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Dong

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(54) RANDOM NUMBER GENERATOR AND RANDOM NUMBER GENERATING METHOD THEREOF

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G06F 1/02 (2006.01)
G06F 7/58 (2006.01)

(52) **U.S. Cl.**
USPC **708/254**

(58) **Field of Classification Search**
None
See application file for complete search history.

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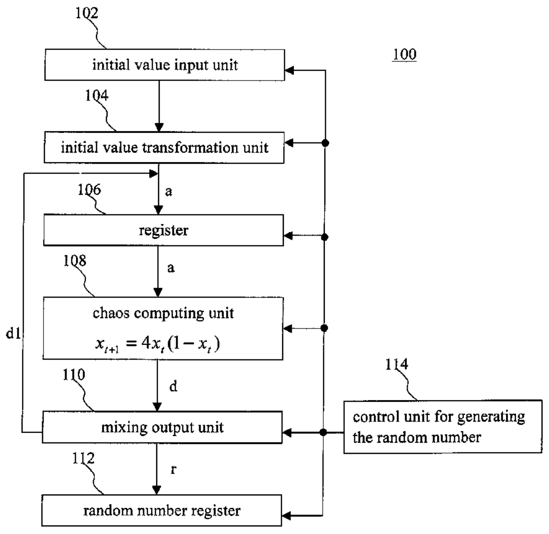
(57) **ABSTRACT**

A random number generator utilizes nonlinear function to obtain high generating speed, long cycle and great quality. By utilizing equation (1): $x_{t+1}=4x_t(1-x_t)$ to perform the steps of setting a binary integer having N bits ($N\geq2$ and N is an integer) as an initial value; transforming a binary sequence having N bits into an integer of 2^m carry number having $[((N-1)/m)]+1$ digits ($m\geq1$ and m is an integer; inputting to a chaos computing unit having calculating precision with N bits and calculation result with 2N bits; utilizing the chaos computing unit to generate a binary sequence $d(d_0d_1 \ldots d_{2N-1})$ with 2N bits; and setting fore-N bits of a result with 2N bits $d(d_0d_1 \ldots d_{2N-1})$ as the input value $a(a_0a_1 \ldots a_{N-1})$ required for a repetitive calculation wherein a one-to-one excluding logical calculation ($r_i=d_i\oplus d_{i+N}$) is performed between d_i and d_{i+N}, ($i=0, 1, \ldots N-1$) and can obtain a result characterized in that outputting the random number $r(r_0 r_1 \ldots r_{n-1})$.

2 Claims, 16 Drawing Sheets



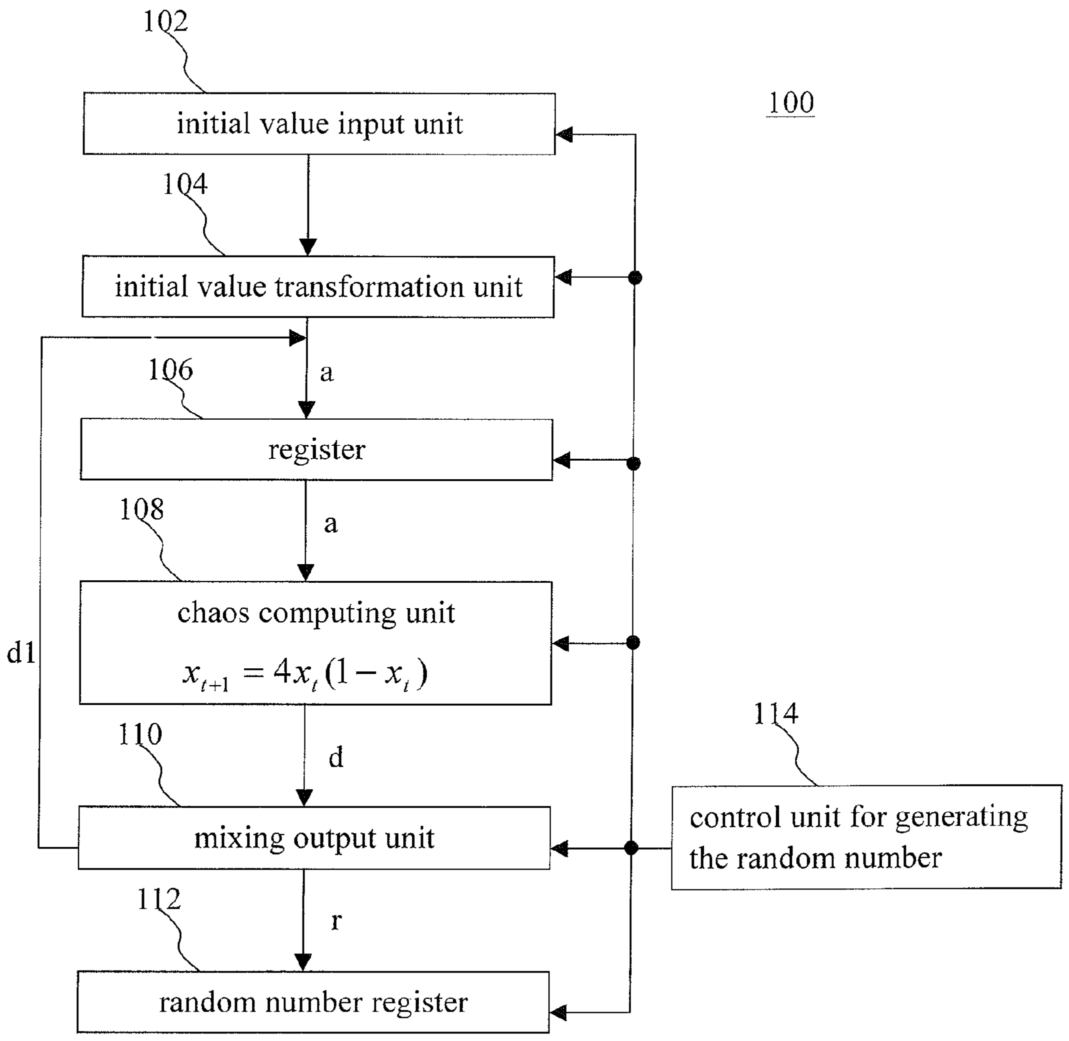

102
100
initial value input unit
104
initial value transformation unit
106
a
register
108
a
chaos computing unit
$x_{t+1} = 4x_t(1 - x_t)$
d1
110
d
114
mixing output unit
control unit for generating the random number
112
r
random number register

FIG. 1

computing precision N（bit）	32	64	96	128	160	192	224	256
function computing speed (x10^6times/sec)	58	16	7.4	4.4	3.2	2.2	1.6	1.2

（Genuine Intel（R）CPU 1.5GHz 0.99GB RAM）

FIG. 2

$$
\begin{array}{ccccccccc}
 & & & & & a_0 & a_1 & \cdots & a_{N-1} \\
 & & & & \times & b_0 & b_1 & \cdots & b_{N-1} \\
\cline{5-9}
 & & & & & a_0 b_{N-1} & a_1 b_{N-1} & \cdots & a_{N-1} b_{N-1} \\
 & & & & & & \cdots & & \\
 & & & a_0 b_1 & a_1 b_1 & \iddots & a_{N-1} b_1 & \vdots & \\
+ & & a_0 b_0 & a_1 b_0 & \cdots & a_{N-1} b_0 & & & \\
\hline
 & c_0 & c_1 & \cdots & & c_N & c_{N+1} & \cdots & c_{2N-1}
\end{array}
$$

