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The Improvement of the Automatic Chemical-Balance-Type Magnetometer with I. C. Semiconductor

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§ Introduction

A chemical-balance-type magnetometer is used in our laboratory in order to measure the magnetization of a sample by detecting the Farady force which acts upon the magnetic sample situated in the inhomogeneous magnetic field. To counterbalance the Farady force, a force is given by the current which flows in the feedback coil as shown in Fig. 1. Therefore, a change of a magnetization in a sample can be obtained as a change of the current.

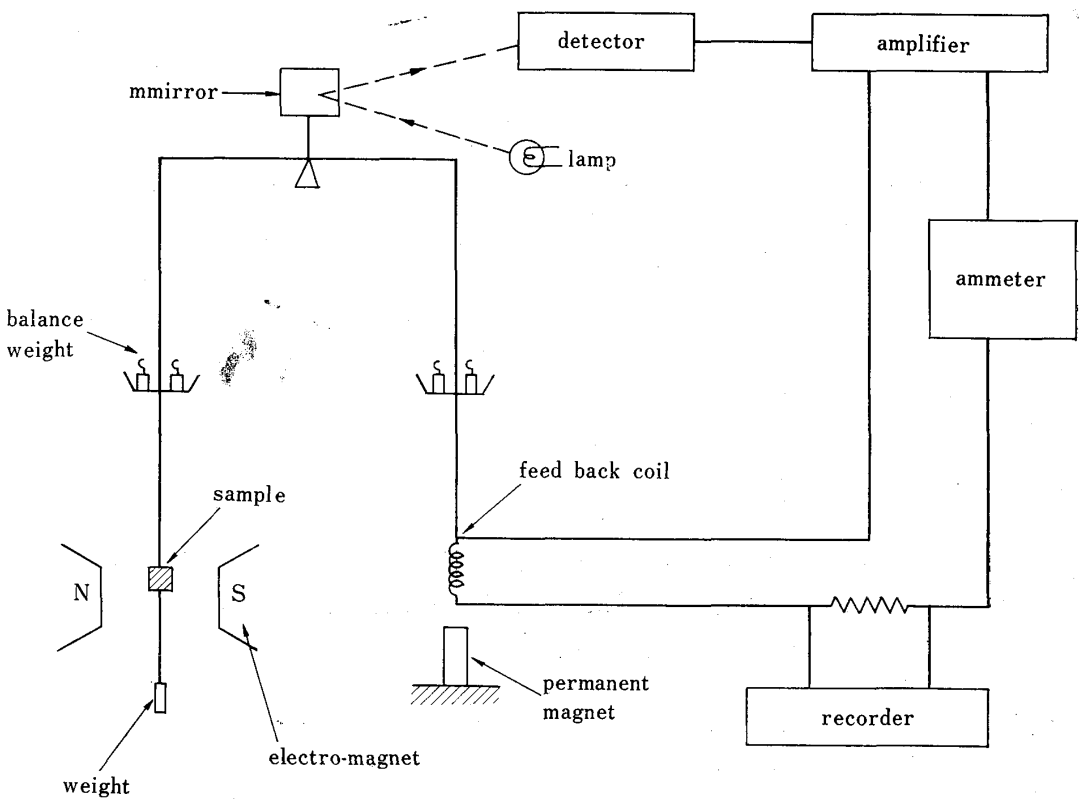


Fig. 1. Block-diagram of our magnetometer.

The system for detecting the Farady force through this balance is composed of a lamp and mirror, a photo-sensitive detector, an amplifier and a feedback coil.

We have improved a photo-sensitive detector and an amphifier of this system by the following reason.

1) The production of the phototube has stopped recently.

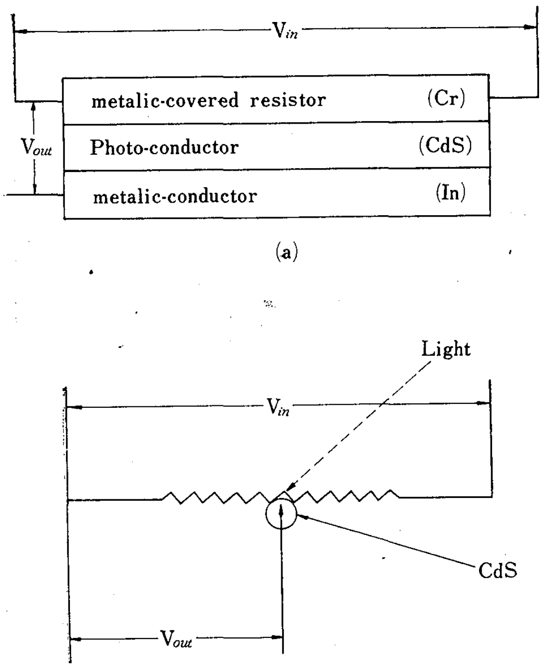
2) As an output of a detector with a phototube has a very high impeadance, its output voltage is influenced by a noise.

