Glossary of Symbols

Throughout this book, a few formulas are repeated for easier reference during reading. In such cases, the repeated earlier equation number is typeset in italics, like in (4.11).

\( a_k, b_k \)  
Fourier coefficients

\( A \)  
signal amplitude

\( A_{pp} \)  
signal peak-to-peak amplitude

\( A^T \)  
transpose of \( A \)

\( A^* \)  
complex conjugate transpose of \( A \)

\( \bar{A} \)  
complex conjugate of \( A \)

\( B \)  
bandwidth, or the number of bits in a fixed-point number

\( \text{cov}\{x, y\} \)  
covariance, page 42

\( C(\tau) \)  
covariance function

\( d \)  
dither, page 485

\( \frac{dx}{dt} \)  
derivative

\( \exp(\cdot) \)  
exponential function, also \( e^{(\cdot)} \)

\( E(f) \)  
energy density spectrum

\( E\{x\} \)  
expected value (mean value)

\( f \)  
frequency

\( f_s \)  
sampling frequency, sampling rate

\( f_0 \)  
center frequency of a bandpass filter

\( f_1 \)  
fundamental frequency, or first harmonic

\( f_x(x) \)  
probability density function (PDF), page 31

\( F_x(x) \)  
probability distribution function, \( F_x(x_0) = P(x < x_0) \)

\( \Phi_x(u) \)  
characteristic function (CF): \( \Phi_x(u) = \int_{-\infty}^{\infty} f_x(x) e^{jux} \, dx = E\{e^{jux}\} \)

Eq. (2.17), page 27

\( \mathcal{F}\{\cdot\} \)  
Fourier transform: \( \mathcal{F}\{x(t)\} = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} \, dt \)

for the PDF–CF pair, the Fourier transform is defined as \( \int_{-\infty}^{\infty} f(x) e^{jux} \, dx \)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{F}^{-1}{\cdot}$</td>
<td>inverse Fourier transform: $\mathcal{F}^{-1}{X(f)} = \int_{-\infty}^{\infty} X(f)e^{j2\pi ft} , df$ for the PDF–CF pair, the inverse Fourier transform is $\frac{1}{2\pi} \int_{-\infty}^{\infty} \Phi(u)e^{-jux} , du$</td>
</tr>
<tr>
<td>$h(t)$</td>
<td>impulse response</td>
</tr>
<tr>
<td>$H(f)$</td>
<td>transfer function</td>
</tr>
<tr>
<td>$\text{Im}{\cdot}$</td>
<td>imaginary part</td>
</tr>
<tr>
<td>$j$</td>
<td>$\sqrt{-1}$</td>
</tr>
<tr>
<td>$k$</td>
<td>running index in time domain series</td>
</tr>
<tr>
<td>$\lg(\cdot)$</td>
<td>base-10 logarithm</td>
</tr>
<tr>
<td>$\ln(\cdot)$</td>
<td>natural logarithm (base $e$)</td>
</tr>
<tr>
<td>$M_r$</td>
<td>$r$th moment difference with PQN: $E{(x')^r} - E{x'^r}$ Eq. (4.27), page 81</td>
</tr>
<tr>
<td>$\tilde{M}_r$</td>
<td>$r$th centralized moment difference with PQN: $E{(\tilde{x}')^r} - E{\tilde{x}'^r}$</td>
</tr>
<tr>
<td>$n$</td>
<td>pseudo quantization noise (PQN), page 69</td>
</tr>
<tr>
<td>$\text{N}$</td>
<td>number of samples</td>
</tr>
<tr>
<td>$N_r$</td>
<td>small (usually negligible) terms in the $r$th moment: $E{(x')^r} = E{x'^r} + M_r + N_r$, Eq. (B.1) of Appendix B, page 597</td>
</tr>
<tr>
<td>$\tilde{N}_r$</td>
<td>small (usually negligible) terms in the $r$th centralized moment: $E{(\tilde{x}')^r} = E{\tilde{x}'^r} + \tilde{M}_r + \tilde{N}_r$</td>
</tr>
<tr>
<td>$N(\mu, \sigma)$</td>
<td>normal distribution, page 49</td>
</tr>
<tr>
<td>$O(x)$</td>
<td>decrease as quickly as $x$ for $x \to 0$</td>
</tr>
<tr>
<td>$p$</td>
<td>precision in floating-point</td>
</tr>
<tr>
<td>$p_i$</td>
<td>probability</td>
</tr>
<tr>
<td>$P{\cdot}$</td>
<td>probability of an event</td>
</tr>
<tr>
<td>$q$</td>
<td>quantum size in quantization, page 25</td>
</tr>
<tr>
<td>$q_d$</td>
<td>quantum size of a digital dither, page 686</td>
</tr>
<tr>
<td>$q_h$</td>
<td>step size of the hidden quantizer, page 357</td>
</tr>
<tr>
<td>$Q$</td>
<td>quality factor or weighting coefficient</td>
</tr>
<tr>
<td>$R(\tau)$</td>
<td>correlation function, Eq. (3.40), page 42</td>
</tr>
<tr>
<td>$R_{xy}(\tau)$</td>
<td>crosscorrelation function, $R_{xy}(\tau) = E{x(t)y(t+\tau)}$ Eq. (3.41), page 42</td>
</tr>
<tr>
<td>$R_r$</td>
<td>residual error of Sheppard’s $r$th correction Eq. (B.7) of Appendix B, page 602</td>
</tr>
<tr>
<td>$\tilde{R}_r$</td>
<td>residual error of the $r$th Kind correction</td>
</tr>
<tr>
<td>$\text{Re}{\cdot}$</td>
<td>real part</td>
</tr>
<tr>
<td>$\text{rect}(z)$</td>
<td>rectangular pulse function, 1 if $</td>
</tr>
<tr>
<td>$\text{rectw}(z)$</td>
<td>rectangular wave, 1 if $-0.25 \leq z &lt; 0.25$; $-1$ if $0.25 \leq z &lt; 0.75$; repeated with period 1</td>
</tr>
<tr>
<td>$s$</td>
<td>Laplace variable, or empirical standard deviation</td>
</tr>
<tr>
<td>$s^*$</td>
<td>corrected empirical standard deviation</td>
</tr>
<tr>
<td>$S_r$</td>
<td>Sheppard’s $r$th correction, Eq. (4.29), page 82</td>
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</tbody>
</table>
Glossary of Symbols

