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Measurements of Ion Currents by a Conventional Sampling Method

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Precise measurements of ion current of 10^{-10}–10^{-13} A produced in an ionization chamber by radioactive sources have been attempted by means of a conventional sampling method. By the use of a vibrating-reed electrometer (VRE), a digital multimeter (DMM), and a multi-channel analyzer (MCA) in multi-channel scaling (MCS) mode, it was found that the ion current can be determined within experimental errors of 0.03 %.

I. INTRODUCTION

Measurements of analogue values changing every moment are in general performed by using an X-Y or other analogue recorder. However, since mathematical or statistical analysis of analogue values observed is usually in difficulties, it is, in some cases, preferred to convert analogue to digital at the initial stage of measuring system. Because of the recent remarkable advance of digital multimeters, analogue-to-digital conversion can be easily achieved as far as extremely high sampling rate is not required. Furthermore, most DMM's have a BCD output terminal so as to be able to transfer signals to a printer or other electric calculator.

In the field of study of nuclear radiation, there are two ways for measurements of radiations. One is the counting method in which each radioactive ray incident upon a detector is counted by applying the pulse technique. The other is direct measurement of ion current produced in a detector by radioactive rays. Selections of these methods depend on various factors, but the intensity of radioactive source in question has an important role.

Even adopting an ionization chamber as a detector, the situation is true. The counting method can be applied to sources producing ion currents of 10^{-14} A or less, and probably down to 10^{-20} A, if statistical error is reduced by accumulating counts. These techniques for minute current have been developed mainly in the field of mass spectroscopy.[1~5] However, for larger current of 10^{-10}–10^{-13} A, the counting method is not always appropriate because of the difficulty in dead time correction for the measuring system.

By this reason, for a source producing ion currents of 10^{-13} A or more, the second method, direct-current measurement, seems to be more reliable compared with the counting method. In the direct-current method, ion current is directly measured through a DC amplifier or VRE. Multiplications of ion current by a

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secondary-electron multiplier permit us to measure the current down to about 10^{-18} A.

In this method, however, statistical fluctuations of ion sources can not be eliminated even through an amplifier with large time constant. In order to obtain the average value of ion current varying every moment, a conventional sampling method was developed with VRE, DMM, and MCA in MCS mode. In the present paper, we wish to report details of our experimental work on this problem, especially on the interface developed for connection of DMM and MCA.

II. FUNCTIONS OF DEVICE

The block diagram of the measuring system is shown in Fig. 1. Details of the construction of ionization chamber are previously reported.[6] The chamber is actually double ionization chamber for the differential method, but for the present purpose, a single chamber was used and the opposite one was kept off. As radioactive sources, ^{57}Co (122 keV gamma rays) of about 1 mCi and ^{99m}Tc (140 keV gamma rays) with the initial intensity of about 20 mCi were used. The ion current produced in the chamber by these sources are of the order of 10^{-12} A (^{57}Co) and 10^{-10} A (^{99m}Tc).

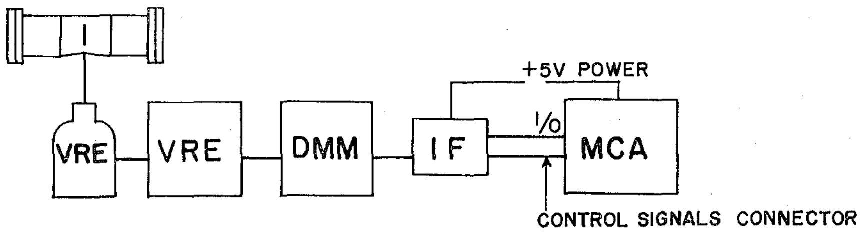


Fig. 1. Block diagram of the measuring system: I, ionization chamber; VRE, vibrating reed electrometer; DMM, digital multimeter; IF, interface; MCA, multichannel analyzer.

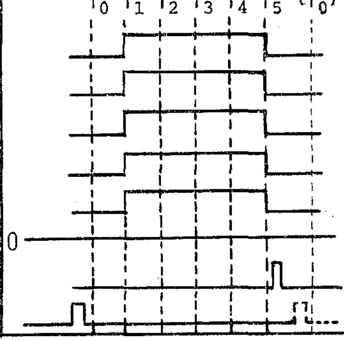
The input impedance of VRE was chosen as 10^{10} Ω, where the time constant is about 1 sec. The output voltage from VRE naturally shows considerable statistical fluctuations due to nuclear decay phenomena and it is difficult to determine the mean value on a meter or a recorder.

