Ultra Low Power Consumption Magnetic Microsystem for IoT Applications

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Abstract— **Smart sensor applications have recently grown at an unprecedented pace. The possibility of monitoring specific situations is further increased by applying Internet of Things (IoT) technology. Many key advances have been triggered by sensors improvements such as extended compatibilities and by the use of wireless communication. This also calls for a battery operation. Ideally, a battery operated sensor should be capable of operating for a minimum of 5 years without battery replacement. At the same time, it should be capable of communicating at the required predefined time or on a particular event. If more and more sensor functions are requested, the challenge is how to realize the sensor device to optimize different requirements regardless of the operation timing of the sensors, their current consumption and wireless communication demands. The presented paper is an attempt to provide some solutions for the optimization of the cost/performance ratio of a magnetic microsystem sensor designed using the 0.35µm Complementary Metal Oxide Semiconductor (CMOS) technology.**

Keywords-ultra low power consumption; magnetic microsystem; IoT applications.

I. INTRODUCTION

In this paper, a magnetic microsystem for various applications is presented. It includes two spatially positioned integrated magnetic sensors [1], which can provide a variety of information of the permanent magnet position relative to the microsystem position by signal processing of both sensor outputs [2]. The integrated circuits and permanent magnets are shown in Figures 1 and 2 as an example of linear and angular movement.

The cost effectiveness of different integrated or discrete magnetic sensors i.e. the standard integrated Hall element, Anisotropic Magnetoresistance (AMR) and Tunnel Magnetoresistance (TMR), including the required signal processing, has been analysed. The main finding was that the highest performance/cost is achieved by using a six terminal Hall sensor array, which has been introduced in 1995 [4] and comprises the on board integrated microcoil for internal generation of the magnetic field.

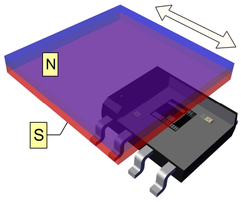

Figure 1. Permanent magnet linear movement.

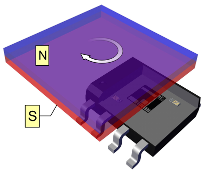

Figure 2. Permanent magnet angular movement.

The rest of the paper is structured as follows. In Section 2, we describe the idea of minimizing the current consumption of the Hall element. In Section 3, we present the microsystem and its design. Finally, we summarize the paper in Section 4.

II. SENSOR CURRENT CONSUMPTION MINIMIZATION

The Hall element sensitivity is directly proportional to the bias current of the Hall element; therefore, its high sensitivity brings the main drawback of the Hall element, which is large power consumption [3]. Most of our microsystem applications target a slow variation of the measured magnetic field. Therefore, the average current consumption should be below µA, when the Hall element bias current is several mA. The refresh rate of the signal should be up to 10Hz. These figures call for measurement duty cycle down to 10^{-4} or 0.1%.

The full measurement cycle should only take a few microseconds. Fortunately, the bandwidth of Hall element is not a limiting factor in this case, however the signal

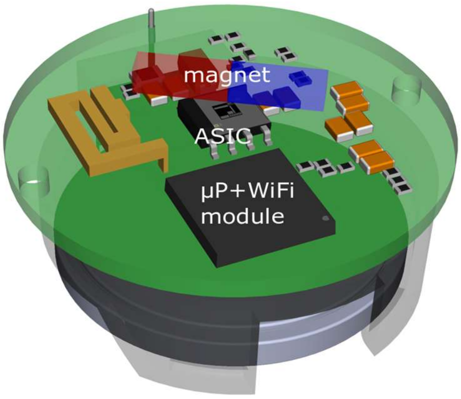

Figure 3. Magnetic microsystem.

