

Calculation of π to 100,000 Decimals

By Daniel Shanks and John W. Wrench, Jr.

1. Introduction. The following comparison of the previous calculations of π performed on electronic computers shows the rapid increase in computational speeds which has taken place.

| Author | | Machine | Date | Precision | Time |
|--------------------|-----|---------|------|-----------|-----------|
| Reitwiesner | [1] | ENIAC | 1949 | 2037D | 70 hours |
| Nicholson & Jeenel | [2] | NORC | 1954 | 3089D | 13 min. |
| Felton | [3] | Pegasus | 1958 | 10000D | 33 hours |
| Genuys | [4] | IBM 704 | 1958 | 10000D | 100 min. |
| Unpublished | [5] | IBM 704 | 1959 | 16167D | 4.3 hours |

All these computations, except Felton's, used Machin's formula:

$$(1) \quad \pi = 16 \tan^{-1} \frac{1}{5} - 4 \tan^{-1} \frac{1}{239}.$$

Other things being equal, that is, assuming the use of the same machine and the same program, an increase in precision by a factor f requires f times as much memory, and f^2 times as much machine time. For example, a hypothetical computation of π to 100,000D using Genuys' program would require 167 hours on an IBM 704 system and more than 38,000 words of core memory. However, since the latter is not available, the program would require modification, and this would extend the running time. Further, since the probability of a machine error would be more than 100 times that during Genuys' computation, prudence would require still other program modifications, and, therefore, still more machine time.

2. A New Program. We discuss here a computation of π to more than 100,000D, which required 8 hours 43 minutes on an IBM 7090 system. This increase in speed by a factor of about 20 is largely due to the increased speed of the 7090 (it is about 7 times as fast as a 704), but substantial gains were also obtained by programming changes.

The formula we used, namely,

$$(2) \quad \pi = 24 \tan^{-1} \frac{1}{8} + 8 \tan^{-1} \frac{1}{57} + 4 \tan^{-1} \frac{1}{239},$$

is due to Störmer [6], and has not been previously used in high-precision computation. The computation time breaks down as follows:

$8 \tan^{-1} \frac{1}{57}$: 3 hours 7 minutes

$4 \tan^{-1} \frac{1}{239}$: 2 hours 20 minutes

$24 \tan^{-1} \frac{1}{8}$: 2 hours 34 minutes

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Conversion (binary-to-decimal): 42 minutes.

To obtain these favorable times, two devices were used.

a) Instead of evaluating the Taylor series

$$(3) \quad A \tan^{-1} \frac{1}{m} = \sum_{k=0}^{\infty} \frac{(-1)^k A m}{(2k+1)m^{2(k+1)}}$$

term by term, one may compute two terms at a time by using

$$(4) \quad A \tan^{-1} \frac{1}{m} = \sum_{k=0}^{\infty} \frac{Am[(4k+3)m^2 - (4k+1)]}{(16k^2 + 16k + 3)m^{4(k+1)}}.$$

This substitutes 2 (multi-precision) divisions, 1 multiplication, and 1 addition for 4 divisions, 1 subtraction, and 1 addition, and this eliminates 27% of the computation time. Further improvement in this direction, i.e., three terms at a time, is not possible here, since the divisors in (4), m^4 and $(16k^2 + 16k + 3)$, already tend to fill a 7090 word, whose maximum numerical size is $2^{35} - 1$.

b) Since the 7090 is a binary machine, the (multi-precision) division by m^4 and the multiplication by $[(4k+3)m^2 - (4k+1)]$ may be replaced by a simple shifting operation for the case $m = 8$ in $24 \tan^{-1} \frac{1}{8}$. Had this not been done the 2 hours 34 minutes listed above would be, instead, 6 hours 7 minutes with the double-term formula, (4), or 8 hours 21 minutes with (3).

The program using (4) requires three blocks of storage, one for the current $Am/m^{4(k+1)}$, one for the current term, and one for the partial sum. Since a 7090 word is equivalent to 10.536 decimal digits, the working storage for an N -place π is $3N/10.536$. Therefore, a core memory of 32,768 easily suffices for a computation to more than 100,000D.

3. The Check. Inasmuch as such a computation requires *billions* of (arithmetical) operations, it is clear that a check is necessary. This was obtained with Gauss's formula [7]:

$$(5) \quad \pi = 48 \tan^{-1} \frac{1}{18} + 32 \tan^{-1} \frac{1}{57} - 20 \tan^{-1} \frac{1}{239}.$$

During the computation, using (2), the numbers

$$A = 8 \tan^{-1} \frac{1}{57}$$

and

$$B = 8 \tan^{-1} \frac{1}{57} + 4 \tan^{-1} \frac{1}{239}$$

were written on tape. At the start of the check A and B were read into memory and $9A - 5B = 32 \tan^{-1} \frac{1}{57} - 20 \tan^{-1} \frac{1}{239}$ was computed (in 1 second). To this difference was added the new number $48 \tan^{-1} \frac{1}{18}$, which was computed by (4) in 4 hours 22 minutes. The check, therefore, takes less time than the original run (8 hours 1 minute), and is perfectly valid, since an error in any of the four arc-tangents will lead to a discrepancy between the results of (2) and (5).

4. The Result. The run and the check were both made on July 29, 1961, and such a discrepancy did in fact occur. The two values of π , in binary form, were compared by the machine in $\frac{1}{6}$ second, and were found to agree to only 234,848 bits. This is equivalent to 70,695 decimal places. Subsequently the error was isolated. It

was found to have occurred in the computation of $24 \tan^{-1} \frac{1}{8}$. The second value of π , computed using (5), was therefore correct throughout. When $24 \tan^{-1} \frac{1}{8}$ was recomputed, the two values of π agreed up to the last word. This comprised 333,075 bits, or 100,265 decimal places. The first 100,000 of these are given here.

