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INTEGRATED MAGNETIC SENSORS DESIGN EXAMPLES

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Abstract: Various design examples for integrated magnetic sensor ASICs are presented. They include current and energy metering, proximity switches position and angle measurements and complex two-dimensional magnetic field measurements. Design approach based on Hall element array is iintroduced. Sensor properties optimization by design approach is analyzed. Potentials of micromachining sensor element are discussed.

Primeri načrtovanja integriranih magnetnih senzorjev

Ključne besede: senzorji magnetni integrirani, senzorji magnetni inteligentni, MFS senzorji polja magnetnega, primeri snovanja, ASIC vezja integrirana za aplikacije specifične, meritve toka električnega, merjenje energije električne, senzorji bližinski, stikala bližinska, meritve položaja, polja magnetna dvodimenzionalna

Povzetek: Prikazani so razni primeri načrtovanja vezij ASIC z integriranimi magnetnimi senzorji. Med njimi so primeri vezij za merjenje toka in energije, magnetna stikala, vezja za merjenje pozicije in kota ter za merjenje kompleksnih dvodimenzionalnih magnetnih polj. Uvedena je načrtovalska metoda s poljem Hallovih elementov. Predlagana je optimizacija lastnosti senzorjev s pomočjo načrtovalske metode. Prikazane so možnosti za mikroobdelavo senzorskega elementa.

1. Introduction

Integrated magnetic sensors can be used in a variety of applications. Classification of the ASIC with integrated magnetic circuit could be either by its application or it could rather be based on the design approach. By design approach one can distinguish between two classes. In the first class there are the ASICs with open loop approach. This means that such circuit relies on the actual sensitivity of the integrated sensor, so sensor sensitivity should be very well calibrated during ASIC testing and the ASIC should provide good compensation of the temperature coefficient of the sensor and of sensitivity changes due to other internal or external conditions.

The other alternative is a closed loop approach. In this case a magnetic signal is feed-back to the sensor which is used only as a signal source for the error amplifier. The accuracy of such ASICs is therefore dependent only on the feed-back elements of the magnetic circuit.

The magnetic circuit providing the feed back can be either external or it could be integrated. In the second case the field strength is limited by the capability of the integrated coils. If this is not enough it is necessary to use a combination of open loop and closed loop approach.

In the paper various design examples of these design approaches are presented.

2. Design Approaches for ASICs with Integrated Magnetic Sensors

Table 1 shows different design approaches for various applications. The simplest application is a proximity switch. Typical specification for such ASIC is the magnetic field, usually of both polarities and its current consumption. To achieve the lowest current consumption the reaction time of the ASIC is relatively slow. Figure 1 shows the block diagram of such ASIC. Some of the design approaches for such ASIC were already described /1/.

Table 1

OPEN LOOP	CLOSED LOOP	COMBINED
Absolute magnetic field measurement: 1. Proximity switches 2. Relative/absolute position/angle measurement 3. Current/energy measurement	Current measurement Energy measurement	Accurate field measurement for position, current or energy measurement

