A NOVEL OFFSET REDUCTION METHOD USING A TWO – OUTPUTS SILICON PARALLEL-FIELD HALL DEVICE

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A novel offset reduction method using a two - outputs parallel-field Hall sensor is proposed and experimentally investigated. It is established that the sensitivities of the two outputs have equal values, but are opposite in sign, and the two offsets are nearly equal. The device structures are fabricated using standard silicon IC technology. By appropriate conditioning circuit, subtracting the two output signals, a drastic reduction of the residual offset and its temperature drift more than two orders in a large temperature range $-10 \leq T \leq 80$°C is achieved. The obtained magnetosensitivities of the two sensor outputs are $S_{RI} = 32$ V/AT, the non-linearity of the outputs at field $B \leq \pm 0.2$ T does not exceed $NL \leq 0.1$ % and the lowest detectable magnetic field is $12 \div 15$ μT in a frequency range of 1 to 10^3 Hz. This high quality performance of two - outputs parallel-field Hall microsensors is very promising.

Keywords: Hall microsensor, offset reduction, output temperature drift

1. INTRODUCTION

The origin of the offset phenomenon in Hall devices is due mainly to: crystal damage, geometrical errors in mask alignments, mechanical stress and strain, non-uniform temperature distribution and heat dissipation in the substrate, generation of a thermoelectric voltage across Hall leads, Peltiez effect, etc. Up to now overcoming of the offset, which is a major drawback of Hall plates, is achieved by improvement of the fabrication technology and device symmetry, variety of static and dynamic compensation techniques, spinning current method included, etc. [1-7]. Unfortunately they are not effective enough and increase considerably the production cost.

In this paper are reported two - outputs parallel-field four-contact Hall microsensors, where the offset and the offset temperature drift are simultaneously reduced with more than two orders.

2. DEVICE STRUCTURE AND OPERATION

The proposed for the first time in [1] four-contacts parallel-field Hall microsensor is particularly improved and is applied for overcoming of the offset problem. On Fig.1 is presented the first silicon Hall microdevice. It consist of four ohmic contacts C_1 - C_4, two constant current supplies I_1 and I_2 and two differential outputs $V_{C1,4}(\boldsymbol{B})$ and $V_{C2,3}(\boldsymbol{B})$. The magnetic field $\boldsymbol{B}$ is parallel to the chip surface. Specific feature of the biasing circuit is that the polarity of outer C_1 and C_4 terminals is the same as the one of the inner contacts C_2 and C_3, but opposite in sign. The inevitable even geometrical magnetoresistance MR ~ B^2 in this Hall sensor is neutralized by the differential outputs and the structure symmetry. In spite of the unusual mode of operation, the action principle of this transducer is the Hall effect. Due to the opposite directions of the both currents I_1 and I_2 in the zone between the contacts C_2 and C_3, the influence of the magnetic field $\boldsymbol{B}_x$ on the carriers is practically neutralized. It can be assumed that the both currents I_1 and I_2 "virtually" flow between the contacts C_2 and C_1 only, as well as between C_3 and C_4 respectively. The occurrence of the Hall signal requires an alternating rank of biasing and sense contacts. For example, for the supply contacts C_3 and C_4, the Hall lead is C_2, but for the contacts C_2 and C_1, the Hall lead is C_3. The Hall signal on C_2 has opposite sign with respect to the Hall signal on C_3. The appearance of the Hall effect on external C_1 and C_4 contacts is analogical. That is why the generated signals in a magnetic field $\boldsymbol{B}_x$ on C_1 and C_4, and on C_2 and C_3 leads respectively, have Hall nature. The selected mode of operation of the four-contact structure on Fig. 1 reduces in some extent the offset values of the both outputs. The analysis of the new transducer showed that Hall signals $V_{C1,4}(\boldsymbol{B})$ and $V_{C2,3}(\boldsymbol{B})$ are *opposite in signs* $V_{C1,4}(\boldsymbol{B}) = |-V_{C2,3}(\boldsymbol{B})|$, the magnetosenstitvities of the two outputs are equal $S_{C1,4}(\boldsymbol{B}) = S_{C2,3}(\boldsymbol{B})$ at currents $I_1 = I_2$, and the offsets $V_{C1,4}(B = 0)$ and $V_{C2,3}(B = 0)$ are *nearly equal* too, $V_{C1,4}(0) \approx V_{C2,3}(0)$.

