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COMPONENT FAILURE RATES AND THEIR ROLE  
IN RELIABILITY PREDICTION

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ABSTRACT

This report details various sources of failure rate data, illustrating their uses and limitations. Failure rate data from eight sources is included. The principles involved in using this data to predict equipment reliability are included, and examples of the type of calculation involved for various systems are fully described. Useful predictions are possible but great care is necessary both in the choice of failure rate data and the actual use to which the prediction is put.

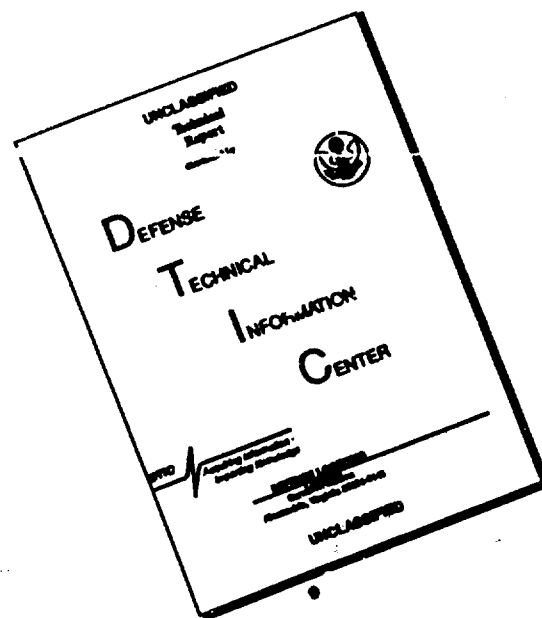
Brief mention is made of other methods of prediction eg multiple regression analysis.

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## COMPONENT FAILURE RATES AND THEIR ROLE IN RELIABILITY PREDICTION

### 1. INTRODUCTION

The prediction of reliability has become an essential part of any reliability programme, (References 8 to 12). This programme is usually carried out during the design, development and production phases of the electronic equipment. Accurate prediction becomes increasingly more difficult as the number of unrelated sources of component failure rate data used increases. Correspondingly reliability demonstration becomes that much more difficult due to the high cost and increased time required for proof of the demonstration. The outcome of a reliability prediction depends on the basic component failure rate data employed in the assessment, and the K factors applied to these failure rates. The K factors must be included to take into account the various stress levels, temperatures and environmental conditions which the equipment and components will experience during their service life. Even if the greatest care is taken in the choice of the source of data, the actual results of prediction from "component count" predictions must be treated with caution. There also appears to be some confusion on the use of component failure rates in prediction method. The object of this report is to clarify the position and to highlight many of the problem areas.

### 2. COMPONENT FAILURE RATE DATA

#### 2.1 Basic Failure Rates

There are many sources of component failure rate data available to the designer. These include data supplied by the component manufacturer, in-service records kept by the equipment manufacturer in the case of the Navy the Ship Maintenance Authority. There are also other general sources such as SRDE, RRE, UKAEA etc. Appendix A lists component failure rates from eight of these sources, the variation between the predicted reliability of an equipment when these different sources are employed can be as much as 10:1, and specific failure rates of a given component can differ by several orders of magnitude. (Reference 1). Most component failure rate tables refer to basic component failure rates. These represent the average failure rate expected from repetitive use, at a standard electrical stress level, at temperatures in the range 10-20°C and for components working in a laboratory environment. It is usually considered that 0.1 is the minimum derating factor ie ratio of operating to rated electrical stress level which should be applied to components. The failure rate is not expected to decrease significantly for stress levels below this level of 0.1. This is true for most components, although carbon composition resistors should not be so lightly loaded, and there is some indication that the failure rate for electrolytic capacitors in fact increases as the stress level is decreased. (References 2 and 3).

#### 2.2 Failure Rate Modification Factors

Failure rate modification factors are usually quoted in the published tables of component failure rates. In addition some table from American sources have included modification factors which are applied according to the manufacturer concerned. Particular examples are switches and relays. This is obviously a very complicated procedure which has not been adopted in this country.

Reliability predictions are carried out using failure rate data which is usually based on previous results or experience. This data may not be applicable to the components in current use since they may be of a new technology. Generally it can be assumed that component reliability increases with developing technology, and experience of use.

### 3. FACTORS AFFECTING EQUIPMENT RELIABILITY

#### 3.1 Component Reliability

Equipment reliability is defined as the probability that the equipment will perform its specified function under the specified conditions for which it is designed, for a specified period of time. A predicted reliability for an equipment, based on component failure rate data can take into account the "specified conditions" but does not usually include any "unspecified conditions" such as degradation introduced by the user, by transport hazards or by the maintenance personnel. Any attempts to include factors to allow for such conditions would require a knowledge of the users works facilities, what sort of maintenance organisations and personnel skills existed, and many other factors difficult to define.

These external factors must be borne in mind by the equipment designers during the design and development and production of an equipment. The effects of such external factors should be minimised by ensuring that the equipment is difficult to misuse and simple to maintain. The predicted reliability of an electronic equipment is largely dependent on the individual components that form the equipment, together with the wiring and inter-connections. The achieved reliability is governed, to a larger extent, by the manufacturers organisational procedures, such as purchasing, inspection and quality control, partly by the mechanical design and layout of the components in the equipment, and partly by the users ability to maintain the equipment adequately.

An equipment designer may achieve the required performance for a given function by means of several different circuit configurations, but it is the number and type of components involved in that circuit that will primarily influence the reliability. Sub-division of the equipment into separate units and considerations of the method of connecting these units together with the use of redundancy has an important bearing on the reliability and will be discussed further in Section 4.

#### 3.2 Component Failures

The causes of equipment failures can be divided into two categories. The first category is "equipment manufacturers error". This includes broken wires, unsoldered joints, incorrect component tolerances, setting up errors etc. The second category is "component failure". This latter may be further sub-divided to include the cause of the component failure. For example:-

- (a) User error, eg misuse.
- (b) Equipment manufacturers error, eg incorrect component choice.
- (c) Design error, eg incorrect tolerance, overload, or poor circuit design.
- (d) Failure due to physical properties of the component - (end of life).
- (e) Component manufacturers error, eg faulty batch etc.
- (f) Random failure.

#### 3.3 Equipment Reliability

If the equipment is of sufficient importance to warrant extensive reliability studies in the design phase the number of failures associated with the component stress levels will be comparatively small. Such failures, if they occur

unexpectedly, are usually design errors, and because the causes are known, they can be rectified before the equipment goes into production. If it has already gone into production before the fault is discovered, a post design modification can be carried out to prevent a reoccurrence of the failure. If the frequency of occurrence of the failures is acceptable and in general agreement with the predicted reliability, these could be assumed to be random failures and there would be no need for any action. However, if the frequency of failure is unacceptable and the equipment reliability does not come up to the predicted required value, a major modification might be necessary and consideration should then be given to the possible use of redundancy. Size and weight limitations might rule out its successful adoption. The breakdown of a large equipment into various identifiable sub-units can be useful to determine which units are the least reliable and where extra attention should be focused. A "measles" chart can often prove most helpful and this approach will be discussed more fully in a later report.

