

Contents

1 INTRODUCTION	1
1.1 Definition of reliability	1
1.2 Historical development perspective	2
1.3 Quality and reliability	3
1.4 Economics and optimisation	5
1.5 Probability; basic laws	5
1.5.1 Probability distributions	6
1.5.2 Basic reliability distribution theory	9
1.6 Specific terms	11
1.6.1 The generalised definition of I and MTBF	13
1.7 Failures types	15
1.7.1 Failures classification	16
1.8 Reliability estimates	17
1.9 “Bath–tub” failure curve	19
1.10 Reliability of electronic systems	20
1.10.1 Can the batch reliability be increased?	20
1.10.2 What is the utility of screening tests?	21
1.10.3 Derating technique	24
1.10.4 About the testability of electronic and telecommunication systems	25
1.10.5 Accelerated ageing methods for equipped boards	26
1.10.6 Operational failures	27
1.10.7 FMEA/FMECA method	29
1.10.8 Fault tree analysis (FTA)	30
1.10.8.1 Monte Carlo techniques	30
1.10.9 Practical recommendations	32
1.10.10 Component reliability and market economy	33

1.11 Some examples	35
References	37
2 STATE OF THE ART IN RELIABILITY	43
2.1 Cultural features	44
2.1.1 Quality and reliability assurance	44
2.1.2 Total quality management (TQM)	46
2.1.3 Building-in reliability (BIR)	48
2.1.4 Concurrent engineering (CE)	49
2.1.5 Acquisition reform	50
2.2 Reliability building	51
2.2.1 Design for reliability	51
2.2.2 Process reliability	52
2.2.2.1 Technological synergies	53
2.2.3 Screening and burn-in	54
2.2.3.1 Burn-in	56
2.2.3.2 Economic aspects of burn-in	59
2.2.3.3 Other screening tests	60
2.2.3.4 Monitoring the screening	61
2.3 Reliability evaluation	65
2.3.1 Environmental reliability testing	66
2.3.1.1 Synergy of environmental factors	68
2.3.1.2 Temperature cycling	70
2.3.1.3 Behavior in a radiation field	72
2.3.2 Life testing with noncontinuous inspection	73
2.3.3 Accelerated testing	75
2.3.3.1 Activation energy depends on the stress level	77
2.3.4 Physics of failure	78
2.3.4.1 Drift, drift failures and drift behaviour	81
2.3.5 Prediction methods	83
2.3.5.1 Prediction methods based on failure physics	84
2.3.5.2 Laboratory versus operational reliability	86
2.4 Standardisation	87
2.4.1 Quality systems	87
2.4.2 Dependability	87
References	87

3	RELIABILITY OF PASSIVE ELECTRONIC PARTS	93
3.1	How parts fail	93
3.2	Resistors	94
3.2.1	Some important parameters	97
3.2.2	Characteristics	98
3.2.3	Reasons for inconstant resistors [3.8]...[3.10]	100
3.2.3.1	Carbon film resistors (Fig. 3.4)	101
3.2.3.2	Metal film resistors	101
3.2.3.3	Composite resistors (on inorganic basis)	101
3.2.4	Some design rules	101
3.2.5	Some typical defects of resistors	102
3.2.5.1	Carbon film resistors	104
3.2.5.2	Metal film resistors	104
3.2.5.3	Film resistors	105
3.2.5.4	Fixed wirewound resistors	105
3.2.5.5	Variable wirewound resistors	105
3.2.5.6	Noise behaviour	105
3.3	Reliability of capacitors	105
3.3.1	Introduction	105
3.3.2	Aluminium electrolytic capacitors	107
3.3.2.1	Characteristics	108
3.3.2.2	Results of reliability research studies	110
3.3.2.3	Reliability data	111
3.3.2.4	Main failures types	111
3.3.2.5	Causes of failures	112
3.3.3	Tantalum capacitors	112
3.3.3.1	Introduction	112
3.3.3.2	Structure and properties	113
3.3.3.3	Reliability considerations	115
3.3.3.4	$\Delta C/C_0$ variation with temperature	116
3.3.3.5	The failure rate and the product CU	117
3.3.3.6	Loss factor	117
3.3.3.7	Impedance at 100 Hz	117
3.3.3.8	Investigating the stability of 35 V tantalum capacitor	117
3.3.3.9	The failure rate model	121
3.3.4	Reliability comparison	121
3.3.5	Another reliability comparison	123
3.3.6	Polyester film / foil capacitors	124
3.3.6.1	Introduction	124
3.3.6.2	Life testing	125
3.3.6.3	λ as a function of temperature and load	126
3.3.6.4	Reliability conclusions	127
3.3.7	Wound capacitors	129
3.3.8	Reliability and screening methods [3.37] [3.38]	131

