

MOBILE FADING CHANNELS

A horizontal dotted line consisting of small white dots, extending across the width of the cover below the title.

Matthias Pätzold

Contents

1	INTRODUCTION	1
1.1	THE EVOLUTION OF MOBILE RADIO SYSTEMS	1
1.2	BASIC KNOWLEDGE OF MOBILE RADIO CHANNELS	3
1.3	STRUCTURE OF THIS BOOK	7
2	RANDOM VARIABLES, STOCHASTIC PROCESSES, AND DETERMINISTIC SIGNALS	11
2.1	RANDOM VARIABLES	11
2.1.1	Important Probability Density Functions	15
2.1.2	Functions of Random Variables	19
2.2	STOCHASTIC PROCESSES	20
2.2.1	Stationary Processes	22
2.2.2	Ergodic Processes	25
2.2.3	Level-Crossing Rate and Average Duration of Fades	25
2.3	DETERMINISTIC CONTINUOUS-TIME SIGNALS	27
2.4	DETERMINISTIC DISCRETE-TIME SIGNALS	29
3	RAYLEIGH AND RICE PROCESSES AS REFERENCE MODELS 33	
3.1	GENERAL DESCRIPTION OF RICE AND RAYLEIGH PROCESSES 34	
3.2	ELEMENTARY PROPERTIES OF RICE AND RAYLEIGH PROCESSES 35	
3.3	STATISTICAL PROPERTIES OF RICE AND RAYLEIGH PROCESSES 39	
3.3.1	Probability Density Function of the Amplitude and the Phase . 39	
3.3.2	Level-Crossing Rate and Average Duration of Fades 41	
3.3.3	The Statistics of the Fading Intervals of Rayleigh Processes . . 46	
4	INTRODUCTION TO THE THEORY OF DETERMINISTIC PROCESSES 55	
4.1	PRINCIPLE OF DETERMINISTIC CHANNEL MODELLING 56	
4.2	ELEMENTARY PROPERTIES OF DETERMINISTIC PROCESSES 59	
4.3	STATISTICAL PROPERTIES OF DETERMINISTIC PROCESSES . 63	
4.3.1	Probability Density Function of the Amplitude and the Phase . 64	
4.3.2	Level-Crossing Rate and Average Duration of Fades 72	
4.3.3	Statistics of the Fading Intervals at Low Levels 77	

4.3.4	Ergodicity and Criteria for the Performance Evaluation	78
5	METHODS FOR THE COMPUTATION OF THE MODEL PARAMETERS OF DETERMINISTIC PROCESSES	81
5.1	METHODS FOR THE COMPUTATION OF THE DISCRETE DOPPLER FREQUENCIES AND DOPPLER COEFFICIENTS	83
5.1.1	Method of Equal Distances (MED)	83
5.1.2	Mean-Square-Error Method (MSEM)	90
5.1.3	Method of Equal Areas (MEA)	95
5.1.4	Monte Carlo Method (MCM)	104
5.1.5	L_p -Norm Method (LPNM)	113
5.1.6	Method of Exact Doppler Spread (MEDS)	128
5.1.7	Jakes Method (JM)	133
5.2	METHODS FOR THE COMPUTATION OF THE DOPPLER PHASES	143
5.3	FADING INTERVALS OF DETERMINISTIC RAYLEIGH PROCESSES	145
6	FREQUENCY-NONSELECTIVE STOCHASTIC AND DETER- MINISTIC CHANNEL MODELS	155
6.1	THE EXTENDED SUZUKI PROCESS OF TYPE I	157
6.1.1	Modelling and Analysis of the Short-Term Fading	157
6.1.1.1	Probability Density Function of the Amplitude and the Phase	165
6.1.1.2	Level-Crossing Rate and Average Duration of Fades	166
6.1.2	Modelling and Analysis of the Long-Term Fading	169
6.1.3	The Stochastic Extended Suzuki Process of Type I	172
6.1.4	The Deterministic Extended Suzuki Process of Type I	176
6.1.5	Applications and Simulation Results	181
6.2	THE EXTENDED SUZUKI PROCESS OF TYPE II	185
6.2.1	Modelling and Analysis of the Short-Term Fading	186
6.2.1.1	Probability Density Function of the Amplitude and the Phase	190
6.2.1.2	Level-Crossing Rate and Average Duration of Fades	193
6.2.2	The Stochastic Extended Suzuki Process of Type II	196
6.2.3	The Deterministic Extended Suzuki Process of Type II	200
6.2.4	Applications and Simulation Results	205
6.3	THE GENERALIZED RICE PROCESS	208
6.3.1	The Stochastic Generalized Rice Process	209
6.3.2	The Deterministic Generalized Rice Process	213
6.3.3	Applications and Simulation Results	217
6.4	THE MODIFIED LOO MODEL	218
6.4.1	The Stochastic Modified Loo Model	218
6.4.1.1	Autocorrelation Function and Doppler Power Spectral Density	222
6.4.1.2	Probability Density Function of the Amplitude and the Phase	225
6.4.1.3	Level-Crossing Rate and Average Duration of Fades	228
6.4.2	The Deterministic Modified Loo Model	230

