# Magnetic Sensor Cross-Axis Effect

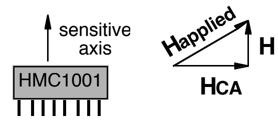
AN-205

Bharat B. Pant, Ph.D., Physics
Mike Caruso, Sensor Applications Engineer

Magnetic sensors are generally sensitive to an applied magnetic field in a single direction, or axis. These sensors can also exhibit a change in sensitivity based on the applied field in the transverse, or cross-axis, direction. This application note will describe the cross-axis field effect for the Honeywell HMC1001 and HMC1002 magnetoresistive magnetic sensor microcircuits.

The output voltage of the magnetic sensor bridge can be expressed by the following formula:

$$V = \frac{a \cdot H}{H_S + H_{CA}} \qquad (1)$$




where, V: voltage output (with null offset removed)

a: constant proportional to anisotropic magnetoresistance $\Delta\rho/\rho$

$H_S$: field scale constant -- sum of anisotropy and demagnetizing field in the constituent strips of the transducer

$H_{CA}$: applied field strength in the cross-axis direction

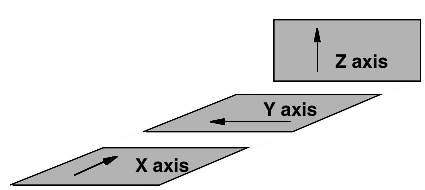
H: applied field strength in the sensitive direction

This formula has been experimentally verified on the HMC1002 microcircuit for values of:
$a \approx 22$ mV/V, and $H_S \approx 8$ Oe.

If three such sensors are mounted orthogonally to each other in such a way that the x sensor is mounted in the x-y plane, y sensor in the y-x plane and the z sensor in the z-y plane, then the output of the three sensors are coupled to each other. The output of the x sensor depends on the y field. Assume that it does not depend on the z field since that direction is perpendicular to the film plane, which is very insensitive. Likewise, the output of the y sensor depends on the x field, and the output of the z sensor depends on the y field.

Assume that the performance parameters characterizing the three sensors are (ax, $H_{Sx}$), (ay, $H_{Sy}$), and (az, $H_{Sz}$). Then the output voltages of the three sensors are given by

$$V_X = \frac{a_X \cdot H_X}{H_{SX} + H_Y}$$
$$V_Y = \frac{a_Y \cdot H_Y}{H_{SY} + H_X} \qquad (2)$$
$$V_Z = \frac{a_Z \cdot H_Z}{H_{SZ} + H_Y}$$




where Hx, Hy, and Hz are the three components of the applied field to be sensed.

If the three voltages are known, the three field values can be calculated using the following iteration scheme. The zeroth order iterate is given by

$$H_X^{(0)} = \frac{V_X \cdot H_{SX}}{a_X}$$
$$H_Y^{(0)} = \frac{V_Y \cdot H_{SY}}{a_Y} \qquad (3)$$
$$H_Z^{(0)} = \frac{V_Z \cdot H_{SZ}}{a_Z}$$

The $(n+1)^{th}$ order iterate is given in terms of the $n^{th}$ order iterate as follows:

$$H_X^{(n+1)} = \frac{V_X(H_{SX} + H_Y^{(n)})}{a_X}$$
$$H_Y^{(n+1)} = \frac{V_Y(H_{SY} + H_X^{(n)})}{a_Y} \qquad (4)$$
$$H_Z^{(n+1)} = \frac{V_Z(H_{SZ} + H_Y^{(n)})}{a_Z}$$

**Numerical experiment**

A numerical experiment was performed to test the rate of convergence of this iteration scheme. The parameters: ax = 25.0 mV/V, $H_{Sx}$ = 9.0 Oe, ay = 26.0 mV/V, $H_{Sy}$ = 8.5 Oe, and az = 27.0 mV/V, $H_{Sz}$ = 10.0 Oe were used as estimates for this example. This resulted in a sensitivity (a/Hs) at zero bias field of Sx = 2.78 mV/VOe, Sy = 3.01 mV/VOe, and Sz = 2.7 mV/VOe, typical of our magnetic sensor microcircuits. A simple spreadsheet was created to accept three values (Hx, Hy, Hz) of an applied field and internally calculate the three output voltages using Eq. 2. Several iterations using Eq. 4 was performed and for each component of the field the difference between the calculated value and the applied input value was expressed as a percentage of full scale (4 gauss) at each iteration. The tables below show this percent error as a function of the iteration for two different sets of input field values.

