Georgia Institute of Technology School of Electrical and Computer Engineering

ECE6604 Personal & Mobile Communications

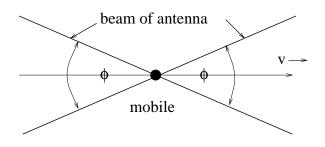
Final Exam

Fall 2018

Friday December 7, 11:20am - 2:10pm

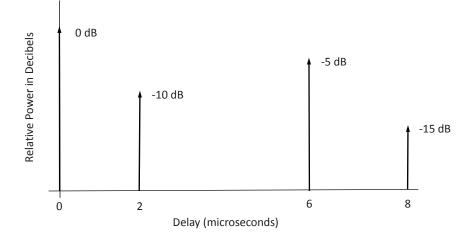
- Attempt all questions.
- All questions are of equal value.
- Open book, open notes, exam.
- Math tables are attached at the end of this exam. You do not need to turn them in.

1) Consider the situation shown below where the mobile station employs a directional antenna with a beam width of ϕ° . Assume a 2-D isotropic scattering environment.



- a) (5 marks:) In receiving a radio transmission at 850 MHz, a Doppler frequency of 20 to 60 Hz is observed. What is the beam width of the mobile station antenna, and how fast is the mobile station traveling?
- b) (5 marks:) Suppose that the mobile station antenna has a beam width of 13°. What is the level-crossing rate with respect to the rms envelope level, assuming that the mobile station is traveling at a speed of 30 km/h?

2) The following power-delay profile is observed for a multipath-fading channel in hilly terrain.



- a) (2 marks:) Compute the mean delay.
- b) (3 marks:) Compute the rms delay spread.
- c) (5 marks:) What is the frequency correlation function of the channel?

3) Consider BPSK modulation on a fading channel with L = 2 receiver diversity. The channel gain for Antenna 1, α_1 , has the probability density function

$$p_{\alpha_1}(x) = 0.9\delta(x - 1.0) + 0.1\delta(x - 0.05)$$

while the channel gain for Antenna 2, α_2 , has the probability density function

$$p_{\alpha_2}(x) = 0.7\delta(x - 1.0) + 0.3\delta(x - 0.05)$$
,

and α_1 and α_2 are independent.

Each diversity branch is affected by independent complex AWGN with noise power spectral density N_o watts/Hz.

Assume maximal ratio combining.

- a) (2 marks:) What is the average bit-energy-to-noise, $\bar{\gamma}_b^{\rm mr}$, at the output of the combiner.
- b) (4 marks:) What is the probability density function of the bit-energy-tonoise, $\gamma_b^{\rm mr}$, at the output of the combiner. Express your result in terms of $\bar{\gamma}_b^{\rm mr}$.
- c) (4 marks:) Derive an expression for the bit error probability. Express your result in terms of $\bar{\gamma}_b^{\rm mr}$.

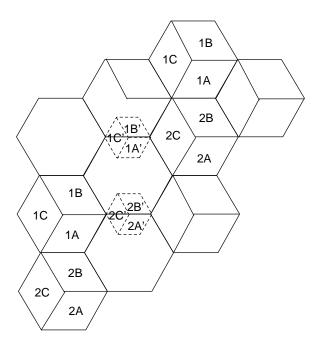
- 4) Consider BPSK modulation with simple binary repetition coding on a Rayleigh fading channel. Each data bit is assumed to be repeated L times, and each copy is transmitted with energy E_b/L , where E_b is the energy per data bit. Each copy is affected by independent Rayleigh fading and independent noise. The receiver is assumed to have a single antenna.
 - a) 8 marks: At the receiver, selective combining is used to combine together the *L* copies of each data bit that are transmitted. Derive an expression for the probability of bit error, P_b , as a function of the average received bit energy to noise ratio $\bar{\gamma}_b$.
 - **b) 2 marks:** Evaluate P_b for L = 3 and $\bar{\gamma}_b = 10 \text{ dB}$.

5) Cell splitting is a process whereby smaller cells are introduced into an existing cellular deployment. If heavy traffic loading is experienced at the midpoint between the two cells labeled 1 in the figure below, then a split cell labeled 1' can be introduced at that location. Likewise, the split cell labeled 2' can be introduced at the midpoint between the two cells labeled 2.

Assume propagation path loss according to the following model:

$$\mu_{\Omega_p}(d) = \mu_{\Omega_p}(d_o, h_{b_o}, h_{m_o}) \frac{[(h_b/h_{b_o})(h_m/h_{m_o})]^2}{(d/d_o)^{\beta}}$$

where $\mu_{\Omega_{p}(dBm)} = -70$ dBm at $d_o = 1$ km, $\beta = 3.5$, $h_{b_o} = 70$ m, $h_{m_o} = 1.5$ m. Assume that $h_b = h_{b_o} = 70$ m and $h_m = h_{m_o} = 1.5$ m unless otherwise specified.



- a) (2 marks:) Convert the path loss model to dBm units.
- b) (2 marks:) If the receiver sensitivity is -115 dBm, and the transmit and receive antenna gains are unity (0 dB), what is the radius of the original cells?
- c) (2 marks:) What is the radius of the split cells?
- d) (2 marks:) If the MS is to receive a signal level of -115 dBm on the corner of the split cell, by how much should $\mu_{\Omega_p}(d_o, h_{b_o}, h_{m_o})$ or, equivalently, the BS transmit power be reduced or increased?
- e) (2 marks:) Repeat part c) if the split cell uses an antenna height of only 30 m.