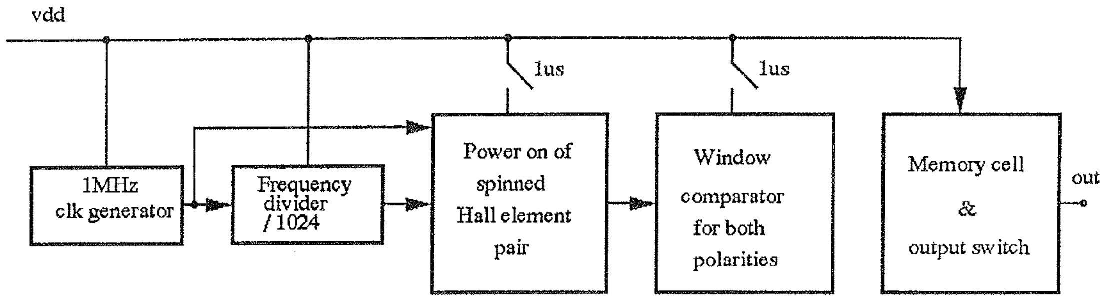

Fig.1: Block diagram of battery operated magnetic switch

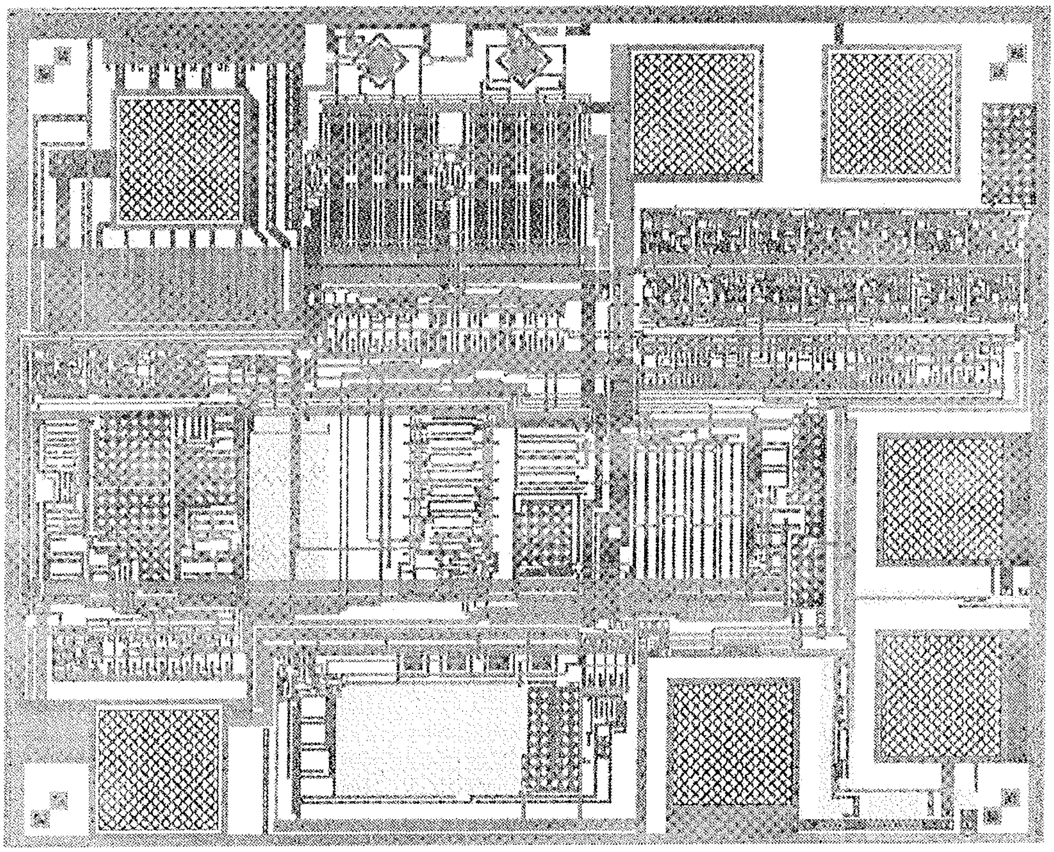

Fig. 2: Realization of magnetic switch

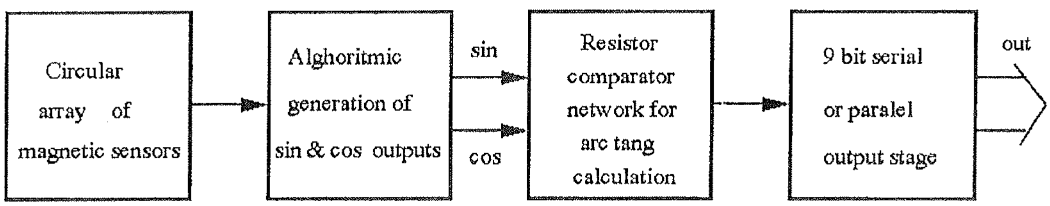

Fig. 3: Block diagram of absolute angular encoder ASIC

The critical specifications for such magnetic switch are continuous current consumption, the response time, accuracy and chip size.

Figure 2 shows the realization of such magnetic switch, while Table 2 summarizes some of the most important parameters.

