Chavdar Roumenin[1],
Konstantin Dimitrov[2]

Institute of Control and System Research at Bulgaria Academy of Sciences,
1113 Sofia, "Acad. G. Bonchev" str., Bl.2, POBox 79, Bulgaria tel/fax: (+359 2) 737 822,
[1]*e-mail:* roumenin@bas.bg, [2]*e-mail:* kdimitrov@iusi.bas.bg

MICROSYSTEM FOR 2-D MAGNETIC-FIELD MEASUREMENT

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2-D measurement of magnetic field.

A new silicon microsystem for simultaneous and independent measurement of the in-plane B_x and B_y components of the magnetic field vector B has been designed, fabricated and tested. It consists of two functionally integrated triple parallel-field Hall sensors with mutually perpendicular orientation. The obtained characteristics of this 2-D mag-netometer are very promising

1. INTRODUCTION

The well known magnetic sensors in general detect one component (1-D) of the vector $\boldsymbol{B}$. However, there are many applications in the field of microsystems where the simultaneous and independent registration of more than 1-D component is needed [1-6]. The magnetic devices for multidimensional sensing are based on magnetodiodes [1, 3], magnetotransistors [1, 2, 4, 5] and orthogonal and parallel-field Hall transducers [1, 2, 7-9]. The integration of more than one sensor function in the active region of the silicon substrate is a novel trend in the measurement of the strength and direction of the individual orthogonal fields $\boldsymbol{B}_x$, $\boldsymbol{B}_y$ and $\boldsymbol{B}_z$, the temperature T of the environment and the visible light Φ, etc [1, 2]. This very prospective functional approach guarantees the following advantages: an extremely high spatial resolution; improved orthogonality; the position of the 3-D sensor with respect to the magnetic source is not as critical as in case of 1-D device; optimum electrical, thermal and processing compatibility of the $\boldsymbol{B}_x$, $\boldsymbol{B}_y$ and $\boldsymbol{B}_z$ channels, etc. In our view the 2-D and 3-D microsystems for magnetic field based on the Hall effect principle is preferable. This phenomenon is well defined and predicable with clear galvanomagnetic behavior. The paper describe a new fully integrated 2-D silicon microsystem for magnetic field, using the parallel-field Hall effect. Its advantages are on-line measurement by separate differential outputs the in-plane vector components $\boldsymbol{B}_x$ and $\boldsymbol{B}_z$; reduced cross-sensitivity and noise; suitable transducer efficiency for many practical applications.

2. DEVICE STRUCTURE AND OPERATION

Figure1 shows the novel functionally integrated 2-D silicon vector microsystem. It consists two triple parallel-field Hall sensors [7] replaced each other on the 90^0 in-plane x-y. The device contains a central square current contact C_0 and one contact on each side C_1-C_4 symmetrically situated around C_0. The two differential outputs generate $V_H(\boldsymbol{B}_x)$ and $V_H(\boldsymbol{B}_y)$ Hall voltages, proportionally to the x- and y- components of the magnetic field. The absolute value of the magnetic vector $\boldsymbol{B}$ is given by the relation $|\boldsymbol{B}| = \sqrt{B_x{}^2 + B_y{}^2}$, [1].

