ISSN 1726-5479

SENSORS & TRANSDUCERS

1/09 vol. 100

vol. 100

Sensor Instrumentation, DAQ and Virtual Instruments

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 100
January 2009

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal

Contents

Volume 100
Issue 1
January 2009

www.sensorsportal.com

ISSN 1726-5479

Editorial

Research Articles

New e-Book

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

Sensors & Transducers Journal, Vol. 100, Issue 1, January 2009, pp. 85-91

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

A Novel Hall Effect Sensor Using Elaborate Offset Cancellation Method

Vlassis N. Petoussis, Panos D. Dimitropoulos and George Stamoulis
University of Thessaly. Department of Computer & Communication Engineering
Tel.: +30 24210 66594, e-mail: petousis@inf.uth.gr

Received: 18 December 2008 /Accepted: 19 January 2009 /Published: 26 January 2009

Abstract: The Hall effect is caused by a traverse force that is formed in the electrons or holes of metal element or semiconductor when are polarized by current source and simultaneously all the system it is found vertical in external magnetic field. Result is finally the production of difference of potential (Hall voltage) in address vertical in that of current and magnetic field directions. In the present work is presented a new Hall sensor exploiting the former operation. In combination with his pioneering form and using dynamic spinning current technique with an elaborate sequence, it leads to satisfactory results of produced Hall voltage with small noise in a presence of external magnetic field. Anyone can see both the spinning current and anti-Hall technique in the same sensor simultaneously. *Copyright © 2009 IFSA.*

Keywords: Hall plate, Magnetic sensor, Dynamic offset reduction, Wheel hall sensor

1. Introduction

Hall plates are used in a wide variety of applications to measure static and dynamic magnetic fields. A major drawback of these sensors is their high offset voltage, i.e., an output signal in the absence of a magnetic induction. According to [1] the effects which contribute to the offset voltage are piezoresistive effects, geometrical errors, temperature gradients, nonhomogeneities, etc. However, the offset voltage with a spatially periodic nature differs from the Hall voltage, which is constant. One way to reduce the offset caused by orthogonal asymmetries is to use coupled symmetric Hall plates [2]. However, the offset can never be completely cancelled because there will always be small differences between the Hall devices. To overcome the mismatch, the bias current of a single four contact Hall device is spun by contact commutating and the resulting output voltages are averaged over time. The orientation dependence of the offset sources in silicon suggests that orthogonal switching is not sufficient. To cancel components of higher asymmetries a multicontact Hall plate with more than four terminals is necessary. The method presented in this paper is based on Hall device with sixteen outside and sixteen inside contacts. The spinning current vector is generated by two harmonic biasing currents. As a result, the output signal becomes spatially continuously accessible, hence, asymmetries of higher order can be cancelled out.

Aim of present work is the presentation of new Hall sensor with pioneering form that reminds cogwheel with two lines teeth, one internally and one externally (for this reason we named Wheel Hall Sensor) but also with different way in the cancellation of offset voltage and finally 1/f noise rejection. Initially the designing constituted fundamental objective that as aim had the respect and compatibility in the existing techniques of reduction 1/f noise and also offset voltage. For this aim was selected the circular structure (Fig. 3) but with the differentiation, that the interior of circle is empty from material and besides is not unexploited but constitutes part region of expiry of Hall voltage with periodical phase of operation.