FIG. 3

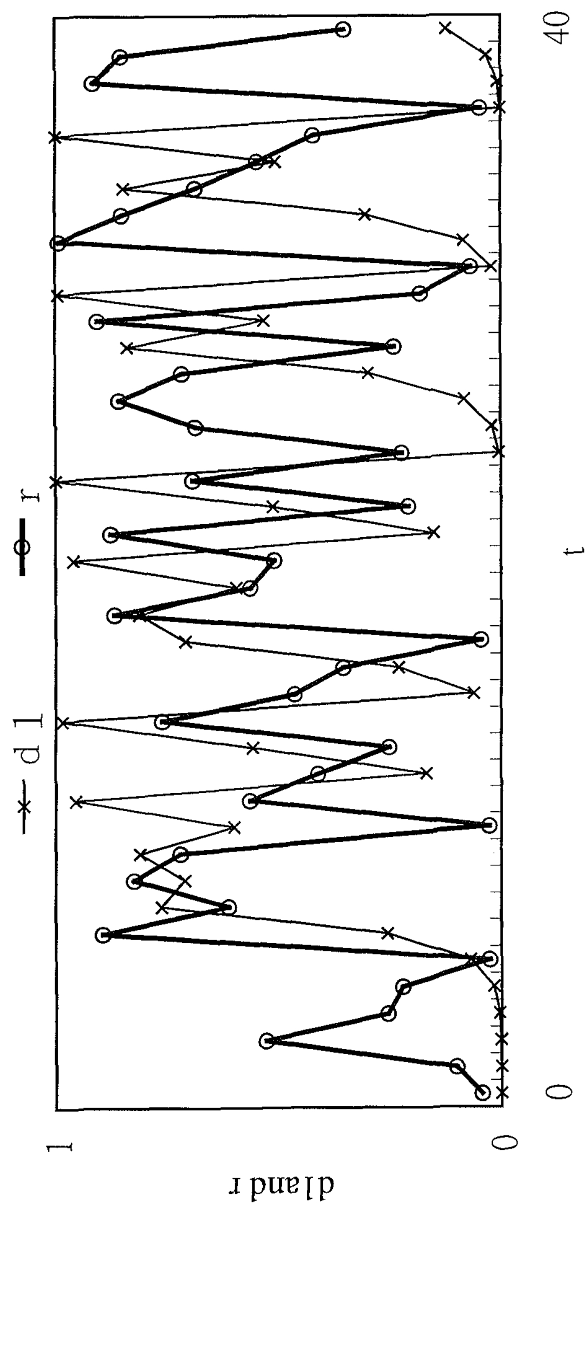


FIG. 4

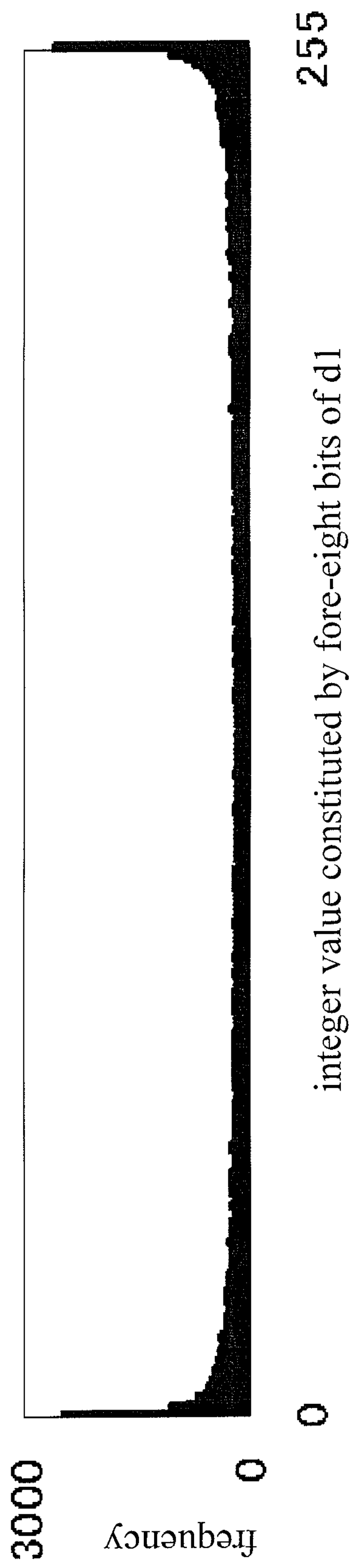

3000
0
frequency
0
255
integer value constituted by fore-eight bits of d1

FIG. 5

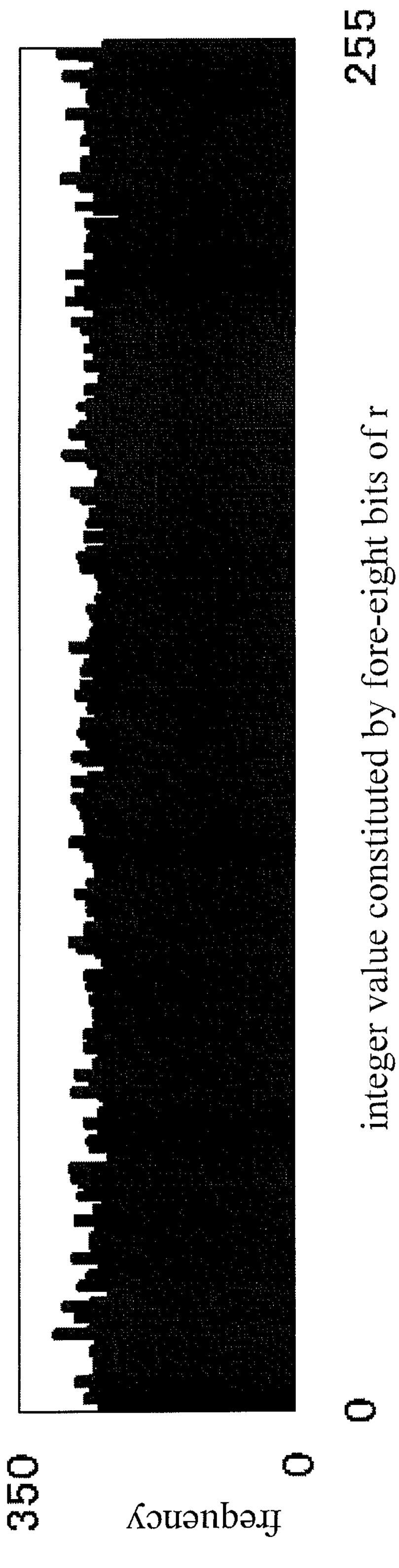

350
frequency
0
0
255
integer value constituted by fore-eight bits of r

FIG. 6

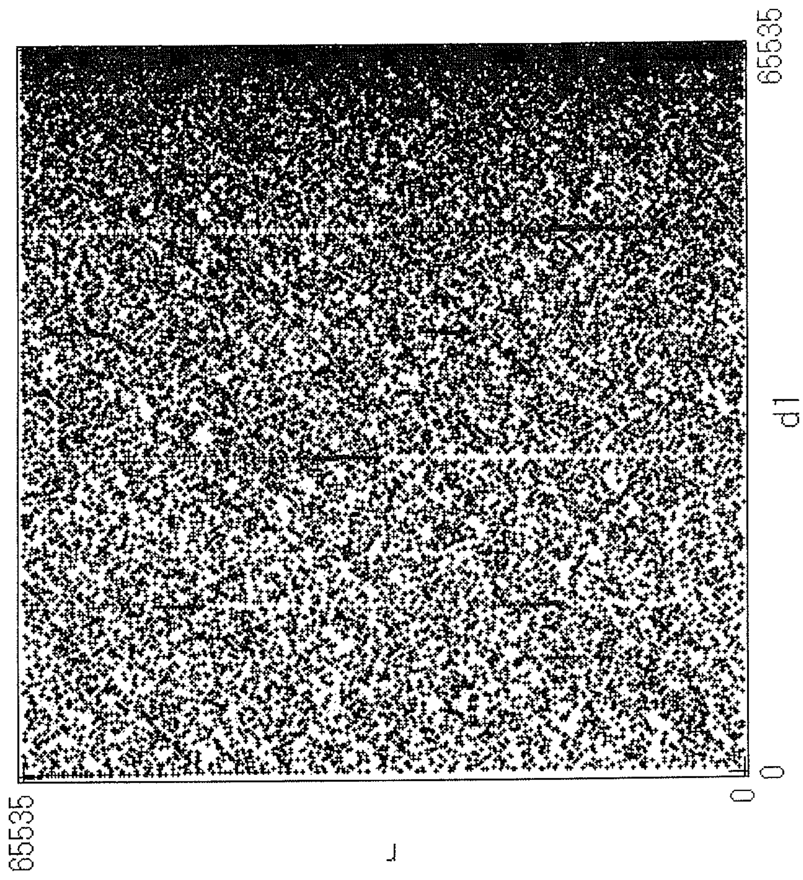


FIG. 7

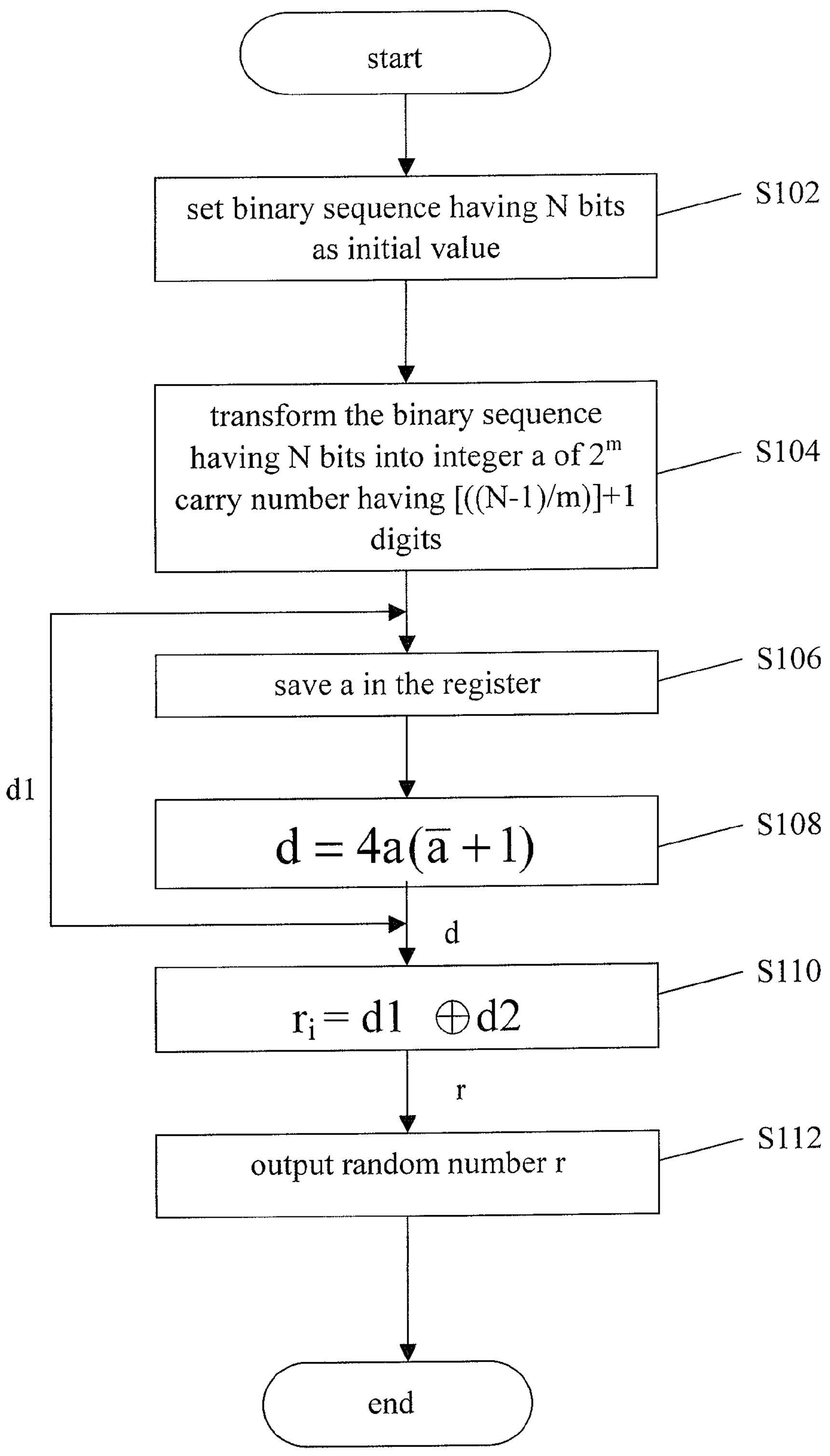

start
set binary sequence having N bits as initial value
S102
