

LOW VOLTAGE MAGNETIC FIELD SENSOR SYSTEM WITH A NEGATIVE FEEDBACK TECHNIQUE

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Abstract

In this paper, a low voltage system for magnetic field sensor is being proposed. The complete system is working with 1.5 Volt single power supply. The system is composed of two main components. The first component is the magnet field sensor using AMR technology with an integrated compensation coil. The second part is an operational amplifier which needed to amplify the output signal from the sensor. The amplified signal then is being sent back to the integrated compensation coil inside the sensor to generate a new magnetic field (H_c) for compensating the magnetic field (H_y) sensed by the sensor. This H_c introduces a negative feedback into the system. With this technique we can have a sensor system with a high accuracy.

The system performances are evaluated by simulation.

Keywords: AMR, magnetic field sensor system, negative feedback, compensation magnetic field

INTRODUCTION

Magnetic field sensor is used in wide range of applications [1]. From a car to a mobile phone we can find that a magnetic field sensor is being used to fulfill a specific task. Many systems are available to provide a good solution for magnetic field sensors [1][2]. Applications nowadays demand not only a high accuracy sensor system, but in addition to that a sensor system with a low voltage specification is preferable. There are always tradeoffs because of these two requirements.

In this paper we will show a possible basic system that can fulfill these two requirements with some limitations. The system performances are evaluated by simulation. The results of the simulation will be showed in this paper. The realization of the system will be using 0.35 μ m CMOS technology.

BASIC SYSTEM

The proposed system is consisted from two main components. The first component is the sensor. The magnetic field sensor which is being used for this work is an anisotropic magnetoresistance (AMR) sensor. The AMR sensor used for this work has an additional coil for generating a compensation magnetic field (H_c) which has the direction opposite to the

input magnetic field sensed by the sensor. With this technique we operate the sensor most of the time near the zero point which means the linearity problem can be reduced significantly. Figure 1 shows the input-output characteristic of the typical AMR sensor [2].

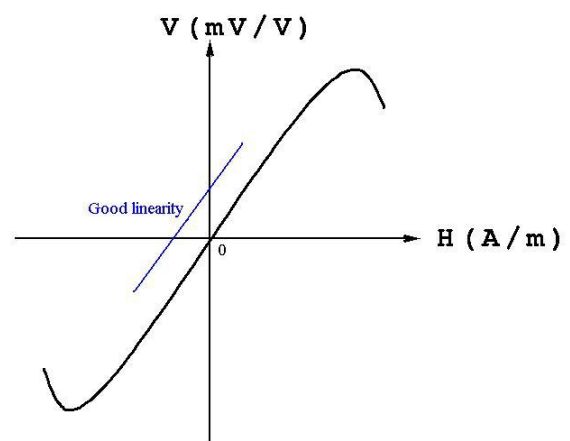


Fig. 1. Input-output characteristic of an AMR sensor. The input is magnetic field (H) measured in Ampere/meter (A/m).

As shown in Figure 1, the sensor has a good linearity in a range around the zero point. As we go higher to the maximum range or minimum range, the non-linearity characteristic can cause a serious problem to the system.

Therefore these ranges are strictly avoided since it will affect the accuracy of the system. For the purpose of simulation, the magnetic field sensor, which is used for this work, is being made in VHDL-AMS language.

The compensation coil has a resistance (R_c) equal to 47Ω . H_c is generated depending on the current (I_c) flowing through the R_c . H_c can be calculated by using Eqs. (1),

$$(1) \quad H_c = (I_c * K_i) * K_f$$

where K_i is a multiplying factor used in the sensor to minimize the value of I_c , K_f is a compensation factor used for generating H_c from I_c . The K_i from the sensor model used in this work is 1000 and K_f is 41.7.

The second part of the system is an operational amplifier which needed to amplify the output of the sensor. The output signal from the sensor is a differential signal with the difference between is in a range of mV to μ V. After the amplification process then the amplified signal is being sent to the compensation coil back, integrated in the sensor, to generate H_c . This technique introduces to the complete system a negative feedback. This negative feedback makes the system self-correcting which means the system can quickly reach the stability point. I_c will adjust the value of H_c so that it will continuously compensate the magnetic field sensed by the sensor (H_y).

$$(2) \quad H_c = -H_y$$

It results the sensor to operate always near to the zero point.

By measuring I_c , H_c can be known therefore H_y is known as well. To measure I_c , an external resistor is needed. Figure 2(a) shows the complete system and the block diagram is shown in Figure 2(b).