3.4 Zinc oxide (ZnO) varistors [3.39]...[3.45]	132
3.4.1 Pulse behaviour of ZnO varistors	134
3.4.2 Reliability results	138
3.5 Connectors	138
3.5.1 Specifications profile	139
3.5.2 Elements of a test plan	140
References	141
4 RELIABILITY OF DIODES	145
4.1 Introduction	145
4.2 Semiconductor diodes	146
4.2.1 Structure and properties	146
4.2.2 Reliability tests and results	146
4.2.3 Failure mechanisms	148
a. Mechanical failure mechanisms	148
b. Electrical failure mechanisms	148
4.2.4 New technologies	149
4.2.5 Correlation between technology and reliability	150
4.2.6 Intermittent short-circuits	153
4.3 Z diodes	154
4.3.1 Characteristics	154
4.3.2 Reliability investigations and results	155
4.3.3 Failure mechanisms	158
4.3.3.1 Failure mechanisms of Z diodes	159
4.3.3.2 Design for reliability	160
4.3.3.3 Some general remarks	161
4.3.3.4 Catastrophic failures	162
4.3.3.5 Degradation failures	162
4.4 Trans-Zorb diodes	163
4.4.1 Introduction	163
4.4.2 Structure and characteristics	163
4.5 Impatt (IMPact Avalanche and Transit-Time) diodes	163
4.5.1 Reliability test results for HP silicon single drift Impatt diodes	165
4.5.2 Reliability test results for HP silicon double drift Impatt diodes	166
4.5.3 Factors affecting the reliability and safe operation	166
References	169

5	RELIABILITY OF SILICON TRANSISTORS	171
5.1	Introduction	171
5.2	Technologies and power limitations	172
5.2.1	Bipolar transistors	173
5.2.2	Unipolar transistors	173
5.3	Electrical characteristics	175
5.3.1	Recommendations	176
5.3.2	Safety Limits	176
5.3.3	The du/dt phenomenon	177
5.4	Reliability characteristics	178
5.5	Thermal fatigue	180
5.6	Causes of failures	182
5.6.1	Failure mechanisms	182
5.6.2	Failure modes	183
5.6.3	A check-up for the users	185
5.6.4	Bipolar transistor peripherics	185
5.7	The package problem	185
5.8	Accelerated tests	186
5.8.1	The Arrhenius model	187
5.8.2	Thermal cycling	188
5.9	How to improve the reliability	190
5.10	Some recommendations	191
	References	193
6	RELIABILITY OF THYRISTORS	197
6.1	Introduction	197
6.2	Design and reliability	199
6.2.1	Failure mechanisms	199
6.2.2	Plastic and hermetic package problems	202
6.2.3	Humidity problem	204
6.2.4	Evaluating the reliability	204
6.2.5	Thyristor failure rates	206

6.3 Derating	207
6.4 Reliability screens by General Electric	209
6.5 New technology in preparation: SITH	210
References	213
7. RELIABILITY OF INTEGRATED CIRCUITS	215
7.1 Introduction	215
7.2 Reliability evaluation	219
7.2.1 Some reliability problems	219
7.2.2 Evaluation of integrated circuit reliability	219
7.2.3 Accelerated thermal test	221
7.2.4 Humidity environment	222
7.2.5 Dynamic life testing	223
7.3 Failure analysis	224
7.3.1. Failure mechanisms	224
7.3.1.1 Gate oxide breakdown	225
7.3.1.2 Surface charges	226
7.3.1.3 Hot carrier effects	226
7.3.1.4 Metal diffusion	226
7.3.1.5 Electromigration	227
7.3.1.6 Fatigue	228
7.3.1.7 Aluminium-gold system	229
7.3.1.8 Brittle fracture	229
7.3.1.9 Electrostatic Discharge (ESD)	229
7.3.2 Early failures	230
7.3.3 Modeling IC reliability	231
7.4 Screening and burn-in	233
7.4.1 The necessity of screening	233
7.4.2 Efficiency and necessity of burn-in	235
7.4.3 Failures at screening and burn-in	237
7.5 Comparison between the IC families TTL Standard and TTL-LS	240
7.6 Application Specific Integrated Circuits (ASIC)	240
References	241

8 RELIABILITY OF HYBRIDS	247
8.1 Introduction	247
8.2 Thin-film hybrid circuits	250
8.2.1 Reliability characteristics of resistors	250
8.2.2 Reliability of throughout-contacts	251
8.3 Thick-film hybrids	252
8.3.1 Failure types	253
8.3.2 Reliability of resistors and capacitors	254
8.3.3 Reliability of “beam-leads“	254
8.4 Thick-film versus thin-film hybrids	257
8.5 Reliability of hybrid ICs	259
8.6 Causes of failures	261
8.7 Influence of radiation	264
8.8 Prospect outlook of the hybrid technology	264
8.9 Die attach and bonding techniques	270
8.9.1 Introduction	270
8.9.2 Hybrid package styles	271
8.10 Failure mechanisms	274
References	275
9 RELIABILITY OF MEMORIES	277
9.1 Introduction	277
9.2 Process-related reliability aspects	283
9.3 Possible memories classifications	288
9.4 Silicon On Insulator (SOI) technologies	290
9.4.1 Silicon on sapphire (SOS) technology	291
9.5 Failure frequency of small geometry memories	291

