
Contents

Preface	xiii
Author biographies	xvii
List of abbreviations	xix
1 Introduction	1
1.1 The phenomena of antenna coupling	1
1.2 Characterisation via a measurement process	3
1.3 Measurable properties of antennas	6
1.3.1 Antenna gain and directivity	9
1.3.2 Antenna cross-section	11
1.3.3 Free-space radiation pattern	13
1.3.4 Polarisation	18
1.3.5 The far-field	19
1.3.6 The phase in the measurement	21
1.3.7 Reciprocity	22
1.3.8 Measurement limitations	23
1.4 The content of this text	23
References	26
2 EM theory and the mechanism behind antenna coupling	29
2.1 Maxwell's classical electromagnetic field theory	29
2.2 Electric charge and EM fields	30
2.3 Power flux in an EM field	34
2.4 Maxwell's equations	38
2.5 The electric and magnetic potentials	42
2.5.1 Static potentials	42
2.5.2 Retarded potentials	43
2.6 The inapplicability of source excitation as a measurement methodology	53
2.7 Field equivalence principle	53
2.8 Characterising vector electromagnetic fields	56
2.9 Reflection and scattering of electromagnetic fields by extended objects	58
2.10 Antenna port definition	59
2.11 Summary	61
References	62

3	Antenna measurements	63
3.1	Antenna measurements and alignment	63
3.2	Rotation methodologies	64
3.3	Far-field ranges	66
3.4	Free-space conditions	67
3.5	Alternatives to far-field ranges	77
3.5.1	The compact antenna test range	77
3.6	Indirect measurements	80
3.6.1	Spherical near-field ranges	81
3.6.2	Planar near-field measurements	83
3.6.3	Cylindrical near-field measurements	83
3.7	Other geometries for scanning measurements	85
3.8	Attributes common to all near-field measurement techniques	86
3.8.1	The scanning probe	86
3.8.2	Generic near-field antenna measurement process	87
3.9	Summary	89
	References	90
4	Compact range measurements	93
4.1	Introduction	93
4.2	Collimation of electromagnetic fields	96
4.2.1	Reflector edge diffraction	99
4.2.2	Feed spillover	109
4.2.3	Lenses as collimators	110
4.2.4	Hologram CATRs	111
4.2.5	Reflector surface errors and panel gaps	113
4.2.6	Time-gating and the absorber-less chamber	117
4.3	Types of ranges and their design issues	121
4.3.1	Single offset reflector CATR	121
4.3.2	Dual cylindrical reflector CATR	122
4.3.3	Dual shaped reflector CATR	122
4.3.4	Tri-reflector CATR	122
4.3.5	Hologram CATR	124
4.3.6	Lens CATR	125
4.4	Quiet zones and performance evaluation	125
4.4.1	How does a CATR actually work?	125
4.4.2	Measurement of the quiet zone by field probing	135
4.4.3	Phase-less quiet zone scanning	137
4.4.4	Quiet zone evaluation using RCS of a known target	138
4.4.5	Improving measured CATR patterns	140
4.4.6	Feed scanning for static AUT measurements	146
4.5	Radiation pattern and power parameter measurement	148
4.5.1	Radiation pattern measurement	148
4.5.2	Power parameter measurement	150

