A Monolithically Integrated Two-Axis Magnetic Field Sensor System

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Abstract

We report on a monolithically integrated two-axis magnetic field sensor system consisting of two fluxgate sensors and a CMOS driver- and readout circuitry. The system exhibits a sensitivity of 12mV/µT over a magnetic field range of +/-150µT. The 3dB bandwidth of the system is 300Hz. The sensor system drains 20mA from a 5V power supply.

Introduction

Fluxgate magnetic field sensors are widely used in measuring applications in the nT and µT range. The monolithic integration of this sensor in a standard IC-process is of great interest and a great challenge for technologist and circuit designers [1-3]. The tasks to realize a monolithically integrated fluxgate system cover the development of deposition and structuring process steps for the ferromagnetic materials and the development of a driver- and readout electronics which is able to supply the excitation current to the sensor and to detect the weak and noisy signals. The fluxgate principle offers high resolution and the possibility to include the additional fabrication steps into a standard CMOS proceess. The sensor fabrication is done as a postprocessing step between the deposition of the metal layers. No electrical contacts to the ferromagnetic material are necessary.

Fluxgate Sensor

The fluxgate sensor is based on the nonlinear B-H curve of ferromagnetic materials. An excitation coil drives the core periodically into saturation. A pick-up coil located on the same core measures the changes of the magnetic flux within the core. The sensor signal shows higher harmonics of the excitation frequency due to the nonlinear behaviour of the ferromagnetic material. Especially the even harmonics (2f, 4f...) depend on the magnetic field parallel to the axis of the core. Fig. 1 depicts a schematic view of an one-axis fluxgate sensor.

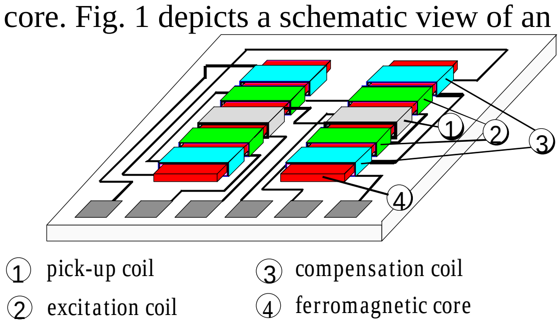

Fig. 1 Principle schematic of a planar fluxgate sensor

The sensor consists of two parallel ferromagnetic nickel-iron cores, surrounded by several coils, fabricated using the metal-1, metal-2 layers of a standard CMOS-process [4]. Each core is about 1300µm long, 100µm wide and 0.5µm thick. The pick-up coil (40 turns, 220Ω) is located at the center of the core, followed by the excitation coil (100 turns, 520Ω) and the compensation coil (100 turns, 520Ω), both divided into two parts. By connecting the pick-up coil in a difference arrangement the odd-harmonics of the sensor signal are suppressed while even, magnetic related, harmonics are added, thus increasing the sensitivity and the signal to noise ratio of the sensor. Fig. 2 shows the behaviour of the first four harmonics of the sensor signal versus an applied magnetic field. The excitation coils were driven by a sine wave current of 4mA peak-to-peak value with a frequency of 20kHz. Measuring the second harmonic (2f) we found a sensitivity of 0.15V/(kHz*T). The fourth harmonic (4f) shows a similar behaviour. The suppression of the excitation works well. The odd harmonics (1f, 3f), caused by capacitive coupling and sensor mismatch, show a constant value of about 30µV which is practically independent of the applied magnetic field.

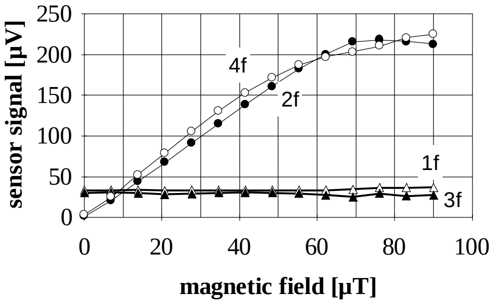

Fig. 2: Harmonics of the sensor signal versus magnetic field.

CMOS Sensor Electronics

Due to the sensor characteristics given in fig. 2 we chose a readout concept of selective detection of the even harmonics. Furthermore, the sensor is operated under zero-field condition using a feedback control loop and compensating the external field by a magnetic field in the compensation coils. Assuming the gain of the feedback-loop is sufficiently high, the compensation current (which is a measure the magnetic field) in the compensation coils is nearly independent of sensor sensitivity, the excitation current, and the gain of the readout circuitry. Therefore, the overall system sensitivity depends only on the inductive coupling between compensation and pickup-coil. To save chip area and to avoid interference between X- and Y-sensor we use one electronics switched between the sensors with a frequency of about 2kHz and an output sample-and-hold stage for each direction. The electronics consists of three major parts: a signal generator and driver for the excitations coils, a amplification and demodulation stage, and the feedback circuitry formed by an integrator and a voltage-to-current converter. A symmetric triangular voltage of a frequency of about 350kHz is generated by charging and discharging a capacitor using a constant current source. Two signal pathes are used for the two magnetic cores of each sensor. Fig. 3 shows the block diagram of the circuit.