Fourier-transform pairs	Fourier Transform	$T \operatorname{sinc}(fT)$	$\frac{1}{2W} \operatorname{rect}\left(\frac{f}{2W}\right)$	$rac{1}{lpha+j2\pi f}$	$\frac{2a}{a^2+(2\pi f)^2}$	$\exp(-\pi f^{-})$ T $\operatorname{sinc}^2(fT)$	1	$\delta(f) = \exp(-j2\pi ft_0)$	$\delta(f-f_c) = \frac{1}{2} [\delta(f-f_c)+\delta(f_c+f_c)]$	$rac{1}{2j}\left[\delta(f-f_c)-\delta(f+f_c) ight]$	$\frac{1}{j\pi f}$	$-j \operatorname{sgn}(f)$.	$\frac{1}{2} \delta(f) + \frac{1}{j2\pi f}$	$rac{1}{T_0}\sum_{n=-\infty}^\infty\deltaigg(f-rac{n}{T_0}igg)$	
TABLE A6.3 Fourier	Time Function	$\operatorname{rect}\!\left(rac{t}{T} ight)$	\sqrt{t} sinc(2 Wt)	$\exp(-at)u(t), \qquad a > 0$	$\exp(-a t), a > 0$	$\left\{ \begin{aligned} \exp(-\pi t^{2}) \\ \left\{ 1 - \frac{ t }{T}, t < T \end{aligned} \right. \end{aligned}$	$\begin{cases} 0, & t \ge T\\ \delta(t) & \end{cases}$	$rac{1}{\delta(t-t_0)}$	$\exp(j2\pi f_c t)$ $\cos(2\pi f_c t)$	$\sin(2\pi f_c t)$	$\operatorname{sgn}(t)$	1 一 和	u(t)	$\sum_{i=-\infty}^{\infty} \delta(t-iT_0)$	Notes: $u(t) = unit step function$ $\delta(t) = delta function, or unit impulse rect(t) = rectangular function of unit duration centered on the origin sgn(t) = signum functionsinc(t) = sinc function$

TABLE A6.2 Summary of properties of the Fourier transform

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Property	Mathematical Description
1. Linearity	$ag_1(t) + bg_2(t) \rightleftharpoons aG_1(f) + bG_2(f)$ where a and b are constants
2. Time scaling	$g(at) \rightleftharpoons \frac{1}{ a } G\left(\frac{f}{a}\right)$ where a is a constant
3. Duality	If $g(t) \rightleftharpoons G(f)$, then $G(t) \rightleftharpoons g(-f)$
 Time shifting Frequency shifting 	$g(t - t_0) \rightleftharpoons G(f) \exp(-j2\pi f t_0)$ $\exp(j2\pi f_c t)g(t) \rightleftharpoons G(f - f_c)$
6. Area under g(t)	$\int_{-\infty}^{\infty} g(t) dt = G(0)$
7. Area under $G(f)$	$g(0) = \int_{-\infty}^{\infty} G(f) df$
8. Differentiation in the time domain	$\frac{d}{dt}g(t) \rightleftharpoons j2\pi fG(f)$
9. Integration in the time domain	$\int_{-\infty}^{t} g(\tau) \ d\tau \rightleftharpoons \frac{1}{j2\pi f} \ G(f) + \frac{G(0)}{2} \ \delta(f)$
10. Conjugate functions	If $g(t) \rightleftharpoons G(f)$, then $g^*(t) \rightleftharpoons G^*(-f)$
11. Multiplication in the time domain	$g_1(t)g_2(t) \rightleftharpoons \int_{-\infty}^{\infty} G_1(\lambda)G_2(f-\lambda) d\lambda$
12. Convolution in the time domain	$\int_{-\infty}^{\infty} g_1(\tau) g_2(t-\tau) \ d\tau \rightleftharpoons G_1(f) G_2(f)$

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Formulas

Pythagorean relations

 $1 + \cot^2 \alpha = \csc^2 \alpha$ $1 + \tan^2 \alpha = \sec^2 \alpha$, $\sin^2\alpha + \cos^2\alpha = 1,$

Angle-sum and angle-difference relations

 $\cos(\alpha + \beta)\cos(\alpha - \beta) = \cos^2 \alpha - \sin^2 \beta = \cos^2 \beta - \sin^2 \alpha$ $\sin(\alpha + \beta)\sin(\alpha - \beta) = \sin^2 \alpha - \sin^2 \beta = \cos^2 \beta - \cos^2 \alpha$ $\sin (\alpha + \beta) = \sin \alpha \cos \beta + \cos \alpha \sin \beta$ $\sin (\alpha - \beta) = \sin \alpha \cos \beta - \cos \alpha \sin \beta$ $\cos (\alpha + \beta) = \cos \alpha \cos \beta - \sin \alpha \sin \beta$ $\cos (\alpha - \beta) = \cos \alpha \cos \beta + \sin \alpha \sin \beta$ $\tan \left(\alpha + \beta \right) = \frac{\tan \alpha + \tan \beta}{1 - \tan \alpha \tan \beta}$ $1 + \tan \alpha \tan \beta$ $\cot(\alpha - \beta) = \frac{1}{\cot\beta - \cot\alpha}$ $\cot(\alpha + \beta) = \frac{\cos \beta}{\cot \beta + \cot \alpha}$ $\tan \alpha - \tan \beta$ U $\tan(\alpha - \beta)$

Double-angle relations

 $1 - \tan^2 \alpha$ $1 + \tan^2 \alpha$ $\cos 2\alpha = \cos^2 \alpha - \sin^2 \alpha = 2\cos^2 \alpha - 1 = 1 - 2\sin^2 \alpha = 0$ $\cot 2\alpha = \frac{\cot^2 \alpha}{2} - 1$ $2 \cot \alpha$ $1 + \tan^2 \alpha$ $2 \tan \alpha$ $\sin 2\alpha = 2 \sin \alpha \cos \alpha = 1 - \tan^2 \alpha$ $2 \tan \alpha$ $\tan 2\alpha = -$

