RELIABILITY EVALUATION
OF
ELECTRONIC CIRCUITS

A DISSERTATION

submitted in partial fulfilment of
the requirements for the award of the degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(With Specialization in System Engineering & Operations Research)

By

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TO MA & BABA

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled, 'RELIABILITY EVALUATION OF ELECTRONIC CIRCUITS', in partial fulfilment of the requirements for the award of the degree of MASTER OF ENGINEERING in ELECTRICAL ENGINEERING with specialization in SYSTEM ENGINEERING AND OPERATIONS RESEARCH, submitted in the Department of Electrical Engineering, University of Roorkee, Roorkee, is an authentic record of my own work carried out during the period from August 1987 to March 1988 under the supervision of Dr. J.D.Sharma, Professor, Department of Electrical Engineering, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

Debasish Basak

Dated: April 13, 1988

(DEBASISH BASAK)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

The complexity of electronic circuits has increased rapidly with the advancement of integrated circuit technology. A detailed study of electronic circuit design is thus necessiated prior to its fabrication. Reliability evaluation of the circuits is the most urgent step in the design process.

An effort has been made to evaluate the component failure rate of electronic circuits with database structures of failure rate data. Part stress analysis technique is adopted to quantify the part failure models of different components in the circuit. The loading (electrical stress) of each component is calculated from the circuit analysis (d.c. and transient behaviour of the circuit). A menu-driven program is written using dBASE III PLUS package to calculate the part failure rates. The electrical stress (loading) and other factors (like temperature, environment, parts quality etc.) are the inputs to the program written. Since the program is menu-driven, all the required inputs, for a particular component selected can be displayed on C.R.T. terminal. Finally, the total failure rate of the circuit is stored in a database structure and can be obtained in any desired report form. It is assumed that failure of any component will cause the failure of the circuit.

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(DEBASISH BASAK)

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CHAPTER - I

INTRODUCTION

Considerable interaction between the circuit elements of the modern complex electronic circuits arises due to higher speed and frequency and miniaturization. It necessiates to perform an elaborate study of circuit design prior to fabrication. The circuit design process may be classified into following separate but interacting phases:

(i) feasibility study - consisting of initial structure of the circuit with satisfied loose specifications.

(ii) preliminary design phase - consisting of tighter design specifications with optimal choice of designable parameters using appropriate circuit analysis topology.

(iii) detailed design phase - consisting of physical design with detailed component specifications and reliability studies.

The flow chart for the electronic circuit design is shown in Fig. 1.1.

Initial structure of the circuit is made first and this structure lists the components necessary for circuit implementation and their functional relationships. Whether certain loose specifications are satisfied or not is now tested. Some methods of circuit analysis and computer

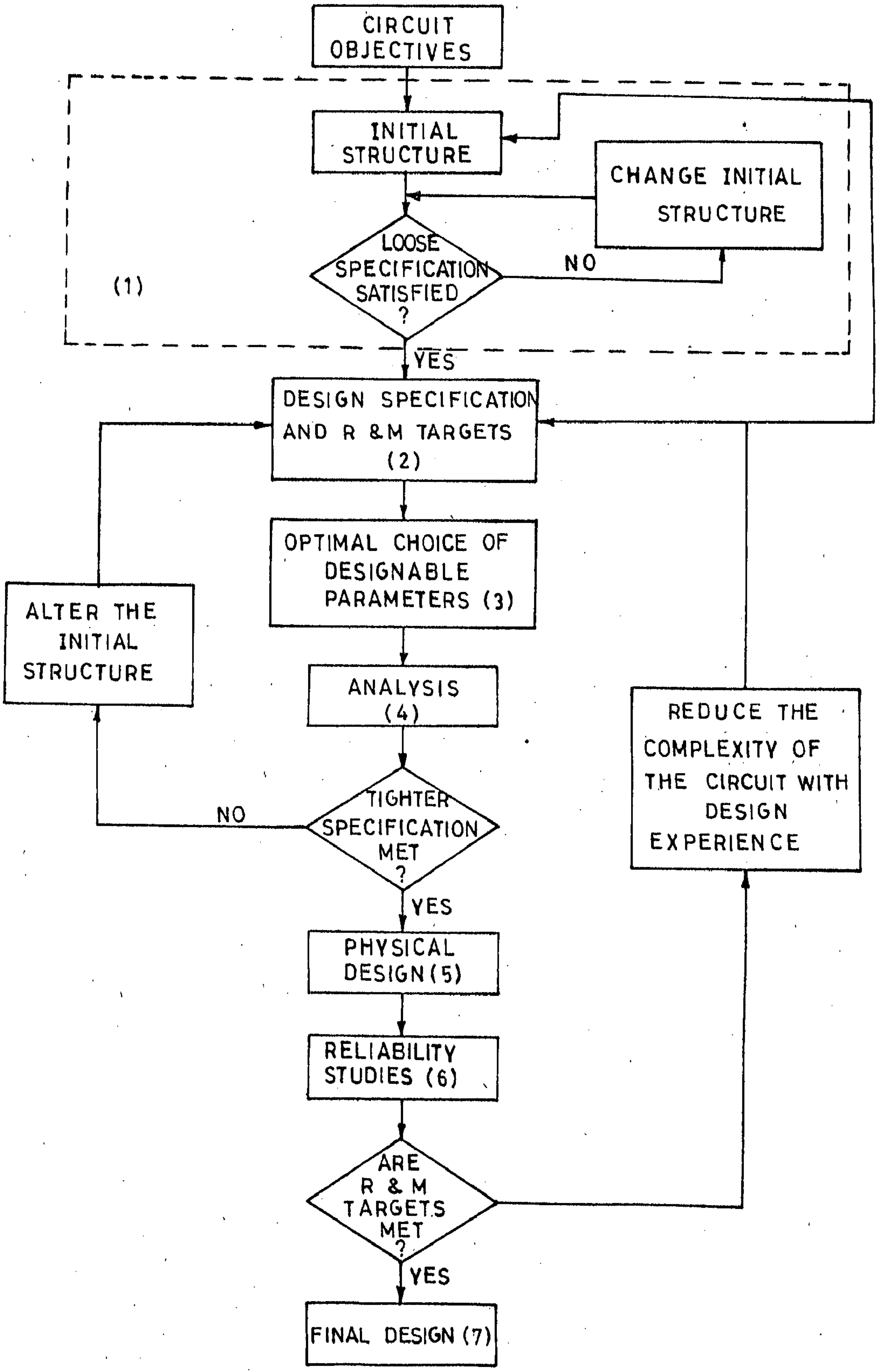


FIG. 1·1–ELECTRONIC CIRCUIT DESIGN PROCESS

LIST OF FIGURES AND TABLES

simulation are involved in this process and is continued until the loose specification satisfies the designer from technological ability, skill and past experience.

A set of tighter and complete design specifications, incorporating operating characteristics under normal and abnormal conditions, reliability, physical realizability, dimension requirement and economic soundness, are defined. The designer now optimizes the circuit by varying the designable parameters to achieve the desired specifications. If the design specification is not satisfied by varying the circuit parameters, then the topology of the circuit is altered and the previous design steps are repeated, otherwise next step is followed.

Now comes the physical design of the circuit which determines the mechanical layout of circuit on the printed circuit board, suitable for production with the electrical and physical constraints.

Reliability evaluation of the circuit is the next very important step in design. Reliability analysis of the circuit is required to have an estimate of the theoritically achievable reliability, availability and to point out the areas of high-failure rate concentration in the circuit. These areas of high failure rates may be eliminated by judicious use of redundancy techniques, using highly reliable components or by reducing the circuit complexity.

Reliability can be assessed precisely in the design process. But some divergences are always expected. The component failure rate data are seldom precise and tests show the deviations caused by divergences between actual and expected operating conditions, such as temperature, environment, loadings of components etc. Total part reliability can be implicitly determined during design process of an electronic circuit. Therefore, it is essential to have a tool which successfully measures the reliability . The tool is obviously the failure rate prediction system based on the physical properties of components.

Out of the two methods, Parts Count and Part Stress Analysis, the latter is more accurate as it takes into account all the factors (electrical stress, temperature, environment etc.) which are responsible for a part failure.

The different analytical part failure models for different part types are available in MIL-HDBK-217D. The field data are recorded in that book to calculate the different factors in the part failure rate models. Before using these factors, loading of each component on an electronic circuit is necessary as it affects the base failure rate of the component. Loadings can only be obtained when the non-linear circuit equations, representing relations between component parts in terms of voltages or currents, are solved. The circuit analysis [20,21] is utilized to find out the loading of each component in the circuit.

In this dissertation, a software is developed for reliability evaluation of electronic circuits. At first database structures are designed. Failure rate data for different components (resistors, capacitors, transistors & diodes) are stored in these database files. The structure of database files for these components are listed in Appendix B. A menu-driven program using dBASE III PLUS package has been written to evaluate the reliability of the electronic circuits in terms of failure rate (no. of failures/10^6 hour) utilizing Part Stress analysis technique. The loadings of constituent components of the circuit as determined in the circuit analysis have been combined with other input factors in this program to evaluate the electronic circuits. It has been assumed that the specified circuit will fail when any one of its components fail and failure rate of the circuit is equal to the sum of the failure rates of its components [17, 22, 34].

chapter 2

CHAPTER - II

BASIC RELIABILITY THEORY AND APPLICATION

2.1 INTRODUCTION

The reliability of a complex circuit depends on the reliability of its components. The measure of a component's reliability is the frequency at which failures occur in a given time period. The useful failure pattern that can be anticipated for electronic components is shown in Fig. 2.1. Reliability distinguishes three characteristic types of failures (excluding damage caused by careless handling, storing or improper operation by users) which may be inherent in the electronic equipments and occur without any fault on the part of the operator [4, 15, 32, 34].

Initially, the item population exhibits a high failure rate. This failure rate decreases rapidly during this first period (often called the "infant mortality", "burn-in" or debugging period), and stabilizes at an approximate value (at time T_B) when the weak units have died out. It may be caused by manufacturing deviations from the design intent, transportation damage or installation errors. This is usually pronounced in new equipment. Many of these early failures can be prevented by improving the control over manufacturing process.

The item population, after having been burned-in,

e level, which is normally
y constant failure rate, accom-
ry gradual changes due to wear.
T_B and T_W in Fig. 2.1) is called
is characterized mainly by the
used by sudden stress accumulations
n of the component. The exponential
widely used as a mathematical model
period which is the most signifi-
lity prediction and assessment acti-
c components, it is found that excessive
ge levels, either steady-state, transient
rates, are the two most destructive
vibration, shock and altitude contri-
of design strength devices.

nd final life period occurs when the item
s the point where the failure rate starts
eably (T_W). This point identifies the end
r the start of wear out. Wearout failures
of component aging.

AL FAILURE MODEL

e characteristic curve shown in Fig. 2.1 can
fined by three failure components which pre-
ring the three periods of an item's life.
lustrates these components in terms of an

reaches its lowest failure rate level, which is normally characterised by a relatively constant failure rate, accompanied by negligible or very gradual changes due to wear. This second period (between T_B and T_W in Fig. 2.1) is called the useful life period, and is characterized mainly by the occurrence of failures caused by sudden stress accumulations beyond the design strength of the component. The exponential failure distribution is widely used as a mathematical model to approximate this time period which is the most significant period for reliability prediction and assessment activities. For electronic components, it is found that excessive temperature and voltage levels, either steady-state, transient or changing at rapid rates, are the two most destructive stresses. Humidity, vibration, shock and altitude contribute to the failure of design strength devices.

The third and final life period occurs when the item population reaches the point where the failure rate starts to increase noticeably (T_W). This point identifies the end of useful life or the start of wear out. Wearout failures are a symptom of component aging.

2.2 EXPONENTIAL FAILURE MODEL

The life characteristic curve shown in Fig. 2.1 can be further defined by three failure components which predominate during the three periods of an item's life. Fig. 2.2 illustrates these components in terms of an

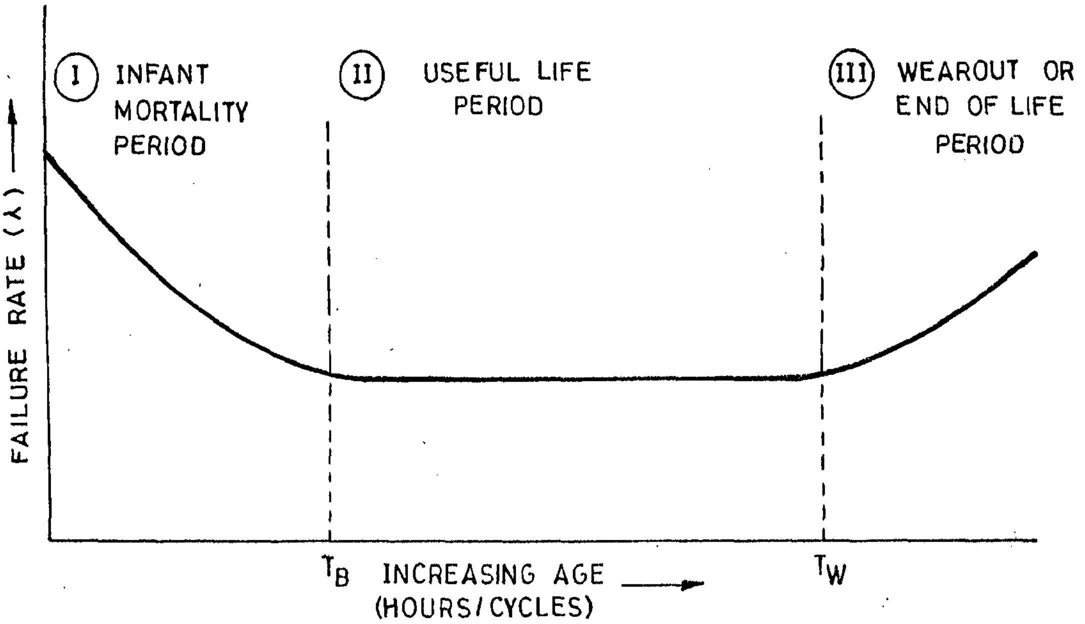


FIG. 2·1–ELECTRONIC EQUIPMENT AND COMPONENTS FAILURE PATTERN

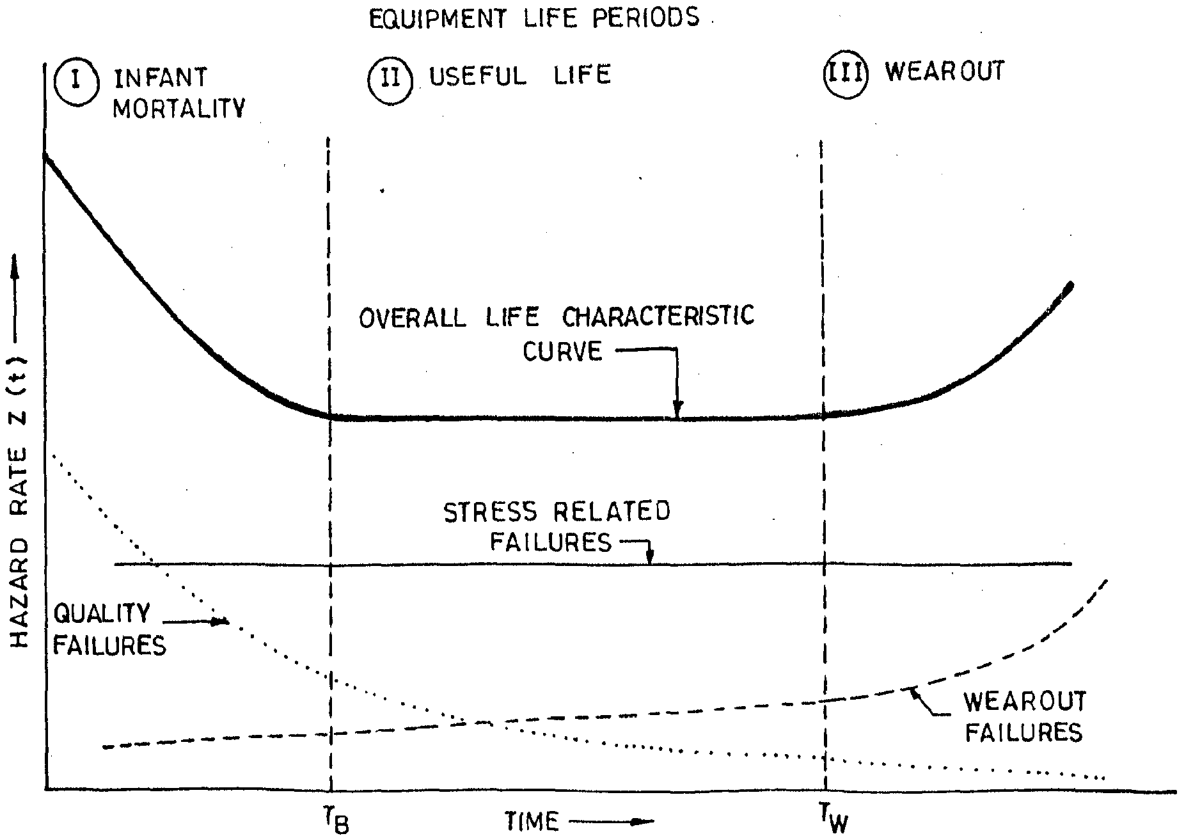


FIG.2·2–COMPONENTS OF FAILURE

equipment hazard rate, Z(t), which is simply stated as the conditional probability of failure. The failure components shown in Fig. 2.2 include:

(1) Early failure due to design and quality-related manufacturing defects and which have a decreasing hazard rate.