The computation was of such a character that it was known *a priori* that the term involving $\tan^{-1} \frac{1}{239}$ contains most of the round-off and truncation error, and consequently that we have the inequalities:

$$\pi \text{ computed by (2)} < \pi < \pi \text{ computed by (5)}.$$

Thus the check and the computation give upper and lower bounds respectively, and, to the extent that they agree, π is determined absolutely.

Care has been taken in the output routines—in writing and printing—and, since the reproduction here is photographic, we believe that this value is entirely free from error.

5. A Million Decimals? Can π be computed to 1,000,000 decimals with the computers of today? From the remarks in the first section we see that the program which we have described would require times of the order of *months*. But since the memory of a 7090 is too small, by a factor of ten, a modified program, which writes and reads partial results, would take longer still. One would really want a computer 100 times as fast, 100 times as reliable, and with a memory 10 times as large. No such machine now exists.

There are, of course, many other formulas similar to (1), (2), and (5), and other programming devices are also possible, but it seems unlikely that any such modification can lead to more than a rather small improvement.

Are there *entirely different* procedures? This is, of course, possible. We cite the following: compute $1/\pi$ and then take its reciprocal. This sounds fantastic, but, in fact, it can be faster than the use of equation (2). One can compute $1/\pi$ by Ramanujan's formula [8]:

$$(6) \quad \frac{1}{\pi} = \frac{1}{4} \left(\frac{1123}{882} - \frac{22583}{882^3} \frac{1}{2} \cdot \frac{1 \cdot 3}{4^2} + \frac{44043}{882^5} \frac{1 \cdot 3}{2 \cdot 4} \cdot \frac{1 \cdot 3 \cdot 5 \cdot 7}{4^2 \cdot 8^2} - \dots \right).$$

The first factors here are given by $(-1)^k (1123 + 21460k)$. A binary value of $1/\pi$ equivalent to 100,000D, can be computed on a 7090 using equation (6) in 6 hours instead of the 8 hours required for the application of equation (2).* To reciprocate this value of $1/\pi$ would take about 1 hour. Thus, we can reduce the time required by (2) by an hour. But unfortunately we lose our overlapping check, and, in any case, this small gain is quite inadequate for the present question.

One could hope for a theoretical approach to this question of optimization—a theory of the “*depth*” of numbers—but no such theory now exists. One can guess that e is not as “deep” as π ,† but try to prove it!

Such a theory would, of course, take years to develop. In the meantime—say, in 5 to 7 years—such a computer as we suggested above (100 times as fast, 100 times as reliable, and with 10 times the memory) will, no doubt, become a reality. At that time a computation of π to 1,000,000D will not be difficult.

* We have computed $1/\pi$ by (6) to over 5000D in less than a minute.

† We have computed e on a 7090 to 100,265D by the obvious program. This takes 2.5 hours instead of the 8-hour run for π by (2).

6. Acknowledgement. We wish to thank the IBM Corporation for its generosity in allowing us to use, free of charge, the 7090 in the IBM Data Processing Center, New York, for the computation described above.

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2. S. C. NICHOLSON & J. JEENEL, "Some comments on a NORC computation of π ," *MTAC*, v. 9, 1955, p. 162-164.
3. G. E. FELTON, "Electronic computers and mathematicians," *Abbreviated Proceedings of the Oxford Mathematical Conference for Schooleteachers and Industrialists at Trinity College, Oxford, April 8-18, 1957*, p. 12-17, footnote p. 12-53. This published result is correct to only 7480D, as was established by Felton in a second calculation, using formula (5), completed in 1958 but apparently unpublished. For a detailed account of calculations of π see J. W. WRENCH, JR., "The evolution of extended decimal approximations to π ," *The Mathematics Teacher*, v. 53, 1960, p. 644-650.
4. F. GENUYS, "Dix mille décimales de π ," *Chiffres*, v. 1, 1958, p. 17-22.
5. This unpublished value of π to 16167D was computed on an IBM 704 system at the Commissariat à l'Energie Atomique in Paris, by means of the program of Genuys.
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Note added in proof, December 1, 1961. J. M. GERARD of IBM United Kingdom Limited, who was then unaware of the computation described above, computed π to 20,000 D on the 7090 in the London Data Centre on July 31, 1961. His program used Machin's formula, (1), and required 39 minutes running time. His result agrees with ours to that number of decimals.

PI = 3.+

| | | | | | | | | | |
|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1415926535 | 89793223846 | 2643383219 | 5028841971 | 6939937510 | 5820971944 | 5923078164 | 6826620899 | 8620834825 | 3421170679 |
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| 6222247715 | 8915049530 | 9844489333 | 0963408780 | 7693259939 | 7805419341 | 4473774418 | 4263129860 | 8099888687 | 4132604721 |