#### 3.4 Use of Burn-in

The type of failure where the cause is discoverable and assignable although troublesome and undesirable, can nearly always be designed out (given enough time and money). Eventually these faults and failures become less predominant than those failures due to manufacturing defects and random failures. These latter failures are unpredictable and are not necessarily accelerated by the stresses in the working environment. However, the use of burn-in at the component level can greatly reduce the number of components in a new equipment developing these defects. The added cost of carrying out the burn-in tests must be compared with the expected gain in reliability in order to determine its cost effectiveness. For example at a cost of approximately 5p per transistor it would represent value for money if the number of premature failures is reduced as a result. It is proposed to publish a much more detailed report in the near future on the effectiveness of burn-in as a procedure for improving equipment reliability.

#### 3.5 Other Failures

All electronic equipment contains other sources of failure apart from component failure - eg soldered, welded, wrapped joints, connecting wires and even setting up and adjusting procedures can be considered as faults. These all contribute to the potential unreliability of an equipment and should be included in any reliability prediction. Failure rates for these "hidden components" are found in most failure rate data tables but they are often found to vary by as much as 500:1.

#### 3.6 Element of Doubt

If the basic failure rate for components was defined as the failure rate that would be achieved by the components operating under the most suitable conditions for their physical and mechanical structure, then the inherent reliability of an equipment composed of such components would be determined solely by the reliability of the components working under their own individual conditions. All the activities involved in preparing the component to become part of an equipment, designed to fulfil a specified role, eg assembling the components on to printed circuit boards, operating the components under stresses that are likely to affect their basic reliability, subjecting them to vibration or shock can only degrade the inherent reliability of that component. Whilst there are variations in the procedures for derating and applying failure rate corrections for different electrical stresses and ambient temperatures, these are not as serious as the variations that exist in the common basic failure rate tables from various sources. (Reference 4 and Appendix I). There are several reasons why these basic variations exist - the use of usage data from different sources being the prime reason. These

variations in basic failure rate are so diverse that they have created an element of doubt about the value of prediction as a useful tool. Many people believe this doubt will only be overcome when a British failure rate handbook, on the lines of the US documents listed as References 5, 6 and 7, is compiled. To create such a handbook, which if available would enable every equipment manufacturer to accurately predict the reliability of his equipment and which would enable a user to assess the reliability of an equipment that he has ordered, is a very difficult problem. Even if such a handbook could be produced, reliability prediction would still be looked upon as an incomplete and suspect procedure, until valid measurements have been carried out to determine the magnitude of the factors affecting reliability, i.e. the application factors to allow for non perfect conditions. The exclusion of an application factor, such as the human error factor, can result in large differences between the predicted reliability and the reliability actually observed in use. A single handbook employed generally, however, would be an improvement over the present situation where the most convenient source of information is often chosen with little regard to the validity of the data for the particular equipment under study. Assuming such a handbook could be produced, the next need would be for a set of rules to apply application factors. In order to achieve these application factors it would be necessary for all component failures observed in the use environment to be related to user error, equipment design, manufacturers error, known failure modes for the component etc, then it might be possible to achieve accurate values for these application factors which would then be applied to the basic failure rate data. It is unlikely and probably impractical for all failures observed on board HM Ships to be assigned to a specific 'cause of failure' category. Another major difficulty would be the allocation of failure rate data to components manufactured by specific manufacturers although it is highly improbable that all components manufacturers could produce a component made to meet a specification which all had identical failure rates. Thus even if the components are manufactured to meet the same specification, the failure rates for different manufacturers are still likely to vary. A fully comprehensive common source of failure rate data for components would therefore have to specify the manufacturers, the electrical stress and the temperature which would apply for that given component. The final outcome in practice is likely to be some compromise of a given failure rate for a generic type of component. Failures caused by defective manufacture cannot be controlled by the equipment manufacturer (unless burn-in is employed) because it is dependent on the component manufacturers processes. (Reference 8.) This leads to a basic requirement discussed above for a failure rate handbook, which in addition to identifying the component by the specification to which it is designed and manufactured, would also name the manufacturer and allocate failure rates based on his manufacturing processes and controls, or specify a failure rate which must be modified by a given factor related to the component manufacturers capability. This appears an impractical requirement. With the adaptation of BS9000, however, any variation in the manufacturers processes which result in varying component quality and reliability will be immediately observed by reference to the Certified Test Records for samples which will be taken from every production lot. This in itself should help keep variations between manufacturers to a minimum, but components outside of BS9000 will be more difficult to assess.

#### 4. RELIABILITY PREDICTION

A reliability prediction based on a simple component count assumes that the component failures will occur independently and that no component failure will influence the chance of failure of other components. It also assumes that the component failure rate will be constant during the useful life of the equipment. This assumption implies a mathematical model based on the exponential distribution. This is the most widely used distribution in the field of reliability and may be expressed as follows:-

$$R(t) = e^{-\lambda t}$$

where  $R(t)$  is the reliability function, ie the probability that the equipment will function without failure during a time  $t$ , and  $\lambda$  is the failure rate for the equipment.  $\lambda$  must be assessed by an acceptable method if the equation is to be valid.

#### 4.1 Series Systems

The simplest method of estimating the reliability of an electronic equipment is to assume that all the components are capable of causing equipment failure and that they are connected in series. The equipment reliability is determined by summing the component failure rate data and substituting in the exponential expression. The result is derived from the product rule of reliability which (1) states that the reliability  $R(t)$  of a circuit consisting of  $n$  components, is the product of the individual components.

$$\text{ie } R(t) = R_1(t) \times R_2(t) \times R_3(t) \times \dots \times R_n(t) \quad (2)$$

$$\text{or } e^{-\lambda t} = e^{-\lambda_1 t} \times e^{-\lambda_2 t} \times e^{-\lambda_3 t} \times \dots \times e^{-\lambda_n t} \quad (3)$$

$$\text{ie } \lambda = \lambda_1 + \lambda_2 + \lambda_3 + \dots + \lambda_n \quad (4)$$

This expression indicates that in order to obtain the reliability of an equipment ( $\lambda$ ), consisting of a series system, in the same terms as those used for components, it is only necessary to add up all the component failure rates. If the application factors are the same for all the components, it can be applied to the overall failure rate, but if the application factors are different then they must be applied at the component level and not at the system level.

#### 4.2 Reliability Index

A reliability index often quoted is the meantime between failure, MTBF. This usually represents the average time between failures which can be expected for an equipment during the portion of its life cycle in which the exponential law applies. The value of the equipment MTBF is determined from the integral:

$$MTBF = \int_0^{\infty} R(t) dt$$

In the special case of the exponential distribution  $R(t) = e^{-\lambda t}$

$$\therefore MTBF = \int_0^{\infty} e^{-\lambda t} dt = \left[ \frac{-e^{-\lambda t}}{\lambda} \right]_0^{\infty} = \frac{1}{\lambda}$$

Thus the MTBF of a series system in the exponential case is given by

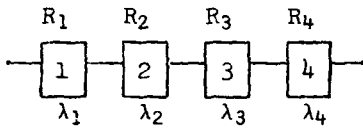
$$MTBF = \frac{1}{\lambda} = \frac{1}{\lambda_1 + \lambda_2 + \lambda_3 + \dots + \lambda_n}$$

The same rule applies when the failure rate of an equipment consisting of several sub-units is required. The failure rate for each sub-unit is calculated, assuming a series system for the components within that sub-unit, and then these failure rates are summed to give the equipment failure rate.



