A Novel Method of Zero Offset Reduction in Hall Effect Sensors with Applications to Magnetic Field Measurement

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A Novel Method of Zero Offset Reduction in Hall Effect Sensors with Applications to Magnetic Field Measurement

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Abstract. The paper presents a novel method to reduce the zero offset in Hall-Effect based magnetic measurement with single power supply. This method consists of a coarse zero compensation and a fine zero adjustment afterwards. By using the proposed method the zero output offset of Hall Effect sensors under using single power supply can be controlled within 0.2%. This method can be applied to all Hall Effect sensors with analog output and other similar sensors, which are powered with a single voltage or current source.

Keywords: Magnetic Field Measurement, Magnetic Field Sensing, Magnetic Field Detection, Gaussmeter, Magnetometer, Hall-Effect Sensor, Zero Offset Adjustment, Measuring System.

1. Introduction

With the development and wide applications of permanent magnets and electromagnets, magnetic field sensing has become rapidly a very important section of measurement technology. Magnetic field measurement is widely used in many industrial branches such as motors, generators, wind turbines, automotive, loudspeakers, brain wave activities, magnetic sensors/transducers, controlling systems, medical instruments and other machines [1, 5].

There exist a lot of magnetic field measurement techniques. The most common methods are based on superconducting quantum interference device (SQUID), magnetometers (fiber optic, nuclear precession, optically pumped and fluxgate), magnetoresistive sensors (AMR, GMR), inductive sensors, Hall-effect sensors and magneto-optic sensors [1, 2]. Some of them are used for low-field measurements (< 1mT), like magnetometers and SQUID. Magnetoresistive sensors are more robust and cheaper to sense medium fields (< 100mT). Inductive sensors (< 2T) and Hall-effect sensors (< 8T) are good candidate for the high field measurement, and magneto-optic sensors is for very high field measurement (up to 10T).

The most useful magnetic field range is 1µT~5T for medical and industrial applications. Only Hall Effect sensor elements cover this magnetic field range. They have the benefits of easy handling, robustness, small package and cheap price in comparison with other sensors mentioned above. In addition to pure magnetic field measurement, Hall sensors can also be found in many position, proximity, angle, speed and current sensing applications [3]. Therefore Hall Effect sensors are preferred for magnetic field measurement.

In order to get a useful analog output signal for controlling systems and measuring instruments, the Hall voltage at the sensor output has to be further processed by a differential amplifier with high input impedance, gain and zero offset adjustments [2]. Under using double power supplies, adequate results are available. Nevertheless, double power supplies are exceptions in many applications. When the Hall Effect sensor is powered with a single constant voltage or current source, the sensor output will get a remarkable offset voltage even after a normal offset adjustment. For reducing the offset output

voltage, various kinds of efforts are done, for instance, by using a DC-DC-voltage converter in order to generate an additional negative power supply internally. This causes a higher current consumption, more complicated circuit, and higher costs of the sensor systems.
This paper proposes a novel method of zero offset reduction in Hall-Effect based magnetic measurement with single power supply. This method consists of a coarse zero compensation and a fine zero adjustment afterwards. By using the proposed method the zero output offset of Hall Effect sensors under using single power supply can be controlled within 0.2%. This method can be applied to all Hall Effect sensors with analog output and other similar sensors, which are powered with a single voltage or current source.

2. Zero Offset Origin

Figure 1 shows a SIP package of a Hall sensor element, which has two supply pins (+Vcc, –Vcc/GND) and two output pins (+Vh, -Vh). The Hall element is powered with a constant voltage or current source through its supply pins, in order to get a reliable linear output voltage for measuring a magnetic field. In absence of magnetic field, a voltage difference exists between the two output pins (+Vh, -Vh), due to manufacturing tolerances and inhomogeneity in the semiconductor material [3]. A Hall element can be modeled as a resistive bridge (see figure 2). The output voltage difference is the result of mismatches between the resistances R1, R2, R3 and R4 [6].

