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Analysis and Suppression of Low-Frequency Noise for Two-Dimensional Integrated Magnetic Sensor

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Abstract

The noise in output signals from two-dimensional integrated magnetic sensors has been investigated in order to improve the accuracy of position sensing that is applicable to control of a magnetic self-levitation motor. The two-dimensional integrated magnetic sensor investigated herein was composed of a 64×64 array of Hall sensors and fabricated by a 0.18-μm complementary metal-oxide-semiconductor (CMOS) standard process. The size of Hall element was 2.7×2.7μm^2. The dimension of one pixel in which Hall element was embedded was 7×7 μm^2. From the measurement results of magnetic field, output fluctuation caused by the random telegraph noise (RTN) was observed and the value was about 5mV$_{p-p}$. To reduce RTN, correlated double sampling (CDS) was introduced to integrated magnetic sensor. Using CDS, the noise voltage was reduced to 2.1mV$_{p-p}$. It is revealed that CDS is useful method to suppress low-frequency noise which occurs on metal oxide semiconductor field effect transistor (MOSFET) in a pixel by RTN.

1. Introduction

Development of an artificial heart has been ongoing in an attempt to improve the quality of life. Recently, in order to achieve a longer lifetime, magnetically suspended motors have been developed. The rotation of the impeller in a magnetically suspended motor is controlled by the feedback of the impeller position and the control accuracy is important to reduce abnormal vibration which occurs in motor axis. In order to realize the system, integrated two-dimensional magnetic sensor systems have been proposed [1] for the impeller position sensing. In these systems, Si Hall elements [2] are used. In the previous works [3-5], two-dimensional magnetic field distribution from a Nd-Fe-B rare-earth permanent magnet was successfully measured by the two-dimensional magnetic sensor. However, residual noise after offset subtraction was found as shown in Fig. 1. This noise was caused by the RTN [6]. RTN increases remarkably when the size of a MOSFET was reduced. In the two-dimensional magnetic sensor, smallest size of MOSFET is W/L=0.46 μm /0.18μm. The size of MOSFETs in the pixel has to be reduced because decrease of pixel size are required. The fluctuation of output voltage was observed as shown in Fig. 2. This fluctuation is also called flicker (1/f) noise. The fluctuation was about 5mV$_{p-p}$. This noise will decrease the accuracy of the position sensing and has to be reduced.

In the present paper, to suppress the residual noise after offset subtraction, low-frequency noise characteristics of two-dimensional magnetic sensor will be analyzed, and the method to control RTN will be proposed.

2. Structure of the Magnetic Sensor

In a magnetic sensor used in this study, Hall effect is occurred in inversion layer of an n-channel MOSFET as a Hall element. This Hall element has two probes for sensing Hall voltage. The sensor was designed for the 1-poly 5-metal standard 0.18-μm CMOS process. Output buffer circuits consisting of operational amplifiers (OP-AMP) were also integrated onto the same chip. A pixel size was 7×7 μm^2. 2.7×2.7μm^2 magnetic sensors were placed in a 64×64 array. Figure 3 shows the simplified readout circuit diagram. Signals on two probes of Hall element are picked up by source followers by p-channel MOSFETs in the pixel. Then, signals are amplified by source followers by n-channel MOSFETs and a differential amplifier consists of three OP-AMPs. The voltage gain of the differential amplifier was set to 10.

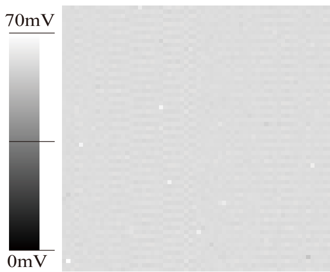

Fig. 1 reproduced image with residual noise.

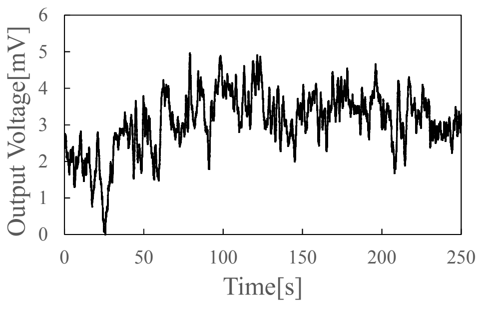

Fig. 2 Fluctuation on output signals.

3. Noise Analysis and Discussions

First, a feature of noise as shown in Fig. 2 was investigated. Figure 4 shows a frequency distribution of output signals after low-pass filtering. Magnetic field was not applied.