CALCULATION OF π TO 100,000 DECIMALS

81

| FROM | 5001D | T0 | 10000D |
|-------------|-------------|-------------|-------------|
| 5695162396 | 586457302 | 6315981931 | 951673381 |
| 4037014163 | 1406589794 | 0924532789 | 6907067779 |
| 5578297352 | 334604281 | 5126272037 | 3431165319 |
| 3162498341 | 9318146809 | 2777110386 | 387733177 |
| 3166636528 | 6193266863 | 360673567 | 630354776 |
| 9456127531 | 8134078320 | 3362542327 | 8394497538 |
| 0408591337 | 4641442822 | 6768346594 | 7047458784 |
| 8350493163 | 128402512 | 192651798 | 0694113528 |
| 956258586 | 550552690 | 4965209858 | 033850224 |
| 4803040829 | 0058760758 | 2510474709 | 1643961362 |
| 2901618766 | 7952406163 | 425257719 | 5429164991 |
| 2784768872 | 5135711136 | 9410911939 | 32521910760 |
| 196012228 | 599371623 | 3017114448 | 646300890 |
| 2283345085 | 0486082503 | 9302133219 | 7155118306 |
| 4611996653 | 8581538421 | 5685125340 | 2830871123 |
| 2183561622 | 0134967151 | 8811980497 | 3407239610 |
| 956730292 | 1913933918 | 5680344903 | 9820595510 |
| 2711172364 | 3135439478 | 2218185286 | 2408510066 |
| 0516553190 | 6866273333 | 9958511562 | 5784322988 |
| 4460477464 | 9159950549 | 5738712917 | 487233083 |
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| 9699050919 | 2116977177 | 9699050919 | 2116977177 |
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| 881833510 | 881833510 | 881833510 | 881833510 |
| 3936383047 | 3936383047 | 3936383047 | 3936383047 |
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| 8878579993 2237495519 1221951903 4244523075 351330685 680735444 995127203 7448719540 3976107308 0602691062 | 5801602029 273145252 078079941 8420063884 437349681 4582733720 372016767 628660004 1308350884 | 6584152148 9912761065 1374153913 565211390 8109998697 2216128524 897425555 1607631767 5054896173 0168096138 |
| 4025116399 1936833225 557338969 05374902662 0923261318 8558915808 3245557194 4453875628 7861288590 04160607 3716501402 6278240273 4696252221 7174941582 3317492396 8353013617 3773995100 6589528877 | | |

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| 496615226 | 1473539907 | 4051584998 | 603552953 2924575238 881036202 341636202 5581643869 786307627 3655047423 |
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| 6734052420 | 3109140220 | 990518821 | 9493913207 534317098 002736590 789164346 5337118779 |
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| 4017938255 | 7036016736 | 9909886111 | 3210979889 7070517280 7555519121 6993067309 9250704070 2456685077 8679694776 |
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| 1642187898 | 8574107164 | 9069191851 | 1628152854 86794117563 8904653885 7642291583 4250067361 2453849160 6741314301 |
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| 7493126163 | 3950012395 | 9924050845 | 4375958057 9570462226 646900010 3500490183 0341535458 4283376437 811988556 |
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| 9088113119 | 4487994171 | 5408120341 | 2190847094 080254039 3294294549 3878860230 5129271190 9751353600 0921911105 |
| 4120946831 | 1151632370 | 7419916463 | 5430284870 0731206580 3262641711 6165957613 2723515666 6253667271 8995268848 8995268848 8995268848 |
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| 1017341407 | 3348847610 | 8340711014 | 9808478138 |
| 8547041946 | 6437131229 | 0566401824 | 2392192695 |
| 4626087948 | 2018644887 | 626746533 | 8099801966 |
| 0569605513 | 1838131142 | 908825196 | 5698646262 |
| 6815855778 | 1034323175 | 3064784983 | 2106297184 |
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| 265321559 | 0354102092 | 8466592529 | 4180851800 |
| 521332614 | 4362531449 | 9914353791 | 626982230 |
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| 9197120948 | 964717530 | 1625313647 | 6482094635 |
| 8066061078 | 8544000050 | 8216757035 | 587484818 |
| 8338787034 | 871802184 | 4373421122 | 5077889171 |
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| 3380183601 | 1932368578 | 5604215625 | 7375720994 |
| 7167245377 | 9428313380 | 6905832083 | 6369822359 |
| 8796932354 | 4428531307 | 5301105285 | 7138296437 |
| 9874831638 | 2804040848 | 9054203985 | 9909353694 |
| 6439925470 | 2016721593 | 804040848 | 9872650697 |
| 3518280460 | 3634779818 | 5655572957 | 1447476825 |
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| 90963041 | 1183066710 | 8189303110 | 5601812337 |
| 5811350185 | 9004781536 | 8938137718 | 87871728167 |
| 3779582601 | 6211842368 | 6728147519 | 5195776573 |
| 5912359601 | 8801376254 | 2192709476 | 7337191987 |
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| 5264008125 | 2027665557 | 6774959696 | 5057467387 |
| 9478495734 | 6226065942 | 2661260456 | 5245684086 |
| 6378918523 | 2321501897 | 6126034373 | 6840671941 |
| 3911449677 | 5312864260 | 9252115376 | 9303776688 |
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| 5568214377 | 4396578900 | 7972687438 | 3712720508 |
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| 8650728905 | 3285485614 | 3316081269 | 3005693785 |
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| 3948083314 | 397084673 | 0840795893 | 8685046450 |
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| 4433021828 | 7026655610 | 655035310 | 5021631820 |
| 8733579771 | 8081848784 | 5886650433 | 6017609217 |
| 1155482479 | 3940359768 | 1188117282 | 4721582501 |
| 8358297193 | 010788834 | 467061533 | 1970269507 |
| 5674167811 | 2143782304 | 2143782304 | 2143782304 |
| 3395790575 | 5853214739 | 5853214739 | 5853214739 |
| 2253552959 | 7809353571 | 7809353571 | 7809353571 |
| 4908305081 | 116438189 | 116438189 | 116438189 |
| 7381885667 | 5193533195 | 5193533195 | 5193533195 |
| 5053340261 | 5053340261 | 5053340261 | 5053340261 |
| 5794088881 | 748134298 | 748134298 | 748134298 |
| 2600739281 | 491694161 | 491694161 | 491694161 |
| 5219708932 | 5219708932 | 5219708932 | 5219708932 |
| 8032475777 | 5219708932 | 5219708932 | 5219708932 |
| 5219708932 | 5219708932 | 5219708932 | 5219708932 |
| 1995888869 | 4891376652 | 4891376652 | 4891376652 |
| 30001D | 30001D | 30001D | 30001D |
| 35000D | 35000D | 35000D | 35000D |

