

## TABLE OF CONTENTS

	<b>Page</b>
1.0 INTRODUCTION.....	1
2.0 OPTOELECTRONIC SEMICONDUCTOR DEVICES.....	3
2.1 Laser Diodes.....	3
2.1.1 Semiconductor Laser Fundamentals .....	3
2.1.2 Semiconductor Laser Characteristics .....	4
2.2 Light Emitting Diodes (LEDS) .....	7
2.2.1 LED Semiconductor Chips.....	7
2.2.2 LED Packaging.....	10
2.3 Photodiodes .....	12
2.3.1 PIN Photodiodes.....	13
2.3.2 Avalanche Photodiodes .....	13
2.4 Opto Isolators .....	14
2.4.1 Photo Emitter .....	16
2.4.2 Optical Medium.....	17
2.4.3 Isolator Packaging .....	17
2.4.3.1 Packaging of Plastic DIP Isolators .....	17
2.4.3.2 Packaging of High Reliability Isolators.....	17
2.5 Degradation Mechanisms .....	18
2.5.1 Emitter Failure Mode/Mechanisms .....	18
2.5.1.1 GaAs LED's.....	21
2.5.1.2 Laser Diodes.....	22
2.5.1.2.1 Catastrophic Degradation.....	22
2.5.1.2.2 Gradual Degradation .....	22
2.5.1.2.3 Functional Degradation .....	23
2.5.1.2.4 ESD Degradation.....	24
2.5.2 Detection and Location of Dark Spot Defects.....	25
2.5.3 Reliability Assessment Of High Power Surface Light Emitting Diodes (SLEDs).....	27
2.5.4 Reliability Degradation In Distributed Feedback Lasers.....	28
2.5.5 Detector Failure Mechanisms.....	29
2.5.5.1 APD Dark Current.....	31
2.5.5.2 PIN Dark Current .....	31
2.5.5.3 Humidity.....	31
2.5.5.4 Temperature Cycling .....	32
2.5.5.5 Reliability of InGaAs Detectors .....	32
2.5.6 Opto-Isolator Degradation.....	32
2.5.6.1 Current Transfer Ratio .....	32
2.5.6.2 Cause of CTR Degradation .....	33
2.6 Testing Techniques .....	37
2.6.1 Emitter Testing Techniques .....	37
2.6.1.1 Characterization Prior To Testing.....	37
2.6.1.2 Unbiased Humidity and Temperature Tests .....	38
2.6.1.3 High Temperature Burn-In.....	38

## TABLE OF CONTENTS (CONT'D)

	<b>Page</b>
2.6.1.4 Active Stressing.....	39
2.6.1.5 Wearout Degradation Mode Burn-In.....	39
2.6.1.6 Testing Results Precautions .....	39
2.6.1.7 Degradation Accelerants .....	40
2.6.1.8 Testing of AlGaAs/GaAs Double Heterostructure Laser Diodes Grown by Chemical Vapor Deposition.....	40
2.6.2 Detector Testing Techniques.....	41
2.6.2.1 Screen Tests.....	41
2.6.2.2 Reliability Purge Test of SAGCM InGaAs/InP Avalanche Photodiodes (APDs).....	42
2.7 Optoelectronic Part Failure Rates.....	43
3.0 FIBER OPTICS .....	51
3.1 Optical Fibers .....	51
3.1.1 Multimode Fiber.....	52
3.1.2 Single Mode Fiber Types .....	52
3.1.3 Common Failure Mechanisms and Their Causes.....	53
3.1.4 Critical Design Criteria and Approaches to Minimize Common Failures .....	55
3.1.5 Design Tests .....	57
3.1.5.1 Fiber Tests .....	57
3.1.5.2 Cable Tests .....	59
3.2 Connectors and Splices .....	61
3.2.1 Fabrication Techniques .....	62
3.2.2 Common Failure Mechanisms .....	62
3.2.2.1 Splice Failures .....	62
3.2.2.2 Connector Failures .....	65
3.2.3 Design Tests .....	68
3.2.3.1 Splice Tests .....	68
3.2.3.2 Connector Tests.....	68
3.3 Switches .....	70
3.3.1 Degradation Mechanisms .....	71
3.3.1.1 Fiber Alignment Switches.....	71
3.3.1.2 Prism and Mirror Movement Switches .....	71
3.3.1.3 Motor-Driven Optical Switches .....	72
3.3.1.4 Integrated Electro-Optic Switches.....	72
3.3.2 Lifetime Data.....	73
3.4 Optical Multiplexers/Demultiplexers/Couplers .....	73
3.4.1 Environmental Tests.....	74
3.4.2 Field Performance .....	75
Appendix A: Failure Rate Data.....	77
Appendix B: Failure Mode Data .....	97
Appendix C: Acronyms & Abbreviations .....	109

