Novel Fast Angle Magnetic Sensor - FAMAS

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Abstract. This paper describes a novel Fast Angle Magnetic Sensor (FAMAS), which will allow to disrupt in the magnetic field sensor global market with a product with a very fast response (<1us) and very high resolution (<0.1°), highest rotational speed (200,000 rpm), and with the lowest price in the market. FAMAS is an innovative cost effective, fast and accurate magnetic angular sensor. It is an integrated magnetic field sensor that allows the measurement of the rotation angle of the in-plane component of a magnetic field, such as that of a permanent magnet attached to a rotating shaft. The novel concept and the unique approach are introduced, the new sensor is compared with the market state-of-the-art and some major applications of the new sensor are mentioned.

1. Introduction
A magnetic angle sensor consists of a magnet attached to a rotating shaft and a magnetic field sensor.[1] The magnetic field sensor therein is usually a dedicated integrated Hall sensor, which may be based on conventional Hall plates [2], on an integrated combination of Hall plates and magnetic flux concentrators (IMC-Hall) [3], on vertical Hall devices [4], or on the circular Hall device [5]; (three out of these four concepts are based on the work of Prof. Popovic and his teams) [6], [7]. A magnetic angle sensor based on the conventional Hall plates requires a magnet with a size and position well adapted to the magnetic sensor chip. The IMC-Hall technology provides magnetic gain and so the sensor can work with smaller or more distant magnets. However, the ferromagnetic part in IMC-Hall sensor introduces hysteresis and may saturate. The magnetic angle sensor based on the vertical and circular Hall devices work with larger and stronger magnets, and therefore, they are the most robust.
In any case, the integrated Hall magnetic sensor part includes biasing and signal conditioning electronics. Several approaches have been used for the retrieval of the rotation angle, including the application of CORDIC algorithm, the calculation of tangent and finding arc tangent from a look-up table, and by interpolation of the signals from an array of several Hall devices positioned around a circle. If the circular vertical Hall device is used, the result of angle measurement appears as the phase shift between two ac signals, which can be measured by a phase detection circuit.
In this paper, we describe a novel magnetic angle sensor based on SENIS’ much improved vertical Hall devices [8] and novel approach in the retrieval of the magnetic rotation angle [9]. Our new magnetic angle sensor FAMAS has significant advantages over existing solutions. In particular, while keeping the robustness of the known sensors based on the vertical Hall devices, it shall offer very high magnetic resolution and operation at an unprecedentedly high rotation velocity.
The innovative cost effective, fast and accurate magnetic angle sensor FAMAS is an integrated magnetic field sensor that allows the measurement of the rotation angle of the in-plane component of a magnetic field, such as that of a permanent magnet attached to a rotating shaft. The co-integrated
signal processing circuits provide digital information about these parameters: a) the absolute angular position of the magnetic field; b) rotation direction; c) incremental angular velocity. It also includes the on-chip analog and digital signal conditioning, compensation and calibration.

We have already developed the first stages of our FAMAS. The proof of concept is done and our first FAMAS prototype in discrete technology has already been developed during 2017. The design of the integration on a IC chip, which will be the final FAMAS commercial form has been manufactured and is being tested in relevant conditions.

2. Market state-of-the-art
Fully integrated angle sensors in the market can be quite precise. However, the state-of-the-art for measurement errors is in the range of 0.8º measured as offset errors with very slow signals (near DC). Our goal is to allow the measurement of the absolute angular position of fast rotating motors at speeds of up to 200,000 rpm and a resolution less than 0.1º. The new FAMAS sensor will allow a very fast response and very low time delay of signals (latency <1us).

Table 1 shows FAMAS in comparison to the best performances extracted from available angle sensors specs. We can conclude that FAMAS is far ahead its competitors as it is a disruptive fast angle sensor with 1) higher sensitivity (0.08º), 2) much faster response (latency <1 us) and 3) the highest rotational speed (200,000 rpm) at very competitive price.

Table 1: FAMAS alternatives comparison.

| Parameter | SENIS FAMAS | Best competitor combination |
|-----------|-------------|-----------------------------|
| Sensor type | Digital | Digital |
| Vsupply [V] | 5 | 3.3 or 5 |
| Isup [mA] | <15 | 10 |
| Toper [*C] | [-40,125] | [-40,150] |
| Magnetic field[mT] | 20-200 | 50-200 |
| Power-up time[ms] | 2 | 2 |
| Rotational speed[rpm] | 200'000 | 100'000 |
| | 50'000 | |
| Angle resolution[*] | 0.08 | 0.1 |
| | 0.35 | |
| Latency [us] | 2.8 | 3 |
| | 1 | 3 |
| INL [*] (Integ. nonlinearity) | 0.3 | 1 |
| | 0.03 | 0.03 |
| Vout vs Temp[deg/C] | 12 | 16 |