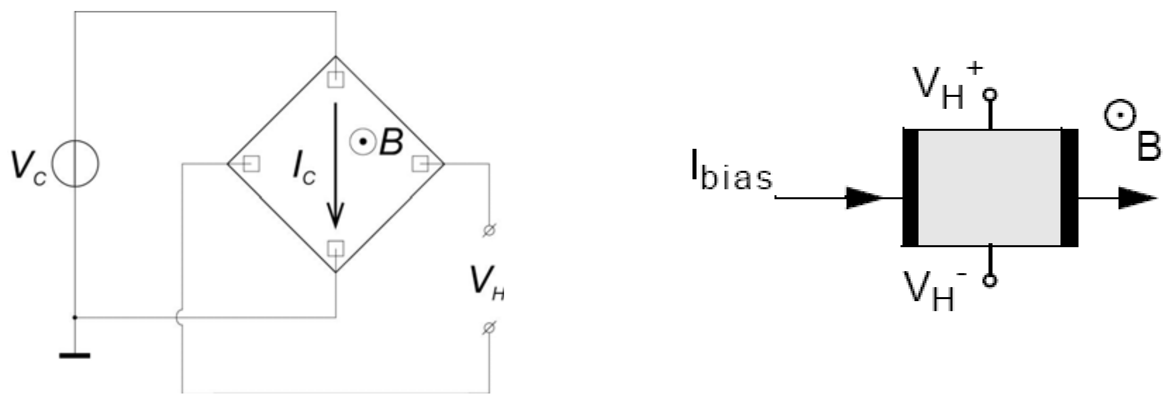
2. Hall Type Devices (without Offset)

The simplest Hall element uses a square plate of N-well in a p-type epitaxial layer. Each corner of the plate has one contact. When a voltage V_C is supplied across one pair of contacts, then a magnetic field B perpendicular to the Hall plate generates a voltage V_H across the sensing pair of contacts according to:

$$V_H = S_H V_C B \text{ (for Voltage bias)} \tag{1}$$

$$V_H = I_{bias} S B \text{ (for Current bias),} \tag{2}$$

where S_H represents de sensitivity of the Hall plate in mV/VT.



(a) (b)

Fig. 1. Basic Hall-sensor structure: with voltage bias (a) and with current bias (b).

Typical sensitivities of Hall plates fabricated in standard CMOS technology are in the order of 100 mV/VT. Most applications require magnetic field strengths to be measured in the signal range of 40 µT (earth-magnetic field) up to 250 mT (strong magnet). It is the lower end of this range that make the use of CMOS Hall sensors very difficult. The main problem for realizing a low-cost compass using silicon Hall sensors is its offset and, even more important, the drift of the sensor offset. Commercially available Hall sensors typically operate over ranges that start at 1mT and have noise levels in the order of 50-100 μT.

3. Hall Type Devices (With Offset)

Made in a standard IC process Hall plates have the advantage of cheap and small. Therefore they are quite often used in applications where the permanent magnet is combined with the sensor. Because Hall plates show a large offset the magnet used in these applications have to be a strong magnets. The offset of the Hall plate is the voltage that is measured when no magnetic field is applied. Equation 2 represents the theoretical situation, when an offset is added this equation becomes:

$$V_H = I_{bias} SB + V_{offset} \quad (3)$$

To reduce the offset, which is time variant, spinning current Hall plates was developed [3]. These are symmetrical Hall plates with 4,8,16 or more contacts. In this multi contact Hall plates the bias current is switched in for example, eight directions through the Hall plate and the corresponding voltages are measured, see Fig. 2. [4]