(2) Stress related failure due to application stresses and which have a constant hazard rate.

(3) Wearout failures due to aging and/or deterioration and which have an increasing hazard rate.

The combination of these three failure components in the infant mortality period characterizes a high but rapidly decreasing hazard rate. The combination results in a constant hazard rate in the useful life period because the decreasing quality failures and increasing wearout failures tend to offset each other, and because the stress related failures exhibit a relatively large amplitude. The wearout period is characterized by an increasing hazard rate.

The use of this type of "failure law" for complex electronic systems can be explained in the following ways:

(i) Many forces like stress/strength relationship and varying environmental conditions can act upon the item and produce failure.

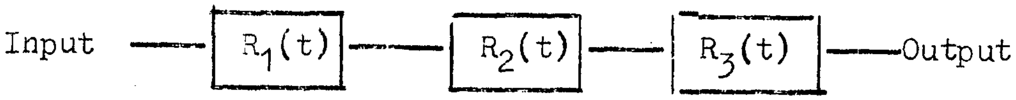
(ii) It signifies "approach to a stable state" which results from the mixing of part ages when failed elements in the system are replaced or repaired. Over a period of time, the system hazard rate oscillates, but this cyclic movement diminishes in time and approaches a stable state with a constant hazard rate.

(iii) Exponential distribution function approximates some other function over a particular interval of time for which the true hazard rate is essentially constant.

2.3 RELIABILITY CONFIGURATIONS

A method is needed to reflect the reliability connectivity of the many part types having different stress-determined failure rates that would normally make up a complex equipment.

In general, the serial equipment configuration is represented by the following block diagram:



Failure of any one part in the series would result in failure of the equipment. Further, it is assumed that failure of any part would occur independently of the operation of other components.

Hence $R_s(t) = R_1(t).R_2(t)...R_i(t)...R_n(t)$

where

$R_s(t)$ is the series reliability, and $R_i(t)$ is the reliability of the "ith" block for the time "t".

Introducing constant failure rate concept, the system reliability as a function of the reliability of parts and components becomes

$$R(t) = \prod_{i=1}^{n} e^{-\lambda_i t} = e^{-\lambda_1 t} \cdot e^{-\lambda_2 t} \dots e^{-\lambda_n t} .$$

Simplifying, $R(t) = e^{-(\lambda_1+\lambda_2+\dots \lambda_n)t}$

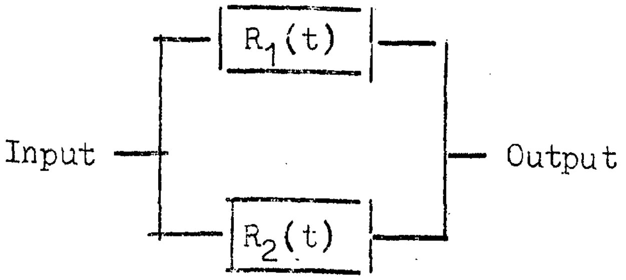
The general form of this expression becomes

$$R(t) = \exp \left[-t \sum_{i=1}^{n} \lambda_i \right]$$

The failure-rate parameter is valid both for the conditions of component-part testing and for application in complete equipments, the failure rate for the equipment is the sum of the part failure rates.

$$\lambda(\text{equipment}) = \Sigma \lambda(\text{parts})$$

A parallel configuration shows that when a part fails there is an alternate part or item configuration designed to insure equipment success. A two element parallel reliability configuration is represented by the following block diagram:



The reliability of the parallel configuration can be represented by:

$$R_p = 1 - (1-R_1).(1-R_2)$$

For n blocks connected in a parallel reliability configuration, the reliability of the configuration can be expressed by :

$$R_p(t) = 1-(1-R_1).(1-R_2) \ldots (1-R_n)$$

The series and parallel reliability configuration (and conbinations of these) represent the basic concepts involved in estimating the reliability of complex equipment.

2.4 PART FAILURE MODELING

The basic concept which underlies reliability evaluation is that system failure is a reflection of part failure. A method for estimating part failure rates is thus needed. The most direct approach to estimating part failure rates involves the use of large scale data collection efforts to obtain the relationships (i.e., models) between engineering and reliability variables. This approach utilizes controlled test data to:

(a) derive relationships between design and generic reliability factors, and

(b) develop factors for adjusting the reliability to estimate field reliability when considering application conditions.

These data have been included in MIL-HDBK-217D in a form suitable for estimating stress-related failure rates.

Part failure models vary with different part types, however, their general form is:

$$\lambda_{part} = (\lambda_b)(\pi_E)(\pi_A)(\pi_Q)\dots(\pi_n)$$

where

λ_{part} is the total part failure rate,

λ_b is the base failure rate,

π_E is the environmental adjustment factor,

π_A is the application adjustment factor,

π_Q is the quality adjustment factor,

π_n is the symbol for a number of additional adjustment factors which account for cycling effect, construction class and other factors that modify failure rate.

Base failure rates, in general, have been established from tests conducted under accelerated stress conditions which speed up the aging process. Field data collection and analysis efforts have indicated part failure rates well above those determined from laboratory testing. To account for the adverse influence of the application environment and to align the base failure rate (λ_b) with experience, a series of factors, have been developed to account for specific production operation and maintenance and application environment stress factors. MIL-HDBK-217D completely describes failure rate models , failure rate data and adjustment factors to be used in estimating the failure rate for the individual part types.

1. COMPOSITION RESISTORS
2. FILM RESISTORS
3. POWER FILM RESISTORS
4. WIREWOUND ACCURATE RESISTORS

$$\lambda_p = (\lambda_b).(\pi_E).(\pi_R).(\pi_Q)$$

5. RESISTOR NETWORK

$$\lambda_p = 0.00066\,(N_R).(\pi_T).(\pi_E).(\pi_Q)$$

6. VARIABLE WIREWOUND RESISTORS
7. WIREWOUND SEMIPRECISION RESISTORS
8. VARIABLE COMPOSITION RESISTORS
9. VARIABLE FILM & PRECISION RESISTORS

$$\lambda_p = (\lambda_b).(\pi_{TAPS}).(\pi_E).(\pi_R).(\pi_Q).(\pi_V)$$

10. WIREWOUND PRECISION RESISTORS
11. WIREWOUND POWER RESISTORS
12. VARIABLE NONWIREWOUND RESISTORS

$$\lambda_p = (\lambda_b).(\pi_{TAPS}).(\pi_R).(\pi_V).(\pi_Q).(\pi_E)$$

TABLE 2.1(a)

1. Si/Ge (NPN/PNP) TRANSISTORS

$\lambda_p = (\lambda_b)(\pi_E)(\pi_A)(\pi_Q)(\pi_{S2})(\pi_C)(\pi_R)$

2. SILICON/GALIUM FIELD EFFECT TRANSISTORS

$\lambda_p = (\lambda_b)(\pi_E)(\pi_A)(\pi_Q)(\pi_C)$

3. UNIJUNCTION TRANSISTORS

$\lambda_p = (\lambda_b)(\pi_E)(\pi_Q)$

TABLE 2.1(b)

1. PAPER & PLASTIC FILM CAPACITORS
2. MICA CAPACITORS
4. CERAMIC CAPACITORS
5. ALUMINIUM ELECTROLYTIC CAPACITORS

$\lambda_p = (\lambda_b)(\pi_E)(\pi_Q)(\pi_{CV})$

6. TANTALUM ELECTROLYTIC CAPACITORS

$\lambda_p = (\lambda_b)(\pi_E)(\pi_{SR})(\pi_Q)(\pi_{CV})$

7. VARIABLE CERAMIC CAPACITORS
8. VARIABLE PISTON TYPE CAPACITORS
9. VARIABLE AIR TRIMMER CAPACITORS

$\lambda_p = (\lambda_b)(\pi_E)(\pi_Q)$

10. VACUUM OR GAS CAPACITORS

$\lambda_p = (\lambda_b)(\pi_E)(\pi_Q)(\pi_{CF})$

TABLE 2.1(c)

1. GENERAL PURPOSE (Si/Ge) DIODES

$$\lambda_p = (\lambda_b)(\pi_E)(\pi_Q)(\pi_R)(\pi_A)(\pi_{S2})(\pi_C)$$

2. AVALANCHE & ZENER DIODES

$$\lambda_p = (\lambda_b)(\pi_E)(\pi_A)(\pi_Q)$$

3. THYRISTORS

$$\lambda_p = (\lambda_b)(\pi_Q)(\pi_E)(\pi_R)$$

TABLE 2.1 (d)

The TABLES 2.1(a), 2.1(b), 2.1(c), 2.1(d) show the part failure rate models of different types of Resistors, Transistors, Capacitors and Diodes respectively where λ_p is in failures/10^6 hours.

The details of different factors in the part failure rate models are described in CHAPTER-III.

chapter 3

CHAPTER - III

RELIABILITY COMPUTATION METHODS

3.1 PARTS COUNT METHOD

This prediction method is useful in bid (proposal) stage when the design of an electronic circuit has not advanced to the goal where detailed component lists and part stresses are known . The Parts Count Method requires less information. The quantity of different component types, quality level of the components and the application environment are dealt with in this method. The general expression for circuit failure rate with this method is given below:

$$\lambda_{(circuit)} = \sum_{i=1}^{n} N_i \, (\lambda_G \pi_Q)_i \;\ldots. \qquad (3.1)$$

for a given environment

where

$\lambda_{(circuit)}$ = total circuit failure rate (failures/10^6hr.)

λ_G = generic failure rate for the ith generic component (failures/10^6hr.)

π_Q = quality factor for the ith generic component

N_i = quantity of ith generic component

n = number of different generic component categories

When the several units of a circuit or equipment are operated in different environmental conditions, the different environment-affected failure rates are calculated and then added to determine the total circuit or equipment failure rate. The quality factors used with electronic components are not necessarily the same values used in section 3.2,i.e., Part Stress Analysis.

3.2 PART STRESS ANALYSIS METHOD

Greatest amount of detail is needed in this method. The Part Stress Analysis method is appropriate when the electronic circuit design has advanced to a goal where detailed component lists are available and the stresses encountered by the components in the circuit are calculated. The general expression for circuit failure rate has been mentioned in the previous chapter (Chapter-II, section 2.4). Factors influencing part failure rates for different part categories are described in the following sub-sections[26].

3.2.1 Base Failure Rate

MIL-HDBK-217D gives base failure rates, λ_b, to the various part categories.

The general model used to quantify the term λ_b for specific types or classes of resistors is as follows:

$$\lambda_b = A\, e^{B\left(\frac{T+273}{N_T}\right)^G} e^{\left[\left(\frac{S}{N_s}\right)\left(\frac{T+273}{273}\right)\right]^H}$$

where

A	is an adjustment factor for each type of resistor to adjust the model to the appropriate failure rate level.
e	is the natural logarithm base, 2.718
T	is the ambient operating temperature (^{o}C)
N_T	is a temperature constant
B	is a shaping parameter
G, H, J	are acceleration constants
N_s	is a stress constant
S	is the electrical stress and is the ratio of operating power to rated power.

The general model for capacitor base failure rates (λ_b) is as follows:

$$\lambda_b = A\left[\left(\frac{S}{N_s}\right)^{H} + 1\right] \cdot e^{B\left(\frac{T+273}{N_T}\right)^{G}}$$

where,

A	is an adjustment factor for each different type of capacitor, to adjust the model to the proper failure rate.
S	represents the ratio of operating to rated voltage
N_s	is the stress constant
e	is the natural logarithm, 2.718
T	is the operating ambient temperature (^{o}C)

N_T is a temperature constant

B is a shaping parameter

G and H are acceleration constants

The equation for the base failure rate (λ_b) for semiconductor diodes and transistors is as follows:

$$\lambda_b = Ae^x$$

where

$$x \text{ is } \left[\frac{N_T}{273+T+(\Delta T)S}\right] + \left[\frac{273+T+(\Delta T)S}{T_M}\right]^P$$

A is a failure rate scaling factor

e is the natural logarithm base, 2.718

N_T, T_M and P are shaping parameters

T is the operating temperature (°C)

T is the difference between typical maximum allowable temperature with no junction current or power and the typical maximum allowable temperature with full rated junction current or power.

S is the stress ratio of operating electrical stress to rated electrical stress.

For calculating S the necessary informations are listed below:

(1) For Transistors

(a) Single device in use

$$S = \frac{P_{OP}}{P_{MAX}} \text{ for Germanium}$$

and $$S = \frac{P_{OP}}{P_{MAX}} \quad (C.F)$$

where

P_{OP} = actual power dissipated

P_{MAX} = maximum rated power at T_S

(b) Dual device in single case (equally rated).

$$S = \left[\frac{P_1}{P_S} + P_2 \left(\frac{2P_S - P_T}{P_T \times P_S} \right) \right] .(C.F)$$

where

S = stress ratio of side being evaluated

P_1 = power dissipation in side being evaluated

P_2 = power dissipation in the other side of device

P_S = maximum power rating at T_S on one side with other side not operating

P_T = maximum/ power rating at T_S with both sides operating

(2) For General Purpose Diodes and Thyristors

$$S = \frac{I_{OP}}{I_{MAX}} \quad \text{for Germanium}$$

$$= \frac{I_{OP}}{I_{MAX}} .(C.F.)$$

where

I_{OP} = operating average forward current

I_{MAX} = maximum rated average forward current at T_S

(3) For Zener Diodes

$$S = \frac{P_{OP}}{P_{MAX}} .(C.F) \quad \text{or} \quad S = \frac{I_{Z(OP)}}{I_{Z(MAX)}} . (C.F)$$

where

P_{OP} = actual power dissipated

P_{MAX} = maximum rated power at T_S

$I_{Z(OP)}$ = actual operating Zener current

$I_{Z(MAX)}$ = maximum rated Zener current at T_S

C.F. = stress correction factor

If $T_S = 25^\circ C$ and $175^\circ C \leq T_{MAX} \leq 200^\circ C$

C.F. = 1

If $T_S > 25^\circ C$ and $175^\circ C \leq T_{MAX} \leq 200^\circ C$

$$C.F. = \frac{175 - T_S}{150}$$

If $T_S = 25^\circ C$ and $T_{MAX} < 175^\circ C$

$$C.F. = \frac{T_{MAX} - 25}{150} \quad \text{and} \quad T = T_A (\text{or } T_C) + (175 - T_{MAX})$$

If $T_S > 25^\circ C$ and $T_{MAX} < 175^\circ C$

$$C.F. = \frac{T_{MAX} - T_S}{150},$$

and $T = T_A$ (or T_C) + $(175 - T_{MAX})$

where

T_A is ambient temperature (°C)

T_C is case temperature (°C)

The higher the temperature at which an electronic part operates, the shorter its lifetime. Accordingly, the failure rate will be higher for higher temperatures of operation. The use of electronic components below their rated voltage or power increases their reliability.

