
Contents

About the authors	xi
Abbreviations and acronyms	xiii
List of symbols used	xv
Foreword	xvii
Preface	xix
Acknowledgements	xxiii
1 Introduction	1
References	3
2 Review of electromagnetic theory	5
2.1 Maxwell's equations	5
2.2 Boundary conditions	6
2.3 Energy and power	7
2.4 Reciprocity theorem	8
2.4.1 Source-free region	8
2.4.2 Infinite region or a region bounded by perfect conductors	9
2.5 Vector and scalar potentials	9
2.5.1 Electric vector potential	10
2.6 The image principle	11
2.7 The field equivalence principle	12
2.8 Green's functions	13
2.8.1 Free-space Green's function	13
2.8.2 Dyadic Green's function for the magnetic field of a magnetic current in a rectangular waveguide	14
References	15
3 History	17
3.1 The early years	17
3.2 The golden years	17
3.3 Waveguide slot antennas	18
3.4 The many shapes of slotted waveguide array antennas	18
References	23
4 The slot antenna	25
4.1 An aperture in an infinite ground plane	25
4.1.1 Problem formulation	25
4.1.2 Far field	26

4.1.3	General field expressions	27
4.1.4	Radiated complex power	29
4.1.5	The aperture admittance	29
4.2	The rectangular slot antenna	30
4.3	Waveguide modes	33
4.3.1	Definitions	33
4.3.2	The rectangular waveguide	34
4.3.3	The TE ₁₀ mode case	36
4.4	The longitudinal slot in a waveguide wall	36
4.4.1	Preliminaries	36
4.4.2	The longitudinal rectangular slot	38
4.4.3	Rectangular waveguide and TE ₁₀ mode scattering	39
4.4.4	The equivalent slot conductance	40
4.5	Mutual coupling	43
4.5.1	Introduction	43
4.5.2	Mutual coupling calculations	44
4.5.3	Finite ground plane effects	55
	References	57
5	Slot models	59
5.1	Modelling principles	59
5.1.1	Using experimental data	59
5.1.2	Equivalent circuit approach	60
5.1.3	Electromagnetic models	62
5.1.4	Finite wall thickness	66
5.2	Integral equation solution	68
5.2.1	The internal field	68
5.2.2	The external field	70
5.2.3	Matrix elements	71
5.3	Longitudinal slot characteristics	72
5.3.1	Slot electric field distribution	72
5.3.2	Slot magnetic field distribution	76
5.3.3	Experimental verification	79
5.3.4	Weakly excited slots	82
5.4	Transverse slots	83
5.4.1	Introduction	83
5.4.2	Theoretical analysis	84
5.4.3	Results	86
	References	88
6	The linear slotted waveguide array antenna	93
6.1	Introduction	93
6.1.1	Overview of design approaches	95
6.2	The accuracy of the slot array model	97
6.2.1	Slot model	97

6.2.2	Network model	97
6.2.3	Ground plane	97
6.2.4	Mutual coupling	97
6.3	The Elliott design equations	99
6.3.1	The first design equation	99
6.3.2	The second design equation	101
6.3.3	The iterative design algorithm for standing wave arrays	102
6.4	Mutual coupling	104
6.4.1	Efficient computation of the external mutual coupling terms	104
6.4.2	The self-admittance	106
6.4.3	Internal TE_{20} mode coupling	109
6.4.4	Full wave analysis	111
6.4.5	Mutual coupling compensation	111
6.5	Design example of a standing wave array	112
6.5.1	Slot data needed for the design algorithm	112
6.5.2	Design of a -30 dB sidelobe-level Dolph–Chebyshev array	113
6.6	Design of a travelling wave array	116
6.6.1	Design equations for travelling wave array	118
6.6.2	Design algorithm	118
6.6.3	Example of a 21-element travelling wave array	119
6.7	Array design using the concept of incremental conductance	126
6.8	Array design in terms of scattering parameters	128
6.9	Improvement to Elliott’s design procedure	130
	References	132
7	Design of planar slotted waveguide array antennas	135
7.1	Introduction	135
7.2	Elliott’s design procedure for planar standing wave arrays	136
7.2.1	Design algorithm	139
7.2.2	Example of a 6×6 planar array	141
7.3	Design of large arrays using the infinite array mutual coupling model	145
7.3.1	Infinite array mutual coupling expression	146
7.4	Choice of total slot conductance in radiating waveguides and resistance in feed waveguides	149
7.5	Sub-array architectures	151
7.5.1	A planar array of 160×160 elements consisting of 10×10 element sub-arrays	151
7.5.2	A slot array with 8×8 radiating elements consisting of two sub-arrays	151
7.5.3	A slot array with four-element sub-arrays	152
7.6	Examples of planar slot array designs	156
7.6.1	Large array design using the infinite array model	156
7.6.2	An 8×8 slot array for radiometer application	160

