**TABLE A3.1** *Table of Bessel Functions*[a]

| $n \backslash x$ | 0.5 | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | $J_n(x)$ | | | | |
| 0 | 0.9385 | 0.7652 | 0.2239 | −0.2601 | −0.3971 | 0.1506 | 0.1717 | −0.2459 | 0.0477 |
| 1 | 0.2423 | 0.4401 | 0.5767 | 0.3391 | −0.0660 | −0.2767 | 0.2346 | 0.0435 | −0.2234 |
| 2 | 0.0306 | 0.1149 | 0.3528 | 0.4861 | 0.3641 | −0.2429 | −0.1130 | 0.2546 | −0.0849 |
| 3 | 0.0026 | 0.0196 | 0.1289 | 0.3091 | 0.4302 | 0.1148 | −0.2911 | 0.0584 | 0.1951 |
| 4 | 0.0002 | 0.0025 | 0.0340 | 0.1320 | 0.2811 | 0.3576 | −0.1054 | −0.2196 | 0.1825 |
| 5 | — | 0.0002 | 0.0070 | 0.0430 | 0.1321 | 0.3621 | 0.1858 | −0.2341 | −0.0735 |
| 6 | | — | 0.0012 | 0.0114 | 0.0491 | 0.2458 | 0.3376 | −0.0145 | −0.2437 |
| 7 | | | 0.0002 | 0.0025 | 0.0152 | 0.1296 | 0.3206 | 0.2167 | −0.1703 |
| 8 | | | — | 0.0005 | 0.0040 | 0.0565 | 0.2235 | 0.3179 | 0.0451 |
| 9 | | | | 0.0001 | 0.0009 | 0.0212 | 0.1263 | 0.2919 | 0.2304 |
| 10 | | | | — | 0.0002 | 0.0070 | 0.0608 | 0.2075 | 0.3005 |
| 11 | | | | | — | 0.0020 | 0.0256 | 0.1231 | 0.2704 |
| 12 | | | | | | 0.0005 | 0.0096 | 0.0634 | 0.1953 |
| 13 | | | | | | 0.0001 | 0.0033 | 0.0290 | 0.1201 |
| 14 | | | | | | — | 0.0010 | 0.0120 | 0.0650 |

[a]For more extensive tables of Bessel functions, see Abramowitz and Stegun (1965, pp. 358–406).

## TABLE A6.4 *Trigonometric Identities*

$$\exp(\pm j\theta) = \cos\theta \pm j\sin\theta$$

$$\cos\theta = \tfrac{1}{2}[\exp(j\theta) + \exp(-j\theta)]$$

$$\sin\theta = \frac{1}{2j}[\exp(j\theta) - \exp(-j\theta)]$$

$$\sin^2\theta + \cos^2\theta = 1$$

$$\cos^2\theta - \sin^2\theta = \cos(2\theta)$$

$$\cos^2\theta = \tfrac{1}{2}[1 + \cos(2\theta)]$$

$$\sin^2\theta = \tfrac{1}{2}[1 - \cos(2\theta)]$$

$$2\sin\theta\cos\theta = \sin(2\theta)$$

$$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$$

$$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$$

$$\tan(\alpha \pm \beta) = \frac{\tan\alpha \pm \tan\beta}{1 \mp \tan\alpha\tan\beta}$$

$$\sin\alpha\sin\beta = \tfrac{1}{2}[\cos(\alpha - \beta) - \cos(\alpha + \beta)]$$

$$\cos\alpha\cos\beta = \tfrac{1}{2}[\cos(\alpha - \beta) + \cos(\alpha + \beta)]$$

$$\sin\alpha\cos\beta = \tfrac{1}{2}[\sin(\alpha - \beta) + \sin(\alpha + \beta)]$$