The base failure rates as functions of temperature and electrical stress are tabulated in MIL-HDBK-217D for different part type. These tables are used to calculate the base failure rates of different components in the actual electronic circuit.

3.2.2. Part Quality

The quality of a part is taken into account in part failure rate model and is designated by π_Q. If a particular part is purchased to a multilevel quality specification (established reliability, ER), the appropriate value for π_Q is selected. Parts which are not covered by multilevel quality specifications (non-ER), have two quality levels designated as "MIL-SPEC" and "LOWER". If the part is used in complete accordance with the applicable specification, π_Q value for "MIL-SPEC" should be used. If the requirements are waived, π_Q value for "LOWER" should be used. The different parts with their multi-level quality specifications are listed in Table 3.1.

PART	QUALITY DESIGNATORS
1. Transistors	JANTXV, JANTX, JAN
2. Diodes	JANTXV, JANTX, JAN
3. Capacitors, Established Reliability (ER)	L, M, P, R, S
4. Resistors, Established Reliability (ER)	M,P,R,S

Table 3.1 Parts with Multi - level Quality Specifications.

If the diodes and transistors are sealed or encapsulated with organic materials, another quality designator "PLASTIC" can be used.

3.2.3 Environment

The factor π_E is used to consider the effects of various environmental stresses excepting ionizational potential in all part failure rate models and value of this factor is described by MIL-HDBK for the specific part types. These environments cover the major areas of component use and a brief description of these environments are shown in Table 3.2 [26, 32, 34, 35].

Environment	π_E Symbol	Description
Ground, Benign	G_B	Optimum engineering operation and maintenance for laboratory environment.
Ground, Fixed	G_F	Less severe than ideal for installation in unheated buildings.
Ground, Mobile	G_M	Conditions more severe than G_F mostly for vibration and shock.
Space, Flight	S_F	Approaches G_M without access for maintenance.
Manpack	M_P	Portable electronic equipment being manually transported while in operation.
Naval, Sheltered	N_S	Conditions similar to G_F subject to occasional high shock and vibration.
Naval, Unsheltered	N_U	Similar to N_S subject to repetitive high levels of shock and vibration.
Naval, Undersea, Unsheltered	N_{UU}	Equipment immersed in salt water.
Naval, Submarine	N_{SB}	Equipment installed in submarines
Naval, Hydrofoil	N_H	Equipment installed in hydrofoil vessel.
Airborne, Inhabited, Transport	A_{IT}	Conditions without environmental extremes of pressure, temperature, shock and vibration in aircraft transports or bombers.
Airborne, Inhabited, Fighter	A_{IF}	Same as A_{IT} but installed on aircraft fighters.

Airborne, Uninhabited, Transport	A_{UT}	Extreme pressure, vibration and temperature cycling may be intensified by contamination from oil, hydraulic fluid and engine exhaust.
Airborne, Uninhabited, Fighter	A_{UF}	Same as A_{UT} but installed on aircraft fighters.
Airborne, Rotary, Winged	A_{RW}	Equipment installed on helicopters.
Missile, Launch	M_L	Severe conditions of noise, vibration and other environments related to missile launch.
Cannon, Launch	C_L	Same as M_L related to cannon launching to target impact.
Undersea, Launch	U_{SL}	Undersea torpedo mission and missile launch.
Missile, Free Flight	M_{FF}	Missiles in non-powered free flight.
Airbreathing Missile Flight	M_{FA}	Powered flight of air breathing missile.

Table 3.2 Environmental Symbol Identification and Description. (Source; MIL-HDBK-217D).

3.2.4 Other π Factors

The π factors excepting π_E and π_Q applied to specific part failure rate models are defined in MIL-HDBK-217D for each part. Table 3.3 presents an overall listing of π factors used in failure rate models as applicable to resistors, capacitors, transistors and diodes.

π Factor	Description
	Resistors
π_R	Resistance Factor Effect of resistor ohmic values.
π_T	Temperature Factor-Effect of temperature for resistor network
π_C	Construction class factor-Influence of construction class of various resistors.
π_V	Voltage Factor - Effect of applied voltage in variable resistors in addition to wattage included within λ_b.
π_{TAPS}	Effect of multiple taps on variable resistors.
	Capacitors
π_{SR}	Series Resistance Factor - Effect of series resistance in circuit application of some electrolytic capacitors.
π_{CV}	Capacitance Factor - Effect of capacitance value.
π_{CF}	Configuration Factor - Effect of fixed and variable constructions on vacuum or Gas capacitors.

Transistors and Diodes	
π_A	Application Factor - Effect of application in terms of circuit function
π_R	Rating Factor - Effect of maximum power or current rating
π_C	Complexity Factor-Effect of multiple devices in a single package.
π_{S2}	Voltage Stress Factor - Effect of second electrical stress (application voltage) in addition to voltage included in λ_b.

Table 3.3 π Factors (except π_E and π_Q) for Resistors, Capacitors, Transistors and Diodes.

chapter 4

CHAPTER - IV

CIRCUIT RELIABILITY EVALUATION

4.1 INTRODUCTION

Calculation of failure rate for an electronic assembly, unit or system requires knowledge of the failure rate of each part of which the item is comprised. If we assume that the item will fail when any of its parts fail, the failure rate of the item will equal to the sum of the failure rate of its parts. This can be expressed as:

$$\lambda = \sum_{i=1}^{n} \lambda_i$$

where,

λ_i = failure rate of the ith parts,

n = number of parts

Generally, two methods discussed in the previous chapters (Chapter - III) are used to make reliability estimates. The Parts Count method is normally used at a preliminary stage of design and is the least accurate of the two methods. Failure rates from Parts Count are stress independent except for the environmental condition.

The Parts Stress Analysis is more cumbersome with many factors and is applicable during the later design phases where actual hardware and circuits are being designed. It should be noted, however, that the parts stress analysis method may also be used during any phase provided that enough detailed information is available.

The obtainable accuracy in system failure rate prediction can be achieved by the designer if a tool more powerful than Parts Count and faster to use than Parts stress Analysis. This involves database programming which is best suited for homogeneous data. All component data are stored and all tables are handled by the system.

The only factor needed from circuit analysis is the component loading. When load on each component is specified, the contents of the failure rate table is multiplied by the component factors from the component database.

4.2 CREATING DATABASE FILES USING dBASE III PLUS

In the previous chapter (Chapter - III), we have seen that base failure rate, λ_b, is dependent on operating temperature and loading (electrical stress) of each component. The base failure rate values for each component part corresponding to different temperatures (starting from zero) and loadings (starting from 0.1 to 1.0 with a gap of 0.1) are recorded in MIL-HDBK-217D. These values are recorded at each $5^{\circ}C$ interval or $10^{\circ}C$ interval. λ_b value corresponding to a particular loading at any temperature in this interval is very close the value recorded at the immediate next temperature value with the same loading. Same is the case where temperature is fixed and loading value lies in between the loading interval written in MIL-HDBK-217D.

Database files using dBASE II PLUS are created first and the values of λ_b are stored in these files. These files look like the tables of base failure rate, λ_b, of different components where first record, corresponds to 0^oC temperature and the fields correspond to 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 loadings respectively. The second record corresponds to 5^oC temperature and so on. For resistors, these tables are TRES1, TRES2, TRES3,...etc. For capacitors, these tables are CAP1, CAP2, CAP3,...etc. For diodes, these are DIOD1, DIOD2, DIOD3, ... etc. For transistors, these tables are TRAN1, TRAN2, TRAN3, ...etc.

Besides these database files, one file named MODE is also created where a particular record corresponds to a particular component type and the different fields denote the different environments i.e. G_B, S_F, G_F, ... etc. Environmental mode factor, $_E$, can be found out corresponding to a particular component type and specified environment. The details of these databases are described in Appendix - A and listed in Appendix - B.

4.3 CALCULATION OF LOADING (ELECTRICAL STRESS)

For the computer aided analysis of an electronic circuit, the circuit is represented in terms of circuit equations with the help of suitable device models. Therefore, a large set of algebraic differential equations has to be solved for the analysis of large electronic circuits. Such non-linear equation can be solved with the help of Newton's method based algorithms. But Newton's method gives overflow or slow convergence problem as higher order derivatives are neglected in this method. Hence, Newton's method is modified to overcome this problem. The software packages [20, 21] have been implemented for d.c. and transient analysis of the practical electronic circuits.

4.3.1 Transient Analysis:

The transient analysis denotes the time domain response of the circuit. The circuit equations are solved at successive time points, begining with initial conditions computed in d.c. analysis. The circuit equations which express the transient behaviour of a circuit can be written by a set of algebraic and differential equations of the form:

$$G(W, q, \dot{q}, t) = 0 \qquad \ldots(4.1)$$

The vector function G comprises Kirchhoff's voltage and current law equations and the branch constitutive equations, The vectors $W(t)$ and $q(t)$ are computed by solving (4.1) for all the values of time in the interval $t_0 \leqslant t \leqslant t_{max}$. The step-wise procedure for transient analysis is described as:

Step 1 : Given the initial time t_0 and initial conditions, determine $W(t_0)$, $q(t_0)$ by d.c. solution, choose an initial step size h_1 and set $i = 1$.

Step 2 : Set $t_i = t_{i-1} + h_i$

Step 3 : Discretize $\dot{q}(t_i)$

Step 4 : Values of $W(t_i)$ and $q(t_i)$ are predicted from their previous corresponding values using modified Newton's method. These predicted values are used as initial estimate for the solution of nonlinear equations in step 5.

Step 5 : Estimate the truncation error in the discretization. If the convergence criteria is not met within specified maximum iterations then set $h_i = h_i/2$ and go to step 2. Otherwise,compute new time step h_{i+1} such that h_{i+1} is maximum step size with the allowable truncation error.

Step 6 : If $t_i < t_{max}$, then set $i = i+1$ and go to step 2. Otherwise, the transient analysis is complete.

4.3.2 D.C. Analysis:

In d.c. analysis, the non-linear equations representing the circuit behaviour are linearized around an initial estimate. The ideal capacitors and inductors are replaced by open and short circuit respectively and the source value remains fixed in d.c. analysis. The d.c. analysis of a circuit representing equation (4.1) gives the values W and q for which $\dot{q} = 0$. Now, equation (4.1) becomes:

$$G\,(W,\ q,\ 0,\ t_0) = 0 \qquad \ldots.(4.2)$$

The stepwise procedure for d.c. analysis is as follows:

Step 1 : Read circuit data and select suitable values for unknown nodal voltages.

Step 2 : Determine the minimal spanning tree.

Step 3 ; Formulate the linearized circuit equations by including contribution of each element of the circuit in the admittance matrix G and current vector B.

Step 4 : Solve linearized circuit equations formulated in step 3 to calculate Newton's correction vector in nodal voltages.

Step 5 : Obtain the new values of unknown node voltages by adding algebraically. Newton's correction vector to the corresponding nodal voltages.

Step 6 : Compute the branch voltages from node voltages. Modify the junction voltages of the diodes and transistors (foreward biased) appropriately.

Step 7 : Determine the nodal voltages from branch voltages using the minimal spanning tree and node to datum path matrix.

Step 8 : If the circuit equations are satisfied with specified tolerances, stop; otherwise go to step 3.

The software packages [20, 21] for circuit analysis (d.c. and transient behaviour) has been utilized and modified to get the loadings of each component in the circuit. The loadings are either the voltage ratios (operating/rated) or the power ratios (operating/rated).

4.4 COMBINATION OF LOADING AND OTHER FACTORS IN dBASE PROGRAMMING

For each component specification, the analytical model for the part failure rate, λ_p, has been used. For the calculation of part failure rate of each component in the circuit, a program is written using dBASE III PLUS programming language. The loading of each component alongwith other factors (temperature, environment, part specification, quality level etc.) are given as inputs to this program. Finally, the failure rate of each component has been calculated and recorded in a database file. At the end of this output file, total part failure rate is also recorded.

The program developed is a menu-driven system where options can be simply selected to calculate the part failure rate of a particular component in the circuit. The details of this software package is described in Appendix-A.

chapter 5

CHAPTER - V

COMPUTATIONS AND RESULTS

5.1 COMPUTATIONS

Before component parts can be properly selected for a specific circuit, the performance requirements and environmental conditions under which the circuit is to operate must first be determined. The final choice is based on electrical circuit conditions and upon the physical dimensions.

A prime source of data on electronic component parts, and their ability to perform under various environmental conditions, is the military specification which applies to the particular component parts.

A bipolar ECL Schmitt Trigger circuit, comprising of five resistors and two transistors, shown in Fig. 5.1(a) is considered for reliability evaluation. The input is set for a trapezoidal function of time as shown in Fig. 5.1(b). The detailed information about the specifications and dimensions of the constituent component parts are listed in Table 5.1.

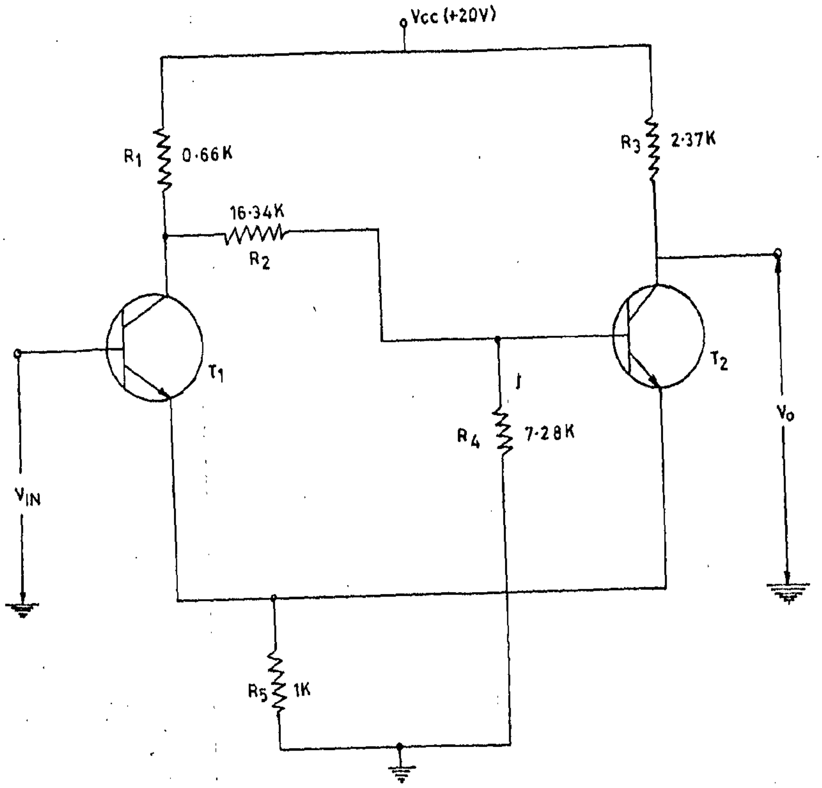
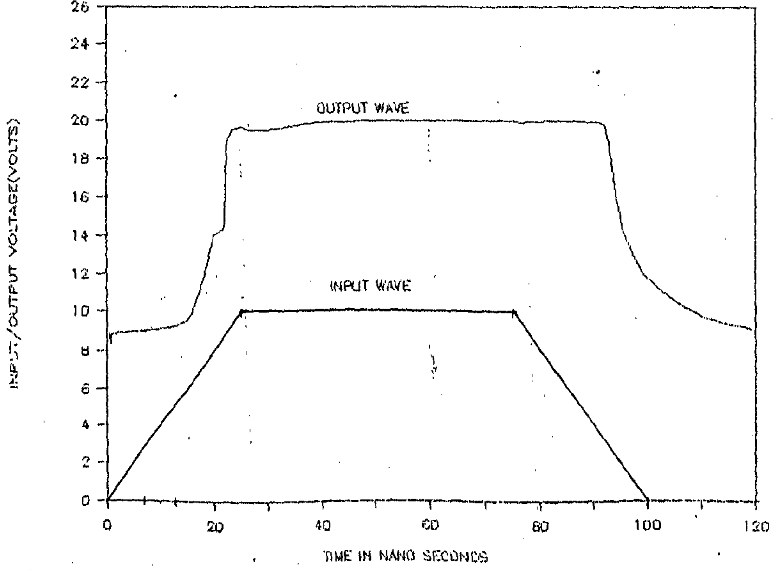


FIG. 5·1(a)–ECL SCHMITT TRIGGER CIRCUIT

I/O CHARACTERISTICS OF SCHMITT TRIGGER

FIGURE–5.1(B)



The operating temperature is 30°C. The environment is Ground, Mobile and its symbol is G_M. The values of the resistances (in kilo-ohms) are defined in the Fig. 5.1(a).

