

Appendix A

Fourier Transform Tables

We here collect several of the Fourier transform pairs developed in the book, including both ordinary and generalized forms. This provides a handy summary and reference and makes explicit several results implicit in the book. We also use the elementary properties of Fourier transforms to extend some of the results.

We begin in Tables A.1 and A.2 with several of the basic transforms derived for the continuous time infinite duration case. Note that both the Dirac delta $\delta(x)$ and the Kronecker delta δ_x appear in the tables. The Kronecker delta is useful if the argument x is continuous or discrete for representations of the form $h(x) = f(x)\delta_x + g(x)(1 - \delta_x)$ which means that $h(0) = f(0)$ and $h(x) = g(x)$ when $x \neq 0$.

The transforms in Table A.2 are all obtained from transforms in Table A.1 by the duality property, that is, by reversing the roles of time and frequency.

Several of the previous signals are time-limited (i.e., are infinite duration signals which are nonzero only in a finite interval) and hence have corresponding finite duration signals. The Fourier transforms are the same for any fixed real frequency f , but we have seen that the appropriate frequency domain S is no longer the real line but only a discrete subset. Table A.3 provides some examples.

Table A.4 collects several discrete time infinite duration transforms. Remember that for these results a difference or sum in the frequency domain is interpreted modulo that domain.

Table A.5 collects some of the more common closed form DFTs.

Table A.6 collects several two-dimensional transforms.

g	$\mathcal{F}(g)$
$\{\square(t); t \in \mathcal{R}\}$	$\{\text{sinc}(f); f \in \mathcal{R}\}$
$\{\square_T(t); t \in \mathcal{R}\}$	$\{2T \text{sinc}(2Tf); f \in \mathcal{R}\}$
$\{e^{-t}u_{-1}(t); t \in \mathcal{R}\}$	$\{\frac{1}{1+2\pi if}; f \in \mathcal{R}\}$
$\{e^{- t }; t \in \mathcal{R}\}$	$\{\frac{2}{1+(2\pi f)^2}; f \in \mathcal{R}\}$
$\{t \square(t - \frac{1}{2}); t \in \mathcal{R}\}$	$\{\frac{1}{2}\delta_f + (\frac{ie^{-i2\pi f}}{2\pi f} + \frac{e^{-i2\pi f}-1}{(2\pi f)^2})(1-\delta_f); f \in \mathcal{R}\}$
$\{\wedge(t); t \in \mathcal{R}\}$	$\{\text{sinc}^2(f); f \in \mathcal{R}\}$
$\{e^{-\pi t^2}; t \in \mathcal{R}\}$	$\{e^{-\pi f^2}; f \in \mathcal{R}\}$
$\{e^{+i\pi t^2}; t \in \mathcal{R}\}$	$\{\frac{1}{\sqrt{-i}}e^{-i2\pi f^2}; f \in \mathcal{R}\}$
$\{\text{sgn}(t); t \in \mathcal{R}\}$	$\{\frac{-i}{\pi f}; f \in \mathcal{R}\}$
$\{u_{-1}(t); t \in \mathcal{R}\}$	$\{\frac{1}{2}\delta(f) - \frac{i}{2\pi f}(1-\delta_f); f \in \mathcal{R}\}$
$\{\delta(t-t_0); t \in \mathcal{R}\}$	$\{e^{-i2\pi f t_0}; f \in \mathcal{R}\}$
$\{\delta(at+b); t \in \mathcal{R}\}$	$\{\frac{1}{ a }e^{-i2\pi f \frac{b}{a}}; f \in \mathcal{R}\}$
$\{\delta(t); t \in \mathcal{R}\}$	$\{1; f \in \mathcal{R}\}$
$\{\delta'(t); t \in \mathcal{R}\}$	$\{i2\pi f; f \in \mathcal{R}\}$
$\{\Psi_T(t) = \sum_{n=-\infty}^{\infty} \delta(t-nT); t \in \mathcal{R}\}$	$\{\frac{1}{T}\Psi_{1/T}(f); f \in \mathcal{R}\}$
$\{\text{III}(t); t \in \mathcal{R}\}$	$\{\text{III}(f); f \in \mathcal{R}\}$
$\{\frac{1}{2}(\delta(t+\frac{1}{2})+\delta(t-\frac{1}{2})); t \in \mathcal{R}\}$	$\{\cos(\pi f); f \in \mathcal{R}\}$
$\{\frac{1}{2}(\delta(t+\frac{1}{2})-\delta(t-\frac{1}{2})); t \in \mathcal{R}\}$	$\{i \sin(\pi f); f \in \mathcal{R}\}$
$\{\text{sech}(\pi t); t \in \mathcal{R}\}$	$\{\text{sech}(\pi f); f \in \mathcal{R}\}$
$\{J_0(2\pi t); t \in \mathcal{R}\}$	$\begin{cases} \frac{1}{\pi\sqrt{1-f^2}} & f \in \mathcal{R}, f < 1 \\ 0 & \text{otherwise} \end{cases}$