4.6	Radar cross-section measurements	154
4.6.1	RCS measurement in a CATR	154
4.6.2	Sources of RCS measurement error in a CATR	158
4.6.3	RCS model towers	160
4.6.4	Time-gating for RCS	160
4.6.5	Target imaging	162
	References	164
5	Planar near-field antenna measurements	171
5.1	Introduction	171
5.2	Near-field measurement facility	171
5.2.1	RF sub-system	172
5.2.2	Robotics positioner system	175
5.2.3	Near-field probe	177
5.3	Limitations in the accuracy of the near-field measurement data	177
5.3.1	Mechanically based limitations	177
5.3.2	RF system limitations	178
5.4	Solution of Maxwell's equations in Cartesian coordinates	180
5.4.1	Plane wave spectrum	180
5.5	Probe pattern compensation	182
5.5.1	Effect of the probe pattern on far-field data	184
5.5.2	Scanning probe characteristics	186
5.6	Plane-polar near-field antenna measurements	187
5.6.1	Application of spectral methods to plane-polar antenna measurements	187
5.6.2	Conventional and alternate plane acquisition types	196
5.6.3	Plane-polar alignment	200
5.7	Summary	207
	References	208
6	Cylindrical near-field antenna measurements	211
6.1	Introduction	211
6.2	Solution of Maxwell's equation in cylindrical coordinates	216
6.3	Solution of the scalar wave equation in cylindrical coordinates	219
6.4	Construction of vector fields	229
6.5	Derivation of cylindrical mode coefficients from cylindrical near-field data	235
6.5.1	Orthogonality properties of cylindrical wave vectors	235
6.5.2	Determining cylindrical mode coefficients from measured near-electric field components	240
6.6	Derivation of asymptotic far-field parameters from cylindrical mode coefficients	245
6.7	Development of the transmission formula	252
6.7.1	The coupling equation – derivation of probe-compensated cylindrical near-field antenna measurements	253

6.7.2	Probe and test antenna	255
6.7.3	Effect of probe compensation in cylindrical near-field measurements	261
6.7.4	Calculation of probe cylindrical mode coefficients from far-field data	264
6.8	Sampling requirements for cylindrical near-field measurements	267
6.9	Implementation of cylindrical near-field to far-field transformation	274
6.10	Conical near-field antenna measurements	279
6.11	Summary	284
	References	285
7	Spherical near-field antenna measurements	287
7.1	Introduction	287
7.2	Types of SNF ranges	293
7.2.1	Roll over azimuth – (ϕ/θ) systems	293
7.2.2	Swing arm – (θ/ϕ) systems	295
7.2.3	Arch-roll rotated – (θ/ϕ) systems	297
7.2.4	Articulating arm – (θ/ϕ) systems	299
7.2.5	Robotic arm SNF systems	300
7.3	A Solution to Maxwell's equations in spherical coordinates	302
7.4	Relating spherical mode coefficients to spherical near-field data	312
7.5	Sampling requirements and spherical mode truncation	319
7.6	Development of the transmission formula	332
7.7	Near-field probe correction	337
7.8	Far-field expressions	345
7.9	Practical acquisition schemes and examples	347
7.10	Summary	351
	References	351
8	Near-field range assessment	355
8.1	Introduction	355
8.2	A framework for measurement uncertainty	355
8.3	The effects of unwanted signals on vector measurements	356
8.4	The statistical nature of error signals	365
8.5	Probe/Illuminator related errors	374
8.5.1	Probe relative pattern	374
8.5.2	Probe polarisation purity	381
8.5.3	Probe alignment	383
8.6	Mechanical/Positioner related errors	386
8.6.1	AUT alignment	387
8.6.2	PNF probe (x, y) position error	388
8.6.3	PNF probe z position (planarity) error	394
8.6.4	CNF probe ρ position error	400

8.6.5	SNF (θ, ϕ, r) positioning uncertainty	404
8.6.6	SNF axis non-orthogonality	422
8.6.7	SNF axis (θ, ϕ) non-intersection error	422
8.7	Absolute power level related errors	428
8.7.1	Gain standard uncertainty	428
8.7.2	Normalisation constant	429
8.7.3	Impedance mismatch	431
8.8	Processing related errors	443
8.8.1	Aliasing	443
8.8.2	Measurement area truncation	444
8.9	RF sub-system related errors	448
8.9.1	Receiver amplitude linearity	448
8.9.2	Systematic phase	451
8.9.3	Leakage	456
8.9.4	Receiver dynamic range	457
8.10	Environmental errors	460
8.10.1	Probe structure reflection	460
8.10.2	Chamber reflection	464
8.10.3	Random errors	468
8.11	Combining uncertainties	468
8.12	Inter-range comparisons	469
8.13	Summary	477
	References	478
9	Mobile and body-centric antenna measurements	481
9.1	Introduction	481
9.2	Indoor far-field antenna measurements	481
9.3	Spherical near-field measurements	484
9.3.1	Over-the-air measurements	488
9.4	Low-gain antenna and S -Parameter measurement methods	491
9.5	Corruption by cables: the use of optical fibre links	494
9.6	On-body measurements	497
9.7	Efficiency measurement using wheeler cap	502
9.8	UWB antenna measurements	504
9.8.1	Return loss	506
9.8.2	Radiation pattern	506
9.8.3	UWB pseudo-time domain measurements	508
9.8.4	Fidelity analysis	511
9.8.5	True time domain measurements	512
9.8.6	Mean gain	515
9.9	Special facilities	516
9.9.1	Over-the-air multipath environment simulation for MIMO testing	516
9.9.2	Reverberation chamber measurements	516
	References	518

