuit.
HIGH VOLTAGE SOURCE.

OVEN AT HIGH TEMPERATURE.

+V+ CURRENT LEAKAGE DETECTION & CLOCK CIRCUITS.

Figure 3.4 Circuit for testing capacitors.
failure. The program LOOKCER is run. This program switches the first relay on, measures the d.c. resistance and displays the result on the screen. The relay is then switched off and the process is repeated for the next relay. A low reading for resistance displayed on the screen corresponds to the failed capacitor.

The programs CERAM* and LOOKCER are listed in Appendix 5.

3.3.1.2 Results from Step Stress Program

The Results from the Step Stress Program were stored on disc and analysed. The results were used to assess the relationship between relative voltage stress and times to failure and to look at the effect of temperature upon degradation.

The first thing that was noticed was that all failures were due to the same failure mode, the drop in insulation resistance from an effective open circuit to an effective closed circuit (open circuit $R \approx 1 \, \text{G}\Omega$, closed circuit $R \approx 10 \, \text{k}\Omega$).

The results from this step stress are laid out in tabular form in Figures 3.5 and 3.6. If the parallel resistance of a capacitor fell below a certain value, then it was considered to have failed. If a capacitor's a.c. parallel resistance fell below 150 kΩ it was classed as a failure. 50 kΩ and 10 kΩ thresholds were also considered producing the same results and conclusions [4]. (The failure level is arbitrary, and in a piece of equipment would depend
<table>
<thead>
<tr>
<th>No. Failures (⁄60)</th>
<th>Time (hours)</th>
<th>No. Steps</th>
<th>Non Acc. Time</th>
<th>% No. Failure Ranked</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<tr>
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<td>1,375</td>
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<tr>
<td>3</td>
<td>1,109</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<td>7</td>
<td>1,221</td>
<td>3</td>
<td>2,896</td>
<td>11.1</td>
</tr>
<tr>
<td>8</td>
<td>1,228</td>
<td>3</td>
<td>3,008</td>
<td>12.7</td>
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<tr>
<td>9</td>
<td>1,247</td>
<td>4</td>
<td>3,407</td>
<td>14.4</td>
</tr>
<tr>
<td>14</td>
<td>1,318</td>
<td>6</td>
<td>5,488</td>
<td>22.7</td>
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<tr>
<td>15</td>
<td>1,321</td>
<td>6</td>
<td>5,728</td>
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</tr>
<tr>
<td>16</td>
<td>1,341</td>
<td>7</td>
<td>6,441</td>
<td>26.0</td>
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<tr>
<td>16</td>
<td>1,365</td>
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<tr>
<td>17</td>
<td>1,390</td>
<td>9</td>
<td>9,162</td>
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</tr>
<tr>
<td>18</td>
<td>1,443</td>
<td>13</td>
<td>13,510</td>
<td>29.3</td>
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<td>18</td>
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<tr>
<td>18</td>
<td>1,453</td>
<td>14</td>
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<td></td>
</tr>
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</table>

Fig. 3.5 Results of Step Stressing, Voltage Increasing and Temperature Constant
<table>
<thead>
<tr>
<th>No. Failures</th>
<th>Time (hrs)</th>
<th>No. Steps</th>
<th>Time Real</th>
<th>% No. Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>0</td>
</tr>
<tr>
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<td>718</td>
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<tr>
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<td>1,082</td>
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<td>1,376</td>
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<td>1,592</td>
<td>6.13</td>
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<td>1,247</td>
<td>4</td>
<td>3,407</td>
<td>17.7</td>
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<td>37.6</td>
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<td>5,616</td>
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<td>1,341</td>
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<td>6,160</td>
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<td>6,928</td>
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<td>1,390</td>
<td>8</td>
<td>7,728</td>
<td>44.2</td>
</tr>
<tr>
<td>28</td>
<td>1,446</td>
<td>10</td>
<td>9,520</td>
<td>45.8</td>
</tr>
<tr>
<td>32</td>
<td>1,462</td>
<td>10</td>
<td>10,032</td>
<td>52.4</td>
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<tr>
<td>34</td>
<td>1,482</td>
<td>11</td>
<td>10,672</td>
<td>55.8</td>
</tr>
<tr>
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<td>1,505</td>
<td>11</td>
<td>11,465</td>
<td>67.4</td>
</tr>
<tr>
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<td>1,510</td>
<td>12</td>
<td>11,568</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>1,528</td>
<td>12</td>
<td>12,144</td>
<td>72.3</td>
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<td>46</td>
<td>1,534</td>
<td>12</td>
<td>12,272</td>
<td>75.6</td>
</tr>
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<td>47</td>
<td>1,559</td>
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<td>13,136</td>
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<td>13,712</td>
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<td>1,582</td>
<td>14</td>
<td>13,872</td>
<td>82.3</td>
</tr>
</tbody>
</table>

Fig. 3.6 Results from Step Stress with Voltage, Then Temperature
on the particular use of a component. This failure level will vary from use to use).

The results from the first part of the experiment, the step stressing, were used to investigate the Inverse Power Law which states:

"When the life of a system is an inverse power function of the accelerating stress variable, the inverse power law is commonly used. The characteristic life is given by:

\[
\eta(V) = \frac{1}{KV^n} \tag{1}
\]

where \( V \) is the accelerating stress and \( K \) and \( n \) are positive parameters characteristic of the material and test method."[5],[16]

From this equation we can say that the characteristic life at an accelerated voltage \( V_A \) will be given by

\[
\eta_A = \frac{1}{KV_A^n} \tag{2}
\]

and the characteristic life at the usual voltage stress will be given by

\[
\eta_U = \frac{1}{KV_u^n} \tag{3}
\]

Dividing equation (3) by equation (2) yields equation (4):
Using equation (4) the value of n is estimated graphically by plotting results of times to failure on Weibull [7] paper, see Figures 3.7 to 3.8. See Appendix 4 for a discussion on the Weibull distribution.

Figure 3.7 represents the times to failure for capacitors that were voltage step stressed at a constant temperature of 125°C. The times to failure are calculated assuming that the acceleration factor, n, (see equations 1 to 4) is equal to three. The graph is a reasonably straight line indicating that the acceleration factor of three is correct. An incorrect acceleration factor would bend the curve (upwards (n estimated too low) or downwards (n estimated too high)).

In Figure 3.8 an acceleration factor of three is again assumed. The graph again fits a straight line indicating the correct acceleration factor. Towards the top end of the graph it turns upwards. This corresponds to increasing temperature indicating that higher temperatures decrease characteristic lifetimes.

A detailed analysis of the results from phase 1 was carried out by Mr P. Crawley of STC Components, Gt. Yarmouth, whose conclusions were in accord with those above [8].
Weibull Plot for Ceramics, Voltage Step Stressing

Fig. 3.7 Weibull Plot for Ceramics, Voltage Step Stressing

cumulative per cent. failure

age at failure (hours)
Weibull Plot for Ceramics, Voltage then Temperature Step Stressing

Fig. 3.8 Weibull Plot for Ceramics, Voltage Then Temperature Step Stressing

cumulative percent failure

age at failure (hours)
3.3.1.3 Results from the Matrix Life Tests

After the step stress was completed, further Life Tests were conducted. These tests were to give more accurate times to failure. Multilayer Ceramic Capacitors similar to those used in the step stress were used. The only difference was that these capacitors were rated to 100 volts as opposed to 50 volts.

The capacitors were mounted on boards made of the asbestos substitute 'Superlux'. Each board held 128 capacitors. Groups of capacitors were then placed on test, 128 capacitors in each group, at different sets of conditions, see Figure 3.9.

<table>
<thead>
<tr>
<th></th>
<th>125°C</th>
<th>160°C</th>
<th>200°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 volts</td>
<td>128 units</td>
<td>128 units</td>
<td>128 units</td>
</tr>
<tr>
<td>400 volts</td>
<td>128 units</td>
<td>128 units</td>
<td>128 units</td>
</tr>
</tbody>
</table>

Fig. 3.9 Conditions for Life Testing Multilayer Ceramic Capacitors

The times to failure for each set of conditions are given in Figure 3.10 together with the cumulative number of failures.
<table>
<thead>
<tr>
<th>n</th>
<th>100 Volts</th>
<th></th>
<th></th>
<th>400 Volts</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>125°C</td>
<td>160°C</td>
<td>200°C</td>
<td>125°C</td>
<td>160°C</td>
<td>200°C</td>
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<td>1</td>
<td>265.0</td>
<td>67.8</td>
<td>7.6</td>
<td>0.45</td>
<td>1.0</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>1,036.5</td>
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<td>14.6</td>
<td>3.8</td>
<td>2.9</td>
<td>0.1</td>
</tr>
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<td>3.7</td>
<td>0.1</td>
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<tr>
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<td>5.5</td>
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<td>6.5</td>
<td>7.6</td>
<td>0.8</td>
<td></td>
</tr>
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<td>9.5</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
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<td>530.7</td>
<td>31.1</td>
<td>11.4</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>623.5</td>
<td>36.3</td>
<td>11.5</td>
<td>1.2</td>
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<td></td>
</tr>
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<td>43.9</td>
<td>12.1</td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>13.0</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>3.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td>3.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td>3.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All times to failure are in hours

Fig. 3.10 Times to Failure for Matrix Life Tests
All these results have been plotted on Weibull paper using ranked data [7]. From these results the characteristic life of the capacitors was estimated for each set of conditions. Arrhenius Plots were made by estimating the likely maximum and minimum characteristic lives from the Weibull graphs (Figures 3.11 to 3.18). From these graphs activation energies are estimated and the nature of the mechanisms causing failure are interpreted.

The likely maximum and minimum characteristic lives are shown in Figure 3.19, as estimated [7], the figure also includes the natural logarithms of these lifetimes.

From the Arrhenius Plots (Figures 3.17 and 3.18) it is possible to make an estimate of the activation energies. There appears to be more than one failure mechanism, (as discussed later in this section) but using the Arrhenius method of plotting failure rates or characteristic life against temperature (see Section 1.1.2) we can estimate the activation energy using the equation

\[ E_A = k \cdot \text{gradient} \]  \hspace{1cm} (5)

where \( k \) is Boltzman's constant = \( 8.625 \times 10^{-5} \) eV/K and gradient is the gradient of the graph \( E_A \) is in electron volts.

It is possible to plot a straight line through both sets of data which would correspond to thermal runaway and to have another
Weibull Plot for Ceramics at 100 Volts and 125 Celsius
Fig. 3.12 Weibull Plot for Ceramics at 100 Volts and 160 Celsius
Weibull Plot for Ceramics at 100 Volts and 200 Celsius
Weibull Plot for Ceramics at 400 Volts and 125 Celsius

Fig. 3.14 Weibull Plot for Ceramics at 400 Volts and 125 Celsius
Weibull Plot for Ceramics at 400 Volts and 160 Celsius

Fig. 3.15 Weibull Plot for Ceramics at 400 Volts and 160 Celsius

cumulative per cent. failure

age at failure (hours)
Weibull Plot for Ceramics at 400 Volts and 200 Celsius
Arrhenius Plot for Ceramics at 100 Volt Bias
Arrhenius Plot for Ceramics at 400 Volt Bias
<table>
<thead>
<tr>
<th>Temp. 125 (°C)</th>
<th>Voltage (Volts)</th>
<th>100</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100,000-1,000,000 hrs.</td>
<td>8,000-90,000 hrs.</td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>2,400-9,000</td>
<td>165-800 hrs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.783-9.104</td>
<td>5.105-6.684</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>180-2,400</td>
<td>38-1,200 hrs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.192-7.783</td>
<td>3.637-7.090</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3.19 Likely Maximum and Minimum Lifetimes for Multilayer Ceramic Capacitors Under Different Conditions
(lower figures are natural logarithms of the times)
line for the avalanche breakdown on the 400 volt graph. This gives an estimate for the thermal runaway activation energy of 1.0 eV. The figure of 0.43 eV for the avalanche breakdown can not be regarded as being accurate due to the wide ranges of characteristic lives at higher temperatures. These values compare well with those obtained by L. C. Burton [8] and B. S. Rawal and N. H. Chan [9] in their own respective studies on multilayer ceramic capacitors.

The Weibull Plots, Figures 3.11 to 3.16, show two distinct failure patterns for the two different voltage stresses, with temperature affecting the times to failure rather than failure patterns. These indicates that for the 100 volt failures there is one failure mechanism. For the 400 volt failures there is more than one failure mechanism. This is borne out by the Arrhenius Plots, see Figures 3.17 and 3.18, the 100 volt failures produce a reasonably straight line, the 400 volt failures produce an obviously not straight line. The effect of high voltage stressing has been more severe than high temperature stressing.

It is known that degradation of insulation resistance is the primary failure concern for multilayer ceramic capacitors [10]. This has been observed in the experiments at Loughborough.

