

**Lokenath Debnath  
Dambaru Bhatta**

$$f(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \left[ \int_{-\infty}^{\infty} f(\xi) e^{-ik\xi} d\xi \right] e^{ikx} dk$$

# Integral Transforms and Their Applications

**Second Edition**



**CRC Press**  
Taylor & Francis Group

A CHAPMAN & HALL BOOK

**Special Indian Edition**

---

## *Contents*

<b>1 Integral Transforms</b>	<b>1</b>
1.1 Brief Historical Introduction . . . . .	1
1.2 Basic Concepts and Definitions . . . . .	6
<b>2 Fourier Transforms and Their Applications</b>	<b>9</b>
2.1 Introduction . . . . .	9
2.2 The Fourier Integral Formulas . . . . .	10
2.3 Definition of the Fourier Transform and Examples . . . . .	12
2.4 Fourier Transforms of Generalized Functions . . . . .	17
2.5 Basic Properties of Fourier Transforms . . . . .	28
2.6 Poisson's Summation Formula . . . . .	37
2.7 The Shannon Sampling Theorem . . . . .	44
2.8 Gibbs' Phenomenon . . . . .	54
2.9 Heisenberg's Uncertainty Principle . . . . .	57
2.10 Applications of Fourier Transforms to Ordinary Differential Equations . . . . .	60
2.11 Solutions of Integral Equations . . . . .	65
2.12 Solutions of Partial Differential Equations . . . . .	68
2.13 Fourier Cosine and Sine Transforms with Examples . . . . .	91
2.14 Properties of Fourier Cosine and Sine Transforms . . . . .	93
2.15 Applications of Fourier Cosine and Sine Transforms to Partial Differential Equations . . . . .	96
2.16 Evaluation of Definite Integrals . . . . .	100
2.17 Applications of Fourier Transforms in Mathematical Statistics	103
2.18 Multiple Fourier Transforms and Their Applications . . . . .	109
2.19 Exercises . . . . .	119
<b>3 Laplace Transforms and Their Basic Properties</b>	<b>133</b>
3.1 Introduction . . . . .	133
3.2 Definition of the Laplace Transform and Examples . . . . .	134
3.3 Existence Conditions for the Laplace Transform . . . . .	139
3.4 Basic Properties of Laplace Transforms . . . . .	140
3.5 The Convolution Theorem and Properties of Convolution . . . . .	145
3.6 Differentiation and Integration of Laplace Transforms . . . . .	151
3.7 The Inverse Laplace Transform and Examples . . . . .	154
3.8 Tauberian Theorems and Watson's Lemma . . . . .	168

3.9	Exercises . . . . .	173
<b>4</b>	<b>Applications of Laplace Transforms</b>	
4.1	Introduction . . . . .	181
4.2	Solutions of Ordinary Differential Equations . . . . .	181
4.3	Partial Differential Equations, Initial and Boundary Value Problems . . . . .	182
4.4	Solutions of Integral Equations . . . . .	207
4.5	Solutions of Boundary Value Problems . . . . .	222
4.6	Evaluation of Definite Integrals . . . . .	225
4.7	Solutions of Difference and Differential-Difference Equations . . . . .	228
4.8	Applications of the Joint Laplace and Fourier Transform . . . . .	230
4.9	Summation of Infinite Series . . . . .	237
4.10	Transfer Function and Impulse Response Function of a Linear System . . . . .	251
4.11	Exercises . . . . .	256
<b>5</b>	<b>Fractional Calculus and Its Applications</b>	269
5.1	Introduction . . . . .	269
5.2	Historical Comments . . . . .	270
5.3	Fractional Derivatives and Integrals . . . . .	272
5.4	Applications of Fractional Calculus . . . . .	279
5.5	Exercises . . . . .	282
<b>6</b>	<b>Applications of Integral Transforms to Fractional Differential and Integral Equations</b>	283
6.1	Introduction . . . . .	283
6.2	Laplace Transforms of Fractional Integrals and Fractional Derivatives . . . . .	284
6.3	Fractional Ordinary Differential Equations . . . . .	287
6.4	Fractional Integral Equations . . . . .	290
6.5	Initial Value Problems for Fractional Differential Equations . . . . .	295
6.6	Green's Functions of Fractional Differential Equations . . . . .	298
6.7	Fractional Partial Differential Equations . . . . .	299
6.8	Exercises . . . . .	312
<b>7</b>	<b>Hankel Transforms and Their Applications</b>	315
7.1	Introduction . . . . .	315
7.2	The Hankel Transform and Examples . . . . .	316
7.3	Operational Properties of the Hankel Transform . . . . .	319
7.4	Applications of Hankel Transforms to Partial Differential Equations . . . . .	322
7.5	Exercises . . . . .	331

