Principles of Planar Near-Field Antenna Measurements

Stuart Gregson, John McCormick and Clive Parini

The Institution of Engineering and Technology

Contents

Pr	Preface				
1	Introduction				
	1.1	.1 The phenomena of antenna coupling			
	1.2	.2 Characterisation via the measurement process			
		1.2.1 Free space radiation pattern	. 6		
		1.2.2 Polarisation	7		
		1.2.3 Bandwidth	8		
	1.3	The organisation of the book	11		
	1.4	References	12		
2	Maxwell's equations and electromagnetic wave propagation				
	2.1	Electric charge	13		
	2.2	The EM field	14		
	2.3	Accelerated charges	16		
	2.4	Maxwell's equations	18		
	2.5	The electric and magnetic potentials	24		
		2.5.1 Static potentials	24		
		2.5.2 Retarded potentials	24		
	2.6	The inapplicability of source excitation as a measurement			
		methodology	28		
	2.7	Field equivalence principle	28		
	2.8	Characterising vector EM fields	30		
	2.9	Summary	33		
	2.10	References	33		
3	Introduction to near-field antenna measurements				
	3.1	Introduction	35		
	3.2	Antenna measurements	35		

4

3.3	Forms of near-field antenna measurements	40
3.4	Plane rectilinear near-field antenna measurements	43
3.5	Chambers, screening and absorber	44
3.6	RF subsystem	47
3.7	Robotics positioner subsystem	52
3.8	Near-field probe	56
3.9	Generic antenna measurement process	58
3.10	Summary	60
3.11	References	60
Plane	wave spectrum representation of electromagnetic	
waves	3	63
4.1	Introduction	63
4.2	Overview of the derivation of the PWS	64
4.3	Solution of the scalar Helmholtz equation	
	in Cartesian coordinates	65
	4.3.1 Introduction to integral transforms	65
	4.3.2 Fourier transform solution of the scalar Helmholtz	
	equation	65
4.4	On the choice of boundary conditions	78
4.5	Operator substitution (derivative of a Fourier transform)	79
4.6	Solution of the vector Helmholtz equation in Cartesian	
	coordinates	81
4.7	Solution of the vector magnetic wave equation in Cartesian	
	coordinates	83
4.8	The relationship between electric and magnetic spectral	
	components	84
4.9	The free-space propagation vector \underline{k}	87
4.10	Plane wave impedance	88
4.11	Interpretation as an angular spectrum of plane waves	90
4.12	Far-field antenna radiation patterns: approximated by the angular	
	spectrum	92
4.13	Stationary phase evaluation of a double integral	95
4.14	Coordinate free form of the near-field to angular spectrum	
	transform	101
4.15	Reduction of the coordinate free form of the near-field to far-field	
	transform to Huygens' principle	104
4.16	Far-fields from non-planar apertures	106
4.17	Microwave holographic metrology (plane-to-plane transform)	107
4.18	Far-field to near-field transform	108
4.19	Radiated power and the angular spectrum	112
4.20	Summary of conventional near-field to far-field	
	transform	115
4.21	References	117

5	Measurements – practicalities of planar near-field antenna				
		urement	-	119	
	5.1	Introdu	ction	119	
	5.2	Sampli	ng (interpolation theory)	120	
	5.3		ion, spectral leakage and finite area scan errors	121	
	5.4	Antenna-to-antenna coupling (transmission) formula		125	
		5.4.1	Attenuation of evanescent plane wave mode		
			coefficients	136	
		5.4.2	Simple scattering model of a near-field probe during a		
			planar measurement	137	
	5.5	Evaluat	ion of the conventional near-field to far-field		
		transform			
		5.5.1	Standard techniques for the evaluation of a double		
			Fourier integral	139	
	5.6	General	antenna coupling formula: arbitrarily orientated		
		antenna	S	143	
	5.7	Plane-p	olar and plane-bipolar near-field to far-field		
		transfor	m	148	
		5.7.1	Boundary values known in plane-polar coordinates	150	
		5.7.2	Boundary values known in plane-bipolar		
			coordinates	151	
	5.8	Regular	azimuth over elevation and elevation over azimuth		
			ate systems	156	
	5.9		ation basis and antenna measurements	159	
		5.9.1	Cartesian polarisation basis – Ludwig I	159	
		5.9.2	Polar spherical polarisation basis	160	
		5.9.3	Azimuth over elevation basis – Ludwig II	161	
		5.9.4	Copolar and cross-polar polarisation		
			basis – Ludwig III	163	
		5.9.5	Circular polarisation basis – RHCP and LHCP	165	
	5.10		ew of antenna alignment corrections	169	
		5.10.1	Scalar rotation of far-field antenna patterns	169	
		5.10.2	Vector rotation of far-field antenna patterns	171	
		5.10.4	Rotation of copolar polarisation basis – generalized		
			Ludwig III	173	
		5.10.5	Generalized compound vector rotation of far-field		
			antenna patterns	174	
	5.11		escription of near-field coordinate systems	175	
		5.11.1	Range fixed system	176	
		5.11.2	Antenna mechanical system	177	
		5.11.3	Antenna electrical system	178	
		5.11.4	Far-field azimuth and elevation coordinates	178	
		5.11.5	Ludwig III copolar and cross-polar definition	178	
		5.11.6	Probe alignment definition (SPP)	178	
		5.11.7	General vector rotation of antenna radiation patterns	179	