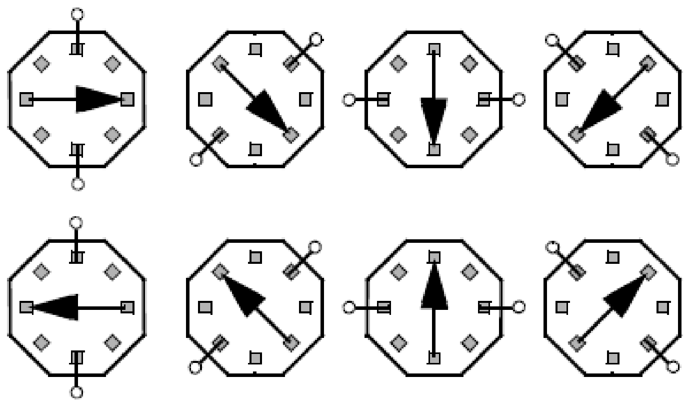
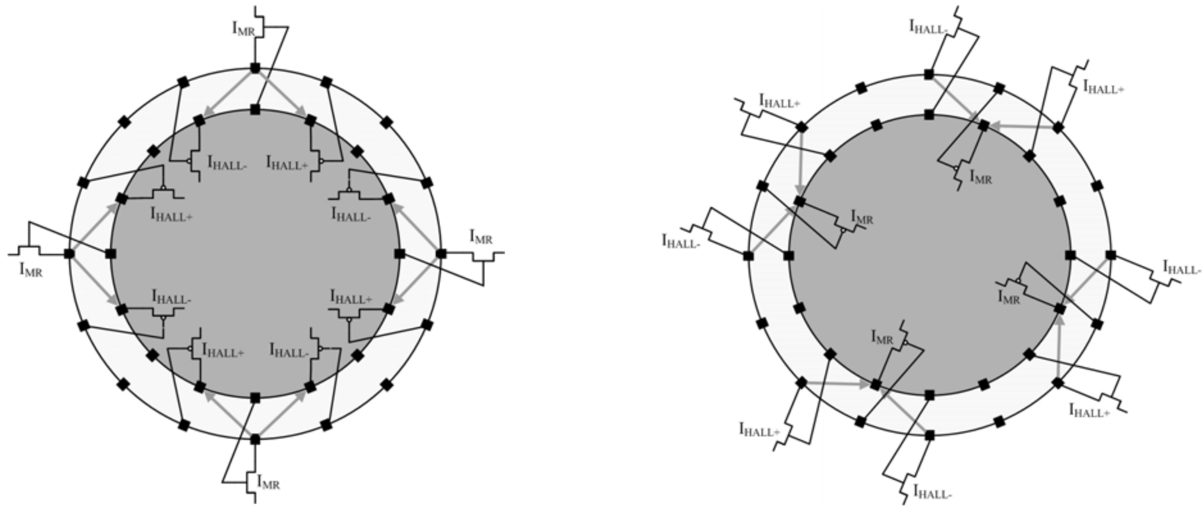


Fig. 2. An eight contact spinning-current Hall plate with the possible bias current directions.

The measured voltages represent one period of a (radial spatial) periodic signal. The spinning current method uses this periodicity, it separates transduction effects according to their spatial radial periodicity. From the output signal a Fourier transform is calculated. The Hall effect itself does not depend on bias current direction and is therefore present in the DC component. Offset voltages that contribute to the higher Fourier coefficients are eliminated. So, a spinning-current Hall plate solves one of the most important drawbacks in integrated silicon Hall plates: their offset. But it involves more interface electronics to realize the sensor on one chip.

4. Wheel Hall Sensor (WHS) Device Structure

In university of Thessaly we designed and we are ready to develop a novel Hall sensor device which uses elaborate spinning current technique. The novel Hall device that we call “Wheel Hall Senor” is presented in Figs. 3a and 3b. The current enters the device, as presented in the aforementioned figures, in two phases namely the even phase (PHASE-P) and the odd phase (PHASE-N).



(a) (b)

Fig. 3. The novel Hall device that we call "Wheel Hall Senor" or WHS:
(a) The even phase (PHASE-P); (b) the odd phase (PHASE-N).

The device exploits the signals attributed to Hall voltage, Hall current and geometric MR effect. As a result the device is equivalent to an "ideal" voltage or current Hall sensor with geometrical factor of one ($G_H = 1$). Moreover it provides for high-speed spinning, given that the voltage distribution changes moderately between different phases. This is equivalent to minimum charge injection that 0 in turn – allows spinning frequency increase. The device senses all 3 filed dimensions, namely the flux-density of B_Z is proportional to the DC component of the output signal, whereas the B_X and B_Y components are proportional to the first harmonic of the output signal. Finally the device can be made in a way to reuse the current, if integrated in a BiCMOS technology providing for matched JFETs.

