

CONTENTS

PREFACE	xi
ACKNOWLEDGMENTS	xiii
1 INTRODUCTION	1
1.1 Enabling Technological Advances and Benefits of Fiber Optic Links	6
1.2 Analog Versus Digital Fiber Optic Links	13
1.3 Basic Fiber Optic Components	18
1.4 Analog Links Within RF Systems	27
References	28
2 ANALOG PERFORMANCE METRICS	33
2.1 The Scattering Matrix	34
2.2 Noise Figure	36
2.3 Dynamic Range	39
2.3.1 Compression Dynamic Range	39
2.3.2 Spurious-Free Dynamic Range	43

2.4 Cascade Analysis	52
References	54
3 SOURCES OF NOISE IN FIBER OPTIC LINKS	57
3.1 Basic Concepts	58
3.2 Thermal Noise	62
3.3 Shot Noise	69
3.4 Lasers	74
3.5 Optical Amplifiers	93
3.5.1 Erbium-Doped Fiber Amplifiers	94
3.5.2 Raman and Brillouin Fiber Amplifiers	108
3.5.3 Semiconductor Optical Amplifiers	112
3.6 Photodetection	113
References	117
4 DISTORTION IN FIBER OPTIC LINKS	124
4.1 Introduction	124
4.2 Distortion in Electrical-to-Optical Conversion	130
4.3 Optical Amplifier Distortion	134
4.4 Photodetector Distortion	138
4.4.1 Photodetector Distortion Measurement Systems	141
4.4.2 Photodetector Nonlinear Mechanisms	144
References	161
5 PROPAGATION EFFECTS	166
5.1 Introduction	166
5.2 Double Rayleigh Scattering	168
5.3 RF Phase in Fiber Optic Links	170
5.4 Chromatic Dispersion	173
5.5 Stimulated Brillouin Scattering	184
5.6 Stimulated Raman Scattering	190
5.7 Cross-Phase Modulation	193
5.8 Four-Wave Mixing	198
5.9 Polarization Effects	200
References	205

6 EXTERNAL INTENSITY MODULATION WITH DIRECT DETECTION	212
6.1 Concept and Link Architectures	213
6.2 Signal Transfer and Gain	216
6.3 Noise and Performance Metrics	233
6.3.1 General Equations	234
6.3.2 Shot-Noise-Limited Equations	242
6.3.3 RIN-Limited Equations	247
6.3.4 Trade Space Analysis	250
6.4 Photodetector Issues and Solutions	251
6.5 Linearization Techniques	260
6.6 Propagation Effects	264
References	270
7 EXTERNAL PHASE MODULATION WITH INTERFEROMETRIC DETECTION	273
7.1 Introduction	273
7.2 Signal Transfer and Gain	275
7.3 Noise and Performance Metrics	287
7.4 Linearization Techniques	295
7.5 Propagation Effects	299
7.6 Other Techniques for Optical Phase Demodulation	304
References	308
8 OTHER ANALOG OPTICAL MODULATION METHODS	312
8.1 Direct Laser Modulation	313
8.1.1 Direct Intensity Modulation	314
8.1.2 Direct Frequency Modulation	319
8.2 Suppressed Carrier Modulation with a Low Biased MZM	321
8.3 Single-Sideband Modulation	328
8.4 Sampled Analog Optical Links	330
8.4.1 RF Downconversion Via Sampled Analog Optical Links	333
8.4.2 Mitigation of Stimulated Brillouin Scattering with Sampled Links	336
8.5 Polarization Modulation	340
References	344

9 HIGH CURRENT PHOTODETECTORS	351
9.1 Photodetector Compression	352
9.2 Effects Due to Finite Series Resistance	355
9.3 Thermal Limitations	359
9.4 Space-Charge Effects	365
9.5 Photodetector Power Conversion Efficiency	370
9.6 State of the Art for Power Photodetectors	376
References	378
10 APPLICATIONS AND TRENDS	383
10.1 Point-to-Point Links	384
10.2 Analog Fiber Optic Delay Lines	393
10.3 Photonic-Based RF Signal Processing	398
10.3.1 Wideband Channelization	399
10.3.2 Instantaneous Frequency Measurement	401
10.3.3 Downconversion	404
10.3.4 Phased-Array Beamforming	405
10.4 Photonic Methods for RF Signal Generation	407
10.5 Millimeter-Wave Photonics	415
10.6 Integrated Microwave Photonics	419
References	427
APPENDIX I UNITS AND PHYSICAL CONSTANTS	446
APPENDIX II ELECTROMAGNETIC RADIATION	450
APPENDIX III POWER, VOLTAGE AND CURRENT FOR A SINUSOID	453
APPENDIX IV TRIGONOMETRIC FUNCTIONS	455
APPENDIX V FOURIER TRANSFORMS	458
APPENDIX VI BESSEL FUNCTIONS	460
INDEX	463