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간단한 Analog 기억장치의 제작과 그 응용

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A Simple Fast Analog Storage Device and Its Applications

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요 약. 큰 입력저항을 갖는 20개의 sample and hold가 MOSFET으로 switching되는 간편하면서도 비용이 적게드는 analog 기억장치를 제작하였다. 이것은 digital로 3 KHz.까지 임의로 조절되는 shift register로 연결되어 있다. 이 장치의 유용성을 보이기 위해 square와 sine파 및 fast-scan voltammetry와 differential pulse polarography의 전류—시간 변화와 같은 전기화학적 실험을 행하였다.

ABSTRACT. An inexpensive, yet convenient analog storage device was constructed. Sequentially MOSFET-switched 20 sample and holds equipped with a high input impedance preamplifier were parallelly matched to the digitally controlled shift register system in variable speeds up to 3 kHz.

To verify its usefulness, square wave train, sinusoidal wave and some electrochemical data, such as fast-scan voltammogram and transient current-time curves of differential pulse polarography were tested.

1. INTRODUCTION

Storing fast transient signals is often encountered in kinetics and electrochemistry. Generally, an oscilloscope is used for this purpose; the oscilloscopic signial, however, cannot be used for precise data because of considerable reading error. Thus, the digital computer is suitable for this purpose. But the cost of the digital computer system increases rapidly as the speed requirements for the analog-to-digital-converter and the momory capacity become more demanding.

A new class of integrated circuits performing high speed acquisition, so called charge coupled device[1,2] and bucket brigade device[3~5] have been developed, and an analog storage register of the speed up to several MHz with the cost of $1,000 has been appeared[6]. Recently, a microprocessor has been employed for the data acqisition and processing[7,8].

In general, though the analog storage system is instrumentally simple, it has technical difficulties in maintaining the precision, compared to the digital memory system; *i.e.*, it is not possible to store the analog signal for a long time without deterioration despite the fact that it is convenient to control the speed because the sampling speed is determined only by RC time constant of the sample and hold circuit.

Since it is very desirable to have a simple fast data acquisition device in the laboratory, a new improved inexpensive (~$170) analog device using high input impedance MOSFET switches and FET operational amplifiers was constructed. Its function and application to some electrochemical experiments using this device to show the usefulness are described.

2. INSTRUMENTATION

Simple sample and hold circuits[9] with two bipolar transistors which are used as switches instead of mechanical ones are shown in *Fig.* 1. The replacement of mechanical switches is mainly due to the improvement of its acquisition time characteristics[10].

In *Fig.* 1, as transistor Q_1 is ON for 5RC, the input voltage is attained across the C(R is equal to the sum of the ON-resistance of Q_1 and the output impedance of the input signal source). When Q_1 is OFF and Q_2 is ON, the output of the voltage follower is read for the measurement. However, the operational amplifier A has a problem of bias current in two inputs, so the bias current-compensated sample and hold circuit[11] often be used.

The storage part of our device is illustrated in *Fig.* 2. S_1 and S_2 are MOSFET-switches (CD4016, RCA) whose ON-resistance is about 50 ohms, while the OFF-resistance is on the order of 10^{12} ohms(in *Fig.* 2, it is drawn simply as FET-type but each switch consists of four MOSFETS)[12].

The leakage of the switch of this type is reported to be negligible[13]: also, the voltage drop error can be minimized by reading the output voltage with a follower circuit whose input impedance is 10^{12} ohms(μA 740, Fairchild). Other 19 identical channels as the circuit in the dotted enclosure are parallelly connected. As twenty 'a' terminals are actuated sequentially by the high speed logic circuit suitable for experimental speed, the output voltage of the preamplifier is sampled sequentially into 20 channels. The sampled signals may be recorded on a strip-chart recorder by actuating 'b' terminals sequentially with a low speed pulses which is slow enough for recording.

