

Contents

Part I Physics of High Speed Lasers

1	Basic Description of Laser Diode Dynamics by Spatially Averaged Rate Equations: Conditions of Validity	3
1.1	The “Local” Rate Equations	3
1.2	Spatially Averaged Rate Equations and their Range of Validity	5
2	Basic “Small-Signal” Modulation Response	11
3	Distortions in Direct Modulation of Laser Diodes	19
3.1	Perturbation Analytic Prediction of Fundamental Distortions in Directly Modulated Laser Diodes	19
3.2	Intermodulation Distortion	22
4	Direct Modulation Beyond X-Band by Operation at High Optical Power Density	29
5	Improvement in Direct-Modulation Speed by Enhanced Differential Optical Gain and Quantum Confinement	35
5.1	Demonstration of the Explicit Dependence of Direct-Modulation Bandwidth on Differential Gain by Low-Temperature Operation	35
5.1.1	Direct-Modulation Results	35
5.1.2	Parasitic-Free Photo Mixing Modulation Experiment	38
5.2	Attainment of High-Modulation Bandwidths Through Quantum-Confined Materials	40
6	Dynamic Longitudinal Mode Spectral Behavior of Laser Diodes Under Direct High-Frequency Modulation	45
6.1	Introduction	45
6.2	Experimental Observations	46
6.3	Time Evolution Equations for Fractional Modal Intensities	50
6.4	A Two-Mode Laser	51

6.5	Solution to the Many-Mode Problem	55
6.5.1	An Approximate Analytic Solution of $\alpha_0 \sum_i \frac{1}{1+ci^2} = 1$	58
6.6	Lasing Spectrum Under CW High-Frequency Microwave Modulation	59
6.7	Dynamic Wavelength “Chirping” Under Direct Modulation	61
6.8	Summary and Conclusions	62
7	Signal-Induced Noise in Fiber Links	65
7.1	Introduction	65
7.2	Measurements	67
7.3	Analysis and Comparison With Measurements	72
7.3.1	Mode-Partition Noise and Noise Transposition in Fiber Links Using Multimode Lasers	73
7.3.2	Transposed Interferometric Noise in Fiber Links Using Single-Frequency Lasers	78
7.4	Mode-Partition Noise in an Almost Single-Mode Laser	82
7.5	Conclusion	83
 Part II Direct Modulation of Semiconductor Lasers Beyond Relaxation Oscillation		
8	Illustration of Resonant Modulation	87
9	Resonant Modulation of Monolithic Laser Diodes at Millimeter-Wave Frequencies	93
9.1	Active Mode-Locking	95
9.2	Passive Mode-Locking	97
10	Performance of Resonant Modulation in the Millimeter-Wave Frequency Range: Multi-Subcarrier Modulation	101
11	Resonant Modulation of Single-Contact Lasers	107
 Part III Fiber Transmission Effects, System Perspectives and Innovative Approach to Broadband mm-Wave Subcarrier Optical Signals		
12	Fiber Chromatic Dispersion Effects of Broadband mm-Wave Subcarrier Optical Signals and Its Elimination	115
12.1	Effects on Multichannel Digital Millimeter-Wave Transmission	115
12.2	Elimination of Fiber Chromatic Dispersion Penalty on 1,550 nm Millimeter-Wave Optical Transmission	120

13	Transmission Demonstrations	125
13.1	1550-nm Transmission of Digitally Modulated 28-GHz Subcarriers Over 77 km of Non-Dispersion Shifted Fiber	125
13.2	39 GHz Fiber-Wireless Transmission of Broadband Multi-Channel Compressed Digital Video	130
14	Application of Linear Fiber Links to Wireless Signal Distribution: A High-level System Perspective	135
15	Improvements in Baseband Fiber Optic Transmission by Superposition of High-Frequency Microwave Modulation	141
15.1	Introduction	141
15.2	Interferometric Noise	142
15.2.1	Superimposed High-Frequency Modulation: External Phase Modulation	144
15.2.2	Directly Modulated Laser Diode	147
15.2.3	Superimposed Modulation With Band-Pass Gaussian Noise	149
15.3	Multimode Fiber: Modal Noise	152
15.4	Conclusion	153
16	Millimeter-Wave Signal Transport Over Optical Fiber Links by “Feed-Forward Modulation”	155
16.1	Principle of “Feed-Forward Modulation” for mm-Wave Signal Transport Over an Optical Carrier	155
16.2	Demonstration of “Feed-Forward Modulation” for Optical Transmission of Digitally Modulated mm-Wave Subcarrier	161
17	Frequency Planning for Minimal Intermodulation Distortion	165
17.1	Introduction	165
17.2	Algorithms for Single-Link Frequency Planning	166
17.2.1	Babcock Spacing	166
17.2.2	Okinaka’s Algorithm	168
17.3	Multi-Link Frequency Planning Algorithm	170
17.3.1	Modified Okinaka Algorithm for Multi-Link Frequency Planning	171
17.3.2	Measurements	173
17.4	Discussion and Conclusion	176
18	Erbium Fiber Amplifiers in Linear Lightwave Transmission	177
18.1	Introduction	177
18.2	Distortion Characteristics	178
18.2.1	EDFA Distortion Model	178
18.2.2	Experimental Results	181

18.2.3	Comparisons Between Distortions in Laser Diode with EDFA.....	187
18.3	CNR Optimization	188
18.3.1	Operation Point	189
18.3.2	Fan-Out and Fiber Loss	192
18.3.3	CNR Versus Length of EDFA.....	193
18.4	Discussions and Conclusions	195
Part IV Appendices		
A	Notes on RF Link Metrics	199
A.1	Notes on Relation Between Distortion Products, Noise, Spur (Spurious)-Free Dynamic Range (SFDR)	199
A.2	Notes on Intermodulation Distortion in a Multichannel Subcarrier Transmission System: CTB and CSO	201
A.2.1	Composite Triple Beat (CTB).....	201
A.2.2	Composite Second-Order Intermodulation (CSO) Distortion	203
A.3	Graphical Illustrations of RF Signals.....	204
B	Ultrahigh Frequency Photodiodes and Receivers	207
B.1	Ultrahigh Speed PIN Photodiodes	207
B.2	Resonant Receivers.....	211
C	High Frequency Optical Modulators	213
C.1	Mach Zehnder Interferometric Optical Modulator	214
C.2	Electroabsorption Optical Modulator	215
D	Modulation Response of Superluminescent Lasers	219
D.1	Introduction	219
D.2	The Small Signal Superluminescent Equations and Numerical Results	220
D.3	Effect of a Small but Finite Mirror Reflectivity	224
E	Broadband Microwave Fiber-Optic Links With RF Phase Control for Phased-Array Antennas	229
F	Small Signal Traveling Wave Rate Equations for Erbium-Doped Fiber Amplifiers.....	235
G	Applications of High Frequency Linear Fiber-Optic Links in Defense Systems.....	237
G.1	Electronic Counter Measure: Aerial Towed Fiber-Optic Decoy	237
G.2	Nuclear Test Diagnostic Instrumentation	238
References.....		241
Index.....		253