CALCULATION OF π TO 100,000 DECIMALS

87

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| 9096773869 | 064041589 | 7361047683 | 6500068077 |
| 8926903089 | 118566798 | 5218170513 | 1056567184 |
| 9146979837 | 826874311 | 5988321090 | 432461129 |
| 746438427 | 4652563163 | 2300555130 | 6464541278 |
| 1322620544 | 6424101103 | 595464190 | 5811686230 |
| 4604752277 | 0167005684 | 543969234 | 417108988 |
| 8685473937 | 6564336319 | 7978680467 | 1830709319 |
| 2415083288 | 5839529054 | 2637687068 | 9688050333 |
| 2502417880 | 7972253859 | 1342458131 | 4404984770 |
| 9890367654 | 176979936 | 2375528452 | 6375733763 |
| 6361498567 | 3021752313 | 252926535 | 8964151714 |
| 82762265748 | 5810439112 | 232618790 | 599415406 |
| 8720920280 | 9297526498 | 1256916342 | 5000522908 |
| 700539227 | 8915351056 | 8883938113 | 2497570713 |
| 0355620370 | 9466025414 | 6468830302 | 525608927403 |
| 1546199305 | 0983869825 | 4284640725 | 5540927403 |
| 5465958716 | 3835875018 | 1593387174 | 2360615511 |
| 0086157853 | 9336078622 | 7395581857 | 9758725874 |
| 9071865980 | 5636171376 | 9222729376 | 4197755177 |
| 226976603 | 052498085 | 5759471631 | 078701332 |
| 1981035987 | 074380469 | 8219420563 | 8125583343 |
| 9271494003 | 3197828613 | 1818618881 | 1118408257 |
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| 3457797574 | 8524647837 | 92195631 | 58491597 |
| 9421963331 | 5028695611 | 9201222688 | 9887006079 |
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| 36529406516 | 9201983152 | 10962414874 | 2650980392 |
| 2026240089 | 0215016616 | 3813538381 | 5150377350 |
| 3100485482 | 4454580718 | 8976330032 | 3252582158 |
| 6131719593 | 3247110746 | 6222850571 | 066117703 |
| 8088666949 | 1413209771 | 6736900277 | 7585026866 |
| 0548711723 | 594649105 | 70509902 | 1844126974 |
| 5081083483 | 880438847 | 8441884003 | 1488997891 |
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| 8768865075 | 6429271605 | 2153765175 | 1492169763 |
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| 5444768909 | 8505020301 | 5044880834 | 2618452087 |
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| 5177015521 | 9626522725 | 4058507386 | 4058507386 |
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| 7464544435 | 735194157 | 735194157 | 735194157 |
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| 7464544435 | 5776253250 | 5776253250 | 5776253250 |
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| 7464544435 | 2409076898 | 2409076898 | 2409076898 |
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| 7464544435 | 2375963277 | 2375963277 | 2375963277 |
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| 7464544435 | 5620535790 | 5620535790 | 5620535790 |
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| 7464544435 | 8526213325 | 8526213325 | 8526213325 |
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| 1966189140 4 14495270 | 4808154205 | 7787064521 5940092897 7760133075 6847966992 9554335561 | 3984773805 |
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| 9965474815 689135548 | 972289198 671470438 | 661360202766 6613602040 5816811919 | 671470438 351949863 |
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| 487890806 02182878578 | 6216512738 5635132901 | 4890350988 3270617258 9325753639 | 9397905572 9175160097 6154590447 |
| 7169226580 6315111028 | 0384360173 7471215247 | 6085152099 0161585823 | 1257159073 3421736576 |
| 1505095633 092806684 | 5893764946 4913190609 | 6274063353 1089792464 | 271423904 7827958728 |
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CALCULATION OF π TO 100,000 DECIMALS