4.3 Redundancy

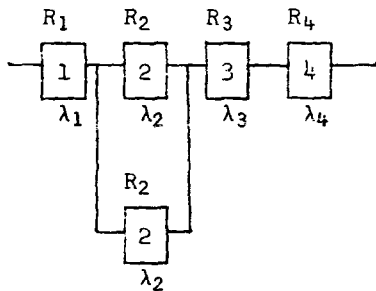
If the reliability of a sub-unit contained in an equipment is too low and the equipment reliability does not come up to the required level, then a similar sub-unit may be connected in parallel either as an operating unit or as a standby unit, in order to improve the reliability. This is known as redundancy. Consider first of all the case of an active parallel redundant system ie one in which both units are working. Assume that an equipment consists of four sub-units, 1 to 4, and that the failure rate of unit 2 is too high:-



The reliability of the equipment as shown above is:-

$$R = R_1 \times R_2 \times R_3 \times R_4$$

If a second, similar, sub-unit is connected in parallel with 2, the reliability is increased as shown below:-



To Calculate

The effective reliability of sub-unit 2 is calculated as below:-

Let  $R_2^1$  be the new reliability of the parallel combination,

then  $Q_2$  is the unreliability of a unit  $R_2$

Thus unreliability of the parallel combination  $R_2$  with  $R_2$  is  $(Q_2)^2$

Hence reliability of the parallel combination =  $R_2^1 = 1 - (Q_2)^2$

But  $Q_2 = (1 - R_2)$

Hence  $R_2^1 = 1 - (1 - R_2)^2$

$$= 1 - 1 + 2R_2 - (R_2)^2$$

$$= 2R_2 - (R_2)^2$$

and the equipment reliability becomes:-

$$R^1 = R_1(2R_2 - R_2^2)R_3R_4$$

$$= 2R_1R_2R_3R_4 - R_1R_2^2R_3R_4.$$

But since reliability index can never be greater than 1, then  $R_1R_2^2R_3R_4$  must be less than  $R_1R_2R_3R_4$  and hence the original reliability  $R$  must be less than the new reliability  $R^1$ .

The mean time between failure of the two units in parallel is determined as follows:-

$$MTBF = \int_0^{\infty} R_2^1 dt = \int_0^{\infty} (2R_2 - R_2^2) dt$$

$$= \int_0^{\infty} (2e^{-\lambda t} - e^{-2\lambda t}) dt$$

$$= \frac{3}{2\lambda}$$

ie the MTBF of two similar units connected in parallel is one and a half times the MTBF of one such unit.

Another type of redundancy often employed in sequential redundancy in which one sub-unit operates until failure and then another takes over after a switching operation. The simplest way of representing the reliability of two identical units with failure rates  $\lambda$ , assuming 100% reliability for the sensing and switching device is obtained by taking the first two terms of the Poisson distribution:-

$$R = e^{-\lambda t}(1 + \lambda t)$$

If the reliability of the switching device is taken into account then this expression has to be modified to:-

$$R = e^{-\lambda t}(1 + R_{SS} \lambda t)$$

where  $R_{SS}$  represents the reliability of the switching device. The MTBF of the system with perfect switching can be determined as follows:-

$$MTBF = \int_0^{\infty} e^{-\lambda t}(1 + \lambda t) dt = \frac{2}{\lambda}$$

ie the MTBF is twice the MTBF of one unit - as expected for a system with perfect switching. The reliability of a sequential system can be determined only if the reliability of the switching device is known.

#### 4.4 Estimation of Equipment Failure Rate

The principle of estimating the failure rate of an equipment is relatively simple, although the manner in which it is carried out can become very complicated. It is usual to predict the equipment reliability at specified stages of design where various K factors are applied. These K factors can be any or all of the following: electrical stress, temperature effects, application and operational conditions, failure mode distribution, packaging, transit hazards etc. There appears to be no data available to support the choice of the values which are assumed for the above

K factors, but it is usual to adopt generally accepted standard eg MIL STD 217A, etc. The reliability prediction techniques described in this report are indicated in the following example of an amplifier circuit.

#### 4.5 Example of Reliability Prediction

During a feasibility study, it is estimated that a proposed circuit to be manufactured will consist of 8 resistors, 4 capacitors, 2 transistors, 2 diodes, 1 variable resistor and 30 soldered joints.

The predicted MTBF for this circuit is determined as follows:-

| Components         | No off | Failure rate<br>% per 1000 hrs | Total failure rate<br>% per 1000 hrs | Type of<br>Component |
|--------------------|--------|--------------------------------|--------------------------------------|----------------------|
| Resistors          | 8      | 0.005                          | 0.04                                 | Fixed<br>Composition |
| Capacitors         | 4      | 0.05                           | 0.20                                 | Metallised<br>Paper  |
| Transistors        | 2      | 0.008                          | 0.016                                | Silicon <1 W         |
| Variable Resistors | 1      | 0.3                            | 0.30                                 | Wirewound            |
| Soldered Joints    | 30     | 0.001                          | 0.03                                 | -                    |
| Diodes             | 2      | 0.005                          | 0.01                                 | Silicon <1 W         |
| TOTAL              |        |                                | 0.596 per 1000 hours                 |                      |

$\therefore \text{MTBF} = \frac{10^5}{0.596} = 167,800 \text{ hrs.}$  This purely on theoretical grounds using basic failure rates which assume that the components are operating at 0.1 stress level.

A revised prediction of the MTBF is then carried out during the design stage when the circuit diagram is available and the components have been selected and their characteristics are known, together with the stresses. The stressed for rating would result from a computer design exercise performed on the circuit.

The modified reliability prediction based on the actual circuit diagram (figure 1) is shown in Table 1. The various K factors are assumed to be known, or available from some source.