transform the binary sequence having N bits into integer a of 2^m carry number having [((N-1)/m)]+1 digits
S104
save a in the register
S106
d1
$d = 4a(\overline{a}+1)$
S108
d
$r_i = d1 \oplus d2$
S110
r
output random number r
S112
end

FIG. 8

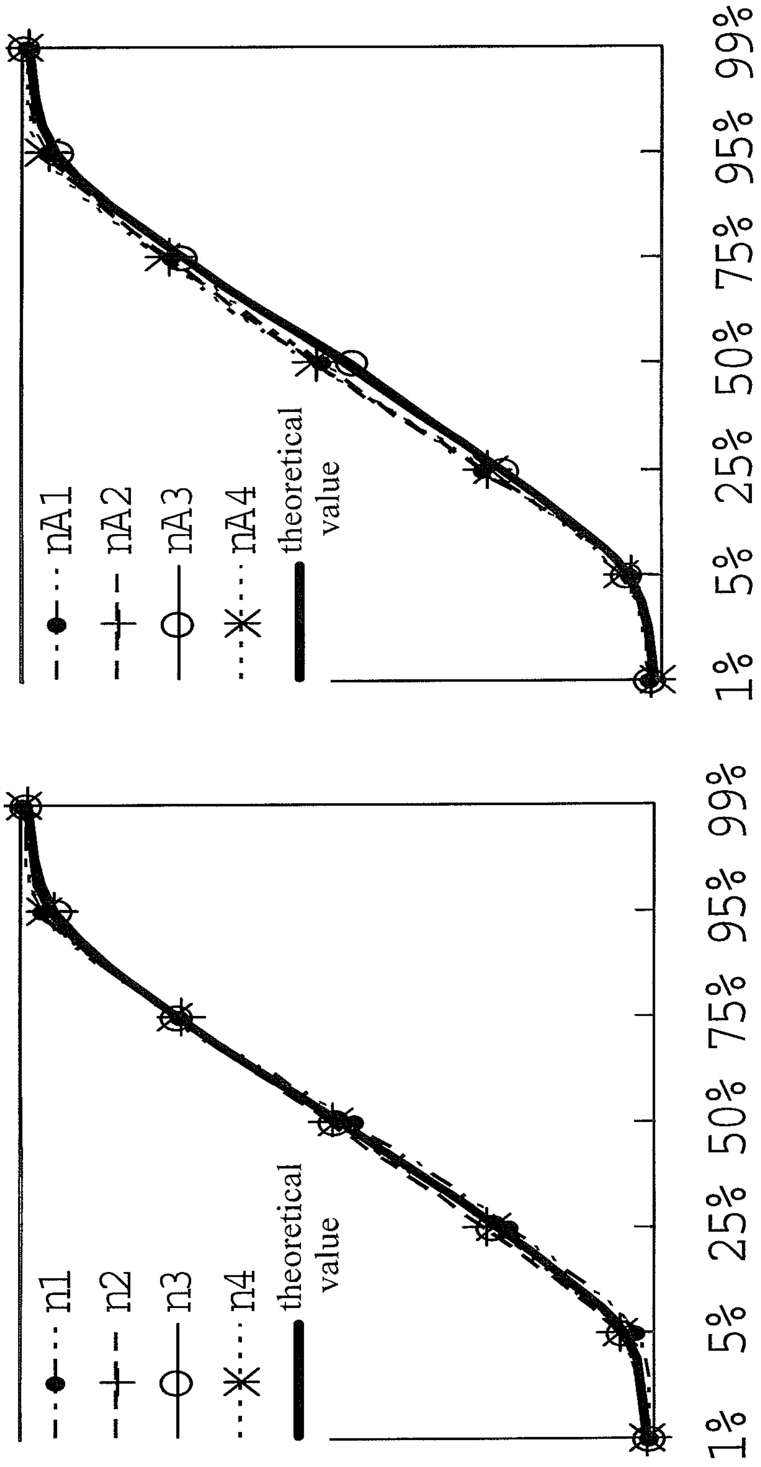

nA1
nA2
nA3
nA4
theoretical value
1%
5%
25%
50%
75%
95%
99%
n1
n2
n3
n4
theoretical value
1%
5%
25%
50%
75%
95%
99%

FIG. 9

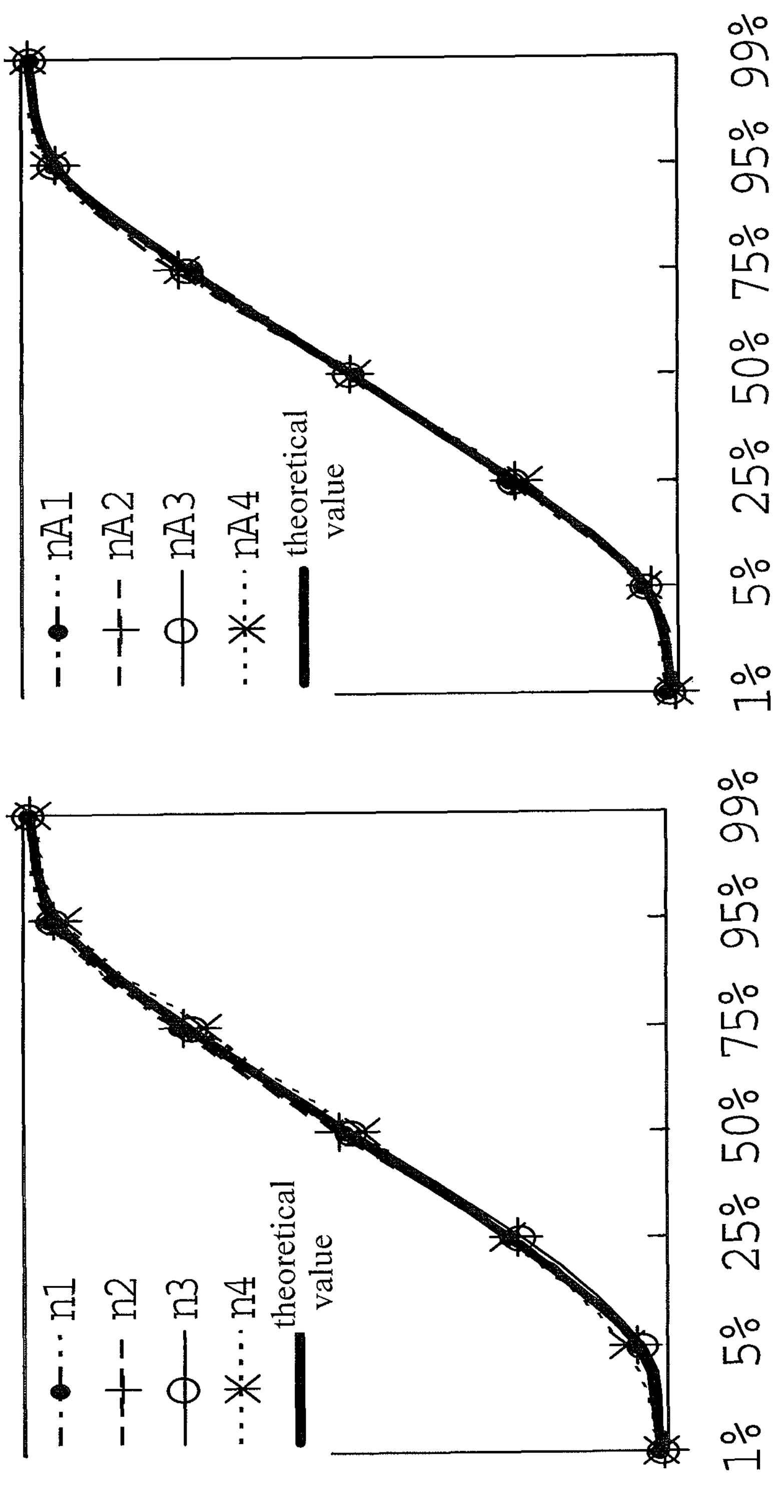
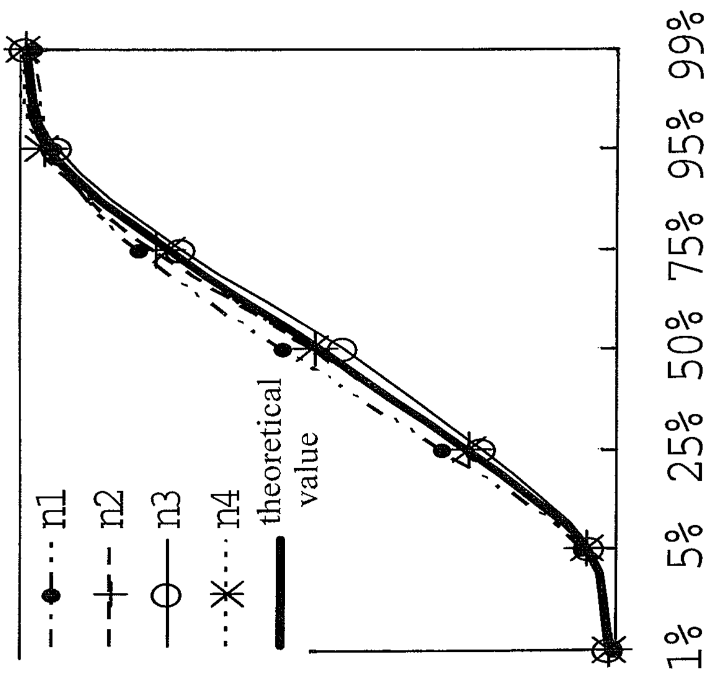

