ADAPTIVE ARRAY
MEASUREMENTS IN
COMMUNICATIONS



## **Contents**

	Preface	xiii
	Introduction	χv
1	Fundamental Concepts	1
	Introduction	1
1.1	Conceptual Representation of Adaptive Arrays	1
1.2	The Linear Array	2
1.2.1	Structure and Behavior of a Linear Array	3
1.2.2	Array Radiation Formulas and Patterns	5
1.3	The Beam Former	10
1.3.1	The Definition and Function of a Beam Former	11
1.3.2	Characteristics of Orthogonal Beam Formers	11
1.3.3	Separation of Desired and Undesired Signals	12
1.3.4	Measurement of Array Radiation Patterns	14
1.4	The Signals	16
1.4.1	Distribution of Signal Sources and Signals	16
1.4.2	System with Two Transmitting Signal Sources	17

1.5	Signal Processing Network	19
1.5.1	Removal of Interference Signals by the Signal Processing Network	19
1.5.2	Final Output Signal	20
1.5.3	Final Output Power	20
1.5.4	Cancellation of the Interference Signal	22
1.6	Adaptive Signal Processing	26
	Reference	27
2	Simplified Analysis	29
	Introduction	29
2.1	The Signals	30
2.1.1	Signals at the Input and Output Ports of a Beam Former	30
2.1.2	Space Transfer Functions	31
2.1.3	Signals at the Input Ports of the Beam Former	33
2.1.4	Beam Former Transfer Functions	33
2.1.5	Signals at the Beam Former Output Ports	34
2.1.6	Signals at the Input Ports of the Signal Processing Network	37
2.2	Two-Source, Two-Output System	38
2.2.1	The Signals	38
2.2.2	Signal Processing Network	39
2.2.3	Final Output Power	45
2.2.4	Cancellation of Interference Signal and the Null Depth	46
2.3	Two-Source, Three-Output System	50
2.3.1	The Signals	50
2.3.2	Signal Processing Network	52
2.3.3	Final Output Power	59
2.3.4	Null Depth	59

Contents ix

2.4	Two-Source, Multioutput System	63
2.4.1	The Signals	63
2.4.2	Signal Processing Network	65
2.4.3	Final Output Power	71
2.4.4	Alternate Method for Estimating the Null Depth	72
2.5	Three-Source, Two-Output System	73
2.5.1	The Signals	73
2.5.2	Signal Processing Network	75
2:5.3	Final Output Power	78
2.5.4	Null Depth	80
2.6	Three-Source, Three-Output System	81
2.6.1	The Signals	81
2.6.2	Signal Processing Network	83
2.6.3	Final Output Power	87
2.6.4	Null Depth	88
2.7	Multisource, Two-Output System	90
2.7.1	The Signals	90
2.7.2	Signal Processing Network	92
2.7.3	Final Output Power	95
2.7.4	Null Depth	97
2.8	Multisource, Multioutput System	97
2.8.1	The Signals	98
2.8.2	Signal Processing Network	100
2.8.3	General Expression for Null Depth	103
2.8.4	Alternate Expressions for Null Depth	107
2.8.5	The Tradeoff	108
2.8.6	Number of Undesired Signals and the Active Output Ports	108

2.9	Leakage of the Desired Signal into the AUX  Ports	109
2.9.1	The Leakage	109
2.9.2	The Signals	109
2.9.3	Signal Processing Network	110
2.9.4	Final Output Power	113
2.9.5	Null Depth	114
2.9.6	Minimization of Leakage of the Desired Signal into an AUX Port	116
2.10	Effect of Offset Voltage on System Performance	117
2.10.1	Offset Voltage	118
2.10.2	The Signals	118
2.10.3	Signal Processing Network	120
2.10.4	Final Output Power	123
2.10.5	Null Depth	124
2.10.6	Feedback Loop with Phase Detector	126
2.11	Effect of Space Noise on System Performance	126
2.11.1	The Noise	126
2.11.2	The Signals	126
2.11.3	Signal Processing Network	129
2.11.4	Final Output Power	131
2.11.5	Null Depth	133
2.11.6	Final Output Noise	134
2.12	Feedback Loop	136
2.12.1	Stability of the Feedback Loop	136
2.12.2	Closed-Loop Transfer Function of a Feedback Loop	137
2.12.3	Feedback Loop and the Convergence Time	139
2.13	Examples of Practical Beam Formers	153
2.13.1	The Signals	153
2.13.2	Typical 4 × 4 Beam Former	155

Contents xi

2.13.3	Typical 8 × 8 Beam Former	160
2.13.4	Beam Formers with Real Signals	162
2.14	Phase Shifters and Hybrids	170
2.14.1	Introduction	170
2.14.2	Phase Shifters	170
2.14.3	180° Hybrids	187
	References	192
3	Basic Matrix Expressions	193
	Introduction	193
3.1	The Signals	194
3.1.1	Distribution of Signal Sources and Signals	194
3.1.2	Space Transfer Functions	194
3.1.3	Signals at the Beam Former Input Ports	196
3.1.4	Beam Former Transfer Functions	198
3.1.5	Signals at the Beam Former Output Ports	199
3.2	Signal Processing Network	200
3.2.1	Total Output Signal	201
3.2.2	Total Output Power	202
3.2.3	Cancellation of Interference Signals	204
3.3	Modal Representation of Matrix Expressions	206
3.3.1	Linear Expressions for Matrix Equations	206
3.3.2	Modal Decomposition of the Matrix Expressions	207
3.3.3	Steady-State Values of the Weighters in Modal Notation	210
3.3.4	Feedback Loop	214
3.4	Physical Significance of Eigenvalues	215
3.4.1	Signal Matrix in Terms of Signal Powers and Eigenvalues	216
3.4.2	Characteristics of the Transfer Function or	217

3.4.3	Relation Between Eigenvalues and Signal Powers	22
	References	227
	Appendix A: Final Output Power for a Two- Source, Two-Output System	22
	Appendix B: Final Output Power for a Two- Source, Three-Output System	23
	Appendix C: Final Output Power for a Three-Source, Two-Output System	23!
	Appendix D: Final Output Power for a Three-Source, Three-Output System	239
	Appendix E: Final Output Power for a Multisource, Two-Output System	243
	Appendix F: Final Output Power in the Presence of Leakage	249
	Appendix G: Final Output Power in the Presence of Offset Voltage	251
	Appendix H: Final Output Power in the Presence of Space Noise	253
	Appendix I: Basic Matrix Relations	255
	Appendix J: Touchstone-Generated Phase Values for Cross-Coupled Transmission Lines	259
	Appendix K: Derivation of the Input Signal in Figure 2.21	295
	About the Author	297
	Index	299