Multiple-angle relations

 $\sin 6\alpha = 32^{\circ}\cos^{5}\alpha \sin \alpha - 32\cos^{3}\alpha \sin \alpha + 6\cos \alpha \sin \alpha$ $\cos n\alpha = 2\cos(n-1)\alpha\cos\alpha - \cos(n-2)\alpha$ $\cos 6\alpha = 32 \cos^6 \alpha - 48 \cos^4 \alpha + 18 \cos^2 \alpha \sin n\alpha = 2\sin(n-1)\alpha\cos\alpha - \sin(n-2)\alpha$ $\cos 5\alpha = 16\cos^5\alpha - 20\cos^3\alpha + 5\cos\alpha$ $\sin 5\alpha = 5\sin \alpha - 20\sin^3 \alpha + 16\sin^5 \alpha$ $\sin 4\alpha = 4\sin\alpha\cos\alpha - 8\sin^3\alpha\cos\alpha$ $1 - \tan(n - 1) \alpha \tan \alpha$ $\cos 4\alpha = 8\cos^4 \alpha - 8\cos^2 \alpha + 1$ $\tan(n-1)\alpha + \tan \alpha$ $1 - 6 \tan^2 \alpha + \tan^4 \alpha$ $4 \tan \alpha - 4 \tan^3 \alpha$ $\cos 3\alpha = 4\cos^3 \alpha - 3\cos \alpha$ $\sin 3\alpha = 3\sin \alpha - 4\sin^3 \alpha$ $3 \tan \alpha - \tan^3 \alpha$ $1 - 3 \tan^2 \alpha$ $\tan 3\alpha =$ $\tan n\alpha =$ $\tan 4\alpha =$

Formulas for Use in Trigonometry

 $= \cot \frac{1}{2}(\beta - \alpha)$ $\cot \alpha - \cot \beta = \frac{\sin(\beta - \alpha)}{\cdot}$ $\cos \alpha \cos \beta$ $\sin(\alpha - \beta)$ $\tan \alpha - \tan \beta =$ $\cos \alpha - \cos \beta$ $\sin \alpha + \sin \beta$ $\cos \alpha - \cos \beta = -2 \sin \frac{1}{2} (\alpha + \beta) \sin \frac{1}{2} (\alpha - \beta)$ $\cos \alpha + \cos \beta = 2\cos \frac{1}{2}(\alpha + \beta)\cos \frac{1}{2}(\alpha - \beta)$ $\sin \alpha - \sin \beta = 2\cos \frac{1}{2}(\alpha + \beta)\sin \frac{1}{2}(\alpha - \beta)$ $\sin \alpha + \sin \beta = 2 \sin \frac{1}{2} (\alpha + \beta) \cos \frac{1}{2} (\alpha - \beta)$ $\sin \alpha \sin \beta = \frac{1}{2} \cos(\alpha - \beta) - \frac{1}{2} \cos(\alpha + \beta)$ $\cos \alpha \cos \beta = \frac{1}{2} \cos(\alpha - \beta) + \frac{1}{2} \cos(\alpha + \beta)$ $\sin \alpha \cos \beta = \frac{1}{2} \sin(\alpha + \beta) + \frac{1}{2} \sin(\alpha - \beta)$ $\cos \alpha \sin \beta = \frac{1}{2} \sin(\alpha + \beta) - \frac{1}{2} \sin(\alpha - \beta)$ Function-sum and function-difference relations $\tan \alpha + \tan \beta = \frac{\sin(\alpha + \beta)}{\cos \alpha \cos \beta},$ $\tan \frac{1}{2}(\alpha - \beta)$ $\tan \frac{1}{2}(\alpha + \beta)$ $\sin(\alpha + \beta)$ $\cot \alpha + \cot \beta = \frac{1}{\sin \alpha \sin \beta}$ Function-product relations H $\sin \alpha + \sin \beta$ $\sin \alpha - \sin \beta$

Half-angle relations

 $\frac{1}{\cos\alpha + \cos\beta} = \tan\frac{1}{2}(\alpha - \beta)$

 $\sin \alpha - \sin \beta$

 $\frac{\sin \alpha + \sin \beta}{\cos \alpha + \cos \beta} = \tan \frac{1}{2}(\alpha + \beta),$

$\pm \sqrt{\frac{1+\cos\alpha}{2}}$	sin a	$1 + \cos \alpha$	sin a	$1 - \cos \alpha$	3
$\cos \frac{\alpha}{2} =$	$1 - \cos \alpha$	sin a	$1 + \cos \alpha$	sin a	
$\sqrt{\frac{1-\cos\alpha}{2}},$	$\sqrt{1-\cos\alpha}$	$/1 + \cos \alpha$	$\sqrt{1 + \cos \alpha}$	$/1 - \cos \alpha$	
- + =	+	1	+		1
$\sin \frac{\alpha}{2}$	$\tan \frac{\alpha}{\alpha}$	5	cot a		

Power relations

 $\cos^3 \alpha = \frac{1}{4}(3\cos \alpha + \cos 3\alpha)$ $\sin^3 \alpha = \frac{1}{4} (3 \sin \alpha - \sin 3\alpha)$ $1 + \cos 2\alpha$ $-\cos 2\alpha$ $\cot^2 \alpha = \sin^4 \alpha = \frac{1}{8}(3 - 4\cos 2\alpha + \cos 4\alpha)$ $\cos^4 \alpha = \frac{1}{8}(3 + 4\cos 2\alpha + \cos 4\alpha)$ $\cos^2 \alpha = \frac{1}{2}(1 + \cos 2\alpha),$ $\sin^2 \alpha = \frac{1}{2}(1 - \cos 2\alpha),$ $\frac{1-\cos 2\alpha}{1+\cos 2\alpha},$ $\tan^2 \alpha = \frac{1}{2}$