At high voltages the electric field across the dielectric is very high (~ $10^6$ volts/meter) [11]. There are two likely failure mechanisms, thermal runaway and avalanche breakdown [11]. Avalanche breakdown is prevalent at high field strengths. The dielectric for
an X7R, 100 nF, 100V capacitor was approximately $4 \times 10^5$ m or 40 μm thick. This means that a 400 volt bias produces a field of intensity of approximately $10 \times 10^6$ V/m.

At lower voltages there appears to be only one failure mechanism, this could be thermal runaway.

The conduction mechanisms for barium titanate ceramics are beyond the scope of these experiments. However, previous work gives some clue as to the mechanism. Rawal and Chan [9] suggest that conduction is by electrons rather than ions. The likely current type is space charge limited emission for the degrading ceramic [10]. The likely mode of electron transport is small polaron hopping [10], [11]. Schottky currents or Poole-Frenkel currents are not considered likely current mechanisms [12].

3.3.1.4 Conclusions of Ceramic Capacitor Experiment

From the results obtained there are several important conclusions.

(1) The voltage acceleration factor is approximately three.
(2) Failure mechanisms depend on the applied voltage stress.
(3) Screen printed ceramics do not appear to differ significantly from other ceramics.

As a result of this work a paper has been written to be presented at CARTS-EUROPE in October 1987 at Brighton, see Appendix 6.
3.3.2 Optocouplers

Accelerated life tests are being undertaken on optocouplers (or optoisolators as they are otherwise known) at Loughborough University of Technology. This work is the result of pilot studies on optocouplers by Dr V. Williams at the University [13]. The optocouplers being studied are type CNY65 manufactured by Telefunken of Denmark.

3.3.2.1 Work Being Carried Out by the Danish Academy

The Danish Academy of Engineering, under Professor Jan Møltoft, are conducting a parallel study on optocouplers [14] which are individually identified, have been placed in equipments which are in use. Any failures of these optocouplers will be noted. It will therefore be possible to produce a picture of optocoupler reliability in commercial use.

The results from the work carried out by the Danish Academy of Engineering will be compared with the results from Loughborough University of Technology, and this will enable the accelerated life tests to be verified.

3.3.2.2 Reverse Recovery Times of Optocouplers

An optocoupler consists of a light emitting diode (L.E.D.) optically coupled to a photosensitive transistor. The reverse
recovery time of a diode is a measure of the time that a diode will conduct if it has a reverse bias applied suddenly. The diode must have been in a steady state forward biased condition previously [15].

It has been suggested [15] by T. Takahashi et al. that the reverse recovery time of an optocoupler can be used as a screening method for removing bad optocouplers. With this in mind, reverse recovery times of optocouplers have been measured, using a reverse recovery meter built at Loughborough University of Technology. If it is possible to use reverse recovery times as a non-destructive screening method, then those optocouplers that fail first will correspond to those with the unusual reverse recovery times.

The accelerated life tests on optocouplers will be able to investigate whether it is possible to use this screening process effectively.

3.3.2.3 Accelerated Life Testing of Optocouplers

Optocouplers are being accelerated under ten different sets of conditions (two different L.E.D. currents and five different temperatures), see Figure 3.20.

The optocouplers, with 96 at each set of conditions, are aged in ovens which regulate to the required temperature. Periodically the optocouplers are removed from the ovens and allowed to cool to
<table>
<thead>
<tr>
<th>20 mA</th>
<th>20 mA</th>
<th>20 mA</th>
<th>20 mA</th>
<th>20 mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C</td>
<td>50°C</td>
<td>70°C</td>
<td>85°C</td>
<td>100°C</td>
</tr>
<tr>
<td>F</td>
<td>G</td>
<td>H</td>
<td>I</td>
<td>J</td>
</tr>
<tr>
<td>8 mA</td>
<td>8 mA</td>
<td>8 mA</td>
<td>8 mA</td>
<td>8 mA</td>
</tr>
<tr>
<td>25°C</td>
<td>50°C</td>
<td>70°C</td>
<td>85°C</td>
<td>100°C</td>
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<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
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Fig. 3.20 Table Showing Different Conditions for Accelerated Life Testing of Optocouplers
room temperature. They then each have 20 mA applied through the L.E.D. and 6.5 volts across the transistor. Under these conditions the following measurements are made.

\[ V_F \] the forward voltage across the L.E.D. for a fixed diode current

CTR the ratio of current passed by the transistor for a given diode current

\[ V_{SAT} \] the saturation voltage of the phototransistor for a given diode current.

The measurements are made initially before the tests begin and then at regular intervals, see Figure 3.21.

Measurements are taken more regularly at the beginning of the experiment because this will enable the times to failure of early failures to be calculated.

The optocouplers are mounted upon printed circuit boards. Each board holds 32 optocouplers and connections for applying bias to the optocouplers, and 34 way sockets which connect to the switching boxes for selecting specific optocouplers, see Figure 3.22.
<table>
<thead>
<tr>
<th>Measurement Number</th>
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</tr>
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<tr>
<td>13</td>
<td>200</td>
</tr>
<tr>
<td>14</td>
<td>350</td>
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</table>

Fig. 3.21 Table of Measurement Times for Optocouplers
Fig. 3.22 Photograph of a Printed Circuit Board Holding Optocouplers for Accelerated Life Testing

In addition to the four 34 way d.i.l. sockets (female) which connect to the relays, there is another 34 way socket which is used to common all the connections to it during measurement. There are also five 4 mm banana plugs. Two provide positive and negative terminals for biasing the thirty-two optocouplers in series during the accelerated life tests. The remaining three banana plugs provide connections to the optocoupler's, anode, collector and ground terminals during measurements.

All the measurements are made using the Data Logger connected to a Solatron 7065 Digital Voltmeter. In order to measure current,
as for measuring current transfer ratio and saturation voltages the voltage drop across a known resistance is measured. Current is then calculated using Ohm’s Law.

When using the Data Logger to take the measurements of forward voltage, current transfer ratio and saturation voltage, the optocouplers are connected to the relays as in Figure 3.23.

In order to measure forward voltages of the optocouplers relays 1 and 2 are closed. 20 mA is passed from the anode through the diode to ground, the voltage from anode to ground is measured and recorded as the forward voltage of that optocoupler. Relays 1 and 2 are opened and the process is repeated for the next optocoupler.

Unfortunately, owing to the complicated nature of the printed circuit boards which hold the optocouplers, it was not possible to have consecutive relays for consecutive optocouplers, and so the relay combinations are as in Figure 3.24.

In order to measure current transfer ratio the current is measured as it passes along the connection to the collector, a bias of 6.5 volts being applied between collector and ground. This value is converted to milliamps and divided by 20 (the current through the diode is 20 mA) to give a result for current transfer ratio.

For measurements of saturation voltage a similar procedure takes place. However the collector current is measured for voltages
Fig. 3.23  Schematic diagram of relay connections when measuring optocouplers.
<table>
<thead>
<tr>
<th>Optocoupler</th>
<th>Relay Combinations</th>
<th>Optocoupler</th>
<th>Relay Combinations</th>
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<td>15</td>
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<td>31</td>
<td>55 56</td>
</tr>
<tr>
<td>16</td>
<td>32 41</td>
<td>32</td>
<td>64 9</td>
</tr>
</tbody>
</table>

Fig. 3.24 Relay Combinations to Select Optocouplers
across the collector to ground, starting at 0.3 volts and increasing in steps of 0.2 volts. The gradient of a graph of current (in mA) versus voltage (volts) is considered, and where the gradient would be 5 this is considered to be the saturation voltage. The actual point where the gradient equals five is calculated by considering the gradient on either side and using the Newton-Ralphson method of approximation, see Figures 3.25 and 3.26.

The results for forward voltage \( V_F \) are all 4% higher for the Data Logger. This is accounted for by voltage drop across relays and measurement leads. The figure of 4% difference has remained constant so far through the experiment (see Figure 3.27).

The differences in current transfer ratio are accountable to the fact that when a voltage is applied across the optocoupler's transistor it heats up. This means the impedance changes. With the Data Logger measurements are taken exactly at the same time after the voltage is applied. This is not possible when measuring by hand. Considering this difficulty the results for current transfer ratio are good.

3.3.2.5 Future Work with Optocouplers

Fourteen sets of measurements are planned to be taken for the optocouplers undergoing accelerated life tests. This corresponds to a period of about two years. Future work will include continuing these measurements.
Gradient $n = \frac{I_n - I_{n-1}}{V_n - V_{n-1}}$

Fig. 3.25 Calculating Saturation Voltage (1)

Fig. 3.26 Calculating Saturation Voltage (2)
<table>
<thead>
<tr>
<th>$V_F$ (V)</th>
<th>CTR</th>
<th>$V_P$ (V)</th>
<th>CTR</th>
</tr>
</thead>
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<tr>
<td>1.170</td>
<td>2.4</td>
<td>1.2178</td>
<td>2.025</td>
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<tr>
<td>1.172</td>
<td>2.9</td>
<td>1.2181</td>
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<td>1.168</td>
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<tr>
<td>1.177</td>
<td>3.0</td>
<td>1.2213</td>
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<td>3.5</td>
<td>1.2092</td>
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<td>1.2207</td>
<td>1.726</td>
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<td>1.169</td>
<td>3.2</td>
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<td>2.482</td>
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<tr>
<td>1.171</td>
<td>3.7</td>
<td>1.2175</td>
<td>2.757</td>
</tr>
</tbody>
</table>

Fig. 3.27 Results from Data Logger Compared with Same Measurements Taken by Hand
The IBM PC AT is being used to archive all the information in two forms. Firstly each set of measurements is stored as a file.

e.g. AFOR.003

this means measurements of forward voltage upon the A block of optocouplers (8 mA, 25°C acceleration conditions), third set of readings (i.e. after 1½ day aging period).

Secondly a file is also being kept for each optocoupler's measurements, which records how a certain parameter will vary with time.

e.g. C58.CTR

this records the values of current transfer ratio that were measured and their respective times under accelerated conditions in hours, for the 58th optocoupler of the C block (8 mA, 70°C acceleration conditions).

Analysis of results will be undertaken using this archive of information and results can be compared with those achieved by Dr V. Williams [4]. It will be possible to compare accelerated life test results withs results from the field, from Denmark [5].

It may be possible to develop other models for optocoupler degradation. It is anticipated that specialist statistical advice may be needed for the correct analysis of such a large amount of
data. (Approximately 40,000 separate results when all measurements are taken).

3.3.3 Other Components

The Data Logger is currently (as of February 1987) being used to take measurements for other components. The Component Technology Group at Loughborough is conducting research on thick film resistors and surface mount technology. The Data Logger is used by other members of the group to take measurements on these components, using the equipment and ideas that have been detailed here.

3.4 SUMMARY

The Data Logger has been designed to help make measurements on components that have been shown to be troublemakers. These troublemakers may be spotted using the component data base at Loughborough.

Many different components can be measured using the Data Logger. The Data Logger is best measuring simple components.

The Data Logger has been used to take measurements for an experiment on accelerated life testing of ceramic capacitors. The results from this experiment has yielded information about the behaviour of ceramic capacitors and shown that the Data Logger is capable of being used as a research tool. This has lead to it being used for another bigger accelerated life testing experiment on opto-couplers. The Data Logger is now also used by other members of the Component Technology Research Group.
3.5 REFERENCES


4. CONCLUSIONS

4.1 DESIGN

The Data Logger was designed to measure discrete electronic components, to be used in a laboratory for research work. It has met these needs by drawing on available research tools and instruments. They have been combined together to produce a data logger. A trolley has been built to carry the hardware, and the switches were purchased to be used specifically with the Data Logger. The trolley provides space to hold the hardware, a flat top for a working space, and it is on castors so that it may be wheeled about the laboratory.

The Data Logger is a very flexible system. It can be used for a variety of applications (see section 4.3). Instruments which are IEEE compatible can be easily added or removed, as and when necessary.

The Data Logger runs from a 240 volt a.c. supply which is filtered from the mains to protect the sensitive computer and measuring equipment from surges and sudden variations in the supply. The IEEE-488 interface is used for the control of instruments. The interface is a fixed standard which is recognised worldwide and used extensively [1].

The IEEE interface and the use of a trolley make it very easy to tailor the Data Logger to a particular requirement as it is easy to change instruments around.
4.2 Software

The software for the Data Logger has been written in Basic.

Basic was used for two reasons:

(i) It is easy to use as a development language, being very easy to alter and run a program and immediately alter again and re-run.

(ii) It was well understood by the author.

Unfortunately, using Basic means that a program will not run very fast. It is also very important that the software is well commented, otherwise it becomes difficult to understand. A large program written in Basic tends to be very difficult to follow and to write without making mistakes. It is also laborious to store the information from the Data Logger on an Apple format disc and then to have to transfer it to the IBM PC for analysis.

In order to solve these problems an IBM compatible personal computer is going to replace the Apple. It will use Pascal as a programming language. This means that the data stored by the Data Logger will be stored in IBM format. Pascal is a better language to use for an established system as it uses procedures. Procedures are
like miniature programs. This suits the idea of having a library very well.

Apart from this the software has worked well. Measurement programs and simple analysis programs have been written using the library of software to cover several different applications of the Data Logger. This approach has shown itself to be simple, easy to use and can be applied to many different situations.