**TABLE A6.2 *Fourier-Transform Pairs***

| *Time Function* | *Fourier Transform* |
|---|---|
| $\text{rect}\left(\frac{t}{T}\right)$ | $T\,\text{sinc}\,(fT)$ |
| $\text{sinc}\,(2Wt)$ | $\frac{1}{2W}\text{rect}\left(\frac{f}{2W}\right)$ |
| $\exp(-at)u(t), \quad a > 0$ | $\frac{1}{a + j2\pi f}$ |
| $\exp(-a\|t\|), \quad a > 0$ | $\frac{2a}{a^2 + (2\pi f)^2}$ |
| $\exp(-\pi t^2)$ | $\exp(-\pi f^2)$ |
| $\begin{cases} 1 - \frac{\|t\|}{T}, & \|t\| < T \\ 0, & \|t\| \geq T \end{cases}$ | $T\,\text{sinc}^2(fT)$ |
| $\delta(t)$ | $1$ |
| $1$ | $\delta(f)$ |
| $\delta(t - t_0)$ | $\exp(-j2\pi f t_0)$ |
| $\exp(j2\pi f_c t)$ | $\delta(f - f_c)$ |
| $\cos(2\pi f_c t)$ | $\frac{1}{2}[\delta(f - f_c) + \delta(f + f_c)]$ |
| $\sin(2\pi f_c t)$ | $\frac{1}{2j}[\delta(f - f_c) - \delta(f + f_c)]$ |
| $\text{sgn}(t)$ | $\frac{1}{j\pi f}$ |
| $\frac{1}{\pi t}$ | $-j\,\text{sgn}(f)$ |
| $u(t)$ | $\frac{1}{2}\delta(f) + \frac{1}{j2\pi f}$ |
| $\sum_{i=-\infty}^{\infty} \delta(t - iT_0)$ | $\frac{1}{T_0}\sum_{n=-\infty}^{\infty} \delta\left(f - \frac{n}{T_0}\right)$ |

*Notes:* $u(t)$ = unit step function
$\delta(t)$ = Dirac delta function
$\text{rect}(t)$ = rectangular function
$\text{sgn}(t)$ = signum function
$\text{sinc}(t)$ = sinc function

ASK Non-coherent: $P_e = \frac{1}{2} e^{\frac{-E_b}{2N_o}}$

ASK Coherent: $P_e = Q(\sqrt{\frac{E_b}{N_o}})$

BPSK: $P_e = Q(\sqrt{\frac{2E_b}{N_o}})$

QPSK: $P_e = Q(\sqrt{\frac{2E_b}{N_o}})$

M-QAM: $P_e = \frac{4}{\gamma}(1 - \sqrt{\frac{1}{M}})Q(\sqrt{(\frac{3\gamma}{(M-1)})\frac{E_b}{N_o}}$