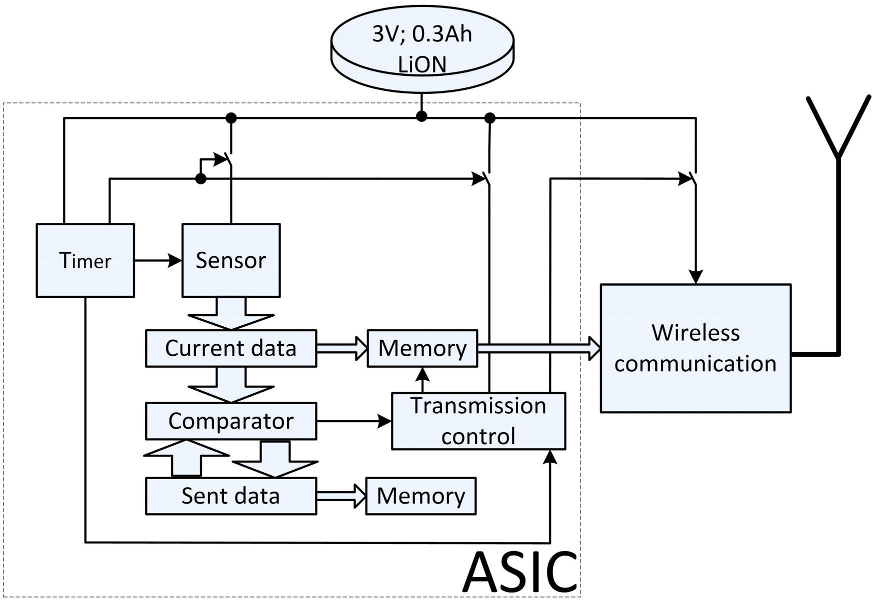

Figure 4. Block diagram of the proposed system.

processing circuitry should be fast, which results in higher power consumption.

III. MICROSYSTEM SYSTEM DESIGN

The magnetic microsystem is shown in Figure 3 with permanent magnet, which is attached to the valve. The valve is not shown in Figure 3. The sensors indicate the position of the valve and returns α as tan^{-1}, where α is the rotation angle of the magnet. The electronic circuit is placed on top of a battery holder, which contains 300mAh 3V lithium coin cell battery.

The block diagram of the Application Specific Integrated Circuit (ASIC) is shown in Figure 4 with external wireless communication module. It consists of extremely low current consumption timer, Hall element sensors and associated circuitry, signal processing unit, digital signal processing and data memory. The strategy for current consumption optimization is the following.

The circuit is divided into two parts. The part which needs to be connected to the battery constantly and the part which can be switched on only a fraction of the time to perform the sensing function and the send and receive function. The part of the circuit which is constantly connected to power supply is further divided into the static part and to the dynamic part. The static part consists of the logic where only leakage current of the parasitic diodes exists. This current accounts for only a small part of the power supply losses of the system, however, special care was taken to minimize the drain area of those nodes.

The dynamic part of the circuit is the main consumer of the supply current. The dynamic current consumption is the sum of the switching current and charging and discharging parasitic capacitance. The dynamic current consumption is given by (1):

$$I = \sum_{i=1}^{n} c_i V_{dd}^2 \cdot f_s, \qquad (1)$$

where c_i is parasitic capacitance of nodes, n is the number of nodes, V_{dd} is a power supply voltage and f_S is the switching frequency.

To minimize this dynamic consumption, the layout minimization of node capacitance has been carried out.

In addition, the oscillation frequency has been reduced for further optimization of the current consumption. A large current loss originates also in the cross conducting during the

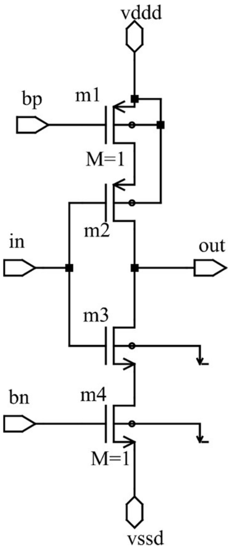

Figure 5. Special low cross-conducting current inverter *invbia*.

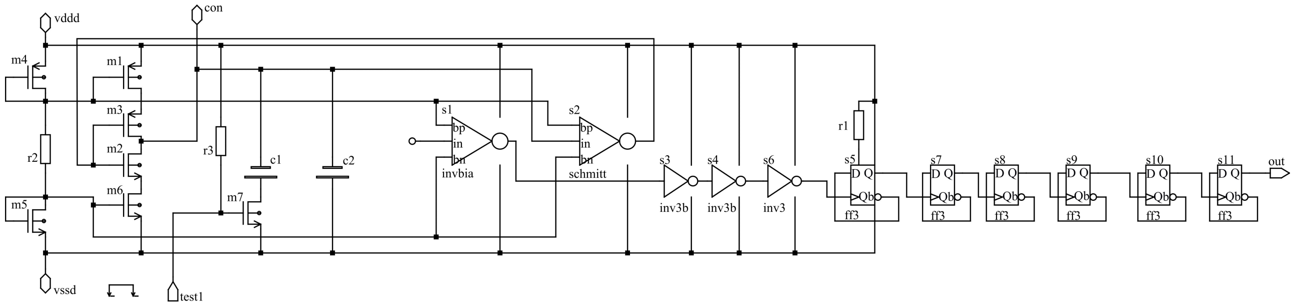

Figure 6. Timer schematic diagram.

slow switching of the logic gates and inverters. Therefore, a special inverter *invbia* we designed for the timer section, shown in Figure 5, to control the cross conduction current. It consists of a current switching approach for the inverters with limited current to only 50nA. *Bp* and *bn* voltages control transistors *m1* and *m4*. *In* and *Out* represent the input and output of the special inverter. *Vddd* and *vssd* are power supply connections. *M* represents the transistor size multiplication factor. With this approach, the average current consumption of the dynamic part of the circuit has been reduced to less than 100nA.