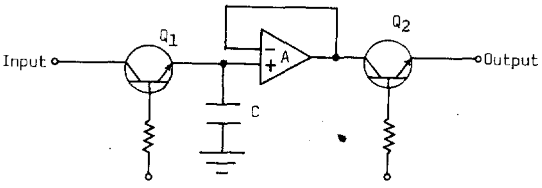

Fig. 1. Transitor-switched sample and hold.

The schematic diagram of the logic board which carries out sequential switchings of the storage part is shown in *Fig.* 3. When a pulse is entered the flip-flops through the start-switch, the logic circuit consisting of flip-flops and AND-gates activates the shift registers (7496, Fairchild), and the shift registers transfer one pulse each sequentially from right to left corresponding to the clock signal generated from the astable multivibrator (timer 555, Fairchild) of which the frequency has been adjusted precisely. Meanwhile the light emission of a LED indicates the shift register in operation. The common emitter configuration of the transistor array (FμA3045, Fairchild) lift the output of the TTL (5 volts) to the gate input of the

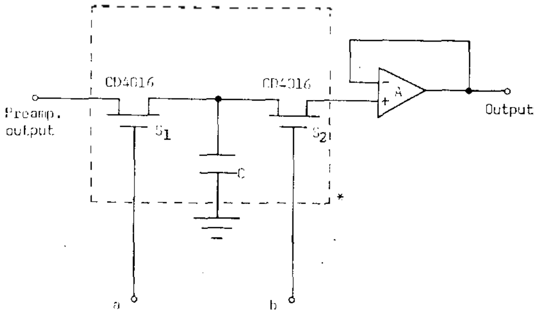

Fig. 2. Storage section. A : μA740, C : 1μF. Terminals. *a* and *b* are for switchings.

