Optical Information Processing

Adolf W. Lohmann

Edited by Stefan Sinzinger



Universitätsverlag Ilmenau 2006

Contents

Pr	Preface to the 2006 edition Preface to the third edition		
Pr			
Pr	reface volume 1	17	
1	Outline	19	
2	Fourier Series 2.1 Introduction 2.2 Some Useful Properties of Fourier Series 2.3 Fourier Series for Two-Dimensional Functions	21 21 29 34	
3	The Moiré Effect 3.1 Measurement of small shifts 3.2 Moiré of two equal, rotating gratings 3.3 Moiré illustrations	37 37 38 42	
4	An Optical Analog Computer for Fourier Transformation	43	
5	Some More Moiré Effects 5.1 Fourier series representation of quasi-periodic functions 5.2 Schuster fringes The Dirac or Delta "Function"	49 49 49 57	
U	6.1 Introduction6.2 Several forms of $\delta(x)$ 6.2 Several forms of $\delta(x)$		
7	The Fourier Integral Transformation7.1Some general properties7.2Some specific properties7.3Polar coordinates7.4More about the Fourier-Integral transformation7.5Now some examples	68 69 73	
8	Some Additions About the Analog Computer	81	

Contents

9	Nonlinear Transforms	87
	9.1 Graphical solution	87
	9.2 Polynomial Nonlinearity	88
	9.3 FM-Nonlinearity	89
	9.4 Hardclipping	89
	9.5 Amplitude height analysis	90
10	Schwarz Inequality	91
11	Sampling Theorem	93
	11.1 Properties of the SINC-Function	93
	11.2 Sampling at Shifted Points	94
	11.3 Sampling of periodic functions	95
	11.4 Sampling at the wrong interval	98
	11.5 Sampling in two dimensions	100
	11.6 Fourier transform by digital computation	101
	11.7 Large digital Fourier transform	102
12	Fresnel-Transformation	105
14	12.1 Definitions	105
	12.2 Shift-theorem	105
	12.3 Tilt-theorem	100
	12.4 Sampling theorem for Fresnel transform pairs	100
		107
13	The Stationary Phase Integral	111
13	13.1 Fourier transform of the step-function	111
13	13.1 Fourier transform of the step-function	111 112
13	 13.1 Fourier transform of the step-function	111 112 113
13	13.1 Fourier transform of the step-function	111 112
	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method 	111 112 113
	 13.1 Fourier transform of the step-function	111 112 113 116
	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method 	111112113116119
	 13.1 Fourier transform of the step-function	 111 112 113 116 119 119
	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method What is Light? 14.1 History 14.2 What is Observable? 14.3 The wave equation 	 111 112 113 116 119 119 120
	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method What is Light? 14.1 History 14.2 What is Observable? 14.3 The wave equation 14.4 Complex representation of the wavefield 	 111 112 113 116 119 119 120 121
	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method What is Light? 14.1 History 14.2 What is Observable? 14.3 The wave equation 	 111 112 113 116 119 119 120 121 122
14	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method What is Light? 14.1 History 14.2 What is Observable? 14.3 The wave equation 14.4 Complex representation of the wavefield 14.5 Frequency averages 14.6 The envelope representation of complex signals 	 111 112 113 116 119 120 121 122 125 126
14	13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method 13.4 Saddle-point method What is Light? 14.1 History 14.2 What is Observable? 14.3 The wave equation 14.4 Complex representation of the wavefield 14.5 Frequency averages 14.6 The envelope representation of complex signals 14.6 The envelope representation of complex signals	 111 112 113 116 119 120 121 122 125 126 129
14	13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method 14.1 History 14.2 What is Observable? 14.3 The wave equation 14.4 Complex representation of the wavefield 14.5 Frequency averages 14.6 The envelope representation of complex signals 14.6 The envelope representation of complex signals 15.1 The usual derivation	 111 112 113 116 119 120 121 122 125 126 129
14	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method What is Light? 14.1 History 14.2 What is Observable? 14.3 The wave equation 14.4 Complex representation of the wavefield 14.5 Frequency averages 14.6 The envelope representation of complex signals 14.6 The uncertainty Principle 15.1 The usual derivation 15.2 The uncertainty of some specific fields 	 111 112 113 116 119 120 121 122 125 126 129 132
14	13.1 Fourier transform of the step-function13.2 The Fresnel integral13.3 The method of stationary phase13.4 Saddle-point method13.4 Saddle-point method14.1 History14.2 What is Observable?14.3 The wave equation14.4 Complex representation of the wavefield14.5 Frequency averages14.6 The envelope representation of complex signals14.7 The usual derivation15.2 The uncertainty of some specific fields15.3 Other definitions of x - and ν - spreads	 111 112 113 116 119 120 121 122 125 126 129 132 135
14	 13.1 Fourier transform of the step-function 13.2 The Fresnel integral 13.3 The method of stationary phase 13.4 Saddle-point method What is Light? 14.1 History 14.2 What is Observable? 14.3 The wave equation 14.4 Complex representation of the wavefield 14.5 Frequency averages 14.6 The envelope representation of complex signals 14.6 The uncertainty Principle 15.1 The usual derivation 15.2 The uncertainty of some specific fields 	 111 112 113 116 119 120 121 122 125 126 129 132
14	13.1 Fourier transform of the step-function13.2 The Fresnel integral13.3 The method of stationary phase13.4 Saddle-point method13.4 Saddle-point method14.1 History14.2 What is Observable?14.3 The wave equation14.4 Complex representation of the wavefield14.5 Frequency averages14.6 The envelope representation of complex signals14.7 The usual derivation15.2 The uncertainty of some specific fields15.3 Other definitions of x - and ν - spreads	 111 112 113 116 119 120 121 122 125 126 129 132 135

