## Georgia Institute of Technology School of Electrical and Computer Engineering

### ECE6604 Personal & Mobile Communications

Final Exam

# Fall 2015

Thursday December 10, 8:00am - 10:50pm

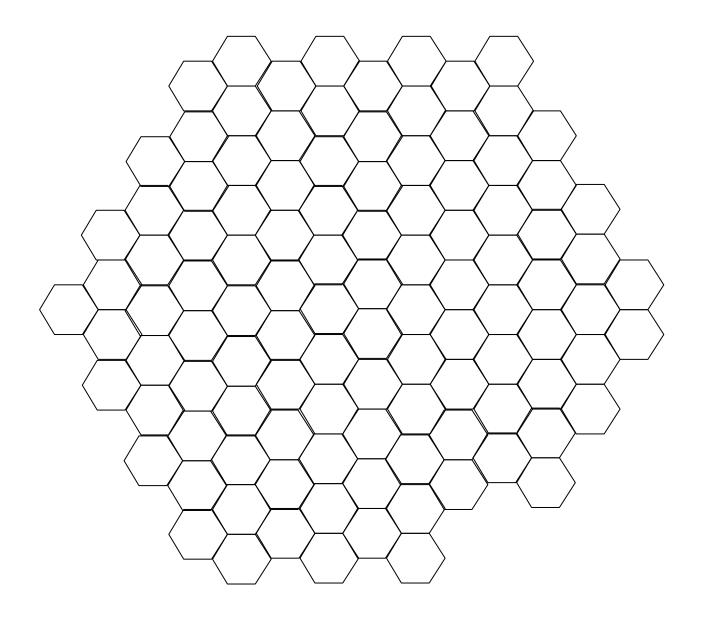
- Attempt all questions.
- All questions are of equal value.
- Open book, open notes, exam.
- Math tables are attached at the end of this exam. You do not need to turn them in.

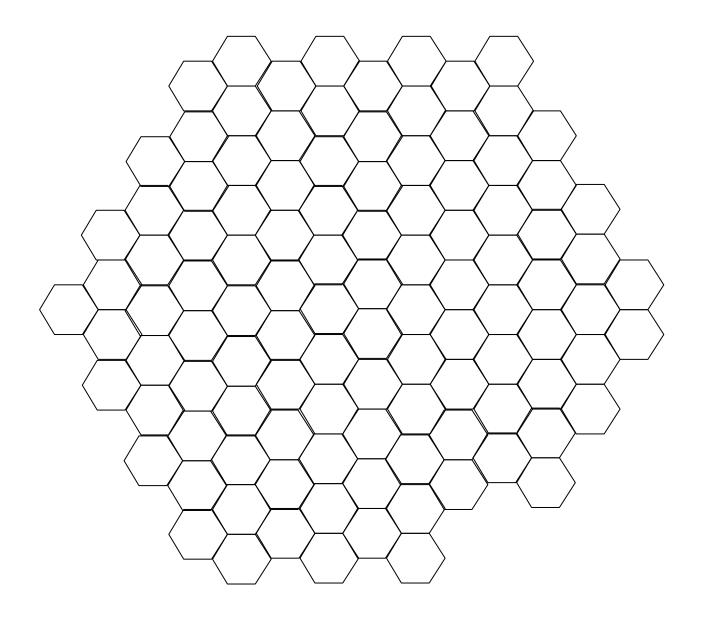
1) Consider the reverse link of a cellular system that uses a 7-cell reuse cluster with omnidirectional base station antennas. Ignore envelope fading and shadowing, and assume the simple path loss model

$$\mu_{\Omega_{p (dBm)}}(d) = \mu_{\Omega_{p (dBm)}}(d_o) - 10\beta \log_{10}(d/d_o) (dBm) ,$$

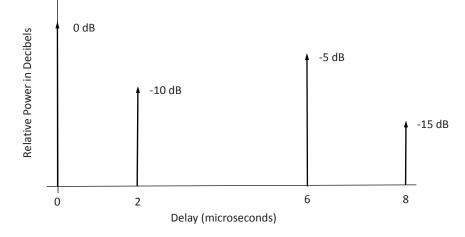
where  $\beta = 3.5$ . Also assume that all mobile stations are transmitting at the same power level.