TABLE 1

| Circuit Reference    | Failure Rate % per 1000 hrs | Maximum Stress | In use Stress | K <sub>1</sub> (rating) | K <sub>2</sub> (environment) | K <sub>3</sub> (temperature) | In use Failure Rate % per 1000 hrs |
|----------------------|-----------------------------|----------------|---------------|-------------------------|------------------------------|------------------------------|------------------------------------|
| R1                   | 0.01                        | 1.5 W          | 0.36 W        | 1.2                     | 1.5                          | 1.5                          | 0.027                              |
| R2                   | 0.005                       | 150 mW         | 15 mW         | 1.0                     | 1.5                          | 1.5                          | 0.01125                            |
| R3                   | 0.005                       | 150 mW         | 10 mW         | 1.0                     | 1.5                          | 1.5                          | 0.01125                            |
| R4                   | 0.005                       | 150 mW         | 15 mW         | 1.0                     | 1.5                          | 1.5                          | 0.01125                            |
| R5                   | 0.005                       | 150 mW         | 5 mW          | 1.0                     | 1.5                          | 1.5                          | 0.01125                            |
| R6                   | 0.005                       | 150 mW         | 36 mW         | 1.2                     | 1.5                          | 1.5                          | 0.0135                             |
| C1                   | 0.05                        | 120 V          | 12 V          | 1.0                     | 1.5                          | 1.5                          | 0.1125                             |
| C2                   | 0.05                        | 100 V          | 8 V           | 1.0                     | 1.5                          | 1.5                          | 0.1125                             |
| C3                   | 0.04                        | 12 V           | 5 V           | 3.0                     | 1.5                          | 1.5                          | 0.1125                             |
| TR1                  | 0.008                       | 125 mW         | 6 mW          | 1.0                     | 1.5                          | 1.5                          | 0.018                              |
| TR2                  | 0.008                       | 125 mW         | 15 mW         | 1.0                     | 1.5                          | 1.5                          | 0.018                              |
| D1                   | 0.005                       | 150 mW         | 1 mW          | 1.0                     | 1.5                          | 1.5                          | 0.01125                            |
| D2                   | 0.005                       | 150 mW         | 1 mW          | 1.0                     | 1.5                          | 1.5                          | 0.01125                            |
| D3(Zener)            | 0.01                        | 150 mW         | 10 mW         | 1.0                     | 1.5                          | 1.5                          | 0.0225                             |
| VR1                  | 0.30                        | 1 W            | 30 mW         | 1.0                     | 1.5                          | 1.5                          | 0.675                              |
| Solder Joints = 33   | 0.033                       | -              | -             | 1.0                     | 1.5                          | 1.5                          | 0.07425                            |
| ie MTBF = 70,921 hrs |                             |                |               |                         |                              | TOTAL                        | 1.41075                            |

A comparison of the two predicted MTBF's indicates that the estimated MTBF has decreased from the initial value of 167,800 hrs to a final value of 70,921 hrs when the actual circuit diagram is available and the component stresses etc are known and allowed for. It should be noted that the final circuit chosen had a slightly different component count.

##### 5. THE USE OF A COMPUTER FOR PREDICTION

From the above table, the simplicity of the method is obvious, but the designers' great difficulty is in obtaining the data to put into the table.

The calculations etc can be very easily performed using a computer, and a program exists (Reference 8), in which allowance can be made for the various K factors shown in the table.

It is hoped in a later technical report to show the use of this program on an actual Naval equipment.

## 6. CONCLUSIONS

The predicted MTBF calculated by the technique described above is based on random failure rate data, and, therefore, any component failures which are due to design faults cannot be allowed for in the prediction. The general disillusionment with the value of reliability prediction is probably due to the fact that the predicted value is expected to be within 5% of the actual value. Reliability predictions are a worthwhile endeavour if carried out without bias and the correct interpretation placed on the outcome. Where a competitive type of assessment is acceptable, ie one design against another the use of general failure rate data is permissible, but where serious attempts are made to estimate with reasonable accuracy the reliability of an equipment, failure rates should be used with extreme caution. To make an assessment of reliability meaningful, the component failure rates employed should be representative of the failure rates observed in the Fleet. It is appreciated that the collection of data to obtain these observed failure rates is difficult, but attempts are being made.

The prediction of reliability is often referred to as the "numbers game" and if used to predict overall equipment reliability, useful figures can be obtained but must be used with caution, realising all the conditions under which the prediction was made. If the prediction for individual components are used for subsequent purposes, much more care must be taken. In the overall prediction a certain amount of swings and roundabouts take place, so that the final result is often acceptably close to the observed result. This swings and roundabouts effect does not operate in the case of individual components.

Lastly in the Appendices are listed basic failure rates from a number of sources. At present no approved Naval list exists, and it will be obvious from this report that there would be considerable difficulty in producing and keeping up to date such a list. Other methods of prediction are possible, one promising one being the use of multiple regression techniques together with feedback for the Fleet. In this method an accurately known component failure rate is not essential to the prediction.

## 7. WARNING

The engineer may often find, after completing a predicted reliability exercise, that figure obtained for the MTBF is grossly optimistic when compared with the first models of the equipment. Typically he may find that his prediction gave say 500 hours MTBF and in practice he is obtaining 20 hours MTBF.

This has been shown by work in the United States (Ref 6.) to be typical. However, after a running in period it is usually found that an accuracy of 2:1 or better is possible.

## 8. ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance given by Dr W D K Davies, formerly of ASWE, in the preparation of this report.