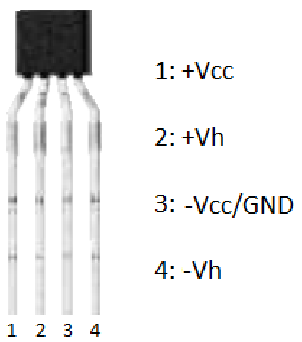

Figure 1. Pin assignment of a Hall element

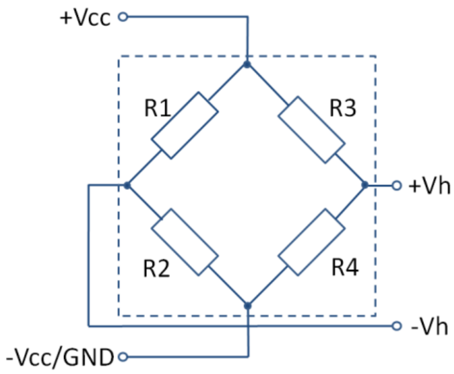

Figure 2. Equivalent circuit of a Hall element

When the output pins (+Vh, -Vh) are connected to a differential amplifier, a zero offset voltage at the amplifier output will be caused by the voltage difference mentioned above. Therefore zero offset adjustment circuit must be built in the signal processing unit of the measuring system, see figure 3.

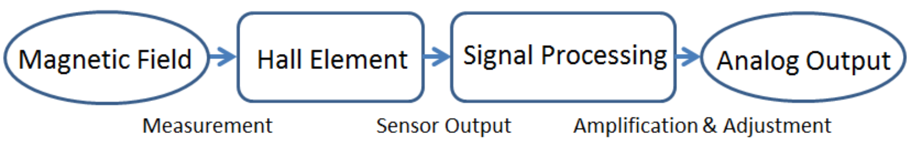

Figure 3. Diagram of Hall-effect based magnetic field measurement.

3. Conventional Zero Offset Adjustment

If the Hall element is powered with double voltage sources, the zero offset voltage can be easily eliminated by using an operational amplifier and a potentiometer (see figure 4).

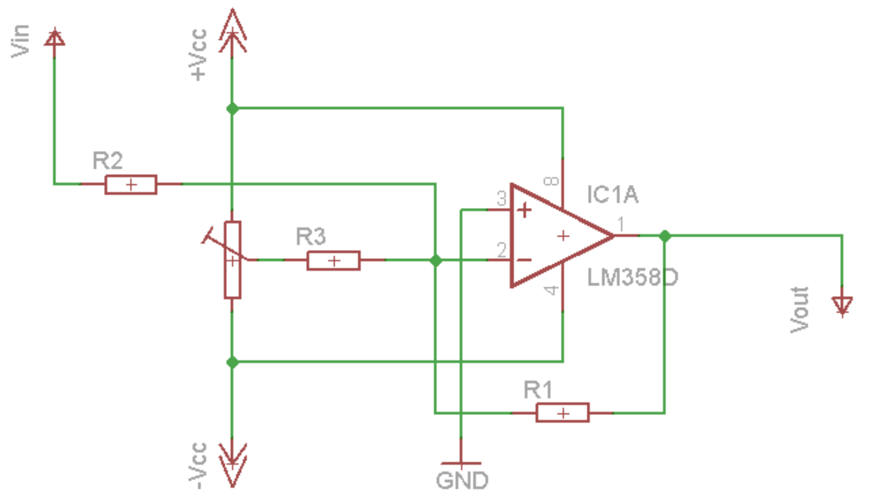

Figure 4. Zero Offset Adjustment with Double Voltage Supplies.

However, the zero offset voltage is difficult to reduce to zero under using a normal adjustment circuit (as like in figure 5) if the Hall element is powered with a single source, i.e. the pin 3 and 4 are connected to ground GND, see figure 1 and 2.