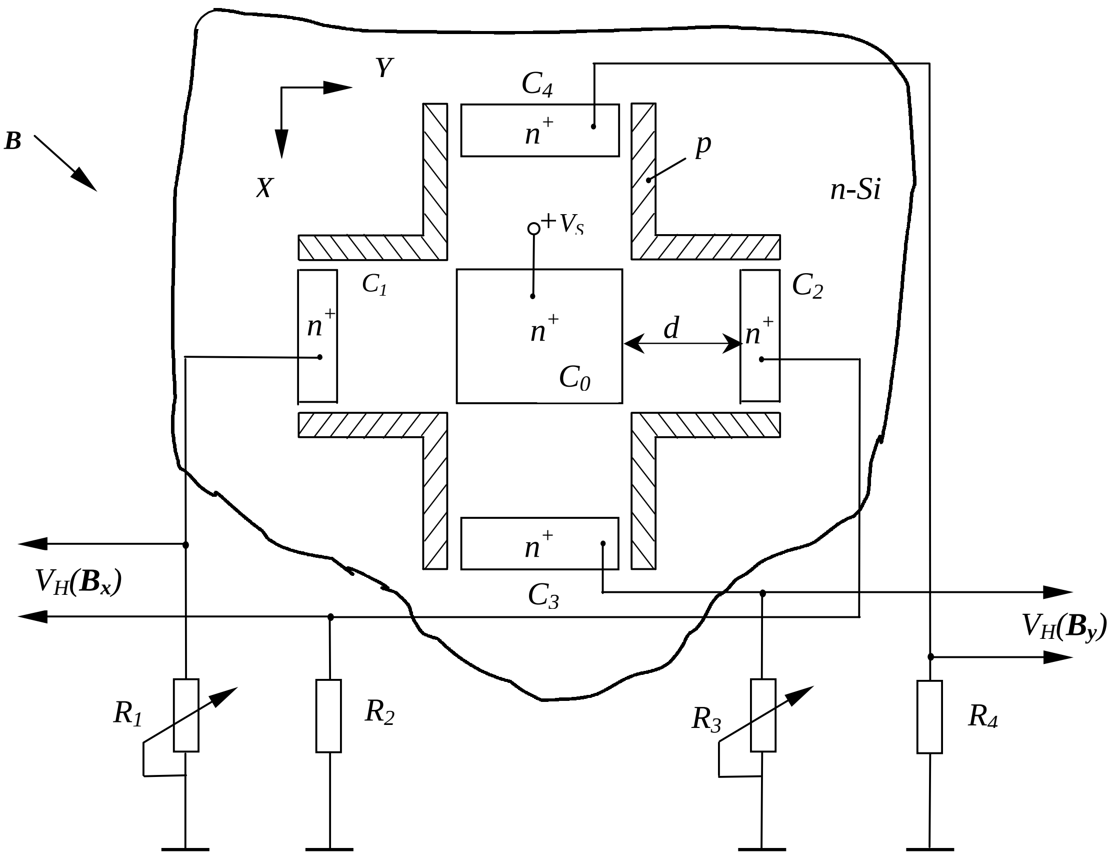

Figure 1. 2-D microsystem for the in-plane $\mathbf{B}_x$ and $\mathbf{B}_y$ magnetic-field components

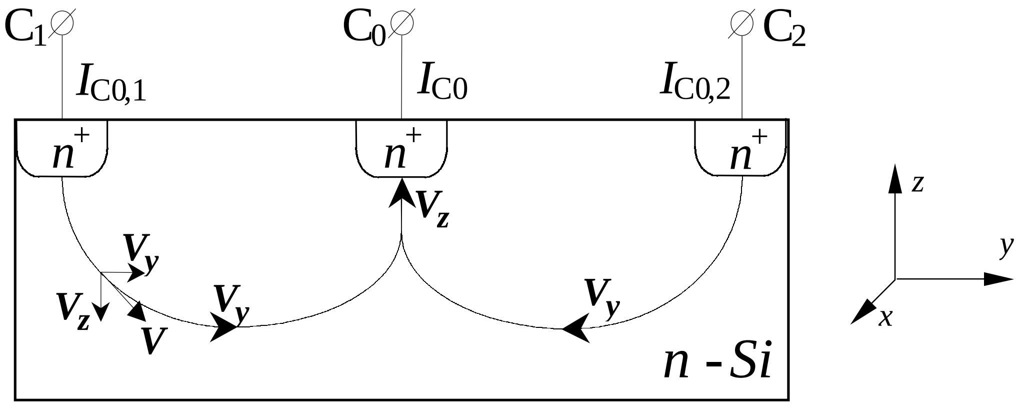

Figure 2. The curvilinear trajectories of the current components $I_{C0,1}$ and $I_{C0,2}$ determining the channel operations of the new Hall 2-D magnetometer.

