Integrated Random-Signal Source Utilizing CMOS Chaos Multivibrator

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Introduction
For the purpose of investigating the electronics application of deterministic chaos, we have developed several types of chaos-generating devices and circuits with simple structures. Among them, the CMOS chaos multivibrator has the merit of self-oscillation and was most easily implemented in the integrated circuit. In this paper we demonstrate its application to random signal generation and discuss its performance.

Chaos Multivibrator
Chaos multivibrator (CMV) is a modification of the conventional CMOS multivibrator with its resistors replaced by inverters as is shown in Fig.1. This allows the pulse width in a certain cycle be determined by the pulse in the preceding cycle following a return-map function. We have fabricated the circuit and experimentally obtained the chaotic waveform as is shown in Fig.2. The Lorenz plot constructed from this was analytically well explained by the circuit model.

Randomness of a Single CMV Output
Figure 3 shows the auto-correlation of the output measured for a single CMV fabricated with the CMOS masterslice. Correlation was below 0.1 when sampled with the period near the approximate period of the circuit as is shown in Fig.3(b). The approximate frequency (or period) was roughly determined from the observed chaotic waveform and has the meaning of the frequency determined by C and the average resistance of the inverter used.

Although the correlation below 0.1 seemed to show that the output from the single CMV was sufficiently random, the correlation plot between the adjacent sampled data Xn and Xn+1, shown in Fig.4 revealed the tendency of positive correlation. This originates from the return-mapping nature of chaos creation.

Summation of Two CMV Outputs
Therefore, to obtain sufficiently random signals, the output from two identical CMVs were summed. Although the units are identical, they produce different waveform after operating for a few cycles thanks to the sensitiveness of chaos creation to the initial condition. The resultant correlation plots are shown in Fig.5. When sampled with the interval of 10 times of the approximate period, as is shown in the figure, the correlation almost vanished.

Data of appearance interval were obtained from the experimental results. The signal height was divided in 10 sections and the relationship between the appearance frequency and the interval was obtained for every section. Figure 6 shows an example for the section of the height 80 to 90%. If the event occurs completely random with the probability p, the probability Pn for the occurrence of such event with the interval r is described by the geometrical distribution Pn = p(1-p)^n. In Fig.6 this distribution is drawn by the broken line and it fairly fits to the measured distribution.

Figure 8 shows the height distribution of the signal obtained from 102400 measured data. The distribution shows nearly symmetrical and Gaussian shape.

Features
Results mentioned above show that the summation of two CMVs' output can be considered as a random signal. This type of random signal source occupies much smaller area, dissipates smaller power and has wider bandwidth than the random signal source obtained by the amplification of the thermal noise. Due to its sensitiveness to the initial condition, CMV -pair noise source does not fluctuate in accordance with the fluctuation of the power source even if a pair is installed on the same chip.

Summary
A novel random-signal source with the CMOS chaos multivibrator was fabricated and its performance was experimentally demonstrated. This is superior to the random signal sources ever proposed to be implemented in the integrated circuit. This signal source is therefore applicable to the Boltzmann machine and other novel computation architecture.

Acknowledgement
Part of this work was supported by the Ministry of Education, Science, Sports and Culture under the Grant-in-Aid for Scientific Research on the Priority Area, “Ultimate Integration of Intelligence on Silicon Electronic Systems”.

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Fig.1CMOS Chaos multivibrator(CMV).

Fig.2 (A)Waveform and (B)Lorenz plot of CMV output.

Fig.3 Auto-correlation of the single CMV output sampled with (a)50 ns/ Sample and (b) 2.5 µs/ Sample.

Fig.4 Correlation plot of a single CMV output.

Fig.5 Correlation plot of the summed output of CMVs.

Fig.6 Appearance distribution of the summed output.

Fig.7 Signal height distribution of the summed output.