3) A differential amplifier with electronic-tubes has large drift and it takes much time to stabilize.

We used a CdS-cell instead of a phototube and a operational amplifier instead of a electronic-tube as a differential amplifier, because the quality of the semi-conductor devices has been greatly improved.

§ Photo-sensitive detecter

Fig. 2 shows the function of the CdS-cell. We can use this CdS-cell[1] as a variable resistance. The value of resistance can be changed by light. The total value of resistance is 2 kΩ. But in usual experimental condition, only a few percent of it is used. This CdS-cell has not noise caused by direct connection and has a low impeadance. Therefore, it has an advantage that the signal-to-noise-ratio is very high.



(a)

(b)

Fig. 2.

§ Amplifier

Fig. 3 shows the amplifier. It is composed of two circuits. One is a d. c. amplifier and the other is a differential circuit. The former is necessary to supply the feedback d. c. current and the latter is used to counterbalance the balance rapidly.

The operational amplifier used is SN72741 (made in Texas Instrument). The characteristic constants of the circuits are determined as follows.

When an idealized operational amplifier is assumed that the input impeadance is infinite and output impeadance is zero. The gain is

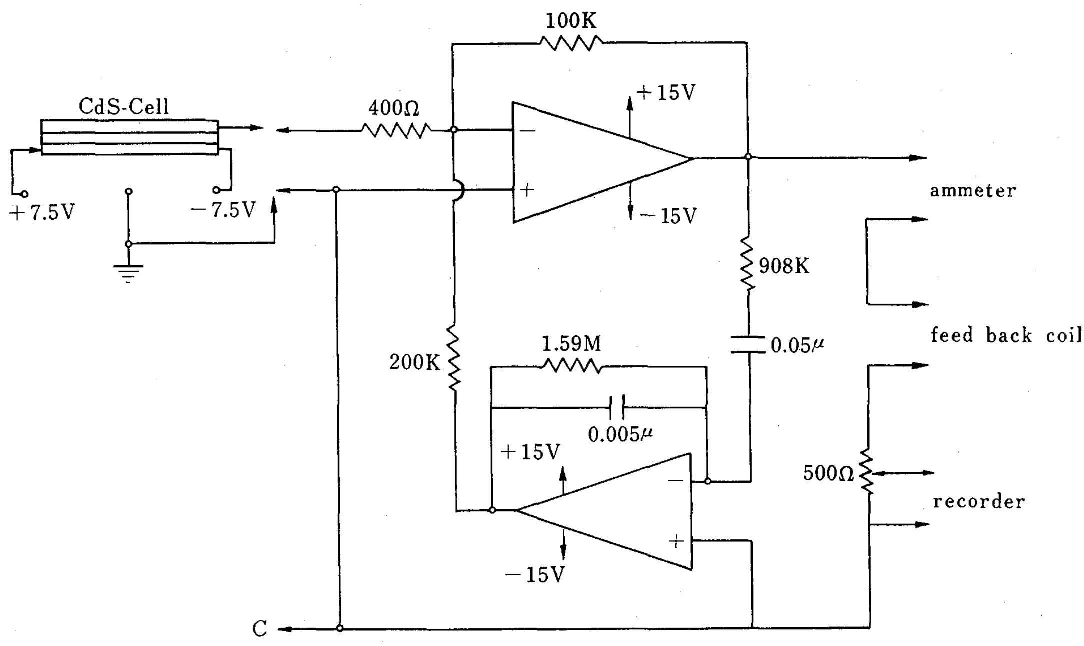


Fig. 3.