4.3 COMPONENT APPLICATION

The Data Logger has been used with a variety of different electronic components. It has worked well with all of them. Clearly it is best suited to taking simple measurements on large numbers of components that have just a few terminals, otherwise switching arrangements can become very complicated. It is not suited to very specialised measurements, for instance measurements at very high frequencies.

If a data logger were needed which was for a very specific purpose, then it would be possible to use the architecture and ideas incorporated into this Data Logger but using appropriate instruments and tailoring the necessary fine details.

The Data Logger has shown itself to be effective at laboratory measurements of large numbers of components. In this respect it does what was intended of it.
4.4 IMPROVEMENTS

Following from the initial design and development of the Data Logger, some improvements have been planned for the Data Logger.

The two major areas for improvement of the Data Logger are:

(i) Replacing the Apple IIe with a more powerful computer capable of being more directly compatible with the IBM PCAT.

(ii) Using a programming language other than Basic which would be faster and more efficient.

In order to achieve these aims an Advance 88d personal computer with an IEEE card is to replace the Apple IIe. The Advance is directly compatible with the IBM PCAT. Instead of using Basic as a control language Turbo Pascal will be used. Turbo Pascal is a compiled language and runs at a much faster pace. It also uses procedures which are called to execute different tasks. This makes it an ideal language for using with a library of existing software, especially in a mature system. The basic language has been useful to develop the Data Logger. Now this has been achieved a more sophisticated language can be used.

In terms of hardware there are no immediate improvements to be made. However, if measurements were needed that required a high
degree of accuracy then a set of very low impedance switches could be useful. Apart from that there is little needed.

4.5 SUMMARY

The Data Logger has been assembled onto a trolley. It has used instruments that are all readily available, and they are all controlled to act as a Data Logger by the Apple IIe computer. Information is conveyed to various parts of the Data Logger over the IEEE-488 interface. The machine is programmed using the Basic computer language.

The Data Logger has been designed to measure discrete electronic components. It has been shown to be capable of this. It is most suitable for taking large numbers of very simple repetitive measurements.

An experiment on life testing of ceramic capacitors has taken place. This experiment used the Data Logger to locate failures. The experiment has provided information on those types of ceramic capacitors. It has also shown that the Data Logger is a useful research tool which has a practical use. The Data Logger is now being used for a larger experiment investigating the degradation of optocouplers.

It has been found that the Data Logger works effectively. The Data Logger is going to be improved. This will be achieved by
replacing the Apple IIe with an IBM PC compatible computer, and by implementing a library of software which will need to be programmed in Turbo Pascal. This will mean that the Data Logger will work faster and be directly IBM compatible, which will speed up the analysis of results.
4.6 REFERENCES

APPENDIX 1

Automation Data Loggers Survey

Automation, pp. 36-43, October 1984.
# Automation Data Loggers Survey

<table>
<thead>
<tr>
<th><strong>Software</strong></th>
<th><strong>Function</strong></th>
<th><strong>BERMCO Advanced Instrumentation HRT 14</strong></th>
<th><strong>BERMCO Advanced Instrumentation KET 512</strong></th>
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<th><strong>BERMCO Advanced Data Loggers</strong></th>
<th><strong>BERMCO Data Logger Systems</strong></th>
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<td>x</td>
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<th><strong>Fault finding</strong></th>
<th><strong>System has self check mode or diagnosis programme</strong></th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
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</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td><strong>Cost of the basic system including all modules to store basic inputs, display, and relay via a RS232C interface</strong></td>
<td>£6000</td>
<td>£1500+</td>
<td>£2500+</td>
<td>£500+</td>
<td>£7152</td>
<td>£10391+</td>
<td>£2070</td>
<td>£1100</td>
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<td>Cost of input channel block (32)</td>
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<td>e</td>
<td>e</td>
<td>e</td>
<td>e</td>
<td>e</td>
<td>e</td>
<td>£208+ &amp; 18ch</td>
<td>£208+</td>
</tr>
</tbody>
</table>

| **Delivery** | **Delivery time for basic system (33)** | 0-6 wks | 2-6 wks | 2-6 wks | 6 wks | 6 wks | 6 wks | 3 wks |

| **Enquiries** | **For more information enter** | 500 | 501 | 502 | 503 | 504 | 505+ | 506+ | 507+ |

111
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<td>C000+</td>
<td>Aurlea (Kaye Instruments)</td>
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<td>C000</td>
<td>Aurlea (Daytronic)</td>
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<td>C000</td>
<td>Canberra Imaca 50</td>
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<td>C000</td>
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<td>C000</td>
<td>Control &amp; Readout CRA 703</td>
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<td>C000</td>
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<td>C000</td>
<td>Data &amp; Research Services FDL7</td>
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<tr>
<td>----------------------</td>
<td>---------------</td>
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<td>Software</td>
<td></td>
</tr>
<tr>
<td>Logger is pre-programmed with essential software supplied (Key part 1)</td>
<td>✓</td>
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<tr>
<td>Programming language used by the logger (2)</td>
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<tr>
<td>Logger is totally programmable by the user</td>
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<td>Data logging &amp; analysis software is supplied (4)</td>
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<td>Analogous inputs</td>
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<td>12/16</td>
</tr>
<tr>
<td>Logger inputs</td>
<td>Basic number of analogue inputs (6)</td>
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<tr>
<td>Basic number of digital inputs (7)</td>
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<tr>
<td>Expansion inputs</td>
<td>How many expansion/slave units can be driven from the basic system (8)</td>
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<tr>
<td>Strain gauges? (12)</td>
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</tr>
<tr>
<td>Pulse counter inputs (15)</td>
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</tr>
<tr>
<td>Flow meters (16)</td>
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<tr>
<td>Status (17)</td>
<td></td>
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<tr>
<td>Event (18)</td>
<td></td>
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<td>BCD (19)</td>
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<td>Technical specification (0)</td>
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<tr>
<td>Accuracy of measurement (percent)</td>
<td>0.1%</td>
</tr>
<tr>
<td>What speed of logging and recording can be achieved (channels per second)</td>
<td></td>
</tr>
<tr>
<td>Recording medium</td>
<td>Type of magnetic tape/disc used (22)</td>
</tr>
<tr>
<td>Separate reader or transfer unit available with RS232C interface</td>
<td></td>
</tr>
<tr>
<td>System uses solid state recording</td>
<td></td>
</tr>
<tr>
<td>Number of raw/processed readings that can be recorded using solid state</td>
<td></td>
</tr>
<tr>
<td>How many readings can be recorded with optional memory cards</td>
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<td>Interfaces</td>
<td>Logger interfaces (27)</td>
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<td>Number of control outputs (28)</td>
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</tr>
<tr>
<td>Number of outputs that can be used with the logger when using expansion/slave units (29)</td>
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<tr>
<td>Fault finding</td>
<td>System has self check mode or diagnosis programme</td>
</tr>
<tr>
<td>Cost</td>
<td>Cost of the basic system including all modules to store basic inputs, display, and relay via a RS232C interface</td>
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<tr>
<td>Cost of input channel block (22)</td>
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<td>Delivery</td>
<td>Delivery time for basic system (33)</td>
</tr>
<tr>
<td>Enquiries</td>
<td>For more information enter</td>
</tr>
<tr>
<td>Model</td>
<td>Year</td>
</tr>
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<td>Microdata M1880</td>
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<td>Software</td>
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<td>---------------------------------------------------------------------</td>
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<table>
<thead>
<tr>
<th>Analogue</th>
<th>How many bits each system resolves (A)</th>
<th>Range (B)</th>
<th>Resolution (C)</th>
<th>Accuracy (D)</th>
<th>How many auxillary analogue inputs can be driven from the basic system (8)</th>
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<th>Transducers/inputs that can be connected directly to the sysrem</th>
<th>Number of types of thermocouple including cold junction compensation &amp; linearisation (10)</th>
<th>RTDs including linearisation? (11)</th>
<th>Strain gauges? (12)</th>
<th>Pulse counter inputs (15)</th>
<th>Flow meters (18)</th>
<th>Status (17)</th>
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<td></td>
<td>5</td>
<td>2</td>
<td>a</td>
<td>—</td>
<td>b</td>
<td>a</td>
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<th>Accuracy of measurement (A)</th>
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<th>Separate reader or transfer unit available with RS232C interface</th>
<th>System uses solid state recording</th>
<th>Number of raw/processed readings that can be recorded using solid state</th>
<th>How many readings can be recorded with optional memory cards</th>
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<tr>
<td></td>
<td>e</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td></td>
<td>f</td>
<td>—</td>
<td>○</td>
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<td>h</td>
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<td>—</td>
<td>—</td>
<td>60k</td>
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<th>Interfaces</th>
<th>Number of control outputs (28)</th>
<th>Number of outputs that can be used with the logger when using expansion slave units (19)</th>
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<td>4096</td>
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<table>
<thead>
<tr>
<th>Fault finding</th>
<th>System has self check mode or diagnosis programme</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>●</td>
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</table>

<table>
<thead>
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<th>Cost</th>
<th>Cost of the basic system including all modules in standard basic inputs, display and relay via a RS232C interface (22)</th>
<th>Cost of input channel block (32)</th>
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<td>12 wks</td>
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<tr>
<td></td>
<td>6 wks</td>
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<td></td>
<td>4 wks</td>
</tr>
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<td></td>
<td>8 wks</td>
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<td>4 wks</td>
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<td></td>
<td>18 wks</td>
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<tr>
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<td>6-8 wks</td>
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<th>Enquiries</th>
<th>For more information enter...</th>
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# Automation Data Loggers Survey

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<th>Software</th>
<th>Logger is preprogrammed with essential software supplied (Key part 1)</th>
<th>Programming language used by the logger (2)</th>
<th>Logger is totally programmable by the user</th>
<th>Data logging &amp; analysis software is supplied (4)</th>
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<tbody>
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<td></td>
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<tr>
<td>Analog</td>
<td>How many bits can the system resolve</td>
<td>Basic number of analogue inputs (6)</td>
<td>Basic number of digital inputs (7)</td>
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<tr>
<td>Logger</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inputs</td>
<td></td>
<td>Basic number of analogue inputs (6)</td>
<td>Basic number of digital inputs (7)</td>
<td></td>
</tr>
<tr>
<td>Exp.</td>
<td>How many expansion/slide units can be driven from the basic system (8)</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Trans.</td>
<td>Number of types of thermocouples including cold junction compensation &amp; linearisation (10)</td>
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<td></td>
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</tr>
<tr>
<td>Interfaces</td>
<td>Type of magnetic tape/disc used (22)</td>
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</tr>
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<td></td>
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<td></td>
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<tr>
<td>Fault</td>
<td>System has self check mode or diagnosis programme</td>
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<tr>
<td>Finding</td>
<td></td>
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<tr>
<td>Cost</td>
<td>Cost of the basic system including all modules to store basic inputs, display, and relay via a RS232C interface</td>
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<tr>
<td>Delivery</td>
<td>Delivery time for basic system (33)</td>
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<tr>
<td>Enquiries</td>
<td>For more information enter</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DATA LOGGER SURVEY EXPLANATORY KEY

1. Logger preprogrammed with essential software supplied:
   a. Optional
   b. Essential

2. Programming language used by the logger:
   a. ASCII
   b. assembler
   c. FORTRAN
   d. Pascal
   e. Mcneal
   f. Machine code
   g. Menu driven
   h. Micro VERA
   i. Micro code
   j. Microsoft
   k. PLM
   l. 1ASM60
   m. Push button
   n. Other
   o. Digital

3. Is data logging & analysis software supplied:
   a. Optional
   b. Essential

4. Total number of analogue inputs in the basic system:
   a. As required
   b. Analogue plus digital

5. Total number of digital inputs in the basic system:
   a. As required
   b. Analogue plus digital

6. How many expansion inputs are available from the basic system?
   a. Unlimited
   b. Limited

7. How far can the expansion unit be from the basic system?
   a. Not answered

8. Number of types of thermocouples including cold junction compensation & linearisation:
   a. Plus customized fits
   b. As required

9. RTDs including linearisation:
   a. Any

10. Number of channels:
    a. As required

11. Flowmeters:
    a. Available to special order
    b. As required

12. Strain gauges including creep resistance:
    a. To special order
    b. As required

13. Pulse counter inputs:
    a. Available to special order
    b. As required

14. Frequency counter inputs:
    a. Available to special order
    b. As required

15. Flowmeters:
    a. Available to special order
    b. As required

16. Event:
    a. Available to special order
    b. As required

17. BCD:
    a. Available to special order

18. Magnetic tape devices:
    a. Audio cassette
    b. FM/AM
    c. CD
    d. DC100A
    e. Other
    f. External

19. Delivery time for basic system:
    a. Variies

20. Loggers interfaced with computer:
    a. Serial or parallel
    b. IBM bus

21. Number of outputs:
    a. Expandable
    b. As required

22. Type of analog output:
    a. Optional

23. Delivery time for basic system:
    a. Expandable
    b. As required

24. User specified

25. ABBREVIATIONS:
   • Yes
   • No/not applicable
   • Optional
   • Digital
   • Analogue
   • Card
   • Mod
   • Per Card
   • Per Module
   • Per Channel

