

# Contents and Subject Index

INTRODUCTION	1
<b>SECTION I</b> <b>RECOMMENDATIONS AND GUIDELINES</b>	
INDEX TO RECOMMENDATIONS AND GUIDELINES	8
RECOMMENDATIONS AND GUIDELINES	.. 11
I. Environmental	.. 11
1. Temperature	.. 11
2. Humidity	.. 18
3. Ultraviolet Radiation	.. 19
4. Rodent Population	.. 19
5. Chemicals	.. 19
6. Flame/Fire	.. 20
7. Nuclear Radiation	.. 21
8. Lightning	.. 21
9. Explosive Fumes	.. 21
II. Physical Layout and Installation	.. 22
1. Ancillary Equipment	.. 22
2. Link Length	.. 22
3. Installation Constraints	.. 23
III. Operational/Optical Requirements	.. 26
1. Optical Power Budget	.. 26
2. Bandwidth Analysis	.. 26
IV. Manufacturing	.. 27
1. Screening	.. 27
2. Design Considerations	.. 29
V. Logistics	.. 44

Contents and Subject Index

1. Storage, Transportation and Handling	44
2. Supportability	45
<b>VI Maintenance</b>	<b>46</b>
1. Accessibility and Repairability	46

**SECTION II**  
**NUMERICAL RELIABILITY SUMMARY**

<b>SUMMARY OF NUMERICAL RELIABILITY DATA</b>	<b>51</b>
<b>Components</b>	<b>51</b>
Fiber	51
Cable	51
Splices	52
Connectors	52
Light Emitting Diodes	53
Laser Diodes	54
Laser Modules	56
Photodetectors	56
Photodetector Modules	57
Couplers	58
Switches	58
Enclosures	58
<b>Systems</b>	<b>59</b>
AN/FAC-3	59
AV-8B CNI System	59
FOTS-LH	59

**SECTION III**  
**COMPONENTS**

<b>1. FIBER AND CABLE</b>	<b>62</b>
<b>I. Description of Fiber Types</b>	<b>62</b>
1. Multimode Fiber Types	62
2. Single Mode Fiber Types	64
<b>II. Description of Cable Types</b>	<b>68</b>
1. Loose Tube	68
2. Tight Tube	70
3. Plenum Cable	71
4. Ribbon Cable	73
5. Submarine Cable	75
<b>III. Filling Compounds</b>	<b>78</b>
<b>IV. Strength Members</b>	<b>79</b>
<b>V. Impact of Radiation Exposure to Optical Fibers</b>	<b>82</b>
<b>VI. Manufacturing Techniques</b>	<b>84</b>
1. Fiber	84
2. Cable Construction	86
<b>VII. Design Tests</b>	<b>88</b>
1. Fiber Tests	88

2. Cable Tests . . . . .	90
VIII. <b>Common Failure Mechanisms and Their Causes</b> . . . . .	92
IX. <b>Critical Design Criteria and Approaches to Minimize Common Failures</b> . . . . .	99
X. <b>Maintenance</b> . . . . .	101
XI. <b>Logistics Considerations</b> . . . . .	103
XII. <b>Summary</b> . . . . .	105
2. <b>SPLICES AND CONNECTORS</b> . . . . .	106
I. <b>Optical Loss Mechanisms</b> . . . . .	106
II. <b>Description of Splice Types</b> . . . . .	111
1. <b>Mechanical Splices</b> . . . . .	111
a. <b>Loose Tube Splice</b> . . . . .	111
b. <b>Three Rod Splice</b> . . . . .	112
c. <b>Elastomeric Splice</b> . . . . .	114
d. <b>Rotary Splice</b> . . . . .	115
e. <b>Silicon Chip Array</b> . . . . .	116
f. <b>Rapid Ribbon Splice</b> . . . . .	117
2. <b>Fusion Splices</b> . . . . .	118
III. <b>Description of Connector Types</b> . . . . .	120
1. <b>Butt Joint</b> . . . . .	120
2. <b>Biconic Sleeves</b> . . . . .	120
3. <b>Lensed</b> . . . . .	124
4. <b>Fused Lens</b> . . . . .	124
IV. <b>Fabrication</b> . . . . .	124
1. <b>Materials</b> . . . . .	125
2. <b>Fabrication Techniques</b> . . . . .	127
V. <b>Design Tests</b> . . . . .	127
1. <b>Splice Tests</b> . . . . .	127
2. <b>Connector Tests</b> . . . . .	129
VI. <b>Common Failure Mechanisms</b> . . . . .	130
1. <b>Splice Failures</b> . . . . .	130
2. <b>Connector Failures</b> . . . . .	137
VII. <b>Factors Impacting Selection and Performance</b> . . . . .	141
1. <b>Splice Selection</b> . . . . .	141
2. <b>Connector Selection</b> . . . . .	142
3. <b>Connector Performance</b> . . . . .	144
4. <b>Connector Assembly</b> . . . . .	145
VIII. <b>Maintenance Requirements</b> . . . . .	145
1. <b>Splices</b> . . . . .	145
2. <b>Connectors</b> . . . . .	145
IX. <b>Logistics Considerations</b> . . . . .	146
X. <b>Summary</b> . . . . .	148
1. <b>Splices</b> . . . . .	148
2. <b>Connectors</b> . . . . .	148
3. <b>EMITTERS</b> . . . . .	150
I. <b>Fundamental Physical Concepts</b> . . . . .	150