Hx = 1.0 Oe, Hy = 0.5 Oe, Hz = 0.8 Oe (without set/reset)

| iteration | Hx | Hy | Hz | ΔHx (%) | ΔHy (%) | ΔHz (%) |
|---|---|---|---|---|---|---|
| 0 | 0.947 | 0.447 | 0.762 | -1.32 | -1.32 | -0.95 |
| 1 | 0.994 | 0.497 | 0.796 | -0.14 | -0.07 | -0.10 |
| 2 | 1.000 | 0.500 | 0.800 | -0.01 | -0.01 | -0.01 |
| 3 | 1.000 | 0.500 | 0.800 | 0.00 | 0.00 | 0.00 |

Hx = 0.5 Oe, Hy = 0.5 Oe, Hz = -0.5 Oe

| iteration | Hx | Hy | Hz | ΔHx (%) | ΔHy (%) | ΔHz (%) |
|---|---|---|---|---|---|---|
| 0 | 0.474 | 0.472 | -0.476 | -0.66 | -0.69 | 0.60 |
| 1 | 0.499 | 0.499 | -0.499 | -0.04 | -0.04 | 0.03 |
| 2 | 0.500 | 0.500 | -0.500 | 0.00 | 0.00 | 0.00 |
| 3 | 0.500 | 0.500 | -0.500 | 0.00 | 0.00 | 0.00 |

The error after the second iteration is less than 0.10% in both cases.

If a set/reset circuit is used during the magnetic sensing, the effect of cross-axis errors can be greatly reduced. (refer to AN-201 for set/reset circuits) That is, after a set pulse is applied to the sensor store the reading as Vset. After a reset pulse, store the reading as Vreset. The final reading will be:

$$\begin{aligned} \text{Vout} &= \frac{\text{Vset} - \text{Vreset}}{2} \\ &= \frac{a \cdot H}{2}\left(\frac{1}{H_S + H_B} - \frac{1}{-H_S + H_B}\right) \\ &= \frac{a \cdot H}{2}\left(\frac{2H_S}{H_S^{\,2} - H_B^{\,2}}\right) \\ &= \frac{a \cdot H \cdot H_S}{H_S^{\,2} - H_B^{\,2}} \end{aligned} \tag{5}$$

Using this formula for the output voltage yields the following for the X, Y, and Z axis.

$$\begin{aligned} \text{Vout}_X &= a_X \cdot H_{SX}\left(\frac{H_X}{H_{SX}^{\,2} - H_Y^{\,2}}\right) \\ \text{Vout}_Y &= a_Y \cdot H_{SY}\left(\frac{H_Y}{H_{SY}^{\,2} - H_X^{\,2}}\right) \\ \text{Vout}_Z &= a_Z \cdot H_{SZ}\left(\frac{H_Z}{H_{SZ}^{\,2} - H_Y^{\,2}}\right) \end{aligned} \tag{6}$$

And, the iteration equations will be

$$\begin{aligned} H_X^{(n+1)} &= \text{Vout}_X \frac{H_{SX}^{\,2} - H_Y^{\,2(n)}}{a_X H_{SX}} \\ H_Y^{(n+1)} &= \text{Vout}_Y \frac{H_{SY}^{\,2} - H_X^{\,2(n)}}{a_Y H_{SY}} \\ H_Z^{(n+1)} &= \text{Vout}_Z \frac{H_{SZ}^{\,2} - H_Y^{\,2(n)}}{a_Z H_{SZ}} \end{aligned} \tag{7}$$

with,

$$\begin{aligned} H_X^{(0)} &= \frac{\text{Vout}_X \cdot H_{SX}}{a_X} \\ H_Y^{(0)} &= \frac{\text{Vout}_Y \cdot H_{SY}}{a_Y} \\ H_Z^{(0)} &= \frac{\text{Vout}_Z \cdot H_{SZ}}{a_Z} \end{aligned} \tag{8}$$

Performing the same analysis as above, but instead using the iterations for the set/reset sensor operation, yields a much smaller initial error and quicker convergence to zero error.