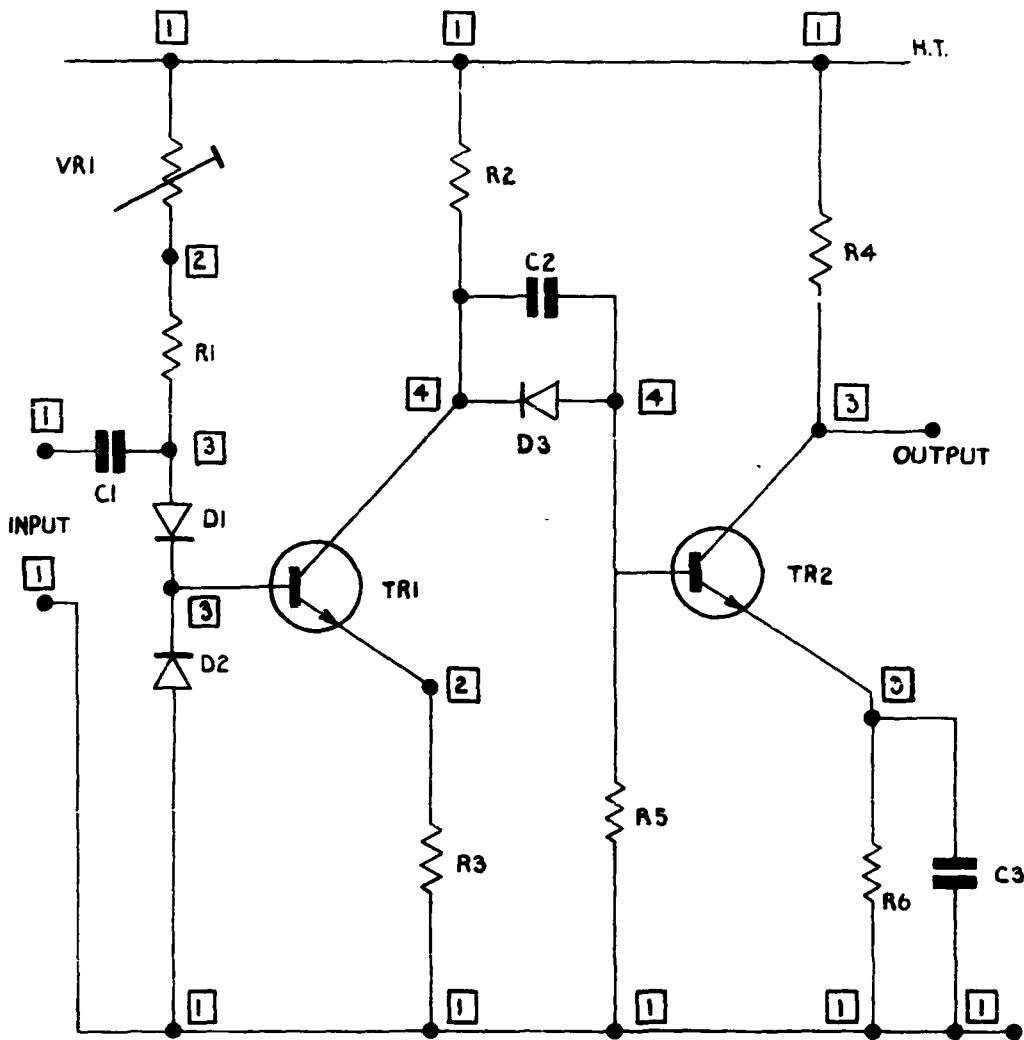
9. REFERENCES

1. Davies W D K and Collins C J. "Equipment Reliability, (U)", 1970. Unpublished MOD Report.
2. Sage M G. "Service, life and reliability of Mullard electrolytic capacitors". Mullard Technical Communications, Vol 8, No 79, Jan 1966, pp 275-282.
3. Mason D. "High-grade long-life electrolytic capacitors: the 106/107 series in power supply design". Mullard Technical Communications, Vol 11, No 106, July 1970, pp 122-129.
4. Davies W D K and Collins C J. "Component reliability observed in Type 993, 965 and 978 radars (U)", 1970. Unpublished MOD Report.
5. "Reliability stress and failure rate data for electronic equipment", 1965. Unpublished US DOD Report.
6. Reliability Notebook, Vol II, 1967. Unpublished USAF Report.
7. Failure Rate Data Handbook, 1965. Unpublished USN Report.
8. Program RELIAB, Redac Software Ltd, Tewkesbury, Glos.
9. Davies W D K and Walter N A "Reliability Demonstration". Unpublished MOD Report.
10. Walter N A. "Monte Carlo circuit analysis and reliability", 1971. Unpublished MOD Report.
11. Walter N A. "Device modelling for use in computer-aided design", 1970. Unpublished MOD Report.
12. Walter N A. "Models of operational amplifiers and active devices for use in Computer-aided design", 1970. Unpublished MOD Report.

Reports quoted are not necessarily available to members of the public or to commercial organisations.

# THEORETICAL CIRCUIT OF AMPLIFIER FOR RELIABILITY ANALYSIS

1



□ = No. OF SOLDERED JOINTS

APPENDIX A

COMPONENT FAILURE RATE DATA

Basic failure rate data (in % per 1000 hours) from several sources has been collected and tabulated. The failure rates quoted in A, B, C, D and F refer to a "fixed ground" environment, ie equipment operating under ideal laboratory conditions. The failure rate data quoted in E, G and H refers to airborne equipment.

Failure rates tabulated assume the following ratings:-

|                 |                           |  |   |
|-----------------|---------------------------|--|---|
| <u>Source A</u> | resistors                 | $\frac{1}{10}$ th max watts            |   |
|                 | capacitors                | $\frac{1}{10}$ th max volts            |   |
|                 | transistors/diodes        | $\frac{1}{10}$ th max power            |   |
|                 | temperature               | 10 °C to 20°C                          |   |
| <u>Source F</u> | resistors and transistors | 75% of rated power at operating temp   |   |
|                 | diodes                    | 50% of rated power at operating temp   |   |
|                 | transformers              | 80% of rated power at operating temp   |   |
|                 | capacitors                | 75% of rated voltage at operating temp |   |
| <u>Source E</u> | transistors               | 75% of rated power                     |   |
|                 | diodes                    | 50% of rated power                     |   |
|                 | resistors                 | 80% of rated power                     |   |
|                 | capacitors                | 75% of rated voltage                   |   |
|                 | transformers              | 80% of rated power                     |   |
| <u>Source D</u> | resistors                 | (i) power derating factor              | 0.2 to 0.5  |
|                 |                           | (ii) ambient temperature               | 40°C  |
|                 |                           | (iii) relative humidity                | < 60%   |
|                 | capacitors                | (i) voltage derating factor            | 0.2 to 0.5  |
|                 |                           | (ii) ambient temperature               | 40°C  |
|                 |                           | (iii) relative humidity                | < 60%   |
|                 | semiconductors            | (i)                                    | in between 0.3 and 0.5  |
|                 |                           | (ii) relative humidity                 | < 60%   |
|                 |                           | (iii)                                  | failure rates apply only to digital circuits, for analogue applications, multiply failure rate by 2 |
|                 | IC's                      | (i) ambient temperature                | 40°C  |
|                 |                           | (ii) relative humidity                 | < 60%   |



BEARINGS

| Source<br>Type  | A | B | C   | D | E | F    | G | H     |
|-----------------|---|---|-----|---|---|------|---|-------|
| Ball Heavy Duty |   |   | 2.0 |   |   | )    |   |       |
| Ball Light Duty |   |   | 1.0 |   |   | )    |   | 0.019 |
| Plain           |   |   |     |   |   | )0.4 |   | 0.002 |
| Roller          |   |   | 0.5 |   |   | )    |   |       |
| Sleeve          |   |   | 0.5 |   |   | )    |   |       |

FIXED CAPACITORS

|                              |      |      |      |       |     |      |      |       |
|------------------------------|------|------|------|-------|-----|------|------|-------|
| Paper                        | 0.1  | 0.1  | 0.1  | 0.004 | 0.5 | 0.06 | 0.02 | 0.003 |
| Metallized Paper             | 0.05 | 0.08 | 0.05 |       | 0.3 | 0.06 |      |       |
| Plastic Film                 | 0.01 |      |      |       |     |      |      | 0.038 |
| Glass and Mica               | 0.03 | 0.05 | 0.03 | 0.004 | 0.2 | 0.03 | 0.03 |       |
| Ceramic                      | 0.01 | 0.07 | 0.01 | 0.001 | 0.2 | 0.03 |      | 0.006 |
| Electrolytic,<br>Al. Foil    | 0.2  | 0.4  | 0.1  | 0.08  | 1.0 |      |      |       |
| Electrolytic,<br>Tant. Foil  | 0.1  | 0.1  | 0.1  | 0.01  | 1.0 |      |      |       |
| Electrolytic,<br>Tant. Wet   | 0.02 | 0.05 | 0.05 | 0.002 | 1.0 |      | 0.02 | 0.007 |
| Electrolytic,<br>Tant, Solid | 0.04 | 0.07 | 0.01 | 0.015 | 0.5 |      | 0.04 | 0.023 |