Reading, Berks
Te1: 0734 8564
Solentronic
124 Victoria Rd
Farnborough, Hants
Tel: 0252 544433
STC
West Rd
Harlow, Essex
Te1: 0279 2522
Southern
13 De Vere Parade
Horham, West Sussex
Tel: 0403 51366
Systemic Micro
Index Hse
Ascot, Berks
Tel: 0900 23377
Syron Donner
St Mary’s Rd.
Leamington Spa
Warwicks
Te1: 0206 3541
Tequipment
Bonsall St
Long Eaton, Nottingham
Tel: 0562 721695
Teledyne
Doman Rd
York Town Ind. Estate
Camberley, Surrey
Tel: 0276 26517
Wellman Microtechnology
Robert Hse
Cornwall Rd
Warley, West Midlands
Tel: 021 665 2706

ABBREVIATIONS:
• Yes
• No/not applicable
• Optional
• Digital
• Analogue
• Per Card
• Per Module
• Per Channel
APPENDIX 2

GENERIC DESCRIPTION OF COMPONENTS

CAPACITORS

Aluminium, foil
Aluminium foil, solid electrolyte
Aluminium, sintered, solid electrolyte
Tantalum, foil
Tantalum, sintered, solid electrolyte
Tantalum, sintered, liquid electrolyte

Mica, metallised
Mica, foil
Mica, button

Ceramic multilayer
Ceramic disc
Ceramic barrier layer

Glass

Paper, foil
Paper, metallised
Paper, foil and plastics
Paper, metallised and plastics

119
Polystyrene, foil
Polyester (PTP), foil
Polyester (PTP), metallised
Polycarbonate, foil
Polycarbonate, metallised
Polypropylene, foil
Polypropylene, metallised

(variable)
Tuning/Trimmer
Preset

RESISTORS

(a) FIXED
Carbon
Carbon film
Carbon ceramic

Metal Oxide

Wirewound
Metal foil
Metal film

Thick film
Conducting plastic
Cermet thin film

Tantalum nitride film
Networks of thick film resistors
Networks of thin film resistors

(b) VARIABLE
Carbon
Carbon film

Metal oxide

Wirewound
Metal foil
Metal film

Thick film
Conducting plastic

(c) NON LINEAR
Thermistors (-ve temp. coeff.)
Thermistors (+ve temp. coeff.)
Varistors
Strain gauges
Pressure transducers

TRANSFORMERS

Transformers
Air cored transformers
Pulse transformers
INDUCTORS

Air cored inductor
Loaded inductor

PASSIVE MICROWAVE DEVICES

Wave guides ) TRANSMISSION
) )
Strip lines ) LINES
) )
Micro strip )

Couplers

Attenuators

Isolators ) )
) )
Circulators ) FERRITES
) )
Phase shifters )

Filters

Cavities

Microwave switches

CONNECTORS

(non-permanent)

Rectangular

Edge
RELAYS

Coil activated
Coil activated/mercury wetted
Reed

SWITCHES

Push button
Rocker
Keyboard
Rotary
Proximity

DISCRETE SEMICONDUCTORS

(a) DIODES

pn Junction
Varactors
Avalanche
Tunnel
Impatt
Shottkey barrier
Gunn
PIN
(b) TRANSMITORS

Bipolar
JFET
MOSFET enhancement
MOSFET depletion
CCD
MESFET

(c) OPTOELECTRONIC DEVICES

Photosensitive diodes
L.E.Ds
Displays
Optoisolators

INTEGRATED CIRCUITS
To be classified in the following 5 categories

(a) BIPOLAR
This group to contain all TTL, DTL, ECL and TIL devices

(b) MOS
To include all metal oxide semiconductor microcircuits which includes NMOS, CMOS and MNOS fabricated on various substrates such as sapphire, polycrystalline or single crystal silicon.

(c) BIPOLAR/MOS
To include combinations (if any) of both groupings
(d) **JFET**

To include any JFET Logic circuits

(e) **MESFET**

To include any GaAs microcircuit devices

**HYBRID SUBSYSTEMS**

All hybrid subsystems
Reliability

The ability of an item to perform a required function under stated conditions for a stated period of time.

Redundancy

The existence of more than one means for accomplishing a given function. Each means of accomplishing the function need not necessarily be identical.

Failure

The termination of the ability of an item to perform a required function.

Observed Failure Rate

For a stated period in the life of an item, the ratio of the total number of failures in a sample to the cumulative observed time in that sample. The observed failure rate is associated with particular and stated time intervals (or summation of intervals) in the life of an item, and under stated conditions.

Observed Mean Time to Failure

For a stated period in the life of an item, the ratio of the cumulative time for a sample to the total number of failures in the sample during the period under stated conditions.
APPENDIX 4

THE WEIBULL DISTRIBUTION AND WEIBULL ANALYSIS

The Weibull distribution was developed by the Swedish scientist Waloddi Weibull who used it to describe the breaking strength of materials and the life properties of ball bearings [1]. He published papers on its application in the 1940's and 1950's [2]. The distribution is used widely in reliability as it is suitable for modelling to a variety of situations involving catastrophic failures [3].

A.4.1. Statistical Basis of the Distribution

The Weibull distribution function is described in terms of the reliability function as:

\[ R(t) = 1 - F(t) = e^{-\left(\frac{t - t_o}{\eta - t_o}\right)^\beta} \]  

(1)

where

- \( F(t) \) : the cumulative distribution function
- \( \beta \) : the shape parameter
- \( \eta \) : the characteristic lifetime
- \( t_o \) : the time location parameter
- \( t \) : time
This expression can be transformed into the two parameter Weibull distribution by using the transformation \( t' = t - t_0 \), giving:

\[
R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}
\]

and

\[
F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}
\]  

Differentiating (3) we get the probability density function, \( f(t) \).

\[
f(t) = \frac{\beta}{\eta} \left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}}
\]

and the hazard rate, \( h(t) \) is

\[
h(t) = \frac{\beta}{\eta} \left(\frac{t}{\eta}\right)^{\beta-1}
\]

Manipulating (2) we get

\[
\ln\ln\left[\frac{1}{1 - F(t)}\right] = \beta \ln(t) - \beta \ln \eta
\]

If the lifetimes are Weibull distributed then plotting the results on Weibull paper, where the ordinates are scaled in accordance with (6), will yield a straight line. Comparing (6) with the equation

\[
\eta = mx + c
\]
we can see that the gradient is equivalent to $\beta$ and that $\eta$ corresponds to the time $t$ for when $F(t) = 62.3\%$.

In lifetesting the lifetimes of components are measured and a cumulative distribution is formulated. It is important that the data is ranked (1) in order to compare the sample of results with the whole population. This is achieved using the median rank formula which states:

$$\hat{F}(t) = \frac{i - 0.3}{n + 0.4} \times 100\%$$

where $\hat{F}(t)$: best estimate of $F(t)$ for the whole population

$i$ : rank of component

$n$ : total size of sample

A.4.2 Two Examples of the Use of the Weibull Distribution

Two examples are used here to illustrate how the Weibull distribution can be used to estimate characteristic lifetimes and to interpret these graphs. Both examples are hypothetical but typical of results from lifetesting.

Example 1

In this example 20 components are tested and times to failure (t.t.f.) are recorded as in Figure A.4.1.
The rank order is calculated from equation (8). These results are then plotted on Weibull paper, Figure A.4.2. From the graph in Figure A.4.2 we can draw a straight line through the points plotted, this indicates the data is Weibull distributed. It is now possible to estimate $\eta$, the characteristic life of these components and $\beta$ the Weibull shape parameter.

The characteristic lifetime is estimated by extrapolating the line drawn through the data points so that it is possible to estimate the age at failure for a 62.9% cumulative failure, this age is called the characteristic life $\eta$. For these components $\eta = 900$ hours.

The Weibull shape parameter $\beta$, which determines the shape of the Weibull curve (see equations (1) and (2)), is estimated by calculating the gradient of the graph. On some graph paper there is an estimation point. A tangent to the line through the data is drawn.
<table>
<thead>
<tr>
<th>Test Number</th>
<th>Article and Source</th>
<th>Sample Size</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Type of Test</td>
<td>Shape</td>
<td>β</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Characteristic Life</td>
<td>γ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum Life</td>
<td></td>
</tr>
</tbody>
</table>

Fig. A4.2 Weibull Plot of Results from Lifetest on 20 Components
which passes through the estimation point. \( \beta \) is read off a scale.

For these components \( \beta \approx 0.9 \).

Example 2.

In this example 100 components are tested and times to failure are recorded as in Figure A.4.3. Once again the rank order is calculated from equation (8) and the results are then plotted on Weibull paper, Figure A.4.4.

When the data is plotted it is immediately apparent that the data does not easily fit to a single straight line. This is because there is more than one distribution within the data. (For a classic example of this see 'Behind the "Bathtub" Curve, a New Model and Its Consequences' by J. Møltoft [4]).

<table>
<thead>
<tr>
<th>n</th>
<th>t.t.f. (hours)</th>
<th>Rank Order (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0.697</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>1.69</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>2.69</td>
</tr>
<tr>
<td>4</td>
<td>47</td>
<td>3.68</td>
</tr>
<tr>
<td>5</td>
<td>84</td>
<td>4.68</td>
</tr>
<tr>
<td>6</td>
<td>93</td>
<td>5.67</td>
</tr>
<tr>
<td>7</td>
<td>102</td>
<td>6.67</td>
</tr>
<tr>
<td>8</td>
<td>107</td>
<td>7.66</td>
</tr>
<tr>
<td>9</td>
<td>108</td>
<td>8.66</td>
</tr>
<tr>
<td>10</td>
<td>110</td>
<td>9.66</td>
</tr>
</tbody>
</table>

Fig. A.4.3. Results from Lifetest on 100
<table>
<thead>
<tr>
<th>Test Number</th>
<th>Article and Source</th>
<th>Sample Size</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Type of Test</td>
<td>Shape ( \beta )</td>
<td></td>
</tr>
<tr>
<td>( P_1 )</td>
<td>( 26 )</td>
<td>Mean ( \mu )</td>
<td></td>
</tr>
<tr>
<td>( 27 )</td>
<td>( 27 )</td>
<td>Characteristic Life</td>
<td></td>
</tr>
<tr>
<td>( 28 )</td>
<td>( 28 )</td>
<td>Minimum Life</td>
<td></td>
</tr>
</tbody>
</table>

Fig. A4.4 Weibull Plot of Results from Lifetest on 100 Components
The graph shows an 'S' shape characteristic of two distributions. The data can be split up into two separate Weibull distributions [4]. The physical significance of an 'S' shape result is that in the sample under test there are two different batches of components, with different failure rates and characteristic lifetimes. This could correspond to a weak population of components within a normally strong population.
REFERENCES AND FURTHER READING