Table 2

Operating voltage	2V - 3V
Current consumption	< 15 μA
Response time	< 1 msec
"ON" magnetic field	± 2 mT_{min}, ± 3 mT_{max}
"OFF" magnetic field	± 1 mT_{min}, ± 2 mT_{max}
chip size	<0.5mm^2

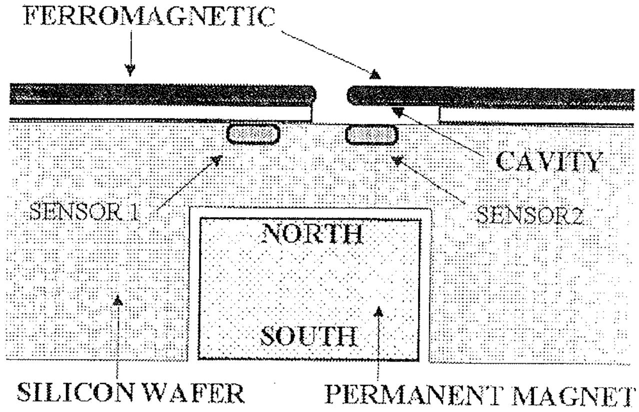

Fig. 6: Proposal for micromachined accelerometer based on integrated magnetic sensor

Another example for open loop approach is absolute angular encoder ASIC. Block diagram of such ASIC is shown in figure 3.

In this ASIC a patented algorithm was used to generate an accurate absolute angle position of North-South polarized permanent magnet to the ASIC.

Since only a ratio of sin/cos signals determine the angle neither accurate magnetic field strengths nor accurate absolute sensitivity of sensors is required to obtain 9-bit absolute accuracy with less than 0.2LSB relative accuracy, the result which will allow this type of ASICs to take over a big part of the opto-encoders market due to lower price and high robustness of the design. Figure 4 shows the realization of this circuit. Energy metering using Hall element approach has been a design goal of many electricity meters producers, but only few succeeded. The design approach for such high performance ASIC was described in /2/.

A design example of such meter ASIC is shown in figure 5. It was designed in 1.2 μm CMOS process. The die size of less than 10mm^2 offers a price advantage compared to other types of electronic meters specially the ones using digital signal processing of the current transformers or shunts for current sensing.

3. Micromachining of Magnetic Sensors

Micromachining offers a possibility to make Hall element perpendiculars to the ASIC plane. Such vertical Hall element allows various possibilities to measure a complete vector of the magnetic field strength, not only the vector component which perpendiculars to the ASIC plane.

Typical volume application for such devices are electronic compass and personal dosimeter of exposure to various magnetic fields.

Table 3

	Achieved	New designs
Sensitivity	10 mV/G; 100 V/T	not limited
Linearity	> 0.1%	limited by test equipment
TC	100 ppm	50 ppm
Offset voltage -40 °C 150 °C	1.5 G; 150 μT ± 8 G; 800 μT	0.5 G; 50 μT 2 G; 200 μT (10 mG; 1 μT) special cases
Noise	2 mG/√Hz; 200nT/√Hz	1mG/√Hz; 100 nT/√Hz (0.1 mG/√Hz; 10 nT/√Hz) for B > 100 kHz
Frequency response	10 MHz	application dependent
Current consumption	10 μA	application dependent
Resolution	10 μm; 40′	2.5 μm, 20′
Accuracy	20 μm/m; 40′	10 μm/m; 20′