However it is well known that the offset can not be distinguished from the Hall voltage [1-3]. In our case the offset problem is resolved by *subtraction of the two output signals* $(V_{C1,4}(\boldsymbol{B}) + V_{C1,4}(0))$ and $(-V_{C2,3}(\boldsymbol{B}) + V_{C2,3}(0))$. For a given magnetic field $\boldsymbol{B}_x$ orientation a relation is valid:

$$V_{C1,4}(\boldsymbol{B}) + V_{C2,3}(\boldsymbol{B}) + V_{C1,4}(0) - V_{C2,3}(0) = 2V_{C1,4}(\boldsymbol{B}) + [V_{C1,4}(0) - V_{C2,3}(0)] \tag{1}$$

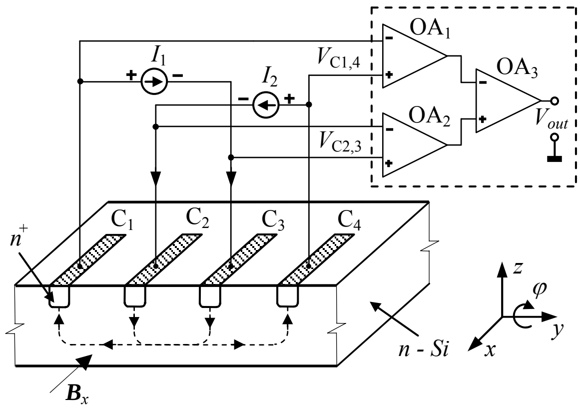

Figure 1. A two – outputs four n^+ contact parallel-field Hall microsensor. The conditioning circuit based on AD8554, consisting operational amplifiers OA_1, OA_2 and OA_3 for reduction of the offset and offset temperature drift is shown.

In the circuit on Fig. 1 the two sensor voltages $V_{C1,4}(\boldsymbol{B})$ and $V_{C2,3}(\boldsymbol{B})$ after amplification by op-amps OA_1 and OA_2 are *subtracted* by op-amp OA_3. The output signal of OA_3 is defined as $V_{out} = 2V_H(\boldsymbol{B}) + V_{off}$. This is why in the novel Hall microsensor according to (1) the residual offset V_{off} can be *very low*. At the same time the temperature offset drifts of the two outputs are equal, because they originate from *one and the same sensor zone*. By this reason the residual temperature offset drift $V_{off}(T) = V_{C1,4}(0,T) - V_{C2,3}(0,T)$ should be dramatically reduced.

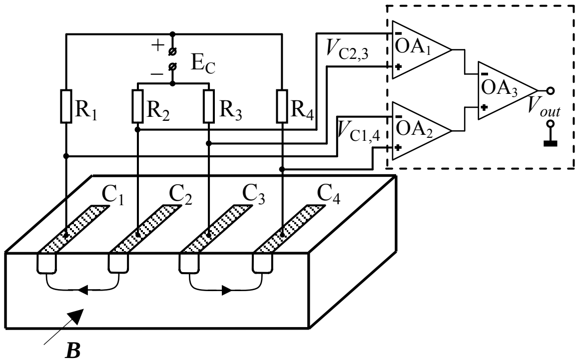

Figure 2. A novel four-contact parallel-field microsensor with two linear and odd outputs. The curvilinear trajectories are shown. Conditioning circuit is based on AD8554.

On Figure 2 is present another modification two - outputs parallel-field Hall microsensor. In distinguish to the device from Fig. 1, the two supply currents $I_{C1,2}$ and $I_{C3,4}$ are not crossed in the region between contacts C_2 and C_3. The theoretical analysis shows that at one and the same sizes of the devices from Fig. 1 and Fig. 2 their performances should be identical.

3. Experimental Results

Experimentally investigated are silicon Hall microdevices from Fig. 1 and Fig. 2 fabricated in a standard planar technology on *n*-Si wafers with ρ = 6-9 Ω.cm., where the substrate serves as an active transducer region. In Fig.3 are presented the dependences of the two Hall voltages on the magnetic field $\boldsymbol{B}_x$.

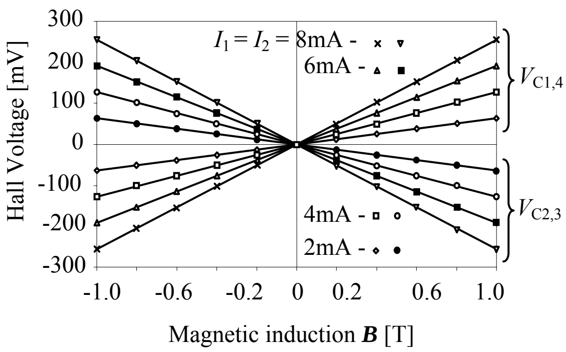

Figure 3. The magnetic response of the two output voltages $V_{C1,4}$ and $V_{C2,3}$ for the Hall element from Fig. 1, the currents $I_1 = I_2$ as a parameter, T = 20°C. The initial offsets are nullified in advance.