From the analysis of the circuit it is found that electrical stress ratios of different components are 0.566, 0.245, 0.327, 0.345, 0.221, 0.001 and 0.127 respectively. Moreover V_{CE}/V_{CEO} of the two transistors are found to be 0.10 and 0.40 approximately. The total failure rate of the circuit applying "Parts Count" and "Part-stress Analysis" methods are computated in the following way.

(1) Parts Count Method

The general expression for circuit failure rate as described in chapter-III can be definêd as follows:

$$\lambda_{Circuit} = \sum_{i=1}^{n} \cdot N_i \, (\lambda_G \, \pi_Q)_i \;\; f./10^6 \text{ hr.} \quad .. \qquad (5.1)$$

From MIL-HDBK-217D (Tables 5.2-10, 5.2-11, 5.2-12, 5.2-14), generic failure rate (λ_G) and quality factor (π_Q) can be found.

No. of fixed, wirewound resistors = 3

$\lambda_G = 0.095$ and $\pi_Q = 1.0$

No. of fixed, film resistor = 1

$\lambda_G = 0.012$, $\pi_Q = 1.0$

No. of fixed, power film resistor = 1

$\lambda_G = 0.12$, $\pi_Q = 1.0$

No. of Silicon, NPN transistor = 2

$\lambda_G = 0.062, \quad \pi_Q = 1.0$

The values of λ_G and π_Q are valid for environment 'G_M' and quality level 'M' for resistors and 'JAN' for transistors.

Now, equation 5.1 becomes

$$\lambda_{CIRCUIT} = 3x0.095x1.0+1x0.012x1.0+1x0.12x1.0+2x0.062x1.0$$

$$= 0.285 + 0.012 + 0.12 + 0.124$$

$$= 0.541$$

Hence, in Parts count method the total failure rate of the Schmitt trigger circuit is 0.541 failures/10^6 hour.

(B) Part-stress Analysis Method

The general part failure rate model for fixed resistors described in Chapter-III is as follows:

$$\lambda_p = \lambda_b \, (\pi_E \times \pi_R \times \pi_Q) \text{ failures/}10^6 \text{ hour} \quad \ldots \quad (5.2)$$

where the general model to quantify $_b$ is as follows:

$$\lambda_b = A \, e^{B\left(\frac{T+273}{N_T}\right)^G} \, e^{\left[\left(\frac{S}{N_S}\right)\left(\frac{T+273}{273}\right)^J\right]^H} \quad \ldots \quad (5.3)$$

The general part failure rate model for transistors described in Chapter-III is as follows:

Table 5.1 SPECIFICATION & DIMENSION OF COMPONENT PARTS

COMPONENT	COMPONENT TYPE	POWER RATING (watts)	QUALITY LEVEL	SPEC.	STYLE	APPLICATION	COMPLEXITY
R1	Fixed,Wirewound	1.000	M	MIL-R-39005	RBR		
R2	Fixed,Film	0.050	M	MIL-R-55182	RNR		
R3	Fixed,Wirewound	0.100	M	MIL-R-39005	RBR		
R4	Fixed,Power Film	0.125	MIL-SPEC	MIL-R-11804	RD		
R5	Fixed,Wirewound	0.125	M	MIL-R-39005	RBR		
T1	Silicon,NPN	0.150	JAN	MIL-S-19500		LINEAR	SINGLE TRANSISTOR
T2	Silicon,NPN	0.150	JAN	MIL-S-19500		LINEAR	SINGLE TRANSISTOR

Table 5.2 FAILURE RATE OF SCHMITT TRIGGER CIRCUIT

COMPONENT	STRESS	BASE FAILURE RATE(LAMDAB) f./10^6 hr.	PIE	PIR	PIQ	PIA	PIC	PIS2	PART FAILURE RATE(LAMDAP) f./10^6 hr.
R	0.566	0.005000	9.80	1.00	1.00	0.00	0.00	0.000	0.049000
R	0.245	0.00100	7.80	1.00	1.00	0.00	0.00	0.000	0.007800
R	0.327	0.00440	9.80	1.00	1.00	0.00	0.00	0.000	0.043120
R	0.345	0.01200	8.80	1.00	1.00	0.00	0.00	0.000	0.105600
R	0.221	0.00400	9.80	1.00	1.00	0.00	0.00	0.000	0.039200
T	0.001	0.00070	18.00	1.00	1.20	1.50	1.00	0.300	0.006804
T	0.127	0.00084	18.00	1.00	1.20	1.50	1.00	0.477	0.012970
*** Total ***									0.264494

TABLE 5.1(A) CALCULATION OF FAILURE RATE

MPO- NT	π_A	π_E	π_Q	π_R	π_C	π_{S_2}	P	A	B	N_T	G	N_S	H	J	T (°C)	ΔT	T_M	S	λ_b	λ_p
R_1	-	9.8	1.0	1	-	-	-	$3.1(10)^{-3}$	1	398	10	1	1.5	1	30	-	-	0.566	0.00545	0.05341
R_2	-	9.8	1.0	1	-	-	-	$5.0(10)^{-5}$	3.5	398	1	1	1	1	30	-	-	0.245	0.00094	0.00733
R_3	-	9.8	1.0	1	-	-	-	$3.1(10)^{-3}$	1	398	10	1	1.5	1	30	-	-	0.327	0.00412	0.040376
R_4	-	8.8	1.0	1	-	-	-	$7.33(10)^{-3}$	0.202	298	2.6	1.45	1.3	0.89	30	-	-	0.345	0.01072	0.094336
R_5	-	9.8	1.0	1	-	-	-	$3.1(10)^{-3}$	1	398	10	1	1.5	1	30	-	-	0.221	0.00374	0.036652
T_1	1.5	18.0	1.2	1	1	0.3	10.5	0.0189	-	-1052	-	-	-	-	30	150	448	0.001	0.0005978	0.0058
T_2	1.5	18.0	1.2	1	1	0.4766	10.5	0.0189	-	-1052	-	-	-	-	30	150	448	0.127	0.000743	0.01147
																		Total		0.249384

λ_b and λ_p are the number of failures/10^6 hour.

$$\lambda_p = \lambda_b (\pi_E \times \pi_A \times \pi_Q \times \pi_R \times \pi_{S2} \times \pi_C) \text{ failures}/10^6\text{hr.} \quad \ldots(5.4)$$

where $\lambda_b = A\, e^x$ ...(5.5)

and $x = \left(\frac{N_T}{273+T+(\Delta T)S} \right) + \left(\frac{273+T+(\Delta T)S}{T_M} \right)^P$ ...(5.6)

The total failure rate is given in Table 5.1(A).

5.2 RESULTS

The tables of λ_b (for different temperatures Vs. electrical stress ratios) are in the form that temperatures are described at a regular gap of 5 or 10°C and the stress has 10 columns starting from 0.1 with a gap of 0.1. These tables have been utilized here to calculate the part failure rates in such a way that for any intermediate values of temperature or stress, immediate next values of λ_b has been taken into account. This may cause a slight deviation from the values of λ_b computed earlier. But this deviation is too small to consider for total circuit failure rate calculation. Moreover, the data base structure is utilized here for calculating λ_b. The results in the report form is tabulated in Table 5.2.

chapter 6

CHAPTER - VI

CONCLUSIONS

Reliability is a consideration at all levels of electronics from materials to operating systems because components are made up of materials ; these components are used in a circuit of increasing complexity. Therefore, at any level of development and design of electronic circuits, it is necessary to find the reliability of the circuit. An attempt has been made in this dissertation to evaluate the electronic circuits, with the failure rate data obtained from field use of past system, using the database structures for the various data records.

Two main limitations of reliability evaluation are the ability to accumulate data of known validity for future application and the complexity of reliability evaluation technique. Data useful to design of electronic circuits for the selection, specification and use of components is highly scattered. But a thorough study and knowledge of the military component part specifications is the first and probably the most useful source. Out of the two techniques for evaluating electronic circuits described in Chapter - III, the second one, Part stress analysis technique, which required greatest amount of detail and is applicable during the later design phase, is adopted in this dissertation to calculate the failure rate of any electronic circuit. As an example, Schmitt Trigger circuit [fig. 5.1(a)] is taken for its reliability evaluation. The database structures for base failure rates of different types of components are made. These structures are handled in the program written to calculate the part failure rate of the components. The different types of models of part failure rate are described in Chapter - II.

The use of database structures and menu-driven program show that for evaluating any component part in the circuit one has to select the type of the component first and then the other factors responsible for part failure of the associated part are to be given accordingly. Final values of part failure rates are stored in a database structure to have an idea of different application factors as well as the failure rates.

APPENDIX - A

SOFTWARE PACKAGE USING DATABASE STRUCTURES

Figure A-1 shows the organization of the computer program for reliability evaluation of electronic circuits using database structures for the failure rate data. The brief description of various sub-programs are given below:

RELCKT :	This is the main program for reliability evaluation of electronic circuits (circuits consisting of capacitors, diodes, resistors and transistors). When this program is executed, it shows 4 options to the user. Options are the component types (capacitors, diodes, resistors and transistors).
CAPREL :	This sub-program calculates the failure rate of any capacitor. When executed independently or opted from main program (RELCKT), it shows 10 choices for 10 types of capacitors. If a particular capacitor type is selected, it calculates the failure rate using suitable part failure model of that type of capacitor (as shown in table 2.1(c)).
DIODREL :	This sub-program calculates the failure rate of any diode. When executed independently or opted from main program (RELCKT), it shows 3 choices for 3 types of diodes. If a particular diode type is selected, it calculates the failure rate using proper part failure model as described in table 2.1(d).

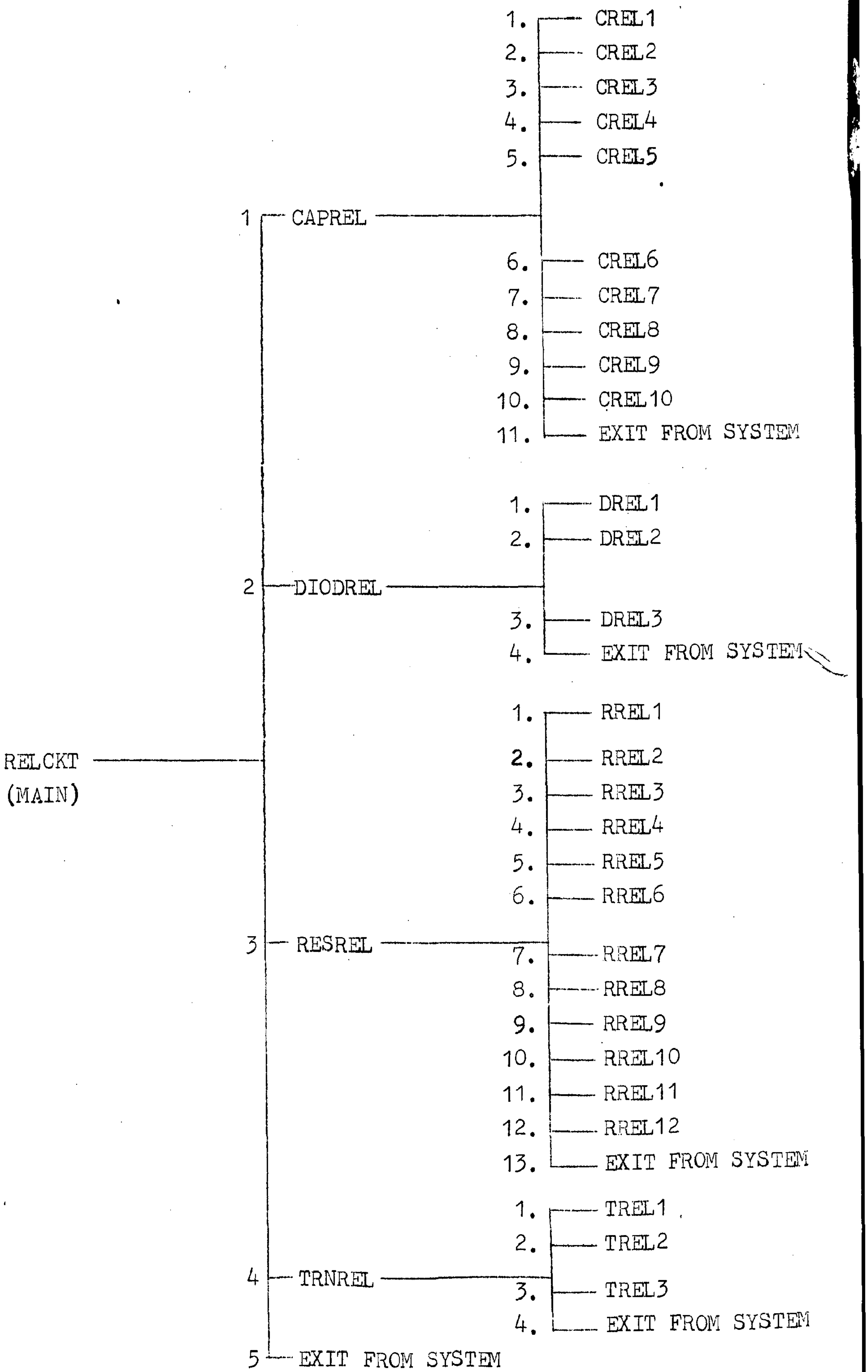


Fig. A-1 Organization of sub-programs for reliability evaluation of electronic circuits.

RESREL : This sub-program calculates the failure rate of any resistor. When executed independently or opted from main program (RELCKT), it displays 12 choices for 12 types of resistors. If a particular resistor type is selected, it calculates the failure rate using the appropriate part failure model as described in table 2.1(a).

TRNREL : This sub-program calculates the failure rate of any transistor. When executed independently or opted from main program (RELCKT), it displays 3 choices for 3 types of transistors. If a particular transistor type is selected, it calculates the failure rate using suitable part failure model as described in table 2.1(b).