VARIABLE CAPACITORS

|         |       |  |     |       |     |  |      |  |
|---------|-------|--|-----|-------|-----|--|------|--|
| Air     | 0.005 |  | 0.2 | 0.008 | 1.0 |  |      |  |
| Ceramic | 0.04  |  | 0.2 | 0.015 | 1.0 |  |      |  |
| Piston  | 0.01  |  |     | 0.008 | 1.0 |  |      |  |
| Glass   |       |  |     |       | 1.0 |  | 0.01 |  |

CONNECTIONS

|                   |        |        |       |          |       |        |  |         |
|-------------------|--------|--------|-------|----------|-------|--------|--|---------|
| Soldered          | 0.001  | 0.005  | 0.002 |          |       |        |  | 0.00073 |
| Crimped           | 0.002  | 0.005  |       |          | 0.005 | 0.001  |  |         |
| Welded            | 0.004  | 0.0005 |       |          | 0.001 | 0.0005 |  |         |
| Wrapped           | 0.0001 | 0.001  |       | 0.000007 | 0.001 | 0.0007 |  |         |
| Soldered, Hand    |        |        |       | 0.00007  | 0.02  | 0.005  |  |         |
| Soldered, Machine |        |        |       | 0.00005  | 0.003 | 0.001  |  |         |

CONNECTORS

| Type \ Source                   | A     | B     | C    | D      | E  | F     | G | H |
|---------------------------------|-------|-------|------|--------|--|-------|---|---|
| Coaxial                         | 0.2   | 0.1   |      | 0.05   | 1.0  |       |   |   |
| Multipin (Per Pin)              | 0.005 |       |      |        | 0.05<br>) sealed<br>) 0.03<br>) non-<br>) sealed |       |   |   |
| Edge (Per Pin)                  | 0.01  | 0.005 |      | 0.0002 |  | 0.001 |   |   |
| Multipin, Circular (Per Pin)    |       | 0.02  |      |        |  |       |   |   |
| Multipin, Rectangular (Per Pin) |       | 0.01  |      |        |  |       |   |   |
| Printed CCT Contact (Per Pin)   |       |       | 0.01 |        | 0.01   |       |   |   |
| External Connectors (Per Pin)   |       |       |      |        |  | 0.01  |   |   |

DIODES

|                               |   |      |       |  |      |  |                           |       |
|-------------------------------|---|------|-------|--|------|--|---------------------------|-------|
| Germanium Alloy Junction      | 0.08                                      |      | 0.02  | 0.03                                       |      | 1.0                                    |                           |       |
| Germanium Gold Banded         |   | 0.05 | 0.02  |  |      |  |                           |       |
| Germanium Pointed Contact     |   |      | 0.05  |  |      |  |                           |       |
| Germanium Signal Microwave    |   |      |       |  |      |  | 1.0<br>) 2.0 to<br>) 10.0 |       |
| Silicon                       | <1 watt<br>) 0.005<br>) >1 watt<br>) 0.05 | 0.05 |       | >1 watt<br>) 0.002<br>) >1 watt<br>) 0.005 |      | Planar<br>) 0.005<br>) other<br>) .025 |                           | 0.013 |
| Silicon Alloy Junction Signal |   |      | 0.01  |  |      |  | 0.1                       |       |
| Silicon Planar                |   |      | 0.002 |  |      |  | <0.001                    |       |
| Silicon Power                 |   |      |       |  |      |  | 0.2                       |       |
| Silicon Zener Signal          | 0.01                                      |      | 0.1   |  | 0.05 |  |                           | 0.065 |
| Zener                         |   | 0.1  |       | 0.01                                       | 0.1  | 0.05                                   |                           |       |
| Zener or Varactors            |   |      |       |  | 1.0  |  |                           |       |
| Power                         |   |      |       |  | 0.2  |  |                           |       |

FILTERS

|                             |  |     |  |  |     |  |     |  |
|-----------------------------|--|-----|--|--|-----|--|-----|--|
| LF<br>Low Pass<br>R.F. I.F. |  | 0.8 |  |  | 1.0 |  | 0.2 |  |
|-----------------------------|--|-----|--|--|-----|--|-----|--|

GYROS

| Type \ Source   | A | B | C   | D | E    | F   | G | H     |
|-----------------|---|---|-----|---|------|-----|---|-------|
| Gyro Rate       |   |   |     |   |      |     |   | 0.586 |
| Position        |   |   |     |   |      |     |   | 3.37  |
| Gyroscope, Free |   |   | 5.0 |   | 4.0  | 5.0 |   |       |
| Rate            |   |   |     |   | 10.0 | 7.5 |   |       |

INDUCTORS

|        |      |     |      |      |     |      |  |  |
|--------|------|-----|------|------|-----|------|--|--|
| A.F.   | 0.05 |     |      |      |     |      |  |  |
| R.F.   | 0.08 | 0.1 | 0.03 |      | 0.5 |      |  |  |
| I.F.   | 0.05 |     |      |      |     |      |  |  |
| Choke  |      |     |      |      |     | 0.02 |  |  |
| Power  |      |     |      | 0.03 |     |      |  |  |
| Signal |      |     |      | 0.01 |     |      |  |  |

INTEGRATED CIRCUITS

|  |      |  |  |      |   |       |   |      |
|--|------|--|--|------|---|-------|---|------|
| Thin Film - Nickel - Chromium resistors, silicon dioxide capacitors, gold wiring on glass or ceramic substances, flip-flop transistors | 0.08 |  |  | 0.08 | ) |       |   |      |
| Thin Film - All tantalum, with flip-chip transistors   | 0.05 |  |  | 0.05 | ) |       |   |      |
| Thick Film: All types with flip-chip transistors   | 0.1  |  |  | 0.1  | ) | 0.3   |   |      |
| SIC. Linear in TO5 etc. containers   | 0.03 |  |  | 0.03 | ) | )     |   |      |
| Linear in flatpack containers  | 0.03 |  |  | 0.03 | ) | )     |   |      |
| Linear in plastic containers   | 0.04 |  |  | 0.04 | ) | 0.125 | ) | 0.05 |
| Linear in flip-chips containers  | 0.06 |  |  | 0.06 | ) | )     |   |      |
| Digital. In TO5 etc containers   | 0.01 |  |  | 0.01 | ) | )     |   |      |
| In Flatpack containers   | 0.01 |  |  | 0.01 | ) | )     |   |      |
| In Plastic containers  | 0.02 |  |  | 0.02 | ) | 0.05  | ) | 0.02 |
| In Flip-chips containers   | 0.05 |  |  | 0.05 | ) | )     |   |      |

LAMPS

| Type \ Source   | A    | B    | C   | D | E    | F    | G | H |
|-----------------|------|------|-----|---|------|------|---|---|
| Neon            | 0.02 | 0.05 |     |   | 0.05 | 0.05 |   |   |
| Filament        | 0.1  | 1.0  | 1.0 |   | 0.5  | 0.5  |   |   |
| Fluorescent     |      |      | 1.0 |   |      |      |   |   |
| Neon Indicators |      |      | 0.2 |   |      |      |   |   |
| Lamp Holders    |      |      |     |   |      |      |   |   |