6

Contents

	16.3 16.4 16.5 16.6	Kirchhoff-approximation	142 143 147 152 156 157
17		e About Evanescent Waves	163
			163
	17.2	A more abstract look at evanescent waves	167
18	Fres	nel Diffraction on Periodic Objects — The Talbot-Effect (1836)	183
10		HFK-theory of the Talbot effect	184
			184
		Plane wave theory of the Talbot effect	185
		What are these modulated plane waves, really?	187
		A Fourier spectrometer based on the Talbot effect	190
		The walk-off effect	194
		Yet another look at Talbot images	196
19		nel Diffraction on Zone Plates and Lenses	207
		About inventing	207
	19.3	Image formation in terms of Fresnel diffraction	210
20	Wha	t is a Light Ray?	213
	20.1	Motivation of our approach	213
	20.2	The Fermat Principle as a consequence of wave optics	214
	20.3	What are Shadows or "Non-Rays"?	218
	20.4	Two examples of parageometrical optics	220
		20.4.1 Tilted plane wave falling onto wide screen	221
		20.4.2 A spherical wave falling onto a wide slit	224
		20.4.3 An application of parageometric optics:	227
21	App	lication of Fresnel Diffraction to Signal Detection	229
~~	T.		001
22		inhofer Diffraction	231
		Observer at distance <i>R</i> —no lens is involved	231
		Plane wave illumination—single lens	233
		About the lens used for creating "infinity"	235
		The "light tube"	237
		Convergent illumination	238
		Divergent illumination	239
		Fraunhofer diffraction by an array of equal objects	240
	22.8	Babinet's principle	243