The obtained relative magnetosensitivities of the two outputs $V_{C1,4}(\boldsymbol{B})$ and $V_{C2,3}(\boldsymbol{B})$ are S_{RI} = 32 V/AT. The non-linearity of the voltages $V_{C1,4}(\boldsymbol{B})$, $V_{C2,3}(\boldsymbol{B})$ and $V_{out}(\boldsymbol{B})$ at induction $B \leq \pm$ 0.2T does not exceed NL ≤ 0.1% and at induction $B \leq \pm$1T - no more than NL ≤ 1%. The determined temperature coefficient of magnetosensitivity of the two outputs is T.C. = 0.1 % /°C. On Fig.4 can be seen that the individual offsets at $I_1 = I_2$ = const. *are almost equal*.

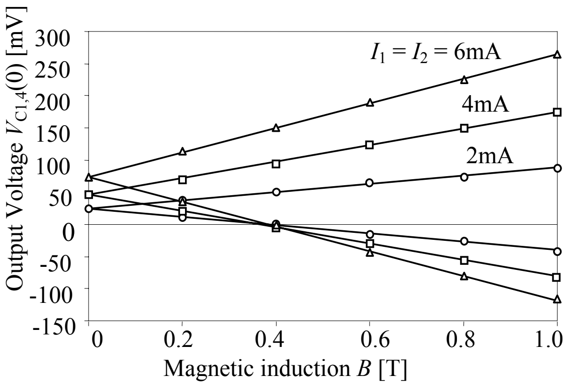

Figure 4. The output voltages $V_{C1,4}$ as a function of the magnetic field, the currents $I_1 = I_2$ as a parameter. The behavior of $V_{C2,3}$ is the same. The respective initial offsets $V_{C1,4}(0)$ and $V_{C2,3}(0)$ are nearly equal, $T = 20°C$.

The residual offset V_{out} from op-amp OA3 is about *130 times lower* than the individual ones. Figure 5 presents separately the temperature dependence of the offset voltages $V_{C1,4}(0,T)$ and $V_{out}(0,T)$. It is established that the offset drift $V_{off}(T)$ is about *150 times lower* than the drifts of the two signals $V_{C1,4}(0,T)$ and $V_{C2,3}(0,T)$. By calibration at any temperature T_0, a very low value of the offset V_{off} in a large temperature interval $-10°C \leq T \leq 80°C$ is achieved.

The experiments carried out with the two - outputs parallel-field Hall device from Fig. 2 show that does not exist any difference between the obtained sensor characteristics at one and the same dimensions.

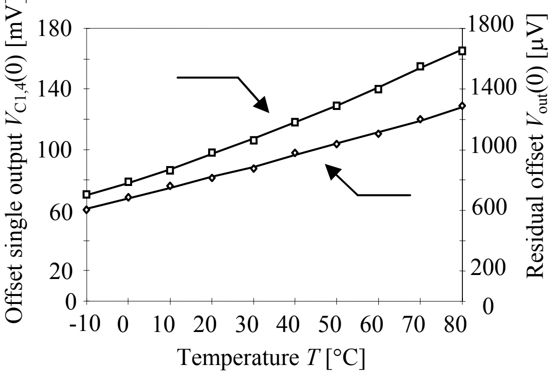

Figure 5. Temperature dependence of the offset voltage for one of the outputs as well as for residual offset voltage $V_{out}(0)$, $I_1 = I_2 = 8$ mA.

Of a special interest is the use of the novel microsensor for the purposes of wear-free angular detection systems. For this reason on Fig. 6 is presented the angle dependence of the two output signals $V_{C1,4}(\varphi)$ and $V_{C2,3}(\varphi)$ at induction B = 0.15 T. The Hall microsensor is mounted on non-magnetic package. The experiments are carried out at T = 20°C with a rotatable pair of magnetic field coils. The device is centered on the axis of rotation.