91

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| 9375709685 | 5455938151 | 3789565039 | 2510149532 | 6562814701 | 1998362992 | 2006663528 | 7537471313 | 5236421589 | 2651262040 |
| 7288771657 | 83580405219 | 646054054 | 3544364626 | 6562244565 | 75429990102 | 5658692277 | 9142752931 | 1720297939 | 3775132610 |
| 605228125 | 3733510683 | 8712438699 | 3853343891 | 7571376360 | 872319760 | 8166044646 | 8393737258 | 6092327379 | |
| 5234867029 | 1691042636 | 9262909199 | 605204120 | 0 | 316014085 | 872319760 | 8164273995 | 3493465463 | |
| 1450404019 | 9528537252 | 0049578052 | 5465625115 | 410252437 | 991322627 | 136090940 | 2902262062 | 827335968 | 0506518393 |
| 4057450112 | 0924414649 | 184332364 | 6569371725 | 914893241 | 590064202 | 0612885732 | 9261335968 | 0872650004 | 5628284557 |
| 5745965921 | 2053034131 | 0111827501 | 306915098 | 3551563200 | 43101784601 | 0645654938 | 6345252522 | 9161991819 | 9596027523 |
| 2770224985 | 5738824899 | 8820714659 | 5692853768 | 6761722682 | 4991147261 | 5732035007 | 642981162 | 4401331673 | 7892788489 |
| 5615925306 | 7347945689 | 4907053236 | 3568196331 | 861722682 | 4991147261 | 5732035007 | 642981162 | 4401331673 | 7892788489 |
| 2290325933 | 4986179702 | 199481925 | 739617630 | 758441709 | 855922170 | 1718257127 | 7753449150 | 8205278430 | 9046194608 |
| 3521740200 | 5836672849 | 7094110232 | 6695392144 | 5461066215 | 0064106747 | 4020700918 | 9191951376 | 4669648112 | 6725369153 |
| 7162290791 | 3854039375 | 4007783515 | 337467747 | 9421003840 | 0230805185 | 0994548779 | 033461222 | 028650616 | 0503511776 |
| 2648316111 | 5335558770 | 507354279 | 249909853 | 734378708 | 1194230555 | 1214369797 | 499495186 | 0353920403 | 8302357163 |
| 5272763087 | 4693219622 | 19006462608 | 8618367610 | 3346002255 | 47774778136 | 4101269190 | 656968495 | 126883762 | 9690723396 |
| 1276287223 | 041118136 | 1006026404 | 4030035916 | 98889199458 | 2739742411 | 4613744804 | 056970625 | 7767472376 | 6065541618 |
| 5746905212 | 2923822827 | 5186799156 | 9833907476 | 7114610302 | 2776666020 | 0612468764 | 772881909 | 6791613354 | 0198814027 |
| 5799217416 | 7670799231 | 6038455694 | 6128515363 | 707219540 | 6111767673 | 8737255172 | 8529400456 | 0230754469 | |
| 3869307813 | 4951103521 | 8253282972 | 60455320 | 797887291 | 1511237550 | 6023878537 | 3484125708 | 6061062052 | |
| 0584521227 | 5455384800 | 820532450 | 456517695 | 1857691320 | 0042816758 | 0549248117 | 8051983264 | 6032445792 | 8297301291 |
| 0531838543 | 6821206215 | 5312866685 | 6495651261 | 38928261367 | 0640929533 | 3457052298 | 6996962350 | 3530942245 | 4386527667 |
| 7673027580 | 402102463 | 441044500 | 9147151353 | 441044500 | 92736526960 | 8407048333 | 9346153940 | 75765583705 | |
| 381261956 | 834428605 | 7956696622 | 1547216956 | 2080103172 | 1490610555 | 1490610555 | 2353279311 | 2232507148 | 6302069512 |
| 4539500373 | 5723346807 | 094654830 | 8920980153 | 4878070533 | 4910933660 | 5755405084 | 4111521444 | 881436304 | 3727327104 |
| 5027768661 | 9531078583 | 2333435784 | 0297160925 | 2153260925 | 589325560 | 0672124359 | 4642550659 | 9677177038 | 8445396181 |
| 6332879644 | 6081778927 | 2171836908 | 8801267782 | 0743010642 | 2524634807 | 4543004764 | 9288555340 | 9062185153 | 6543554741 |
| 2547615216 | 9722667769 | 7272770583 | 158014128 | 5688011705 | 0283622755 | 4321480348 | 8003442979 | 0456416195 | |
| 7212784508 | 9284899804 | 4494742709 | 057912969 | 2178072987 | 94777511 | 2447305991 | 6040506299 | 6898128093 | 0104216116 |
| 6299356148 | 2830998887 | 074522716 | 0484336308 | 1801412646 | 963725843 | 094185422 | 1655908457 | 6146074858 | 5624738149 |
| 3142707826 | 6215185541 | 6038702068 | 7698046174 | 7400808324 | 34336053823 | 5455510944 | 9848431093 | 4947399446 | 7267336535 |
| 2517662706 | 772194183 | 1977197637 | 19261780169 | 8035671345 | 4643671776 | 4340564487 | 1656964422 | 1656964422 | |
| 0418285956 | 453498138 | 8412890420 | 68204700716 | 1555691684 | 3038993438 | 3667735034 | 4921032811 | 3363184722 | 5923055343 |
| 8305820694 | 1675629992 | 033731754 | 8912203123 | 0389072681 | 0685345450 | 5599356182 | 3576312837 | 6764063110 | 1312533321 |
| 2141994611 | 8635508331 | 7658185204 | 2123646331 | 2267651299 | 6417132521 | 751353261 | 8876819423 | 3879036546 | 8908001827 |
| 1352835848 | 884441176 | 1234101179 | 9187092365 | 0718485785 | 6221021104 | 0097769944 | 5312179502 | 2479578069 | 5065329659 |
| 4038398736 | 9907240797 | 670008267 | 9400761872 | 9507835963 | 4927839045 | 7697366164 | 3409359792 | 2192858705 | 7495748169 |
| 6694062334 | 2726197335 | 1813662606 | 5735982575 | 5521965849 | 072601366 | 828365028 | 3418558437 | 2558970883 | |
| 6355937574 | 3778011480 | 5594422987 | 301819080 | 8085647265 | 7135476128 | 316292004 | 980315402 | 1055305970 | 7666362714 |
| 9328308916 | 8899323592 | 90078874 | 1985717881 | 4321804242 | 7491269878 | 4721296428 | 164352514 | 164352514 | |
| 4295220153 | 6170298575 | 1055943264 | 614685045 | 2684975764 | 807800092 | 213581137 | 8117749271 | 768550755 | 3832878687 |
| 4474591593 | 73162470460 | 827502244 | 8292492484 | 8259447763 | 8749499797 | 840468292 | 5736096853 | 4549844226 | |
| 5336862844 | 8935570411 | 1817793806 | 441616531 | 2360021491 | 8768769467 | 3984057171 | 7630751684 | 98565359201 | 4868929453 |
| 0594020245 | 7939622924 | 5666448819 | 6757629434 | 9535326382 | 171613957 | 5779076637 | 0764569570 | 2597388004 | 3841580589 |