Exponential relations (α in radians), Euler's equation

 $\cos \alpha = \frac{e^{l\alpha}}{l\alpha} + e^{-l\alpha}$ $e^{i\alpha} = \cos \alpha + i \sin \alpha, \quad i = \sqrt{-1}$ $e^{i\alpha} - e^{-i\alpha}$ $\sin \alpha =$ $\tan \alpha =$

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55567 39505 64 73801 32307 115 87286 55756 39323 65 74215 32307 115 8708 57536 39323 65 74215 3105 116 8708 57535 39104 70 75804 31125 120 88906 57535 39104 71 75115 31006 121 8806 57535 39104 71 76115 31006 121 8806 58317 39034 71 76115 31016 121 8806 58971 38904 71 7613 30134 127 8906 58971 38966 76 7733 30114 125 8907 58971 38667 75 7733 30134 127 8997 59913 3816 76 7733 30134 127 8997 50105 38213 38134 7733 30134 <td< td=""><td>12</td><td>55172</td><td>39550</td><td>63</td><td>73565</td><td>32713</td><td>1.13</td><td>87076</td><td>.2106</td></td<>	12	55172	39550	63	73565	32713	1.13	87076	.2106
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56356 39387 66 7457 32086 1.16 87638 57735 39233 67 74577 31874 1.17 87900 57535 39114 77 7430 31143 1.19 87900 57535 39104 71 75135 31056 1.20 88493 57335 39104 71 76115 31066 1.21 88298 58935 38933 73 76115 31036 1.23 89053 59035 38835 73 77335 30134 1.23 89053 59045 38566 75 77335 30134 1.23 89455 59035 38351 73 77335 30134 1.23 89455 50043 38136 77 77935 29559 1.20 89435 50173 38166 77 77935 29559 1.27 89455 50179 501317 28639 1.27 <	15	.55982	.39448	.65	.74215	.32297	1.15	.87493	.2059
56750 59322 67 74857 51874 117 81900 57142 39213 68 75175 31874 117 81900 57142 39213 68 75175 31163 112 81900 57305 39104 71 76115 31006 1.21 8846 58906 3853 77 75730 30553 1.22 8845 58905 38536 77 77303 30114 1.25 89055 58906 77 77303 30139 1.23 89055 58836 77 77303 30134 1.27 89055 59831 76 7733 30114 1.25 89455 61005 38361 78 7733 30114 1.25 89455 6109 3133 80 78814 29365 1.26 89455 6100 3133 80 78814 23905 1.27 89955	16	SKASK	19197	99	74537	32086	1.16	87698	2035
57142 39233 56 75175 31659 11.8 88100 57335 39104 72 75413 31006 1.21 8843 57335 39104 71 76115 31006 1.21 8846 58317 39034 71 76115 31006 1.21 8846 58931 38963 73 77337 30134 1.27 8847 58931 38762 73 77337 30114 1.27 8845 59933 38361 75 77337 30114 1.27 8845 59933 38361 75 77337 30114 1.27 8945 61026 38361 76 7733 30134 1.27 8945 61026 38361 78 7733 29339 1.28 89417 61026 38361 78 7833 2823 1.29 8945 61026 38361 78 77738 28906	17	02095	CCF05	23	74857	31874	1.17	87900	2012
57335 90181 66 75400 31443 1119 88298 57926 39104 70 75804 31125 12.0 88493 58317 39904 71 76115 31005 12.2 88866 58935 77 76713 30136 12.2 88865 59935 3853 77 76730 30563 12.2 88465 59045 38766 77 7737 30134 12.5 89045 59045 38566 77 7737 30134 12.5 89445 59166 3851 76 7737 30134 12.6 89417 50191 38766 77 77935 29959 12.7 89455 51026 3813 76 7813 28963 12.9 99435 51076 38164 27930 29311 12.9 99435 51079 3823 7793 28639 12.9 99446	10	CALCS	20053	89	75175	31659	1.18	.88100	1988
57926 59104 70 75804 51225 1.20 88493 58917 39034 71 76115 31006 1.21 88685 58906 38833 73 76470 30365 1.22 88687 58905 38833 73 76730 30365 1.21 88665 59871 38667 73 77337 30114 1.25 89951 59871 38466 77 77935 29431 1.26 89951 61026 38361 76 7783 29559 1.27 89951 61026 38366 77 77935 29659 1.27 89951 61026 38366 77 77935 28659 1.29 99047 61026 38361 78 78230 29431 1.28 89951 61026 38303 31732 28731 1.31 90020 90147 61301 37534 29339 28659	10	55572	30181	69	75490	31443	1.19	.88298	.1965
58317 39024 71 76115 31006 1.21 88686 58706 38940 72 76415 30785 1.22 88671 59705 38946 73 76514 30785 1.23 88675 59871 38667 75 77337 30114 1.23 88675 59871 3866 76 77637 30039 1.24 89965 60257 38346 76 77637 30014 1.26 89957 60135 38346 76 77337 30114 1.26 89973 61026 38346 76 77832 29431 1.27 89973 611401 38239 27837 29309 1.29 89973 611402 382307 37534 282 79339 28234 1.39 90490 62307 37534 282 79339 28234 1.39 90430 63307 37553 287 27798	20	57926	39104	.70	.75804	.31225	1.20	.88493	.1941