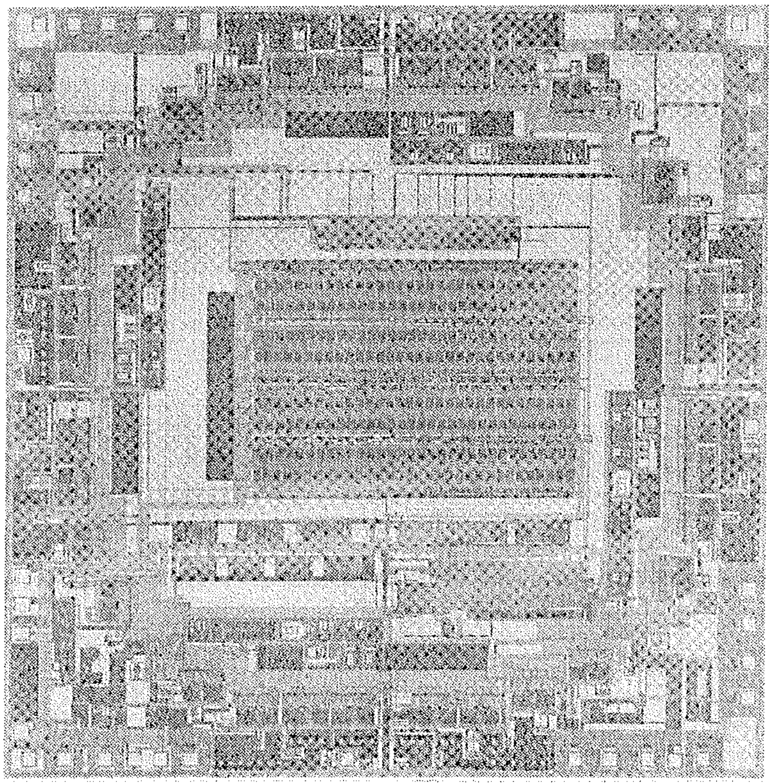

Fig.4: 9-bit absolute angular encoder, die size 5mm x 5mm

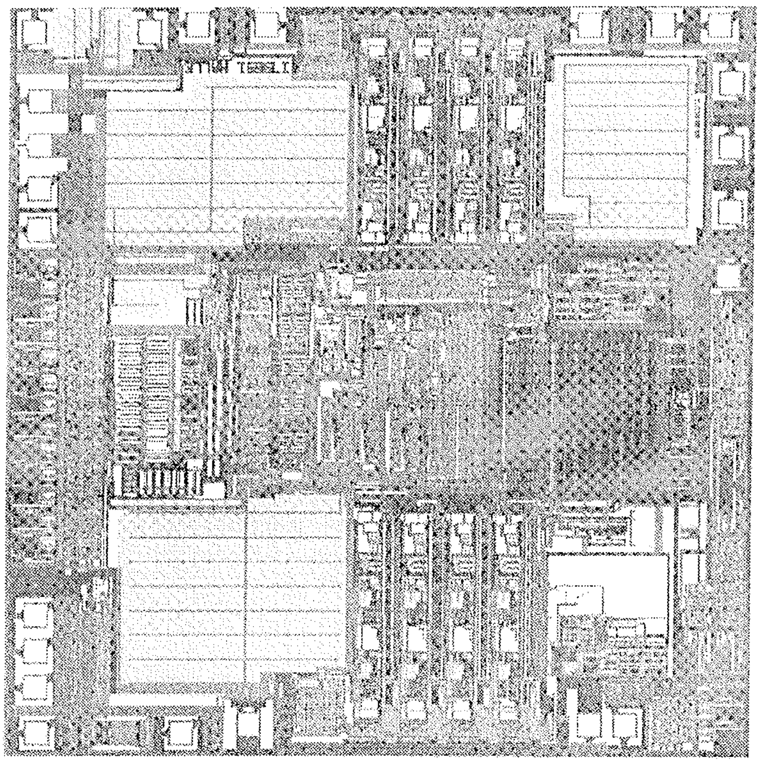

Fig.5: Realization of electrical energy meter ASIC

An interesting application of micromachined magnetic systems is accelerometer. Cross-section of such accelerometer is shown in figure 6.

The system consists of classical ASIC with micromachined cavity to insert a permanent magnet. On the top of the sensor 2 there is a micromachined movable membrane made of ferromagnetic material. The same material is above the sensor 1 but fixed. By this arrangement a differential measurement of the field modulation due to membrane movements is possible.

A closed loop approach with integrated coils /2/ to measure field strengths difference is appropriate since the differential field strengths quite small.

The described approach has also the advantage over other solution due to the possibility to calibrate the sensor using external magnetic field to move the ferromagnetic membrane instead of a real accelerometric force.

4. Conclusion

Several designs using integrated magnetic sensors were realized in Laboratory for microelectronics on Faculty of Electrical Engineering. Some of the achievements are summarized in Table 3.

5. References

/1/ J.Trontelj, "Smart Integrated Magnetic Sensor Cell", Informacije MIDEM, št.3(91), 1999

/2/ J.Trontelj, "Optimization of Integrated Magnetic Sensor by Mixed Signal Processing", Proc. of 16th IEEE International and Measurement Technology Conference, IMTC´99, Venice, Italy, pp 299-302, 1999

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