Design and Simulation of Interface ASIC for Micro-fluxgate Sensor

Chao Zuo Shi Chen¹ Shaobin Wu Jun Ouyang Lei Yu Xiaofei Yang
Department of Electronic Science and Technology, Huazhong University of Science and Technology, Wuhan, China

E-mail: s_chen@mail.hust.edu.cn

Abstract. Application Specific Integrated Circuits (ASIC) for micro-fluxgate sensor, based on the Complementary Metal Oxide Semiconductor (CMOS) fabrication, was designed by a 0.5 μm n-well 2p-2m process, which has the advantage of small dimension and low-power consumption. In consideration of the structure and specification of the micro-fluxgate sensor, the excitation and sensing circuits were designed based on second-harmonic operation principle. The functions and parameters of circuits were verified by simulation, and the area of chip was 2.1mm×2.8mm.

1. Introduction
Fluxgate sensors measure dc or low-frequency ac magnetic fields. They are vector devices and sensitive to the field direction in the range of up to 1mT with achievable resolution down to 10 pT [1]. The first fluxgate sensors appeared in early 1930s and these sensors are still being used in many applications. However, Recent development of magnetoresistors, especially anisotropic magnetoresistance sensors (AMR), limit the market for classical fluxgate to applications requiring high precision and small size.
Small-size fluxgates are needed and used in many applications, such as magnetic ink reading or sensor arrays. But it is complicated to miniaturize the fluxgate, because the fabrication of micro-fluxgate is complex. With improvement of integration technology, the preparation of fluxgate probe and its driving circuit becomes compatible. Recently, several portable micro-fluxgate sensors with Micro-Electro-Mechanical Systems (MEMS) fabrication have been developed. The MEMS micro-fluxgate sensors keep progressing in miniaturization, integrated, systematization and intelligent with semiconductor materials technology [2]. In order to solve the traditional drive circuits' shortcomings such as complex wiring, electromagnetic crosstalk, high power consumption and large size, a chip of application specific integrated circuits (ASIC) was designed in this paper.

2. Structure of micro-fluxgate sensor
As shown in Fig.1 [1]. T The excitation current I_{ext} through the excitation coil produces field that periodically saturates (in both directions) the soft magnetic material of the sensor core. In saturation the core permeability drops down and the DC flux associated with the measured dc magnetic field B_0 is decreased. When the measured field is present, the voltage V_{ind} is induced into the sensing coil at the second and higher even harmonics of the excitation frequency. This voltage, proportional to the measured field, is the sensor output.
The system circuits were based on second harmonic operation principle [3], as shown in Fig.2. The square-wave oscillator and divider generated excitation current. The amplifier enhanced the sensing signal and the filter picked up the second harmonic components. After the phase-sensitive detection and low-pass filter, the output signal was directly proportional to the external magnetic field.

The micro-fluxgate probe was designed as a runway model's structure and consist a runway model's magnetic core based on cobalt-based amorphous alloy and two coils sputtered by copper [4], as shown in Fig.3. The excitation coils were designed as 32 turns and the sensing coils had 14 turns. The size of whole micro-fluxgate probe was $5.7\text{mm} \times 7.1\text{mm} \times 60\ \mu\text{m}$.

3. Design of interface circuit

3.1. Excitation circuit
As shown in Fig.4, G1~G3, R, Rs and C make up the RC ring oscillator to provide the square wave. Rs is the over current protection resistor and R, C are time delay components. Known by the circuit principle, the frequency can be achieved:

\[ f = \frac{1}{2.2RC} \]  

(a). Structure.  
(b). Transistor.

**Figure 4. Circuit diagram of square wave.**

According to design requirements, the RC parameters were adjusted to make the square wave frequency at 31.114 kHz with duty cycle of 51.612%. As shown in Fig.5, the square wave is standardized by wave-shaping circuit with inverter G4 and G5 to provide the reference signal for phase-sensitive detection. And the wave divided by D trigger is the source of excitation coils, with 15.617 kHz and duty cycle of 50.021%.

(a). Structure.  
(b). Transistor.

**Figure 5. Circuit diagram of divider.**

3.2. Sensing circuit

The signal of sensor is weak and a preamplifier is designed as shown in Fig.6, and the gain of differential AMP is 91.154 dB [5].
A Butterworth first-order band-pass filter is designed to collect the second harmonic, as shown in Fig.7, with centre frequency at 31.212 kHz, band pass width of 4.048 kHz and quality factor to 8.276.

As shown in Fig.8, a dual AMP and an analog switch compose the phase sensitive detection circuit. The switch phase sensitive detection circuit maintains the input waveform during the positive half-cycle and reverses the wave in the Negative half-cycle. The following second-order active low-pass filter circuit make the signal a DC output, with the cut-off frequency of 100 Hz.

### 4. Layout-design and post-simulation
With Cadence Virtuoso layout tools, the layout is designed in digital-analog mixed environment based on the model of a 0.5 μm n-well 2p-2m process, includes 24 Pads, 254 transistors, 19 resistors and 8 capacitors. As shown in Fig.9, the whole ship takes a size of $2100 \times 2800 \mu m^2$, with the digital part and analog part be separated.
The simulation of overall circuit has been completed after the design of micro-fluxgate interface circuit, based on standard library by HSPICE. As shown in Fig.10, the system output goes to stability in 10ms.

Figure 9. Layout diagram of fluxgate interface circuit.

Figure 10. Simulation waveform of fluxgate interface circuit.
5. Conclusions
In this paper, a micro-fluxgate interface ASIC is designed based on the principle of second harmonic detection of the sensing signal, and the layout and the simulation of the whole circuit have been completed. The feasibility of the circuit's function has been verified by simulation. The future work will be focused on the design of a micro-fluxgate sensor contains both the probe and circuit on one chip [6]. Because the function of MEMS-based micro-fluxgate sensor probe with runway-shaped Co-based amorphous alloy core could not be tested effectively at present, the sensor's functionalities such as sensitivity and frequency response will be discussed in a future article.

References
[1] P Ripka. Advances in fluxgate sensors. Sensors and Actuators A. 2003, 106: 8-14.
[2] J Lenz, A S Edelstein. Magnetic Sensors and Their Applications. Sensors and Actuators A. 2006, 10(2):631-647
[3] Ripka P. Advances in fluxgate sensors. Sensors and actuators A. 2003, 106:8-14
[4] P M Wu, C H Ahn. A Fully Integrated Ring-Type Fluxgate Sensor Based on a Localized Core Saturation Method. IEEE Transactions on Magnetics. 2007, 43(3):1040-1043
[5] Behzad Razavi. Design Considerations for Direct-Conversion Receivers. IEEE Transactions on Circuits and Systems- II: Analog and Digital Signal Processing. 1997, Vol.44 (No.6):22-25P
[6] A Baschirotto, E Dallago. A CMOS 2D Micro-Fluxgate Earth Magnetic Field. 2007 IEEE International Solid-State Circuits Conference. 2007:33-38