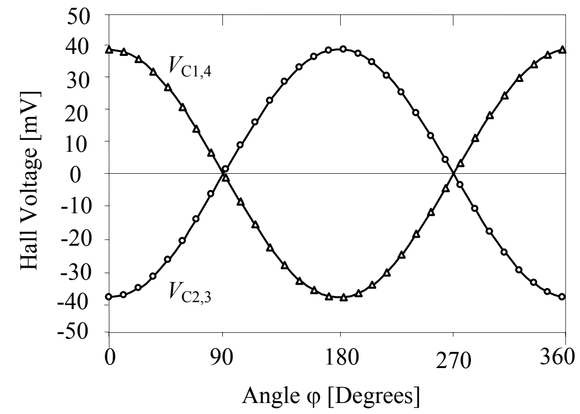

Figure 6. Angle dependence of the two output signals $V_{C1,4}(\varphi)$ and $V_{C2,3}(\varphi)$ at a constant induction B = 0.15 T and currents $I_1 = I_2$ = 8 mA.

The magnetic field $\boldsymbol{B}$ was rotated around the Hall element in the *x*-*z* plane. As it can be seen, the two Hall voltages are *cosine* function of the φ angle and are opposite by sign.

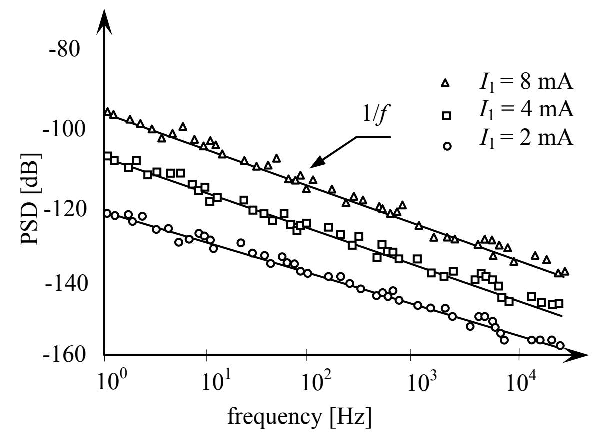

Figure 7. Power spectral density of internal noise for the new parallel-field Hall device, the supply currents $I_1 = I_2$ as a parameter, T = 20 °C, the magnetic field is zero.

One of the important sensor characteristics for low-field magnetometry – the power spectral density of the internal Hall sensor noise is shown on Fig. 7. In low frequency the 1/*f* noise dominates, when raising the currents $I_1 = I_2$ the noise increases too. The lowest detected magnetic induction at signal/noise ratio S/N = 1 is about $B_{min} \approx$ 12 - 15 µT, in a frequency range of 1 to 10^3 Hz. The main conclusion is that the noise behavior in the novel parallel-field Hall device is similar with the other bulk Hall transducers [1].

4. APPLICATIONS

Designing contactless instruments based on the new Hall microdevices based on the relative displacement of the sensor with respect to constant magnet implies the development of magnetic circuits with a gradient $\Delta B/\Delta$x. Various configurations including the novel parallel-field Hall microsensors from Fig. 1 and Fig. 2 and magnetic modulating systems are classified in Fig. 8. All these devices are very promising for industrial applications.

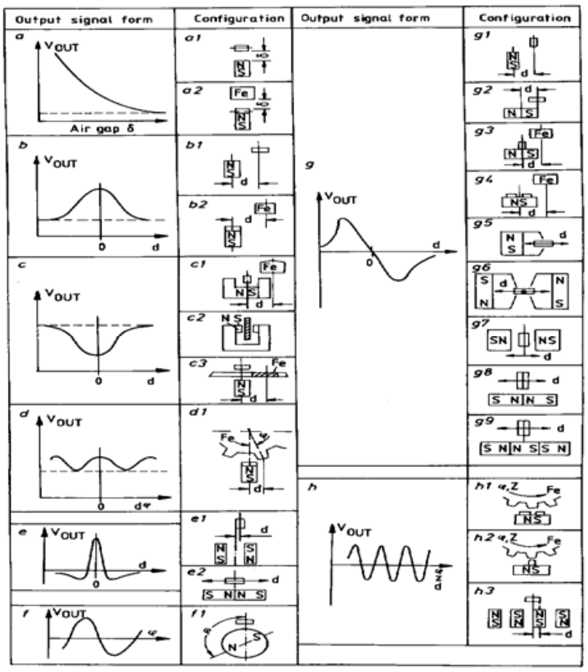

Figure 8. Magnetic circuits with the new Hall microsensors, configuration and forms of output signals are presented.

5. CONCLUSION

These results based on the original concept for offset reduction method using a new Hall effect device are very promising. Actually this device is a functional multisensor for magnetic field by itself. If sophisticated IC technologies are used for the two - outputs microsensor, the offset behavior and its temperature drift can be improved considerably. This solution presents an accurate microsystem for magnetic field with universal metrological and industrial applications.

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