n1
n2
n3
n4
theoretical value
nA1
nA2
nA3
nA4
theoretical value
1%
5%
25%
50%
75%
95%
99%

FIG. 10


n1
n2
n3
n4
theoretical value
1%
5%
25%
50%
75%
95%
99%

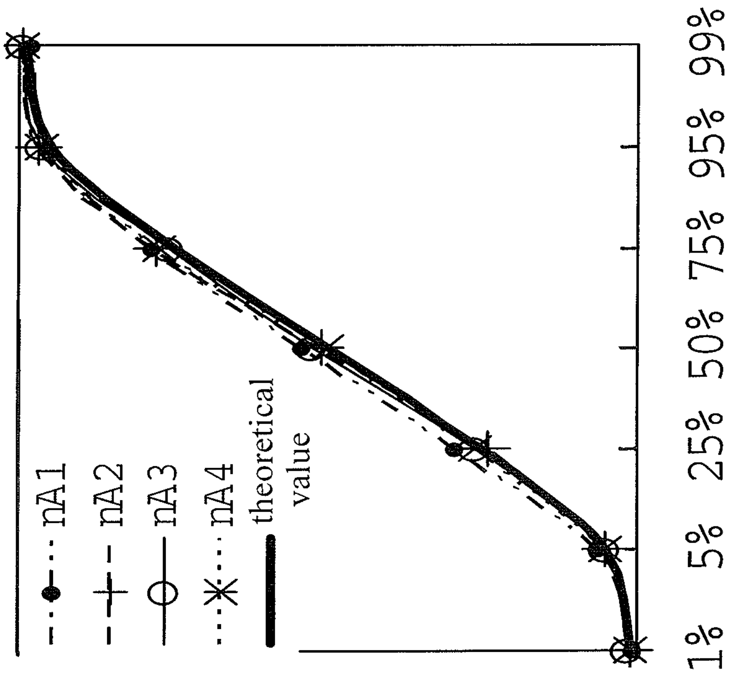
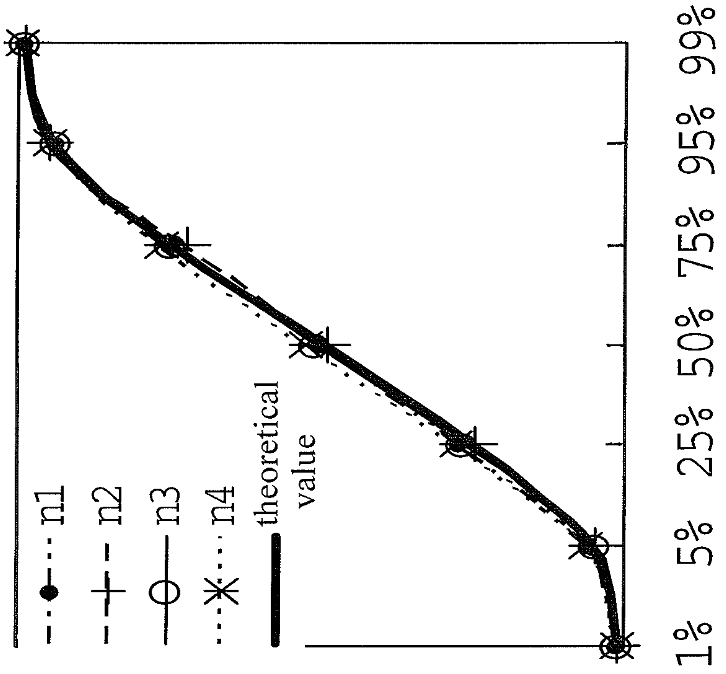