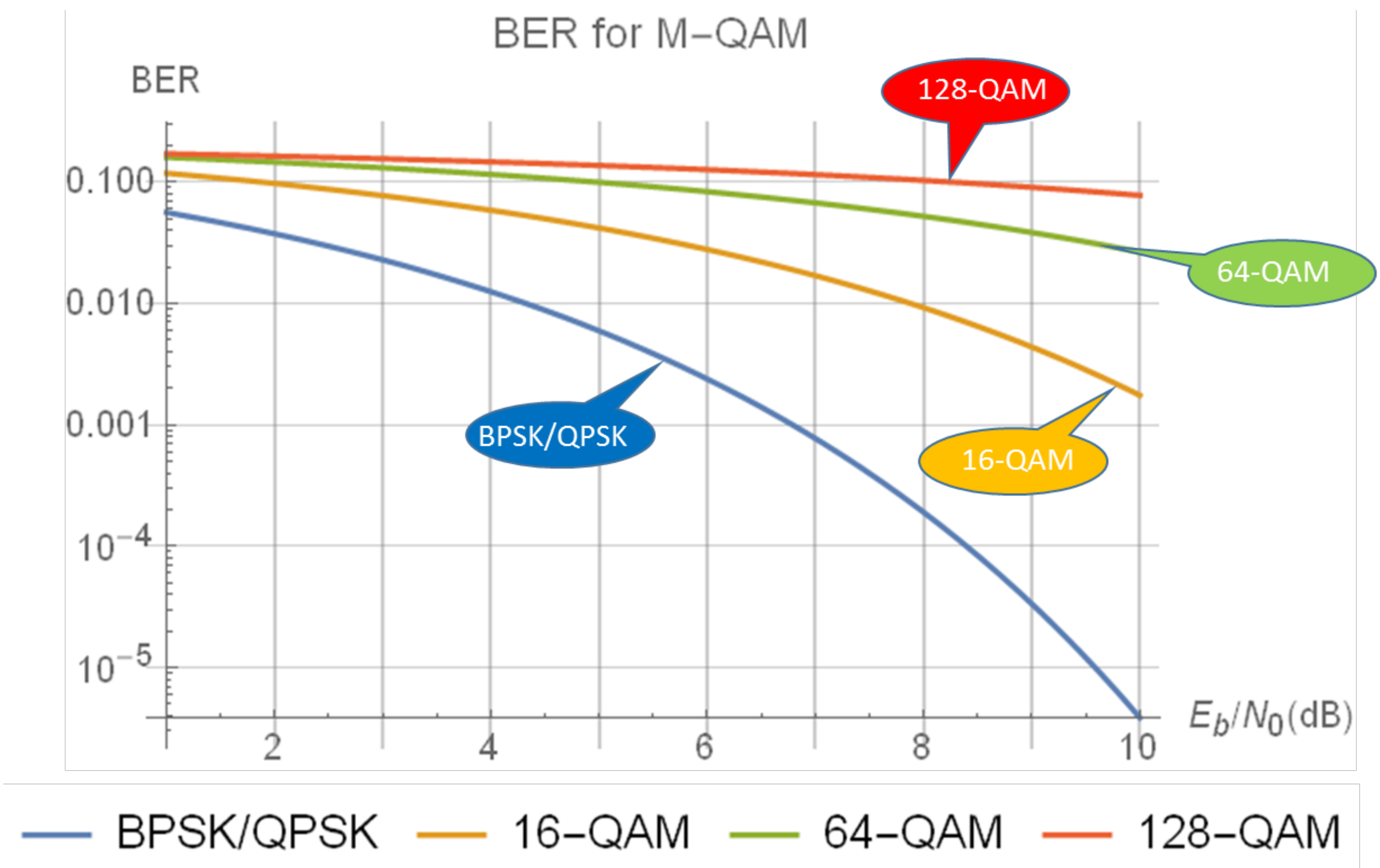

**TABLE D.1** GUASSIAN PROBABILITIES

| $y$ | $Q(y)$ | $y$ | $Q(y)$ | $y$ | $Q(y)$ | $Q(y)$ | $y$ |
|---|---|---|---|---|---|---|---|
| .05 | .4801 | 1.05 | .1469 | 2.10 | .0179 | | |
| .10 | .4602 | 1.10 | .1357 | 2.20 | .0139 | | |
| .15 | .4405 | 1.15 | .1251 | 2.30 | .0107 | $10^{-3}$ | 3.10 |
| .20 | .4207 | 1.20 | .1151 | 2.40 | .0082 | | |
| .25 | .4013 | 1.25 | .1056 | 2.50 | .0062 | | |
| .30 | .3821 | 1.30 | .0968 | 2.60 | .0047 | $\frac{10^{-3}}{2}$ | 3.28 |
| .35 | .3632 | 1.35 | .0885 | 2.70 | .0035 | | |
| .40 | .3446 | 1.40 | .0808 | 2.80 | .0026 | | |
| .45 | .3264 | 1.45 | .0735 | 2.90 | .0019 | | |
| .50 | .3085 | 1.50 | .0668 | 3.00 | .0013 | $10^{-4}$ | 3.70 |
| .55 | .2912 | 1.55 | .0606 | 3.10 | .0010 | | |
| .60 | .2743 | 1.60 | .0548 | 3.20 | .00069 | | |
| .65 | .2578 | 1.65 | .0495 | 3.30 | .00048 | $\frac{10^{-4}}{2}$ | 3.90 |
| .70 | .2420 | 1.70 | .0446 | 3.40 | .00034 | | |
| .75 | .2266 | 1.75 | .0401 | 3.50 | .00023 | | |
| .80 | .2119 | 1.80 | .0359 | 3.60 | .00016 | $10^{-5}$ | 4.27 |
| .85 | .1977 | 1.85 | .0322 | 3.70 | .00010 | | |
| .90 | .1841 | 1.90 | .0287 | 3.80 | .00007 | | |
| .95 | .1711 | 1.95 | .0256 | 3.90 | .00005 | $10^{-6}$ | 4.78 |
| 1.00 | .1587 | 2.00 | .0228 | 4.00 | .00003 | | |

*Source:* K. Sam Shanmugan, *Digital and Analog Communication Systems*, John Wiley & Sons, New York, 1979, pp. 583–84.

$k = 1.38x10^{-23}$ $\lambda = \frac{c}{f_c}$ (m) with $c = 3x10^8 m/s$

$T_e = T_o(F-1)$ $T_o = 290$

$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2}$$

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

$$G_{Ant} = \frac{4\pi A_{eff}}{\lambda^2}$$

For dish (circular) antenna $G_{Ant} = \left(\frac{\pi D}{\lambda}\right)^2$ D=Diameter(m)

Path Loss $= L_p = \left(\frac{4\pi r}{\lambda}\right)^2$ $r =$ distance (m)

$P_T =$ Tx Power: $G_T =$ Tx Ant Gain: $G_R =$ Rec Ant Gain

$$P_R = \frac{P_T G_T G_R}{L_p}$$

$$\left(\frac{S}{N}\right)_{Pre} = \frac{P_T G_T G_R}{L_p k(T_a + T_e) B_N} = \frac{P_T G_T G_R}{L_p k(T_a + T_o(F-1)) B_N}$$