3. FAMAS – Fast Magnetic Angle Sensor

3.1. The main characteristics of FAMAS
FAMAS is an integrated magnetic field sensor that allows the measurement of the rotation angle of the in-plane component of a magnetic field, such as that of a permanent magnet attached to a rotating shaft. The co-integrated signal processing circuits provide digital information about the absolute angular position of the magnetic field, rotation direction, and incremental angular velocity, including the on-chip analog and digital signal conditioning, compensation and calibration. Figure 1 shows the IC layout design of the FAMAS sensor and its main functions. FAMAS sensor has three modes of
operation that balance the speed and resolution: 1) very fast (200,000 rpm), 2) balanced (50,000 rpm) and 3) high resolution (25,000 rpm). Regarding cost-reduction, as only established CMOS technologies are used in manufacturing, cost is directly proportional to the silicon area used for the device. We have achieved so by improving the design of our FAMAS. In addition, our solution is a single chip sensor that can be used in various applications, whereas the competitors might need two or more sensor products.

1. Look up table logic  2. Sine 8 bit current source 3. Cosine 8 bit current source 4. X sensor 5. Y sensor, 6. X Drive measure matrix 7. Y Drive measure matrix 8. Preamp 9. Amplifier 10. Rectifier 11. Power management regulator 12. Comparator 13. Digital electronics

**Figure 1.** left: IC layout design of the chip FAMAS and its main functional blocks; right: Main characteristics of FAMAS

### 3.2. The principle of operation

Our magnetic angle sensor FAMAS incorporates two vertical Hall devices – see Figure 1, left. One of the two Hall devices is oriented so that it responds to the x-component, and the other responds to the y-component of a magnetic field. These two Hall devices are further referred to as the X sensor and the Y sensors. The X and Y sensors are biased by two current sources. The two Hall biasing currents $I_x$ and $I_y$ are proportional to the sine and cosine of an angle $\alpha$, respectively. The output voltages of the X and Y sensors are summed up to give the common sensor output voltage $V_{xy}$. The combination of the X and Y sensors can be considered as a sensor system XY. The output voltage $V_{xy}$ of the sensor system XY is given by the scalar product of the sensitivity vector $S_{xy}$ of the sensor system XY and a magnetic field $B$. The sensitivity vector $S_{xy}$ is parallel with the plane of the die of the sensor IC, and its angular orientation is a function of the Hall biasing currents $I_x$ and $I_y$. In particular, when the Hall biasing currents $I_x$ and $I_y$ change as a consequence of a little change of the angle $\alpha$, the sensitivity vector $S_{xy}$ rotates a little in the chip plane.

The electronic system of FAMAS works as a servo system, which adjusts the value of the angle $\alpha$, and so also the currents $I_x$ and $I_y$, so as to keep the output voltage $V_{xy}$ at zero. We can interpret such an operation by saying that the servo system keeps the sensitivity vector $S_{xy}$ in the perpendicular position with respect with the in-the-chip-plane component of the magnetic field $B$.

The actual value of the angle $\alpha$ is kept in the memory of the sensor and updated within a period of time, which is limited only by the reaction time of the servo system. Therefore, the retrieval of the
measured angle does not require any calculation or any other complex operation. In this way we achieve an unprecedented short reaction time of the new angle sensor FAMAS. FAMAS is based on SENIS’ patented invention [9]. The key enabling components of FAMAS are very low-noise vertical Hall devices designed according to another SENIS’ patented invention [8], [10].

4. Conclusions and Applications

FAMAS (Fast Magnetic Angle Sensor) with its key advantages can find several applications in the automotive, medical, energy and consumer industry.

Application of FAMAS for the Automotive OEMs: The automotive industry is among the major markets for magnetic field sensors. Some of the major applications of magnetic field sensors in this market are anti-lock braking systems and engine control management systems. Some of the other important applications of magnetic field sensors in the automotive industry are the detection of vehicle position, inspection of automated machines, electronic stability control (ESC) systems, tire pressure monitoring systems (TPMS). In the present scenario, this industry is leading in terms of the maximum utilization of magnetic field sensors, specifically Hall Effect sensors.

Application of FAMAS for consumer electronics: The usage of magnetic field sensors, in consumer electronic devices such as air conditioners, smartphones, smart toys, computers and joysticks, has increased in recent years, which in turn has helped the market to grow. The rise in demand for consumer electronic devices, along with the increase in the popularity of navigation equipment and electronic compasses, has increased the consumption of magnetic field angle sensors.

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6. References

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