58705 38940 72 76424 30785 1122 88877 59945 38767 73 77337 30114 1124 89647 59871 38762 73 77337 30114 1124 89647 59845 75 77337 30114 1126 89647 59871 38765 75 77337 30114 1126 89435 60257 38366 76 77637 30339 1128 89437 61026 38361 78 78230 29431 127 8973 61103 38351 78 7833 2859 123 99036 61103 38251 78 7834 28909 1.29 90430 61205 37534 28 7933 2853 79673 29058 61307 37534 287 1732 29034 1.37 90430 61307 37533 28 8031 27798 1.37 </td <td>16</td> <td>58317</td> <td>1000F</td> <td>11</td> <td>76115</td> <td>31006</td> <td>1.21</td> <td>88686</td> <td>1918</td>	16	58317	1000F	11	76115	31006	1.21	88686	1918
5905 3855 77 76730 30563 1123 80665 59441 38672 74 7737 3014 125 89617 59441 38672 74 7737 3014 125 89617 50455 38466 77 7737 3014 125 89617 60757 38566 77 7757 7337 3014 125 89617 61026 38561 76 77637 29887 126 89617 61190 38251 78 78524 29909 1129 89796 61307 38163 77 71935 29659 1137 90147 65307 3754 64 79955 28096 133 90490 65307 3754 64 79955 28064 133 90490 65307 3764 64 79735 28069 137 90490 65307 3764 64 79736 <t< td=""><td></td><td>58706</td><td>38940</td><td>22</td><td>76424</td><td>30785</td><td>1.22</td><td>88877</td><td>1895</td></t<>		58706	38940	22	76424	30785	1.22	88877	1895
59484 38762 74 77105 30339 1.24 89251 59771 38667 75 77337 30114 1.25 89753 60635 38466 77 77935 29659 1.27 89795 61026 38361 78 78230 29431 1.26 89795 61026 38361 78 78230 29431 1.27 89795 61026 38361 78 78230 29431 1.29 89793 611791 38133 28737 1.31 900400 50330 5173 90147 61791 37534 287 7955 28737 1.31 90490 63307 37534 287 7955 28034 1.32 90468 63307 37534 287 79764 1.32 90468 63307 37534 287 27764 1.36 90466 64053 37764 28793 27796 1.36	23	59095	38853	13	76730	.30563	1.23	89065	.1872
59871 38667 75 77337 30114 1.25 89435 60257 38568 76 77637 29887 1.26 89617 610265 38366 77 77333 29887 1.26 89617 610265 38366 77 77333 29887 1.26 89617 610265 38351 79 78330 29431 1.28 89973 611901 38131 79 78814 29000 1.28 89973 611791 38139 87 78617 231 1.37 90149 61230 37534 87 79355 28704 1.37 90838 63307 37534 86 80511 27798 1.37 90838 65173 37554 86 80511 27562 1.36 91496 6405 37535 87 80351 27738 1.37 90838 65773 36973 28034 1.37	24	59484	.38762	.74	.77035	.30339	1.24	.89251	.1849
60757 38568 76 77637 2987 1.26 89617 610643 38361 77 77935 29659 1.27 89765 61170 38361 77 77935 29659 1.27 89765 61171 38136 77 778524 29200 1.29 90473 61171 38033 8114 28959 1.31 90490 62172 38033 81 78524 29200 1.29 90320 63177 37554 87 79332 28734 1.31 90490 63307 37554 87 79335 28250 1.37 90486 63307 37554 87 80751 27708 1.37 90486 64031 37754 87 77738 1.37 91466 64031 37755 8 81037 27066 1.37 91466 64031 37755 8 81037 27738 1.47 <t< td=""><td>.25</td><td>.59871</td><td>.38667</td><td>.75</td><td>.77337</td><td>.30114</td><td>1.25</td><td>.89435</td><td>.1826</td></t<>	.25	.59871	.38667	.75	.77337	.30114	1.25	.89435	.1826
60645 38466 77 77935 29559 1.27 89796 611036 38331 78 78334 229200 1.29 80971 611791 38136 79 78524 229200 1.29 90147 611791 38139 80 7814 28969 1.30 90130 611791 38139 80 7814 28969 1.31 90490 62337 31780 33 79673 28209 1.33 90490 63307 37654 54 79955 28209 1.33 90496 64331 37780 33 79673 28269 1.37 90498 64331 37554 56 80234 27734 1.37 91466 64303 37715 58 8077 27086 1.37 9088 64333 37254 56 8057 27086 1.37 91466 64303 37115 88 81057 <	26	12009	38568	26	77637	.29887	1.26	89617	.1803
61026 38361 78 78230 29431 1/28 89973 61191 381351 78 78230 29431 1/28 89973 61191 381351 78 78544 28969 1/20 90130 62172 38023 81 79103 28737 1/31 90490 62172 38023 81 79103 28737 1/31 90490 62330 37534 87 79553 28873 1/31 90490 63307 37534 87 79555 28034 1/32 90480 63307 37534 87 79555 28034 1/37 90480 64038 377534 86 8051 27764 1/36 90936 64031 371155 88 81037 27764 1/36 91946 64033 36677 9211 27764 1/36 91924 65542 36577 92639 1/42 9124	27	60643	.38466	11.	.77935	.29659	1.27	36796	.1781
