
Contents

Preface

Introduction		
1.1	Some preliminary definitions	7
1.2	Review of DF techniques	7
1.3	The impact of new techniques	10
1.4	The value of computer simulations	11
1.5	Other applications of DF techniques	
2	Ionospheric modes	15
2.1	General description	15
2.2	Mode identification	
2.3	Fading	18
2.3.1	Amplitude distributions	18
2.3.2	Fading rates	20
2.3.3	Diversity distances	20
2.3.4	Fading models	21
2.4	Specular and diffracted components	23
2.5	Experiments on fine structure	25
2.6	Theory of phase measurements	26
2.6.1	General survey	26
2.6.2	Full theory	27
2.6.3	Approximations	28
2.7	Experimental results	28
2.8	Comment	28
2.9	Reflection of radiowaves at the ground	29
2.9.1	Complex reflection coefficient	29
2.9.2	Effects of ground reflection	30
3	Wave-field models	34
3.1	Essential features of wave-field models	34
3.2	Wavefronts and wavefront curvature	36
3.2.1	Phase path	36
3.2.2	Wavefront curvature	36
3.3	Lines of constant phase for one ray	38

3.4	Properties of two-ray wave-fields	39
3.4.1	Notation	39
3.4.2	Surfaces of constant amplitude	40
3.4.3	Surfaces of constant phase	42
3.5	Three or more rays	44
3.6	Wave-fields in the vertical plane	47
3.7	The significance of pattern repetition	47
3.8	Computer plots	48
3.8.1	Method of construction	48
3.8.2	Patterns in the ground plane	51
3.8.3	Patterns in the vertical plane	55
3.9	Summary	59
4	Zero-aperture bearings in two-ray wave-fields	62
4.1	Definition of zero-aperture bearing	62
4.2	Lines of constant phase	63
4.3	Bearing swing	64
4.4	Mean bearing	66
4.5	Bearing as a function of phase	67
4.6	Statistical distributions with constant amplitudes	69
4.6.1	Probability density function	69
4.6.2	Cumulative distribution function	71
4.6.3	Determination of the ray parameters	74
4.7	Statistical distributions with Rayleigh fading	75
4.7.1	P.D.F. of the amplitude ratio	75
4.7.2	P.D.F. of the bearing	76
4.7.3	C.D.F. of the bearing	77
4.7.4	Determination of the parameters of fading rays	78
4.8	Conclusions	78
5	Directive array patterns	81
5.1	Radiation patterns and spatial angular spectra	81
5.2	Deconvolution of a continuous distribution	83
5.3	Pattern synthesis	85
5.4	Beam-forming networks	86
5.4.1	Components	86
5.4.2	Doublet	87
5.4.3	Goniometer	89
5.5	Phase centre	91
5.6	Mutual coupling	91
5.7	Radiation patterns: additive processing	95
5.7.1	Circular WADF	95
5.7.2	Linear array	96
5.8	Multiplicative processing	97
6	Instrumental and site errors	102
6.1	Introduction	102
6.2	Instrumental errors	103
6.3	Calibration procedures	104

6.4	Effects of re-radiators on measurements of azimuth angle	105
6.4.1	Introduction	105
6.4.2	Calculation of susceptibility to site errors	106
6.4.3	Maximum DF error	108
6.4.4	An alternative model	110
6.4.5	Summary	110
6.5	Effects of the site on the measurement of elevation angles	111
6.5.1	Introduction	111
6.5.2	Size of Fresnel zones	112
6.5.3	Uniform ground slope	114
6.5.4	Imperfect reflection	114
6.5.5	Effects on elevation angles of nulls	118
6.5.6	Calibration with airborne transmitter	119
6.6	Conclusions	121
7	An introduction to resolution techniques	123
7.1	The resolution goal	123
7.2	A simple example	124
7.3	More complicated situations	125
7.4	The value of elevation-angle measurements	126
7.5	Terminology and notation	127
7.6	Restriction on the type of direction finder	129
7.7	The processor: general considerations	130
7.7.1	Amplitude and phase systems	130
7.7.2	The value of aperture	132
7.7.3	Comparison of processors in two-ray fields	136
8	Wave interference effects for circular arrays	138
8.1	Introduction	138
8.2	Wullenweber array	139
8.2.1	Simulated waveforms	139
8.2.2	Definition of segment bearing	140
8.2.3	Variation of segment bearing with phase	141
8.2.4	Variation of swing with amplitude ratio	143
8.2.5	Variation of swing with other parameters	145
8.3	Other types of DF	146
8.3.1	The Adcock	146
8.3.2	Doppler-type CDAA	147
8.3.3	Comparison of Adcock and Doppler systems	148
8.4	Capture effect	148
8.5	One-ray interpretation of multiray fields	149
8.6	Analysis of waveforms	150
8.6.1	Introduction	150
8.6.2	Analysis of single waveforms	150
8.6.3	Analysis of sequences of waveforms	152
8.7	Summary	159
9	Wave interference effects for interferometers	161
9.1	Introduction	161