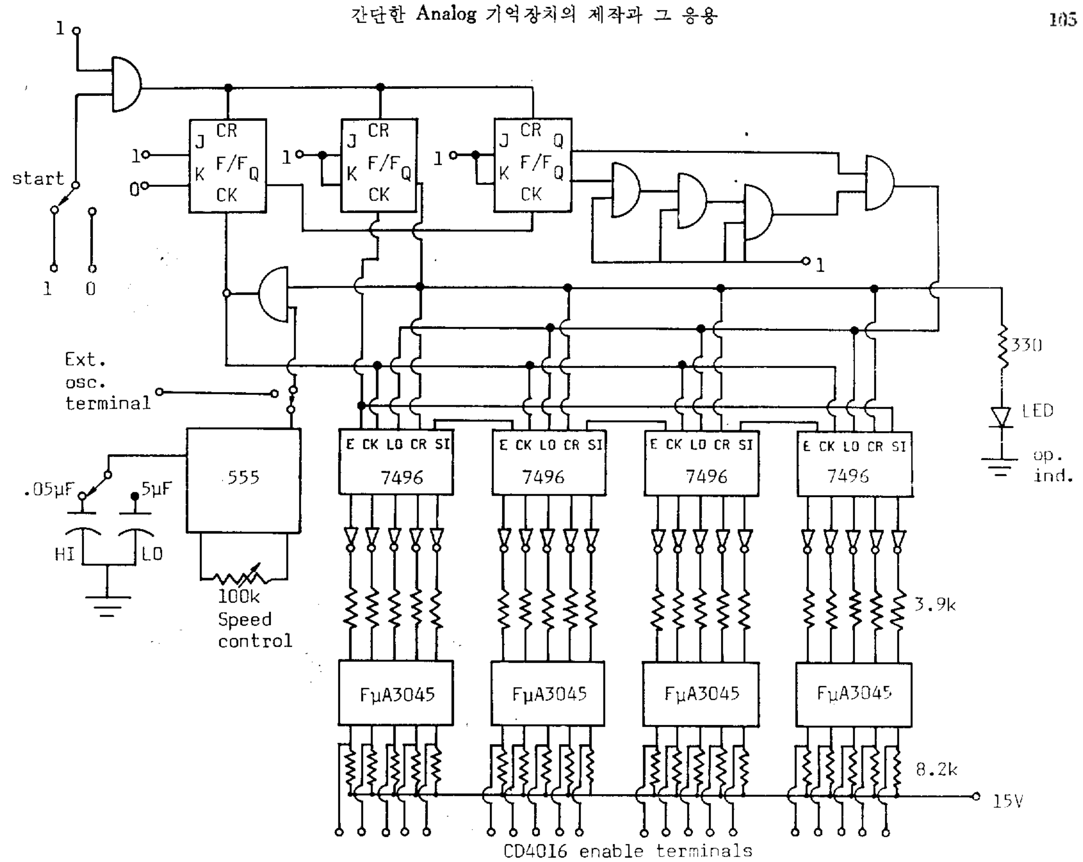

Fig. 3. **Digital logic circuit for switchings.**

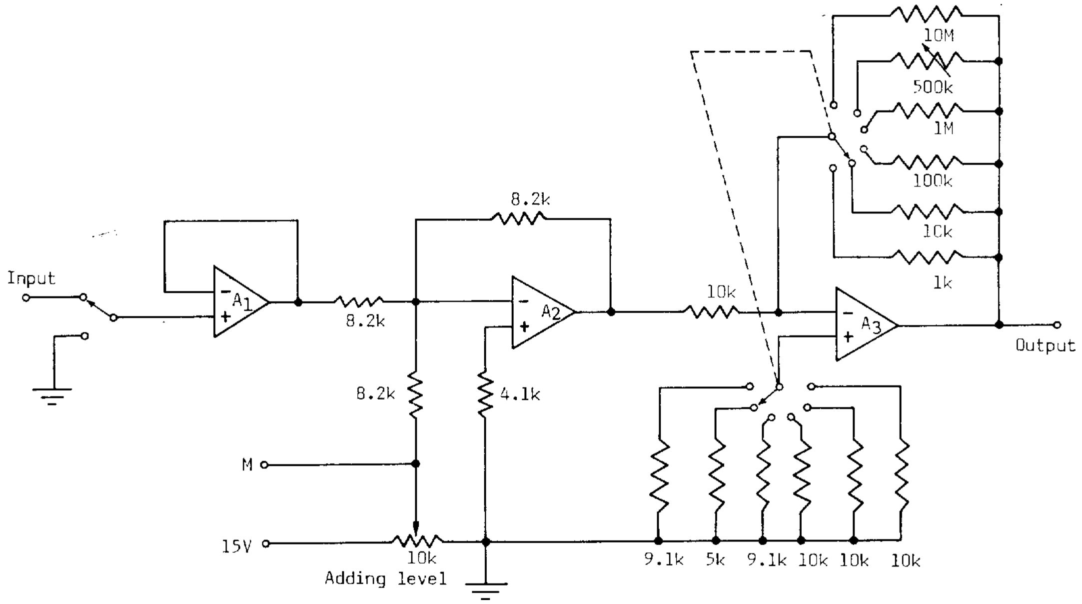

Fig. 4. **Preamplifier.** A_1 : μA308; A_2 and A_3 : μA747.