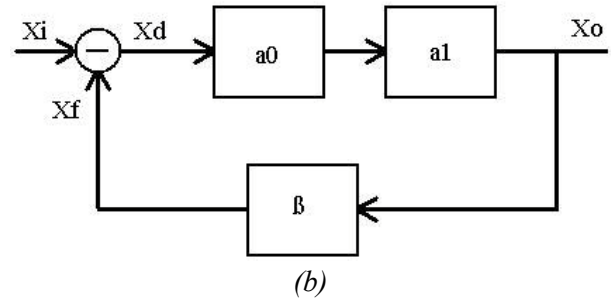
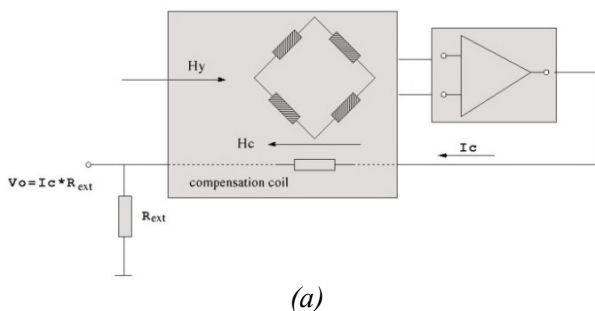


Fig. 2. Complete system for a low voltage magnetic field sensor system with a negative feedback to improve the accuracy: (a) Block components, (b) Transfer function block diagram.

From Figure 2(b) X_i is equal to H_y , X_f is equal to H_c . The transfer function of the system is:

$$(3) \quad Av = \frac{V_o}{V_i} = \frac{X_o}{X_i} = \frac{a0 \cdot a1}{1 + a0 \cdot a1 \cdot \beta}$$

where:

$a0$ = Gain from the operational amplifier,
 $a1$ = Compensation factor ($K_f = 41.7$),
 β = Feedback gain.

In this system β is equal to 1, therefore X_o has the same value as X_f so that $H_c = H_y$. It means Av of the system should be 1. This is the ideal condition for the system and from the Eqs. (3), it can be seen that it is possible if the $a0$ equal to ∞ .

CIRCUIT IMPLEMENTATION

The comparator is realized in CMOS circuit technique. Since the output signal from the sensor is a differential signal, a differential input stage is chosen. In addition to that a positive feedback configuration [3][4] is being used for achieving a high gain. M1 and M2 form a PMOS differential input and M3, M4, M5, and M6 form the positive feedback configuration.

The operational amplifier is designed to be able to work with single polarity power supply. The challenge here is to design an operational amplifier which can sense a very small differential input signal and make it work with a low voltage requirement. The complete input stage can be seen in Figure 3.

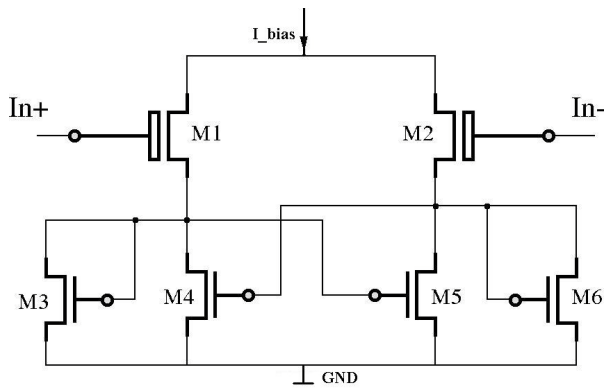


Fig. 3. Input stage of the operational amplifier used in the system.

The input-output characteristics of the operational amplifier and the gain achieved are shown in Figure 4 below. It can be seen that an open-loop gain of 74k is possible with this configuration and the power supply is 1.5V. The current needed to bias the operational amplifier is 1.5 μ A.

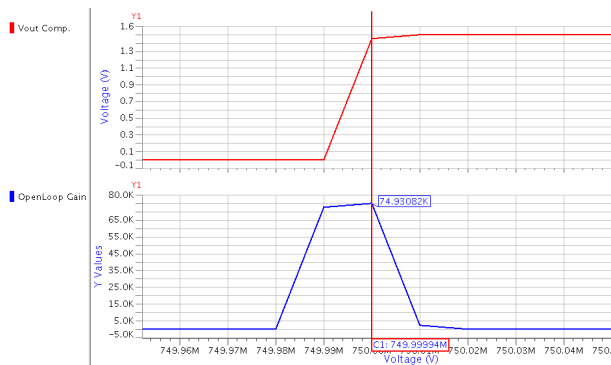


Fig. 4. Input-output curve from the operational amplifier and the maximum open-loop gain achieved.

The operational amplifier then will be realized in 0.35 μ m CMOS technology. The layout of the operational amplifier is shown partly in Figure 5.