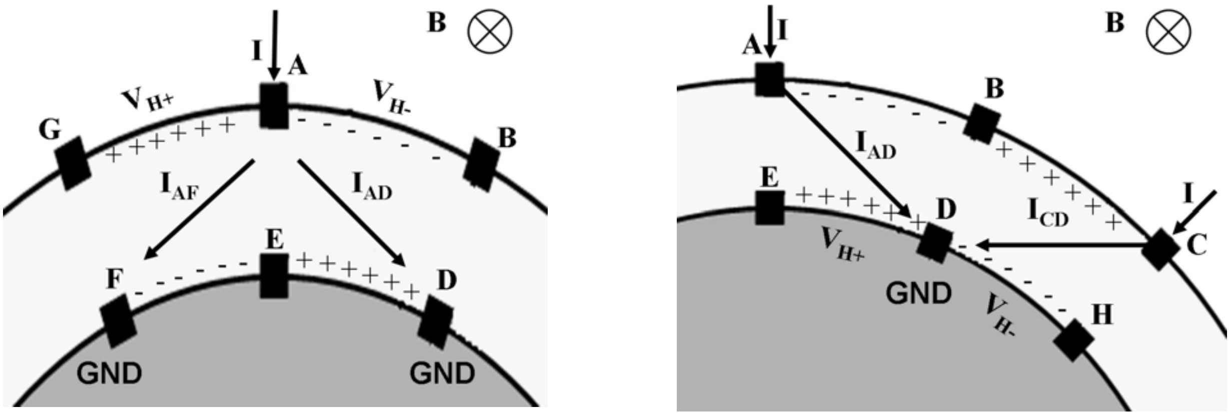
5. Wheel Hall Sensor (WHS) Device. Offset Reduction - Theory

To reduce the offset, the spinning-current Hall plate may be developed in SPICE-like EDA simulators (CADENCE). A spinning-current Hall plate is a symmetrical Hall plate in which the direction of the bias current is spited right and left and the corresponding output voltage is measured on the contacts in ±45º to the current direction in each phase. The total number of measurements at each phase is in four places like a cross and all phases give as the total Hall voltage. When sixteen outside and sixteen inside contacts are used, the bias current is switched ±45º for each measurement, the voltage contacts are switched outside to inside respectively (Fig. 4). For each phase of the bias current, four output (V_{H+} and V_{H-}) and input (V_{H-} and V_{H+}) voltages are measured in a rotating clock wise. Finally for each turn in PHASE-P and PHASE-N, totally sixteen Hall voltages are measured (Fig. 5). Each harmonic biasing current in each phase produces an offset voltage witch totally in turns gives us the offset cancellation. So offset caused from current I_{AD} in phase P cancel the offset caused from current I_{CD} in phase N and I_{AD} in phase N cancel the offset caused from current I_{AF} in phase P. Finally the one offset in one phase cancel the other in next phase. Anyone can see both the spinning current and anti-Hall technique in the same sensor simultaneously [5], [6].

6. Electronic Circuitry

To control the spinning-current Hall plate we need:
1. A current source to generate the bias current;

2. Current switches to connect the bias current source to the right contacts of the spinning-current Hall plate;
3. Voltages switches to connect the right measure contacts of the spinning-current Hall plate to the amplifiers;
4. Amplifiers;
5. Analog-to-digital converter.



(a) (b)

Fig. 4. The even phases (a) and the odd phases (b). With **I** we denote the current bias in 45^0 direction in each measurement and V_{H+} and V_{H-} denoted the two Hall Voltage references in each phase (for n-type material).

