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Studies on Response Speed and Sensitivity of Two-Dimensional Integrated Magnetic Sensor

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Abstract

Two-dimensional integrated magnetic sensors have been investigated in order to reduce size of a magnetic sensor 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. The average sensitivities of the arrayed Hall sensors were 0.125mV/mT at 210 frame per second (fps) and 0.117mV/mT at 6100fps. Degradation of the sensitivity was within 10%. These results reveal that 2.7×2.7 μm^2 sized Hall element at high-frame-rate has enough sensitivity for sensing the impeller position of magnetically suspended motor.

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 and improve biocompatibility of the blood pump, 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 compact system, integrated two-dimensional magnetic sensor systems have been proposed [1-4]. In these systems, Si Hall elements [5] are used for the compatibility between Hall elements and the circuitry. In the previous work [6], two-dimensional magnetic field distribution from a Nd-Fe-B rare-earth permanent magnet and sensitivity was successfully measured by the two-dimensional magnetic sensor that consists of 2.7×2.7μm^2 Si Hall elements placed in 6×6μm^2 pixel. However, the characteristics of response speed wasn't measured.

In the present paper, to reveal the responsivity of the two-dimensional magnetic sensor, sensitivity and noise characteristic will be evaluated in high frame rate.

2. Structure of the Magnetic Sensor and Measurement System

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. These probes are same as source/drain diffusion region. Figure 1 shows the photograph of the two-dimensional integrated magnetic field sensor. The sensor was designed for the 1-poly 5-metal standard 0.18-μm CMOS process. Vertical and horizontal shift registers and output buffer circuits consisting of operational amplifiers 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. Two signals from Hall elements are amplified by a differential amplifier. The differential amplifier is composed from on-chip operational amplifiers. The voltage gain of the differential amplifier is set to 10.

The Hall voltage from the magnetic sensors was converted to digital signals by an off-chip 18-bit analog-to-digital converter (ADC). The digitized Hall voltage signal, which was a magnetic field image, was buffered once to field programmable gate array (FPGA) and the buffered images were read into the personal computer (PC) via universal serial bus (USB) 2.0 interface.

The static uniform magnetic field for the input of the sensitivity sensing was provided by an electromagnet. A 1mmϕ×10mm Nd-Fe-B permanent magnet was also used for sensing the shape of magnetic field. Operation voltage of the sensor was set to 1.8V and frame rates were set to 610 and 2100 frames per second (fps). Maximum frame rate is limited by performance of FPGA's.

In the case of calculation of sensitivity, the signals were captured 200 times and averaged pixel-by-pixel to eliminate random noise in the pixel.

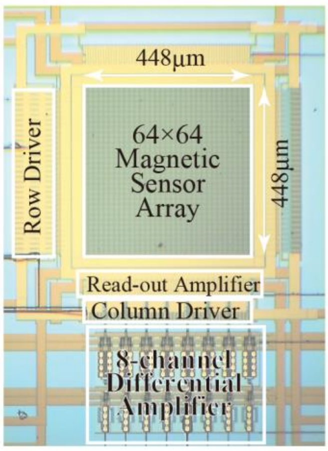

Fig. 1 Photograph of a magnetic sensor.

3. Results and Discussion

In high frame rate sensing, noise from digital circuits is the issue which has to be carefully measured. Random noise on pixel-by-pixel was evaluated from reproduced 200 images at 610fps and 2100fps. No magnetic field applied to the magnetic sensor. The results were shown in Table I. Noise was increased about $1mV_{rms}$ and peak-to-peak noise voltage about 6mV while the frame rate increased three times. The magnitude of the noise, however, is enough small for position sensing, because the input magnetic flux from permanent magnet is enough large.

Figure 2 shows reproduced image measured at 2100fps. Figure 2(a) shows a noise eliminated image by averaging 200 images and Fig. 2(b) one-frame image. Both images represents magnetic field from a 1mmϕ×10mm Nd-Fe-B permanent magnet. From Fig. 2(a), circular shape of the magnetic field from the magnet can be recognized. From Fig. 2(b), circular shape can be recognized, but it seems that noise will decrease the accuracy of the position detection of the magnet.

Figure 3 plots the relationship between the input static magnetic flux density and the output Hall voltage at two frame rates, 610 and 2100 fps. Good linearity exists between the input magnetic field and the output voltage at two frame rates. The sensitivities calculated from Fig. 3 were 0.125mV/mT at 610fps and 0.117mV/mT at 2100fps, respectively. Sensitivity degradation was within 10%. This fact means that the sensitivity degradation isn't critical for sensing magnetic field at high frame rate. This degradation of the sensitivity will be caused by insufficient response time of amplifiers in the pixel. Optimization of the pixel amplifier will be able to recover the sensitivity degradation at high frame rate sensing.

From the results, it is obvious that the degradation of the sensitivity at high frame rate is successfully suppressed within 10%. The increase of the noise is also suppressed within 30% but smaller noise is suitable for the accuracy of the position detection. To use this sensor for the impeller position of magnetically suspended motor, noise suppression is critical issue.

Table I Noise at different frame rates.

frame rate [fps]	noise [mV_{rms}]	peak-to-peak noise voltage [mV_{p-p}]
610	2.35	12.8
2100	3.08	18.9

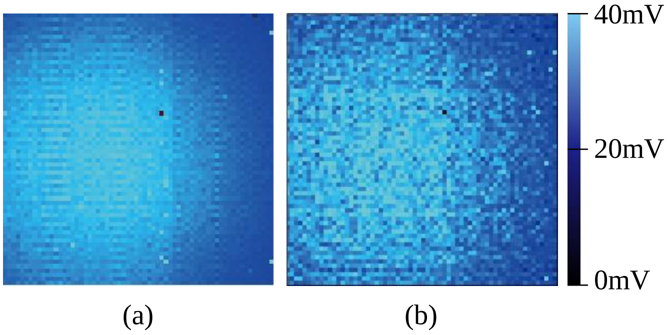

Fig. 2 Reproduced image captured at 2100fps. (a) noise eliminated image by averaging and (b) one-frame image.

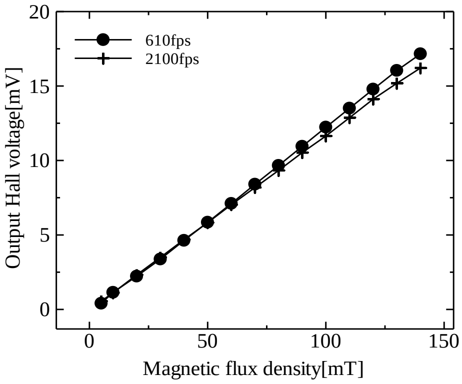

Fig. 3 Relationship between strength of input magnetic flux density and output HALL voltage at the two frame rate, 610 and 2100fps.

3. Conclusions

In order to reduce the size of a magnetic sensor, two-dimensional integrated magnetic sensors have been investigated. The two-dimensional integrated magnetic sensor was composed of a 64×64 array of Hall sensors and was fabricated by the standard 0.18-μm CMOS process. The noise voltages were $2.35mV_{rms}$ and $3.08mV_{rms}$ at 610fps and 2100fps. Reproduced image showed circular shape of the magnetic field from magnet, but noise will decrease the accuracy of the position detection of magnet. The average sensitivities of the magnetic sensors were 0.125mV/mT at 610fps and 0.117mV/mT at 2100fps, respectively. However the degradation is in 10% and not critical. The fabricated sensor has the potential for the impeller position sensing of magnetically suspended motor, but noise suppression is critical issue to realize the position sensing at high accuracy.

Acknowledgements

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