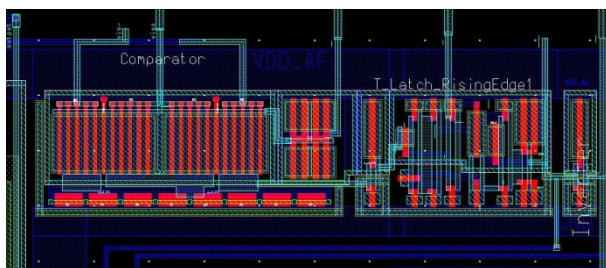


Fig. 5. Layout of the operational amplifier in 0.35 μ m technology

COMPARISON OF THE RESULTS

For a comparison purpose, we have compared the system using an operational amplifier designed in CMOS technique and an ideal operational amplifier which is made in VHDL-AMS language. As an ideal component, the operational amplifier has no offsets and the gain is adjustable. The result of the system with an ideal component is needed to examine the theoretical performance that can be achieved by the system.

The stimulus for the magnetic field sensor (H_y) is generated by using a voltage source. 1V is equal to 1A/m for the sensor. The VDD for this simulation is 1.5V for the operational amplifier as well as for the sensor.

First the characteristic curve from the model sensor is evaluated.

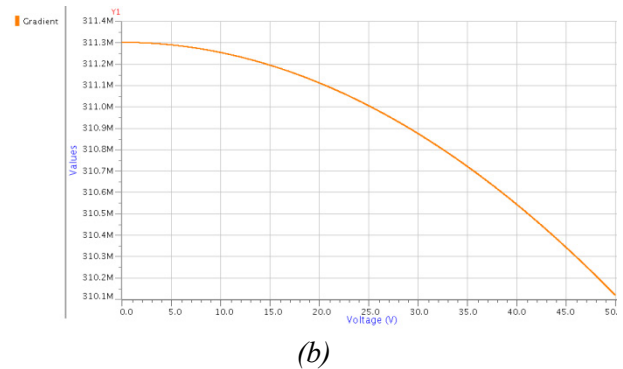
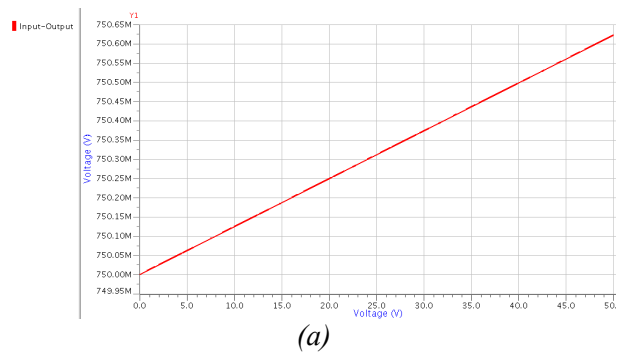


Fig. 6. (a) Characteristic curve from the sensor used for H_y from 0-50A/m. (b) the gradient of the curve showing the non-linearity of the sensor

It can be seen from Figure 6(b) that the higher the H_y , the higher the non-linearity of the sensor. Thus the sensor should be operated in the range 0A/m to 5A/m for a maximal result and one key to operate the sensor in this range is by applying a negative feedback technique.

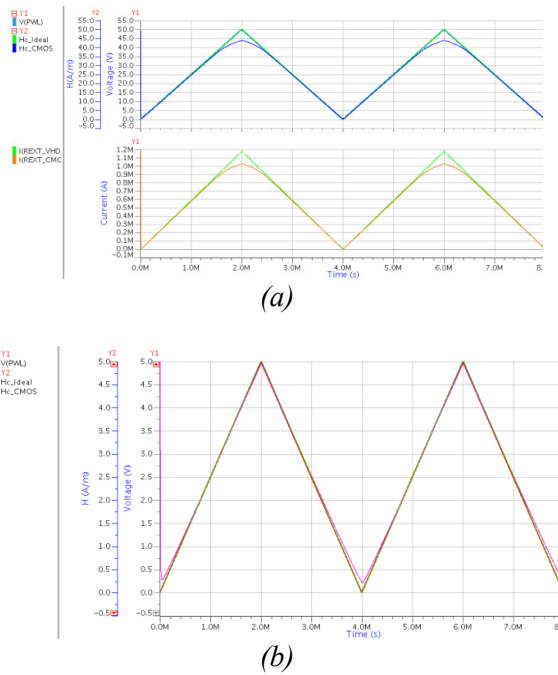


Fig. 7. Results of the simulation for a magnetic field input range from: (a) 0-50A/m (b) 0-5A/m

Figure 7 show promising results. For results using an ideal operational amplifier, the graphics show match result with the H_y . Some collected values from simulation results are being listed in Table 1 below.