The action of the new 2-D microsensor is the following. For example, for $\boldsymbol{B_x}$ direction the trajectory of the equal in value currents $I_{C0,1}$ and $I_{C0,2}$ to the left and to the right of contact C_0 are curvilinear- they begin and end to the upper surface of the chip, Fig. 2. Therefore the origin of the two Hall effects is related to the carrier Lorenz deflections in fields $\boldsymbol{B_x}$ and $\boldsymbol{B_y}$ caused by the horizontal $\boldsymbol{v_x}$ and vertical $\boldsymbol{v_z}$ components of the velocity $\boldsymbol{v}$, Fig.2. The registration of the respective Hall voltages $V_H(\boldsymbol{B_x})$ and $V_H(\boldsymbol{B_y})$ is carried out by the contacts C_1 and C_2 for the component $\boldsymbol{B_x}$ and C_3 and C_4- for $\boldsymbol{B_y}$, Fig. 1. The confinement of the supply current by a deep p- ring, as is shown on Fig. 1, will be enhanced the magnetosensitivities of the two channels and reduced their cross-sensitivity.

Some of the device parameters are: the *n*-Si substrate with thickness ~300 μm is with bulk resistivity 7.5 Ω.cm ($n_0 \sim 10^{15}$ cm^{-3}), the heavely doped n^+- regions are with concentration 10^{19} cm^{-3}, the size of the contacts is as follow: C_0- 150 x 150 *μm*, C_1-C_4 are 20 x 150 *μm*; the distance *d* of the contacts C_1-C_4 to the central contact C_0 is 100 *μm.*

The experiments were carried out in the range of magnetic fields $-1.0\ \mathrm{T} \le B \le +1.0\ \mathrm{T}$.

3. EXPERIMENTAL RESULTS

Figure 3 shows the output characteristics $V_H(\boldsymbol{B_x})$ for the *x*- channel of the vector magnetometer (for the *y*- channel they are the same), where the inevitable offset of the channels is nullified in advance. The output voltages $V_H(\boldsymbol{B_x})$ and $V_H(\boldsymbol{B_y})$ exhibit a linear and odd de-pendence on the magnetic field, their non- linearity factor (NL) in the range of $-100\ \mathrm{mT} \le B \le 100\ \mathrm{mT}$ being about 0.4 % and in the interval $-1\ \mathrm{T} \le B \le 1\ \mathrm{T}$ the NL does not exceed 1 %. The temperature coefficient of magnetosensitivity for the two channels is 0.15 %/^{0}C.