CALCULATION OF π TO 100,000 DECIMALS

95

| FROM | 75001D | T0 | 80000D |
|-------------|-------------|-------------|-------------|
| 4336137106 | 5518599876 | 0075492418 | 7211714889 |
| 4592715757 | 2771521858 | 9916948117 | 9406444663 |
| 154203612 | 3593397312 | 6282285691 | 9943237004 |
| 382236791 | 847386091 | 4768310814 | 1358275755 |
| 143386640 | 6845069742 | 0787700280 | 8536435977 |
| 363755666 | 8678067610 | 5449285763 | 2165032827 |
| 480953810 | 4065702543 | 2760438570 | 780313422 |
| 086792734 | 289557355 | 925723805 | 8696887873 |
| 911273318 | 9423400547 | 959846698 | 1108899196 |
| 0452995313 | 0714090846 | 0849965376 | 647871224 |
| 0567629729 | 3146491149 | 3708624469 | 1452035777 |
| 6085962611 | 2660501289 | 2959656356 | 2114608115 |
| 5679991516 | 5890250164 | 8686142720 | 4349982665 |
| 960565230 | 9146263844 | 7386296039 | 4798772405 |
| 4884113956 | 0349480376 | 21007350083 | 5667527800 |
| 1925040997 | 6153190768 | 5577032768 | 492850903 |
| 2741631234 | 882145240 | 134716529 | 425481944 |
| 0849369031 | 3130100799 | 9771913622 | 491784281 |
| 4288072803 | 50930582513 | 4816660927 | 9268349628 |
| 4683776352 | 8258765213 | 9156480972 | 4402194463 |
| 5698837622 | 6261846365 | 4524234976 | 4557551071 |
| 3250099951 | 4026015116 | 7532975057 | 646908974 |
| 9582513264 | 9914595026 | 0917069347 | 528377304 |
| 6966602647 | 9535951097 | 1276591362 | 848923861 |
| 6467636723 | 2057145168 | 46959170908 | 8729850777 |
| 2693347869 | 2189524062 | 2657921043 | 2165040282 |
| 175134722 | 6472547010 | 7917939969 | 205936202 |
| 2567638723 | 4279407088 | 504047429 | 2133289718 |
| 5917171506 | 6911148002 | 0779432012 | 619896377 |
| 6819861855 | 3780982018 | 4711541636 | 3032626569 |
| 3775854429 | 6779770146 | 6029438748 | 7225115363 |
| 961624134 | 180129513 | 0633638609 | 8011917581 |
| 8409272394 | 403340244 | 909545580 | 5402812042 |
| 0870109560 | 9514704169 | 141702741 | 5181010301 |
| 4601424242 | 5368246069 | 8772581311 | 7640646076 |
| 584161632 | 4271611419 | 8178024825 | 12471611419 |
| 704842714 | 194351832 | 267762641 | 5956545490 |
| 1852668901 | 5150471334 | 0356100310 | 5059148178 |
| 1959418997 | 5418393234 | 4474242907 | 52110303475 |
| 9762452056 | 1985576257 | 60008070817 | 3534394673 |
| 1744201696 | 0009062641 | 5612732297 | 7702212179 |
| 211836062 | 2527011541 | 1222838027 | 5186837635 |
| 307115132 | 9619045590 | 0793806427 | 9049020342 |
| 806252503 | 5212845192 | 50613296593 | 6679625237 |
| 3256685145 | 5344391660 | 2242577755 | 1291620077 |
| 292764747 | 8501926114 | 5041327487 | 2796852629 |
| 7592517247 | 8732288149 | 1155915605 | 27132377916 |
| 580750827 | 3431765944 | 0504982697 | 652693457 |
| 60792020628 | 3169998200 | 7205481152 | 0768500199 |
| 64566821749 | 1407562376 | 7618453775 | 988655386 |