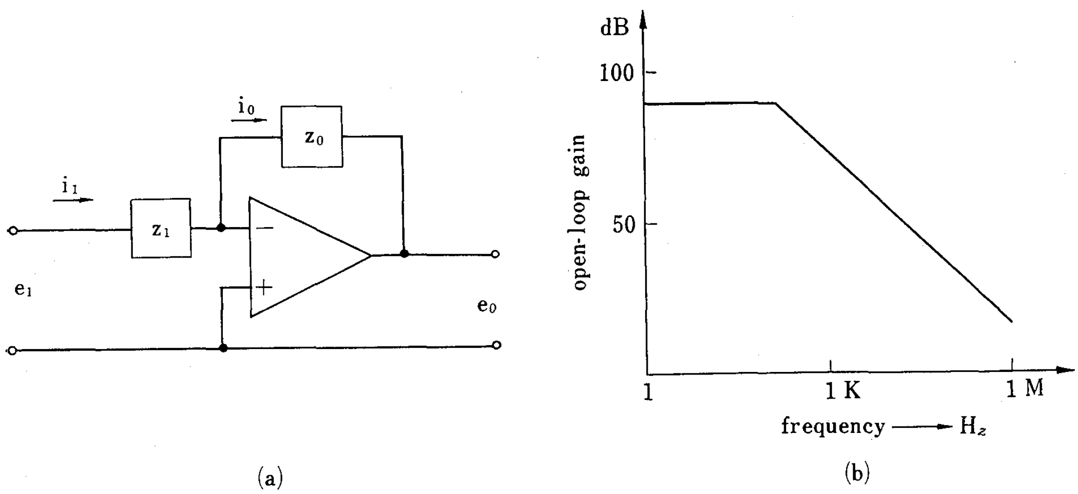


Fig. 4.

given by eq. (1) for the circuit in Fig. 4-a.

$$\frac{e_0}{e_1}=-\frac{1}{Z_1}\bigg/\left\{\frac{1}{Z_0}+\frac{1}{A_0}\left(\frac{1}{Z_0}+\frac{1}{Z_1}\right)\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots \text{(1)},$$

where,

e_1=input voltage e_0=output voltage

A_0=gain Z_1 or Z_0=impeadance.

If $A_0 \gg 1$,

$$e_0/e_1=-Z_0/Z_1 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(2)}.$$

Input impeadance of SN72741 is equal to 2 MΩ, output impeadance is equal to 75 Ω and A_0 is equal to 90 dB. Eq. (2) is used for low frequency and eq. (1) is used for high frequency, because A_0 decreases with frequency as shown in Fig. 4-b.

In order to d. c. gain is -250, we selected resistances R_1 for Z_1 and R_0 for Z_0 as follows

$$e_0/e_1 = -R_0/R_1 = -\frac{100\times10^3\Omega}{400\ \Omega} = -250$$

If capacitance C_1 for Z_1 and resistance R_0 for Z_0 are used, a differential circuit is obtained. Though its d. c. gain is equal to zero in this circuit, a. c. gain increases as frequency increases (Fig. 5-a).