Table A.1: Continuous Time, Infinite Duration

g	$\mathcal{F}(g)$
$\{\text{sinc}(t); t \in \mathcal{R}\}$	$\{\sqcap(f); f \in \mathcal{R}\}$
$\{\text{sinc}^2(t); t \in \mathcal{R}\}$	$\{\wedge(f); f \in \mathcal{R}\}$
$\{\frac{1}{\pi t}; t \in \mathcal{R}\}$	$\{-i\text{sgn}(f); f \in \mathcal{R}\}$
$\{e^{-i2\pi f_0 t}; t \in \mathcal{R}\}$	$\{\delta(f + f_0); f \in \mathcal{R}\}$
$\{1; t \in \mathcal{R}\}$	$\{\delta(f); f \in \mathcal{R}\}$
$\{\cos(\pi t); t \in \mathcal{R}\}$	$\{II(f); f \in \mathcal{R}\}$
$\{\sin(\pi t); t \in \mathcal{R}\}$	$\{iI_I(f); f \in \mathcal{R}\}$
$\{\frac{1}{2}\delta(t) + \frac{i}{2\pi t}(1 - \delta_t); t \in \mathcal{R}\}$	$\{u_{-1}(f); f \in \mathcal{R}\}$

Table A.2: Continuous Time, Infinite Duration (Duals)

g	$\mathcal{F}(g)$
$\{\Pi(t); t \in [-\frac{T}{2}, \frac{T}{2}]\}, T \geq 1$	$\{\text{sinc}(f); f \in \{\frac{k}{T}; k \in \mathcal{Z}\}\}$
$\{\wedge(t); t \in [-\frac{T}{2}, \frac{T}{2}]\}, T \geq 2$	$\{\text{sinc}^2(f); f \in \{\frac{k}{T}; k \in \mathcal{Z}\}\}$
$\{\delta(t); t \in [-\frac{T}{2}, \frac{T}{2}]\}$	$\{1; f \in \{\frac{k}{T}; k \in \mathcal{Z}\}\}$
$\{II(t); t \in [-\frac{T}{2}, \frac{T}{2}]\}, T > 1$	$\{\cos(\pi f); f \in \{\frac{k}{T}; k \in \mathcal{Z}\}\}$
$\{I_I(t); t \in [-\frac{T}{2}, \frac{T}{2}]\}, T > 1$	$\{i \sin(\pi f); f \in \{\frac{k}{T}; k \in \mathcal{Z}\}\}$
$\{t; t \in [0, 1)\}$	$\{\frac{1}{2}\delta_k + \frac{i}{2\pi k}(1 - \delta_k); k \in \mathcal{Z}\}$