| FROM | 80001D TO | 85000D |
|---|--|---|
| 9482843662 9980037414 5276277165 4762382554 6170883189 8108688068 4785370553 6480469350 9588180253 6052974079 | 3538676511 1950193732 8208314626 8960071075 1755206144 3378811454 9950134432 443281933 4638905093 6545714506 | 9008644834 4018042836 3390513587 1572739133 3453728426 3372174065 7757710198 3051755572 1036719576 901889584 |
| 913019599 9573017901 8139019488 403249327 347936692 34008184897 6059037958 0916960417 547423578123 | 2123424391 8853841689 7227755219 403249327 347936692 34008184897 6059037958 0916960417 547423578123 | 1607370623 7944767320 7968291627 6689680188 |
| 9476461478 3292697654 5162202081 701100478 4603875654 4151739433 960489153 1881757665 0500951697 402415447 | 7129365661 4253949368 8842305174 0012992553 6834289853 897926699 5677702708 9466513736 8922601044 1548166215 | 6804219838 4762308717 917590095 2651946820 265138731 1518000181 4341209628 106663523 |
| 3677400978 3778342370 9152644063 0540718978 435586107 2961105550 0204153136 9637304684 9213556837 2654003075 | 3830294639 378983758 3655455991 93400866235 0909679611 3400186702 7123176526 6337107787 2511186035 4037554487 | 0982908936 4612047891 1147530370 498939583 3457824082 817384413 227100296 8311940203 3234564208 2647327623 |
| 6554696277 8511931527 7511344646 8905504248 1133614349 8460484905 1258345683 2664415284 8971397237 6040328212 | 6602535166 9391408204 9947320486 0216277597 9177123475 1097520403 0789357599 3771509502 1751693555 827075339 | 1189233407 022832077 234502377 7474088177 8391015234 1320848894 2345961369 230497998 70704144 6316270721 |
| 4796119456 9757196812 3929719137 9082925050 561619552074 3424329598 2898980529 233364154 1925636738 088949401 | 4712413405 250220406 179435252 552252087 487908656 831382835 167750522 94803056438 5815919526 | 6675828292 9705226127 6287110401 3480178122 4801789684 0524479243 6058272426 74343076721 6452703134 |
| 9688901274 7868010102 513386428 6847948212 1186290403 3769156857 6246912994 724930972 189855423 | 690364492 7033696193 8547372480 329855051 1208919287 982974467 8641291594 1753167560 2533305310 | 60711418148 3239880607 2971102347 2552071349 079839882 3552887239 509936566 7818992383 7125189762 47559944 |
| 3228895388 3773173489 4112285707 1410959709 0479193010 4674705041 1435381782 4646307959 8955523899 1884773781 | 6105041077 350852762 0445891909 789019831 5465280533 985777843 139388399 431044465 6692445508 8594631408 | 1751220331 3900815965 8013133568 921501054685 5211764182 1043342978 8826119830 431133887 8288891345 022613090 |
| 8497754313 9577124323 0616966262 9194039214 3974027089 4777663702 4881551993 2245882297 9020631257 4369109463 | 9325280024 1642476868 4954553249 3801763937 1615636847 8598837159 0238542126 58061615367 2288071311 0267474013 | 1145261063 7653833903 8216196688 2222047570 4375906143 3804017285 386283565 17699881267 7442319582 4182683698 |
| 1630851581 3816196688 2222047570 4375906143 3804017285 386283565 17699881267 7442319582 4182683698 | 1493836349 6629351576 8540613973 4274647089 9885618170 160511048 8097153485 9118617189 6680559735 4170542398 | 5135560018 7203350790 6094648127 1143999156 0461642420 508822535 7734385712 1354385712 3946010865 |
| 7937980586 2043366607 8825219717 8090258173 7087091660 0452279777 1535099103 4073442502 0388386718 2205228796 | 9445838165 2947951048 6607173902 293274542 6785669777 865999234 1683412227 46463015062 1553205026 5534146099 | 5249356050 8519217565 4913483095 8906536175 6358176374 7364418337 897422700 7035452066 6317092960 7519199627 |
| 7324230902 5239744386 101463098 6877333938 8251868431 6501027964 911497375 8288891345 0341148865 9486702154 | 9210108432 8080783428 0894172980 0898329753 6940649699 9031353998 6391958160 1468995220 8806622854 084188427 | 4786281975 5466292788 6462160717 6466292788 6814021340 982916298 8734298507 9247184605 6878828331 381259119 |
| 6601469615 0317542267 5112599331 5522967213 6490468093 4582008181 0618021002 2766458040 0278213336 | 7587370190 1337175461 355313190 3609248909 7246827928 4556299134 0500518029 5707129219 0525567818 | 8991389962 5386662319 3800036113 462242461 02408571232 5662888893 1722116432 9478161905 5486805494 |
| 3441034090 6807160880 2822795968 6950133643 8142682521 7047287086 3010137301 1552368614 1690837567 574737329 | | |