**TABLE OF CONTENTS (CONT'D)**

	<b>Page</b>
Appendix D: Glossary.....	85
Appendix E: References.....	89

**LIST OF TABLES**

Table 1.	GaAs Removal Data From Field Applications.....	18
Table 2.	Common Failure Mechanisms (Transmitters).....	21
Table 3.	Component Failure Rates .....	21
Table 4.	GaAs LED Activation Energies .....	21
Table 5.	GaAs Laser Diode Activation Energies .....	22
Table 6.	Advanced Techniques For DSD Analysis .....	26
Table 7.	Summary Of Device Failures .....	28
Table 8.	Photodetector Characteristics .....	29
Table 9.	Planar and Mesa Avalanche and PIN Photodiode Failure Mechanisms .....	30
Table 10.	Common Failure Mechanisms (Receivers) .....	30
Table 11.	Component Failure Rates .....	30
Table 12.	Typical CTR Degradation vs. Time For Hewlett-Packard Opto Isolators .....	36
Table 13.	Emitter Tests .....	37
Table 14.	Parameters Causing Laser Degradation.....	40
Table 15.	Photodetector Mechanical and Environmental Tests .....	42
Table 16.	Application Environments.....	44
Table 17.	Environment Factor - $\pi_E$ .....	45
Table 18.	Temperature Factor - $\pi_T$ .....	46
Table 19.	Approximate Junction-to-Case Thermal Resistance ( $\Theta_{JC}$ ) for Semiconductor Devices in Various Package Sizes .....	47
Table 20.	Optoelectronics, Detectors, Isolators, Emitters .....	48
Table 21.	Optoelectronics, Laser Diodes .....	49
Table 22.	Fiber Characteristics.....	51
Table 23.	Cable Characteristics.....	51
Table 24.	Common Failure Mechanisms (Fiber & Cable).....	53
Table 25.	Typical Fiber Tests .....	55
Table 26.	Mechanical Property Measurement Procedure.....	58
Table 27.	Environmental Aging Procedures .....	58
Table 28.	Cyclic Fatigue Data .....	59
Table 29.	Typical Mechanical and Environmental Cable Tests .....	60
Table 30.	Typical Optical Performance Cable Tests.....	60
Table 31.	Optical Fiber And Cable Failure Rates .....	60
Table 32.	Splice Criteria.....	62
Table 33.	Field Splice Data Summary.....	64
Table 34.	Factory Fusion Splice Summary .....	65
Table 35.	Field Fusion Splice Data Summary.....	65
Table 36.	Field Linear Array Splice Data Summary .....	65
Table 37.	Connector Loss Criteria.....	66

**LIST OF TABLES (CONT'D)**

	<b>Page</b>
Table 38. Connector Failure Rates .....	66
Table 39. Optical Splice Testing .....	68
Table 40. Results Of Thermal Aging Test.....	70
Table 41. Results Of Humidity Resistance Test.....	70
Table 42. Results Of Thermal Cycling Test.....	70
Table 43. Summary Of All Environmental Tests .....	70
Table 44. Manufacturer Switch Lifetime Data.....	73
Table 45. Environmental Tests for Militarized FBT Star Coupler.....	74
Table 46. Reliability Data for Multiplexers, Demultiplexers and Couplers.....	76

**LIST OF FIGURES**

Figure 1. Cross sectional drawing of a generic buried heterostructure laser (scale is approximate). The dimensions of the active layer are about 1500 nm in width and 100 nm in thickness.....	4
Figure 2. Forward L versus I and $dL/dI$ versus I characteristics measured on a commercial laser as received from the manufacturer.....	5
Figure 3. Spectrum measured from a good commercial laser biased near threshold. A logarithmic vertical axis is used to enable the convenient illustration of all longitudinal modes within the selected wavelength interval.....	6
Figure 4. Direct Gap LED Lamp Normalized Luminous Intensity vs. Operating Life and High Temperature Storage T-1 3/4 Plastic Packages .....	8
Figure 5. Indirect Gap LED Lamp Normalized Luminous Intensity vs. Operating Life and High Temperature Storage T-1 Plastic Packages .....	9
Figure 6. Direct Gap LED Lamp Normalized Luminous Intensity vs. Operating Life TO-18 Hermetic Package .....	9
Figure 7. Expected Rate of Degradation vs. Time for T-1 3/4 Plastic Package .....	10
Figure 8. Typical Mechanical Reliability Data Sheet for a T-1 3/4 Plastic Lamp.....	11
Figure 9. Structure of a P-I-N Photodiode.....	13
Figure 10. Structure of an Avalanche Photodiode.....	14
Figure 11. Mechanical Construction of Hewlett Packard's Plastic Encapsulated Opto Isolators .....	15
Figure 12. Mechanical Construction of Hermetic Opto Isolator Manufactured by Hewlett Packard .....	15
Figure 13. Gain (G) – Bandwidth (B) Optimization in Direct Bandgap Photoemission...	16
Figure 14. Threshold Current Degradation Mode .....	20
Figure 15. Idealized Cause and Effect Model for DSD Type $-\Delta I_V$ Failures Due to the Formation and Movement of Dislocations.....	26
Figure 16. Normalized Luminous Intensity vs. Operating Life for Hermetic 655 nm Lamp (5082-4420) Stressed at 50 mA DC.....	33
Figure 17. Output Current vs. Photocurrent for 5082-4360 Series Opto Isolators.....	34

**LIST OF FIGURES (CONT'D)**

	<b>Page</b>
Figure 18. Normalized Luminous Intensity vs. Operational Life for 700 NM LED Emitters Used for Hewlett-Packard Optically Couple Isolators.....	35
Figure 19. Normalized Current Transfer Ratio vs. Operating life for 5082-4370 Series Opto Isolators .....	36
Figure 20. Typical dL/dI-I Curves .....	38
Figure 21. Cable Strength Members .....	55
Figure 22. Extrinsic Losse .....	61