Contents

23	Application of Fraunhofer Diffraction to Optical Character Recognition	245
24	Coherent Image Formation	247
	24.1 Two setups	247
	24.2 Convolution theory of image formation	248
	24.3 Spatial Filter theory of coherent image formation	252
25	Some Applications of Spatial Filtering	255
	25.1 Historical remarks about Ernst Abbe (1840 - 1905)	255
	25.2 Phase contrast microscopy	
	25.3 Differential interference contrast	
	25.4 Several image enhancement methods	
26	Incoherent Image Formation	263
-0	26.1 Definition of "coherent" and "incoherent" light	
	26.2 Convolution theory of incoherent image formation	
	26.3 Linear filter theory of incoherent image formation	
	26.4 The Duffieux formula	
	26.5 Measurement of the OTF	
	26.6 Incoherent image formation with transparent objects	
	26.7 Lens aberrations	
	26.8 The OTF of a perfect lens	
	26.9 Some specific OTF's	
	26.9.1 Defocussing	
	26.9.2 Other lens aberrations	
	26.9.3 Rough lens surface	
	26.9.4 Double-slit aperture	
	26.9.5 Object Motion	
	26.9.6 Photography	
	26.9.7 The OTF-chain of TV	
	26.10Quality criteria based on the OTF	
	26.110TF synthesis	
	26.11.1 Apodisation	
	26.11.2 Pseude-coherent image formation	
	26.11.3 Synthesis of incoherent matched filters	
27	Theory of Image Formation in Partially-Coherent Light	297
Pr	eface volume II	307
28	Boundary Conditions	309
	28.1 Discontinuities of the Medium	
	28.2 Consequences of the boundary conditions	312
29	Interference	317
	29.1 Division of Wavefront and Division of Amplitude	317

30	Cohe	erence	327
	30.1	Fundamentals of coherence theory	327
	30.2	Coherence and interference by division of amplitude	331
		30.2.1 Monochromatic point source	331
		30.2.2 Polychromatic point source	332
		30.2.3 Monochromatic extended source extended perpendicular to the mirror	334
		30.2.4 Monochromatic extended source extended parallel to mirror, observed	
		at large z	335
	30.3		335
	30.4	Solution of the example # 4, suggested for self-study:	336
	30.5		337
		30.5.1 Polychromatic point source	339
			341
	30.6	Coherence — division by grating diffraction	343
	30.7	Coherence—Division by a scatter plate	
			343
			343
		5	345
	30.10	OGroup velocity	350
31	Pola	rization	353
••			353
			354
	01.2		354
			355
		1	356
		-	357
	31.3		359
22	** 1		262
32		· 8- ·· F 7	363 365
		•	368
			369
			374
			374 380
			383
	52.0		383 384
		32.6.2 Reconstruction	385
		32.6.3 Theory of Off-Line-Fresnel Holography	385
		32.6.4 Theory of the reconstruction process	387
		32.6.5 About the Pseudoscopic Structure of the Conjugate Image	390
		32.6.6 Why is it so tricky to see the pseudoscopic image?	397
		32.6.7 Dynamic angular velocity	399
	327		400
	54.1	32.7.1 Fraunhofer off-line holography	401
		server reasonation of the holography	101

Contents	į
----------	---

		402 403 407
33	Talbot bands	411
34	Influence of the photographic material on spatial data processing	421
	34.1 Effects in a Photographic Emulsion	421
	34.2 (3) Light Scattering During Recording	421
	34.3 (4) The photographic nonlinear effect	424
	34.4 (6) Adjacency Effect	426
	34.5 (5) Grain-Noise	428
	34.6 The influence of light scattering within the emulsion during holographic record-	
	ing	428
	34.6.1 Image holography	428
	34.6.2 Fourier holography	430
	34.6.3 Fresnel hologram	432
35	The Space-Bandwidth-Product SW	433
36	Appendix — publications reprinted from OSA Journals	459
	Theta modulation in optics	460
	Character recognition by incoherent signal filtering	465
	A lateral wavefront shearing interferometry with variable shear	472
	Signal detection by correlation of Fresnel diffraction patterns	476
	Single-sideband holography	481
	Interferograms are image holograms	486
	Nonlinear effects in holography	488
Inc	dex	499