CREL1 : This sub-program, when executed independently or opted from CAPREL, calculates the failure rate of paper & plastic film capacitor. If $T_{MAX} \leqslant 65^{o}C$, it uses database file CAP1 and if $65^{o}C \leqslant T_{MAX} \leqslant 85^{o}$, file CAP2 is used. If $85^{o}C < T_{MAX} \leqslant 125^{o}C$, file CAP3 is used for base failure rate, λ_b, Record number 18 in the database structure MODE shows the π_E values for the different type of environments as discussed in Chapter III.

CREL2 : This is for Mica capacitor. If $T_{MAX} \leqslant 125^{o}C$, database file CAP4 is used and if $125^{o} < T_{MAX} \leqslant$

$150^\circ C$, CAP5 is used for λ_b. Record no. 19 in MODE denotes the π_E values for different environments.

CREL3 : For Glass Capacitor. If $T_{MAX} \leqslant 125^\circ C$, CAP6 and if $125^\circ C < T_{MAX} \leqslant 150^\circ C$, CAP7 is used for λ_b values. Record no. 20 in MODE shows the π_E values for different environments.

CREL4 : For Ceramic capacitor. If $T_{MAX} \leqslant 85^\circ C$, file CAP8 and if $85^\circ C < T_{MAX} \leqslant 125^\circ C$, CAP9 is used for λ_b values. Record no. 21 in MODE shows the π_E values for different environments.

CREL5 : For Tantalum Electrolytic capacitor. If $T_{MAX} \leqslant 125^\circ C$, file CAP10 is used for λ_b. Record no. 22 in MODE denotes the π_E values for different environments.

CREL6 : For Aluminium Electrolytic capacitor. File CAP11 is used to find λ_b. Record no. 23 in MODE shows the π_E values for different environments.

CREL7 : For Variable Ceramic capacitor. If $T_{MAX} \leqslant 85^\circ C$, database file CAP12 and if $85^\circ C < T_{MAX} \leqslant 125^\circ C$, file CAP13 is used to find λ_b. Record no. 24 in MODE defines the π_E values for different environments.

CREL8 : For Variable Piston-type capacitor. If $T_{MAX} \leqslant 125^{\circ}C$, file CAP14 and if $125^{\circ}C < T_{MAX} \leqslant 150^{\circ}C$, file CAP15 is used to find λ_b. Record no. 25 in MODE shows the π_E values for different environments.

CREL9 : For Variable Air Trimmer capacitor. File CAP16 is used to find λ_b and $T_{MAX} \leqslant 85^{\circ}C$. Record no. 26 in MODE shows the π_E values for different environments.

CREL10 : For Vacuum on Gas capacitor. If $T_{MAX} \leqslant 85^{\circ}C$, file CAP 17 and if $85^{\circ}C < T_{MAX} \leqslant 100^{\circ}C$, file CAP18 is used to find λ_b. Record no. 27 in MODE defines the π_E values for different environments.

DREL1 : This sub-program, when executed independently or opted from DIODREL, calculates the failure rate of General Purpose (Silicon or Germanium) diodes. If a silicon diode is selected, file DIOD1 and if a Germanium diode is selected, file DIOD2 is used to find λ_b. Record no. 16 in MODE denotes the π_E values for different environment.

DREL2 : This is for Avalanche and Zener diode. File DIOD3 is used to find λ_b. Record no. 17 in MODE defines the π_E values for different environments.

DREL3 : This sub-program is for Thyristors. Database structure DIOD4 is used to find λ_b. The record no. 17 in MODE defines the π_E values for different environments in this case also.

RREL1 : This sub-program, when executed independently or opted from RESREL, calculates the failure rate of Composition resistor. Database file TRES1 is used to find the base failure rate, λ_b. Record no. 1 in MODE defines the π_E values for different environments.

RREL2 : This is for Film resistor. If the specification is either MIL-R-39017 or MIL-R-22684, file TRES2 is used to find λ_b. Otherwise TRE3 is used for that purpose. Record no. 2 in MODE file is defined to give the different π_E values.

RREL3 : For Power Film resistor. File TRES4 is used to find λ_b. Record no. 3 in MODE defines the π_E values for different environments.

RREL4 : For Resistor network (film type). File TREST is used to find the temperature factor π_T. Record no. 4 in MODE file gives the π_E values for different environments.

RREL5 : For Wirewound, accurate resistor. File TRES5 is used to find λ_b. Record no. 5 in MODE shows the different π_E values.

RREL6 : For Variable, Wirewound resistor. File TRES8 is used to find λ_b. Record no. 6 in MODE defines the different π_E values. File TRPTF is used to find π_{TAPS} of variable resistors.

RREL7 : For Wirewound, Precision resistor. File TRES9 is used to find λ_b. Record no. 7 in MODE gives the π_E values for different environments. File TRPTF is used to find π_{TAPS}.

RREL8 : For Wirewound, semiprecision resistor. File TRES10 is used to find λ_b. Record no. 8 in MODE defines the different π_E values. TRPTF is used to find π_{TAPS}.

RREL9 : For Wirewound Power resistor.. File TRES11 is used to find λ_b. Record no. 9 in MODE denotes the π_E values for different environments. TRPTF is used to find π_{TAPS}.

RREL10 : For Variable nonwirewound resistor. File TRES12 is used to find λ_b. Record no. 10 in MODE gives the π_E values for different environments. TRPTF is also used to find π_{TAPS}.

RREL11 : For Variable Composition resistor. File TRES13 is used to find λ_b. Record no. 11 in MODE shows the π_E factor for different environments.

TRPTF is used to find π_{TAPS}.

RREL12 : For Variable Film and Precision resistor. File TRES14 is used when the resistor specification is MIL-R-23285 and file TRES15 is used when the resistor specification is MIL-R-39023. Record no. 12 in MODE denotes the π_E factor for different environments.

TREL1 : This sub-program, when executed independently or opted from TRNREL, calculate the failure rate of Silicon/Germanium (NPN/PNP) transistors. If the type of transistor is Silicon and NPN, file TRAN1 is used. If the selected transistor is Silicon and PNP type, file TRAN2 is used. If the type is Germanium and PNP, file TRAN3 and for Germanium and NPN type transistor, file TRAN4 is used. These TRAN database structures are used to find the base failure rate, λ_b, Record no. 13 in MODE is used to consider the environmental factor, π_E.

TREL2 : This is for Silicon or Gallium Field Effect Transistor. File TRAN5 is used tind λ_b. Record no. 14 in MODE shows the values of π_E for different environments.

TREL3 : For Unijunction transistor. File TRAN6 is used to find λ_b. Record no. 15 gives the π_E values for different environments.

The values of different factors in the part failure models are stored in the sub-programs related to a particular component type. The values of part failure rate for different components in the circuit are calculated and stored in a database file named OUTPUT. In this tstructure all the influencing factors for different component types are also recorded. At the end of this file summation of all part failure rates i.e., the failure rate of the circuit, is stored. The details of various input factors for different component types are listed in figure A-2. The figure A-2 shows the general information needed for different component types. Variable names used of different input factors in this software are also given in the figure.

	CAPACITORS	TEMPERATURE	FAILURE RATELEVEL	VALUE OF CAPACITORS	SPECIFICATION	MAXIMUM TEMPERATURE	
	CAPTYPE(VARIABLE NAME) →	TEMP	RATELEVEL	C	SPEC	T_{MAX} $\leqslant$	
1.	PAPER & PLASTIC FILM CAPACITORS	$\leqslant 65^\circ C$ $\leqslant 85^\circ C$ $\leqslant 125^\circ C$	S,R,P,M,NON-ER,MIL-SPEC,	any value in μF	MIL-C-14157 MIL-C-19978	$65^\circ C$ $85^\circ C$ $125^\circ C$	
2.	MICA CAPACITORS	$\leqslant 125^\circ C$ $\leqslant 150^\circ C$	S,R,P,M,NON-ER,MOLDED,LOWER NON-ER DIPPED,	pF	-	$125^\circ C$ $150^\circ C$	
3.	GLASS CAPACITORS	$\leqslant 125^\circ C$ $\leqslant 200^\circ C$	S,R,P,M,L,NON-ER,MIL-SPEC LOWER	pF	-	$125^\circ C$ $200^\circ C$	
4.	CERAMIC CAPACITORS	$\leqslant 85^\circ C$ $\leqslant 125^\circ C$	S,R,P,M,L,NON-ER,MIL-SPEC, LOWER	pF	-	$85^\circ C$ $125^\circ C$	
5.	TANTALUM ELECTROLYTIC CAPACITORS	$\leqslant 125^\circ C$	S,R,P,M,L,LOWER	μF	-	$125^\circ C$	*CIRCUIT RESISRANCE(OHMS/VOLT); Variable name is CR;range 0.0 to any value
6.	ALUMINIUM ELECTROLYTIC CAPACITORS	$\leqslant 125^\circ C$	S,R,P,M,NON-ER,L, MIL-SPEC,LOWER	μF	-	$125^\circ C$	
7.	VARIABLE CERAMIC CAPACITORS	$\leqslant 85^\circ C$ $\leqslant 125^\circ C$	S,R,P,M,NON-ER,L, MIL-SPEC,LOWER	-	-	$85^\circ C$ $125^\circ C$	
8.	VARIABLE PISTON-TYPE CAPACITORS	$\leqslant 125^\circ C$ $\leqslant 150^\circ C$	S,R,P,M,L,NON-ER, MIL-SPEC,LOWER	-	-	$125^\circ C$ $150^\circ C$	
9.	VARIABLE AIR TRIMMER CAPACITORS	$\leqslant 85^\circ C$	S,R,P,M,L,NON-ER, MIL-SPEC,LOWER	-	-	$85^\circ C$	
10.	VACUUM OR GAS CAPACITORS	$\leqslant 85^\circ C$ $\leqslant 100^\circ C$	S,R,P,M,L,NON-ER, MIL-SPEC,LOWER	-	-	$85^\circ C$ $100^\circ C$	*CONFIGURATION is FIXED or VARIABLE;variable name is CF.

	RESISTORS	TEMPE-RATURE	FAILURE RATELEVEL (QUALITY LEVEL)	VALUE OF RESISTORS (IN KILO OHMS)	SPECIFICATION	No. of FILM RESISTORS USED	NO. OF TAPS USED	APPLIED TO RATED VOLTAGE RATIO
RES TYPE	(VARIABLE NAME) →	TEMP	RATELEVEL	RESVALUE	SPEC	NR	TP	VRATIO
1.	COMPOSITION RESISTORS	≤120°C	S,R,P,M, LOWER, MIL-SPEC	≤ 10,000	-	-	-	-
2.	FILM RESISTORS	≤ 140°C ≤ 170°C	S,R,P,M,LOWER,MIL-SPEC	NO UPPER BOUND	MIL-R-39017 MIL-R-22684 MIL-R-55182 MIL-R-10509	-	-	-
3.	POWER FILM RESISTORS	≤ 210°C	MIL-SPEC, LOWER	NO UPPER BOUND	-	-	-	-
4.	RESISTOR NETWORK (FILM TYPE)	25-125°C	MIL-SPEC, LOWER	-	-	≤ 22	-	-
5.	WIREWOUND, ACCURATE RESISTORS	≤ 140°C	S,R,P,M,LOWER MIL-SPEC	NO UPPER BOUND	-	-	-	-
6.	VARIABLE WIREWOUND RESISTORS	≤ 140°C	S,R,P,M,LOWER MIL-SPEC	≤ 20	-	-	≤ 32	0.00-1.00
7.	WIREWOUND PRECISION RESISTORS	≤ 140°C	MIL-SPEC,LOWER	≤ 500	-	-	≤ 32	0.00-1.00
8.	WIREWOUND SEMIPRECISION RESISTORS	≤ 130°C	MIL-SPEC,LOWER	≤ 10	-	-	≤ 32	0.00-1.00
9.	WIREWOUND POWER RESISTORS	≤ 115°C	S,R,P,M,LOWER, MIL-SPEC	≤ 10			≤ 32	0.00-1.00
10.	VARIABLE NONWIREWOUND RESISTORS	≤ 140°C	S,R,P,M,LOWER MIL-SPEC	≤ 1000	-	-	≤ 32	0.00-1.00
11.	VARIABLE COMPOSITION RESISTORS	≤ 115°C	MIL-SPEC,LOWER	≤ 1000	-	-	≤ 32	0.00-1.00
12.	VARIABLE FILM & PRECISION RESISTORS	≤ 170°C ≤ 115°C	MIL-SPEC,LOWER MIL-SPEC,LOWER	NO UPPER BOUND	MIL-R-23285 MIL-R-39023	-	≤ 32	0.00-1.00

	TRANSISTORS	TEMPE-RATURE	FAILURE RATE LEVEL (QUALITY ~~LEVEL)~~	TYPE OF TRANSIS-TOR	APPLICATION	COMPLEXITY
	TRANSTYPE (VARIABLE WAVE)	TEMP	RATELEVEL	TYPE	APPL	COMP
1.	Si/Ge (NPN/PNP) TRANSISTORS	(Si,*) < 160° (Ge,*) < 90°	JANTXV, JANTX, JAN, LOWER, PLASTIC	(Si, NPN), (Si, PNP), (Se, NPN), (Ge, PNP)	LINEAR, SWITCH, NOISE	SINGLE TRANSISTOR, DUAL (UNMATCHED), DUAL (MATCHED) DARLINGTON, DUAL EMITTER, MULTIPLE EMITTER, COMPLEMENTARY PAIR
2.	SILICON/GALLIUM FIELD EFFECT TRANSISTORS	< 160°	JANTXV, JANTX, JAN, LOWER, PLASTIC, GaAs	-	LINEAR SWITCH, HIGH FREQUENCY LOW NOISE, DRIVER	DUAL COMPLEMENTARY, TETRODE
3.	UNIJUNCTION TRANSISTORS	< 160°	JANTXV, JANTX, JAN, LOWER, PLASTIC	-	-	-