Three peaks corresponding to RTN are confirmed, and an interval between peaks is about 500μV. From the MOSFET size shown in Fig. 3, it is suggested that RTN occurring in source follower by p-channel MOSFET is dominant. Frequency spectrum of RTN is inversely proportional to frequency. It is difficult to eliminate RTN by filtering, because the magnetic sensor used in this paper handles output voltages from Hall elements as DC signals. For the RTN elimination, we introduce correlated double sampling (CDS) by devising the gate drive method on two-dimensional magnetic sensor.

For magnetic field sensing, RTN will generate fluctuation on calculated signals in subtraction process of offset signals. CDS in the higher sampling rate than RTN rate can suppress the effect of RTN, because CDS is accomplished before fluctuation by RTN will be occur. To realize CDS at high sampling rate, new driving method of Hall elements were proposed. Hall elements are biased by applying high voltage signal (1.8V) to its gate, and turned on. This operation is done row by row in the same way of a scanning of an image sensor. On the proposed method, first sampling is done without Hall element bias (gate-off). In this signal, offset data without Hall element bias is captured. Second sampling is done with Hall element bias (gate-on). In this signal, offset data with Hall voltage is captured.

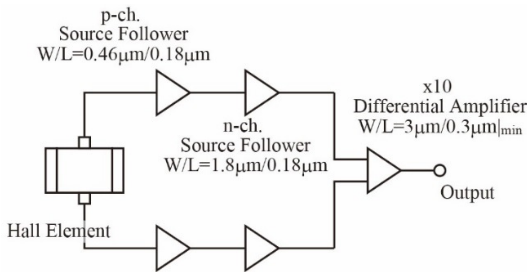

Fig. 3 Simplified circuit from Hall element to output amplifier.

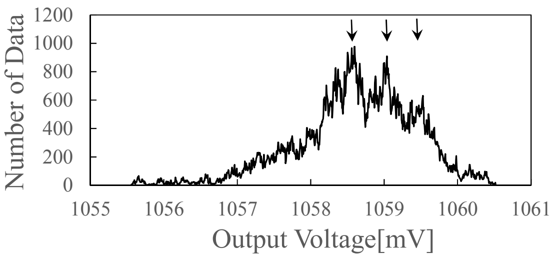

Fig. 4 Output voltage distribution when gate of Hall element was set to on. Arrows indicates the peak caused by RTN.

Figure 5 shows the output signals from a Hall element after low-pass filtering. Offset components on the signals were eliminated. The noise in output signals with gate-on condition was up to $3.7mV_{p-p}$ and with gate-off condition up to $6.1mV_{p-p}$. The reason why the noise level captured by gate-off condition is bigger than that by gate-on will be an effect of feed through from gate to Hall probe in Hall element. This difference can be reduced by multiplying coefficient. It is obvious that the similarity between two signals is high. Residual noise after subtraction between gate-on and off signals was up to $2.1mV_{p-p}$. This value is about half of the signals without CDS. This fact means that low-frequency noise by RTN can be successfully suppress, and CDS is effective method to low-frequency noise occurring on two-dimensional magnetic sensor.

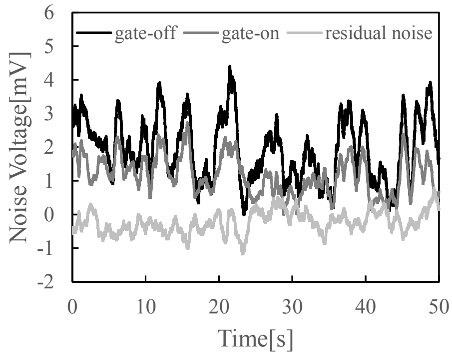

Fig. 5 Low-frequency noise on the sensor output. Black line represents the output from a Hall element with gate-off, dark gray line with gate-on, and light gray line the difference between the output signals with gate-on and off.

4. Conclusions

In order to reduce the residual noise after offset subtraction of a two-dimensional integrated magnetic sensor, the characteristics of low-frequency noise and the method of the noise suppression were investigated. The magnetic sensor was composed of 7×7 μm^2 Hall sensors and was fabricated by the standard 0.18-μm CMOS process. The noise voltages caused by RTN were about $5mV_{p-p}$. By the consideration of the noise including RTN, CDS at high sampling rate would control the occurrence of low-frequency noise by RTN. Using CDS, the noise was suppressed up to $2.1mV_{p-p}$. CDS is useful method to low-frequency noise by RTN occurring on two-dimensional magnetic sensor.

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