61409 38251 79 78534 22000 1.29 90147 61791 38139 80 78814 28960 1.30 90320 62172 38023 81 79813 28504 1.31 90490 65230 37780 82 79380 28504 1.32 90238 65307 37534 83 79673 28269 1.33 90838 65307 37524 85 80341 27938 23326 1.31 90498 65403 37524 86 80511 27562 1.36 91496 64033 37715 86 80511 27562 1.36 90234 64033 37725 87 80785 27734 1.37 91466 64033 37755 87 80785 27324 1.37 91466 64033 37755 87 81037 26609 1.47 92073 6576 36677 36873	28	.61026	.38361	.78	.78230	.29431	1.28	.89973	.1758
61791 38139 360 78814 28969 1.30 90320 62172 38023 81 79103 28737 1.31 90490 62357 37780 37 75613 28737 1.31 90490 63307 37564 54 79955 28209 1.33 90493 63363 37524 55 80234 27738 1.37 90498 64431 37754 56 80234 27738 1.37 90484 64431 37255 58 80234 27738 1.37 90483 64431 37753 28 8057 27086 1.37 90484 64431 37255 36877 90 811954 27734 1.40 91408 65410 37755 1.40 91734 91466 91466 65410 36577 30877 27086 1.40 9174 65410 36571 90 81189 2.5059	29	61409	.38251	62.	.78524	.29200	1.29	.90147	.1736
62172 38023 81 79103 287 731 1.31 90490 65252 377903 82 79533 28569 1.32 90634 65357 37780 82 79533 28559 1.33 90490 65367 3754 53 79535 28504 1.33 90684 65363 37524 55 80234 27798 1.37 90688 64303 37524 55 80734 27798 1.37 9088 64451 37254 56 80511 27562 1.36 9149 65173 36877 36871 28648 1.37 9148 65173 36877 36871 27364 1.40 9174 65173 36877 36871 27648 1.40 92073 65716 36576 92 81121 26129 1.47 92073 65716 36577 96 81394 25406 1.47 <t< td=""><td>.30</td><td>16119.</td><td>.38139</td><td>.80</td><td>.78814</td><td>.28969</td><td>1.30</td><td>.90320</td><td>.1713</td></t<>	.30	16119.	.38139	.80	.78814	.28969	1.30	.90320	.1713
65557 37903 82 79389 28504 1.32 90658 63307 37534 54 79955 28204 1.33 90958 63307 37534 54 79955 28034 1.34 90958 63307 37534 56 8031 27562 1.35 91149 64038 37135 56 80511 27562 1.36 91968 64031 37115 56 80511 27562 1.36 91149 64031 37115 56 80511 27562 1.36 91149 65173 36977 28788 1.37 20958 1.36 9124 65173 36977 28199 26059 1.40 9124 65716 36576 92 81121 26159 1.42 92367 65716 36533 92 82121 26139 1.42 92367 66716 36533 92 82131 25647	31	62172	.38023	18.	.79103	.28737	1.31	.90490	1691
65930 377580 53 79673 28234 1.33 90824 653307 37554 58 79673 28234 1.33 90824 65435 37524 57 805311 27562 1.35 9149 64451 37524 57 80511 27562 1.36 91466 64431 37255 57 80785 27738 1.37 91466 64431 37255 57 80785 27734 1.37 91466 654173 36973 90 81327 27086 1.37 91466 65716 35677 90 81327 27086 1.40 91924 65716 35671 90 81327 27669 1.41 92073 65705 35572 92 81321 25848 1.47 92376 65706 35572 92 8139 25464 1.46 92507 65703 36573 97 81893	.32	.62552	.37903	.82	.79389	.28504	1.32	.90658	.1665
63307 37554 56 79355 280234 21798 1.37 90988 64318 37351 56 80234 27798 1.35 91495 64431 37253 56 80351 27504 1.37 91495 64431 37255 87 80785 27324 1.37 91646 64803 37115 88 81037 27646 1.37 91466 64803 37115 88 81037 27648 1.40 91924 65510 36577 30 81137 25649 1.40 91924 65510 36578 91 81859 25639 1.41 92073 66603 36571 97 81859 25647 1.46 92207 67003 36573 97 82894 25405 1.47 9237 67724 3588 1.47 25164 1.46 92056 67035 36053 97 83947 <	33	.62930	.37780	.83	.79673	.28269	1.33	.90824	.1647
0.05063 J7124 00 00.244 2.1795 1.19 J1145 64058 37115 86 8051 2.7756 1.37 91406 64131 37125 87 8073 89 81057 2.7864 1.37 91406 645173 36877 87 81057 2.7086 1.37 91406 655173 36877 90 81194 2.77086 1.37 91406 65510 36677 90 81394 2.6609 1.41 92073 66276 92 82121 2.6613 1.42 92270 66276 35526 92 82312 25647 1.42 92073 667705 36639 2.5463 1.44 92073 65647 65703 95639 25465 1.46 92076 677065 36639 3.6713 99 83391 2.5406 1.46 92076 67714 35894 2.5406 1.46 92056	4	.63307	37654	-84	.79955	.28034	1.34	93606	162
64058 37391 86 80511 27362 1.36 91308 6403 37115 87 80511 27354 1.36 91406 64303 37115 87 8075 27324 1.37 91466 6431 37115 87 8075 27324 1.37 91466 65173 36973 89 81037 20848 1.39 91774 65510 36576 92 81327 26848 1.40 91924 66276 36571 93 81327 26609 1.41 92073 66376 36571 93 8239 25647 1.46 92056 66703 36517 93 25647 1.46 92056 1.6643 67003 36513 95 82894 25406 1.46 92056 1.6643 66793 35533 95 83846 2463 1.47 92071 1.6643 66793 35553 <t< td=""><td>CF.</td><td>63050.</td><td>47CIS.</td><td>C0.</td><td>40709</td><td>96117</td><td>CC-1</td><td>stife:</td><td></td></t<>	CF.	63050.	47CIS.	C0.	40709	96117	CC-1	stife:	