Table A.3: Continuous Time, Finite Duration

g	$\mathcal{F}(g)$
$\{r^n u_{-1}(n); n \in \mathcal{Z}\} (r < 1)$	$\{\frac{1}{1-re^{-i2\pi f}}; f \in [-\frac{1}{2}, \frac{1}{2})\}$
$\{\square_N(n); n \in \mathcal{Z}\}$	$\{\frac{\sin(2\pi f(N+\frac{1}{2}))}{\sin(\pi f)}; f \in [-\frac{1}{2}, \frac{1}{2})\}$
$\{\text{sgn}(n); n \in \mathcal{Z}\}$	$\{\frac{1-e^{i2\pi f}}{1-\cos 2\pi f}; f \in [-\frac{1}{2}, \frac{1}{2})\}$
$\{\delta_{n-n_0}; n \in \mathcal{Z}\}$	$\{e^{-i2\pi f n_0}; f \in [-\frac{1}{2}, \frac{1}{2})\}$
$\{\delta_n; n \in \mathcal{Z}\}$	$\{1; f \in [-\frac{1}{2}, \frac{1}{2})\}$
$\{e^{-i2\pi \frac{k}{N} n}; n \in \mathcal{Z}\}$	$\{\delta(f + \frac{k}{N}); f \in [-\frac{1}{2}, \frac{1}{2})\}$

Table A.4: Discrete Time, Infinite Duration

g	$\mathcal{F}(g)$
$\{r^n; n \in \mathcal{Z}_N\}$	$\{\frac{1-r^N}{1-re^{-i2\pi k/N}}; k \in \mathcal{Z}_N\}$
$\{1; n \in \mathcal{Z}_N\}$	$\{N\delta_k; k \in \mathcal{Z}_N\}$
$\{\delta_n; n \in \mathcal{Z}_N\}$	$\{1; k \in \mathcal{Z}_N\}$
$\{\delta_{n-k}; n \in \mathcal{Z}_N\}$	$\{e^{-i2\pi \frac{k}{N}}; k \in \mathcal{Z}_N\}$

Table A.5: Discrete Time, Finite Duration (DFT)

Function	Transform
$\{\exp[-\pi(x^2 + y^2)]; x, y \in \mathcal{R}\}$ $\{\square(x) \square(y); x, y \in \mathcal{R}\}$ $\{\Lambda(x) \Lambda(y); x, y \in \mathcal{R}\}$ $\{\delta(x, y); x, y \in \mathcal{R}\}$ $\{\exp[i\pi(x + y)]; x, y \in \mathcal{R}\}$ $\{\text{sgn}(x) \text{sgn}(y); x, y \in \mathcal{R}\}$ $\{\text{comb}(x) \text{comb}(y); x, y \in \mathcal{R}\}$ $\{\exp[i\pi(x^2 + y^2)]; x, y \in \mathcal{R}\}$ $\{\exp[-(x + y)]; x, y \in \mathcal{R}\}$	$\{\exp[-\pi(f_X^2 + f_Y^2)]; f_X, f_Y \in \mathcal{R}\}$ $\{\text{sinc}(f_X) \text{sinc}(f_Y); f_X, f_Y \in \mathcal{R}\}$ $\{\text{sinc}^2(f_X) \text{sinc}^2(f_Y); f_X, f_Y \in \mathcal{R}\}$ $\{1; f_X, f_Y \in \mathcal{R}\}$ $\{\delta(f_X - 1/2, f_Y - 1/2); f_X, f_Y \in \mathcal{R}\}$ $\{\frac{1}{i\pi f_X} \frac{1}{i\pi f_Y}; f_X, f_Y \in \mathcal{R}\}$ $\{\text{comb}(f_X) \text{comb}(f_Y); f_X, f_Y \in \mathcal{R}\}$ $i \exp[-i\pi(f_X^2 + f_Y^2)]; f_X, f_Y \in \mathcal{R}\}$ $\{\frac{2}{1+(2\pi f_X)^2} \frac{2}{1+(2\pi f_Y)^2}; f_X, f_Y \in \mathcal{R}\}$
$\text{circ}(\sqrt{x^2 + y^2}; x, y \in \mathcal{R})$	$\frac{J_1(2\pi\sqrt{f_X^2 + f_Y^2})}{\sqrt{f_X^2 + f_Y^2}}; f_X, f_Y \in \mathcal{R}$
$\delta(\sqrt{x^2 + y^2 + 2}; x, y \in \mathcal{R})$	$2\pi r_0 J_0(2\pi r_0 \sqrt{f_X^2 + f_Y^2}); f_X, f_Y \in \mathcal{R}$

Table A.6: Two-dimensional Fourier transform pairs.