By this reason, the output voltage from VRE was transferred into DMM (YHP; 34702A, 34721A, 34740A), by which the voltages changing moment by moment were indicated in digit with a certain time interval. If the sampling rate is fast enough for fluctuations of the output voltage, the mean value can be obtained by summing up all data recorded and by dividing the sum by the number of sampling times. However, it is actually very troublesome to sum up all digits. To avoid complexity, each voltage sampled is transferred into MCA (1024 channel, Northern Scientific, Inc; NS 710) operated in MCS mode through the interface developed by us, and is stored in each channel of MCA. Then the address is advanced by one to store the next data. This permits us to store data up to 1024 times. After all channels of MCA are occupied, summing up of all stored data is performed by the integration function of MCA.

For operations of the present system described above, it is necessary to prepare an interface which transfers the BCD (1,2,4,8) parallel signals from DMM into the memory core of MCA. These signals specified in both DMM (output) and MCA (input) are listed in Table I. As shown in Fig. 2, the circuit of interface used consists of 17 gated invertors and 4 invertors, which are composed in 6 TTL integrated circuits (SN 7400, quadruple 2-input positive nand gates).

The function of the whole system including the interface is as follows: If the voltage sampling interval in DMM is controlled internally, the voltages appeared at the output terminal of VRE are intermittently indicated on DMM with the specified interval. Setting the channel advance of MCA in the external position, we start MCA. Then MCS (multi-channel scaling; signal indicating units is in MCS mode) becomes logic 0 and the gate of the interface is opened. Under this condition, BCD signals from DMM are transferred into the memory core of MCA through the gated invertors and I/O connector ($R_0 \sim R_{16}$; parallel data inputs to memory scaler and two control bits). When sampling process is completed in DMM, a signal of print command is generated, by which channel is advanced by one. In the same way, each voltage sampled is accumulated in the memory core until the specified final channel is occupied. At this moment, MCS becomes logic 1 and R_0 through R_{16} are all locked at logic 1, where no data can be stored in the memory core any more. By using the integration function of MCA, the sum of all data stored in the memory core can be obtained.

Table I

FROM DMM					TO MCA
SIGNAL	LOGIC LEVEL	SIGNAL DIRECTION	TIMING CHART T_0 T_1 T_2 T_3 T_4 T_5 (T_0) 	LOGIC LEVEL	SIGNAL
UNIT(1,2,4,8,)	1	→		0	$\overline{R}_0 \sim \overline{R}_3$
TENS(1,2,4,8,)	1	→		0	$\overline{R}_4 \sim \overline{R}_7$
HUNDREDS(1,2,4,8,)	1	→		0	$\overline{R}_8 \sim \overline{R}_{11}$
THOUSANDS(1,2,4,8,)	1	→		0	$\overline{R}_{12} \sim \overline{R}_{15}$
OVER RANGE(1,)	1	→		0	$\overline{R}_{16}$
			0	0,1	$\overline{MCS}$
PRINT COMMAND	1	→		0	$\overline{EP}$
EXTERNAL TRIGGER	1	←		0	R

$\overline{R}_0 \sim \overline{R}_{16}$: Parallel data input to memory scaler and two control bits.

$\overline{MCS}$: Multi-channel Scaling ; Signal indicating units is in MCS mode.

$\overline{EP}$: External pulse ; Address advance pulse during MCS when front panel switch is in MCS-OFF position.

R : Readout bistable ; Condition true during all readout modes.

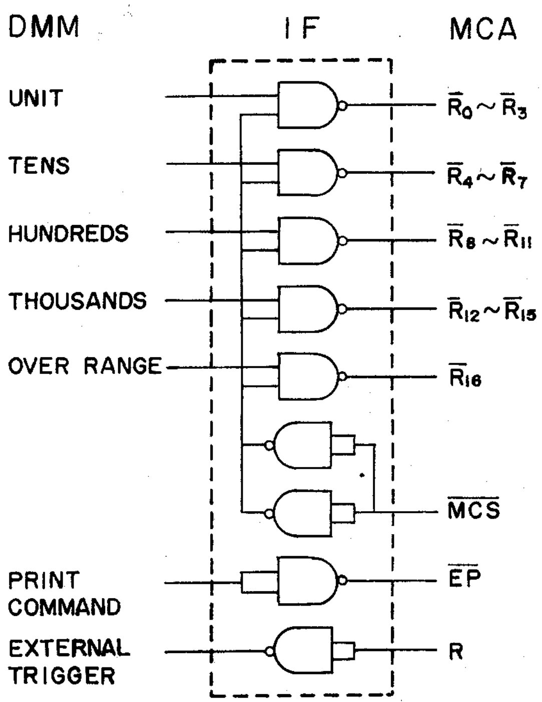


Fig. 2. **Circuits of the interface. Integrated circuits are SN 7400, quadruple 2-input positive nand gates and invertors with totem pole output.**

Instead of using the internal clock of DMM, it is possible to use the external trigger supplied from MCA. This means that the sampling rate in DMM can be controlled by MCA. In the actural measurements, external determination of sampling rate seems to be more profitable, because the rate controlled internally in DMM is pretty sensitive for changes in room temperature.