## Contents and Subject Index

1. Absorbed and Emitted Energy . . . . .	150
2. Direct and Indirect Transitions. . . . .	152
3. Spontaneous Emission, Resonant Absorption and Stimulated Emission . . . . .	153
<b>II. Basic LED Operation . . . . .</b>	<b>155</b>
<b>III. Basic Laser Operation. . . . .</b>	<b>155</b>
<b>IV. Emitter Construction . . . . .</b>	<b>158</b>
1. LED Construction . . . . .	159
a. Planar Surface Emitter . . . . .	159
b. Etched-Well Emitter. . . . .	162
c. Edge Emitter . . . . .	163
2. Laser Construction . . . . .	166
a. Homojunction Lasers . . . . .	167
b. Single Heterojunction Laser. . . . .	169
c. Double Heterojunction Laser. . . . .	170
d. DH Planar Stripe Geometry. . . . .	171
e. Buried Heterojunction (Planar Substrate) Laser. . . . .	174
<b>V. Emitter Degradation Characteristics . . . . .</b>	<b>176</b>
1. LED Degradation . . . . .	178
2. Laser Degradation . . . . .	179
a. Saturable Current Mode . . . . .	181
b. Formation of the Knee. . . . .	182
c. Wear Out Degradation Mode . . . . .	182
d. Catastrophic Degradation . . . . .	186
<b>VI. Emitter Testing Techniques. . . . .</b>	<b>187</b>
1. Characterization Prior to Testing . . . . .	189
2. Unbiased Humidity and Temperature Tests . . . . .	190
3. High Temperature Burn-In . . . . .	190
4. Active Stressing. . . . .	191
5. Wear Out Degradation Mode Burn-In. . . . .	191
6. Testing Results Precautions . . . . .	191
7. Degradation Accelerants . . . . .	192
<b>VII. Failure Predictions. . . . .</b>	<b>193</b>
1. Failure Models . . . . .	193
2. Extrapolated Lifetime Predictions . . . . .	194
<b>VIII. Transmitters. . . . .</b>	<b>201</b>
1. Basic Components . . . . .	201
a. Emitter . . . . .	201
b. Coupling System . . . . .	201
c. Coolers . . . . .	204
d. Monitor Photodectors . . . . .	204
<b>IX. Transmitter Construction . . . . .</b>	<b>205</b>
1. Thermal Characteristic Matching . . . . .	205
2. Maintaining Alignment . . . . .	206
3. Hermetic Sealing . . . . .	207
<b>X. Testing . . . . .</b>	<b>208</b>
<b>XI. Lifetime Predictions. . . . .</b>	<b>209</b>
<b>XII. Summary. . . . .</b>	<b>209</b>

<b>4. PHOTODETECTORS AND RECEIVERS</b> . . . . .	211
<b>I. Basic Theory of Operation</b> . . . . .	211
<b>II. Photodetector Construction</b> . . . . .	215
1. Depletion-Layer P-N Photodetector . . . . .	215
2. Avalanche Photodetector . . . . .	216
3. PIN Photodetector . . . . .	220
4. APD/PIN Performance Comparison . . . . .	223
<b>III. Materials Selection</b> . . . . .	223
1. Impact of Materials on APD Performance . . . . .	224
2. Impact of Materials on PIN Performance . . . . .	227
<b>IV. Receiver Selection</b> . . . . .	228
1. High Impedance Amplifier . . . . .	228
2. Transimpedance Amplifier . . . . .	229
<b>V. Degradation Mechanisms</b> . . . . .	230
1. Dark Current . . . . .	231
2. Humidity . . . . .	232
3. Temperature Cycling . . . . .	232
<b>VI. Screening and Testing Techniques</b> . . . . .	233
1. Screening Early Failure Devices . . . . .	233
2. Mechanical and Environmental Testing . . . . .	234
<b>VII. Accelerated Lifetime Predictions</b> . . . . .	235
<b>VIII. Maintenance</b> . . . . .	240
<b>IX. Logistics</b> . . . . .	240
<b>X. Summary</b> . . . . .	241
<b>5. MULTIPLEXERS, DEMULTIPLEXERS AND COUPLERS</b> . . . . .	242
<b>I. Multiplexers and Demultiplexers</b> . . . . .	243
1. Wavelength Dispersive Devices . . . . .	245
a. Diffraction Grating Characteristics . . . . .	245
2. Wavelength Selective Devices . . . . .	249
a. Interference Filter Characteristics . . . . .	250
3. Evanescent Wave Devices . . . . .	255
a. Single Mode Evanescent Wave Devices . . . . .	256
<b>II. Couplers</b> . . . . .	257
1. Directional Couplers . . . . .	259
2. Star Couplers . . . . .	260
<b>III. Measurement Parameters</b> . . . . .	265
1. Wavelength Isolation . . . . .	265
2. Insertion Loss . . . . .	267
3. Coupling Ratio . . . . .	269
4. Uniformity . . . . .	270
5. Directivity . . . . .	271
<b>IV. Maintenance Requirements</b> . . . . .	272
<b>V. Conditions Effecting Device Performance</b> . . . . .	272
1. Temperature Dependence . . . . .	272
2. Polarization . . . . .	273
3. Humidity . . . . .	274
4. Vibration and Shock . . . . .	275