Figure 6 presents a schematic of the timer, which contains the already presented special inverter *invbia*, Schmitt trigger *Schmitt*, D flip-flops *ff3* and inverters *inv3* and *inv3b*. As the resulting capacitance of the parallel connected capacitors *c1* and *c2* is quite large (this means only a few Hz refresh rate), an additional test pin *test1* with pull-up resistor is added. This pin can be used (connected to ground) to speed up the ASIC for testing purposes. In this block, additional six D flip-flops are used in series to scale down the frequency of the timer by 64 to achieve the requested refresh rate. The *con* pin is used only for the simulation test to set the initial condition. The pin *out* represents an output of the timer. *Vddd* and *vssd* are power supply connections. Transistors *m1*, *m3* and *m4* represent P type of MOS transistors and *m2*, *m5*, *m6* and *m7* represent N type of MOS transistors. Resistor *r3* is a pull up resistor, which connects the gate of transistor *m7* to the *vddd*.

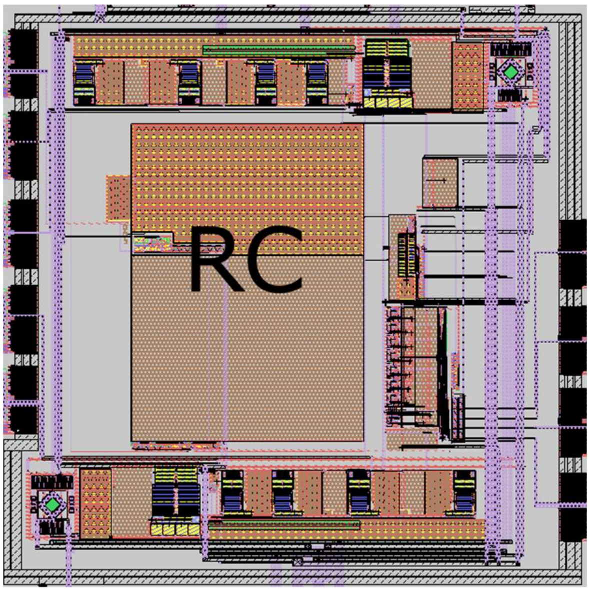

Figure 7. Layout of the ASIC.

As most appropriate, the Resistor-Capacitor (RC) type of the oscillator has been selected. To further minimize the current consumption, the large portion of the ASIC area is occupied by integrated resistor *r2* and capacitor *c1*. Figure 7 presents the layout of the presented ASIC.

As the wireless communication unit used in the system consumes the largest amount of power when transmitting or a bit lower even when the unit is hibernating or in sleep mode, the power consumption of this unit should also be optimized. To minimize the communication unit power consumption, the system turns on the wireless communication only at the maximal required time period, if there is no magnet position change. If there is a change in position, the data is sent out as frequently as specified by the application. Our main targeted application requires measurement refresh rate up to 10 per second and the average position change is a few times per day.

In the ASIC, the constantly measured current position is compared with the last sent data. The transmitter is turned on according to the result of the comparison, therefore a small button type battery provides enough energy to achieve a long life operation of the presented system of over 5 years.

The ASIC is now under evaluation and the measured data are summarized in Table 1. Measurements were done at 3V power supply and 25°C.

TABLE I. MEASUREMENT RESULTS

Function	Simulated	Measured	Units
Current consumption	305	330	nA
Current consumption at measurement	4.9	4.8	mA
Sensitivity	180	200	mV/mT
Magnetic field angle resolution	6.4	6.5	Deg

IV. CONCLUSIONS

A developed magnetic microsystem has been presented and some solutions on how to reduce system power consumption were provided in the paper. The main effort of the design was to achieve average current consumption in the range of µA and retain the measurement cycle of magnet position in the range of microseconds. As the required position data refresh rate, which is transmitted to the main receiver unit, depends on the certain change of the permanent magnet position, and the position is changed only several times daily, the total power consumption could be kept low enough to obtain the long lifetime operation, using a standard button-kind battery.

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