Hx = 1.0 Oe, Hy = 0.5 Oe, Hz = 0.8 Oe (with set/reset method)

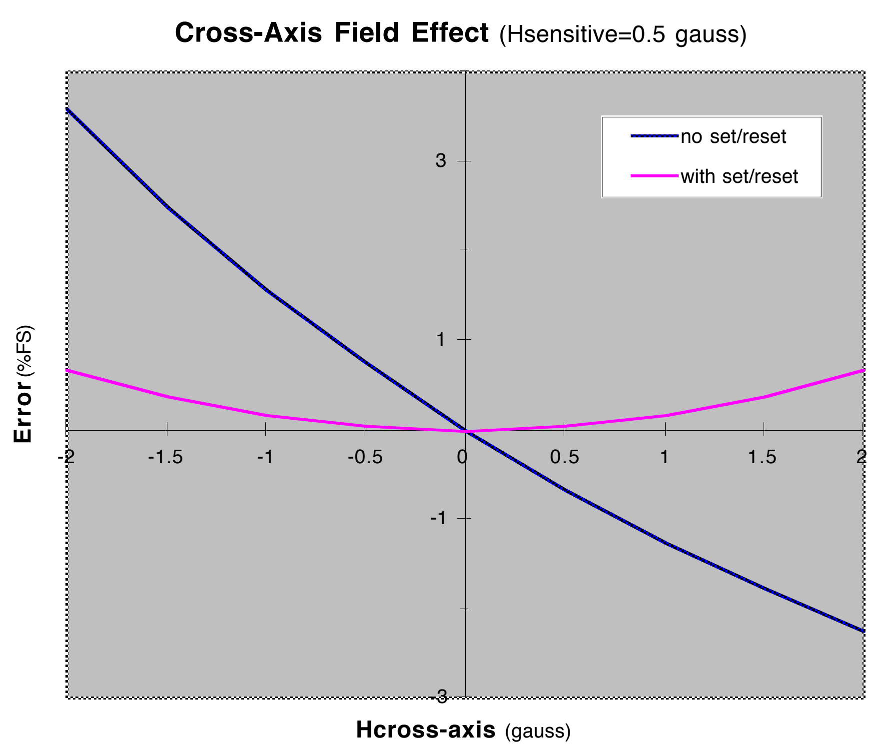
| iteration | Hx | Hy | Hz | ΔHx (%) | ΔHy (%) | ΔHz (%) |
|---|---|---|---|---|---|---|
| 0 | 1.003 | 0.507 | 0.802 | 0.08 | 0.18 | 0.05 |
| 1 | 1.000 | 0.500 | 0.800 | 0.00 | 0.00 | 0.00 |
| 2 | 1.000 | 0.500 | 0.800 | 0.00 | 0.00 | 0.00 |
| 3 | 1.000 | 0.500 | 0.800 | 0.00 | 0.00 | 0.00 |