Bibliography

- [1] B. S. Atal and S. L. Hanauer. Speech analysis and synthesis by linear prediction of the speech wave. *J. Acoust. Soc. Am.*, 50:637–655, 1971.
- [2] W. R. Bennett. Spectra of quantized signals. *Bell Systems Technical Journal*, 27:446–472, July 1948.
- [3] S. Bochner. *Lectures on Fourier Integrals*. Princeton University Press, 1959.
- [4] H. Bohr. *Almost Periodic Functions*. Chelsea, New York, 1947. Translation by Harvey Cohn.
- [5] F. Bowman. *Introduction to Bessel Functions*. Dover, New York, 1958.
- [6] R. Bracewell. *The Fourier Transform and Its Applications*. McGraw-Hill, New York, 1965.
- [7] R. Bracewell. *The Hartley Transform*. Oxford Press, New York, 1987.
- [8] R.N. Bracewell. *Two-Dimensional Imaging*. Prentice Hall, Englewood Cliffs, New Jersey, 1995.
- [9] E. O. Brigham. *The fast Fourier transform*. Prentice-Hall, Englewood Cliffs, New Jersey, 1974.
- [10] H. S. Carslaw. *An Introduction to the Theory of Fourier's Series and Integrals*. Dover, New York, 1950.
- [11] A. G. Clavier, P. F. Panter, and D. D. Grieg. Distortion in a pulse count modulation system. *AIEE Transactions*, 66:989–1005, 1947.
- [12] A. G. Clavier, P. F. Panter, and D. D. Grieg. PCM distortion analysis. *Electrical Engineering*, pages 1110–1122, November 1947.

- [13] J. W. Cooley and J. W. Tukey. An algorithm for the machine calculation of complex Fourier series. *Math. Computation*, 19:297–301, 1965.
- [14] I. Daubechies. *Ten Lectures on Wavelets*. Society for Industrial and Applied Mathematics, Philadelphia, 1992.
- [15] W. B. Davenport and W. L Root. *An Introduction to the Theory of Random Signals and Noise*. McGraw-Hill, New York, 1958.
- [16] J. B. J. Fourier. *Théorie analytique de la chaleur*. 1922. Available as a Dover Reprint.
- [17] R. C. Gonzalez and P. Wintz. *Digital Image Processing*. Addison-Wesley, Reading, Mass., second edition, 1987.
- [18] J.W. Goodman. *Introduction to Fourier Optics*. McGraw-Hill, New York, 1988.
- [19] U. Grenander and G. Szego. *Toeplitz Forms and Their Applications*. University of California Press, Berkeley and Los Angeles, 1958.
- [20] F. Itakura and S. Saito. A statistical method for estimation of speech spectral density and formant frequencies. *Electron. Commun. Japan*, 53-A:36–43, 1970.
- [21] I. Katznelson. *An Introduction to Harmonic Analysis*. Dover, New York, 1976.
- [22] J. D. Markel and A. H. Gray, Jr. *Linear Prediction of Speech*. Springer-Verlag, New York, 1976.
- [23] A. V. Oppenheim and R. W. Schaffer. *Digital Signal Processing*. Prentice Hall, Englewood Cliffs, New Jersey, 1975.
- [24] A. Papoulis. *The Fourier Integral and Its Applications*. McGraw-Hill, New York, 1962.
- [25] J. R. Pierce. *The Science of Musical Sound*. Scientific American Books, New York, 1983.
- [26] M. Rabbani and P. W. Jones. *Digital Image Compression Techniques*, volume TT7 of *Tutorial Texts in Optical Engineering*. SPIE Optical Engineering Press, Bellingham, Washington, 1991.
- [27] D.R. Rao and P. Yip. *Discrete Cosine Transform*. Academic Press, San Diego, California, 1990.