<b>8 Mellin Transforms and Their Applications</b>	<b>339</b>
8.1 Introduction . . . . .	339
8.2 Definition of the Mellin Transform and Examples . . . . .	340
8.3 Basic Operational Properties of Mellin Transforms . . . . .	343
8.4 Applications of Mellin Transforms . . . . .	349
8.5 Mellin Transforms of the Weyl Fractional Integral and the Weyl Fractional Derivative . . . . .	353
8.6 Application of Mellin Transforms to Summation of Series . .	358
8.7 Generalized Mellin Transforms . . . . .	361
8.8 Exercises . . . . .	365
<b>9 Hilbert and Stieltjes Transforms</b>	<b>371</b>
9.1 Introduction . . . . .	371
9.2 Definition of the Hilbert Transform and Examples . . . . .	372
9.3 Basic Properties of Hilbert Transforms . . . . .	375
9.4 Hilbert Transforms in the Complex Plane . . . . .	378
9.5 Applications of Hilbert Transforms . . . . .	380
9.6 Asymptotic Expansions of One-Sided Hilbert Transforms . .	388
9.7 Definition of the Stieltjes Transform and Examples . . . . .	391
9.8 Basic Operational Properties of Stieltjes Transforms . . . . .	394
9.9 Inversion Theorems for Stieltjes Transforms . . . . .	396
9.10 Applications of Stieltjes Transforms . . . . .	399
9.11 The Generalized Stieltjes Transform . . . . .	401
9.12 Basic Properties of the Generalized Stieltjes Transform . .	403
9.13 Exercises . . . . .	404
<b>10 Finite Fourier Sine and Cosine Transforms</b>	<b>407</b>
10.1 Introduction . . . . .	407
10.2 Definitions of the Finite Fourier Sine and Cosine Transforms and Examples . . . . .	408
10.3 Basic Properties of Finite Fourier Sine and Cosine Transforms	410
10.4 Applications of Finite Fourier Sine and Cosine Transforms .	416
10.5 Multiple Finite Fourier Transforms and Their Applications .	422
10.6 Exercises . . . . .	425
<b>11 Finite Laplace Transforms</b>	<b>429</b>
11.1 Introduction . . . . .	429
11.2 Definition of the Finite Laplace Transform and Examples . .	430
11.3 Basic Operational Properties of the Finite Laplace Transform	436
11.4 Applications of Finite Laplace Transforms . . . . .	439
11.5 Tauberian Theorems . . . . .	443
11.6 Exercises . . . . .	443

<b>12 Z Transforms</b>	
12.1 Introduction . . . . .	443
12.2 Dynamic Linear Systems and Impulse Response . . . . .	445
12.3 Definition of the <i>Z</i> Transform and Examples . . . . .	445
12.4 Basic Operational Properties of <i>Z</i> Transforms . . . . .	449
12.5 The Inverse <i>Z</i> Transform and Examples . . . . .	453
12.6 Applications of <i>Z</i> Transforms to Finite Difference Equations . . . . .	459
12.7 Summation of Infinite Series . . . . .	463
12.8 Exercises . . . . .	466
	469
<b>13 Finite Hankel Transforms</b>	473
13.1 Introduction . . . . .	473
13.2 Definition of the Finite Hankel Transform and Examples . . . . .	473
13.3 Basic Operational Properties . . . . .	476
13.4 Applications of Finite Hankel Transforms . . . . .	476
13.5 Exercises . . . . .	481
<b>14 Legendre Transforms</b>	485
14.1 Introduction . . . . .	485
14.2 Definition of the Legendre Transform and Examples . . . . .	486
14.3 Basic Operational Properties of Legendre Transforms . . . . .	489
14.4 Applications of Legendre Transforms to Boundary Value Problems . . . . .	497
14.5 Exercises . . . . .	498
<b>15 Jacobi and Gegenbauer Transforms</b>	501
15.1 Introduction . . . . .	501
15.2 Definition of the Jacobi Transform and Examples . . . . .	501
15.3 Basic Operational Properties . . . . .	504
15.4 Applications of Jacobi Transforms to the Generalized Heat Conduction Problem . . . . .	505
15.5 The Gegenbauer Transform and Its Basic Operational Properties . . . . .	507
15.6 Application of the Gegenbauer Transform . . . . .	510
<b>16 Laguerre Transforms</b>	511
16.1 Introduction . . . . .	511
16.2 Definition of the Laguerre Transform and Examples . . . . .	511
16.3 Basic Operational Properties . . . . .	516
16.4 Applications of Laguerre Transforms . . . . .	520
16.5 Exercises . . . . .	523