	5.12	Directivity and gain		
		5.12.1 Directivity	180	
		5.12.2 Gain – by substitution method	181	
		5.12.3 Gain-transfer (gain-comparison) method	182	
	5.13	Calculating the peak of a pattern	183	
		5.13.1 Peak by polynomial fit	183	
		5.13.2 Peak by centroid	185	
	5.14	Summary	186	
	5.15	References	187	
6	Prob	Probe pattern characterisation		
	6.1	Introduction	189	
	6.2	Effect of the probe pattern on far-field data	189	
	6.3	Desirable characteristics of a near-field probe	191	
	6.4	Acquisition of quasi far-field probe pattern	193	
		6.4.1 Sampling scheme	194	
		6.4.2 Electronic system drift (tie-scan correction)	197	
		6.4.3 Channel-balance correction	198	
		6.4.4 Assessment of chamber multiple reflections	200	
		6.4.5 Correction for rotary errors	202	
		6.4.6 Re-tabulation of probe vector pattern function	205	
		6.4.7 Alternate interpolation formula	209	
		6.4.8 True far-field probe pattern	211	
	6.5	Finite element model of open-ended rectangular waveguide		
	5.5	probe	213	
	6.6	Probe displacement correction	217	
	6.7	Channel-balance correction	217	
	6.8	References	218	
7		putational electromagnetic model of a planar near-field		
		urement process	219	
	7.1	Introduction	219	
	7.2	Method of sub-apertures	220	
	7.3	Aperture set in an infinite perfectly conducting ground plane	223	
		7.3.1 Plane wave spectrum antenna–antenna coupling	225	
	7.4	formula	225	
	7.4	Vector Huygens' method	227 229	
	7.5			
	7.6	Generalized technique for the simulation of near-field antenna measurements		
		7.6.1 Mutual coupling and the reaction theorem	233 234	
	7.7	Near-field measurement simulation	237	
	7.8	Reaction theorem	239	
	1403077-01	7.8.1 Lorentz reciprocity theorem (field reciprocity	100000	
		theorem)	240	

		7.8.2	Generalized reaction theorem	244		
		7.8.3	Mutual impedance and the reaction theorem	247		
	7.9	Summary		247		
	7.10) References				
8	Ante	enna measurement analysis and assessment				
	8.1	Introdu	ction	249		
	8.2	The est	ablishment of the measure from the measurement			
		results		249		
		8.2.1	Measurement errors	250		
		8.2.2	The sources of measurement ambiguity and error	253		
		8.2.3	The examination of measurement result data to establish			
			the measure	256		
	8.3	Measur	rement error budgets	259		
		8.3.1	Applicability of modelling error sources	259		
		8.3.2	The empirical approach to error budgets	260		
	8.4		tative measures of correspondence between data sets	261		
		8.4.1	The requirement for measures of correspondence	261		
	8.5	Compa	rison techniques	263		
		8.5.1	Examples of conventional data set comparison			
			techniques	263		
		8.5.2	Novel data comparison techniques	267		
	8.6	Summa	ary	282 283		
	8.7	References				
9	Adva	Advanced planar near-field antenna measurements				
	9.1	Introduction				
	9.2	Active alignment correction				
		9.2.1	Acquisition of alignment data in a planar near-field			
			facility	287		
		9.2.2	Acquisition of mechanical alignment data in a planar			
			near-field facility	289		
		9.2.3	Example of the application of active alignment			
			correction	291		
	9.3		ude only planar near-field measurements	296		
		9.3.1	PTP phase retrieval algorithm	297		
		9.3.2	PTP phase retrieval algorithm - with aperture			
			constraint	301		
	9.4	Efficien	nt position correction algorithms, in-plane and z -plane			
		corrections				
		9.4.1	Taylor series expansion	305		
		9.4.2	K-correction method	311		
	9.5		scan techniques	315		
		9.5.1	Auxiliary translation	315		
		9.5.2	Rotations of the AUT about the z-axis	319		

	9.5.3	Auxiliary rotation – bi-planar near-field antenna	
		measurements	320
	9.5.4	Near-field to far-field transformation of probe corrected	
		data	329
	9.5.5	Applicability of the poly-planar technique	335
	9.5.6	Complete poly-planar rotational technique	338
9.6	Conclu	ding remarks	342
9.7	Referen	nces	344
Appendix	A: Othe	er theories of interaction	347
A.1	Examp	les of postulated mechanisms of interaction	347
Appendix	B: Mea	surement definitions as used in the text	354
Appendix C: An overview of coordinate systems			357
C.1	Antenn	a mechanical system (AMS)	357
C.2	Antenn	a electrical system (AES)	357
C.3		ld plotting systems	358
C.4	Directi	on cosine	358
C.5	Azimut	th over elevation	360
C.6	Elevati	on over azimuth	361
C.7		pherical	362
C.8		th and elevation (true-view)	364
C.9	Range	of spherical angles	365
C.10		ormation between coordinate systems	366
C.11		nate systems and elemental solid angles	367
C.12		nship between coordinate systems	368
C.13		th, elevation and Roll angles	371
C.14	Euler a	•	373
C.15	Quatern	nion	374
C.16	Elemer	ntal solid angle for a true-view coordinate system	377
Appendix	D: Trap	pezoidal discrete Fourier transform	380
Appendix	Appendix E: Calculating the semi-major axis, semi-minor axis and tilt		
	angle	e of a rotated ellipse	384
Index	Index		