- [28] S. O. Rice. Mathematical analysis of random noise. In N. Wax and N. Wax, editors, *Selected Papers on Noise and Stochastic Processes*, pages 133–294. Dover, New York, NY, 1954. Reprinted from Bell Systems Technical Journal, Vol. 23:282–332 (1944) and Vol. 24: 46–156 (1945).
- [29] O. Rioul and M. Vetterli. Wavelets and signal processing. *IEEE Signal Processing Magazine*, 8(4):14–38, October 1991.
- [30] W. McC. Siebert. *Circuits, Signals, and Systems*. M.I.T. Press, Cambridge, 1986.
- [31] Gilbert Strang. Wavelet transforms versus fourier transforms. *Bulletin (New Series) of the AMS*, 28(2):288–305, April 1993.
- [32] E. C. Titchmarsh. *Introduction to the Theory of Fourier Integrals*. Oxford University Press, Oxford, 1937.
- [33] James S. Walker. *Fourier Analysis*. Oxford University Press, New York, 1988.
- [34] G.K. Wallace. The JPEG still picture compression standard. *Communications of the ACM*, 34(4):30–44, April 1991.
- [35] G. N. Watson. *A Treatise on the Theory of Bessel Functions*. Cambridge University Press, Cambridge, 1980. Second Edition.
- [36] N. Wiener. *The Fourier Integral and Certain of Its Applications*. Cambridge University Press, New York, 1933.
- [37] John W. Woods, editor. *Subband Image Coding*. Kluwer Academic Publishers, Boston, 1991.

Index

- δ -response, 253
- z transform, 53, 72
- 2D Fourier transform, 309
- DTFT (discrete time finite duration Fourier transform), 57
- absolutely integrable, 96, 104
- absolutely summable, 94, 100
- additivity
 - countable, 252
- aliasing, 178, 278
- almost periodic function, 337
- almost periodic signal, 246
- alphabet, 47
- AM, 164
- ambiguity function, 297
- amplitude modulation, 164
- anti-Hermitian, 202
- area, 191
- area property, 191
- arithmetic
 - modular, xx
- Associative Law, 259
- autocorrelation function, 280
- autocorrelation width, 285
- backprojection, 324
- band-limited, 170
- bandlimited, 184
- bandwidth, 170, 190, 279
 - equivalent, 198
 - finite, 144
 - infinite, 144
- Bernoulli, 48
- Bessel function, 17, 77, 139, 336
- Bessinc function, 78
- bilateral, 72
- Binomial, 48
- bit rate, 338
- Bohr-Fourier series, 245, 337
- box function, 8
- boxcar, 43
- boxcar window, 43
- butterfly pattern, 84
- carrier frequency, 164
- Cauchy-Schwartz inequality, 281
- central limit theorem, 290
- central slice theorem, 320
- centroid, 196, 338
- circular convolution, 258
- circularly symmetric, 32
- closed interval, xviii
- Commutative Law, 259
- complete, 146
- compression ratio, 158
- continuous, 126
- convolution, 257, 258, 312
 - circular, 258
 - cyclic, 258
- convolution and backprojection, 324
- convolution identity, 260
- convolution integral, 133, 136, 257
- convolution sum, 256, 258
- convolution, two-dimensional, 312

- correlation coefficient, 281
- Correlation Theorem, 284
- cosine transform, 71
- countable additivity, 252
- countable linearity, 162
- crosscorrelation, 279
- CTFT, 55
- cyclic convolution, 258
- cyclic shift, 25

- DCT, 71, 78
- decimation, 82
- deconvolution, 298
- delay, 24
- delta
 - Kronecker, 9, 117
 - Dirac, 9, 223
- delta function, 9
 - Dirac, 260
 - Kronecker, 260
- Derivative Theorem, 187
- DFT, 57
 - inverse, 117
- Difference theorem, 187
- dilations, 148
- dimension, 146
- Dirac delta, 9
- Dirac delta function, 223
- Dirichlet kernel, 133, 231
- discrete Fourier transform
 - inverse, 117
- distribution, 224
- Distributive Law, 259
- domain, 1
- domain of definition, 1, 3
- dot product, 74
- doublet, 236
- doubly exponential, 48
- downsampling, 82, 183
- DSB-AM, 164
- DSB-SC, 165
- DTFT, 55
 - finite duration, 57
- dual, 66
- dual convolution theorem, 269, 294
- duality, 140