nA1
nA2
nA3
nA4
theoretical value
1%
5%
25%
50%
75%
95%
99%

FIG. 11


n1
n2
n3
n4
theoretical value
1%
5%
25%
50%
75%
95%
99%

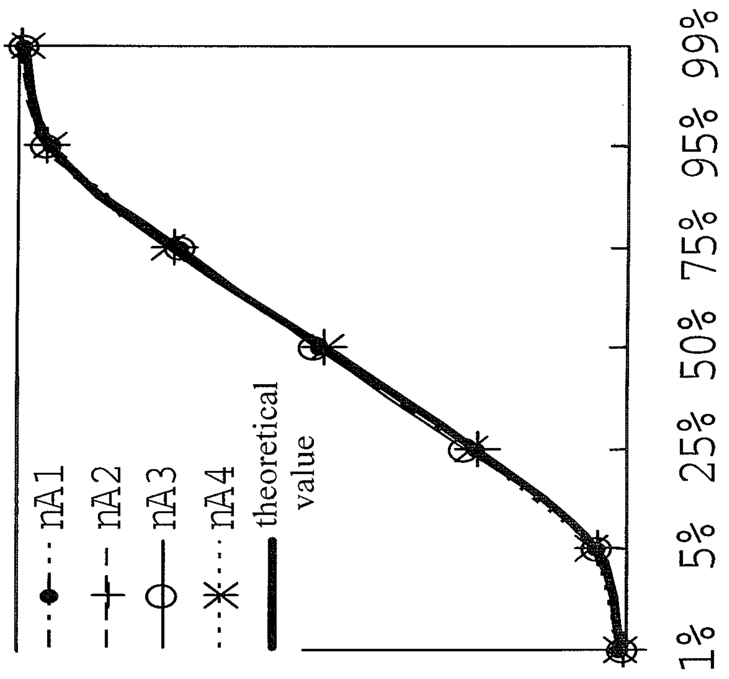

nA1
nA2
nA3
nA4
theoretical value
1%
5%
25%
50%
75%
95%
99%

FIG. 12

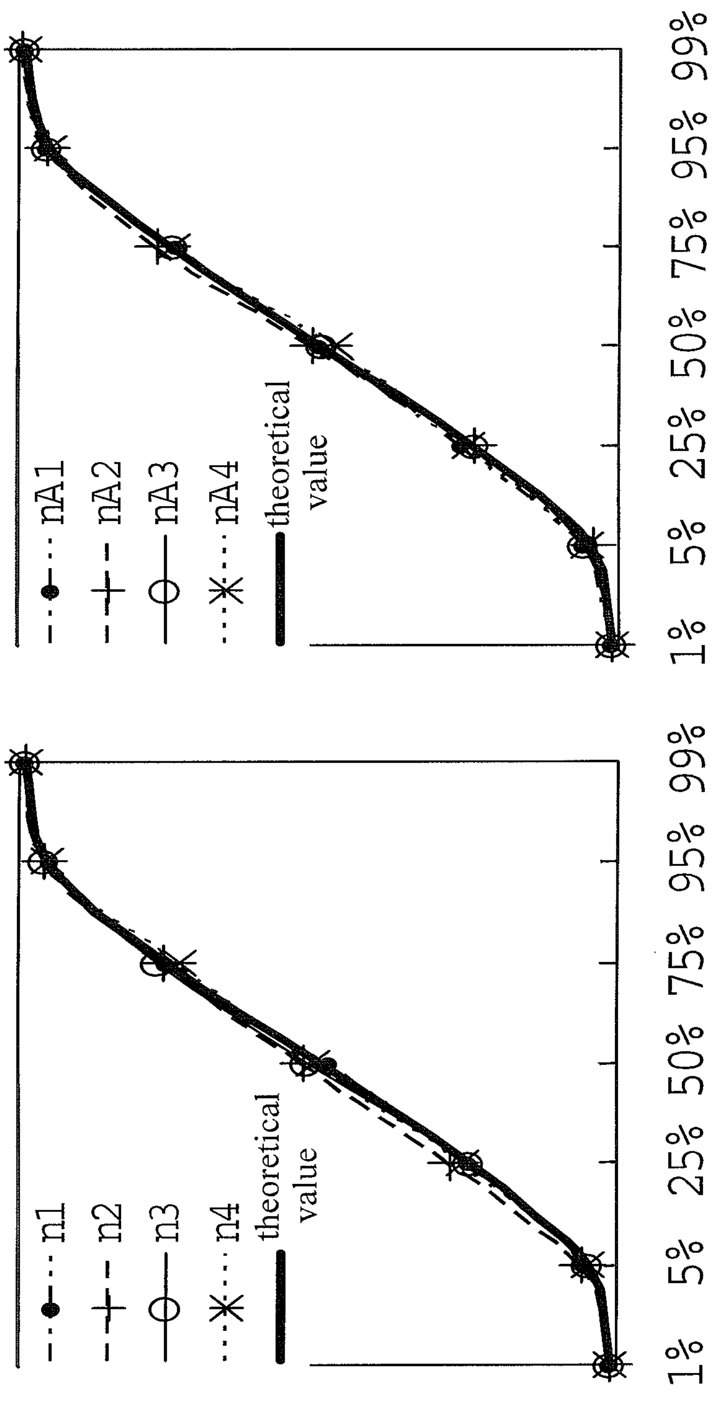
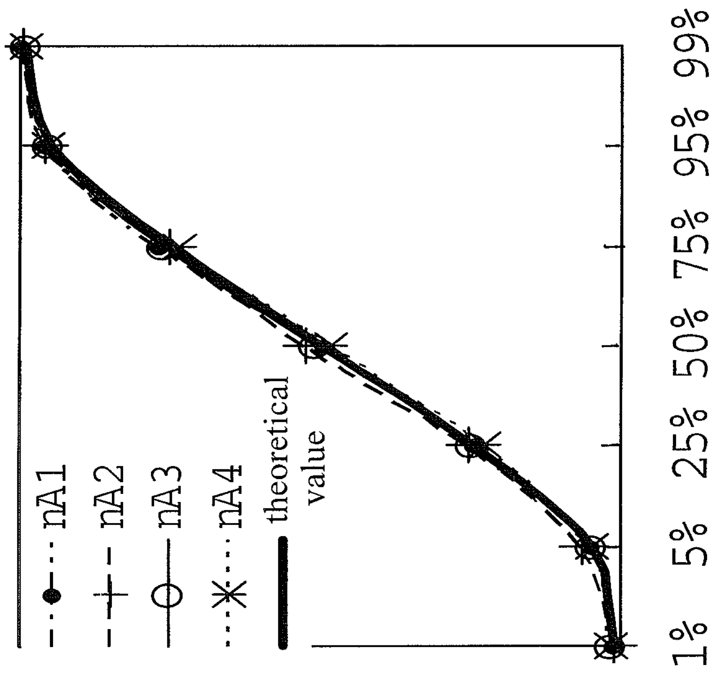

n1
n2
n3
n4
theoretical value
1%
5%
25%
50%
75%
95%
99%
nA1
nA2
nA3
nA4
theoretical value
1%
5%
25%
50%
75%
95%
99%

FIG. 13


nA1
nA2
nA3
nA4
theoretical value
1%
5%
25%
50%
75%
95%
99%

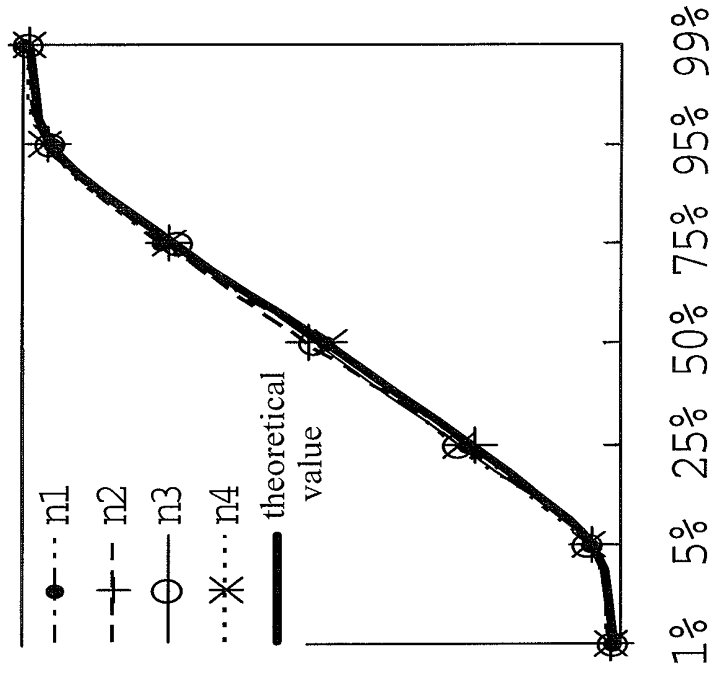

n1
n2
n3
n4
theoretical value
1%
5%
25%
50%
75%
95%
99%

FIG. 14

	n1	n2	n3	n4	nA1	nA2	nA3	nA4
$C < \mu - 2\sigma$	18	33	30	21	22	26	24	18
$C > \mu + 2\sigma$	19	23	17	23	15	24	22	31
$\mu - 2\sigma \leqq C \leqq \mu + 2\sigma$	963	944	953	956	963	950	954	951

FIG. 15

computing precision N (bit)	32	64	96	128	160	192	224	256
generating speed of random number (Gbps)	1.86	1.02	0.71	0.56	0.51	0.42	0.36	0.31

（Genuine Intel（R）CPU 1.5GH_Z 0.99 GB RAM）

FIG. 16

RANDOM NUMBER GENERATOR AND RANDOM NUMBER GENERATING METHOD THEREOF

FIELD OF THE INVENTION

The present invention relates to a random number generator and a random number generating method thereof.

BACKGROUND OF THE INVENTION

Random number has been widely used in various fields, such as computer simulation, sampling, numerical analysis, programming, decision making, encryption, art, entertainment and so on. Therefore, scholars and experts propose various methods for generating random numbers. Owing to high-speed development of the computer, random number generators and random number generating methods are required to meet the needs correspondingly.

Besides, chaos is an expected area for people because it can be simply constituted to generate sequences having various complex variations. Since Von Neumann proposes equation (1) to generate random numbers, many scholars deliver their research report utilizing the equation (1) to generating random numbers.

$$x_{t+1}=4x_t(1-x_t)$$

$$(0<x_t<1,\ t=0,1,2,\ldots) \qquad \text{Equation (1)}$$

Reference 1: Ulam, S. M. and Von Neumann, J., "On Combination of Stochastic Deterministic Processes", Bull, AMS, Vol. 53, p. 1120 (1947).

The reference proposes utilizing equation (1) to generate random numbers.

Reference 2: T. Kohda and A. Kakimoto "Pseudo-random number and chaos", Vol. 27 No. 3 pp. 289-296 (1986).

In reference 2, the threshold value is set to equal 0.5, utilizing equation (1) to generate random numbers can obtain a result with good quality. However, it can output a random number with one bit at one time. It still has disadvantages such as low random number generating speed.

Reference 3: Phatak, S. C. and Rao, S. S., "Logistic map: A Possible Random number Generator", Phys. Rev. E, Vol. 51 No. 4, pp. 3670-3678 (1995).

The reference 3 discloses that utilizing equation (1) can transform x, sequence with U-shaped distribution into uniform sequence. However, the fore-bits and back-bits of transformed sequence are highly related. Utilizing intervals sampling method can decrease the relation. The intervals have to be selected a greater value in order to pass the statistic test.

Reference 4: K. Shono "Chaos engineering", Springer-Verlag Tokyo, Tokyo, 2002.

The reference 4 discloses that utilizing fixed decimal point method implemented in hardware circuit for generating random numbers quickly is effective.

Reference 5: Japanese Invention Patent Application Number 2005-228169.

The reference 5 proposes a method to utilize fixed decimal point method to calculate equation (1) to expand the calculating precision.

These representative references described above disclose methods utilizing equation (1) to generate random numbers. These methods still have problems including the generated random numbers cannot meet several needs required in the

practical field at the same time such as cycle (long cycle), quality (disorder in statistics), generating speed and etc.

SUMMARY OF THE INVENTION

Problems Need to be Solved

The objective of the present invention is to provide a random number generator and a random number generating method both can be adapted to general computers and hardware circuits and utilize equation (1) to generate random numbers and can have many advantages such as high random number generating speed, long cycle, and great quality in practical application.