10	Advanced antenna measurement topics	523
10.1	Introduction	523
10.2	Common topics	523
10.2.1	Probes and probe selection	523
10.2.2	Channel-balance correction for antenna measurements	538
10.2.3	Aperture diagnostics	545
10.2.4	Amplitude and phase drift correction: tie-scan correction	555
10.2.5	Alignment correction (in PNF, CNF and SNF)	559
10.2.6	Introduction to range reflection suppression	568
10.3	PNF topics	577
10.3.1	Bias leakage error	577
10.3.2	Compensation for probe translation effects in dual polarised planar near-field antenna measurements	580
10.3.3	Introduction to phase-less near-field antenna measurements	588
10.3.4	Planar mathematical absorber reflection suppression	596
10.4	CNF topics	611
10.4.1	Cylindrical mathematical absorber reflection suppression	611
10.4.2	Application of C-MARS to far-field and CATR measurements – FF-MARS	627
10.5	SNF topics	632
10.5.1	Spherical near-field electrical alignment	632
10.5.2	The radial distance to MRS ratio	641
10.5.3	Spherical mathematical absorber reflection suppression	642
10.5.4	Rotary joint wow correction for LP antennas	651
10.6	Power parameter definitions and their measurement	653
10.6.1	Directivity	653
10.6.2	Gain	657
10.6.3	Equivalent isotropically radiated power (EIRP)	668
10.6.4	Saturating flux density (SFD)	669
10.7	Summary	669
10.7.1	Summary of MARS	669
	References	670
Appendices		673
A1.1	IEEE standard letter designations for radar-frequency bands	673
A1.2	Standard rectangular waveguide bands and selected properties	674
A1.3	Care and use of microwave coaxial connectors	674
A1.4	Reflection coefficient, return loss, transmission loss as a function of VSWR	678
A1.5	Coordinate systems and antenna measurements	678
A1.5.1	Azimuth over elevation	683
A1.5.2	Elevation over azimuth	685
A1.5.3	Polar spherical	687

A1.5.4	True-view (azimuth and elevation)	689
A1.5.5	Direction cosine	693
A1.5.6	Arcsine-space plotting coordinate system	694
A1.5.7	Transformation between coordinate systems	695
A1.5.8	Coordinate systems and elemental solid angles	698
A1.6	Polarisation basis and antenna measurements	698
A1.6.1	Ludwig I (Cartesian)	700
A1.6.2	Polar spherical	700
A1.6.3	Ludwig II ($az/el, el/az$)	705
A1.6.4	Ludwig III (co-polar, cross-polar and cross-polar discrimination)	710
A1.6.5	Conversion between polarisation bases	716
A1.6.6	Elliptical polarisation, axial ratio and tilt angle	721
A1.6.7	Linear and circular polarisation bases – complex vector representations	729
A1.6.8	Measures of polarisation discrimination	733
A1.7	Isometric rotation of coordinate systems	733
A1.7.1	Azimuth, elevation and roll angles	738
A1.7.2	Euler angles	740
A1.7.3	Antenna pattern plotting	741
	References	743

Index