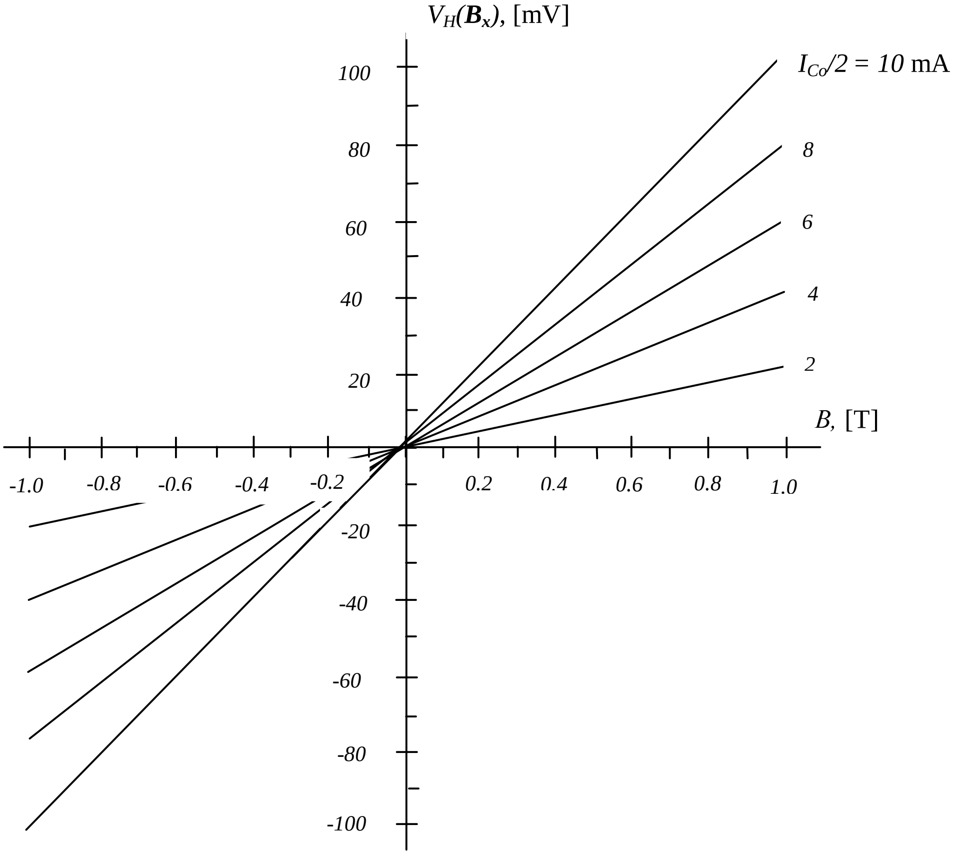

Figure 3. Output characteristics $V_H(\boldsymbol{B_x})$ at T= 300 K for the x- channel of the 2-D microsystem at different values of the supply current, $R_1=R_2=R_3=R_4= 10\ k\Omega$.

Figure 4 shows the angle diagram $V_H(\varphi)$ for the one of the output channels at $B = 0.65$ T and $I_{C0}/2 = 10$ mA. The obtained characteristic presents cosinusoidal behaviour of the φ angle.

The measurement of the cross-sensitivity at current I_{C0} = const., after nullification of the two offsets we achieved, using the following procedure. The first step is an experimental determination of the two channels magnetosensitivities at Hall-voltage mode $V_H(\boldsymbol{B_x})$ and $V_H(\boldsymbol{B_y})$ of operation. The next step is applying a homogeneous variable field B parallel to one of the axis, for example B_x-axis. The other output (parasitic) signal from the y- channel is registered simultaneously. Then the dependence of the relative change of the parasitic signal from the y- direction $V_{Hy}(\boldsymbol{B_x})/V_{Hy}(\boldsymbol{B_y})$ is plotted in % versus the magnetic induction B_x applied to the x- axis. The procedure described above is repeated for the remaining directions. In our case, because of the device symmetry, the relation $S_{xy} = S_{yx}$ and $S_{xz} = S_{yz}$ between respective cross-sensitivity is valid.