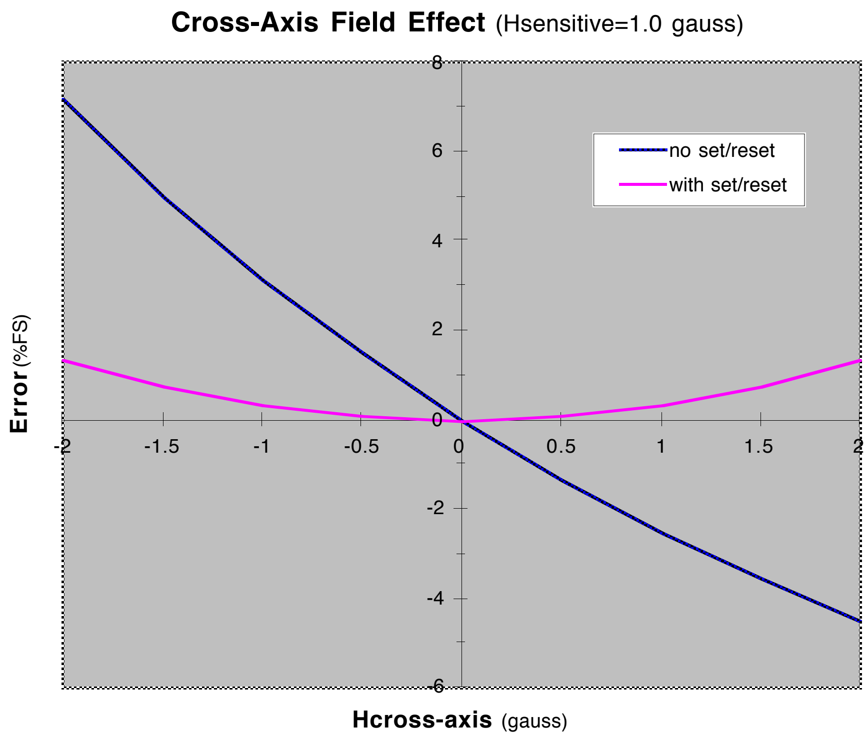
Hx = 0.5 Oe, Hy = 0.5 Oe, Hz = -0.5 Oe

| iteration | Hx | Hy | Hz | ΔHx (%) | ΔHy (%) | ΔHz (%) |
|---|---|---|---|---|---|---|
| 0 | 0.502 | 0.502 | -0.501 | 0.04 | 0.04 | -0.03 |
| 1 | 0.500 | 0.500 | -0.500 | 0.00 | 0.00 | 0.00 |
| 2 | 0.500 | 0.500 | -0.500 | 0.00 | 0.00 | 0.00 |
| 3 | 0.500 | 0.500 | -0.500 | 0.00 | 0.00 | 0.00 |

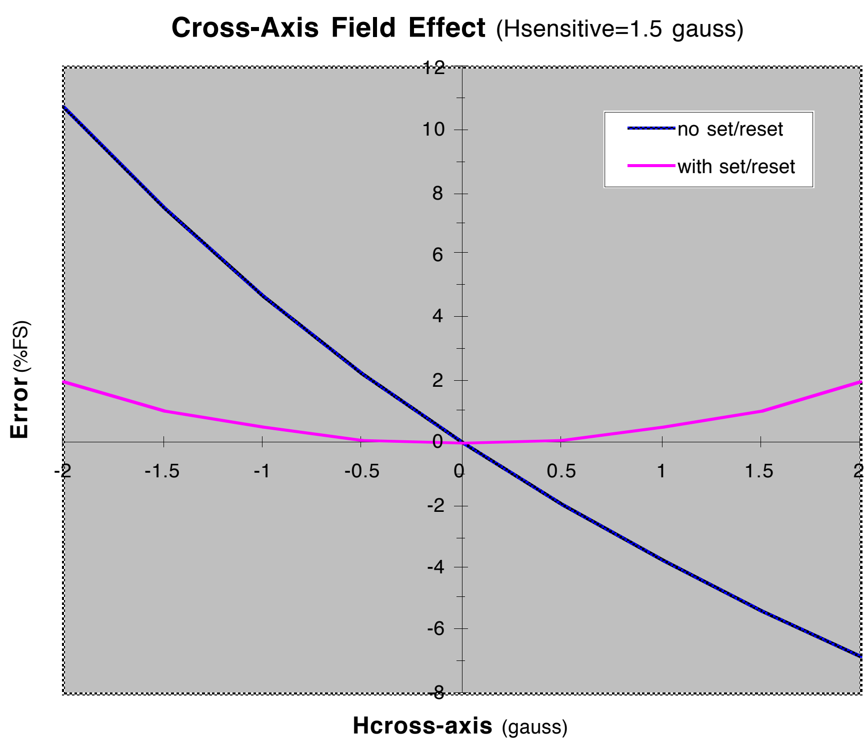
The error after the first iteration is less than 0.01% in both cases.