\( \tilde{S}_r \) \( r \)th Kind correction

\( S(f) \) power spectral density

\( S_c(f) \) covariance power spectral density

\( \text{sign}(x) \) sign function

\( \text{sinc}(x) = \frac{\sin(x)}{x} \)

\( T \) sampling interval

\( T_m \) measurement time

\( T_p \) period length

\( T_r \) record length

\( \text{tr}(z) \) triangular pulse function, \( 1 - |z| \) if \( |z| \leq 1 \), zero elsewhere

\( \text{trw}(z) \) triangular wave, \( 1 - 4|z| \) if \( |z| \leq 0.5 \), repeated with period 1

\( u \) standard normal random variable

\( u(t) \) time function of voltage

\( U \) effective value of voltage

\( U_p \) peak value

\( U_{pp} \) peak-to-peak value

\( \text{var}\{x\} \) variance, same as square of standard deviation: \( \text{var}\{x\} = \sigma_x^2 \)

\( w(t) \) window function in the time domain

\( W(f) \) window function in the frequency domain

\( x \) random variable

\( x' \) quantized variable

\( x' - x \) quantization noise, \( \nu \)

\( \tilde{x} \) centralized random variable, \( x - \mu_x \), Eq. (3.13), page 34

\( x(t) \) input time function

\( X(f) \) Fourier transform of \( x(t) \)

\( X(f, T) \) finite Fourier transform of \( x(t) \)

\( z^{-1} \) delay operator, \( e^{-j2\pi fT} \)

\( \delta \) angle error

\( \Delta f \) frequency increment, \( f_s/N \) in DFT or FFT

\( \epsilon \) error

\( \epsilon_c \) width of confidence interval

\( \epsilon_r \) relative error

\( \phi \) phase angle

\( \gamma(f) \) coherence function: \( \gamma(f) = \frac{S_{xy}(f)}{\sqrt{S_{xx}(f)S_{yy}(f)}} \)

\( \mu \) mean value (expected value)

\( \nu \) quantization error, \( \nu = x' - x \)

\( \Psi \) quantization fineness, \( \Psi = \frac{2\pi}{q} \)

\( \omega \) radian frequency, \( 2\pi f \)

\( \Omega \) sampling radian frequency, page 17

\( \rho \) correlation coefficient (normalized covariance, \( \frac{\text{cov}\{x, y\}}{\sigma_x \sigma_y} \))

Eq. (3.39), page 42
\[\rho(t)\] normalized covariance function
\[\sigma\] standard deviation
\[\Sigma\] covariance matrix
\[\tau\] lag variable (in correlation functions)
\[\zeta\] \(\zeta = d + v\), total quantization error (in nonsubtractive dithering)
\[\in\] element of set, value within given interval
\[\ast\] convolution:
\[
\int_{-\infty}^{\infty} f(z)g(x-z)\,dz = \int_{-\infty}^{\infty} f(x-z)g(z)\,dz
\]
\[\triangleq\] definition
\[\dot{\Phi}\] first derivative, e. g. \(\dot{\Phi}_x(l|\Psi) = \frac{d\Phi(u)}{du} \bigg|_{u=l|\Psi}\)
\[\ddot{\Phi}\] second derivative, e. g. \(\ddot{\Phi}_x(l|\Psi) = \frac{d^2\Phi(u)}{du^2} \bigg|_{u=l|\Psi}\)
\[x'\] quantized version of variable \(x\)
\[\tilde{x}\] centralized version of variable \(\tilde{x} = x - \mu_x\), Eq. (3.13), page 34
\[\hat{x}\] estimated value of random variable \(x\)
\[\lfloor x \rfloor\] nearest integer smaller than or equal to \(x\) (floor\((x)\))
\[\check{x}\] deviation from a given value or variable