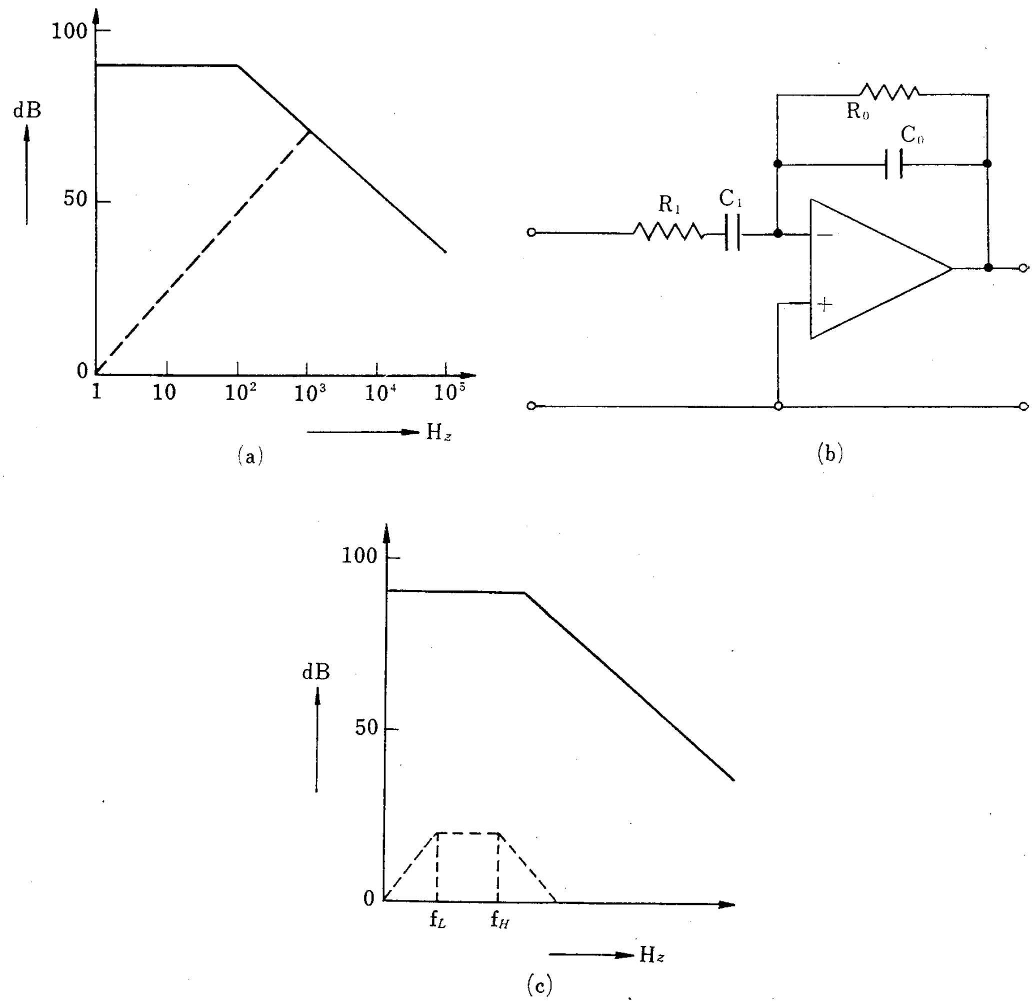


Fig. 5.

Its operation at higher frequency is very unstable by noise. In order to prevent this effect, R_1 and C_0 (shown in Fig. 5-b) are used. As a rough approximation, the cutoff frequencies f_L, f_H are given as follows.