* V_{CE}/V_{CEO} range 0.0 to 100.0; variable name is S_2

* POWER RATING (Watts) range 0 to 200; variable name PWR

Fig. A-2 General Information for Input Variables of Components

appendix B

APPENDIX -B

Fig.B-1 PIE FACTOR FOR RESISTORS,TRANSISTORS,DIODES & CAPACITORS

COMPONENT TYPE	GB	SF	GF	NSB	NS	AIT	MP	MFF	MFA	GM	NH	NUU	AUT	NU	AIF	ARW	USL	AUF	ML	CL
RCOMP	1	1.0	2.9	4.0	5.2	2.8	8.5	8.6	13	8.3	13	14	5.7	12.0	5.7	19	25	11	29	490
RFILM	1	0.4	2.4	4.2	4.7	2.8	8.8	8.9	12	7.8	14	15	8.5	14.0	5.7	19	26	17	30	510
RPOWR	1	1.0	2.4	5.1	5.1	4.2	11.0	12.0	16	8.8	18	19	11.0	15.0	8.5	25	34	21	39	660
RNETW	1	1.0	2.4	4.2	4.7	2.8	8.8	8.9	12	7.8	14	15	8.5	14.0	5.7	19	26	17	30	510
RWIRW	1	1.5	2.4	5.2	5.2	6.0	12.0	12.0	17	9.8	18	20	20.0	16.0	12.0	27	36	40	41	610
RVWR	1	1.0	2.4	5.7	5.7	4.2	15.0	15.0	21	9.8	23	25	8.5	13.0	8.5	33	45	17	51	870
RWRP	1	1.0	2.4	8.4	8.4	5.0	24.0	24.0	34	11.0	37	39	11.0	14.0	10.0	53	71	21	81	1400
RWSP	1	1.0	2.4	7.0	7.0	5.0	17.0	0.0	0	16.0	27	29	0.0	0.0	10.0	38	0	0	0	0
RWPR	1	1.0	3.0	7.0	7.0	5.0	17.0	0.0	0	16.0	27	29	0.0	0.0	10.0	38	0	0	0	0
RVNW	1	1.0	2.9	5.7	5.7	5.0	18.0	18.0	25	11.0	27	29	11.0	15.0	10.0	39	53	21	61	1000
RVCOM	1	1.0	1.8	8.0	8.0	6.0	21.0	21.0	29	17.0	32	34	27.0	21.0	12.0	46	62	54	71	1200
RVFP	1	1.0	2.9	7.2	7.2	5.0	18.0	18.0	25	11.0	27	29	15.0	15.0	10.0	39	53	30	61	1000
TRAN	1	0.4	5.8	9.8	9.8	12.0	12.0	12.0	17	18.0	19	20	20.0	21.0	25.0	27	36	40	41	690
FET	1	0.6	4.0	6.0	8.6	12.0	12.0	12.0	17	18.0	19	20	20.0	21.0	25.0	27	36	40	41	690
UNIJ	1	1.0	4.0	9.3	9.3	12.0	12.0	12.0	17	18.0	19	20	20.0	21.0	25.0	27	36	40	41	690
DIOD	1	1.0	3.9	4.8	4.8	12.0	12.0	12.0	17	18.0	19	20	20.0	21.0	25.0	27	36	40	41	690
AVATHR	1	1.0	3.9	5.8	8.7	12.0	12.0	12.0	17	18.0	19	20	20.0	21.0	25.0	27	36	40	41	690
PAPER	1	1.0	2.4	4.4	5.7	4.0	9.2	9.3	13	7.8	14	15	11.0	13.0	8.0	20	27	21	31	530
MICA	1	1.0	2.4	5.0	6.2	4.2	11.0	11.0	15	8.8	16	17	17.0	15.0	8.5	23	31	34	36	610
GLASS	1	1.0	1.4	5.0	6.2	4.2	11.0	11.0	15	8.8	16	17	17.0	15.0	8.5	23	31	34	36	610
CERAM	1	0.8	1.6	5.0	5.5	8.5	11.0	11.0	15	7.8	16	18	17.0	12.4	17.0	24	32	34	36	610
TANT	1	0.8	2.4	4.4	4.9	6.0	9.2	9.3	13	7.8	14	15	11.0	13.0	12.0	20	27	21	31	530
ALELEC	1	1.0	2.4	5.8	6.7	8.5	12.0	12.0	17	12.0	19	20	21.0	13.0	17.0	27	36	42	41	690
VARCER	1	0.8	3.4	7.8	7.0	5.7	17.0	17.0	23	9.8	25	27	35.0	20.0	11.0	36	49	70	56	950
VARPIS	1	1.0	2.9	6.9	7.2	5.7	14.0	15.0	20	9.3	22	24	28.0	8.4	11.0	32	43	56	49	830
~~VARAIR~~	~~1~~	~~1.0~~	~~3.4~~	~~7.8~~	~~7.8~~	~~5.7~~	~~17.0~~	~~17.0~~	~~23~~	~~9.8~~	~~25~~	~~27~~	~~35.0~~	~~20.0~~	~~11.0~~	36	49	70	56	950
VACUUM	1	1.0	3.4	8.2	8.2	8.5	18.0	0.0	0	10.0	28	30	53.0	24.0	17.0	40	0	110	0	1000

Fig. B-2 (FILE TRES2) Base Failure Rate of Film Resistors

TEMPERATURE	LOADING 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.0033	0.0035	0.0037	0.0041	0.0045	0.0050	0.0057	0.0065	0.0075	0.0086
5	0.0033	0.0035	0.0038	0.0041	0.0046	0.0051	0.0058	0.0066	0.0077	0.0089
10	0.0033	0.0035	0.0038	0.0042	0.0047	0.0052	0.0059	0.0068	0.0079	0.0092
15	0.0033	0.0036	0.0039	0.0042	0.0047	0.0053	0.0061	0.0070	0.0081	0.0095
20	0.0034	0.0036	0.0039	0.0043	0.0048	0.0054	0.0062	0.0072	0.0084	0.0099
25	0.0034	0.0036	0.0040	0.0044	0.0049	0.0056	0.0064	0.0074	0.0087	0.0100
30	0.0034	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0076	0.0090	0.0110
35	0.0035	0.0037	0.0041	0.0045	0.0051	0.0058	0.0068	0.0079	0.0093	0.0110
40	0.0035	0.0038	0.0042	0.0046	0.0052	0.0060	0.0070	0.0082	0.0097	0.0120
45	0.0036	0.0039	0.0042	0.0047	0.0054	0.0062	0.0072	0.0085	0.0100	0.0120
50	0.0037	0.0039	0.0043	0.0049	0.0055	0.0064	0.0075	0.0088	0.0110	0.0130
55	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0077	0.0092	0.0110	0.0130
60	0.0038	0.0041	0.0046	0.0052	0.0059	0.0069	0.0081	0.0096	0.0120	0.0140
65	0.0039	0.0043	0.0047	0.0053	0.0061	0.0071	0.0084	0.0100	0.0120	0.0150
70	0.0041	0.0044	0.0049	0.0055	0.0064	0.0075	0.0089	0.0110	0.0130	0.0160
75	0.0042	0.0046	0.0051	0.0058	0.0067	0.0079	0.0094	0.0110	0.0140	0.0170
80	0.0044	0.0048	0.0053	0.0061	0.0070	0.0083	0.0099	0.0120	0.0150	0.0180
85	0.0046	0.0050	0.0056	0.0064	0.0075	0.0088	0.0110	0.0130	0.0160	0.0200
90	0.0048	0.0053	0.0059	0.0068	0.0079	0.0094	0.0110	0.0140	0.0170	0.0210
95	0.0051	0.0056	0.0063	0.0073	0.0085	0.0100	0.0120	0.0150	0.0190	0.0230
100	0.0055	0.0060	0.0068	0.0078	0.0092	0.0110	0.0130	0.0160	0.0200	0.0260
105	0.0059	0.0065	0.0074	0.0085	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290
110	0.0065	0.0071	0.0080	0.0093	0.0110	0.0130	0.0160	0.0200	0.0250	0.0320
115	0.0071	0.0078	0.0089	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290	0.0370
120	0.0079	0.0087	0.0099	0.0120	0.0140	0.0170	0.0210	0.0260	0.0330	0.0420
125	0.0089	0.0099	0.0110	0.0130	0.0160	0.0190	0.0240	0.0300	0.0380	0.0490
130	0.0100	0.0110	0.0130	0.0150	0.0180	0.0220	0.0280	0.0000	0.0000	0.0000
135	0.0120	0.0130	0.0150	0.0180	0.0210	0.0000	0.0000	0.0000	0.0000	0.0000
140	0.0140	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Fig. B-3(FILE TRES3) Base Failure Rate of Film Resistors

LOADING

TEMP ERAT URE	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.0033	0.0035	0.0037	0.0041	0.0045	0.0050	0.0057	0.0065	0.0075	0.0086
5	0.0033	0.0035	0.0038	0.0041	0.0046	0.0051	0.0058	0.0066	0.0077	0.0089
10	0.0033	0.0035	0.0038	0.0042	0.0047	0.0052	0.0059	0.0068	0.0079	0.0092
15	0.0033	0.0036	0.0039	0.0042	0.0047	0.0053	0.0061	0.0070	0.0081	0.0095
20	0.0034	0.0036	0.0039	0.0043	0.0048	0.0054	0.0062	0.0072	0.0084	0.0099
25	0.0034	0.0036	0.0040	0.0044	0.0049	0.0056	0.0064	0.0074	0.0087	0.0100
30	0.0034	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0076	0.0090	0.0110
35	0.0035	0.0037	0.0041	0.0045	0.0051	0.0058	0.0068	0.0079	0.0093	0.0110
40	0.0035	0.0038	0.0042	0.0046	0.0052	0.0060	0.0070	0.0082	0.0097	0.0120
45	0.0036	0.0039	0.0042	0.0047	0.0054	0.0062	0.0072	0.0085	0.0100	0.0120
50	0.0037	0.0039	0.0043	0.0049	0.0055	0.0064	0.0075	0.0088	0.0110	0.0130
~~55~~	~~0.0037~~	~~0.0040~~	0.0044	0.0050	0.0057	0.0066	0.0077	0.0092	0.0110	0.0130
60	0.0038	0.0041	0.0046	~~0.0052~~	~~0.0059~~	0.0069	0.0081	0.0096	0.0120	0.0140
65	0.0039	0.0043	0.0047	0.0053	0.0061	0.0071	0.0084	0.0100	0.0120	0.0150
70	0.0041	0.0044	0.0049	0.0055	0.0064	0.0075	0.0089	0.0110	0.0130	0.0160
75	0.0042	0.0046	0.0051	0.0058	0.0067	0.0079	0.0094	0.0110	0.0140	0.0170
80	0.0044	0.0048	0.0053	0.0061	0.0070	0.0083	0.0099	0.0120	0.0150	0.0180
85	0.0046	0.0050	0.0056	0.0064	0.0075	0.0088	0.0110	0.0130	0.0160	0.0200
90	0.0048	0.0053	0.0059	0.0068	0.0079	0.0094	0.0110	0.0140	0.0170	0.0210
95	0.0051	0.0056	0.0063	0.0073	0.0085	0.0100	0.0120	0.0150	0.0190	0.0230
100	0.0055	0.0060	0.0068	0.0078	0.0092	0.0110	0.0130	0.0160	0.0200	0.0260
105	0.0059	0.0065	0.0074	0.0085	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290
110	0.0065	0.0071	0.0080	0.0093	0.0110	0.0130	0.0160	0.0200	0.0250	0.0320
115	0.0071	0.0078	0.0089	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290	0.0370
120	0.0079	0.0087	0.0099	0.0120	0.0140	0.0170	0.0210	0.0260	0.0330	0.0420
125	0.0089	0.0099	0.0110	0.0130	0.0160	0.0190	0.0240	0.0300	0.0380	0.0490
130	0.0100	0.0110	0.0130	0.0150	0.0180	0.0220	0.0280	0.0000	0.0000	0.0000
135	0.0120	0.0130	0.0150	0.0180	0.0210	0.0000	0.0000	0.0000	0.0000	0.0000
140	0.0140	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Fig:B-4(FILE TRES4) Base Failure Rate of Power , Film Resistors

TEMP	LOADING									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.0033	0.0035	0.0037	0.0041	0.0045	0.0050	0.0057	0.0065	0.0075	0.0086
5	0.0033	0.0035	0.0038	0.0041	0.0046	0.0051	0.0058	0.0066	0.0077	0.0089
10	0.0033	0.0035	0.0038	0.0042	0.0047	0.0052	0.0059	0.0068	0.0079	0.0092
15	0.0033	0.0036	0.0039	0.0042	0.0047	0.0053	0.0061	0.0070	0.0081	0.0095
20	0.0034	0.0036	0.0039	0.0043	0.0048	0.0054	0.0062	0.0072	0.0084	0.0099
25	0.0034	0.0036	0.0040	0.0044	0.0049	0.0056	0.0064	0.0074	0.0087	0.0100
30	0.0034	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0076	0.0090	0.0110
35	0.0035	0.0037	0.0041	0.0045	0.0051	0.0058	0.0068	0.0079	0.0093	0.0110
40	0.0035	0.0038	0.0042	0.0046	0.0052	0.0060	0.0070	0.0082	0.0097	0.0120
45	0.0036	0.0039	0.0042	0.0047	0.0054	0.0062	0.0072	0.0085	0.0100	0.0120
50	0.0037	0.0039	0.0043	0.0049	0.0055	0.0064	0.0075	0.0088	0.0110	0.0130
55	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0077	0.0092	0.0110	0.0130
60	0.0038	0.0041	0.0046	0.0052	0.0059	0.0069	0.0081	0.0096	0.0120	0.0140
65	0.0039	0.0043	0.0047	0.0053	0.0061	0.0071	0.0084	0.0100	0.0120	0.0150
70	0.0041	0.0044	0.0049	0.0055	0.0064	0.0075	0.0089	0.0110	0.0130	0.0160
75	0.0042	0.0046	0.0051	0.0058	0.0067	0.0079	0.0094	0.0110	0.0140	0.0170
80	0.0044	0.0048	0.0053	0.0061	0.0070	0.0083	0.0099	0.0120	0.0150	0.0180
85	0.0046	0.0050	0.0056	0.0064	0.0075	0.0088	0.0110	0.0130	0.0160	0.0200
90	0.0048	0.0053	0.0059	0.0068	0.0079	0.0094	0.0110	0.0140	0.0170	0.0210
95	0.0051	0.0056	0.0063	0.0073	0.0085	0.0100	0.0120	0.0150	0.0190	0.0230
100	0.0055	0.0060	0.0068	0.0078	0.0092	0.0110	0.0130	0.0160	0.0200	0.0260
105	0.0059	0.0065	0.0074	0.0085	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290
110	0.0065	0.0071	0.0080	0.0093	0.0110	0.0130	0.0160	0.0200	0.0250	0.0320
115	0.0071	0.0078	0.0089	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290	0.0370
120	0.0079	0.0087	0.0099	0.0120	0.0140	0.0170	0.0210	0.0260	0.0330	0.0420
125	0.0089	0.0099	0.0110	0.0130	0.0160	0.0190	0.0240	0.0300	0.0380	0.0490
130	0.0100	0.0110	0.0130	0.0150	0.0180	0.0220	0.0280	0.0000	0.0000	0.0000
135	0.0120	0.0130	0.0150	0.0180	0.0210	0.0000	0.0000	0.0000	0.0000	0.0000
140	0.0140	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Fig.B-5 (FILE TRES5) Base Failure Rate of Wirewound,Accurate resistors

LOADING

TEMPERATURE	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.0033	0.0035	0.0037	0.0041	0.0045	0.0050	0.0057	0.0065	0.0075	0.0086
5	0.0033	0.0035	0.0038	0.0041	0.0046	0.0051	0.0058	0.0066	0.0077	0.0089
10	0.0033	0.0035	0.0038	0.0042	0.0047	0.0052	0.0059	0.0068	0.0079	0.0092
15	0.0033	0.0036	0.0039	0.0042	0.0047	0.0053	0.0061	0.0070	0.0081	0.0095
20	0.0034	0.0036	0.0039	0.0043	0.0048	0.0054	0.0062	0.0072	0.0084	0.0099
25	0.0034	0.0036	0.0040	0.0044	0.0049	0.0056	0.0064	0.0074	0.0087	0.0100
30	0.0034	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0076	0.0090	0.0110
35	0.0035	0.0037	0.0041	0.0045	0.0051	0.0058	0.0068	0.0079	0.0093	0.0110
40	0.0035	0.0038	0.0042	0.0046	0.0052	0.0060	0.0070	0.0082	0.0097	0.0120
45	0.0036	0.0039	0.0042	0.0047	0.0054	0.0062	0.0072	0.0085	0.0100	0.0120
50	0.0037	0.0039	0.0043	0.0049	0.0055	0.0064	0.0075	0.0088	0.0110	0.0130
55	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0077	0.0092	0.0110	0.0130
60	0.0038	0.0041	0.0046	0.0052	0.0059	0.0069	0.0081	0.0096	0.0120	0.0140
65	0.0039	0.0043	0.0047	0.0053	0.0061	0.0071	0.0084	0.0100	0.0120	0.0150
70	0.0041	0.0044	0.0049	0.0055	0.0064	0.0075	0.0089	0.0110	0.0130	0.0160
75	0.0042	0.0046	0.0051	0.0058	0.0067	0.0079	0.0094	0.0110	0.0140	0.0170
80	0.0044	0.0048	0.0053	0.0061	0.0070	0.0083	0.0099	0.0120	0.0150	0.0180
85	0.0046	0.0050	0.0056	0.0064	0.0075	0.0088	0.0110	0.0130	0.0160	0.0200
90	0.0048	0.0053	0.0059	0.0068	0.0079	0.0094	0.0110	0.0140	0.0170	0.0210
95	0.0051	0.0056	0.0063	0.0073	0.0085	0.0100	0.0120	0.0150	0.0190	0.0230
100	0.0055	0.0060	0.0068	0.0078	0.0092	0.0110	0.0130	0.0160	0.0200	0.0260
105	0.0059	0.0065	0.0074	0.0085	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290
110	0.0065	0.0071	0.0080	0.0093	0.0110	0.0130	0.0160	0.0200	0.0250	0.0320
115	0.0071	0.0078	0.0089	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290	0.0370
120	0.0079	0.0087	0.0099	0.0120	0.0140	0.0170	0.0210	0.0260	0.0330	0.0420
125	0.0089	0.0099	0.0110	0.0130	0.0160	0.0190	0.0240	0.0300	0.0380	0.0490
130	0.0100	0.0110	0.0130	0.0150	0.0180	0.0220	0.0280	0.0000	0.0000	0.0000
135	0.0120	0.0130	0.0150	0.0180	0.0210	0.0000	0.0000	0.0000	0.0000	0.0000
140	0.0140	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Fig. B-6 (FILE TRAN1) Base Failure Rate of Silicon,NPN Transistors