APPENDIX 5

Software - Listings of Data Logger Programs
RELAY CONTROL

REM RELAY CONTROL
PRINT
PRINT
HOME
UTAB 6: HTAB 15
PRINT " RELAY CONTROL "
UTAB 8: HTAB 1
PRINT " THIS PROGRAM CAN BE USED TO CONTROL "
PRINT " THE RELAYS WITHIN THE SWITCHING BOXES "
PRINT " INDIVIDUALLY "
PRINT
REM SET UP
D$ = "": REM CTRL-D
Z$ = "": REM CTRL-Z
PRINT "WHICH BOX"
INPUT BN: IF BN > 8 THEN GOSUB 1000: IF BN > 10 THEN GOTO 121
LA$ = CHR$ (32 + BN): REM LISTEN ADDRESS
LA$ = LA$ + Z$
PRINT
PRINT "INSTRUCTION?"
INPUT A$:
GOSUB 990
PRINT R$
GOSUB 990
PRINT
PRINT "ANOTHER BOX"
INPUT A$:
IF A$ = "N" THEN GOTO 1000
GOTO 1130
HOME
PRINT "RETURHNG TO MAIN MENU"
PRINT "NORMAL"
PRINT D$; "RUN HELLO"
PRINT ""
IF BN = 3 THEN GOTO 1005
IF BN = 10 THEN GOTO 1018
PRINT "THERE ARE ONLY 10 BOXES"
PRINT "1-8 ARE FOR SWITCHING; 9 AND 10 ARE CONTROL": RETURN
PRINT "THIS IS THE CONTROL BOX"
PRINT "ARE YOU SURE YOU WISH TO ALTER THIS?"
INPUT Y$
IF Y$ = "Y" THEN RETURN
GOTO 1
PRINT "THIS BOX CONTROLS THE POWER SUPPLIES"
PRINT "ARE YOU SURE YOU WANT TO CONTINUE?"
INPUT M$
IF M$ = "Y" THEN RETURN
GOTO 1
PRINT "THE BOX CONTROLS THE POWER SUPPLIES"
PRINT "ARE YOU SURE YOU WANT TO CONTINUE?"
INPUT M$
IF M$ = "Y" THEN RETURN
GOTO 1
REM SEND A$ TO SHIB
PRINT D$; "PR#4"
PRINT "RH"; LA$
PRINT "HT"; LA$; A$
PRINT D$; "PR#0"
PRINT D$; "IN#0"
RETURN
REM IEEE SHIB2
100 REM
101 REM
102 REM L IS A LOCAL VARIABLE, USED IN THE SUBROUTINES.
103 REM
104 REM
105 REM
110 OF = ";": REM CTRL-D
120 Z$ = "": REM CTRL-Z
130 NB = 10: REM NUMBER OF BOXES
140 NR = NB / 32: REM NUMBER OF RELAYS
150 DIM LA$(NB): REM LISTEN ADDRESSES FOR BOXES
160 DIM R%(NR): REM STATES OF THE RELAYS
170 REM IF R% = 1 THEN RELAY IS ON
180 REM IF R% = 0 THEN RELAY IS OFF
200 REM
210 FOR BN = 1 TO NB: REM SET UP BOX ADDRESSES
220 NEXT BN
230 BL$ = "D":BL$(1) = "F":BL$(2) = "H":BL$(3) = "L": REM BLOCK CODES
240 LB$ = "a": REM CHAR STARTING AT "!" 
250 TB$ = "t": REM CHAR STARTING AT ":"
260 TB$ = "T": REM CHAR STARTING AT ":"
270 TB$ = "T": REM CHAR STARTING AT ":"
280 TB$ = "T": REM CHAR STARTING AT ":"
290 TB$ = "T": REM CHAR STARTING AT ":"
300 TB$ = "T": REM CHAR STARTING AT ":"
310 REM
320 REM "WHAT IS THE NAME OF THE OUTPUT FILE"
330 INPUT F$: REM OUTPUT FILE NAME
340 PRINT DEF"OPEN ";F$;
9000 REM TURN ON RELAY J IN ADDITION TO OTHERS
9100 R%(J) = 1
9200 GOSUB 9300
9300 RETURN
9400 REM TURN OFF ONLY RELAY J, OTHERS UNALTERED
9500 R%(J) = 0
9600 GOSUB 9300
9700 RETURN
9800 REM TURN ON ONLY RELAY J, OTHERS OFF
9900 GOSUB 95000: REM RESET ALL RELAYS
A000 R%(J) = 1
A100 GOSUB 9300
A200 RETURN
9300 REM SET RELAY J
9310 BL$ = (J - 1) / 8: REM BLOCK NUMBER STARTING AT 0
9320 BL$ = BL$ / 4: REM BOX NUMBER STARTING AT 0
9330 R% = BL$ * 3 + 1: REM START OF THE BLOCK OF EIGHT RELAYS
9340 BL$ = BL$ - 4 * 8: REM LOCAL BLOCK NUMBER 6..3
9350 C1$ = 0:C2$ = 0
9360 FOR L = 3 TO 0 STEP - 1
9370 REM SET UP HEX CODES FOR THE RELAY PATTERN IN THE BLOCK.
9380 C1$ = C1$ / 2 + R%(S% + L)
9390 C2$ = C2$ / 2 + R%(S% + L + 4)
9400 NEXT L
9410 R% = BL$(BL$) + CHR$(C1$ % 48) + CHR$(C2$ % 48)
9420 REM INSTRUCTION TO BE SENT TO SHIB
9430 BN = BL$ + 1: REM BOX NUMBER STARTING AT 1
9440 GOSUB 95000: REM SEND R% TO BOX BN
9450 RETURN

SUBROUTINES
REM SET UP ELECTROMETER FOR RESISTANCE (USES SAME ADDRESS AS VIM)
9400 PRINT "DS:";"PR#4"
9410 PRINT "CL";$LA$
9415 PRINT "RM";$LA$
9420 PRINT "HT";$LA$;"F2D0X"
9425 PRINT D$; PR# 0
9427 RETURN
9430 REM MEASURE WITH ELECTROMETER
9435 PRINT D$;"PR#4"
9440 PRINT D$;"IN#4"
9445 PRINT "RD";T$;Z$; INPUT "";A$
9450 PRINT D$;"PR#0"
9455 PRINT D$;"IN#0"
9460 PRINT A$
9465 RETURN
9500 REM RESET ALL RELAYS
9510 FOR L = 1 TO HR
9520 NEXT L
9530 PRINT D$;"PR#4"
9540 FOR L = 1 TO NB
9550 PRINT "RM";L$(L)
9560 PRINT "HT";L$(L);"DFHL00"
9570 NEXT L
9580 PRINT D$;"PR#0"
9590 PRINT D$;"IN#0"
9600 RETURN
9600 REM CLEAR ALL DEVICES
9610 PRINT D$;"PR#4"
9615 PRINT "SCI"
9620 PRINT "CA"
9630 PRINT D$;"PR#0"
9640 RETURN
9700 REM WRITE A$ INTO THE FILE
9710 PRINT D$;"WRITE ";F$;
9720 PRINT A$
9730 PRINT D$; REM CANCELS WRITE
9740 RETURN
9750 REM INIT OVM & SET RANGES TO OHMS
9750 PRINT D$;"PR#4"
9760 PRINT "CL";$LA$
9765 PRINT "RM";$LA$
9770 PRINT "HT";$LA$;"M1R01"
9775 PRINT D$;"PR#0"
9780 RETURN
9800 REM TAKE A READING INTO A$
9810 PRINT D$;"PR#4"
9820 PRINT D$;"IN#4"
9830 PRINT "RM";$LA$
9840 PRINT "TB";$LA$
9850 PRINT "RD";T$;
9860 INPUT A$
9870 PRINT D$;"PR#0"
9875 PRINT D$;"IN#0"
9880 RETURN
9900 REM SEND A$ TO BOX NUMBER BN
9910 PRINT D$;"PR#4"
9920 PRINT "RM";$LA$(BN)
9930 PRINT "HT";$LA$(BN);A$
9940 PRINT D$;"PR#0"
9950 PRINT D$;"IN#0"
9960 RETURN

SUBROUTINES (continued)

139
5 DIM A$(200): DIM A$(200)
10 D$ = ""
20 DATA "AFOR","BFOR","CFOR","DFOR","EFOR","FFOR","GFOR","HFOR","IFOR","JFOR"
22 DATA "ACTR","BCTR","CCTR","DCTR","ECTR","FCTR","GCTR","HCTR","ICTR","JCTR"
24 DATA ASAT,BSAT,CSAT,DSAT,ESA,T,FSAT,GSAT,HSAT,ISAT,JSAT
28 PRINT
30 READ F$: PRINT F$
40 PRINT D$;"OPEN";F$
50 PRINT D$;"READ";F$
60 INPUT A$
70 FOR I = 1 TO VAL (A$)
80 INPUT A$(I)
90 NEXT I
100 PRINT D$;"CLOSE";F$
110 PRINT "LOWER LIMIT ON DATA IS 0.05"
120 MN = .05
130 PRINT "UPPER LIMIT ON DATA IS 6.00"
140 MAX = 6
150 FOR I = 1 TO VAL (A$)
160 AK(I) = VAL (A$(I))
170 NEXT I
180 N = 1
190 FOR I = 1 TO VAL (A$)
200 IF AK(I) < MN THEN 230
210 AKN = AK(I)
220 N = N + 1: GOTO 240
230 NEXT I
240 NEXT I
250 SUM = 0: REM CALC MEAN
270 FOR I = 1 TO N
280 SUM = SUM + AK(I)
290 NEXT I
300 MEAN = SUM / N
310 PRINT "MEAN IS ",MEAN
320 SUM = 0: REM CALC SD
330 FOR I = 1 TO N
340 SUM = SUM + ((AK(I) - MEAN) ^ 2)
350 NEXT I
360 VAR = SUM / (N - 1)
370 SD = VAR ^ .5
380 PRINT "SD IS ",SD
390 GOTO 28
PRINT " BEFORE USING THIS PROGRAM IT IS " PRINT "NECESSARY TO BOOT THE DISC THIS WILL BE" PRINT "DONE AUTOMATICALLY IF REQUIRED" NORMAL FOR K = 1 TO 1000 REM WAIT NEXT K T = PEEK (116) * 256 + PEEK (115) IF T = 34235 THEN GOTO 270 FLASH: VTAB 20: PRINT "BOOTING THE DISC" PRINT "ENSURE DISC I N DRIVE ONE": NORMAL FOR D$ = "": REM CTRL-D PRINT D$:REM PRINT "ONE RELAY AUTOMATICALLY IF REQUIRED" REM USE THIS Required " FILE IF R% = 1 THEN RELAY IS ON REM IF R%=0 THEN RELAY IS OFF FOR BN = 1 TO NB: REM SET UP BOX ADDRESSES LAH(BN) = CHR$(32 + BN) + Z$ : REM CHARS STARTING AT "!", I.E. HEX 21 NEXT BN BL(0) = "D":BL$(1) = "F":BL$(2) = "H":BL$(3) = "L": REM BLOCK CODES CERAM*
PRINT "Q."

PRINT "FREQUENCY RANGE ENTER SELECTED FREQUENCY RANGE" 
PRINT "ENTER CODE NOW"

PRINT "DO YOU WANT TO NAME INPUT Y$"

INPUT Y$

GOSUB 1710:

6$ = "CRP"

PRINT "NAME OF FILE"

GOTO 1100

PRINT "NAME OF FILE"

INPUT $6$

FOR U = 1 TO H

IF ME$(U) = "C;SE;" THEN P$(U) = "CAPSER"

IF ME$(U) = "C;PA;" THEN P$(U) = "CAPPAR"

IF ME$(U) = "R;SE;" THEN P$(U) = "RESSER"

IF ME$(U) = "R;PA;" THEN P$(U) = "RESPAR"

IF ME$(U) = "L;SE;" THEN P$(U) = "INDSER"

IF ME$(U) = "L;PA;" THEN P$(U) = "INDPAR"

IF ME$(U) = "C;D;" THEN P$(U) = "DISCPAR"

IF ME$(U) = "L;D;" THEN P$(U) = "DISCCAP"

FI$(U) = G$ + SD

FOR U = 1 TO M

NEXT U

FOR I = 1 TO J

PRINT "L" + J: PRINT "CERAM* (continued)"