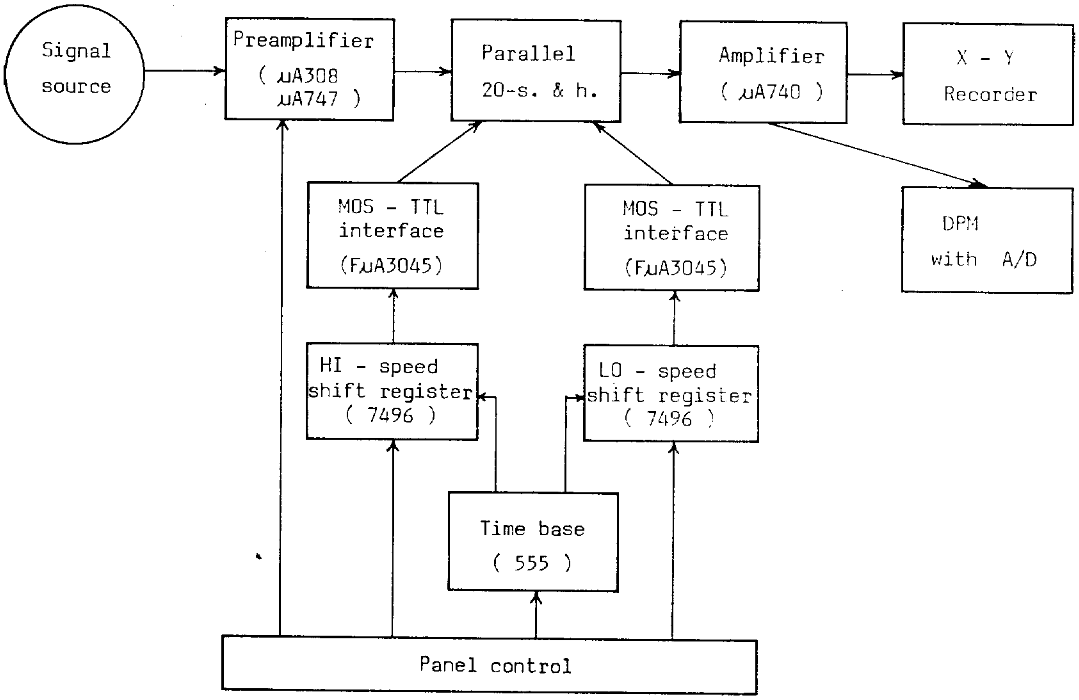

Fig. 5. **Block diagram of the device.**

MOSFET (15 volts) so that the switching performance is nearly leakproof.

Since a proper polarity and amplitude is required for the optimum operation in the storage system, it is necessary to have the output of the preamplifier within such limits. In *Fig*. 4, A_1 is a voltage follower to make the impedance large (μA308, Fairchild; $AZ = 10^5 \times 10^6$ ohms$=10^{11}$ ohms), A_2 is a voltage adder to determine the adding level which is measured at terminal M, and A_3 is a voltage amplifier with the amplifications of 0.100, 1.00, 10.0, 0~50.0, 100, and 1,000.

The block diagram of the whole system described in the present paper is shown in *Fig*. 5.

3. APPLICATIONS AND RESULTS

Basic tests. After this device was tested against square wave pulses and sinusoidal waves, the similarity among 20 different channels were examined by applying a constant voltage to them. In this stage, repeated replacements of capacitors or ICs were made in order to have less than 1 % deviation among these 20 channels. Thes tests were made up to 5 seconds decoding time for each channel.

Fast scan voltammetry[14,15]. Cathodic voltammograms from a solution containing 2 m*M* Cd^{2+} and $10\times10^{-6}M$. Pb^{2+} in 0.2*M* KCl which has been deaerated with nitrogen thoroughly were obtained using a hanging mercury drop electrode.

As shown in the left of *Fig*. 6, a single peak diagram was recorded at the voltage scan of 1 volt/sec which is about the maximum speed of the conventional strip-chart recorder can follow. It shows only cadmium peak and presumably a small lead peak buried under the main peak. The oscilloscopic data (right of Figure 6) definitely shows the presence of the lead peak even at 4 volts/sec scan rate. The recorder used here was Watanabe WX 451 XY recorder which had a pen speed of 80 cm/sec.

Based on this fact and using our device, an acquisition diagram was shown in *Fig.* 7 which

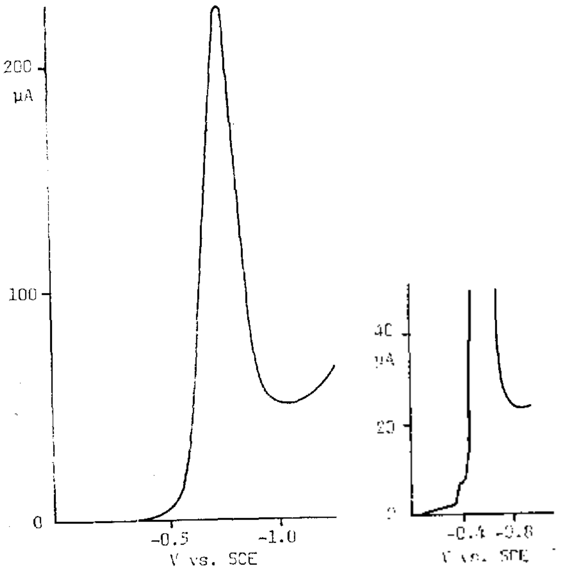

Fig. 6. Voltammograms of $2mM$ Cd^{2+} and $10\times10^{-6}M$ Pb^{2+}. Left: direct recording with the scan rate of 1 V/sec. Right: CRT picture at the scan rate of 4 V/sec.