- a) (3 marks:) Show graphically the worst case co-channel interference geometry for the reverse channel. Use the hex paper that is provided.
- b) (4 marks:) Calculate the worst case carrier-to-interference ratio,  $\Lambda$  in terms of the co-channel reuse factor D/R.
- c) (3 marks:) Repeat parts a) and b) if 120° cell sectoring is used. Use the second hex paper that is provided.





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?

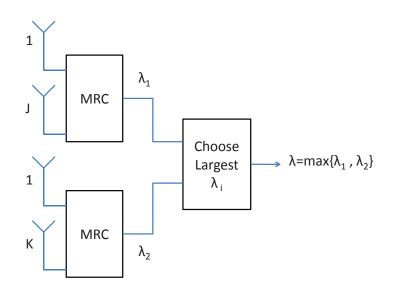
3) Consider the following time-invariant channel model

$$g(t,\tau) = \frac{1}{\sqrt{L}} \sum_{k=1}^{L} \delta(\tau - (k-1)\Delta_{\tau})$$

- a) (6 marks:) Find the magnitude response |T(f)| and phase response  $\angle T(f)$  of the channel, where T(f) is the time-invariant transfer function of the channel. Simplify your expressions as much as possible. Plot |T(f)| and  $\angle T(f)$ .
- **b)** (4 marks:) What is the mean delay  $\mu_{\tau}$  and rms delay spread  $\sigma_{\tau}$  of this channel? *The following may be useful:*

$$\begin{split} \sum_{k=1}^n k &= \frac{n(n+1)}{2} \\ \sum_{k=1}^n k^2 &= \frac{n(n+1)(2n+1)}{6} \\ \sum_{k=0}^n k^3 &= \frac{n^2(n+1)^2}{4} \end{split}$$

4) Consider a system that employs 2-branch selection diversity, where the two diversity branches consists of J and K antennas, respectively, with maximal ratio combining as shown below. Assume that all input MRC diversity branches are equal, i.e., γ<sub>ij</sub> = E[γ<sub>ij</sub>] = γ<sub>c</sub>, i = 1, 2, j = 1, ..., J, K.



- a) 5 marks: Derive an expression for the cumulative distribution function of the symbol energy-to-noise ratio,  $\lambda$ , at the output of the selective combiner in terms of  $\bar{\gamma}_c$ , J and K.
- b) 3 marks: Derive an expression for the probability density function of the symbol energy-to-noise ratio,  $\lambda$ , at the output of the selective combiner in terms of  $\bar{\gamma}_c$ , J and K.
- c) 2 marks: Write down an integral expression for the probability of bit error with BPSK modulation. You do not have to solve the integral!

- 5) A guard interval consisting of a cyclic prefix or cyclic suffix is used in OFDM systems to mitigate the effects of channel time dispersion.
  - a) (5 points) Assess the cost of the cyclic prefix in terms of
    - i) bandwidth and/or data rate.
    - ii) transmitter power.
  - b) (5 points) Suppose the a guard interval of 500 ns is used. The data rate with 64-QAM modulation is 54 Mb/s. The power penalty due to the guard interval is to be kept less than 1 dB. What is the required value of G (constrained to an integer) and minimum the possible OFDM block size (constrained to  $2^k$  for some k)?