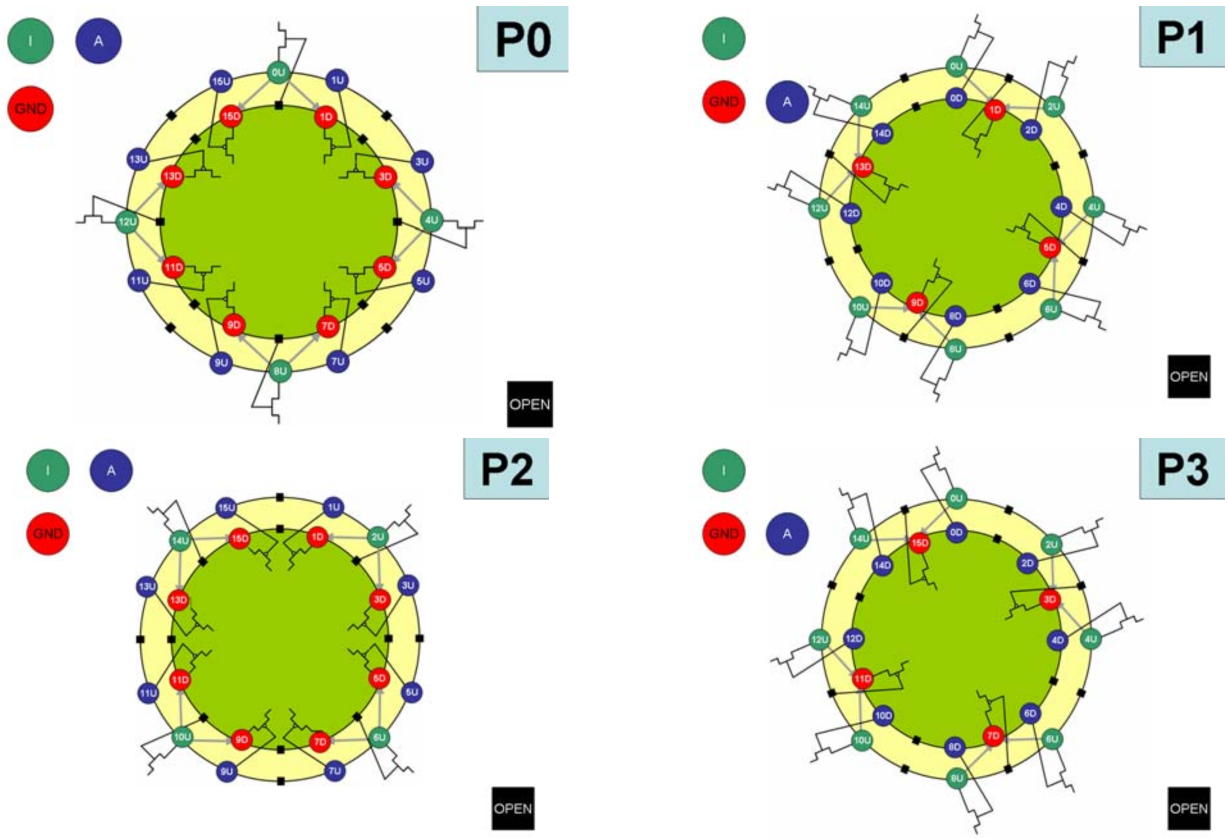


Fig. 5. The novel Hall device in deferent phases for one time period. The even phases (P0-P2) and the odd phases (P1-P3). With **I** we denote the current bias, with **A** the amplifier for Hall Voltage measurements, **GND** for ground and **OPEN** when the conduct is not connected.