The plots below illustrate the reading error as a percent of full scale, for a 0.5, 1.0, and 1.5 gauss field in the sensitive axis verses a cross-axis field that varies from +2 to -2 gauss. The curve with the largest error is for a device not using any set/reset circuitry - errors range from -2.3 to +3.6 %FS. The smaller curve is for a device using a set/reset switching circuit - errors range from 0 to 0.7 %FS. The benefits of using a set/reset circuit is apparent from these plots. The full scale used was 4 gauss (±2 gauss).



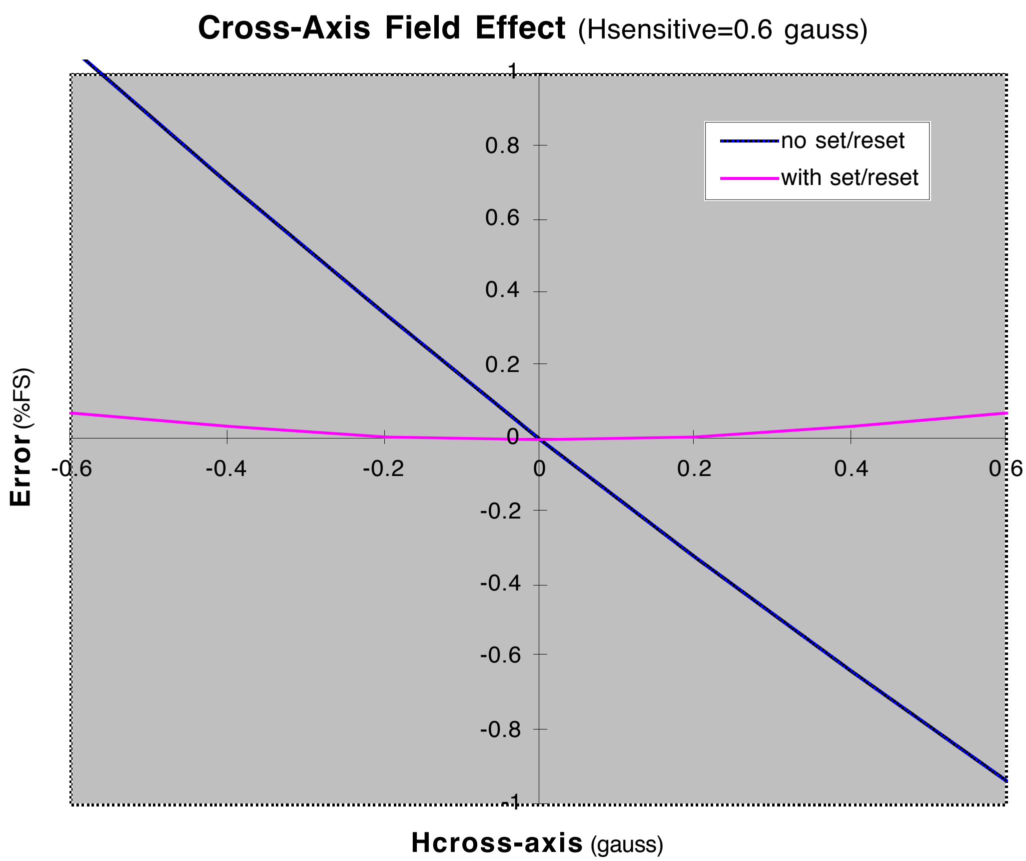


Cross-Axis Field Effect (Hsensitive=1.0 gauss)
no set/reset
with set/reset
Error (%FS)
Hcross-axis (gauss)
8
6
4
2
0
-2
-4
-6
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Cross-Axis Field Effect (Hsensitive=1.5 gauss)
no set/reset
with set/reset
Error (%FS)
Hcross-axis (gauss)
12
10
8
6
4
2
0
-2
-4
-6
-8
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

The cross-axis field verses error (%FS) plot shown below is characteristic of readings within the earth's magnetic field. This plot shows the worst case scenario where one axis is measuring 0.6 gauss (typical maximum field) and the cross-axis field varies from -0.6 to +0.6 gauss. For the device not using set/reset, the error varies from ±1 %FS. For a device using a set/reset circuit, the error varies about ±0.07 %FS.





**Customer Service Representative**

612-954-2888 fax: 612-954-2582
E-Mail: clr@mn14.ssec.honeywell.com
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