9.2	Parameters used for numerical examples	163
9.3	The RF ellipse	163
9.4	The two-ray parallelogram	165
9.4.1	Envelope of ellipses	165
9.4.2	Diagonals of the parallelogram	167
9.5	More than two rays	168
9.6	Practical implementation	168
9.7	Wavefront testing	169
9.8	Combination of observations from two arms	171
10	Wavefront analysis: the concept	174
10.1	Introduction	174
10.2	Definitions	174
10.2.1	Input to the computer program	174
10.2.2	Wave-field model	175
10.2.3	Number of unknowns	175
10.3	Outline of solution method	176
10.4	Numerical examples	177
10.4.1	Introduction	177
10.4.2	Vertical tower, one-frame analysis	177
10.4.3	8-element CDAA, multiframe analysis	180
10.4.4	Discussion of numerical simulations	182
10.5	Further one-dimensional theory	183
10.5.1	Introduction	183
10.5.2	1-ray solution	184
10.5.3	Two rays in phase	185
10.5.4	Five rays from one frame	186
10.6	Basic theorems	187
Wavefront analysis using imperfect data		189
11.1	Introduction	189
11.2	Linear relationships	190
11.2.1	Geometrical interpretation	190
11.2.2	Mathematical generalisation	192
11.2.3	Physical interpretation	193
11.2.4	Angle-free linear relationships	194
11.3	Example of eigenvalues: vertical tower	197
11.4	Later steps in the solution	198
11.4.1	Introduction	198
11.4.2	Calculation of complex amplitudes	198
11.4.3	Reconstruction of antenna signals	200
11.4.4	Comparisons of several possible solutions	200
11.5	Systematic errors	202
11.6	Masquerading	203
11.6.1	Description	203
11.6.2	Discussion	204
11.7	Resolving power	205
11.7.1	Physical factors	205
11.7.2	Accuracy target	205
11.7.3	Vertical array of loops	206
11.7.4	Circular array	207

11.7.5 Multiframe analyses	207
11.7.6 Geometrical interpretation	208
8 Conclusions on wavefront analysis	208
12 Ray paths	211
12.1 Ray re-tracing: the objective	211
12.2 Definitions	212
12.2.1 The ray path	212
12.2.2 Surfaces of constant phase	212
12.2.3 Phase velocity	213
12.2.4 Phase refractive index	213
12.2.5 Wave packets	213
12.2.6 Phase path	214
12.2.7 Group path	214
12.3 Ray tracing in the presence of a magnetic field	214
12.3.1 The Haselgrove equations	214
12.3.2 The Appleton–Hartree expression for refractive index	216
12.3.3 The Millington quadratic	217
12.3.4 The Booker quartic	218
12.3.5 Magneto-ionic deviations	220
12.3.6 Relationship between ray-path deviations in azimuth and elevation	222
12.4 Ray tracing when the earth's field is neglected	223
12.4.1 Parabolic and quasiparabolic layers	223
12.4.2 Other distributions	225
12.5 Phase path and group path	225
12.5.1 Importance in DF	225
12.5.2 Group refractive index	226
12.6 Breit and Tuve's theorem	227
12.6.1 Flat earth, no field	227
12.6.2 Curved earth, no field	228
12.6.3 Curved earth, with field	229
12.6.4 Calculation of approximate ground range	230
12.7 Relationship between phase path and group path	230
12.8 Variation of phase path and group path with frequency	231
13 The effects of ionospheric tilts	235
13.1 Introduction: thin tilted-mirror model	235
13.2 Effective tilt of a thick layer	238
13.2.1 General theory	238
13.2.2 Lateral tilt of a single parabolic layer	240
13.2.3 Longitudinal tilt of a single parabolic layer	240
13.2.4 Modelling of travelling ionospheric disturbances	241
13.3 Tilt-correction schemes	242
13.3.1 Introduction	242
13.3.2 Models and predictions	242
13.3.3 Use of real-time measurements	243

13.4	Determination of the state of the remote ionosphere	248
13.4.1	Objectives	248
13.4.2	General remarks on the analysis of oblique records	249
13.4.3	Oblique ionograms	251
13.4.4	Backscatter ionograms	253
13.5	Summary	255
14	Bearing accuracy and DF plots	260
14.1	Accuracy statistics for individual bearings	260
14.1.1	Definitions	260
14.1.2	Applications	261
14.1.3	Distributions of bearing errors	263
14.1.4	Wild bearings	265
14.2	Accuracy of bearings and sources of error	266
14.2.1	Estimation of variance of a single bearing	266
14.2.2	Influence of propagation conditions on accuracy	268
14.2.3	Consolidated bearings	270
14.3	DF plotting	270
14.3.1	The problem	270
14.3.2	Method of Stansfield	271
14.3.3	Confidence regions and probability regions	275
14.4	Modifications to basic theory	276
14.4.1	Conversion from ellipse to rectangle	276
14.4.2	Spherical geometry	277
14.4.3	Correlated errors	278
14.4.4	Non-normal distributions and <i>a priori</i> information	279
14.4.5	Systematic errors	280
14.5	Dispersion factor and the rejection of bearings	281
14.5.1	Dispersion factor	281
14.5.2	Bearing rejection	281
14.6	Success rate of probability regions	281
14.7	Variance estimation from targets of unknown position	283
14.8	Concluding remarks on plotting	285
15	Conclusions	
Appendix 1	Circular WADF: parameters used in pattern calculations	293
Appendix 2	The theory of multiplicative processing	294
Appendix 3	Vertical array of loops: parameters used in pattern calculations	
Appendix 4	An example of masquerading	
Appendix 5	Magneto-ionic deviations calculated with the Jones three-dimensional ray-tracing program	
Appendix 6	Path integrals for parabolic layers	
Appendix 7	The effective tilt of a parabolic layer	
Appendix 8	Standard deviations of the best point estimate	