7.7	Design of a travelling wave feed for a planar array	162
7.7.1	Design procedure for a travelling wave feed in terms of scattering wave representation of a coupling slot	164
7.7.2	Computed results	166
7.8	A review of other methods for analysis and design in the literature	168
7.9	The generalised scattering matrix model for analysis and design	169
	References	172
8	Concepts and models for advanced designs	175
8.1	Coupling slot models	175
8.1.1	Centred-inclined coupling slot	176
8.1.2	Shunt-series coupling slot	179
8.1.3	Transverse/transverse coupling slot	181
8.2	Edge wall slot	182
8.3	Radiating compound broad wall slot	184
8.4	Iris-excited longitudinal slot	186
8.4.1	Elliott's design procedure for iris-excited slotted waveguide arrays	189
8.5	Slot arrays in ridge waveguides	190
8.6	Slot arrays with a dielectric cover	191
8.7	Higher-order mode coupling between centred-inclined coupling slots	193
8.7.1	Theory for the higher-order mode coupling between centred-inclined coupling slots	195
8.7.2	Procedure to incorporate the higher-order mode coupling in the design of centred-inclined coupling slots	196
8.8	Higher-order mode coupling between a centred-inclined coupling slot and longitudinal radiating slots	197
8.9	Finite ground plane effects	199
8.10	MoM solution to the integral equations of a planar array and applications	201
8.10.1	Formulation of the coupled integral equations	201
8.10.2	MoM solution	203
8.10.3	Improved design procedure using the MoM solution	204
8.11	Global optimisations for improved designs	209
8.11.1	GA optimisation of a travelling wave linear array	209
8.11.2	GA optimisation of a planar standing wave array using the MoM analysis	211
8.11.3	Equivalence between a slot with one basis function and a slot with many basis functions	213
8.11.4	GA optimised results	215
	References	217

9 Antenna systems and special requirements	221
9.1 Phase scanned slotted waveguide arrays	221
9.2 Frequency scanned slotted waveguide arrays	223
9.2.1 Travelling wave linear array	225
9.2.2 Phase reversal travelling array	226
9.2.3 Resonant series feed array	230
9.2.4 Centre-fed travelling array	231
9.3 Dual polarised slotted waveguide arrays	232
9.4 Multiple beam slotted waveguide arrays	237
9.5 Conformal slotted waveguide arrays	239
9.6 Monopulse slotted waveguide arrays	242
9.7 Stripline slotted arrays	245
9.7.1 Introduction	245
9.7.2 Independent excitations	247
9.8 Scattering from slotted waveguide arrays	249
9.8.1 Introduction	249
9.8.2 Scattering by a single slot in a planar ground plane	250
9.8.3 Scattering from an array of slots	252
9.8.4 The feeding network	255
9.8.5 Numerical examples	256
9.8.6 Spatial filters	256
9.9 Second-order lobes	258
9.9.1 Introduction	258
9.9.2 Analysis	258
9.9.3 Reducing the secondary lobes	259
9.10 Omnidirectional slotted waveguide array antennas	266
9.10.1 Slotted rectangular waveguide array	266
9.10.2 Slotted circular waveguide array	266
9.10.3 The pattern ripple problem	269
9.11 On the bandwidth of slotted waveguide array antennas	272
9.11.1 Introduction	272
9.11.2 The slot itself	273
9.11.3 The waveguide-fed longitudinal slot	273
9.11.4 The linear resonant array antenna	275
9.11.5 Overloading	277
9.11.6 Mutual coupling	278
9.11.7 The planar array and feeding arrangements	279
9.11.8 Travelling wave arrays	281
References	282
10 Slot arrays in special waveguide technologies	291
10.1 Slot arrays in circular parallel plate waveguides	291
10.1.1 Circularly polarised radial line slot antenna	291
10.1.2 Slot coupling and the attenuation coefficient of the propagating wave	296

10.1.3	Linearly polarised radial line slot antenna	297
10.1.4	Design of slot coupling coefficients	299
10.1.5	Single-layer radial line slot arrays	301
10.1.6	Radial line antennas for monopulse applications	303
10.1.7	Accurate analysis and design techniques	304
10.2	Slot arrays in rectangular parallel plate waveguides	304
10.3	Slot arrays in substrate integrated waveguides	307
10.4	Slot arrays in gap waveguides	310
	References	313
11	Manufacturing aspects	317
11.1	Tolerance theory	317
11.2	Manufacturing methods	322
11.2.1	Metallic materials	322
11.2.2	Carbon fibre-reinforced plastic materials	324
11.2.3	Microfabrication	326
	References	328
12	Outlook for the future	331
12.1	Defence systems	331
12.2	Millimetre waves	332
12.3	Spaceborne systems	332
12.4	Communication	333
12.5	Manufacturing	333
12.6	Design tools and software	333
12.6.1	HFSS	334
12.6.2	XFdtd	334
12.6.3	CST Microwave Studio	334
12.6.4	WASP-NET	334
12.6.5	SWAN TM	335
	References	335
Appendix	Standard waveguide frequency bands	339
	References	340
Index		341