- eigenfunction, 272
- energy, 166
- equivalent bandwidth, 198
- equivalent pulse width, 198
- equivalent time width, 198
- equivalent width, 198
- error
 - mean squared, 156
 - quantizer, 339
- even, xix
- expansions
 - orthogonal, 155
- exponential, 48
 - discrete time, 8
- extended linearity, 162, 252

- fast Fourier transform, 82
- FFT, 64, 82
- filter, 20
- filtered backprojection, 326
- finite bandwidth, 144
- finite duration, 1, 56
- finite energy, 95, 97
- first moment property, 192
- FM, 17, 344
- Fourier analysis, xi
- Fourier coefficients, 138
- Fourier integral, 123
- Fourier integral kernel, 136
- Fourier series, 120, 121
 - continuous time, 138
 - generalized, 147
- Fourier transform, 53
 - 2D, 309
 - continuous time, 55
 - discrete, 57
 - discrete time, 55

- fast, 64
- finite duration
 - discrete time (see DFT), 57
 - inverse, 115
 - two-dimensional, 309
- Fourier transform pair, 115
- Fourier-Bessel transform, 77, 152
- frequency, 53
- frequency domain signal, 54
- frequency modulation, 17, 344
- frequency scaling, 177
- function, xvii
 - generalized, 11
 - box, 8
- Gaussian pdf, 48
- generalized function, 11, 224
- geometric, 48
- granular noise, 342
- group, 24
- Haar wavelet, 148
- Hankel transform, 77, 152
- hard limiter, 344
- harmonic analysis, xi
- Hartley transform, 71
- Heaviside, 14
- Heaviside step function, 14
- Hermitian, xx, 280
- Hilbert transform, 294
- homogeneous, 23
- ideal sampling function, 241
- IDFT (inverse discrete Fourier transform), 117
- imaginary part, xviii
- impulse pair, 244
- impulse response, 253, 258
- impulse train, 238
- index set, 1, 3
 - multidimensional, 2
- infinite bandwidth, 144
- infinite duration, 1, 56
- inner product, 74, 147, 168
- integral theorem, 274, 275
- interpolation, 299, 331
- inverse Fourier transform, 115
- inversion, 310
- inversion problem, 320
- Jacobi-Anger expansion, 139
- Jacobi-Anger formula, 336
- jinc function, 78
- JPEG, 159
- jump discontinuity, 126
- Kronecker delta, 9, 117
- lag, 279
- Laplace transform, 72
- Laplacian, 48
- limit in the mean, 95, 97, 103
- linear, 22, 251
- linear functional, 228
- linear modulation, 165
- linear operator, 228
- linearity, 109, 310
 - countable, 162
 - extended, 162, 252
- lower limit, 126
- LTI, 256
- mean, 196
- mean square, 95, 97
- mean squared abscissa, 196
- mean squared error, 156, 158
- mean squared width, 286
- Mellin transform, 74
- memoryless nonlinearity, 334
- memoryless system, 20, 334
- mesh, 29
- modular arithmetic, xx
- modulating, 164
- Modulation, 164
- modulation
 - amplitude, 164