#### FOURIER TRANSFORM PAIRS

1

PairNumber $x(t)$	X(f)
1. $\Pi\left(\frac{t}{\tau}\right)$	$ au \operatorname{sinc}( au f)$
2. $2W \operatorname{sinc}(2Wt)$	$\Pi\left(\frac{f}{2W}\right)$
3. $\Lambda\left(\frac{t}{\tau}\right)$	$ au \operatorname{sinc}^2( au f)$
4. $\exp(-\alpha t)u(t), \alpha > 0$	$\frac{1}{\alpha + j2\pi f}$
5. $t \exp(-\alpha t)u(t), \ \alpha > 0$	$\frac{1}{(\alpha + j2\pi f)^2}$
6. $\exp(-\alpha  t ), \alpha > 0$	$\frac{2\alpha}{\alpha^2+(2\pi f)^2}$
7. $\exp(-\alpha t^2)$	$\sqrt{\frac{\pi}{lpha}}\exp\!\left(-\frac{\pi^2 f^2}{lpha} ight)$
8. $\delta(t)$	1
9. 1	$\delta(f)$
10. $\delta(t - t_0)$	$\exp(-j2\pi ft_0)$
11. $\exp(j2\pi f_0 t)$	$\delta(f-f_0)$
12. $\cos 2\pi f_0 t$	$\frac{1}{2}\delta(f-f_0) + \frac{1}{2}\delta(f+f_0)$
13. $\sin 2\pi f_0 t$	$\frac{1}{2j} \delta(f - f_0)  -  \frac{1}{2j} \delta(f + f_0)$
14. $u(t)$	$(j2\pi f)^{-1} + \frac{1}{2}\delta(f)$
15. $\operatorname{sgn}(t)$	$(j\pi f)^{-1}$
16. $\frac{1}{\pi t}$	$-j \operatorname{sgn}(f)$
17. $\hat{x}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(\lambda)}{t - \lambda} d\lambda$	$-j \operatorname{sgn}(f) X(f)$
18. $\sum_{m=-\infty}^{\infty} \delta(t - mT_s)$	$f_s \sum_{m=-\infty}^{\infty} \delta(f - mf_s), f_s = T_s^{-1}$
Note: sinc $u = \frac{\sin \pi u}{\pi u}$	
$\Pi(u) = \begin{cases} 1,  u  \le 1/2\\ 0, \text{ otherwise} \end{cases}$	
$\Lambda(u) = \begin{cases} 1 -  u , &  u  \le 1\\ 0, \text{ otherwise} \end{cases}$	

	Name of Theorem	Signal	Transform
1.	Superposition $(a_1 \text{ and } a_2 \text{ arbitrary constants})$	$a_1 x_1(t) + a_2 x_2(t)$	$a_1X_1(f) + a_2X_2(f)$
2.	Time delay	$x(t-t_0)$	$X(f) \exp(-j 2\pi f t_0)$
a.	Scale change	x(at)	$ a ^{-1}X\left(rac{f}{a} ight)$
b.	Time reversal <sup>1</sup>	x(-t)	$X(-f) = X^*(f)$
ŀ.	Duality	X(t)	x(-f)
5a.	Frequency translation	$x(t) \exp\left(j2\pi f_0 t\right)$	$X(f-f_0)$
őb.	Modulation	$x(t)\cos 2\pi f_0 t$	$\frac{1}{2}X(f-f_0) + \frac{1}{2}X(f+f_0)$
5.	Differentiation	$\frac{d^n x(t)}{dt^n}$	$(j2\pi f)^n X(f)$
<i>.</i>	Integration	$\int_{-\infty}^{t} x(t') dt'$	$(j2\pi f)^{-1}X(f) + \frac{1}{2}X(0)\delta(f)$
3.	Convolution	$\int_{-\infty}^{\infty} x_1(t-t') x_2(t') dt'$	$X_1(f)X_2(f)$
		$= \int_{-\infty}^{\infty} x_1(t') x_2(t-t') dt'$	
€.	Multiplication	$x_1(t)x_2(t)$	$\int_{-\infty}^{\infty} X_1(f-f') X_2(f') df'$
			$= \int_{-\infty}^{\infty} X_1(f') X_2(f-f')  df'$

#### FOURIER TRANSFORM THEOREMS

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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 ( $\alpha$  in radians), Euler's equation