142
REM TEMPORAL INFO TO T$
1710 PRINT D$;"IH#1"
1720 PRINT D$;"PR#1"
1730 RETURN
1740 PRINT D$;"IH#0"
1750 PRINT D$;"PR#0"
1760 RETURN
1770 REM INIT BRIDGE AND MEASUR E
1780 PRINT D$;"PR#4"
1790 PRINT "CL";LB$
1800 RETURN
1810 REM TAKE READING TO A$
1820 PRINT D$;"PR#4"
1830 PRINT "RH";LB$
1840 RETURN
1850 PRINT D$;"PRL0"
1860 PRINT "RH";LB$
1870 PRINT "LO";LB$
1880 PRINT D$;"PRL0"
1890 RETURN
1900 REM TURN ON
1910 R%(L) = 1
1920 GOSUB 2080
1930 RETURN
1940 REM TURN OFF ONLY RELAY J, OTHERS UNALTERED
1950 R%(J) = 0
1960 GOSUB 2080
1970 FOR Y = 1 TO 10
1980 REM TURN ON ONLY RELAY J, OTHERS OFF
1990 GOSUB 2200: REM RESET ALL RELAYS
2000 R%(J) = 1
2010 GOSUB 2080
2020 RETURN
2030 REM SET RELAY J
2040 BLX = (J - 1) / 8: REM BLOC K NUMBER STARTING AT 0
2050 B% = BLX / 4: REM BOX NUMBE R STARTING AT 0
2060 S% = BLX * 8 + 1: REM START OF THE BLOCK OF EIGHT RELAYS
2070 BL% = BLX - 4 * B%: REM LOC AL BLOCK NUMBER 0..3
2080 C1% = C1% + C2% = 0
2090 FOR L = 3 TO 6 STEP - 1
2100 REM SET UP HEX CODES FOR T HE RELAY PATTERN IN THE BLOC K.
2110 C1% = C1% + 2 + RX(S% + L)
2120 C2% = C2% + 2 + RX(S% + L + 1)
2130 NEXT L
2140 REM = BL% (BL%) + CHR$(C1% + 48) + CHR$(C2% + 48)
2200 REM INSTRUCTION TO BE SENT TO SHIB
2210 BN = BL% + 1: REM BOX NUMBER STARTING AT 1
2220 GOSUB 2420: REM SEND A$ TO BOX BN
2230 RETURN
2240 REM RESET ALL RELAYS
2250 FOR L = 1 TO 8
2260 RX(L) = 0
2270 RETURN
2280 PRINT D$;"PRL0"
2290 RETURN
2300 PRINT D$;"PR#0"
2310 PRINT "RH";LB$
2320 RETURN
2330 PRINT D$;"PR#0"
2340 PRINT D$;"IH#0"
2350 RETURN
2360 PRINT D$;"PR#4"
2370 PRINT "RH";LB$
2380 PRINT D$;"PR#0"
2390 RETURN
2400 PRINT D$;"PR#0"
2410 RETURN
2420 PRINT "OPEN N\HESTOP.E.L3"
2430 PRINT D$;"PRL0"
2440 PRINT "RH";LB$
2450 PRINT D$;"PR#0"
2460 PRINT D$;"IH#0"
2470 PRINT D$;"PR#0"
2480 RETURN
2490 PRINT "THAT IS TOO GREAT"
2500 PRINT "RESTART PROGRAM"
2510 END
2520 REM SET UP NAME STORE
2530 PRINT "ADD THESE FILENAMES TO NAME STORE?"
2540 PRINT Y$
2550 IF Y$ = "N" THEN GOTO 1590
2560 PRINT "ADDING FILES TO NAME STORE"
2570 PRINT D$;"OPEN NAMESTORE.L3"
2575 GOSUB 2639
2579 H = 1
2580 FOR Y = S TO S + (U - 2)
2585 U$ = STR$(D)
2590 F$(H) = F$(H) + " + U$
2610 PRINT D$;"WRITE NAMESTORE.R"
2620 PRINT F$(H)
2625 H = H + 1
2630 NEXT Y
2633 PRINT D$;"CLOSE NAMESTORE"
2635 RETURN
2639 REM READ INPUT DATA
2700 PRINT D$;"OPEN NAMESTORE.L3"
2710 HOME: PRINT "HAS NAMESTORE BEEN CREATED BEFORE": INPUT Y$: IF Y$ = "N" THEN GOSUB 5660
CERAM* (continued)
ONERR  GOTO 500
HOME
PRINT
PRINT "THIS PROGRAM CAN BE USED TO READ DATA"
PRINT "COLLECTED BY THE CERAH PROGRAM"
PRINT
PRINT
PRINT
PRINT "OUT OF RANGE ERROR": GOTO 13
PRINT D$:"SAVEO,O";DD
INPUT "NAME OF TEXT FILE";Z$
PRINT "HOW MANY COMPTS ARE THERE"
INPUT N
PRINT D$;"OPEN";Z$
PRINT D$;"READ";Z$
FOR I = 1 TO N
INPUT R$;"SAVEO.O";I$
PRINT I;"B$
NEXT I
PRINT D$;"CLOSE";Z$
IF P$ = "PR" THEN PRINT D$;"PR#0"
PRINT D$;"DELETE 0,O";DD
PRINT "ON WHICH DRIVE IS SYSTEM DISC"
INPUT DD: IF DD > 2 THEN GOTO 125
PRINT D$;"SAVEO,O";OD
PRINT D$;"DELETEO,O";OD
END
500 HOME: VTAB 12: HTAB 15: PRINT "ERROR"
501 PRINT: PRINT : PRINT : PRINT "PRESS ANY KEY TO RESTART:";
502 GET Y$
503 POKE 216,0
504 GOTO 2

LOOKCER
HELLO

100 REM THIS PROGRAM IS CALLED
200 WATCH THE CLOCK
110 DS = "": REM CTRL-D
120 REM TEMPORAL READINGS TO TIME
130 PRINT DS; "IN#1"
140 PRINT DS; "PR#1"
150 INPUT TIME$
160 PRINT DS; "IN#0"
170 PRINT DS; "PR#0"
180 FOR T = 1 TO 25
190 TIME$ = RIGHT$(TIME$, 17)
200 IF TIME$ = T$(T) THEN GOTO 270
210 NEXT T
220 HOME : UTAB 12; HTAB 15: PRINT
"TIME IS TIME$"
230 UTAB 5; HTAB 15: INVERSE : PRINT
"DO NOT SWITCH OFF"
240 UTAB 19; HTAB 15: PRINT "DO
NOT SWITCH OFF"
250 NORMAL
260 GOTO 160
270 HOME : UTAB 12: PRINT "MEASU
REMENTS PROCEEDING"
280 PRINT DS; "LOAD CHAIN, A520"
290 CALL 520"LOAD CHAIN"
300 HOME : UTAB 12; PRINT "VOLTA GE BEING STEPPED UP"
310 PRINT DS; "LOAD CHAIN,A520"
320 CALL 520"CHANGE VOLTAGE"
330 END

1 REM THIS PROGRAM IS CALLED IN
FORMATION
2 REM DIMENSIONS OF ARRAYS AND
VARIABLES
3 DIM T$(25); DIM TV$(25); REM T# = MEAS. TIMES, TV# = CHANGE
VOLTAGE TIMES
10 DIM HOLE$(10)
15 DIM P$(10)
16 DIM ME$(10)
17 DIM DA$(25)
18 DIM F$(10)
19 DIM R$(320)
20 DIM LA$(10)
21 DIM VOLTS$(10)
100 REM PROGRAM FOR TIMED SHITC
HING
110 DS = "": REM CTRL-D
120 HOME : UTAB 2
130 PRINT "PROGRAM FOR TIME CONT
ROL OF CERAM"
140 FOR H = 1 TO 1000
150 REM MONITOR TIMES • T$(N) = "12/18/84 14:19:56"
160 NEXT H
170 HOME : UTAB 12
180 REM MEASUREMENT TIMES , E.G.
. T$(1) = "12/27/84 14:19:56"
190 T$(1) = "12/18/84 12:09:00"
200 T$(2) = "12/16/84 10:00:00"
210 REM VOLTAGE TIMES , SAME FO
RMAT AS ABOVE
220 T$(1) = "............"
230 REM MEAS. TO BE MADE • E.G.
. HOLE$(1) = "C;PA;"
240 HOLE$(1) = "C;PA;"
250 HOLE$(2) = "R;PR;"
260 HOLE$(3) = "C;D;"
270 D = 129: REM NO. OF CAPACI
TORS
280 H = 3: REM NO. OF PARAMETERS
290 NORMAL
300 PRINT DS; "LOAD CHAIN,A520"
310 CALL 520"WATCH THE CLOCK"
320 END

WATCH THE CLOCK

INFORMATION
100 REM L IS A LOCAL VARIABLE, USED IN THE SUBROUTINES.
110 REM
120 D$ = "": REM CTRL-D
130 Z$ = "": REM CTRL-Z
140 NB = 09: REM NUMBER OF BOXE
S
150 NR = NB * 32: REM NUMBER OF RELAYS
160 REM IF R%=1 THEN RELAY IS 0
H
170 REM IF R%=0 THEN RELAY IS 0
FF
180 FOR BN = 1 TO NB: REM SET U
P BOX ADDRESSES
190 LR$(BN) = CHR$(32 + BN) + Z$
$: REM CHARS STARTING AT "!";
I.E. HEX 21
200 NEXT BN
210 BL$(0) = "0":BL$(1) = "F":BL$(
2) = "H":BL$(3) = "L": REM
BLOCK CODES
220 LB$ = "A"
230 TB$ = "T"
240 LB$ = LB$ + Z$
250 TB$ = TB$ + Z$
260 LA$ = "$" + Z$
270 TA$ = "P": REM TALK ADDRESSES
S FOR DVM
280 TA$ = "A" + Z$
290 GOSUB 820: REM READ TIME FROM
OH CLOCK
300 G$ = "CAP" + T$
310 FOR U = 1 TO H
320 HE$(U) = LEFT$(WHOLE$(U),5)
330 IF HE$(U) = "C;SE;" THEN P$(
U) = "CAPSER"
340 IF HE$(U) = "C;PA;" THEN P$(
U) = "CAPPAR"
350 IF HE$(U) = "R;SE;" THEN P$(
U) = "RESSER"
360 IF HE$(U) = "R;PA;" THEN P$(
U) = "RESPAR"
370 IF HE$(U) = "L;SE;" THEN P$(
U) = "INOSER"
380 IF HE$(U) = "L;PA;" THEN P$(
U) = "INOPAR"
390 IF HE$(U) = "Q;SER;" THEN P$(
U) = "QFACSE"
400 IF HE$(U) = "Q;PA;" THEN P$(
U) = "QFACPA"
410 IF HE$(U) = "C;D;" THEN P$(
U) = "DISSIP"
420 IF HE$(U) = "L;U;" THEN P$(
U) = "DFAC"
430 P$(U) = G$ + "" + P$(U)

440 PRINT D$;"OPEN";F$(U)
450 C = 0
460 IF ME$(U) = "C;PA;" THEN GOSU(1650)
470 IF ME$(U) = "C;SE;" THEN GOSU(1650)
480 NEXT U
490 FOR U = 1 TO H
500 FOR K = 1 TO D:J = J + 1
510 IF J = 31 THEN J = 33
520 IF J = 63 THEN J = 65
530 IF J = 95 THEN J = 97
540 IF J = 127 THEN J = 129
550 IF J = 159 THEN J = 161
560 IF J = 191 THEN J = 193
570 IF J = 223 THEN J = 225
580 IF J = 255 THEN GOTO 760
590 BS$ = WHOLE$(U)
600 A = J;J = 270: GOSUB 1150:J =
A
610 GOSUB 1079: REM RELAY ON
620 A = J;J = 270: GOSUB 1110:J =
A
630 N = N + 1
635 J = K
640 IF J = 1 THEN GOSUB 1690
650 GOSUB 890: REM INITIATE AND ME
SURE
660 GOSUB 990: REM READING TO A
$.
670 CA = VAL(AS$) REM REMOVE S
TRAYS
680 CA = CA - C
690 AS$ = STR$(CA)
700 DA$ = AS$ + "" + ME$(U)
710 PRINT D$;"WRITE ";F$(U); REM
WRITE TO FILE
720 PRINT DA$
730 PRINT D$; REM CANCELS WRITE
740 GOSUB 1110
750 NEXT K
755 J = 0
760 NEXT U
770 FOR U = 1 TO H
780 PRINT D$;"CLOSE";F$(U)
790 NEXT U
800 GOTO 1610
810 END

AUTOCERAM

147
10 REM THIS PROGRAM IS CALLED "CHANGE VOLTAGE"
15 REM INCREASES VOLTAGE UNTIL JUST ABOVE REQUIRED LEVEL
20 U = 0
30 U = U + 1
40 GOSUB 7900
50 GOSUB 9800
60 PU2 = 1
70 IF TV(U) > VAL(A$) THEN 30
80 PU2 = PU2 + 1
90 GOSUB 5035
100 BN = 10: GOSUB 9900
110 GOSUB 9800
120 IF VAL(A$) < TV(U) THEN 15
130 GOTO 80
150 PRINT D$; "LOAD CHAIN, AS20"
160 CALL 520; "HATCH THE CLOCK"
170 END
8035 REM CONVERTS REAL NO PU2 INTO STRING (MUST LIE BETWEEN 0 AND 99.99)
6040 V% = PU2
6041 V = V%; H = PU2 * 100
6042 H% = H
6043 H = H%
6044 H = H - (V + 100)
6050 VS = STR$(V); HS = STR$(H)
6064 IF LEN(VS) = 1 THEN VS = "0" + VS
6065 IF LEN(VS) = 0 THEN VS = "00"
6066 IF LEN(HS) = 1 THEN HS = "0" + HS
6067 IF LEN(HS) = 0 THEN HS = "00"
6070 A$ = "D07F85H" + VS + "L" + HS
6071 BN = 10
6075 RETURN
6080 REM READS OUGH AND CONVERTS TO A REAL NO. RES
6090 GOSUB 9800: REM OUGH RESD INTO A$
6100 RES$ = RIGHT$(A$, 14)
6110 RES = VAL(RES$)
6120 RETURN
7900 REM INITIALSE OUGH AND SET RANGES
7901 PRINT D$; "PR#4"
7920 PRINT "CL"; LA$
7930 PRINT "RH"; LA$
7940 PRINT "HT"; LA$; "H00T1"
7950 PRINT D$; "PR#0"
7960 RETURN