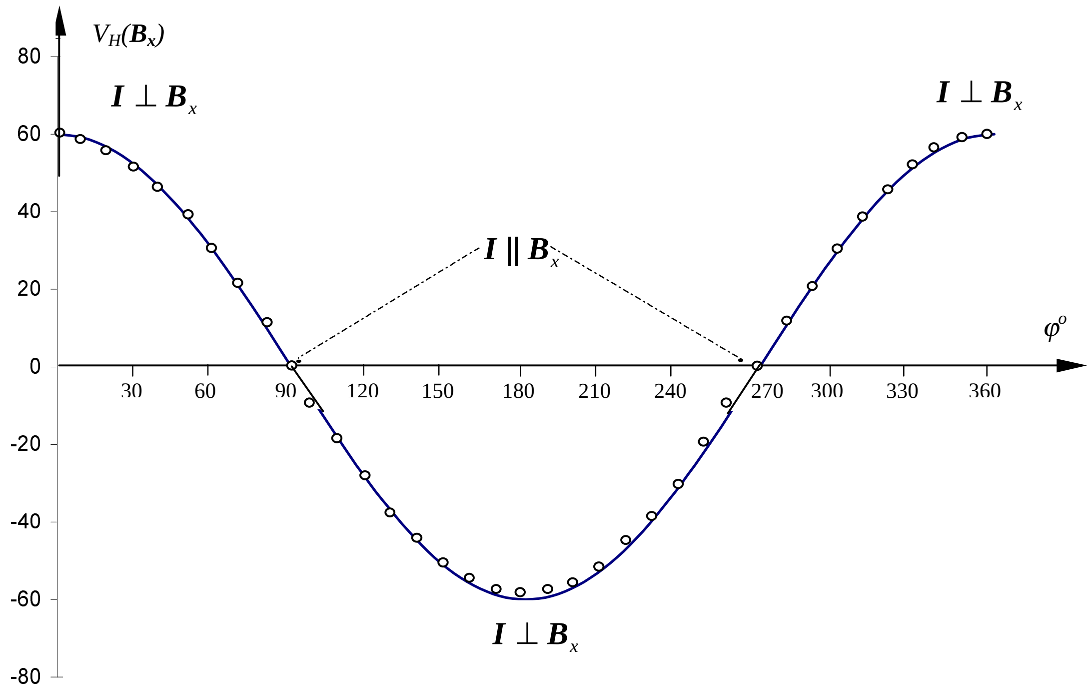

Figure 4. Angle dependence of the output signal $V_H(\boldsymbol{B_y})$ at $T = 300$ K

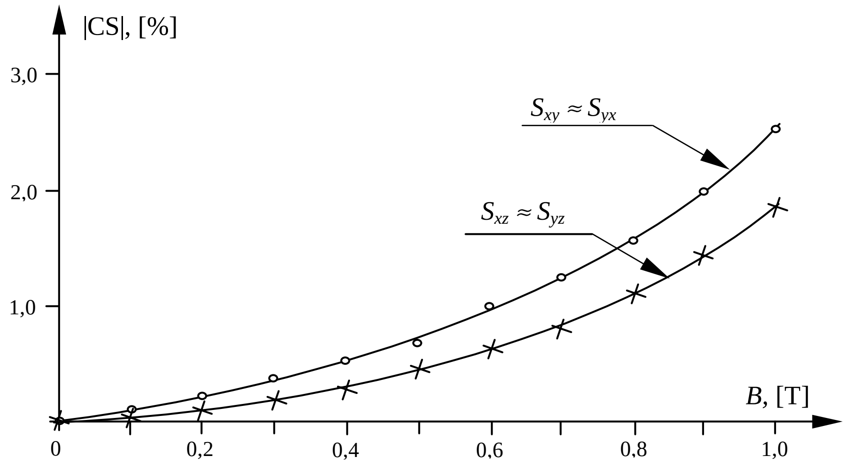

Figure 5. The cross-sensitivity between the x- and y- channels for $I_{C0} = 10$ mA, $T = 300$ K

On Fig. 5 is presented the cross-sensitivity (CS) of the 2-D microsystem. The CS is close to a square function of the induction *B*. This prove the dominant role of the geometrical magnetoresistance in CS.

In Fig. 6 is shown measured noise power spectral density for one of the sensor channels, of the microsystem of Fig. 1, in function of frequency *f* at magnetic field $B = 0$. There is established that the behavior of this important sensor parameter at low frequencies $f \leq 10^3$- 10^4 Hz doesn't differentiate from the expected one, i.e. the *1/f* noise (Flicker noise).