64431 37125 87 80785 27324 1.37 91466 1 64803 37115 88 81057 27324 1.37 91466 1 65133 36973 369 81137 20864 1.39 91774 1 65542 36877 90 81137 26848 1.39 91774 1 65510 36677 90 81137 26848 1.39 91774 1 65516 36771 90 81137 26848 1.40 91924 1 66640 36571 97 81381 25369 1.41 92073 1 66703 36571 97 82339 25547 1.44 9207 1 67703 36073 95 82339 25406 1.46 92367 1 67724 3588 1.47 92073 1.46 92067 1 6477 92507 1 66843 35533 9354	36	.64058	37391	.86	.80511	.27562	1.36	91308	.15822
64803 31113 56 3103 2.0064 2.002 2.024 3103	37	.64431	.37255	.87			1.37	.91466	.1560
551/3 562/3 562/3 593 5124 2009 5124 2009 5124 5121 5123 5121 5123 5121 5123 5121 5123 5124 5124 5124 5124 5124 5124 5126 5123 5123 5121 5125 5121 5613 5124 5124 5124 5124 5124 5124 5124 5126 <	38	.64803	S11/5.	200	/ 5018.	- 090/7	00.1	17016	CC1.
66716 56578 91 81391 25678 91 81301 2571 92 82311 26129 1.42 92037 92136 6676 6676 36571 93 82311 25129 1.42 92036 6703 36517 93 82311 25129 1.42 92036 1.41 92037 671365 671365 93 82389 25467 1.44 92364 1.44 92364 1.44 92364 1.44 92364 1.45 92364 1.46 92364 1.46 92364 1.46 92364 1.46 92364 1.46 92364 1.47 93052 1.47 93052 1.47 93052 1.47 93052 1.47 93052 1.46 93052 1.46 93052 1.46 93052 1.48 93052 1.48 93052 1.48 93052 1.48 93052 1.48 93052 1.48 93052 1.48 93052 1.48 93052 1.48 1.48 1.48<	65.	62173	21405.	60.	17518	26600	1 40	41116	071
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66640 36376 92 82131 26129 1.42 92220 1 66640 36371 93 8231 28128 1.43 92267 1 67365 36033 95 82539 25647 1.44 92507 1 67724 35889 96 83147 25406 1.45 92647 1 68439 35573 98 83546 2.4681 1.46 92786 1 68439 35553 98 83566 2.4481 1.48 93055 1 68439 35551 99 83391 2.4439 1.49 93055 1 68193 35531 99 83391 2.4439 1.49 93055 1 68196 35507 1.00 84134 2.4197 1.50 93319 1		.65910	36678	16.	.81859	.26369	141	.92073	.147
67060 56371 59 2358 24364 245647 1.44 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.14 92567 1.16 925647 1.14 92567 1.16 925647 1.14 92567 1.16 925647 1.16 925647 1.16 92647 1.16 92647 1.16 92647 1.16 92647 1.16 92647 1.16 92647 1.16 92786 1.16 93185 1.16 93185 1.16 93155 1.16 93155 1.16 93189 1.16 93189 1.16 93119 1.16 93119 1.16 93119 1.16 93119 1.16 93119 1.16 1.16 1.16 1.16 1.16 1.16 1.16 1.16 1.16 1.16 1.16 1.16		.66276	36520	76.	17178.	67197	76.1	07776	C61.
67003 J6213 .94 82639 .2546 1.44 9.2647 1. 67365 36053 .95 82894 .25406 1.45 92647 1. 68082 35733 .97 83388 .24923 1.47 92922 1. 68439 35553 .98 83646 .24681 1.48 93056 1. 68793 35531 .99 83846 .24197 1.50 93319 .1. 69146 35507 1.00 .84134 .24197 1.50 93319 .1.	5	060640	1/505.	5	18578.	09907	C6-1	P0524	C61.
07365 J9035 9.2 22894 2.2400 1.42 9.2041 1.46 92786 1. 67724 35889 9.6 83147 25164 1.46 92786 1. 68439 35573 9.8 8346 2.4481 1.48 93056 1. 68439 35531 9.9 833646 2.4439 1.48 93056 1. 68193 35531 9.9 83189 2.4139 1.49 93189 1. 69146 35207 1.00 84134 2.4197 1.50 93319 1.	44	50079.	51795	50	40079.	14007	1.45	10076	141
67724 35889 96 83147 25164 1.46 92786 1 68082 .3573 .97 83384 24923 1.47 92925 1 68439 .3553 .97 83386 2.4023 1.47 93955 1 68793 .35531 .99 833891 .24439 1.48 93056 1 69146 .35207 1.00 .84134 .24197 1.50 .93319 1	4	C06/0.	CCUOC.	6	\$6270.	00407	C+-1	14076	ACT.
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	47	.68082	.35723	.97	83398	.24923	1.47	.92922	.135
. 68793 . 35381/ <i>99</i> . 83891 . 24439 1.499189 .6914635207 1.00 . 8413424197 1.50933191	.48	.68439	.35553	38	.83646	.24681	1.48	.93056	.133
.69146 .35207 1.00 .84134 .24197 1.50 .93319 .1	49	.68793	.35381	66.	16828.	.24439	1.49	63186	161.
	50	.69146	.35207	1.00	.84134	.24197	1.50	93319	.129
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* Abridged from Biometrika Tables for Statisticians, vol. 1 (2nd edition), edited by E. S. Pearson and H. O. Hartley, Cambridge University Press, London, 1958, table 1, with permission of the Biometrika Trustees.