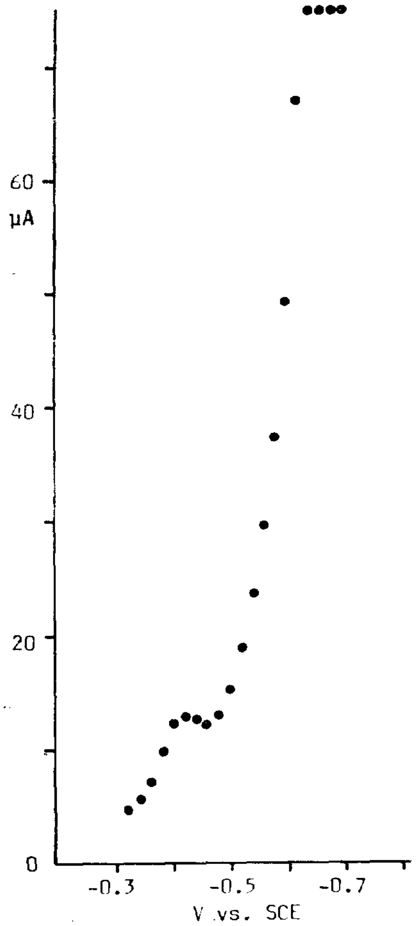

Fig. 7. Sampled voltammogram with the scan rate of 4 V/sec.

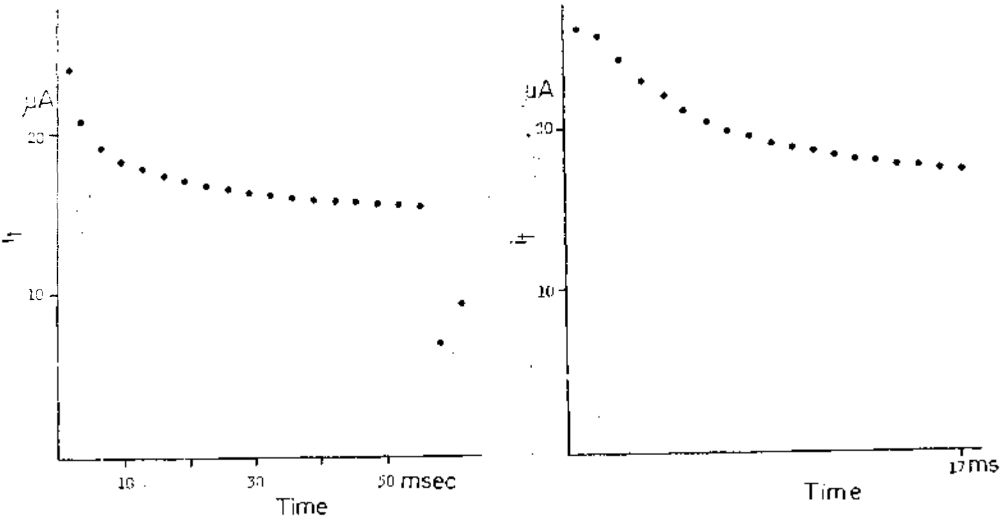

Fig. 8. Current-time profile of an 100 mV pulse at −0.6 V. *vs.* SCE of $2 mM$ Cd^{2+}. Samplng speed. left; 325Hz, right; 1175Hz.