CHANGE VOLTAGE
1 HoME
2 PRINT
3 PRINT
4 PRINT
5 PRINT "MEASUREMENT OF OPTOCOUP
LERS"
6 PRINT
7 PRINT
8 CLEAR
9 DIM C0M192: REM RELAY COMB
INATIONS
10 FOR I = 1 TO 64
11 REM C0M(I)
12 NEXT I
13 DATA 1,2,10,11,3,4,12,13
14 DATA 5,6,14,15,7,8,16,25
15 DATA 17,18,26,27,19,20,28,29
16 DATA 21,22,30,31,23,24,32,41
17 DATA 33,34,42,43,35,38,44,45
18 DATA 37,38,46,47,39,40,48,57
19 DATA 49,50,58,59,51,52,60,61
20 DATA 53,54,62,63,55,56,64,9
21 FOR I = 55 TO 128
22 J = I - 64
23 C0M(J) = C0M(J) + 64
24 NEXT I
25 FOR I = 129 TO 192
26 J = I - 128
27 C0M(J) = C0M(J) + 128
28 NEXT I
100 REM IEEE SWIB2
101 REM
102 REM
103 REM L IS A LOCAL VARIABLE
" USED IN THE SUBROUTINES.
104 Q = 1
105 P = 0
110 D$ = "": REM CTRL-D
120 Z$ = "": REM CTRL-Z
130 NB = 32
140 NR = NB * 32: REM NUMBER OF
REELS
150 DIM LA(K(NB)): REM LISTEN ADD
RESSES FOR BOXES
160 DIM R%X(NR): REM STATES OF T
HE RELAYS
170 REM IF R% = 1 THEN RELAY IS O
H
180 REM IF R% = 0 THEN RELAY IS O
FF
200 BR FOR BN = 1 TO NB: REM SET U
P BOX ADDRESSES
210 LR&(BN) = CHR$(32 + BN) + Z
$: REM CHARS STARTING AT "I"
", I.E. HEY 21
220 NEXT BN
230 BL$@0) = "D": BL$(1) = "F": BL$@2) = "H": BL$(3) = "L": REM
BLOCK CODES
240 LB$ = "4"
250 TB$ = "T"
260 LB$ = LB$ + Z$
270 TB$ = TB$ + Z$
331 LR$ = "X" + Z$
340 TR$ = "P": REM TALK ADDRESSES
S FOR DUM
341 TR$ = "X" + Z$
350 PRINT "WHAT IS THE NAME OF T
HE OUTPUT FILE"
360 INPUT F$: REM OUTPUT FILE N
AME
370 PRINT D$;"OPEN ":F$
1591 PRINT
1592 PRINT
1593 PRINT "PLEASE ENSURE THAT
ALL EQUIPMENT IS SWITCHED O
N, ESPECIALLY SWITCHING BOX
ES AND POWER SUPPLIES. IF NOT
, SWITCH OFF MAINS SUPPLY. S
HITCH ON DEVICES, SWITCH ON
MAINS AND RESTART PROGRAMM.
" 
1594 PRINT "PLEASE ENTER THE NUM
BER OF OPTOCOUPERS TO BE TE
STED"
1595 INPUT N
1596 PRINT
1597 PRINT "PLEASE NOTE ERRORS S
ET AT 0.01 FOR (V,F)"
1598 PRINT
1599 IF N > 256 THEN GOTO 9999
1600 PRINT D$; "WRITE":F$
1610 PRINT N
1620 PRINT D$
2000 REM Uf for N optoisolators
2005 GOSUB 9500: REM RESETS REL
AYS
2070 GOSUB 7900: REM GET DUM REA
DY
2090 FOR Z = 1 TO N: REM TAKE R
EADINGS
2035 J = Z * 2
2037 J = C0M(J)
2090 GOSUB 9000
2055 J = <2 * Z - 1
3087 J = C0M(J)
2100 GOSUB 9000
2105 GOSUB 9000
2187 R$ = MID$(A$,4)
2110 GOSUB 9700
2115 GOSUB 9100
2120 J = Z * 2
2123 J = C0M(J)
2125 GOSUB 9100
2130 NEXT Z
2250 GOSUB 9500: REM CLOSING DO
WH
2255 PRINT D$; "CLOSE":F$
2260 HOME
2261 UTAB 12: FLASH
2262 PRINT "RETURNING TO MAIN M
ENU"
2263 NORMAL
2264 PRINT D$; "RUN MENU.DI"
**Measurement of Optocouplers**

**RELAY COMBINATIONS**

1. For I = 1 to 64:
   - Read COM(I)
   - (I + 1), (I + 2), (I + 3), (I + 4), (I + 5), (I + 6), (I + 7)

2. For I = 65 to 128:
   - J = I - 64
   - COM(I) = COM(J) + 64

3. For I = 129 to 192:
   - J = I - 128
   - COM(I) = COM(J) + 128

**RELAY States**

- 1 is ON
- 0 is OFF

**Library**

- Use in the subroutines.

**Input Specifications**

1. Place all equipment in SHUTDOWN mode, especially switches, except supply.
2. Turn off mains supply.
3. Switch on devices to restore program.
4. Please enter the number of optocouplers to be tested.
5. Input shunt resistance across the voltmeter in ohms.

**Runtime**

1. Please note errors set at 5.00 for IC.
2. If N > 256, go to 9999.
3. Print "Returning to main menu."
DIM CON132): REM RELAY COMBINATIONS
FOR I = 1 TO 64
READ CON13)
NEXT I
DATA 1.2.10.11.3.4.12.13
DATA 5.6.14.15.7.8.16.25
DATA 17.18.26.27.19.20.28.29
DATA 21.22.30.31.23.24.32.41
DATA 33.34.42.43.35.36.44.45
DATA 47.46.47.39.48.49.57.56
DATA 53.54.62.63.55.56.64.9
FOR I = 65 TO 128
J = I - 64
COM(J) = COM(J) + 64
NEXT I
FOR I = 129 TO 192
J = I - 128
COM(J) = COM(J) + 128
NEXT I
REH IEEE SHIB2
REM L IS A LOCAL VARIABLE
REM USED IN THE SUBROUTINES.
REM
10 REM
110 D$ = "\": REM CTRL-D
120 Z$ = "\": REM CTRL-Z
130 HB$ = 7$: REM NO. OF BOXES
140 NR = NB * 32$: REM NUMBER OF RELAYS
150 DIM L((NB)): REM LISTEN ADDRESSES FOR BOXES
160 DIM R(NR): REM STATES OF THE RELAYS
170 REM IF R=1 THEN RELAY IS ON
180 REM IF R=0 THEN RELAY IS OFF
200 FOR EN = 1 TO HB$: REM SET U1 BOX ADDRESSES
210 LB$ = CHR$(32 + EN) + Z$: REM CHAR STARTING AT "l" I.E. HEX 21
220 NEXT EN
230 BL$ = 0$: REM BLOCK CODES
341 TAR = "\" + Z$: REM 1000 HOME
1010 PRINT
1020 PRINT
1030 PRINT
1040 PRINT
1050 PRINT "Measurement of Saturaton Voltage of Optocoupler" $S.
1060 PRINT
1070 PRINT
1080 PRINT
1090 PRINT
1095 GOSUB 9500: REM ALL RELAYS SET TO OFF POSITION
1097 DIM I(150): DIM V(150): DIM UC(150): DIM SLOPE(150)
1100 PRINT "How many optocouplers are you measuring?"
1110 INPUT N: REM number of optocouplers is "N"$.
1115 IF N > 256 60 TO 10000
1120 PRINT "Please type in the value of the shunt resistance across the DUM, in ohms."
1130 INPUT SHUNT
1132 PRINT "What is the name of the output file?"
1133 INPUT FILE$: REM Output file name
1134 PRINT DIS:"OPEN ":FILE$.
1135 PRINT DIS:"WRITE ":FILE$.
1138 PRINT NOP
1139 PRINT DIS:"MEASURING.......
1139 GOSUB 7900: REM MEASURING......
1140 FOR Z = 1 TO N: REM TAKE READINGS
1143 GOSUB 9900: REM ALL RELAY S SET TO OFF POSITION
1144 J = Z + 2*: J = CON(J)
1145 GOSUB 9900
1146 J = (2 * Z) - 1$: J = CON(J)
1148 GOSUB 9900
1150 PZ$ = 0$.
1160 GOSUB 6635
1170 GOSUB 9900: REM voltage from power supplies is now on
1170 GOSUB 9900: REM VOLUMETER READ, value is "RES".
1200 H = 1$: I = 0
1205 A$ = MID$(A$+4): RES = VAL A$(
1210 I(N) = RES / SHUNT: REM give $e
\begin{verbatim}
1215 I(N) = I(N) * 1000: REM CONVERT TO MILLI-AMPS
1220 V(N) = PU2 - RES: REM gives Vce
1230 N = N + 1
1240 PU2 = PU2 + 0.2
1250 GOSUB 6035: REM converts P
    U2 to a string
1260 GOSUB 9900: REM voltage changed
1280 GOSUB 3800: REM voltmeter read, value is 'RES'
1285 A$ = MID$(A$,4):RES = VAL
    (A$)
1290 I(N) = RES / SHUNT
1295 I(N) = I(N) * 1000
1300 V(N) = PU2 - RES: REM gives Vce
1310 SLOPE(N) = (IHO - I(N) - 1) / (V(N) - 1): REM calculates position of Vce(N)
1320 IF SLOPE(N) > 20 THEN GOTO 1230
1330 V(N) = (V(N) + V(N - 1)) / 2: REM calculates position of Vce(N)
1340 V(N - 1) = (V(N - 1) + V(N - 2)) / 2: REM calculates position of Vce(N-1)
1345 IF SLOPE(N) = SLOPE(N - 1) THEN
    SRN = 0: GOTO 1360
1350 SRN = V(N) + (V(N - 1) - V(N)) * (SLOPE(N)) / (SLOPE(N - 1) - SLOPE(N)): REM calculates saturated voltage
1360 A$ = STR$(SRN)
1380 GOSUB 9700: REM information written to file
1383 GOSUB 9100
1385 J = Z * 2:J = COSK(J)
1387 GOSUB 9100
1390 NEXT Z
1393 PRINT D$; "CLOSE ";F$
1395 PRINT " DATA IN FILE "F$" RUN A LOOK PROGRAM TO READ"
1400 GOSUB 9500: REM all relays reset
1410 END

SAT VOLTA (continued)
\end{verbatim}
APPENDIX 6

A RELIABILITY ANALYSIS OF MULTILAYER CERAMIC CAPACITORS
UNDER VOLTAGE AND TEMPERATURE ACCELERATION

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SUMMARY

Reliability analyses have been carried out on type X7R multilayer ceramic capacitors, manufactured using a screen printing process. The initial purpose of this work was to establish the validity of the 3rd power law under voltage acceleration for capacitors manufactured with this technique. In addition, temperature and temperature/voltage acceleration effects have been investigated.

The preliminary test programme involving temperature and voltage step stressing establishes the existence of a 3rd power law for voltage acceleration. The importance of temperature as an acceleration factor is also highlighted.

The second phase of the work, based on the results of the preliminary programme, involved accelerated life studies of multilayer ceramic capacitors at fixed voltage and temperature combinations.

Results from these experiments have been analysed making use of Weibull analysis techniques to investigate activation energies, characteristic lifetimes and possible failure mechanisms under voltage and temperature acceleration.

At high voltage stress levels (400 volts) two temperature dependent failure mechanisms, thermal runaway and avalanche breakdown, are postulated.

Screen printed type X7R multilayer ceramic capacitors used under rated conditions are shown to have characteristic lifetimes of possibly 25 years.

INTRODUCTION

The reliability of multilayer ceramic capacitors has been well researched in recent years. Many papers have been written on these studies [1-5]. These studies have generally used the model proposed by Prokopowicz and Vaskas [6] when investigating the behaviour of multilayer ceramic capacitors under temperature and voltage acceleration.

The model states:

\[
\frac{t_1}{t_2} = \left( \frac{V_2}{V_1} \right)^n \exp \left( \frac{E_a}{k T_2} \left( \frac{1}{T_1} - \frac{1}{T_2} \right) \right)
\]

where \( t \) is time to failure, \( V \) is applied d.c. voltage, \( T \) is the absolute temperature at the test condition, \( k \) is Boltman's constant, \( E_a \) is the pseudo-activation energy and \( n \) is the voltage acceleration factor.

Calculations of times to failure can thus be made for different combinations of temperature and voltage, assuming that the failure mechanism does not change.

Values of \( n \), the acceleration factor, have been reported between 2 and 4 for medium "K" and high "K" barium titanate based dielectrics [4]. A value of 3 is generally accepted in the industry. Similarly different values of \( E_a \), the pseudo-activation energy, have been reported. However, a value of 1 eV is generally assumed by many researchers [7].

The major concern in the failure of multilayer ceramic capacitors is the degradation of insulation resistance [5]. In accelerated life testing this is monitored directly as insulation resistance, or more usually as a leakage current. Typically a device might be considered a failure if the leakage current exceeds 5 mA.

This paper describes the results of accelerated life test experiments on multilayer ceramic capacitors which have undergone a manufacturing process change. It was consequently of interest to study the general reliability of these components, and to assess to what extent the model stated in equation 1, still held.

The capacitors were manufactured using a new screen printing technique, where both
the dielectric and the ceramic were screen printed, one after the other, building up a block of multilayers which could then be cut and fired in the usual manner.

A programme of work was established which consisted of two phases:

(I) A step-stress programme to determine whether the established third power law of voltage acceleration still held for multilayer ceramic capacitors manufactured by this different process. The effect of temperature would also be investigated.

(II) A larger scale voltage/temperature test matrix based on the results of phase I.

Experimental Details

Phase I of the work involved:

(a) Placing 60 capacitors initially on test at maximum rated voltage and temperature (50 V, 125°C) for 1,040 hours. At the end of the 1,040 hours the voltage was increased in steps, as shown in Table 1. The test times at each voltage were reduced in proportion to \((V_{test}/V_{rated})^3\) in order to investigate the validity of the third power law.