METERS

|                 |      |     |     |   |     |     |  |       |
|-----------------|------|-----|-----|---|-----|-----|--|-------|
| A.C. )          | )    |     |     | ) |     | 0.3 |  |       |
| D.C. )          | )    |     |     | ) |     | 0.5 |  |       |
| With solenoid ) | )    |     |     | ) |     |     |  |       |
| and flag )      | 0.01 | 0.1 |     | ) | 0.3 | 0.7 |  |       |
| Moving Coil )   | )    |     | 0.3 | ) |     |     |  | 0.592 |
| Metrosil )      | )    |     |     | ) |     |     |  | 0.183 |

MICROWAVE ELEMENTS

|                     |  |  |  |       |      |       |    |  |
|---------------------|--|--|--|-------|------|-------|----|--|
| TR Cell             |  |  |  |       | 0.5  | 10    | 10 |  |
| Fixed Cavity        |  |  |  | 0.001 |      | 0.001 |    |  |
| Tuned Cavity        |  |  |  | 0.01  | 0.05 | 0.05  |    |  |
| Fixed Stub          |  |  |  | 0.001 |      | 0.001 |    |  |
| Tuned Stub          |  |  |  | 0.01  | 0.05 | 0.05  |    |  |
| Directional Coupler |  |  |  | 0.001 |      | 0.001 |    |  |

MISCELLANEOUS 1

|                               |       |      |     |   |      |      |  |       |
|-------------------------------|-------|------|-----|---|------|------|--|-------|
| Sensors Low Chamber and loads |       |      | 0.5 |   |      |      |  |       |
| Sensors Photo-electric cells  |       |      | 1.5 |   |      |      |  |       |
| Sensors Strain Gauges         |       |      | 2.5 |   |      |      |  |       |
| Sensors Thermo Couplers       |       |      | 1.0 |   |      |      |  |       |
| Rectifiers Copper) Oxide )    |       |      |     | ) |      |      |  |       |
| Rectifiers Selenium )         | 0.2   |      |     | ) | 1.0  |      |  |       |
| Fuses Cartridge               | 0.002 | 0.08 | 0.5 |   | 0.08 | 0.03 |  |       |
| Fuses Fuse Holders            |       |      | 0.1 |   |      |      |  | 0.018 |

MISCELLANEOUS 2

| Source<br>Type                 | A    | B    | C     | D    | E   | F       | G    | H     |
|--------------------------------|------|------|-------|------|-----|---------|------|-------|
| Accelerometer                  |      |      |       |      | 7.5 | 4.0     |      |       |
| Alternator                     |      |      | 0.7   |      |     |         |      |       |
| Amplifier                      |      |      |       |      |     |         |      | 0.02  |
| Batteries                      |      |      | 0.1   |      |     |         |      |       |
| Belt Drives                    |      |      | 4.0   |      |     |         |      |       |
| Belts                          |      |      | 0.002 |      |     |         |      |       |
| Cams & Followers               |      |      |       |      |     | 0.2     |      | 0.156 |
| Contactors                     |      |      | 0.03  |      |     |         |      |       |
| Crystals                       | 0.05 | 0.05 |       |      | 0.3 | 0.05    | 0.02 |       |
| Encoder                        |      |      |       |      |     | 2.0     |      |       |
| Gears                          |      |      |       |      |     | 0.5     |      | 0.018 |
| Instruments Elect<br>Indicator |      |      |       |      | 0.6 |         |      |       |
| Isolators Power,<br>Ferrite    |      |      |       | 0.2  | 2.5 |         |      |       |
| Synchros                       | 0.5  |      |       |      | 1.0 | ) Brush | 0.4  |       |
|                                |      |      |       |      |     | ) Slab  | 0.1  |       |
| Thermistors                    | 0.06 |      |       | 0.05 |     | 0.03    |      |       |

MOTORS

|                  |     |     |     |  |  |     |     |      |
|------------------|-----|-----|-----|--|--|-----|-----|------|
| Small, General   | 0.5 |     | 1.0 |  |  |     |     |      |
| Small, Stopper   | 0.3 |     |     |  |  |     |     |      |
| Small, Brush     |     |     |     |  | 2.0  | 1.1 |     |      |
| Small, Brushless |     |     |     |  | 0.1  | 0.7 |     |      |
| Generator A.C.   |     |     |     |  |  | 1   |     | 0.38 |
| Generator D.C.   |     |     | 0.9 |  |  | 1.1 |     | 3.37 |
| Servo            |     | 2.0 |     |  | )Inter-<br>)grating<br>)2.5<br>)Position<br>)0.5 | 0.5 | 0.5 |      |

RELAYS

| Source<br>Type                           | A     | B   | C          | D       | E               | F     | G                                    | H     |
|--|-------|-----|------------|---------|-----------------|-------|--------------------------------------|-------|
| General Unsealed<br>(per contact<br>pair | 0.03  |     | )<br>)0.02 |         |                 |       | )<br>)                               |       |
| General Sealed<br>(per contact)          | 0.003 |     | )<br>)     |         |                 |       | )<br>)                               |       |
| General Unsealed<br>(per coil)           | 0.1   |     | )<br>)0.03 |         |                 |       | )<br>)                               |       |
| General Sealed<br>(per coil)             | 0.01  |     | )<br>)     |         |                 |       | )<br>)                               |       |
| Reed (each coil)                         | 0.1   |     |            | )       | )0.5            | )     | )                                    |       |
| Reed (each<br>contact                    | 0.001 |     |            | ) 0.002 | ) per<br>) cap- | ) 0.1 | )                                    |       |
| 2 Compartment<br>sealed                  |       | 0.1 | 0.05       | )       | ) sule<br>0.5   | )     | )                                    |       |
| Single Compartment<br>sealed             |       | 0.4 |            |         | 1.0             | 0.25  | ) 0.3<br>) per<br>) make/<br>) break | 0.133 |
| PO Type General<br>Heavy Duty            |       |     | 0.2<br>0.5 |         |                 |       | ) con-<br>) tact                     |       |
| General High<br>Speed                    |       |     | 0.5        |         |                 |       | )                                    |       |
| Miniature High<br>Speed                  |       |     | 0.7        |         |                 |       | )                                    |       |
| PO Type Fully<br>Tropical Used           |       |     | 0.1        |         |                 |       | )                                    |       |

FIXED RESISTORS

|                        |       |      |      |        |      |  |       |       |
|------------------------|-------|------|------|--------|------|--|-------|-------|
| Composition            | 0.005 |      |      | 0.0007 | 0.1  |  |       |       |
| Carbon Film            | 0.05  |      |      |        | 0.5  |  |       |       |
| Metal Film             | 0.005 |      | 0.02 |        | 0.3  |  |       |       |
| Oxide Film             | 0.002 | 0.01 | 0.01 | 0.0005 | 0.05 |  | 0.005 | 0.008 |
| Film, Power            | 0.01  |      |      |        |      |  |       |       |
| Wirewound GP           | 0.01  | 0.05 | 0.05 |        | 0.3  |  | 0.1   | 0.034 |
| Wirewound<br>Precision | 0.1   | 0.7  |      | 0.02   | 0.5  |  |       |       |
| Wirewound<br>Power     | 0.01  |      |      | 0.03   |      |  |       |       |