Means for Solving Problems

The present invention (claim **1**) relates to a random number generator, comprising:

an initial value input unit setting a binary integer having N bits (N≥2 and N is an integer) as an initial value;

an initial value transformation unit transforming a binary sequence having N bits into an integer of 2^m carry number having [((N−1)/m)]+1 digits (m≥1 and m is an integer; [ ] means rounding part being after decimal point down) to utilize equation (1) for carrying out fixed decimal point calculation;

a register used for saving data transformed from the initial value transformation unit and saving input data required for a repetitive calculation of a chaos computer with calculating precision of N bits;

a chaos computing unit setting the integer of 2^m carry number having [((N−1)/m)]+1 digits as an input value to perform an integer division calculation and have a calculation result with 2N bits;

a mixing output unit utilizing fore-N bits of the calculation result with 2N bits of the chaos computing unit as an input value required for a repetitive calculation of the equation (1) and saved in the register and process one-to-one excluding logical calculation in predetermined bits of the calculation result with 2N bits and utilize result with N bits as an output random number;

a random number register used for saving the random number with N bits outputted from the mixing output unit; and

a control unit for generating random number used for controlling the initial value transformation unit, the chaos computing unit and the mixing output unit to generate the random number;

wherein influenced bits of a binary sequence d ($d_0d_1 \ldots d_{2N-1}$) with 2N bits as a calculation result of an input value a ($a_0a_1 \ldots a_{N-1}$) of the chaos computing unit are different in calculating process of the chaos computing unit and have non-uniform distribution characteristic; the mixing output unit performs one-to-one excluding logical calculation and XOR calculation in predetermined bits of the d ($d_0d_1 \ldots d_{2N-1}$) to generate random number r_i (i=0, 1, … N−1); each bit of the random number r_i (i=0, 1, … N−1) is influenced by the input value a in different form; in the d ($d_0d_1 \ldots d_{2N-1}$) between d_i and d_{i+N} (i=0, 1, … N−1) one-to-one excluding logical calculation ($r_i=d_i \oplus d_{i+N}$) is performed.

Besides, the present invention (claim **2**) relates to a random number generating method, a generating random number according to equation (1): $x_{t+1}=4x_t(1-x_t)$ comprising:

setting a binary integer having N bits (N≥2 and N is an integer) as an initial value;

transforming a binary sequence having N bits into an integer of 2^m carry number having $[((N-1)/m)]+1$ digits ($m \geq 1$ and m is an integer; [ ] means rounding part being after decimal point down);

inputting to a chaos computing unit having calculating precision with N bits and calculation result with 2N bits;

utilizing the chaos computing unit to use the equation (1) for an input value a ($a_0 a_1 \ldots a_{N-1}$) to perform fixed decimal point calculation to generate a binary sequence d ($d_0 d_1 \ldots d_{2N-1}$) with 2N bits; the chaos computing unit means a computer having 2m bits calculating capability (calculating capability including multiplication, addition, shift, and logical calculation capability between bits); the chaos computing unit utilizing an integer with N bits to divide into the integer of 2^m carry number having $[((N-1)/m)]+1$ digits and utilize the equation (1) to perform integer division calculation; and

setting fore-N bits of a result with 2N bits d ($d_0 d_1 \ldots d_{2N-1}$) calculated by the chaos computing unit as the input value a ($a_0 a_1 \ldots a_{N-1}$) required for a repetitive calculation of the equation (1);

wherein influenced bits of the binary sequence d ($d_0 d_1 \ldots d_{2N-1}$) with 2N bits as a calculation result of an input value a ($a_0 a_1 \ldots a_{N-1}$) of the chaos computing unit are different in calculating process of the chaos computing unit and have non-uniform distribution characteristic, each bit of the d ($d_0 d_1 \ldots d_{2N-1}$) with 2N bits performs one-to-one excluding logical calculation between predetermined bits to generate the random number with N bits r ($r_0 r_1 \ldots r_{N-1}$); and

wherein the chaos computing unit performs one-to-one excluding logical calculation and XOR calculation in predetermined bits of the d ($d_0 d_1 \ldots d_{2N-1}$) to generate random number r_i ($i=0, 1, \ldots N-1$); each bit of the random number r_i ($i=0, 1, \ldots N-1$) is influenced by the input value a in different form; in the d($d_0 d_1 \ldots d_{2N-1}$), between d_i and d_{i+N}, ($i=0, 1, \ldots N-1$), one-to-one excluding logical calculation ($r_i = d_i \oplus d_{i \oplus i+N}$) is performed.

Effect of the Present Invention

1. The present invention utilizes fixed decimal point method to calculate equation (1). Therefore, it can calculate more quickly and reasonably than utilizing float decimal point method to calculate.

2. When the present invention utilizes fixed decimal point method to calculate equation (1), the chaos computing unit can perform best division calculating and can make equation (1) be easily expanded and can generate a chaos sequence having a longer cycle.

3. The mixing method of the present invention can generate a binary random number with bits equaling to computing precision and transform the chaos sequence having U-shaped distribution into a uniformly distributed binary random number.

4. The present invention can utilize a simplified process to obtain a random number generator adapted to various computing systems and can be easy to improve the computing precision and can generate a result having high speed, long cycle and great quality in statistics. This kind of industry technique is expected in its simplified process, performance and low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram to show components of a random number generator in accordance with the present invention;

FIG. **2** is a chart to show relation between computing precision and function computing speed while m=32 in accordance with the present invention;

FIG. **3** is an equation to show integer with N bits (c=ab) while being expanded to a binary number in accordance with the present invention;

FIG. **4** is a comparison diagram to show d**1** and r in accordance with the present invention;

FIG. **5** is a distribution diagram to show the relation between frequency and fore-eight bits of d**1** in accordance with the present invention;

FIG. **6** is a distribution diagram to show the relation between frequency and fore-eight bits of r in accordance with the present invention;

FIG. **7** is a diagram to show the relation between r and d**1** in accordance with the present invention;

FIG. **8** is a flowchart to show operation of the random number generator in accordance with the present invention;

FIG. **9** is a graph to show result of equi-distribution test in accordance with the present invention;

FIG. **10** is a graph to show result of serial test in accordance with the present invention;

FIG. **11** is a graph to show result of poker test in accordance with the present invention;

FIG. **12** is a graph to show result of coupon collector's test in accordance with the present invention;

FIG. **13** is a graph to show result of run test in accordance with the present invention;

FIG. **14** is a graph to show result of birthday spacings test in accordance with the present invention;

FIG. **15** is a graph to show result of serial correlation test in accordance with the present invention; and

FIG. **16** is a chart to show relation between computing precision and random number generating speed while m=32 in accordance with the present invention.

DESCRIPTION OF NUMBERS IN THE DRAWINGS

100	random number generator
102	initial value input unit
104	initial value transformation unit
106	register
108	chaos computing unit
110	mixing output unit
112	random number register
114	control unit for generating random number

DETAILED DESCRIPTION OF THE INVENTION

The embodiment and effect of the present invention are described as below referring to drawings. The random number generator and the random number generating method in the present invention take advantage of an effective calculating method and mixing method.

FIG. **1** is an embodiment to show constitution of the random number generator in accordance with the present invention. The random number generator **100** is adapted to a binary sequence with N bits and utilize a chaos computing unit having 2m ($m \geq 1$ and m is an integer) bits calculating capability to perform repetitive calculating. The random number generator **100** is used for excluding logical calculation between fore-N bits and back-N bits of a result with 2N bits generated after each calculating of the chaos computing unit in order to generate a binary random number sequence with good quality and long cycle in high speed. The random number generator **100** includes an initial value input unit **102**, an initial value transformation unit **104**, a register **106**, a chaos computing unit **108**, a mixing output unit **110**, a random number register **112** and a control unit for generating the random number **114**.

The initial value input unit **102** receives the part being after decimal point of the inputted binary sequence with N bits used for performing fixed decimal point. We utilize a fixed decimal point calculation method to calculate equation (1) in order to obtain a better efficiency than utilizing a float decimal point calculation method. In general, scientific calculating with high precision often adopts the float decimal point calculation method. However, when utilizing the float decimal point calculation method (symbol=1 bit; index number=11 bits; value portion=52 bits) to calculate equation (1), we can observe that the used index portion is not beyond six bits. Thus it is so apparent whether calculating in hardware or software, utilizing the fixed decimal point calculation method to calculate equation (1) is more reasonable and effective.

The initial value transformation unit **104** transforms a binary sequence with N bits into an integer of 2^m carry number having [((N−1)/m)]+1 digits (for example, N=128 bits m=32 bits) in order to prepare for utilizing fixed decimal point calculation method to calculate equation (1). Utilizing an integral calculating to calculate equation (1) by the fixed decimal point calculation method can obtain a higher computing speed and an easier expansion of the computing precision. When utilizing a binary computer to calculate equation (1) by the fixed decimal point calculation method with N-bits calculating precision, the value of x_t varies in the divergent interval ($\frac{1}{2}^N$, $1\frac{1}{2}^N$). Therefore, with respect to computing system of 2m bits (such as 64 bits), it can be easy to perform an integral calculating for equation (1) when the computing precision is below m (such as 32 bits). Because multiplication and addition of integral calculating can be easy to expand the precision by division calculating, utilizing integer to perform the fixed decimal point calculation method for equation (1) can easily expand the calculating precision.

The register **106** is used for saving input integer of 2^m carry number having [((N−1)/m)]+1 digits required for a repetitive calculation of a chaos computer. Referring to FIG. **2**, expansion of the computing precision can make the calculating speed of equation (1) lower rapidly. Therefore, it is necessary to achieve that performing one time can generate random number with more bits. Besides, we know how to utilizing a binary sequence with constant length for calculating of bits (such as shift, replacement and logical calculation) to obtain a more complicate sequence. However, the problem also exists that repetitive calculating for generating random number repeated more times can take more time.

The chaos computing unit **108** setting the integer of 2^m carry number having [((N−1)/m)]+1 digits as an input value to process integral calculating for equation (1). The calculating of the integer of 2^m carry number having [((N−1)/m)]+1 digits has the same principles as the decimal system so we neglect the related explanation.