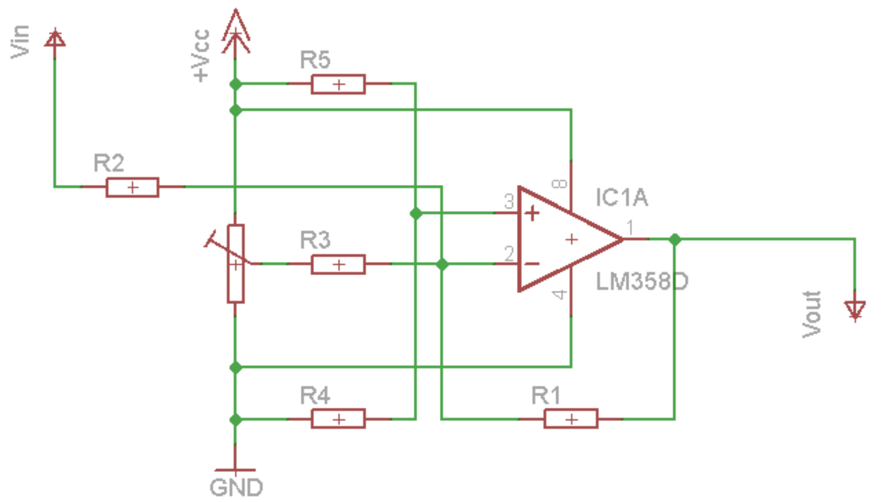

Figure 5. Zero Offset Adjustment with Single Voltage Supply.

In this case, -Vh=0 and the output voltage +Vh can be written by

$$+V_h = \frac{R3}{R3+R4} V_{cc} \tag{1}$$

One gets +Vh=Vcc/2 when R3=R4. For offset compensation, a virtual ground of about +Vcc/2 is needed at the noninverting port of the operational amplifier for compensating the zero offset voltage. Therefore, a higher feedback loop current at R1 is available:

$$I_c = \frac{V_{cc}}{2\times R1} \tag{2}$$

Due to the exist of inner resistance $\boldsymbol{R_{in}}$ at the output of an operational amplifier [4], this feedback loop current I_c causes an offset voltage:

$$\boldsymbol{V_{off} = R_{in} \times I_c = \frac{R_{in}}{2 \times R1} V_{cc}} \quad \textbf{(3)}$$

A noticeable amount of zero offset voltage still remains in the level of 50mV~100mV after the compensation for an output range of 0-5V. This means that the relative zero offset voltage is 1.0%~2.0%, which is not acceptable in many magnetic field measurement applications. Thus a new solution is needed for reduction of the zero offset in this case.

4. Novel Method of Zero Offset Reduction

The proposed novel method for zero offset reduction contains two stages of signal processing, see figure 6. In the first stage, a relative high zero offset voltage under single power supply can be reduced by a coarse zero offset compensation. There is still a rest offset voltage $\boldsymbol{V_{off1}}$, which is caused by the feedback loop current $\boldsymbol{I_{c1}}$ at the inner ouput resistance $\boldsymbol{R_{in}}$ inside the operational amplifier of the first stage and can be calculated by equation (3). The zero offset voltage for the second stage is now lower, so that the feedback loop current $\boldsymbol{I_{c2}}$ at R8 is much smaller than in the first stage or in conventional zero offset adjustment, see Figure 7. $\boldsymbol{I_{c2}}$ can be determined by:

$$\boldsymbol{I_{c2} = \frac{V_{off1}}{R8}} \quad \textbf{(4)}$$

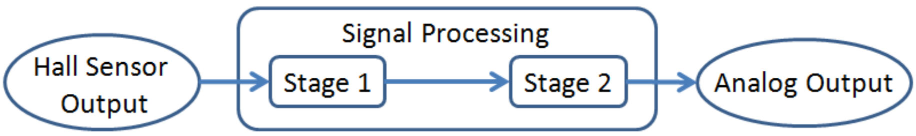

Figure 6. Description of a novel zero offset reduction method.