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

00         5000         9984         50         60146         35301         100         84134         2447           01         5000         9984         57         6647         34639         1101         86137         33331           05         51994         3986         57         70844         34534         1103         86131         33331           05         51994         57         71046         34134         1208         35033         33312         1104         86133         33333           06         53983         39963         67         71306         33112         1107         86033         21304           06         53983         39963         67         71303         33112         1107         8603         21305           11         54175         39033         66         71333         31133         1108         8214         2003           11         54175         39034         67         71333         31133         1117         8796         2104           11         5417         31133         31134         1117         8603         21043         1123           11         55963	00								
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51078         39816         5.2         00841         34671         10.2         84614           51934         39865         5.3         70044         34671         10.2         84614           51934         39875         5.3         70044         34671         10.2         84514           51934         39767         5.7         711266         34423         1.05         85543           51983         39767         5.8         71904         33711         1.07         85543           53188         39763         5.6         71304         33721         1.10         85543           53567         39383         5.6         71393         33521         1.10         85543           53567         39383         5.6         71337         33918         1.12         8564           55367         39383         5.6         71337         33918         1.12         8564           55367         39383         5.6         71337         33918         1.12         8564           55367         39383         7.7         77133         33056         1.12         85660           55376         39383         77133         31659 <td></td> <td>50399</td> <td>.39892</td> <td>.51</td> <td>.69497</td> <td>.35029</td> <td>1.01</td> <td>.84375</td> <td>.23955</td>		50399	.39892	.51	.69497	.35029	1.01	.84375	.23955
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53386         39733         59         77240         33321         1.10         86314           54776         39635         67         77277         33321         1.11         8650-           54776         39635         67         77327         33321         1.11         8650-           55357         399387         65         74355         33713         1.11         8650-           55356         399448         55         74315         32206         1.11         8650-           56356         39337         567         74337         32184         1.117         8650-           56356         39337         67         7437         32086         1.16         87938           57335         39104         70         75804         31225         1.19         88100           57335         39131         5734         31235         1.20         8845           57335         39134         5734         31235         1.20         8845           57926         38835         77         7733         30134         1.27         8945           57936         38667         76         7733         30334         1.27         <	08	53188	39767	.58	.71904	.33718	1.08	.85993	.2226
51983         39665         60         72575         33321         110         8643           54776         39608         63         73857         33121         1112         86680           54776         39508         63         73857         33121         1112         86680           5567         39598         64         73891         33206         114         87286           55982         39948         65         74913         32297         111         86680           56736         39323         66         75175         3104         1117         8100           57935         39104         70         75804         3153         1129         8100           57935         39104         70         75115         31006         121         8970           57935         39104         70         75137         30104         122         8971           58901         3866         77         7733         30136         124         8971           58913         3866         74         7733         3016         127         8991           58913         3866         74         7733         3016	00	53586	39733	59	.72240	.33521	1.09	.86214	.2202
54786         39654         61         72907         33121         1.11'         86590           55367         39539         62         73237         33121         1.11'         86564           55367         39539         62         73237         32391         1.12'         86564           55367         39539         65         74215         32391         1.14'         87286           55356         39323         66         74537         31864         1.16'         8100           57356         39104         71         76115         31006         1.12'         89065           57355         39104         71         76115         31006         1.21'         89065           57356         39934         71         76115         31006         1.21'         89065           58317         39014         71         76113         30114         1.25'         89917           58776         38361         77         7733         30134         1.23'         89917           58716         38714         7733         30134         1.23'         89917           58706         38361         76         77631         30134	10	.53983	39695	.60	.72575	.33322	1.10	.86433	.2178
5776         3908         52         7327         3218         112         5664           55172         39595         65         7457         3206         114         8706           55172         39505         65         7457         3206         114         8706           55162         39505         67         74801         32206         114         8706           55162         39505         67         74801         3143         117         8706           57142         39121         66         7457         3206         112         8709           57143         31659         114         117         8719         8706           57143         31659         112         8193         918         8700           57926         31914         1733         3014         117         8795           59035         3853         77         7713         3013         112         8965           59045         3856         77         7713         3014         125         8965           59045         3836         77         7713         3014         125         8965           59045		00275	10664	19	71007	33121	111.	86650-	2154