CALCULATION OF π TO 100,000 DECIMALS

97

FROM 85001D TO 90000D

| | | | | | | | | | |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|
| 7631851570 | 3810944339 | 0561564468 | 5241850281 | 4810799837 | 6918512127 | 2019350440 | 418040472 | 1626939445 | 7883770901 |
| 0597463321 | 9720558114 | 0781759897 | 720720968 | 9382249303 | 2368305158 | 626728111 | 463798983 | 1375179376 | 2321511125 |
| 234973305 | 2406221052 | 4426553573 | 2905655163 | 4063892061 | 659287821 | 8707510212 | 1760807129 | 7378133518 | 7117931650 |
| 033155238 | 2248773065 | 3444179453 | 4153920454 | 2444970341 | 0120874021 | 881093882 | 6816751204 | 2299404948 | 1734494727 |
| 328947011 | 1574139441 | 22881555218 | 2842492224 | 0658752889 | 1722727808 | 0711675404 | 697308037 | 0396187877 | 966488255 |
| 5614674384 | 3925701158 | 295666135 | 6612973112 | 672007297 | 672007297 | 672007297 | 672007297 | 717564228 | 7442114729 |
| 8816148027 | 5024380681 | 7653573275 | 5786625058 | 7078401320 | 8037932816 | 008790813 | 0049249147 | 368217035 | 3882196190 |
| 390149952 | 3495387105 | 9973511434 | 729233949 | 9187936608 | 6923013755 | 9636653237 | 3806703591 | 144243265 | 6151210940 |
| 4259582639 | 3016780171 | 2866923928 | 3221037658 | 8517140202 | 1119695706 | 4799814031 | 506530451 | 4156441662 | 3163763809 |
| 9044028162 | 5691757648 | 9142569714 | 16355984393 | 1743327023 | 7812336938 | 0430128926 | 2637535266 | 7795034169 | 3343236075 |
| 0024811574 | 1808750368 | 47506949394 | 5489650974 | 0485442635 | 6371649959 | 4992098088 | 4294703636 | 6662975260 | 0326385635 |
| 2945844728 | 9445471662 | 6616877449 | 6616877449 | 6616877449 | 700281611 | 64560404 | 0257363581 | 8966137382 | |
| 647204226 | 4222124201 | 6566150284 | 9713063327 | 95811430251 | 06136694825 | 5670174809 | 3579088965 | 7134926158 | 163469018 |
| 0696508955 | 6310121218 | 4918058479 | 22720209187 | 1696316330 | 048580201 | 02866465785 | 8591269974 | 637616714 | 6335415956 |
| 973955203 | 3146280205 | 189166793 | 50730348884 | 5798460864 | 7370268786 | 7602436777 | 6785364246 | 7339123213 | 1699880354 |
| 073232882 | 8184750105 | 164331189 | 5370348884 | 22696021047 | 8052742490 | 6034920829 | 57475550400 | 3457160184 | 0125745369 |
| 381455117 | 5354210126 | 5578356154 | 988744748 | 042732457 | 8806161873 | 4934156604 | 6352979779 | 4550753593 | 0419568720 |
| 931672536 | 5472083816 | 858560604 | 3801977030 | 7642460834 | 8987610134 | 570994877 | 0029461757 | 9206195254 | 9255757109 |
| 0385251714 | 8852526557 | 105349813 | 4198033906 | 4152987634 | 802776144 | 3776144 | 1393761892 | 1393761892 | 5431317696 |
| 8510184010 | 3844472348 | 9488695209 | 81914353199 | 6506555354 | 6173358140 | 4554483788 | 7475252653 | 9496658699 | 9205841765 |
| 2780125341 | 0338964698 | 1864243003 | 4146791380 | 06785486596 | 07854784407 | 0789705151 | 9462152877 | 730910446 | 7424497979 |
| 9926271209 | 5168477656 | 8482583341 | 4022646772 | 1084332423 | 7593741610 | 5367340419 | 547384419 | 789542535 | 0333018614 |
| 009515476 | 5961476255 | 6518738232 | 9246834735 | 935802896 | 0115367797 | 8730355315 | 937833082 | 2486151777 | 7054157757 |
| 6561759358 | 5120166729 | 6188153886 | 5162159667 | 63188303261 | 1088159356 | 48467979385 | 4257246871 | 614012237 | 8213779774 |
| 1312689772 | 6671299202 | 5922017408 | 7700747956 | 63173932201 | 1088159356 | 2862819185 | 6357189338 | 4598850603 | 8531581797 |
| 6067947984 | 0878360715 | 9601497334 | 205720460 | 3521790605 | 6776032855 | 69277377349 | 5182203236 | 144112584 | 8212624771 |
| 2012035776 | 3888959743 | 1822826787 | 1314108053 | 5335747942 | 9762179678 | 9034668169 | 8895535185 | 047832561 | 6330709476 |
| 951699862 | 47100101971 | 8889205009 | 52191536323 | 7871976487 | 0399223811 | 5403534754 | 6764101150 | 6764101150 | |
| 1406970122 | 6927474793 | 888899438 | 5973045451 | 801061235 | 801061235 | 0306326785 | 8528849356 | 3251585384 | 3832424922 |
| 8908318700 | 7091002373 | 7710657698 | 5056433928 | 8543376583 | 4259677055 | 3715005333 | 514489082 | 9388773755 | 2051459333 |
| 0496265314 | 1514138612 | 4437935885 | 0709466880 | 454869735 | 8170212908 | 4907873478 | 6081436632 | 3322819415 | 8273456713 |
| 564431153 | 7967818058 | 1958524648 | 4008403290 | 9981943781 | 7181773023 | 170039873 | 305049387 | 3561162610 | 239943325 |
| 978012893 | 4326055847 | 102876490 | 107023243 | 5283234098 | 35565686590 | 1070919117 | 32958249129 | 9258697435 | |
| 8170981338 | 9404593447 | 1934793877 | 6242324098 | 660492385 | 1297094532 | 32709453210 | 3600229268 | 6491241749 | |
| 191419896 | 6129558076 | 770795947 | 9530601311 | 9159011773 | 943102090 | 490794244 | 886853086 | 8444937059 | 092600612 |
| 0649425744 | 7103535476 | 5785924270 | 8130406168 | 5462198818 | 3009063438 | 8187387755 | 85627749115 | 8737542106 | 6657951346 |
| 487586715 | 1383801852 | 1382811915 | 8130406168 | 5516019893 | 93285167968 | 722941032 | 4719941032 | 151268777 | 1633452229 |
| 954183968 | 048835229 | 5753612868 | 3722535359 | 0079201666 | 9413390911 | 6875880398 | 8828859216 | 6159759193 | 6159820716 |
| 3516271332 | 8105181876 | 0210485218 | 6755326648 | 6739808909 | 0719513805 | 6262755124 | 3122156916 | 3790227732 | 8703410842 |
| 0378415256 | 8328871804 | 6981952513 | 0732663402 | 7851905941 | 7338920358 | 5403956770 | 3561123935 | 44822585628 | 2876106106 |
| 98229712142 | 0961935309 | 3313121711 | 8789107876 | 6872044548 | 8760894101 | 7479864713 | 7882462153 | 955933332 | 7556200943 |
| 9580434537 | 9197822405 | 7436959927 | 7436959927 | 7786649409 | 6404877781 | 1748336432 | 684022829 | 3240626008 | 198081804 |
| 3909145563 | 5193685806 | 3015089142 | 2898652199 | 8777884934 | 7477729132 | 7972660276 | 584022686 | 1034690508 | 7411421268 |
| 6196968204 | 4126965282 | 9810870454 | 7986159594 | 5338021201 | 1556469799 | 7675573892 | 1086233599 | 3267776894 | 5406050821 |
| 8838227909 | 8336277671 | 2449002676 | 1178498264 | 37707330020 | 8184459000 | 9711235204 | 331997082 | 4209877151 | 4449751017 |
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FROM 95001D TO 100000D

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