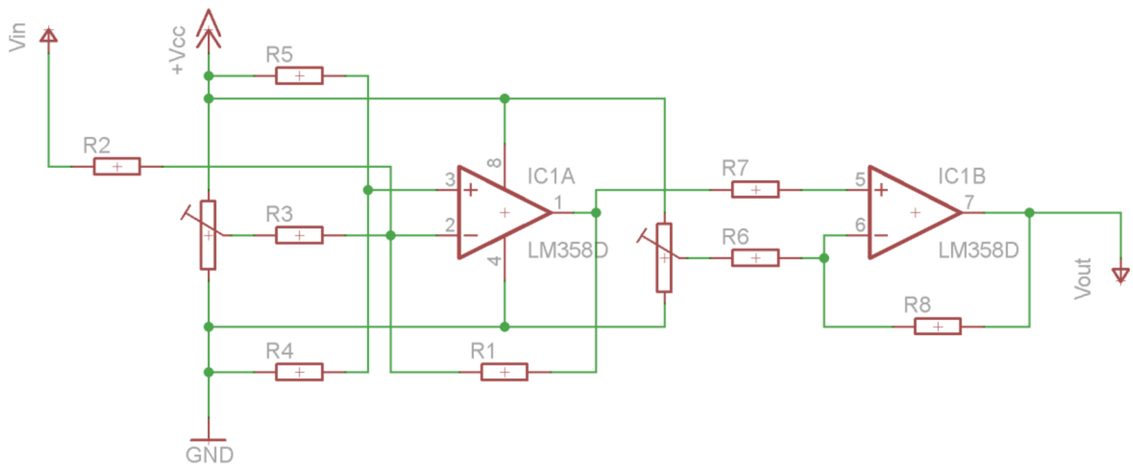

Figure 7. Possible Implementation of the novel Zero Offset Reduction method.

The zero offset voltage $\boldsymbol{V_{off2}}$ can be calculated by

$$\boldsymbol{V_{off2} = R_{in} \times I_{c2} = \frac{Rin}{R8} V_{off1} = \frac{R_{in}^2}{2 \times R1 \times R8} V_{cc}} \quad \textbf{(5)}$$

The zero offset voltage $\boldsymbol{V_{off2}}$ can be reduced within 10mV for voltage output range 0-5V by a fine zero offset adjustment in this second stage. This means a relative zero offset of 0.2%, which can be tolerated in the most magnetic field measurement. The advantages of this method are less power consumption and simplified circuit in comparison to other zero offset adjustment by using an internal negative power supply.

5. Results and Applications

This novel zero offset reduction method can be applied to Hall Effect sensors, magnetoresistive sensors and inductive sensors for magnetic field measurement etc. Figure 8 shows a Hall probe CYHP881 that uses the proposed method. This probe is designed for measuring 0-200mT (unipolar magnetic field) with an analog voltage output 0~4.5V. The probe is powered with a 5V source, and has a linearity of ±0.3%, a zero point offset of 0.2% and an accuracy of 1.0% [5]. The accuracy of the probe can be improved by using precise reference magnets with accuracy of better than 0.2%.

Figure 8. Product photo of Hall probe CYHP881.

Table 1 shows the calibration results of Hall probe CYHP881. By using an electromagnet, a magnetic field up to 198.8mT or even more can be generated. So a full-range calibration of the Hall probe is possible.

Table 1. Calibration results by using magnetic field generated by an electromagnet.

Magnetic field strength (mT)	Output voltage (V)	Relative error (%)	Linearity error (%)
0.0	0.0085	0.189	0.028
24.8	0.5650	0.156	-0.007
49.8	1.1235	0.067	-0.096
74.6	1.6816	0.069	-0.095
99.4	2.2403	0.084	-0.077
124.2	2.7987	0.093	-0.069
149.2	3.3582	0.027	-0.136
173.9	3.9147	0.042	-0.119
198.8	4.4719	-0.024	-0.188

A Hall probe with analog output can be used in many different ways for magnetic field measurement. It is suitable for quick measurements with a digital multimeter, and for integration in different measuring instruments and devices. By using an analog-to-digital converter, the analog output voltage of the Hall probe can be converted into digital signal so that it can be connected to microcontrollers and PC systems. Consumers can use their own software for data acquisition and processing etc. An overview of the Hall effect sensors for magnetic field measurement can be found in the literatures [1] - [3] and [6] - [13].

6. Conclusions

In this paper, a novel offset reduction method has been proposed, which has been used in Hall Effect sensors for magnetic field measurements. From the results one can draw the following conclusions:
For single power supply, the zero offset adjustment is much difficult, because a correction voltage close to one half of the supply voltage is needed. Nevertheless a noticeable amount of zero offset voltage still remains in the level of 50mV~100mV for an output range of 0-5V after zero offset adjustment. For eliminating this rest offset, a second zero offset adjustment stage is introduced. The offset can be reduced to under 10mV in the same output range. This novel zero offset reduction method can be applied to Hall Effect sensors, magnetoresistive sensors and inductive sensors for magnetic field measurement and current measurement and other similar sensors, which are powered with a single voltage or current source.

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