9.6 Causes of hardware failures	292
9.6.1 Read only memories (ROMs)	294
9.6.2 Small geometry devices	296
9.7 Characterisation testing	296
9.7.1 Timing and its influence on characterisation and test	298
9.7.2 Test and characterisation of refresh	298
9.7.2.1 Screening tests and test strategies	299
9.7.3 Test-programmes and –categories	301
9.7.3.1 Test categories	301
9.7.3.2 RAM failure modes	302
9.7.3.3 Radiation environment in space; hardening approaches	303
9.8 Design trends in microprocessor domain	305
9.9 Failure mechanisms of microprocessors	306
References	310
10 RELIABILITY OF OPTOELECTRONICS	313
10.1 Introduction	313
10.2 LED reliability	316
10.3 Optocouplers	318
10.3.1 Introduction	318
10.3.2 Optocouplers ageing problem	318
10.3.3 CTR degradation and its cause	320
10.3.4 Reliability of optocouplers	321
10.3.5 Some basic rules for circuit designers	323
10.4 Liquid crystal displays	324
10.4.1 Quality and reliability of LCDs	325
References	327

11 NOISE AND RELIABILITY	329
11.1 Introduction	329
11.2 Excess noise and reliability	330
11.3 Popcorn noise	331
11.4 Flicker noise	333
11.4.1 Measuring noise	333
11.4.2 Low noise, long life	333
11.5 Noise figure	334
11.6 Improvements in signal quality of digital networks	336
References	336
12 PLASTIC PACKAGE AND RELIABILITY	339
12.1 Historical development	339
12.2 Package problems	341
12.2.1 Package functions	342
12.3 Some reliabilistic aspects of the plastic encapsulation	343
12.4 Reliability tests	344
12.4.1 Passive tests	345
12.4.2 Active tests	346
12.4.3 Life tests	347
12.4.4 Reliability of intermittent functioning plastic encapsulated ICs	349
12.5 Reliability predictions	352
12.6 Failure analysis	353
12.7 Technological improvements	354
12.7.1 Reliability testing of PCB equipped with PEM	356
12.7.2 Chip-Scale packaging	356
12.8 Can we use plastic encapsulated microcircuits (PEM) in high reliability applications?	357
References	359

13 TEST AND TESTABILITY OF LOGIC ICS	363
13.1 Introduction	363
13.2 Test and test systems	364
13.2.1 Indirect tests	365
13.3 Input control tests of electronic components	365
13.3.1 Electrical tests	366
13.3.2 Some economic considerations	367
13.3.3 What is the cost of the tests absence?	368
13.4 LIC selection and connected problems	369
13.4.1 Operational tests of memories	370
13.4.2 Microprocessor test methods	371
13.4.2.1 Selftesting	371
13.4.2.2 Comparison method	371
13.4.2.3 Real time algorithmic method	372
13.4.2.4 Registered patterns method	372
13.4.2.5 Random test of microprocessors	373
13.5 Testability of LICs	373
13.5.1 Constraints	374
13.5.2 Testability of sequential circuits	374
13.5.3 Independent and neutral test laboratories	375
13.6 On the testability of electronic and telecommunications systems	376
References	379
14 FAILURE ANALYSIS	381
14.1 Introduction [14.1]...[14.25]	381
14.2 The purpose of failure analysis	383
14.2.1 Where are discovered the failures?	383
14.2.2 Types of failures	384
14.3 Methods of analysis	386
14.3.1 Electrical analysis	386
14.3.2 X-ray analysis	387
14.3.3 Hermeticity testing methods	388
14.3.4 Conditioning tests	388
14.3.5 Chemical means	388

14.3.6 Mechanical means	389
14.3.7 Microscope analysis	389
14.3.8 Plasma etcher	389
14.3.9 Electron microscope	389
14.3.10 Special means	390
14.4 Failure causes	392
14.5. Some examples	393
References	410
15 APPENDIX	413
15.1 Software-package RAMTOOL++ [15.1]	413
15.1.1 Core and basic module R ³ Trecker	413
15.1.2 RM analyst	414
15.1.3 Mechanicus (Maintainability analysis)	414
15.1.4 Logistics	414
15.1.5 RM FFT-module	415
15.1.6 PPoF-module	415
15.2 Failure rates for components used in telecommunications	415
15.3 Failure types for electronic components [15.2]	418
15.4 Detailed failure modes for some components	419
15.5 Storage reliability data [15.3]	420
15.6 Failure criteria. Some examples	420
15.7 Typical costs for the screening of plastic encapsulated ICs	421
15.8 Results of 1000 h HTB life tests for CMOS microprocessors	421
15.9. Results of 1000 h HTB life tests for linear circuits	422
15.10 Average values of the failure rates for some IC families	422
15.11 Activation energy values for various technologies	423
15.12 Failures at burn-in	424
References	424

GENERAL BIBLIOGRAPHY	425
RELIABILITY GLOSSARY	455
LIST OF ABBREVIATIONS	473
POLYGLOT DICTIONARY OF RELIABILITY TERMS	481
INDEX	501