55172         39539         64         73565         32711         117         8706           55567         39303         65         74537         3206         1115         8706           55565         39448         65         74537         3206         1115         8793           56356         39323         66         74537         33086         1.16         8793           56356         39323         67         74837         31874         1.17         8190           57345         39104         77         76115         31006         1.21         8893           57356         39331         66         7433         30134         1.27         8993           58831         39024         77         7733         30134         1.27         8893           58931         3866         77         7733         30134         1.27         8995           58931         3866         77         7733         30144         1.27         8995           58931         3846         77         7733         30144         1.27         8995           61409         38133         76         7733         30144 <t< td=""><td>11</td><td>92776</td><td>10005</td><td>29</td><td>LECEL</td><td>32918</td><td>1.12</td><td>86864</td><td>2130</td></t<>	11	92776	10005	29	LECEL	32918	1.12	86864	2130
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         8890           57535         39104         71         76115         31006         121         8806           57535         39104         71         76115         31006         121         8906           58317         39034         71         76115         31016         121         8886           58971         38904         71         7613         30134         127         8906           58971         38904         77         77035         30134         127         8997           58971         38667         75         77337         30114         125         8997           58971         38864         76         7933         2014         127         8991           599149         61026         38361         78         7833	12	55172	39550	63	73565	32713	1.13	87076	.2106
55982         39448         65         74215         32297         1.15         87493           56756         39387         66         74537         31869         1.16         87900           57142         39323         67         74537         31869         1.16         87900           57142         39181         69         75490         31443         1.17         87900           57142         39104         71         77153         31056         1.27         8493           57926         39104         71         7613         30136         1.27         8893           58931         3865         77         76730         30563         1.27         88945           58931         3866         77         7733         30134         1.23         8965           59035         38536         76         7751         30356         1.26         8965           59045         3856         77         7793         3014         1.27         8945           59045         38261         77         7793         29659         1.26         8965           50191         3816         77         7793         29659	14	55567	39505	.64	13891	.32506	1.14	.87286	.2083
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         8846           59043         38366         75         77337         30114         1.27         8847           59043         38361         75         77337         30114         1.27         8943           60257         38366         76         77637         29391         1.29         8943           61026         38361         78         7733         20134         1.29         8943           61026         38361         78         7833         2833         29063         1.29         8943           61026         38331         7833         2833	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         7733         20141         12.9         89455           51307         31544         28059         1.20         29931         12.4         90490           6177         381347         28639         28244         1.31         2	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           61102         38339         278         78332         29393         29321         29903           61102         38330         37534         282         79333         28334         1.29         99490           61203         37534         282         78333         28334         1.39         90430           61307         37534         27334	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         38366         76         7733         29359         127         8973           61103         38351         78         78330         29431         127         8973           61103         38351         78         7833         2853         79637         29030           61205         38301         3753         2863         78637         2873         1137           61307         37534         3814         29069         1.39         90490           61307         37533         2874         1.37         90436           63307	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         3764         64         79955         28064         133         90490           65307         3764         64         79955         28064         134         90490           65307         3764         64         79756 <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         90147           61172         38033         817         78524         29200         1.29         90336           623307         37554         87         79332         28734         1.31         90490           63307         37554         87         79335         28269         1.37         90486           63307         37554         87         80751         27064         1.37         91466           64031         37754         87         77738         1.37         91466           64331         37755         88         81037         27038         1.37         91466           64331         37755         88         81037         27066	.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         37734         86         80571         27764         1/37         90988           64031         371155         88         81037         27764         1/36         91149           65173         36677         9211         27764         1/37         91966           65173         36677         9218         1/32         29124	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           64431         37255         87         80785         27794         1.37         90836           64033         37715         86         81037         276646         1.40         91466           64033         37755         87         80785         27734         1.37         91466           64033         37755         87         81037         27660         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         91748         91466         91466           65410         36577         90         811994         2.6059         1.40         91974           65542         36657         91         81899	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         79385         28504         1.34         9088           64363         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         275641         1.40         9174           65173         36877         36879         25698         1.41         92073           65716         36577         36         811397         25698         1.42         92267           65716         36577         36879         25131         25168         1.42	.