LOADING

TEMPERATURE	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.0033	0.0035	0.0037	0.0041	0.0045	0.0050	0.0057	0.0065	0.0075	0.0086
5	0.0033	0.0035	0.0038	0.0041	0.0046	0.0051	0.0058	0.0066	0.0077	0.0089
10	0.0033	0.0035	0.0038	0.0042	0.0047	0.0052	0.0059	0.0068	0.0079	0.0092
15	0.0033	0.0036	0.0039	0.0042	0.0047	0.0053	0.0061	0.0070	0.0081	0.0095
20	0.0034	0.0036	0.0039	0.0043	0.0048	0.0054	0.0062	0.0072	0.0084	0.0099
25	0.0034	0.0036	0.0040	0.0044	0.0049	0.0056	0.0064	0.0074	0.0087	0.0100
30	0.0034	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0076	0.0090	0.0110
35	0.0035	0.0037	0.0041	0.0045	0.0051	0.0058	0.0068	0.0079	0.0093	0.0110
40	0.0035	0.0038	0.0042	0.0046	0.0052	0.0060	0.0070	0.0082	0.0097	0.0120
45	0.0036	0.0039	0.0042	0.0047	0.0054	0.0062	0.0072	0.0085	0.0100	0.0120
50	0.0037	0.0039	0.0043	0.0049	0.0055	0.0064	0.0075	0.0088	0.0110	0.0130
55	0.0037	0.0040	0.0044	0.0050	0.0057	0.0066	0.0077	0.0092	0.0110	0.0130
60	0.0038	0.0041	0.0046	0.0052	0.0059	0.0069	0.0081	0.0096	0.0120	0.0140
65	0.0039	0.0043	0.0047	0.0053	0.0061	0.0071	0.0084	0.0100	0.0120	0.0150
70	0.0041	0.0044	0.0049	0.0055	0.0064	0.0075	0.0089	0.0110	0.0130	0.0160
75	0.0042	0.0046	0.0051	0.0058	0.0067	0.0079	0.0094	0.0110	0.0140	0.0170
80	0.0044	0.0048	0.0053	0.0061	0.0070	0.0083	0.0099	0.0120	0.0150	0.0180
85	0.0046	0.0050	0.0056	0.0064	0.0075	0.0088	0.0110	0.0130	0.0160	0.0200
90	0.0048	0.0053	0.0059	0.0068	0.0079	0.0094	0.0110	0.0140	0.0170	0.0210
95	0.0051	0.0056	0.0063	0.0073	0.0085	0.0100	0.0120	0.0150	0.0190	0.0230
100	0.0055	0.0060	0.0068	0.0078	0.0092	0.0110	0.0130	0.0160	0.0200	0.0260
105	0.0059	0.0065	0.0074	0.0085	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290
110	0.0065	0.0071	0.0080	0.0093	0.0110	0.0130	0.0160	0.0200	0.0250	0.0320
115	0.0071	0.0078	0.0089	0.0100	0.0120	0.0150	0.0180	0.0230	0.0290	0.0370
120	0.0079	0.0087	0.0099	0.0120	0.0140	0.0170	0.0210	0.0260	0.0330	0.0420
125	0.0089	0.0099	0.0110	0.0130	0.0160	0.0190	0.0240	0.0300	0.0380	0.0490
130	0.0100	0.0110	0.0130	0.0150	0.0180	0.0220	0.0280	0.0000	0.0000	0.0000
135	0.0120	0.0130	0.0150	0.0180	0.0210	0.0000	0.0000	0.0000	0.0000	0.0000
140	0.0140	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

```
STRUCTURE FOR FILE:  C:TRES2   .DBF
NUMBER OF RECORDS:   00029
DATE OF LAST UPDATE: 10/27/87
PRIMARY USE DATABASE
FLD       NAME       TYPE WIDTH   DEC
001       TEMP        N    004
002       R1          N    007    005
003       R2          N    007    005
004       R3          N    007    005
005       R4          N    007    005
006       R5          N    007    005
007       R6          N    007    005
008       R7          N    006    004
009       R8          N    006    004
010       R9          N    006    004
011       R10         N    006    004
** TOTAL **              00071
```

```
STRUCTURE FOR FILE:  C:TRES3   .DBF
NUMBER OF RECORDS:   00035
DATE OF LAST UPDATE: 07/09/87
PRIMARY USE DATABASE
FLD       NAME       TYPE WIDTH   DEC
001       TEMP        N    004
002       R1          N    007    005
003       R2          N    007    005
004       R3          N    007    005
005       R4          N    007    005
006       R5          N    007    005
007       R6          N    006    004
008       R7          N    006    004
009       R8          N    006    004
010       R9          N    006    004
011       R10         N    006    004
** TOTAL **              00070
```

```
STRUCTURE FOR FILE:  C:TRES4   .DBF
NUMBER OF RECORDS:   00022
DATE OF LAST UPDATE: 10/27/87
PRIMARY USE DATABASE
FLD       NAME       TYPE WIDTH   DEC
001       TEMP        N    004
002       R1          N    006    004
003       R2          N    006    004
004       R3          N    006    004
005       R4          N    005    003
006       R5          N    005    003
007       R6          N    005    003
008       R7          N    005    003
009       R8          N    005    003
010       R9          N    005    003
011       R10         N    005    003
** TOTAL **              00058
```

```
STRUCTURE FOR FILE:  C:TRES5   .DBF
NUMBER OF RECORDS:   00029
DATE OF LAST UPDATE: 07/08/87
PRIMARY USE DATABASE
FLD       NAME       TYPE WIDTH   DEC
001       TEMP        N    004
002       R1          N    006    004
003       R2          N    006    004
004       R3          N    006    004
005       R4          N    006    004
006       R5          N    006    004
007       R6          N    006    004
008       R7          N    006    004
009       R8          N    006    004
010       R9          N    006    004
011       R10         N    006    004
** TOTAL **              00065
```

```
STRUCTURE FOR FILE:  C:TRAN1   .DBF
NUMBER OF RECORDS:   00029
DATE OF LAST UPDATE: 09/05/87
PRIMARY USE DATABASE
FLD       NAME       TYPE WIDTH   DEC
001       TEMP        N    003
002       R1          N    007    005
003       R2          N    007    005
004       R3          N    007    005
005       R4          N    007    005
006       R5          N    007    005
007       R6          N    006    004
008       R7          N    006    004
009       R8          N    006    004
010       R9          N    006    004
011       R10         N    006    004
** TOTAL **              00069
```

```
     ******************************RELCKT.PRG*************************************
        SET TALK OFF
        STORE 0 TO CHOICE
   DO WHILE CHOICE<4
        CLEAR
    ?'                           M.E. DISSERTATION                ' 
    ?'                                 TOPIC                      '
    ?'             RELIABILITY EVALUATION OF ELECTRONIC CIRCUITS'
    ?'                                  by                        '
    ?'                           DEBASISH BASAK                   '
    ?
    ? '    1.CAPACITORS'
    ? '    2.DIODES'
    ? '    3.RESISTORS'
    ? '    4.TRANSISTORS'
    ? '    5.EXIT FROM THE SYSTEM'
    ?
    ?
    ?
        INPUT 'Enter your choice (1-5) from above:' TO CHOICE
      IF CHOICE=1
        DO A:CAPREL
      ENDIF
      IF CHOICE=2
        DO A:DIODREL
      ENDIF
      IF CHOICE=3
        DO A:RESREL
      ENDIF
      IF CHOICE=4
        DO A:TRNREL
      ENDIF
   ENDDO
      RETURN
**********************************************************************************
**********************************************************************************
```

```
******************************CAPREL.PRG*********************************
  SET TALK OFF
  STORE 0 TO CAPTYPE
  CLEAR
  ?'  1. Paper & Plastic film Capacitors'
  ?'  2. Mica Capacitors'
  ?'  3. Glass Capacitors'
  ?'  4. Ceramic Capacitors'
  ?'  5. Tantalum Electrolytic Capacitors'
  ?'  6. Aluminium Electrolytic Capacitors'
  ?'  7. Variable Ceramic Capacitors'
  ?'  8. Variable Piston Type Capacitors'
  ?'  9. Variable Air Trimmer Capacitors'
  ?' 10. Vacuum or Gas Capacitors'
  ?' 11.EXIT from the system'
  ?
  ?
  ?
    INPUT 'Enter the type of Capacitors (1-10) from above :' TO CAPTYPE
  IF CAPTYPE=1
    DO A:CREL1
  ENDIF
  IF CAPTYPE=2
    DO A:CREL2
  ENDIF
  IF CAPTYPE=3
    DO A:CREL3
  ENDIF
  IF CAPTYPE=4
    DO A:CREL4
  ENDIF
  IF CAPTYPE=5
    DO A:CREL5
  ENDIF
  IF CAPTYPE=6
    DO A:CREL6
  ENDIF
  IF CAPTYPE=7
    DO A:CREL7
  ENDIF
  IF CAPTYPE=8
    DO A:CREL8
  ENDIF
  IF CAPTYPE=9
    DO A:CREL9
  ENDIF
  IF CAPTYPE=10
    DO A:CREL10
  ENDIF
  RETURN
************************************************************************
```

```
*******************************RESREL.PRG****************************************
     SET TALK OFF
     STORE 0 TO RESTYPE
     CLEAR
     ?'   1. Composition Resistors'
     ?'   2. Film Resistors'
     ?'   3. Power Film Resistors'
     ?'   4. Resistor Network(Film type)'
     ?'   5. Wirewound,Accurate Resistors'
     ?'   6. Variable Wirewound Resistors'
     ?'   7. Variable Wirewound,Precision Resistors'
     ?'   8. Variable Wirewound,Semiprecision Resistors'
     ?'   9. Variable Wirewound,Power Resistors'
     ?'  10. Variable Non-wirewound,Power Resistors'
     ?'  11. Variable Composition Resistors'
     ?'  12. Variable Film & Precision Resistors'
     ?'  13. EXIT from the system'
     ?
     ?
     ?
       INPUT 'Enter the type of Resistors (1-12) from above:' TO RESTYPE
     IF RESTYPE=1
       DO A:RREL1
     ENDIF
     IF RESTYPE=2
       DO A:RREL2
     ENDIF
     IF RESTYPE=3
       DO A:RREL3
     ENDIF
     IF RESTYPE=4
       DO A:RREL4
     ENDIF
     IF RESTYPE=5
       DO A:RREL5
     ENDIF
     IF RESTYPE=6
       DO A:RREL6
     ENDIF
     IF RESTYPE=7
       DO A:RRE:7
     ENDIF
     IF RESTYPE=8
       DO A:RREL8
     ENDIF
     IF RESTYPE=9
       DO A:RREL9
     ENDIF
     IF RESTYPE=10
       DO A:RREL10
     ENDIF
     IF RESTYPE=11
       DO A:RREL11
     ENDIF
     IF RESTYPE=12
       DO A:RREL12
     ENDIF
     RETURN
*********************************************************************************
*********************************************************************************
```

```
****************************************DIODREL.PRG*****************************************
      SET TALK OFF
      STORE 0 TO DIODTYPE
      CLEAR
      ?'  1. General Purpose (Si/Ge) Diodes'
      ?'  2. Avalanche & Zener Diodes'
      ?'  3. Thyristors'
      ?'  4. EXIT from the system'
      ?
      ?
      ?
        INPUT 'Enter the tybe of Diodes (1-3) from above:' TO DIODTYPE
      IF DIODTYPE=1
        DO A:DREL1
      ENDIF
      IF DIODTYPE=2
        DO A:DREL2
      ENDIF
      IF DIODTYPE=3
        DO A:DREL3
      ENDIF
      RETURN
*******************************************************************************************************

*******************************************TRNREL.PRG***********************************************
      SET TALK OFF
      STORE 0 TO TRANSTYPE
      CLEAR
      ?'  1. Si/Ge (NPN/PNP) Transistors'
      ?'  2. Silicon/Gallium Field Effect Transistors'
      ?'  3. Unijunction Transistors'
      ?'  4.EXIT from the system'
      ?
      ?
      ?
       INPUT 'Enter the type of Transistors (1-3) from above:' TO TRANSTYPE
      IF TRANSTYPE=1
        DO A:TREL1
      ENDIF
      IF TRANSTYPE=2
        DO A:TREL2
      ENDIF
      IF TRANSTYPE=3
        DO A:TREL3
      ENDIF
      RETURN
*******************************************************************************************************
*******************************************************************************************************
```

```
*******************************RREL2.PRG***************************************
    IF RESTYPE=2
      STORE 0 TO TEMP
      STORE 0.000 TO RATIO
      STORE '     ' TO ENVIR
      STORE '            ' TO RATELEVEL
      STORE 0.00 TO RESVALUE
      @ 1,1 SAY 'GIVE TEMPERATURE' GET TEMP
      @ 2,1 SAY 'GIVE LOADRATIO' GET RATIO
      @ 3,1 SAY 'GIVE ENVIRONMENT' GET ENVIR
      @ 4,1 SAY 'FAILURE RATE LEVEL' GET RATELEVEL
      @ 5,1 SAY 'VALUE OF RESISTORS' GET RESVALUE
      STORE '             ' TO SPEC
      @ 6,1 SAY 'GIVE SPECIFICATION' GET SPEC
      READ