The mixing output unit **110** utilizes fore-N bits (d**1**) of the calculation result with 2N bits (d) of the chaos computing unit **108** as an input value required for a repetitive calculation of the equation (1) and saved in the register **106** and process a one-to-one excluding logical calculation in predetermined bits (between d_i and d_{i+N} (i=0, 1, . . . N−1)) of the calculation result with 2N bits and utilize result with N bits as output random number $r(r_0r_1 \ldots r_{N-1})$. The mixing method the present proposes has a sequence (d) with 2N bits and with apparently non-uniform distribution. By only processing one-to-one excluding logical calculation in predetermined bits, it can generate a random number sequence with uniform distribution and the same calculating precision.

Utilizing integral calculating for equation (1) to expand to a calculating of a binary number and observe it and can infer the mixing method proposed in the present invention. Set the part being after decimal point of a decimal x, with N bits as an integer a $(a_0a_1 \ldots a_{N-1})$ with N bits. Thus, x_t=0.a. Set the part being after decimal point of a decimal $1-x_t$ as an integer b $(b_0b_1 \ldots b_{N-1})$ with N bits. Therefore, $1-x_t$=0.b. The integer a and the integer b are complementary. Here, set c=ab, d=4c (c, d are integers with 2N bits), so d=4ab becomes a form of integral calculating of equation (1). The fore-N bits of d $(d_0 d_1 \ldots d_{2N-1})$ are the part being after decimal point of x_{t+1}.

Set the fore-N bits of d as an integer with N bits d**1** and set the back-N bits of d as an integer with N bits d**2**. Thus, x_{t+1}=0.d**1**. Set integers a, b, c, d to expand to binary numbers. When each bit is $(a_0a_1 \ldots a_{N-1})$, $(b_0b_1 \ldots b_{N-1})$, $(c_0c_1 \ldots c_{2N-1})$, and $(d_0d_1 \ldots d_{2N-1})$, we can investigate the calculating process and result of c=ab, d=4c. Because the multiplication of the integer 4 in d=4c can be accomplished by shifting leftward. We can investigate the calculating process and result of c=ab (two binary integers with N bits a, b).

Referring to FIG. **3**, set c=ab to expand to a binary number. We can know the relation between each bit c_i of c and each bit of a and b can be shown in equation (2).

$$c_i = \begin{cases} 0 + k_{ci} & (i = 0) \\ \sum_{j=1}^{i} (b_{i-j}a_{j-1}) + k_{ci} & (1 \le i \le N) \\ \sum_{j=i}^{2N-1} (b_{j-1-(N-1)}a_{i-j+(N-1)}) + k_{ci} & (N < i \le 2N-1) \end{cases} \quad \text{Equation (2)}$$

(k_{ci} is carried from c_{i+1}, while i=2N+1, k_{ci}=0)

Utilizing c_i to be shown by inputting the function of a to obtain equation (3).

$$c_i = \begin{cases} f_i() & (i = 0) \\ f_i(a_0, \ldots, a_{i-1}) = f_i(a_0 \sim a_{i-1}) & (1 \le i \le N-1) \\ f_i(a_{N-1}, \ldots, a_{i-N}) = f_i(a_{N-1} \sim a_{i-N}) & (N \le i \le 2N-1) \end{cases} \quad \text{Equation (3)}$$

The number of each bit of a in c_i, as complexity of each bit, can be shown in s_{ci}. The complexity of each bit of c can be shown in equation (4).

$$s_{ci} = \begin{cases} i & (0 \le i \le N-1) \\ 2N - i & (N \le i \le 2N-1) \end{cases} \quad \text{Equation (4)}$$

Because d=4c, each bit of d can be expressed in equation (5). While shifting leftward, the bit from the most left position shifts to the most right position.

$$d_i = \begin{cases} c_{i+2} & (0 \le i \le 2N-3) \\ c_{i-2N+2} & (2N-2 \le i \le 2N-1) \end{cases} \quad \text{Equation (5)}$$

According to investigations described above, it is apparent that the goal is each bit for generating a binary sequence having the highest complexity. The mixing method proposed in the present invention is utilizing equation (6) to generate a binary sequence r. Each bit of r has a complexity s. The complexity s_{ri} is N (bits of computing precision).

$$
\begin{aligned}
r &= d1 \oplus d2 \\
&= (d_0 \oplus d_N)(d_1 \oplus d_{N+1}) \ldots (d_{N-1} \oplus d_{2N-1})
\end{aligned}
\qquad \text{Equation (6)}
$$

$\oplus$ means excluding logical calculation (XOR).

The effect of equation (6) as a mixing method can be explained by utilizing FIGS. **4**, **5**, **6** and **7**. FIG. **4** is a locus diagram to show d**1** and r while utilizing the fixed decimal point calculation method (128 bits) to perform equation (1) (Transform d**1** and r as the part being after decimal point performed by the fixed decimal point calculation method into a value between 0 and 1). The locus of d**1** is chaotic and dynamic according to equation (1). When r closes to 0, it shows monotonously increasing rule. However, in the locus of r cannot be found this rule. There is none rule or relation can be seen between d**1** and r. FIG. **5** is a distribution diagram to show the relation between frequency and fore-eight bits of d**1** in accordance with the present invention. FIG. **6** is a distribution diagram to show the relation between frequency and fore-eight bits of r in accordance with the present invention. The samples are 65536. The distribution of d**1** is approximately U-shaped. The distribution of r is approximately uniform. The result of statistic test for r can be described as below.

Because the output random number r with N bits can be generated by equation (6), it may have certain relation between r and d**1**. If there is linear relation between r and d**1**, r can infer d**1**. That is why from a certain binary sequence can infer other binary sequence. Thus, with respect to the corresponding relation between r and d**1**, it has to be recognized in bitmap figure. Because we cannot utilize high precision (such as 128 bits) to calculate to show the corresponding relation between r and d**1**, we utilize computing precision (16 bits) to observe the corresponding relation of r and d**1**. FIG. **7** is a diagram to show the relation between r and d**1** in accordance with the present invention. In FIG. **7**, r is x axis and d**1** is y axis. FIG. **7** is all possible relation between r and d**1** when the computing precision is 16 bits. Further, because equation (1) is symmetrical, we utilize input value a (1-32767) to calculate, we obtain a result that d**1** has 28671 values and r has 32767 values. Referring to FIG. **7**, we can see that the distribution of d**1** calculated from the input value a is not uniform. With respect to the non-uniform distribution of the d**1**, the distribution of r is uniform between 1 to 65535. Thus, by the mixing method in equation (6), non-uniform distribution of d**1** transforms into uniform distribution of random number r. There is no linear relation between r and d**1**. On the basis of the result described above, utilizing equation (1) to calculate can obtain a non-uniform x_t (d**1**) sequence and utilizing the equation (6) to mix can obtain a uniform distribution of random number r. From the investigation of the equation (6) for confirming its effect, it can conclude that the mixing method proposed in present invention is effective.

A random number register **112** is used for saving random number with N bits outputted from the mixing output unit. A control unit for generating random number **114** is used for controlling the initial value transformation unit **104**, the chaos computing unit **108** and the mixing output unit **110** to generate the random number. FIG. **8** is a flowchart to show operation of the random number generator **100** in accordance with the present invention. Set binary sequence having N bits as initial value (s**102**). Then, transform the binary sequence having N bits into integer a of 2^m carry number having [((N−1)/m)]+1 digits (s**104**). For example, we can suppose N=128 bits and m=32 bits in order to be adapted to the practical hardware design. Then, save a in the register (s**106**). Then, the chaos computing unit sets the integer a saved in the register as input value to perform the calculating of the equation (1) (s**108**). Accordingly, the mixing output unit utilizes fore-N bits (d**1**) of the calculation result with 2N bits to save in the register.

Perform the excluding logical calculation between the fore-N bits of d (d**1**) and the back-N bits of d (d**2**) (s**110**). Accordingly, a random number register saves the random number with N bits (output random number r)(s**112**). Then, the operational steps (as shown in the flowchart) end. If the random number has to be generated continuously, the steps between s**108**-s**112** have to be performed repeatedly.

The random number generated from the random number generator while the computing precision N equaling 128 bits, is performed by seven tests. Because the output random number obtained from the random number generator is a binary sequence test χ^2 is adopted. χ^2 distribution is an effective approximate value only when samples are great enough. However, when samples are greater, the partial regularity existing in the sequence may be hidden. Thus, we perform χ^2 test with various quantities of samples.

The statistic test described above is performed with the random number r with 128 bits generated every time. Therefore, the possible regularity between every time of calculating can be hidden. Thus, with respect to the same test, we only obtain a sample data adopting method according to each time to calculate equation (1) and also can perform χ^2 test.

χ^2 test includes equi-distribution test, serial test, poker test, coupon collector's test, run test, birthday spacings test and so on. Each test is performed one thousand times. With respect to one thousand obtained values can be classified to seven intervals such as P<1%, 5%, 25%, 50%, 75%, 95%, 99% to compare with theoretical values. Moreover, it also includes serial correlation test. Serial test is calculated in 95% confidence interval.

With respect to the test of r with 128 bits, the result can be shown when selected samples are n**1**, n**2**, n**3**, n**4**. With respect to the fore-bits of r with 128 bits as one sample, the result can be shown when selected samples are nA**1**, nA**2**, nA**3**, nA**4**. Referring FIGS. **9** to **15**, FIG. **9** is the result of the equi-distribution test when selecting integer with 8 bits as samples. Samples are four such as n**1**(nA**1**)=2^{16}, n**2**(nA**2**)=2^{16}×10, n**3**(nA**3**)=2^{16}×100, n**4**(nA**4**)=2^{16}×1000 revealing good results. FIG. **10** is the result of the serial test when selecting integer with 8 bits as samples. Samples are four such as n**1**(nA**1**)=2^{20}, n**2**(nA**2**)=2^{20}×10, n**3**(nA**3**)=2^{20}×100, n**4** (nA**4**)=2^{20}×1000 revealing good results, too.