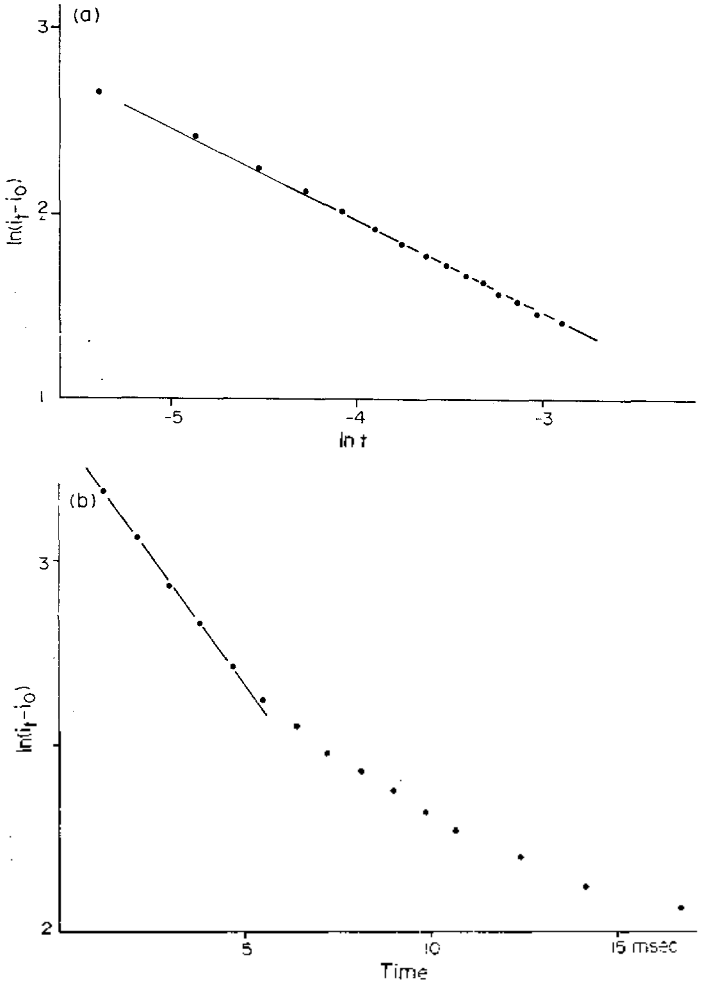

Fig. 9. (a) Logarithmic plot of the whole pulse, the slope is -0.49. (b) Logarithmic plot of the initial part of a pulse, the slope is $-136 \mathrm{sec}^{-1}$.

was recorded at 4 volts/sec. It also shows the presence of lead at -0.4volt *vs.* SCE. This shows the possibility of using this device to do fast scan electrochemistry of trace amount without using a scope.

Differential Pulse Polarography[16~18]. When a pulse was applied to the electrochemical cell, two kinds of process can be occurred simultaneously, one is charging-discharging of the double layer and the other is Faradaic diffusion process. Hence the logarithmic plot of the current-time curve can be used to verify what process is predominant.

Modulated current-time profile was sampled by synchronizing the analog storage device with the differential pulse polarograph (174A, Princeton Applied Research;[19] to check these equations. *Fig.* 8 shows the whole 57ms duration of a pulse at the sampling speed of 325Hz and initial 17 ms portion at 1175 Hz of a solution of 2 m*M* $Cd(NO_3)_2$ in 0.1*M* KCl. Logarithmic plots are shown in *Fig.* 9; a) slope of $\ln(i_t-i_0)$ *vs.* $\ln t$ plot is -0.49, so we can assume the current is nearly diffusion controlled except at the very first part of the pulse, b) gives the slope of $-136(s^{-1})(=-1/RC)$, and the charging current is diminishing within a few milliseconds. These results are in good agreement with the theory, and prove that this simple device is useful in the analysis of the fast changing sinal.

In summary, an analog storage device that has a good performance/price ratio was constructed, and the accuracy of the system was better than 1 %. This device can be used for the acquisition of fast transient signals in variable speed up to 3 kHz, and proved that it can be used in electrochemical and kinetic experiments. Since the storage part consists of simple MOSFET-switches and capacitors, the sampling speed can be extended to MHz, and this device can be connected to the computer as an interface.

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