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         9146           64431         37255         57         80785         27738         1.37         91466           64431         37255         57         80785         27734         1.37         91466           654173         36973         90         81327         27066         1.37         91466           65716         356773         36973         91         81837         27669         1.40         91924           65716         35671         90         81327         27669         1.41         92073           65716         35572         3531         2884         1.43         92367           67003         35573         97         81893         25467         1.44         92073           67003         35573         98         81437	.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         1.40         91924           65810         36877         90         811927         27649         1.40         91924           65545         36877         90         81194         26609         1.40         91924           65546         3677         97         81859         265369         1.41         92073           66501         36578         91         81859         25647         1.46         92207           67035         36573         97         83945         25465         1.46         92056           67035         36535         97         83945         25465         1.46         92056           67035         35553         97	33	.62930	.37780	.83	.79673	.28269	1.33	.90824	.1647
0.05063         J7124         00         00.244         2.1795         1.19         J1145           64058         37115         86         80511         27756         1.37         91406           64131         37125         87         8073         89         811057         27864         1.37         91466           645173         36877         86         81157         27666         1.37         91465           655173         36877         87         81057         276669         1.41         91474           65510         36577         90         811994         26609         1.41         92073           66276         92         82121         26139         1.42         92270           66276         35526         92         82131         25647         1.42         92207           667705         36639         25649         1.44         92073         92647           67003         36771         99         83147         25406         1.46         92067           67724         35639         25647         24631         1.46         93056         93056           68793         35353         99         83347 <td>4</td> <td>.63307</td> <td>37654</td> <td>-84</td> <td>.79955</td> <td>.28034</td> <td>1.34</td> <td>88606</td> <td>162</td>	4	.63307	37654	-84	.79955	.28034	1.34	88606	162
64058         37391         86         80511         27362         1.36         91308           6403         37115         87         80511         27354         1.36         91406           6403         37115         87         8075         27324         1.37         91406           64173         36973         87         81037         20848         1.37         91406           65542         36877         90         81327         26848         1.39         91774           65510         36576         92         81327         26609         1.40         91924           66276         36571         93         81327         26609         1.41         92073           66376         36571         93         8239         25647         1.46         92054           66703         36517         93         25647         1.46         92054           67003         35613         95         82894         25406         1.46         92054           677365         36033         95         82894         25406         1.46         92054           677365         35553         98         83646         2463         1	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           65342         36973         39         81327         26848         1.39         91774         1           65342         36877         90         81327         26848         1.39         91774         1           65310         36678         91         81837         26609         1.40         91924         1           65516         36571         90         81331         26848         1.41         92073         1           66640         36571         93         82381         25609         1.47         92073         1           67365         36371         93         82381         258647         1.46         92267         1           67724         35839         95         82339         25405         1.46         92367         1           67724         35839         93         23533         25405         1.46         92367         1           67734         35839         25405         1.4	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         5124         5124         5124         5124         5124         51264         <	38	.64803	S11/5.	200	/ 5018.	- 090/7	00.1	17016	121
66716         56578         91         81391         25678         91         81301         2571         92         82311         26129         1.42         92037         92136         92364         92364         92364         92364         92364         92364         92364         92364         92364         92364         1.43         92364         92364         1.44         92073         93         93         93         93         93         93         93         93         93         93         93         94         93         93         94         93         94         93         94         93         94         93         94	65.	62173	21405.	60.	17518	26600	1 40	41116	071
65910         36678         91         81859         26360         1.41         92073         1           66640         36571         36371         93         82131         28111         2613         92264         1           66640         36571         93         82331         2888         1.43         92264         1           67003         36571         93         82331         25888         1.45         92264         1           67736         36571         93         82331         25888         1.45         92567         1           67736         36373         95         82894         25406         1.45         92677         1           67724         35893         95         82893         25405         1.46         92786         1           68733         35573         97         83347         25466         1.46         92052         1           68439         35573         98         83646         24439         1.48         93055         1           68193         355207         1.00         84134         24197         1.50         93319         1           69146         355207         1	04	74000	17000	nc.	ACCTO.	60007	04.7	LTCTC.	
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	1.46	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.
68082 35723 97 83398 24923 1.47 92925 1 68439 35553 98 83646 2468 1.48 93056 1 68793 35581 99 83891 24439 1.49 93189 1 69146 35207 1.00 84134 24197 1.50 93319 1	.46	.67724	.35889	96	.83147	.25164	1.46	.92786	.137
	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	36	.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

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(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	55000	.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 00005	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 × 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 1,1145000 1,1145000 1,1145000000000000000000000 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 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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