III. MEASUREMENTS AND RESULTS

As described in the previous section, two kinds of radioactive sources were used check the whole performance of the present system. Here, only the results obtained with ^{57}Co are presented. The ^{57}Co radioactive source of about 1 mCi was set at 3 cm from a surface of the chamber. The ion-collecting voltage supplied to the chamber by dry batteries is +359 V. Setting the input impedance of VRE at $10^{10}\ \Omega$, the output voltage of VRE is indicated on DMM with a specified time interval and also recorded on a recorder. The sampling rate is selected in the range of 18–233/min. Each BCD output sampled is transferred to each channel of MCA through the interface. The statistical fluctuation of output voltages stored in MCA is naturally expected to follow the statistical distribution of nuclear decay phenomena, even through the sampling rate of 233/min, the distribution around the average value of whole data stored is shown in Fig. 3, where fitting by the calculated normal distribution is also indicated by a solid line.

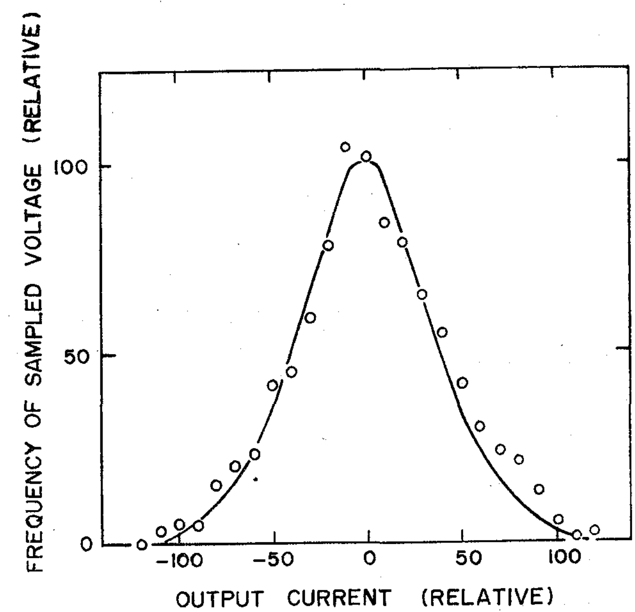


Fig. 3. Distribution of output voltages recorded for 4 min. The sampling rate is 233/min.

In order to find out the accuracy of average values for various sampling rate, the standard deviations of average values for different sampling rate were calculated. The result is shown in Fig. 4. This indicates that for a larger sampling rate the

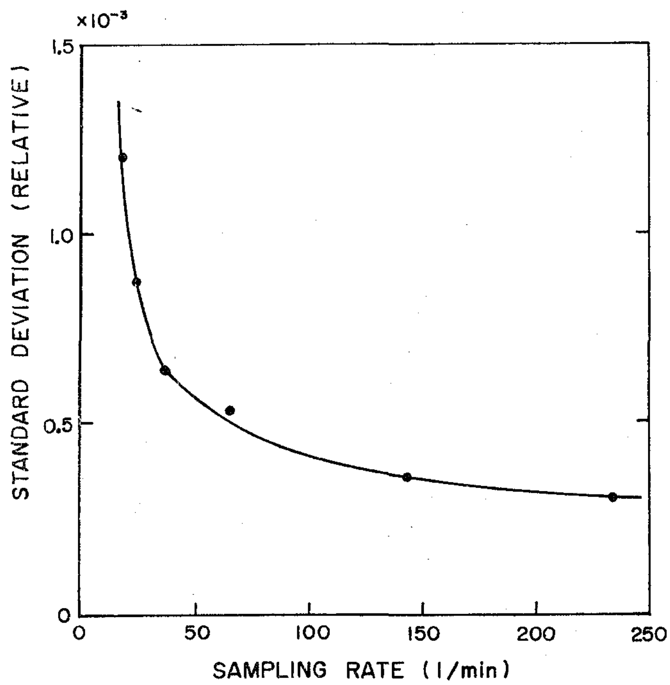


Fig. 4. Standard deviation of average *versus* sampling rate.

standard deviation becomes smaller, nearly proportional to $1/\sqrt{N}$, where N is the number of sampling times.

From this result, one can determine the ion current due to the source within the experimental error down to 0.03 %. Since detection efficiency of the ionization chamber (geometrical and intrinsic) is not precisely known, the present system is not directly applicable for determination of the absolute intensity of radioactive sources. However, the system can be widely applied for precise determination of ion current or other analogue values changing every moment.

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