      STORE 5*INT(TEMP/5) TO X
      IF X<TEMP
        STORE X+5 TO X
      ENDIF
      STORE INT(X/5)+1 TO P
      STORE (1.0*INT(RATIO/0.1)*0.1) TO Y
      IF Y<RATIO
        STORE (Y+0.1) TO Y
      ENDIF
      IF Y<0.1
        STORE (Y+0.1) TO Y
      ENDIF
      STORE INT(Y/0.1) TO Z
      IF Z<10
          STORE STR(Z,1) TO Q
        ELSE
          STORE STR(Z,2) TO Q
      ENDIF
      STORE 'R'+Q TO A
      IF SPEC='MIL-R-39017'.OR.SPEC='MIL-R-22684'
        USE TRES2
        GOTO P
        STORE &A TO LAMDAB
      ENDIF
      IF SPEC='MIL-R-10509'.OR.SPEC='MIL-R-55182'
        USE TRES3
        GOTO P
        STORE &A TO LAMDAB
      ENDIF
      USE MODE
      GOTO 2
      STORE &ENVIR TO PIE
      IF RATELEVEL='S'
        STORE 0.03 TO PIQ
      ENDIF
      IF RATELEVEL='R'
        STORE 0.1 TO PIQ
      ENDIF
      IF RATELEVEL='P'
        STORE 0.3 TO PIQ
      ENDIF
      IF RATELEVEL='M'
        STORE 1.0 TO PIQ
      ENDIF
```

```
      IF RATELEVEL='MIL-SPEC'
        STORE 5.0 TO PIQ
      ENDIF
      IF RATELEVEL='LOWER'
        STORE 15.0 TO PIQ
      ENDIF
      IF RESVALUE<=100000
        STORE 1.0 TO PIR
      ENDIF
      IF RESVALUE>100000
        STORE RESVALUE TO RES
        IF RES<=1000000
          STORE 1.1 TO PIR
        ENDIF
      ENDIF
      IF RESVALUE>1000000
        STORE RESVALUE TO RESV
        IF RESV<=10000000
          STORE 1.6 TO PIR
        ENDIF
      ENDIF
      IF RESVALUE>10000000
        STORE 2.5 TO PIR
      ENDIF
      STORE (LAMDAB*PIE*PIR*PIQ) TO LAMDAP
      CM='R'
      USE OUTPUT
      APPEND BLANK
      REPLACE CMP WITH CM,RVAL WITH RESVALUE,LOAD WITH RATIO
      REPLACE LAMB WITH LAMDAB,PE WITH PIE,PR WITH PIR
      REPLACE PQ WITH PIQ,LAMDA WITH LAMDAP
   ENDIF
      RETURN
*****************************************************************************



******************************RREL3.PRG*************************************
      IF RESTYPE=3
        STORE 0 TO TEMP
        STORE 0.000 TO RATIO
        STORE '     ' TO ENVIR
        STORE'            ' TO RATELEVEL
        STORE 0.00 TO RESVALUE
        @ 1,1 SAY 'GIVE TEMPERATURE'GET TEMP
        @ 2,1 SAY 'GIVE LOADRATIO' GET RATIO
        @ 3,1 SAY 'GIVE ENVIRONMENT' GET ENVIR
        @ 4,1 SAY 'FAILURE RATE LEVEL' GET RATELEVEL
        @ 5,1 SAY 'VALUE OF RESISTORS' GET RESVALUE
        READ
        STORE 5*INT(TEMP/5) TO X
        IF X<TEMP
          STORE X+5 TO X
        ENDIF
        STORE INT(X/5)+1 TO P
        STORE (1.0*INT(RATIO/0.1)+0.1) TO Y
```

```
  IF Y<RATIO
    STORE (Y+0.1) TO Y
  ENDIF
  IF Y<0.1
    STORE (Y+0.1) TO Y
  ENDIF
  STORE INT(Y/0.1) TO Z
  IF Z<10
      STORE STR(Z,1) TO Q
    ELSE
      STORE STR(Z,2) TO Q
  ENDIF
  STORE 'R'+Q TO A
  USE TRES4
  GOTO P
  STORE &A TO LAMDAB
  USE MODE
  GOTO 3
  STORE &ENVIR TO PIE
  IF RATELEVEL='MIL-SPEC'
    STORE 1.0 TO PIQ
  ENDIF
  IF RATELEVEL='LOWER'
    STORE 3.0 TO PIQ
  ENDIF
  IF RESVALUE<=100
    STORE 1.2 TO PIR
  ENDIF
  IF RESVALUE>100
    STORE RESVALUE TO RESV
    IF RESV<=100000
      STORE 1.0 TO PIR
    ENDIF
  ENDIF
  IF RESVALUE>100000
    STORE RESVALUE TO RES
    IF RES<=1000000
      STORE 1.3 TO PIR
    ENDIF
  ENDIF
  IF RESVALUE>1000000
    STORE 3.5 TO PIR
  ENDIF
  STORE (LAMDAB*PIE*PIR*PIQ) TO LAMDAP
  CM='R'
  USE OUTPUT
  APPEND BLANK
  REPLACE CMP WITH CM,LOAD WITH RATIO,RVAL WITH RESVALUE
  REPLACE LAMB WITH LAMDAB,PE WITH PIE,PR WITH PIR
  REPLACE PQ WITH PIQ,LAMDA WITH LAMDAP
ENDIF
  RETURN
****************************************************************************
```

```
****************************RREL5.PRG*********************************
      IF RESTYPE=5
        STORE 0 TO TEMP
        STORE 0.000 TO RATIO
        STORE '    ' TO ENVIR
        STORE '            ' TO RATELEVEL
        STORE 0.00 TO RESVALUE
        @ 1,1 SAY 'GIVE TEMPERATURE' GET TEMP
        @ 2,1 SAY 'GIVE LOADRATIO' GET RATIO
        @ 3,1 SAY 'GIVE ENVIRONMENT' GET ENVIR
        @ 4,1 SAY 'FAILURE RATE LEVEL' GET RATELEVEL
        @ 5,1 SAY 'VALUE OF RESISTORS' GET RESVALUE
        READ
        STORE 5*INT(TEMP/5) TO X
        IF X<TEMP
          STORE X+5 TO X
        ENDIF
        STORE INT(X/5)+1 TO P
        STORE (1.0*INT(RATIO/0.1)*0.1) TO Y
        IF Y<RATIO
          STORE (Y+0.1) TO Y
        ENDIF
        IF Y<0.1
          STORE (Y+0.1) TO Y
        ENDIF
        STORE INT(Y/0.1) TO Z
        IF Z<10
            STORE STR(Z,1) TO Q
          ELSE
            STORE STR(Z,2) TO Q
        ENDIF
        STORE 'R'+Q TO A
        USE TRES5
        GOTO P
        STORE &A TO LAMDAB
        USE MODE
        GOTO 5
        STORE &ENVIR TO PIE
        IF RATELEVEL='S'
          STORE 0.03 TO PIQ
        ENDIF
        IF RATELEVEL='R'
          STORE 0.1 TO PIQ
        ENDIF
        IF RATELEVEL='P'
          STORE 0.3 TO PIQ
        ENDIF
        IF RATELEVEL='M'
          STORE 1.0 TO PIQ
        ENDIF
        IF RATELEVEL='MIL-SPEC'
          STORE 5.0 TO PIQ
        ENDIF
        IF RATELEVEL='LOWER'
          STORE 15.0 TO PIQ
        ENDIF
        IF RESVALUE<=10000
          STORE 1.0 TO PIR
```

```
      ENDIF
      IF RESVALUE>10000
        STORE RESVALUE TO RESV
        IF RESV<=100000
          STORE 1.7 TO PIR
        ENDIF
      ENDIF
      IF RESVALUE>100000
        STORE RESVALUE TO RES
        IF RES<=1000000
          STORE 3.0 TO PIR
        ENDIF
      ENDIF
      IF RESVALUE>1000000
        STORE 5.0 TO PIR
      ENDIF
      STORE (LAMDAB*PIE*PIR*PIQ) TO LAMDAP
      CM='R'
      USE OUTPUT
      APPEND BLANK
      REPLACE CMP WITH CM,LOAD WITH RATIO,RVAL WITH RESVALUE
      REPLACE LAMB WITH LAMDAB,PE WITH PIE,PR WITH PIR,PQ WITH PIQ
      REPLACE LAMDA WITH LAMDAP
    ENDIF
      RETURN
********************************************************************************
```

```
***************************TREL1.PRG**********************************
    IF TRANSTYPE=1
      STORE 0 TO TEMP
      STORE 0,000 TO RATIO
      STORE '      ' TO ENVIR
      STORE '               ' TO RATELEVEL
      STORE 0.000 TO PWR
      @ 1,1 SAY 'GIVE TEMPERATURE' GET TEMP
      @ 2,1 SAY 'GIVE LOADRATIO' GET RATIO
      @ 3,1 SAY 'GIVE ENVIRONMENT' GET ENVIR
      @ 4,1 SAY 'GIVE FAILURE RATELEVEL' GET RATELEVEL
      STORE '          ' TO TYPE
      STORE '                     ' TO COMP
      STORE '             ' TO APPL
      STORE 0.00 TO S2
      @ 5,1 SAY 'Si/Ge,NPN/PNP' GET TYPE
      @ 6,1 SAY 'COMPLEXITY' GET COMP
      @ 7,1 SAY 'APPLICATION' GET APPL
      @ 8,1 SAY '(Applied Vce/Rated Vceo)*100 ' GET S2
      @ 9,1 SAY 'POWER RATING' GET PWR
      READ
      IF TYPE='Si,NPN'
        USE TRAN1
        STORE (1.0*INT(RATIO/0.1)*0.1) TO Y
        IF Y<RATIO
          STORE (Y+0.1) TO Y
        ENDIF
        STORE INT(Y/0.1) TO Z
        IF Z<10
            STORE STR(Z,1) TO X
          ELSE
            STORE STR(Z,2) TO X
        ENDIF
        STORE 'R'+X TO A
        IF TEMP=0
          GOTO 1
        ENDIF
        IF TEMP>0
          STORE TEMP TO TE
          IF TE<=10
            GOTO 2
          ENDIF
        ENDIF
        IF TEMP>10
          STORE TEMP TO TEM
          IF TEM<=20
            GOTO 3
          ENDIF
        ENDIF
        IF TEMP>20
          STORE TEMP TO T
          IF T<=25
            GOTO 4
          ENDIF
        ENDIF
        IF TEMP>25
          STORE TEMP TO TE1
          IF TE1<=30
            GOTO 5
         ENDIF
```

```
  ENDIF
  IF TEMP>30
    STORE TEMP TO TE2
    IF TE2<=40
       GOTO 6
    ENDIF
  ENDIF
  IF TEMP>40
    STORE TEMP TO TE3
    IF TE3<=50
       GOTO 7
    ENDIF
  ENDIF
  IF TEMP>50
    STORE 5*INT(TEMP/5) TO X
    IF X<TEMP
       STORE X+5 TO X
    ENDIF
    STORE INT(X/5)+1 TO P
    STORE (P-4) TO P
    GOTO P
  ENDIF
  STORE &A TO LAMDAB
ENDIF
IF TYPE='Si,PNP'
  STORE (1.0*INT(RATIO/0.1)*0.1) TO Y
  IF Y<RATIO
    STORE (Y+0.1) TO Y
  ENDIF
  IF Y<0.1
    STORE (Y+0.1) TO Y
  ENDIF
  STORE INT(Y/0.1) TO Z
  IF Z<10
      STORE STR(Z,1) TO Q
    ELSE
      STORE STR(Z,2) TO Q
  ENDIF
  STORE 'R'+Q TO A
  USE TRAN2
  IF TEMP=0
    GOTO 1
  ENDIF
  IF TEMP>0
    STORE TEMP TO TE
    IF TE<=10
      GOTO 2
    ENDIF
  ENDIF
  IF TEMP>10
    STORE TEMP TO TEM
    IF TEM<=20
      GOTO 3
    ENDIF
  ENDIF
```

```
  IF TEMP>20
    STORE TEMP TO T
    IF T<=25
      GOTO 4
    ENDIF
  ENDIF
  IF TEMP>25
    STORE TEMP TO TE1
    IF TE1<=30
      GOTO 5
    ENDIF
  ENDIF
  STORE &A TO LAMDAB
ENDIF
IF TYPE='Ge,PNP'
  STORE (1.0*INT(RATIO/0.1)*0.1) TO Y
  IF Y<RATIO
    STORE (Y+0.1) TO Y
  ENDIF
  IF Y<0.1
    STORE (Y+0.1) TO Y
  ENDIF
  STORE INT(Y/0.1) TO Z
  IF Z<10
      STORE STR(Z,1) TO Q
    ELSE
      STORE STR(Z,2) TO Q
  ENDIF
  STORE 'R'+Q TO A
  USE TRAN3
  STORE 5*INT(TEMP/5) TO X
  IF X<TEMP
    STORE X+5 TO X
  ENDIF
  STORE INT(X/5)+1 TO P
  GOTO P
  STORE &A TO LAMDAB
ENDIF
IF TYPE='Ge,NPN'
  STORE (1.0*INT(RATIO/0.1)*0.1) TO Y
  IF Y<RATIO
    STORE (Y+0.1) TO Y
  ENDIF
  IF Y<0.1
    STORE (Y+0.1) TO Y
  ENDIF
  STORE INT(Y/0.1) TO Z
  IF Z<10
      STORE STR(Z,1) TO Q
    ELSE
      STORE STR(Z,2) TO Q
  ENDIF
  STORE 'R'+Q TO A
  USE TRAN4
  STORE 5*INT(TEMP/5) TO X
  IF X<TEMP
    STORE X+5 TO X
  ENDIF
```

```
                          :
   STORE INT(X/5)+1 TO P
   GOTO P
   STORE &A TO LAMDAB
ENDIF
USE MODE
GOTO 13
STORE &ENVIR TO PIE
IF RATELEVEL='LOWER'
   STORE 6.0 TO PIQ
ENDIF
IF RATELEVEL='JANTXV'
   STORE 0.12 TO PIQ
ENDIF
IF RATELEVEL='JANTX'
   STORE 0.24 TO PIQ
ENDIF
IF RATELEVEL='JAN'
   STORE 1.2 TO PIQ
ENDIF
IF RATELEVEL='PLASTIC'
   STORE 12.0 TO PIQ
ENDIF
IF COMP='SINGLE TRANSISTOR'
   STORE 1.0 TO PIC
ENDIF
IF COMP='DUAL(UNMATCHED)'.OR.COMP='COMPLEMENTARY PAIR'
   STORE 0.7 TO PIC
ENDIF
IF COMP='DUAL(MATCHED)'.OR.COMP='MULTIPLE EMITTER'
   STORE 1.2 TO PIC
ENDIF
IF COMP='DARLINGTON'
   STORE 0.8 TO PIC
ENDIF
IF COMP='DUAL EMITTER'
   STORE 1.1 TO PIC
ENDIF
IF APPL='LINEAR'
   STORE 1.5 TO PIA
ENDIF
IF APPL='SWITCH'
   STORE 0.7 TO PIA
ENDIF
IF APPL='LOW NOISE'
   STORE 15.0 TO PIA
ENDIF
IF S2>=25
   PIS2=0.14*(10)**(0.0133*S2)
ENDIF
IF S2<25
   PIS2=0.3
ENDIF
IF PWR<=1.0
   STORE 1.0 TO PIR
ENDIF
```

```
       IF PWR>1.0
         STORE PWR TO P1
         IF P1<=5.0
           STORE 1.5 TO PIR
         ENDIF
       ENDIF
       IF PWR>5.0
         STORE PWR TO P2
         IF P2<=20.0
           STORE 2.0 TO PIR
         ENDIF
       ENDIF
       IF PWR>20.0
         STORE PWR TO P3
         IF P3<=50.0
           STORE 2.5 TO PIR
         ENDIF
       ENDIF
       IF PWR>50.0
         STORE PWR TO P4
         IF P4<=200.0
           STORE 5.0 TO PIR
         ENDIF
       ENDIF
       LAMDAP=LAMDAB*(PIE*PIA*PIQ*PIS2*PIC)
       CM='T'
       USE OUTPUT
       APPEND BLANK
       REPLACE CMP WITH CM,LOAD WITH RATIO,LAMB WITH LAMDAB
       REPLACE PE WITH PIE,PA WITH PIA,PQ WITH PIQ,PS2 WITH PIS2
       REPLACE PC WITH PIC,PR WITH PIR,LAMDA WITH LAMDAP
     ENDIF
       RETURN
******************************************************************************
```

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