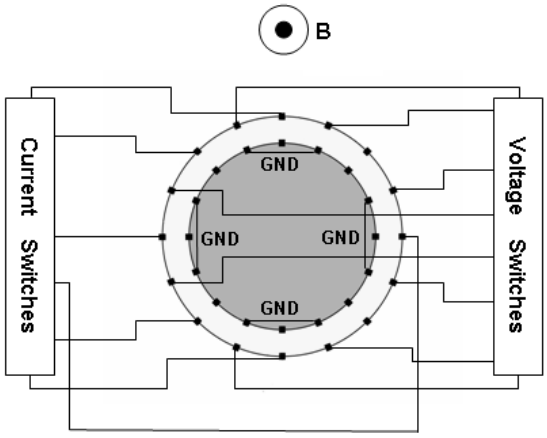


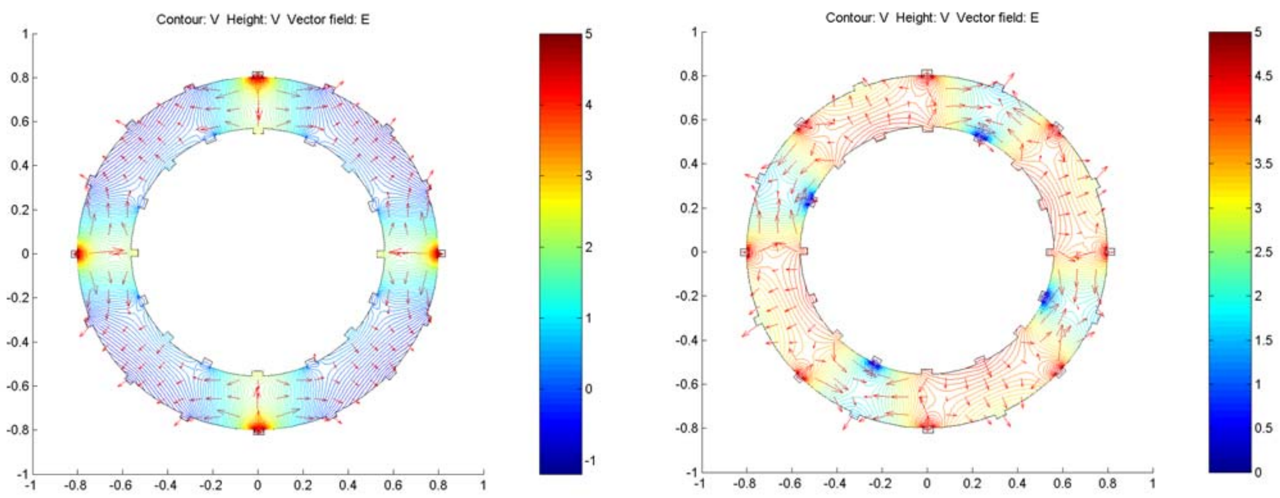
Fig. 6. The measuring set up of the novel Hall device for even phase (PHASE -P) and specific for the phase P0 (see Fig. 3).

7. Simulation of the Device in MatLab Environment

To complete our simulation of the device structure in theoretical approach we develop a theory for control the electric field of the device when it is exposed in perpendicular external magnetic field. We solve the Laplace equation inside the device and from calculations for current densities in each axis direction. After this we define the relationship, which gives us the control of the equipotential lines for each external magnetic field induction.

$$\frac{\partial \phi}{\partial x} = -\frac{J_y \mu B}{1+(\mu B)^2} \tag{4}$$

Finally we simulate the electric field and the equpotential lines inclination in the WHS in a presence of magnetic induction and see the behavior of the device in a real Hall effect conditions and the results represented in Fig. 7a and 7b.



(a) (b)

Fig. 7. The novel Hall device that we call “Wheel Hall Senor” or WHS. (a) The electric field and the equpotential lines in the even phase (PHASE-P) for $B \neq 0$; (b) The electric field and the equpotential lines in the odd phase (PHASE-N) for $B \neq 0$.

Conclusion

In this paper we have defined the method and some of our theoretical simulations in MatLab environment for a new Hall effect sensor, which is use a novel technique to reduce the offset voltage. We have already developed this novel Hall sensor (Wheel Hall Sensor) in the CADANCE simulator to take Hall voltage measurements in semi real conditions. After this we already to publish the results in future papers.

References

[1] A. A. Bellekom and P. J. A. Munter, Offset reduction in spinning current Hall plates, *Sensor and Materials*, 5, 1994, pp. 253- 263.

[2] J. Maupin and M. Geske, The Hall effect in silicon circuits, The Hall Effect and its Applications, ed. C. Chien and C. Westgate, *Plenum Press*, New York, 1980.

[3] Munter P. J. A, A low offset spinning current Hall plate. *Sensors and Actuators*, A21-A23, 1990, pp. 743-746.

[4] Sandra Bellekom, Lina Sarro, Offset reduction of Hall plates in three different crystal planes, in *Proceedings of International Conference on Solid-State Sensors and Actuators (TRANSDUCERS '97)*, Chicago, USA, June 16-19, 1997, pp. 233-236.

[5] C. Muller-Schwanneke, F. Jost, K. Marx, S. Lindenkreuz, K. von Klitzing, Offset reduction in silicon Hall sensors, *Sensors and Actuators*, 81, 2000, pp. 18–22.

[6] R. G. Mania, K. von Klitzing, Method for simultaneously reducing the misalignment offset and separating the Hall voltage from the off-diagonal piezoresistive voltage in Hall effect and piezoresistive devices based on silicon, *Appl. Phys. Lett.*, 67, 15, 9 October 1995.

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information