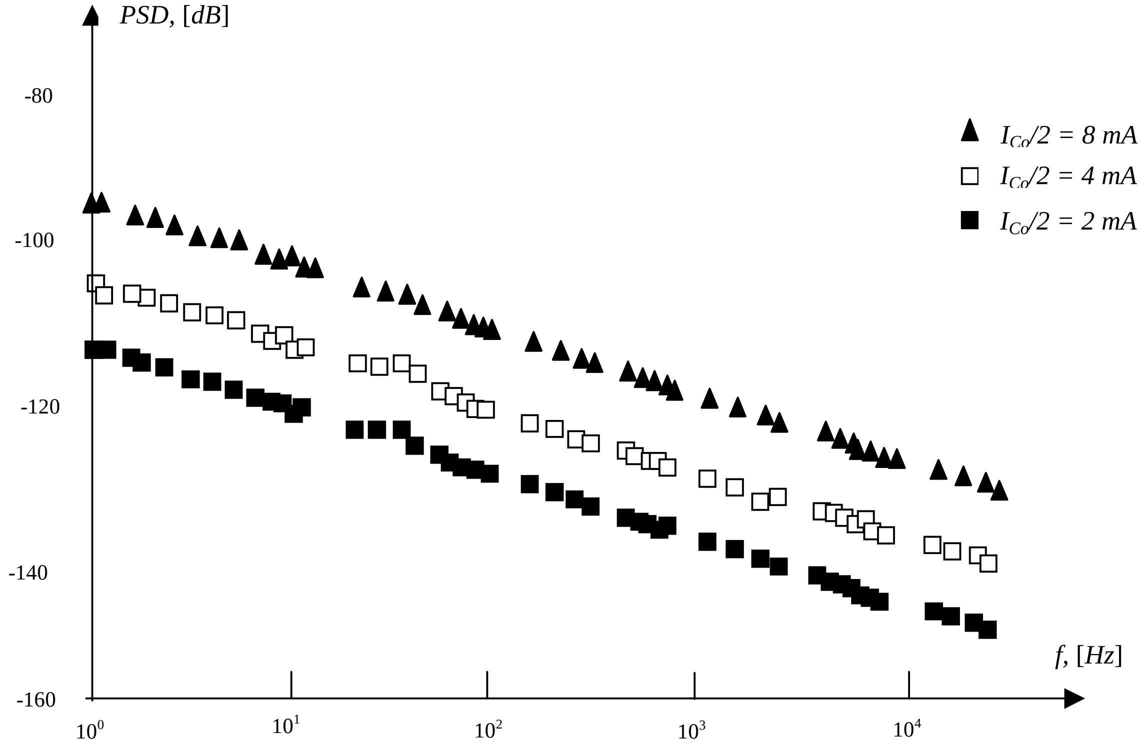

Figure 6. Noise power spectral density for one of the sensor channels. As a parameter is chosen the supply current $I_{C0}/2$

Table 1

Important parameters of the vector microsystem

№	Parameter	Units	Values
1	Output *x*- channel *y*- channel	 differential differential	
2	Magnetosensitivity (S_A) for the two channels	mv/T	100 (at I_s=10 mA)
3	Linearity range	T	±1
4	Non-linearity (NL)	%	≤1 (in the range $B \leq \pm 1$)
5	Temperature coefficient of magnetosensitivity (TC)	%/°C	0.15
6	Min. detected induction (B_{min})	μT	50
7	Offset (without compensation)	mT	7
8	Input resistance (R_{in})	Ω	350
9	Supply current (I)	mA	≤ 15
10	Power consumption (W)	mW	≤ 30
11	Cross-sensitivity	%	0.7 at $B = 0.4$ T
12	Dimensions	μm	390 x 390 x 300

The grow up of the noise level with the increasing of the supply current I_0 is due to the increasing role of the carriers scattering, because of the higher velocity in the electric field. On Table 1 are presented the important parameters of the new 2-D vector microsystem.

4. CONCLUSION

The proposed one-chip 2-D Hall microsystem measures on-line simultaneously and independently with high spatial resolution, accuracy and stability the in-plane components of the magnetic field vector $\boldsymbol{B}$. The obtained results are very promising for applications in the automation, contactless instruments, angular position transducers etc.

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