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

	$J_n(x)$								
$n \backslash x$	*0.5*	*1*	*2*	*3*	*4*	*6*	*8*	*10*	*12*
0	0.9385	0.7652	0.2239	−0.2601	−0.3971	0.1506	0.1717	−0.2459	0.047
1	0.2423	0.4401	0.5767	0.3391	−0.0660	−0.2767	0.2346	0.0435	−0.223
2	0.0306	0.1149	0.3528	0.4861	0.3641	−0.2429	−0.1130	0.2546	−0.084
3	0.0026	0.0196	0.1289	0.3091	0.4302	0.1148	−0.2911	0.0584	0.195
4	0.0002	0.0025	0.0340	0.1320	0.2811	0.3576	−0.1054	−0.2196	0.182
5	—	0.0002	0.0070	0.0430	0.1321	0.3621	0.1858	−0.2341	−0.073
6		—	0.0012	0.0114	0.0491	0.2458	0.3376	−0.0145	−0.243
7			0.0002	0.0025	0.0152	0.1296	0.3206	0.2167	−0.170
8			—	0.0005	0.0040	0.0565	0.2235	0.3179	0.045
9				0.0001	0.0009	0.0212	0.1263	0.2919	0.230
10				—	0.0002	0.0070	0.0608	0.2075	0.300
11					—	0.0020	0.0256	0.1231	0.270
12						0.0005	0.0096	0.0634	0.195
13						0.0001	0.0033	0.0290	0.120
14						—	0.0010	0.0120	0.065

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

$$x_{FM}(t) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \cos(2\pi(f_c + nf_m)t)$$

$k = 1.38 x 10^{-23}$ $\lambda = \frac{c}{f_c}$ **(m) with** $c = 3x10^8 m / s$

$T_e = T_o(F-1)$ with $T_o = 290^o$

$S_n(f) = \frac{N_0}{2} \forall f \quad N_0 = k(T_a + T_e)$

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

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

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

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**

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

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

$(S/N)_{pre}$ (dB)= $P_T + G_T + G_R - L_M - L_p - 10\log(k(T_a + T_0(F-1))) - 10\mathrm{Log}(B_e)$

Time Function	*Fourier Transform*
$\text{rect}\left(\frac{t}{T}\right)$	$T\,\text{sinc}\,(fT)$
$\text{sinc}\,(2Wt)$	$\frac{1}{2W}\text{rect}\left(\frac{f}{2W}\right)$
$\exp(-at)u(t), \quad a > 0$	$\frac{1}{a + j2\pi f}$
$\exp(-a\lvert t\rvert), \quad a > 0$	$\frac{2a}{a^2 + (2\pi f)^2}$
$\exp(-\pi t^2)$	$\exp(-\pi f^2)$
$\begin{cases} 1 - \frac{\lvert t\rvert}{T}, & \lvert t\rvert < T \\ 0, & \lvert t\rvert \geq T \end{cases}$	$T\,\text{sinc}^2(fT)$
$\delta(t)$	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

Here $\text{sinc}(x) = \frac{\sin(\pi x)}{\pi x}$

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$$\exp(\pm j\theta) = \cos\theta \pm j\sin\theta$$
$$\cos\theta = \frac{1}{2}[\exp(j\theta) + \exp(-j\theta)]$$
$$\sin\theta = \frac{1}{2j}[\exp(j\theta) - \exp(-j\theta)]$$
$$\sin^2\theta + \cos^2\theta = 1$$
$$\cos^2\theta - \sin^2\theta = \cos(2\theta)$$
$$\cos^2\theta = \frac{1}{2}[1 + \cos(2\theta)]$$
$$\sin^2\theta = \frac{1}{2}[1 - \cos(2\theta)]$$
$$2\sin\theta\cos\theta = \sin(2\theta)$$
$$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$$
$$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$$
$$\tan(\alpha \pm \beta) = \frac{\tan\alpha \pm \tan\beta}{1 \mp \tan\alpha\tan\beta}$$
$$\sin\alpha\sin\beta = \frac{1}{2}[\cos(\alpha - \beta) - \cos(\alpha + \beta)]$$
$$\cos\alpha\cos\beta = \frac{1}{2}[\cos(\alpha - \beta) + \cos(\alpha + \beta)]$$
$$\sin\alpha\cos\beta = \frac{1}{2}[\sin(\alpha - \beta) + \sin(\alpha + \beta)]$$

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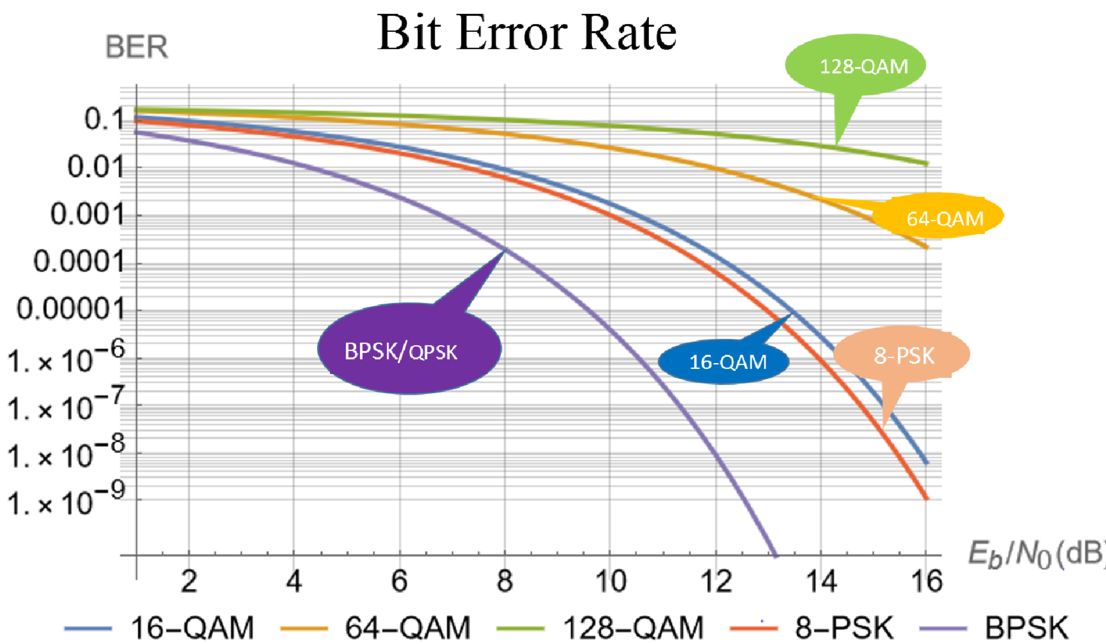