FIG. **11** is the result of the poker test when selecting integer with 3 bits as samples, dividing to five groups and setting the degrees of freedom as four. Samples are n**1**(nA**1**)=2^{10}, n**2**(nA**2**)=2^{10}×10, n**3**(nA**3**)=2^{10}×100, n**4**(nA**4**)=2^{10}×1000. When samples are n**1**(nA**1**)=2^{10}, the quantities of χ^2 values in 1% interval is beyond 2%. However, when samples increase, the remaining three tests reveal good result. Therefore, we can suppose that it is because the samples are too less. FIG. **12** is the result of the coupon collector's test when setting the degrees of freedom as 30. Samples are n**1**(nA**1**)=2^{10}, n**2** (nA**2**)=2^{10}×10, n**3**(nA**3**)=2^{10}×100, n**4**(nA**4**)=2^{10}×1000 revealing good result. FIG. **13** is the result of the Up run test when selecting integer with 32 bits as samples. Samples are n**1**(nA**1**)=2^{16}, n**2**(nA**2**)=2^{16}×10, n**3**(nA**3**)=2^{16}×100, n**4** (nA**4**)=2^{16}×1000 revealing good result, too.

FIG. **14** is the result of the Birthday spacing test when selecting integer with 25 bits as samples, setting reference number $m=2^{25}$, $n=2^9$ and setting the degrees of freedom as three. The sampling times are **n1**(nA**1**)=10^3, **n2**(nA**2**)=10^4, **n3**(nA**3**)=10^5, **n4**(nA**4**)=10^6 revealing good result, too. FIG. **15** is the result of the serial correlation test when selecting integer with 4 bits as samples. Samples are **n1**(nA**1**)=2^{10}, **n2**(nA**2**)=$2^{10}\times10$, **n3**(nA**3**)=$2^{10}\times100$, **n4**(nA**4**)=$2^{10}\times1000$, in 95% confidence interval, revealing good result, too (the quantities of the correlation coefficient c in one thousand tests are basically greater than 950 in the $\mu-2\sigma\le c\le\mu+2\sigma$). The results of strict tests described above reveal that the tested sequence has good characteristics of uniform distribution in statistics. The tests are described in the reference as follows: (Donald E. Knuth, "The Art of Computer Programming Vol. 2, Seminumerical Algorithms, Third Edition").

INDUSTRIAL APPLICABILITY

With respect to the present invention, a random number having a chaotic long cycle generated from a nonlinear function in high generating speed can be investigated by strict statistic tests. The random number can be widely used in various fields, such as computer simulation, sampling, numerical analysis, programming, decision-making, encryption, art, entertainment and so on.

In the present invention, with respect to generating the random number, we just utilize the integral calculation (such as multiplication, addition, shift, logical calculation and so on). Further, the integer can be easy to perform division calculating. Therefore, even in different computing systems (general computer (OS), Hardware circuit, micro computer). As long as performing basic integral calculating, it can be achieved that the same input value can obtain the same output value.

When the computing precision equals N bits in the present invention, each calculating of the equation (1) (mixing one time) can output a random number with N bits and having greatest complexity (N). The present invention solved the problem of the low generating speed due to expanded computing precision. The present invention achieved the goal of the high generating speed. The relation between computing precision and generating speed of random number can be shown in FIG. **16**. It can achieve a high level result in the practical application. Due to the easy integral calculating for computer such as multiplication, addition, shift, logical calculation and etc, it can be very easy to implement to integrated circuit and have a higher generating speed for generating the random number.

The present invent is different from the conventional generating method which cannot be used for securing information safety. The present invention utilizes the chaos function to generate the random number and utilize excluding logical calculation with single direction to generate a partial random number r. Therefore, x_r. cannot be inferred and other random number cannot be inferred either. Thus, the random number generator proposed in present invention can meet various needs and have great expansion and can be used in scientific research, for securing information safety and in various industries.

While the invention herein disclosed has been described by means of specific embodiments, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope and spirit of the invention set forth in the claims.

The invention claimed is:

1. A random number generator utilizing integral calculation, comprising:

an initial value input unit for setting a binary integer having N bits (N≥2 and N is an integer) as an initial value;

an initial value transformation unit for transforming a binary sequence having N bits into an integer of 2^m carry number having [((N−1)/m)]+1 digits (m≥1 and m is an integer wherein [ ] is an operator used to round a part being after decimal point down) to utilize equation (1): $x_{t+1}=4x_t(1-x_t)$, (where $0<x_t<1$, t is a non-negative integer) for carrying out a fixed decimal point calculation;

a register used for saving data transformed from the initial value transformation unit and saving input data required for a repetitive calculation of a chaos computer with calculating precision of N bits;

a chaos computing unit for setting the integer of 2^m carry number having [((N−1)/m)]+1 digits as an input value to perform an integer division calculation and have a calculation result with 2N bits;

a mixing output unit for utilizing fore-N bits of the calculation result with 2N bits of the chaos computing unit as an input value required for a repetitive calculation of the equation (1) and saved in the register, processing a one-to-one excluding logical calculation in predetermined bits of the calculation result with 2N bits, and utilizing the calculation result with N bits as an output random number;

a random number register for saving the output random number with N bits outputted from the mixing output unit; and

a control unit for generating a random number used for controlling the initial value transformation unit, the chaos computing unit, and the mixing output unit to generate another random number;

wherein influenced bits of a binary sequence d ($d_0d_1 \ldots d_{2N-1}$) with 2N bits as a calculation result of an input value a ($a_0a_1 \ldots a_{N-1}$) of the chaos computing unit are different in a calculating process of the chaos computing unit and have a non-uniform distribution characteristic;

the mixing output unit performs a one-to-one excluding logical calculation and an XOR calculation in predetermined bits of the ($d_0d_1 \ldots d_{2N-1}$) to generate a random number r_i (i=0, 1, . . . N−1); each bit of the random number r_i (i=0, 1, . . . N−1) is influenced by the input value a in a different form; and in the ($d_0d_1 \ldots d_{2N-1}$) between d_i and d_{i+N} (i=0, 1, . . . N−1) a one-to-one excluding logical calculation (r_i=d_i{circumflex over (+)}d_{i+N}) is performed, wherein the binary sequence d ($d_0d_1 \ldots d_{2N-1}$) and the input value a ($a_0a_1 \ldots a_{N-1}$) has a predetermined relationship therebetween to generate the random number r_1 with the highest complexity.

2. A random number generating method utilizing integral calculation according to equation (1): $x_{t+1}=4x_t(1-x_t)$, where $0<x_t<1$, t is a non-negative integer, comprising:

setting a binary integer having N bits (N≥2 and N is an integer) as an initial value;

transforming a binary sequence having N bits into an integer of 2^m carry number having [((N−1)/m)]+1 digits (m≥1 and m is an integer wherein [ ] is an operator used to round a part being after decimal point down);

inputting to a chaos computing unit having a calculating precision with N bits and a calculation result with 2N bits;

utilizing the chaos computing unit to perform the equation (1) for an input value a ($a_0a_1 \ldots a_{N-1}$) to perform a fixed decimal point calculation to generate a binary sequence d ($d_0d_1 \ldots d_{2N-1}$) with 2N bits; the chaos computing unit means a computer having 2^m bits calculating capability including multiplication, addition, shift, and logical calculation capability between bits; the chaos computing unit utilizing an integer with N bits to divide into the integer of 2^m carry number having [((N−1)/m)]+1 digits; and

utilizing the equation (1) to perform an integer division calculation; and setting fore-N bits of a result with 2N bits d ($d_0d_1 \ldots d_{2N-1}$) calculated by the chaos computing unit as the input value a ($a_0a_1 \ldots a_{N-1}$) required for a repetitive calculation of the equation (1);

wherein influenced bits of the binary sequence d ($d_0d_1 \ldots d_{2N-1}$) with 2N bits as a calculation result of an input value a ($a_0a_1 \ldots a_{N-1}$) of the chaos computing unit are different in a calculating process of the chaos computing unit and have a non-uniform distribution characteristic,

each bit of the d (($d_0d_1 \ldots d_{2N-1}$) with 2N bits performs a one-to-one excluding logical calculation between predetermined bits to generate a random number with N bits r ($r_0r_1 \ldots r_{N-1}$);

wherein the chaos computing unit performs a one-to-one excluding logical calculation and an XOR calculation in predetermined bits of the d ($d_0d_1 \ldots d_{2N-1}$) to generate a random number r_i (i=0, 1, . . . N−1); each bit of the random number r_i (i=0, 1, . . . N−1) is influenced by the input value a in a different form; and in the d($d_0d_1 \ldots d_{2N-1}$), between d_i and d_{i+N}, (i=0, 1, . . . N−1), a one-to-one excluding logical calculation (r_i=d_i{circumflex over (+)}d_{i+N}) is performed; and wherein the binary sequence d ($d_0d_1 \ldots d_{2N-1}$) and the input value a ($a_0a_1 \ldots a_{N-1}$) has a predetermined relationship therebetween to generate the random number r_i with the highest complexity.

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