6.4.3	Applications and Simulation Results	236
7	FREQUENCY-SELECTIVE STOCHASTIC AND DETERMINISTIC CHANNEL MODELS	241
7.1	THE ELLIPSES MODEL OF PARSONS AND BAJWA	244
7.2	SYSTEM THEORETICAL DESCRIPTION OF FREQUENCY-SELECTIVE CHANNELS	245
7.3	FREQUENCY-SELECTIVE STOCHASTIC CHANNEL MODELS	250
7.3.1	Correlation Functions	250
7.3.2	The WSSUS Model According to Bello	251
7.3.2.1	WSS Models	251
7.3.2.2	US Models	253
7.3.2.3	WSSUS Models	253
7.3.3	The Channel Models According to COST 207	259
7.4	FREQUENCY-SELECTIVE DETERMINISTIC CHANNEL MODELS	267
7.4.1	System Functions of Frequency-Selective Deterministic Channel Models	267
7.4.2	Correlation Functions and Power Spectral Densities of DGUS Models	272
7.4.3	Delay Power Spectral Density, Doppler Power Spectral Density, and Characteristic Quantities of DGUS Models	276
7.4.4	Determination of the Model Parameters of DGUS Models	281
7.4.4.1	Determination of the discrete propagation delays and delay coefficients	281
7.4.4.2	Determination of the discrete Doppler frequencies and Doppler coefficients	283
7.4.4.3	Determination of the Doppler phases	284
7.4.5	Deterministic Simulation Models for the Channel Models According to COST 207	284
8	FAST CHANNEL SIMULATORS	289
8.1	DISCRETE DETERMINISTIC PROCESSES	290
8.2	REALIZATION OF DISCRETE DETERMINISTIC PROCESSES	292
8.2.1	Tables System	292
8.2.2	Matrix System	295
8.2.3	Shift Register System	297
8.3	PROPERTIES OF DISCRETE DETERMINISTIC PROCESSES	297
8.3.1	Elementary Properties of Discrete Deterministic Processes	298
8.3.2	Statistical Properties of Discrete Deterministic Processes	305
8.3.2.1	Probability Density Function and Cumulative Distribution Function of the Amplitude and the Phase	306
8.3.2.2	Level-Crossing Rate and Average Duration of Fades	313
8.4	REALIZATION EXPENDITURE AND SIMULATION SPEED	315
8.5	COMPARISON WITH THE FILTER METHOD	317

Appendix A DERIVATION OF THE JAKES POWER SPECTRAL DENSITY AND THE CORRESPONDING AUTOCORRELATION FUNCTION	321
Appendix B DERIVATION OF THE LEVEL-CROSSING RATE OF RICE PROCESSES WITH DIFFERENT SPECTRAL SHAPES OF THE UNDERLYING GAUSSIAN RANDOM PROCESSES	325
Appendix C DERIVATION OF THE EXACT SOLUTION OF THE LEVEL-CROSSING RATE AND THE AVERAGE DURATION OF FADES OF DETERMINISTIC RICE PROCESSES	329
Appendix D ANALYSIS OF THE RELATIVE MODEL ERROR BY USING THE MONTE CARLO METHOD IN CONNECTION WITH THE JAKES POWER SPECTRAL DENSITY	341
Appendix E SPECIFICATION OF FURTHER \mathcal{L}-PATH CHANNEL MODELS ACCORDING TO COST 207	343
MATLAB-PROGRAMS	347
ABBREVIATIONS	377
SYMBOLS	379
BIBLIOGRAPHY	391
INDEX	409