<b>9. AV-8B HARRIER FIGHTER AIRCRAFT</b> . . . . .	<b>335</b>
<b>I. System Description</b> . . . . .	<b>335</b>
<b>II. Operational Features</b> . . . . .	<b>336</b>
<b>III. Fiber Optic Component Characteristics and Specifications</b>	<b>339</b>
1. Connector . . . . .	339
2. Fiber and Cable. . . . .	340
3. Epoxy. . . . .	345
<b>IV. System Performance</b> . . . . .	<b>345</b>
1. Emitter and Photodetector Reliability Tests . . . . .	346
2. Exhibited Failures . . . . .	348
<b>V. Comparative Performance of Optical and Electrical Links</b> . . . . .	<b>350</b>
<b>VI. Maintenance Requirements</b> . . . . .	<b>350</b>
1. Optical Cable Repair . . . . .	351
2. Optical Connector Repair . . . . .	352
3. Optical Attenuation Test Set Operation. . . . .	353
<b>VII. Logistics Influences</b> . . . . .	<b>354</b>
<b>VIII. Summary</b> . . . . .	<b>354</b>
<b>10. FIBER OPTIC TRANSMISSION SYSTEM—LONG HAUL ARMY COMMUNICATIONS SYSTEM</b> . . . . .	<b>355</b>
<b>I. System Description</b> . . . . .	<b>355</b>
<b>II. System Components</b> . . . . .	<b>357</b>
<b>III. Operational Features</b> . . . . .	<b>357</b>
<b>IV. Environmental Design Considerations</b> . . . . .	<b>359</b>
<b>V. Performance of Fiber Optic System</b> . . . . .	<b>361</b>
<b>VI. Maintenance Requirements</b> . . . . .	<b>364</b>
<b>VII. Logistics Influences</b> . . . . .	<b>366</b>
<b>VIII. Summary</b> . . . . .	<b>366</b>

## SECTION V TESTING

<b>11. OPTICAL SOURCES AND POWER METERS</b> . . . . .	<b>368</b>
<b>I. Description</b> . . . . .	<b>368</b>
1. Physical Characteristics. . . . .	368
2. Optical Sources. . . . .	368
3. Optical Power Meters . . . . .	369
4. Optical Test Sets . . . . .	370
<b>II. Measurement Units</b> . . . . .	<b>371</b>
<b>III. Operation</b> . . . . .	<b>371</b>
1. Fiber Attenuation Measurement by Cutback Method . . . . .	373
2. Connector Insertion Loss Test . . . . .	374
3. Basic Single End Connectorized Cable Loss Test . . . . .	375
4. Double-Ended Cable Loss Test. . . . .	376
5. Loopback Cable Loss Test. . . . .	377
<b>IV. Predicted Production Lot Failure Rate and Maintenance Requirements</b> . . . . .	<b>378</b>
<b>V. Additional Features</b> . . . . .	<b>378</b>

VI. Summary	378
12. OPTICAL TIME DOMAIN REFLECTOMETERS	379
I. Description	379
1. Physical Characteristics	379
2. Operating Physics	379
II. Impact on Fiber Optic System Testing	383
III. Operation	385
IV. Inaccuracies and Anomalies	388
V. Predicted Production Lot Failure Rate and Maintenance Requirements	397
VI. Maintenance and Operational Considerations	398
VII. Logistics Considerations	399
VIII. Summary	400
SECTION VI: CONCLUSIONS	401
SECTION VII: RECOMMENDATIONS	
REFERENCES	
BIBLIOGRAPHY	
APPENDIX	432
Commonly Used Elements and Their Abbreviations	432
Conversion from Lifetime Hours to Years	433
Physical Constants	434