BER Equations

BPSK/QPSK $Q\left(\sqrt{\frac{2 E_b}{N_0}}\right)$ Coherent ASK $Q\left(\sqrt{\frac{E_b}{N_0}}\right)$ Noncoherent ASK $\frac{1}{2} e^{-\frac{E_b}{2 N_0}}$

M-PSK $\frac{2\, Q\left(\sqrt{\frac{2 \log_2(M) E_b}{N_0}} \sin^2\left(\frac{\pi}{M}\right)\right)}{\log_2(M)}$, QAM (Square Grid) $\frac{4\left(\sqrt{M}-1\right)}{\sqrt{M}\log_2(M)}\, Q\left(\sqrt{\frac{3 E_b \log_2(M}{N_0(M-1)}}\right.$

Gaussian Probabilities

(1) $P(X > \mu_X + y\sigma_X) = Q(y) = \int_y^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-z^2}{2}\right) dz$

(2) $Q(0) = \frac{1}{2}$; $Q(-y) = 1 - Q(y)$, when $y \geq 0$

(3) $Q(y) \approx \frac{1}{y\sqrt{2\pi}} \exp\left(\frac{-y^2}{2}\right)$ when $y > 4$

(4) $\text{erfc}(y) \triangleq \frac{2}{\sqrt{\pi}} \int_y^{\infty} \exp(-z^2)\, dz = 2Q(\sqrt{2}y),\ y > 0.$

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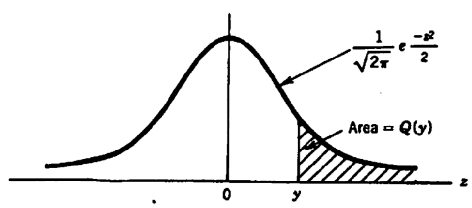
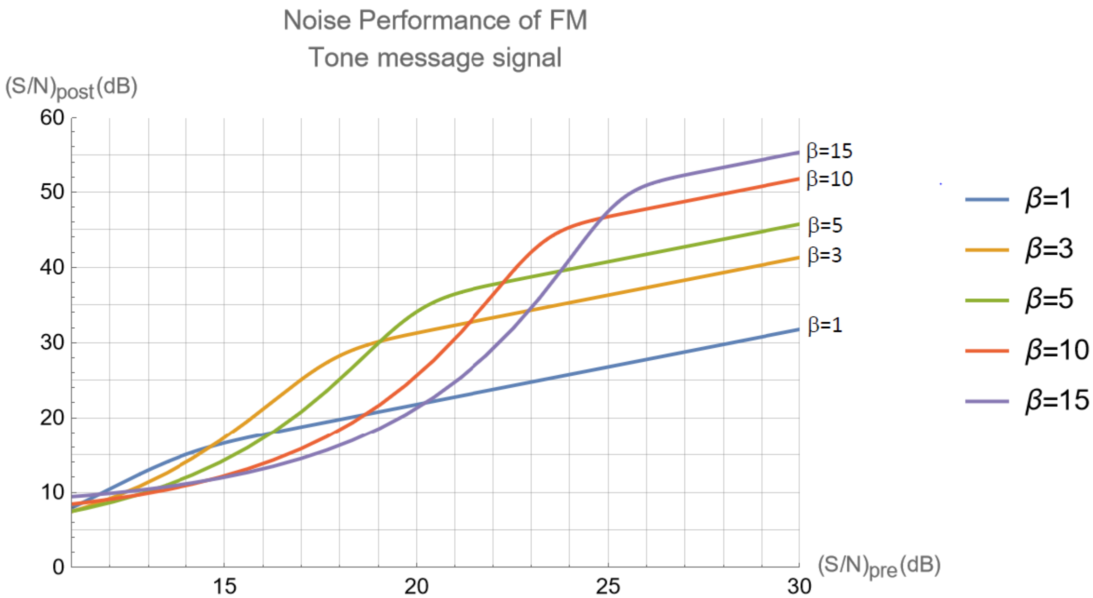
TABLE D.1 GUASSIAN PROBABILITIES

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		
1.00	.1587	2.00	.0228	4.00	.00003	10^{-6}	4.78

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





Noise Performance of FM
Tone message signal
(S/N)post(dB)
60
50
40
30
20
10
0
15
20
25
30
(S/N)pre(dB)
β=15
β=10
β=5
β=3
β=1
β=1
β=3
β=5
β=10
β=15