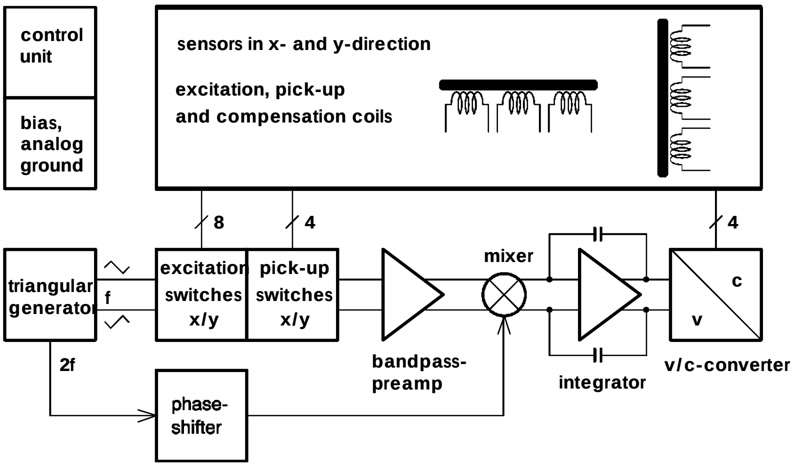

fig. 3: Block diagram of the system electronics

The amplitude of the excitation voltage is controlled by two feedback loops. The average value of both signal pathes is fed back to the current source to assure a dc-free excitation current. A peak-detector/control stage samples the peak voltage and adjustes the current sources. The peak-detector avoids overload voltages which cannot be detected by controlling the average value. Fig. 4 shows some details of the signal generator.

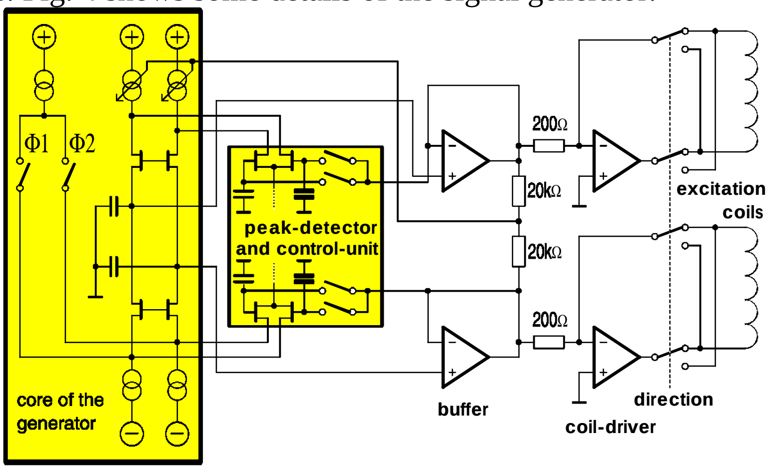

Fig. 4: Signal generator

The input resistor of 200Ω performs the voltage-to-current conversion. The current is fed to the excitation coil which is connected as feedback impedance of the inverting amplifier. It should be noted, that at a frequency of 350kHz the ohmic resistance of the ecitation coils (520Ω) is by a factor of 80 larger than the inductive impedance. The direction switch can be used to change the current direction between two measurement cycles in order to reduce offset generated from dc-currents and sensor mismatch.

The sensor voltage is amplified by a bandpass coupled preamplifier with a gain of about 40dB. The mixer, driven with the frequency 2f converts the 2nd harmonic into a dc-voltage which is integrated over the duration of one measurement cycle. The phase of the 2f mixer signal can be adjusted externally by a five bit word. The output voltage of the integrator is converted (via an external resistor) into a current which generates the compensation field. A sample and hold stage (not shown in fig. 3) stores the voltage of X- and Y-sensor delivering a constant voltage as output signal. An internal RC-oscillator controls the clocking of the circuit. The RC-oscillator runs at a frequency 32 times the frequency of the excitation signal. Fig. 5. shows a microphotograph of the sensor system.

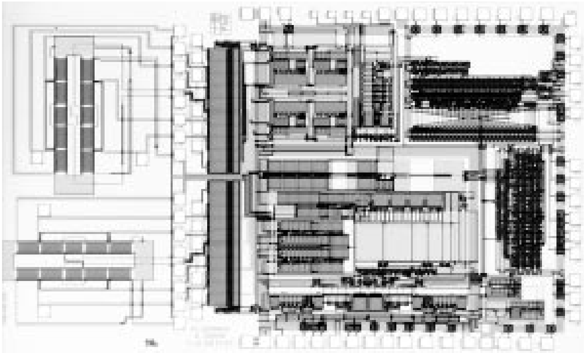

Fig. 5: Microphotograph of the sensor system

At the left one can identify the two sensors. The switch array is located near the vertical arranged sensor testpins. The right side of the photograph shows the sensor electronics. The bottom of the chip contains the readout, feedback, and digital control circuitry, while at the top the signal generator, the driver amplifiers, and the phase-shifter are located. The chip area is about 4x7mm^2. The photo shows a test version with a relative large number of testpins. For operation only few external components (resistors and blocking capacitors) are necessary.

Measurement Results

Fig. 6 shows the system characteristic for both directions.

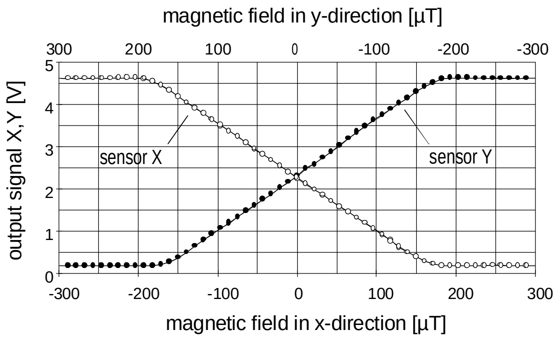

Fig. 6: System characteristic of X- and Y-sensor

The picture shows the good matching between both sensor directions. Table 1 summarizes the technical data of the sensor system.

supply voltage	5V
current consumption	20mA
measurement range	+/- 150µT
system bandwidth	300Hz
excitation frequency	350kHz
excitation current	3mA$_{pp}$
system sensitivity (0^{o}C ..70^{o}C)	12mV/µT +/- 0.3mV/µT

Tab. 1: Data of the magnetic field sensor system

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