(b) A further 60 capacitors underwent the same voltage step-stress programme as outlined in (a). When approximately 15% of these capacitors had failed, at the end of stage 5 (159 V, 32.3 hours), the remainder were held at this voltage i.e. 159 volts and then subjected to a temperature step-stress programme which involved increasing the temperature in 20°C steps and holding the capacitors at each stage for 26 hours.

Phase II of the work consisted of a test matrix involving both voltage and temperature acceleration as shown in Table 2. 128 Capacitors were placed on test at each of the voltage-temperature combinations.

<table>
<thead>
<tr>
<th>Voltage (Volts)</th>
<th>Time (Hours)</th>
<th>Step Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1,040</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>130</td>
<td>2</td>
</tr>
<tr>
<td>126</td>
<td>65</td>
<td>3</td>
</tr>
<tr>
<td>144</td>
<td>43.5</td>
<td>4</td>
</tr>
<tr>
<td>159</td>
<td>32.3</td>
<td>5</td>
</tr>
<tr>
<td>171</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>182</td>
<td>21.6</td>
<td>7</td>
</tr>
<tr>
<td>192</td>
<td>18.4</td>
<td>8</td>
</tr>
<tr>
<td>200</td>
<td>16.3</td>
<td>9</td>
</tr>
<tr>
<td>208</td>
<td>14.4</td>
<td>10</td>
</tr>
<tr>
<td>216</td>
<td>12.9</td>
<td>11</td>
</tr>
<tr>
<td>222</td>
<td>11.9</td>
<td>12</td>
</tr>
<tr>
<td>229</td>
<td>10.8</td>
<td>13</td>
</tr>
<tr>
<td>235</td>
<td>10</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 1.

Voltage-Time Step-Stress Test Program

<table>
<thead>
<tr>
<th>Temperatures and Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>125°C</td>
</tr>
<tr>
<td>100 volts</td>
</tr>
<tr>
<td>400 volts</td>
</tr>
</tbody>
</table>

Table 2.

Measurement Techniques

In order to measure the desired parameters of the components undergoing life test, a data logger system was constructed. This consisted of an Apple IIe microcomputer, which controlled, via an IEEE interface, a number of switching boxes and the various measuring instruments. During Phase I measurements of insulation resistance, dissipation factor and capacitance were made at various time periods using this system.

During the second phase of the work it was necessary to determine the times to failure more accurately. This was achieved by means of a trip circuit. The total current through the 128 capacitors, connected in parallel, was monitored and the circuit was designed to trip out when this exceeded 5 mA. The effect of tripping was to disconnect the bias voltage and to stop a clock. Using the data logger the bank of capacitors could be measured individually to locate the failed capacitor or capacitors.
The results from the two tests in phase I, (a) and (b), are shown respectively in Tables 3 and 4. The non accelerated times shown in these tables are the times to failure converted to the 50 V base level, assuming the third power law holds.

### Table 3.

**Results of Voltage Step-Stress Tests at Constant Temp. (125°C)**

<table>
<thead>
<tr>
<th>Number of Failures (Out of 60)</th>
<th>Time (Hours)</th>
<th>Step Accid. Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>718</td>
<td>1,718</td>
</tr>
<tr>
<td>3</td>
<td>1,082</td>
<td>1,718</td>
</tr>
<tr>
<td>4</td>
<td>1,109</td>
<td>1,829</td>
</tr>
<tr>
<td>5</td>
<td>1,149</td>
<td>2,572</td>
</tr>
<tr>
<td>6</td>
<td>1,197</td>
<td>2,872</td>
</tr>
<tr>
<td>9</td>
<td>1,221</td>
<td>3,622</td>
</tr>
<tr>
<td>11</td>
<td>1,247</td>
<td>4,872</td>
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<td>23</td>
<td>1,318</td>
<td>5,594</td>
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<td>1,324</td>
<td>6,216</td>
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<tr>
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<td>1,341</td>
<td>6,658</td>
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<tr>
<td>25</td>
<td>1,365</td>
<td>7,224</td>
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<tr>
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<td>1,390</td>
<td>7,828</td>
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<td>1,446</td>
<td>9,452</td>
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<td>32</td>
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<td>1,482</td>
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<td>39</td>
<td>1,510</td>
<td>11,558</td>
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<td>44</td>
<td>1,528</td>
<td>12,144</td>
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<td>46</td>
<td>1,534</td>
<td>12,422</td>
</tr>
<tr>
<td>47</td>
<td>1,559</td>
<td>13,136</td>
</tr>
<tr>
<td>49</td>
<td>1,577</td>
<td>13,712</td>
</tr>
<tr>
<td>50</td>
<td>1,582</td>
<td>13,872</td>
</tr>
</tbody>
</table>

The results in Tables 3 and 4 have been plotted on Weibull paper. These are shown in Figures 1 and 2. Assuming that the failures are occurring in the constant failure part of the bathtub curve and increasing voltage does not take them into a wearout situation, a straight line relationship should be obtained on a Weibull plot with a \( B \) value \( \approx 1 \) for the third power law to hold. Within the limits of experimental error it is possible to construct a straight line through the points in Figure 1 with a \( B \) value approximately \( = 1 \). This shows the third power law is approximately correct for capacitors manufactured using screen printing.

### Table 4.

**Result of Combined Voltage and Temperature Step-Stress Test**

<table>
<thead>
<tr>
<th>Number of Failures (Out of 60)</th>
<th>Time (Hours)</th>
<th>Step Accid. Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>718</td>
<td>1,718</td>
</tr>
<tr>
<td>4</td>
<td>1,082</td>
<td>1,718</td>
</tr>
<tr>
<td>5</td>
<td>1,109</td>
<td>1,829</td>
</tr>
<tr>
<td>6</td>
<td>1,149</td>
<td>2,572</td>
</tr>
<tr>
<td>9</td>
<td>1,221</td>
<td>3,622</td>
</tr>
<tr>
<td>11</td>
<td>1,247</td>
<td>4,872</td>
</tr>
<tr>
<td>23</td>
<td>1,318</td>
<td>5,594</td>
</tr>
<tr>
<td>21</td>
<td>1,324</td>
<td>6,216</td>
</tr>
<tr>
<td>24</td>
<td>1,341</td>
<td>6,658</td>
</tr>
<tr>
<td>25</td>
<td>1,365</td>
<td>7,224</td>
</tr>
<tr>
<td>27</td>
<td>1,390</td>
<td>7,828</td>
</tr>
<tr>
<td>28</td>
<td>1,446</td>
<td>9,452</td>
</tr>
<tr>
<td>32</td>
<td>1,462</td>
<td>10,432</td>
</tr>
<tr>
<td>34</td>
<td>1,482</td>
<td>10,672</td>
</tr>
<tr>
<td>41</td>
<td>1,505</td>
<td>11,145</td>
</tr>
<tr>
<td>39</td>
<td>1,510</td>
<td>11,558</td>
</tr>
<tr>
<td>44</td>
<td>1,528</td>
<td>12,144</td>
</tr>
<tr>
<td>46</td>
<td>1,534</td>
<td>12,422</td>
</tr>
<tr>
<td>47</td>
<td>1,559</td>
<td>13,136</td>
</tr>
<tr>
<td>49</td>
<td>1,577</td>
<td>13,712</td>
</tr>
<tr>
<td>50</td>
<td>1,582</td>
<td>13,872</td>
</tr>
</tbody>
</table>

The results in Tables 3 and 4 have been plotted on Weibull paper. Assuming that the failures are occurring in the constant failure part of the bathtub curve and increasing voltage does not take them into a wearout situation, a straight line relationship should be obtained on a Weibull plot with a \( B \) value \( = 1 \) for the third power law to hold. Within the limits of experimental error it is possible to construct a straight line through the points in Figure 1 with a \( B \) value approximately \( = 1 \). This shows the third power law is approximately correct for capacitors manufactured using screen printing.
made for the increased temperature stresses. The figure is shown merely to illustrate that these results indicate the importance of temperature as an accelerating agent.

All failures recorded in Tables 3 and 4 were due to the breakdown in insulation resistance of the capacitor.

Results from Phase II

The observed failure time for each of the temperature-voltage combinations in Phase II are shown plotted in Table 5(a) and 5(b). The results are plotted on Weibull paper and are shown in Figures 3 to 8.

Table 5(a).

| Number of Failures Versus Time as a Function of Voltage and Temperature |
|--------------------------|---------------------|---------------------|---------------------|
| 100 Volts                | 125°C    | 160°C    | 200°C    |
| Number of Failures       |          |          |          |
| 1                         | 265.0    | 67.8     | 7.6      |
| 2                         | 1,036.5  | 137.8    | 14.6     |
| 3                         | 1,227.3  | 166.8    | 15.8     |
| 4                         | 1,656.0  | 246.7    | 19.5     |
| 5                         | 272.3    | 21.4     |          |
| 6                         | 470.3    | 23.0     |          |
| 7                         | 530.7    |          |          |
| 8                         | 623.5    |          |          |
| 9                         | 1,090.1  |          |          |

All times to failure are in hours

Maximum and minimum characteristic lifetimes have been estimated and the results are shown in Table 6.

Table 5(b).

| Number of Failures Versus Time as a Function of Voltage and Temperature |
|--------------------------|---------------------|---------------------|---------------------|
| 400 Volts                | 125°C    | 160°C    | 200°C    |
| Number of Failures       |          |          |          |
| 1                         | 0.45     | 1.0      | 0.01     |
| 2                         | 3.8      | 2.9      | 0.1      |
| 3                         | 4.3      | 3.7      | 0.1      |
| 4                         | 6.2      | 5.5      | 0.4      |
| 5                         | 6.5      | 7.6      | 0.8      |
| 6                         | 28.9     | 9.5      | 1.1      |
| 7                         | 31.1     | 11.4     | 1.2      |
| 8                         | 36.3     | 11.5     | 1.2      |
| 9                         | 43.9     | 12.1     | 1.4      |
| 10                        |          | 13.0     | 1.9      |
| 11                        |          |          | 2.4      |
| 12                        |          |          | 2.5      |
| 13                        |          |          | 2.5      |
| 14                        |          |          | 2.8      |
| 15                        |          |          | 3.2      |
| 16                        |          |          | 3.45     |
| 17                        |          |          | 3.45     |
| 18                        |          |          | 3.5      |

All times to failure are in hours

Maximum and minimum characteristic lifetimes have been estimated and the results are shown in Table 6.

Table 6.

<table>
<thead>
<tr>
<th>Estimated Maximum and Minimum Characteristic Lifetimes in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (Volts)</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>125</td>
</tr>
<tr>
<td>160</td>
</tr>
<tr>
<td>200</td>
</tr>
</tbody>
</table>

Arrhenius plots of these results are shown in Figures 9 and 10. In Figure 9 a straight line is obtained and the activation energy is calculated to be 1.0 eV. In Figure 10 there is no obvious straight line which can be drawn through all three points.
However, based on the work of Rawal and Chan [4], it is postulated that two lines may be drawn as shown, corresponding to thermal runaway and at lower temperatures and avalanche breakdown at higher temperatures. The activation energy for thermal runaway again being 1.0 eV and estimated as 0.4 eV for avalanche breakdown. The maximum and minimum values of characteristic lifetimes are shown on this graph and the values of activation energy are calculated from the best lines drawn considering the associated spread at each point.

CONCLUSIONS

From this work on screen printed type X7R multilayer ceramic capacitors the following important factors have been established:

(i) Screen printed multilayer ceramic capacitors do not differ significantly from those manufactured by traditional methods.

(ii) The voltage acceleration factor, n, is shown to be approximately equal to 3.

(iii) Temperature acceleration has been demonstrated. A more detailed programme is necessary to quantify the situation.

(iv) An activation energy of 1.0 eV is shown for failures due to thermal runaway, predominant at lower voltage stress levels.

An activation energy of 0.4 eV has been estimated for avalanche breakdown failure, which tends to predominate at high voltage and temperature.

(v) Used under rated conditions type X7R screen printed multilayer ceramic capacitors have calculated characteristic lifetimes of 25 years.

REFERENCES


Fig. 1. Weibull Plot for Ceramics, Voltage Step Stressing

Cumulative percent failure vs. age at failure (hours)

Fig. 2. Weibull Plot for Ceramics, Voltage then Temperature Step Stressing

Cumulative percent failure vs. age at failure (hours)

Fig. 3. Weibull Plot for Ceramics at 100 Volts and 125 Celsius

Cumulative percent failure vs. age at failure (hours)

Fig. 4. Weibull Plot for Ceramics at 100 Volts and 160 Celsius

Cumulative percent failure vs. age at failure (hours)
Fig. 5.  
Weibull Plot for Ceramics at 100 Volts and 200 Celsius

Fig. 6.  
Weibull Plot for Ceramics at 400 Volts and 125 Celsius

Fig. 7.  
Weibull Plot for Ceramics at 400 Volts and 160 Celsius

Fig. 8.  
Weibull Plot for Ceramics at 400 Volts and 200 Celsius
Fig. 9. Arrhenius Plot for Ceramics at 100 Volt Bias

Fig. 10. Arrhenius Plot for Ceramics at 400 Volt Bias