- frequency, 344
- linear, 165
- phase, 337
- modulation index, 165
- moment generating function, 190
- moment of inertia, 194
- moment theorem, 193
- moment theorems, 190
- mother wavelet, 148
- MSE, 158
- multiresolution, 150
- natural sampling, 299
- nonlinear, 23
- nonlinearity
 - memoryless, 334
- Nyquist frequency, 172
- Nyquist rate, 172
- odd, xx
- one-sided, 4, 72
- open interval, xviii
- orthogonal, 119
- orthogonal expansions, 155
- orthogonality, 119, 123
- orthonormal, 119, 146, 155
- overload, 342
- PAM, 41, 180, 209
- Parseval's equality, 158
- Parseval's Theorem, 166, 167, 169
- Parseval's theorem, 312
- pdf, 47
 - Laplacian, 48
 - exponential, 48
 - Gaussian, 48
 - uniform, 48
- pel, 29
- period, 5
- periodic extension, 25, 44, 45
- periodic signal, 45
- phase, xviii
- phase modulation, 335, 337
- piecewise continuous, 126
- piecewise smooth, 126
- pixel, 2, 29
- PM, 335
- pmf, 47
 - Bernoulli, 48
 - doubly exponential, 48
 - Poisson, 48
 - Binomial, 48
 - geometric, 48
- Poisson, 48
- Poisson summation, 179
- Poisson summation theorem, 176
- probability density function, 47
- probability mass function, 47
- progression
 - geometric, 2, 61
- projection, 317, 319
- projection-slice theorem, 320, 321
- pulse amplitude modulation, 41
- pulse width, 190
- pulse width, equivalent, 198
- quantization, 17
 - uniform, 338
- quantizer error, 339
- raster, 2
- rate, 338
- Rayleigh's Theorem, 167
- Rayleigh's theorem, 166
- real part, xviii
- region of convergence (ROC), 72
- ROC, 72
- sample-and-hold, 41
- sampling, 37, 170
- sampling frequency, 172
- sampling function
 - ideal, 239
- sampling period, 37, 171
- sampling theorem, 173
- saturation, 342

- scalar product, 74, 147
- second moment property, 194
- separable signal, 29
- sequence, 2
- series
 - Bohr-Fourier, 245, 337
- shah function, 244
- shift, 24, 311
 - cyclic, 25
- shift invariant, 27
- sidebands, 165
- sifting property, 223, 225
- signal, 1, 3
 - continuous time, 2
 - discrete time, 2
 - finite duration, 1, 2
 - frequency domain, 54
 - geometric, 8
 - infinite duration, 2
 - periodic, 45
 - separable, 29
 - time-limited, 1
 - even, xix
 - infinite duration, 1
 - odd, xx
- signum, 217
- similarity, 311
- sinc, 11, 18
- sine transform, 71
- single-sideband modulation, 294
- space invariant, 314
- spectrum, 53, 54
- SSB, 294
- stationary, 27
- stretch, 311
- stretch theorem, 181
- subband filtering, 151
- subsampling, 82
- superposition integral, 255
- superposition property, 161
- superposition summation, 254
- symmetry, 310
- system, 20
 - memoryless, 20, 334
 - linear, 22
- system function, 272
- systems, 19
- Taylor series, 238
- time invariant, 27, 334
- time series, 2
- time width
 - equivalent, 198
- time-limited, 1
- Toeplitz function, 254
- transfer function, 272
- transform
 - z , 53
 - cosine, 71
 - discrete cosine, 78
 - Fourier, 53
 - Fourier-Bessel, 77
 - Hankel, 77
 - Mellin, 74
 - multidimensional, 74
 - sine, 71
 - Fourier-Bessel, 152
 - Hankel, 152
 - Hartley, 71
 - Hilbert, 294
- transform coding, 158
- transform method, 335
- triangle, 14
- trigonometric series representation, 138
- two-dimensional convolution, 312
- two-dimensional Fourier transform, 309
- two-sided, 4, 72
- uncertainty product, 287
- uncertainty relation, 287
- uniform, 48
- uniform quantization, 338

- unilateral, 72
- unit impulse function, 223
- unit sample, 9
- unit sample response, 253
- unit step, 11
- unitary, 119
- upper limit, 126
- upsampling, 187

- variance, 196

- waveform, 2
- wavelet, 147
 - Haar, 148
- wedge, 14
- Whittaker-Shannon-Kotelnikov sampling theorem, 173
- width
 - autocorrelation, 285
 - mean squared, 286
- window, 43
- windowing, 43

- zero filling, 44