Results for the system using a CMOS operational amplifier show some area where the results reach the saturation level. This is due to the performance of the MOS transistor.

Table. 1. Accuracy comparison between system with ideal operational amplifier (VHDL-AMS model) and non-ideal operational amplifier (CMOS)

H_y (A/m)	H_c (Ideal)	Acc. (%)	H_c (CMOS)	Acc. (%)
0.5	0.49968	99.936	0.6339	73.220
0.7	0.69955	99.936	0.812863	83.877
1	0.99936	99.936	1.08737	91.263
3	2.99809	99.936	2.9601	98.670
5	4.99681	99.936	4.93349	98.670
12	11.9923	99.936	11.652	97.100
20	19.9872	99.936	19.41821	97.091
35	34.9777	99.936	33.7784	96.510
50	49.9681	99.936	43.04133	86.083

The figures from table 1 show that the system with an ideal operational amplifier (open loop gain 76k) can achieve accuracy 99.936% for all range of the sensor. The system with a CMOS

operational amplifier can achieve maximum accuracy until 98.67%.

Table. 2. Higher accuracy can be achieved by using an operational amplifier with a higher gain.

H_y (A/m)	H_c (G=74K)	Acc. (%)	H_c (G=74M)	Acc. (%)
0.5	0.49968	99.936	0.4999	99.999
1	0.99936	99.936	0.9999	99.999
3	2.99809	99.936	2.9999	99.999
5	4.99681	99.936	4.9999	99.999
20	19.98720	99.936	19.999	99.999
35	34.97770	99.936	34.9998	99.999
50	49.96814	99.936	49.9997	99.999

From Table 2 we can see that the higher the operational amplifier's gain then the accuracy that can be achieved is also higher as can be analyzed from Eqs. (3).

The proposed system has some limitations that cause the decrement in the dynamic range. This will be shown from the results in Figure 8 below.

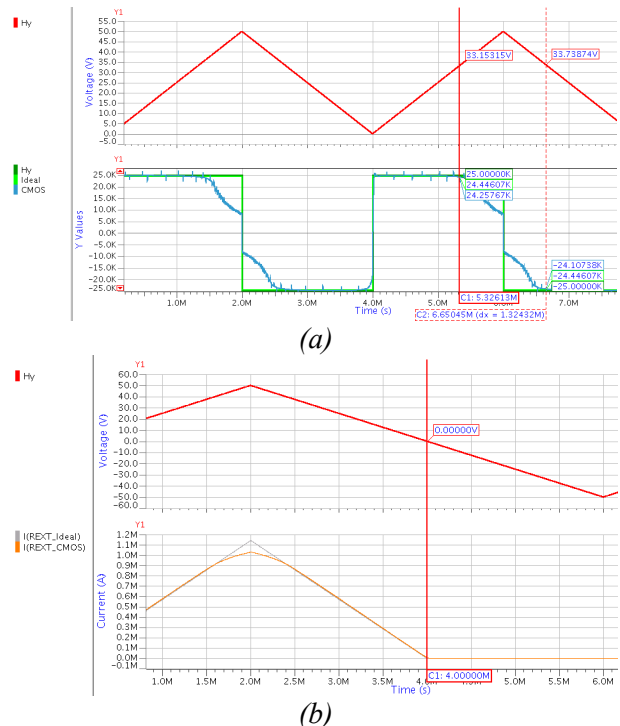


Fig. 8. Limitation of the system proposed: (a). saturation problem for the system using CMOS operational amplifier ;(b).Limitation on the dynamic range

Figure 8(a) shows the upper limit range from the system with CMOS operational amplifier. These as already described above is caused by

the performance of the MOS transistor itself. Figure 8(b) shows another limitation in the dynamic range of the system. Since the system is supplied by a single polarity power supply then the negative range, where the magnetic field input is going to the other direction as for in the positive range, cannot be detected by the system. This limitation can be solved by applying dual polarity power supply. Thus the operational amplifier should be modified as well. The other possibility is by making some architecture that enables the current flowing through the compensation coil in two directions.

CONCLUSION

In this paper, a system for a magnetic field sensor system with a low voltage and high accuracy requirement is being proposed. The system is simple and easy to implement with some tradeoffs. For applications that need to detect magnetic fields in the range from 3A/m to 35A/m and required 1.5V power supply, this proposed system can be one of the promising systems.

To get benefit of all the dynamic range from the sensor with still using a single polarity power supply as well as to get a stable accuracy of the system in all range of the sensor is a challenge. Investigations and researches towards this direction are currently in progress.

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