VARIABLE RESISTORS

| Source<br>Type         | A   | B   | C   | D     | E   | F    | G    | H     |
|------------------------|-----|-----|-----|-------|-----|------|------|-------|
| Composition            | 0.2 | 0.3 |     | 0.025 | 0.5 | 0.07 | 0.02 |       |
| Wirewound GP           | 0.3 | 0.5 | 0.1 | 0.05  | 1.0 | 0.16 | 0.02 | 0.336 |
| Wirewound<br>Precision | 0.6 | 0.8 | 0.3 |       | 0.3 | 0.25 |      |       |
| Lead Screw             | 0.5 |     |     |       |     |      |      |       |

SWITCHES

|              |      |      |      |       |     |       |      |       |
|--------------|------|------|------|-------|-----|-------|------|-------|
| Rotary       | 0.01 | 0.2  | 0.2  | 0.001 | 0.1 |       |      |       |
| Rotary Wafer |      |      | 0.1  |       |     | 0.025 |      |       |
| Push Button  | 0.02 |      | 0.05 | 0.002 |     |       |      |       |
| Toggle       | 0.02 | 0.3  |      | 0.002 | 0.3 | 0.1   | 0.03 | 0.009 |
| Micro        | 0.01 | 0.5  | 0.2  |       | 1.0 | 0.2   |      | 0.2   |
| Liquid Level |      |      |      |       |     |       |      | 0.081 |
| Thermostatic |      |      |      |       |     | 0.3   |      |       |
| Thermistor   |      | 0.06 | 0.05 |       |     |       |      |       |

TRANSFORMERS

|                                     |      |      |       |       |                    |                     |      |       |
|-------------------------------------|------|------|-------|-------|--------------------|---------------------|------|-------|
| Power oil-filled<br>(each winding)  | 0.01 |      | )     | )     | )                  | )per                | )    |       |
|                                     |      |      | )     | )     | )per               | )coil               | )    |       |
| Power potted<br>(each winding)      | 0.02 |      | )     | )0.05 | )coil              | )0.05               | )2.0 | 0.068 |
|                                     |      |      | )     | )     | )                  | )                   | )    |       |
| Power impregnated<br>(each winding) | 0.04 |      | )0.03 | )     | )                  | )                   | )    |       |
|                                     |      |      | )     | )     | )                  | )                   | )    |       |
| Pulse oil-filled<br>(each winding)  | 0.01 | )    | )     | )     | )                  | )                   | )    |       |
|                                     |      | )0.1 | )     | )0.15 | )                  | )                   | )    |       |
| Potted<br>(each winding)            | 0.02 | )    | )     | )     | )                  | )                   | )    |       |
|                                     |      | )    | )     | )     | )                  | )                   | )    |       |
| A.F.                                | 0.01 |      | 0.03  |       |                    |                     |      |       |
| I.F.                                | 0.01 |      | 0.1   |       |                    |                     | )    |       |
| R.F.                                | 0.03 |      |       |       | 0.5                |                     | )0.2 |       |
|                                     |      |      |       |       |                    |                     | )    |       |
| Variable<br>High Voltage            | 0.05 |      | 0.1   |       |                    |                     |      |       |
|                                     |      |      | 0.9   |       |                    |                     |      |       |
| Signal                              |      |      |       | 0.03  | per<br>coil<br>0.1 | per<br>coil<br>0.02 |      | 0.027 |

TRANSISTORS

| Source<br>Type           | A               | B           | C           | D             | E           | F           | G                   | H                 |
|--------------------------|-----------------|-------------|-------------|---------------|-------------|-------------|---------------------|-------------------|
| Germanium PNP<br>1 watt  | )<br>)<br>)0.01 | )<br>)<br>) | )<br>)<br>) | 0.015<br><br> | )<br>)<br>) | )<br>)<br>) | )<br>)<br>)         |                   |
| Germanium NPN<br>1 watt  | )<br>)          | )<br>)      | )<br>)      | 0.015<br><br> | )<br>)<br>) | )<br>)<br>) | )<br>)<br>)         |                   |
| Germanium PNP<br>>1 watt | )<br>)0.05      | )0.15<br>)  | )0.1<br>)   | 0.025<br><br> | )0.5<br>)   | )0.2<br>)   | )1.0<br>)to<br>)7.0 |                   |
| Germanium NPN<br>>1 watt | )<br>)          | )<br>)      | )<br>)      | 0.03<br><br>  | )<br>)      | )<br>)      | )<br>)              |                   |
| Silicon PNP<br>1 watt    | )<br>)0.008     | )<br>)      | )<br>)      | 0.008<br><br> |             |             |                     | )<br>)            |
| Silicon NPN<br>1 watt    | )<br>)          | )<br>)      | )<br>)      | 0.004<br><br> |             |             |                     | )0.0785<br>)<br>) |
| Silicon PNP<br>>1 watt   | )<br>)0.08      | )0.05<br>)  | )0.05<br>)  | 0.02<br><br>  |             |             |                     | )<br>)            |
| Silicon NPN<br>>1 watt   | )<br>)          |             |             | 0.007<br><br> |             |             |                     |                   |
| Silicon Planar           |                 |             |             |               | 0.05        | 0.01        |                     |                   |
| Silicon Other            |                 |             |             |               | 0.25        | 0.05        |                     |                   |
| Field Effect             |                 |             |             | 0.1           |             |             |                     |                   |

VALVES

|                            |      |      |          |  |     |       |       |  |
|----------------------------|------|------|----------|--|-----|-------|-------|--|
| Diode                      | 1.0  |      | 1.2      |  | 1.0 |       |       |  |
| Double Diode               | 1.5  |      | 1.6      |  |     |       |       |  |
| Triode                     | 1.8  |      | 1.9      |  |     |       |       |  |
| Double Triode              | 2.4  |      |          |  |     |       |       |  |
| Tetrode                    | 2.0  |      | 2.1      |  |     |       |       |  |
| Pentode                    | 2.2  |      | 2.3      |  |     |       |       |  |
| Heptode                    | 2.5  |      | )diodes  |  |     |       |       |  |
| Stabilizers                | 1.3  |      | )1.3     |  |     |       |       |  |
|                            |      |      | )triodes |  |     |       |       |  |
|                            |      |      | )1.6     |  |     |       |       |  |
| Rectifiers                 | 2.0  | 2.0  | 2.0      |  |     |       |       |  |
| Thyratrons                 | 3.0  |      | 5.0      |  |     | 5.0   |       |  |
| Magnetrons                 | 5.0  |      |          |  |     | 25-50 | 25-50 |  |
| Klystrons                  |      |      |          |  |     |       |       |  |
| Valve Holders<br>(per pin) | 0.01 | 0.05 |          |  |     |       |       |  |