<b>17 Hermite Transforms</b>	<b>525</b>
17.1 Introduction . . . . .	525
17.2 Definition of the Hermite Transform and Examples . . . . .	526
17.3 Basic Operational Properties . . . . .	529
17.4 Exercises . . . . .	538
<b>18 The Radon Transform and Its Applications</b>	<b>539</b>
18.1 Introduction . . . . .	539
18.2 The Radon Transform . . . . .	541
18.3 Properties of the Radon Transform . . . . .	545
18.4 The Radon Transform of Derivatives . . . . .	550
18.5 Derivatives of the Radon Transform . . . . .	551
18.6 Convolution Theorem for the Radon Transform . . . . .	553
18.7 Inverse of the Radon Transform and the Parseval Relation .	554
18.8 Applications of the Radon Transform . . . . .	560
18.9 Exercises . . . . .	561
<b>19 Wavelets and Wavelet Transforms</b>	<b>563</b>
19.1 Brief Historical Remarks . . . . .	563
19.2 Continuous Wavelet Transforms . . . . .	565
19.3 The Discrete Wavelet Transform . . . . .	573
19.4 Examples of Orthonormal Wavelets . . . . .	575
19.5 Exercises . . . . .	584
<b>Appendix A Some Special Functions and Their Properties</b>	<b>587</b>
A-1 Gamma, Beta, and Error Functions . . . . .	587
A-2 Bessel and Airy Functions . . . . .	592
A-3 Legendre and Associated Legendre Functions . . . . .	598
A-4 Jacobi and Gegenbauer Polynomials . . . . .	601
A-5 Laguerre and Associated Laguerre Functions . . . . .	605
A-6 Hermite Polynomials and Weber-Hermite Functions . . . . .	607
A-7 Mittag Leffler Function . . . . .	609
<b>Appendix B Tables of Integral Transforms</b>	<b>611</b>
B-1 Fourier Transforms . . . . .	611
B-2 Fourier Cosine Transforms . . . . .	615
B-3 Fourier Sine Transforms . . . . .	617
B-4 Laplace Transforms . . . . .	619
B-5 Hankel Transforms . . . . .	624
B-6 Mellin Transforms . . . . .	627
B-7 Hilbert Transforms . . . . .	630
B-8 Stieltjes Transforms . . . . .	633
B-9 Finite Fourier Cosine Transforms . . . . .	636
B-10 Finite Fourier Sine Transforms . . . . .	638
B-11 Finite Laplace Transforms . . . . .	640

B-12 Z Transforms . . . . .	642
B-13 Finite Hankel Transforms . . . . .	644
<b>Answers and Hints to Selected Exercises</b>	<b>645</b>
2.19 Exercises . . . . .	645
3.9 Exercises . . . . .	651
4.11 Exercises . . . . .	655
6.8 Exercises . . . . .	662
7.5 Exercises . . . . .	662
8.8 Exercises . . . . .	663
9.13 Exercises . . . . .	664
10.6 Exercises . . . . .	665
11.6 Exercises . . . . .	667
12.8 Exercises . . . . .	667
13.5 Exercises . . . . .	670
16.5 Exercises . . . . .	670
17.4 Exercises . . . . .	670
18.9 Exercises . . . . .	671
19.5 Exercises . . . . .	671
<b>Bibliography</b>	<b>673</b>
<b>Index</b>	<b>689</b>