Appendix D 509

APPENDIX D

(x)

Φ(x)

Tabulation of the Standard Normal Distribution*

141	.00013	.00013	.00012	.00012	00011	.00011	.00011	.00010	01000'	60000	60000.	60000	80000	80000	.00007	00007	00000	.00006	00000	.00006	00000	.00005	.00005	00003	.00005	.00004	00004	.00004	.00004	,00004	*0000	.00003	.00003	00003	00003	.00003	20000.	.00002	.00002	.00002	20000	20000.	.00002	.00002	20000.	.00002
	79997	79997 7	T99997	769997	L6666.	16666.	86666	86666	86666.	86666	86666	86666	86666	86000	86666	80000	86666	66666	66666	66666	66666	66666	66666	66666	66666	66666	00000	66666	66666	66666	66666	66666	66666	66666'	66666	66666	66666	66666	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	4.00	4.01	4.02	4.03	4.04	4.05	4.06	4.07	4.08	4.09	4.10	4.11	4.12	414	4.15	4.16	4.17	4.18	4.19	4.20	4.21	4.22	4.23	4.25	4.26	4.28	4 20	4.30	4.31	4.32	4 24	4.35	4.36	4.37	4.38	4.39	4.40	4.41	4.42	4.43	4.44	6.40	4.46	4.47	4.48	4.49
	.00087	.00084	.00081	.00079	.00076	.00073	.00071	.00068	.00066	.00063	19000	.00059	1 5000	5000	.00051	.00049	.00047	.00046	.00044	.00042	.00041	00039	.00038	.00035	.00034	.00031	00030	.00029	.00028	.00027	97000	.00024	.00023	.00022	.00021	.00021	07000.	.00019	.00018	.00018	/1000	.00016	.00016	.00015	41000.	.00014
	<i>TT999.</i>	879978	99978	61666.	08666	18666.	18666.	.99982	68666.	.99983	99984	.99985	C8666	09666	78666.	18666	88666	88666	68666	68666	06666	06666	06666	16666	99992	99992	00000	66666	66666	66666	46666	99994	99994	56666.	56666	56666	66666	\$6666.	96666.	96666	96666	96666	96666	96666	16666	16666.
	3.50	3.51	3.52	3.53	3.54	3.55	3.56	3.57	3.58	3.59	3.00	3.61	20.5	2.02	3.65	3.66	3.67	3.68	3.69	3.70	3.71	3.72	3.73	3.75	3.76	3.78	3 70	3.80	3.81	3.82	3.83	3.85	3.86	3.87	3.88	3.89	3.90	3.91	3.92	3.93	3.94	3.95	3.96	3.97	3.98	3.99
	.00443	.00430	.00417	.00405	.00393	.00381	.00370	.00358	.00348	.00337	17500	00317	10500.	86700	.00279	.00271	.00262	.00254	.00246	.00238	.00231	.00224	.00216	.00210	.00196	.00184	00178	.00172	.00167	.00161	90100	.00146	.00141	.00136	.00132	.00127	.00123	.00119	.00115	.00111	10100.	.00104	00100.	16000	00004	06000
	.99865	99866.	.99874	.99878	.99882	.99886	99889.	.99893	76892.	00666.	c0666.	90666	01666	61666	91666	12666	99924	.99926	99929	.99931	.99934	.99936	.99938	.99940	.99944	99948	00000	.99952	539953	.99955	15666	09666	19666.	.99962	99964	.99965	00666.	89666	69666	02666.	12666	21666.	579973	99974	52665	.99976
	3.00	3.01	3.02	3.03	3.04	3.05	3.06	3.07	3.08	3.09	3.10	3.11	3.12	2.1.5	3.15	3.16	3.17	3.18	3.19	3.20	3.21	3.22	3.23	3.24	3.26	3.28	2 20	3.30	3.31	3.32	56.6	3.35	3.36	3.37	3.38	3.39	3.40	3.41	3.42	3.43	3.44	3.45	3.46	3.47	3.48	3.49

0.01506 0.01303 0.01468 0.01323 0.01324 0.01256 0.01256 0.01256 0.01190 0.01190 0.01190 0.01190 0.01190 0.01190 0.01190 0.01190 0.01190 0.01190 0.01190 0.00351 0.00578 0.0057 .01753 .01709 .01667 .01625 .01585 (x) 99379 99396 99413 99430 99446 99477 99547 99547 99547 99557 99557 99557 99557 99557 99557 99577 99577 99577 99577 99577 99774 99774 99774 99774 99774 99774 99774 99774 99774 99774 99774 99774 997755 99775 99775 99775 99775 99775 99775 99775 99775 99775 99775 99819 99825 99831 99836 99836 99846 99851 99856 99861 99865 (x) 22.55 25 * 0.05399 0.04780 0.04879 0.04879 0.04882 0.04882 0.04491 0.04491 0.04491 0.04491 0.04491 0.04491 0.044128 0.033746 0.033748 0.0337 (*) 977725 97778 97831 97882 97932 97932 98030 981077 981077 981079 981079 98250 98331 98331 98331 98539 98539 98578 98 99202 992245 99286 99286 99305 99324 99324 99361 99361 99086 99111 99134 99158 99180 (x) 22.00 22.20 20.00 20.00 20 × 1,2352 1,2558 1,2578 1,2578 1,2578 1,2578 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,114500 1,1145000 1,1145000 1,11450000000000000000000000000000 06438 06316 06195 06077 05959 05844 05618 05508 05508 05399 (x) 94062 94179 94208 94208 94208 94208 94208 94208 94208 94208 94208 94208 94208 94208 94208 95008 95008 95008 95008 95008 95008 95008 95008 95008 95008 95008 95008 93319 93448 93574 93699 93822 93822 93822 97193 97257 97320 97381 97381 97500 97558 97615 97670 97725 (x) 11.50 11.51 11.53 H

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Appendix D. 511