$$f_L = \frac{1}{2\pi R_1 C_1} \qquad f_H = \frac{1}{2\pi R_0 C_0}.$$

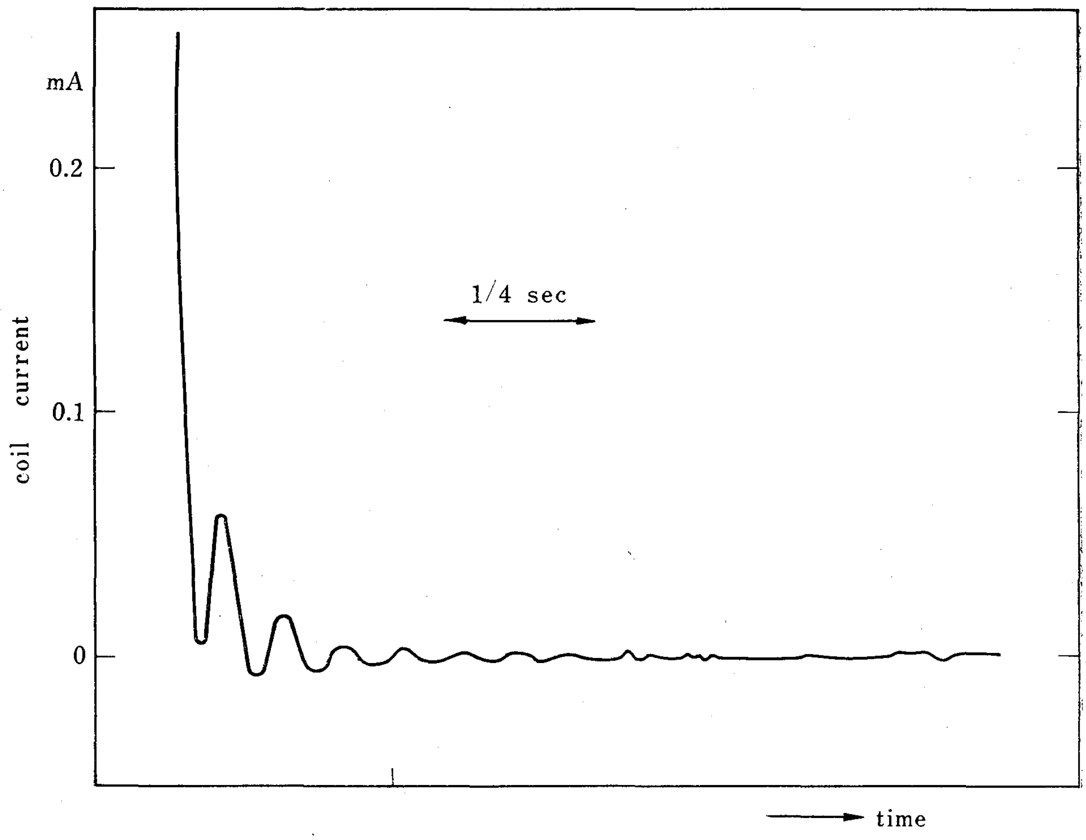


Fig. 6.

When the cutoff frequencies f_L, f_H have been selected 3.5 Hz and 20 Hz respectively, the recoverly time of this system was the shortest. As Fig. 6 shows, it is less than one second. The frequency dependence of experimental gain is compared with theoretical one in Fig. 7-a. That for total circuit is obtained as Fig. 7-b.

§ Characteristics of the improved magnetometer

Essentially this system needs a small inclination of the mirror for the feedback coil, therefore the sample position displaces slightly in proportion to the force. But we may neglect this displacement, because the sample moves only about 0.2 mm downward from original position and the change of a magnetic field gradient is about 0.06%, even if the maximum force (200 mg-weight) acts on a sample.

The minimum sensitivity of this chemical-balance is 0.1 mg-weight and this weight corresponds to the coil current of 1.65μA, since the sensitivity of this system is 1.65 mA/100 mg-weight. Experimentally the fluctuation of the coil current is within $\pm 0.5\mu$A. This value enables us to measure the force of 0.1 mg-weight. The total drift current due to various origins is about 0.6μA/hour and its ratio to time is hardly changed for long time interval.

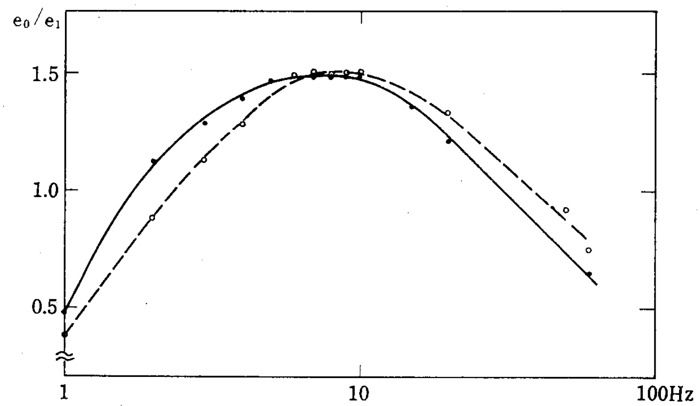


Fig. 7-a

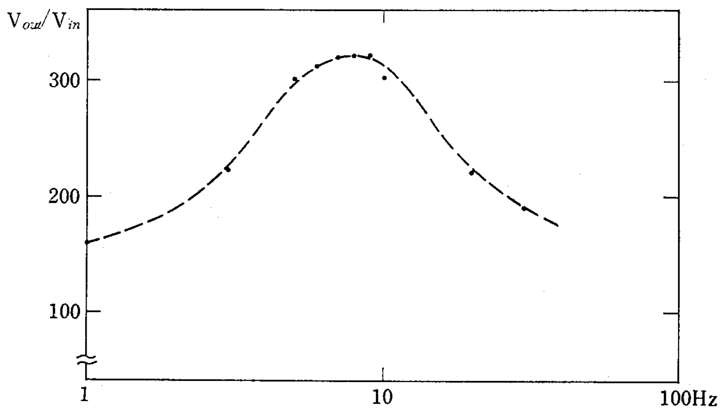


Fig. 7-b

Fig. 7-a. The solid line is theoretical gain.
The dashed line is experimental gain.
Fig. 7-b. The a.c. gain for total circuit.

§ Acknowledgements

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Referenec

1) U. Hiresaki and K. Sekizawa: Solid State Physics 7 (1972) No. 7, 408.