INNOVATION WITH PURPOSE

REDUCING THE INFLUENCE OF EXTERNAL FIELDS AND CROSSTALK FOR CONTACTLESS CURRENT SENSING

By Allegro MicroSystems

INTRODUCTION

Magnetic sensors are useful for measuring electrical current in conductors because the current flow generates a magnetic field around the conductor that can be measured without making electrical contact with the conductor.

One of the issues that must be addressed is the influence of stray magnetic fields—that is, fields that are not generated by the current that is intended to be measured. As discussed in this application note, Accurate measurement of the current in the conductor requires removal of the influence of stray fields.

The stray magnetic field can originate from two sources: 1) common-mode fields from external magnets in the proximity of the current sensor (Figure 1); and 2) current-carrying busbars adjacent to the sensor (Figure 2). This application note presents techniques to minimize the errors due to external fields on the current measurement.

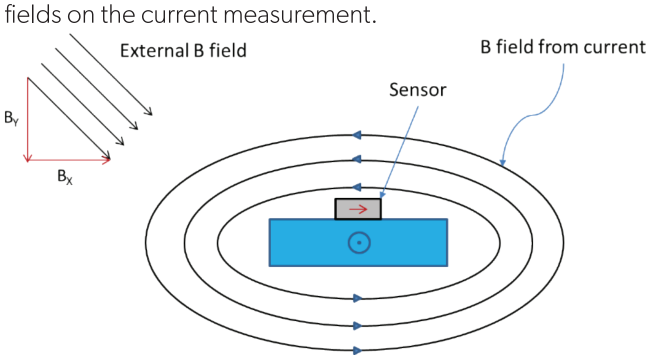

Figure 1: External Common-Mode Field Superimposed on Field Being Measured

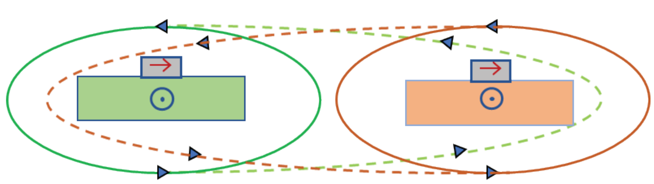

Figure 2:Magnetic Crosstalk Between Multiple Busbars

COMMON-MODE FIELD CORRECTION

Consider a magnetic sensor that is placed above a busbar to measure the current flowing through it. Such an arrangement with a stray external field superimposed on the field generated by the busbar current is shown in Figure 1. In this illustration, the axis of sensitivity for the sensor is shown by the red arrow. The field at the sensor is the vector sum of the fields due to current in the busbar and the external B field. In this case, the X component of the external field is opposite to the X component of the current generated field, which would result in a negative error in the current measurement. The sensor output would be:

$$-k \times B_{X(Current)} + k \times B_{X(External)},$$

where k is the sensor gain in mV/mT. Thus, the output of the sensor cannot be used to calculate the current in the busbar accurately.

Using Multiple Sensors per Conductor

One approach to mitigating the effect of stray fields is using two sensors per bus, one mounted on each side of the bus, with axes of sensitivity antiparallel, as shown in Figure 3. The outputs of the two sensors should be combined using a difference amplifier, as shown in Figure 4.

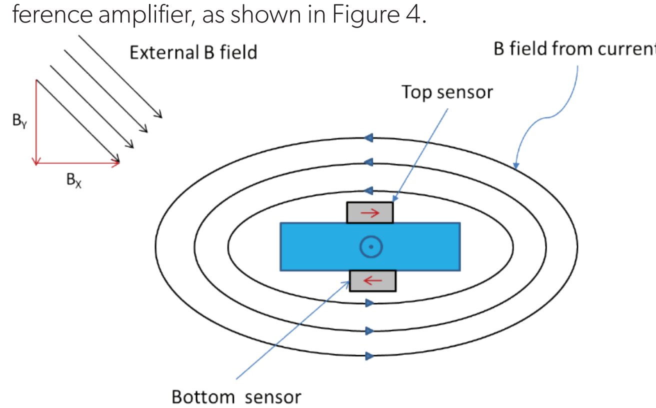

Figure 3: Two Sensors Used to Cancel Common-Mode Field

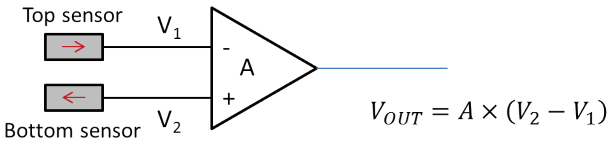

Figure 4: Difference Amplifier on Output of Both Sensors

Assuming equal magnitudes of the B field on opposite sides of the busbar, each would observe the same field magnitude, but with opposite polarities. Taking the output of the top sensor as V_1 and the output of the bottom sensor as V_2 gives:

$$V_1 = -k \times B_{X(Current)} + k \times B_{X(External)};\ and$$

$$V_2 = k \times B_{X(Current)} + k \times B_{X(External)}.$$

Inserting these into the difference amplifier equation gives:

$$V_{OUT} = A \times [(k \times B_{X(Current)} + k \times B_{X(External)}) - (-k \times B_{X(Current)} + k \times B_{X(External)})],$$

which can be simplified to:

$$V_{OUT} = A \times 2kB_{X(Current)}.$$

The output of the individual sensors due to the external B field appears as common-mode voltage on the inputs of the difference amplifier. In the case of an external field that is uniform through the region of the two sensors, the effect of the external field on the outputs of the sensors is eliminated.

If there is a gradient in the external B field between the two sensors, the effect of the external field is reduced, but not eliminated. This is likely to be the case in application, because the sensors are separated by at least the thickness of the busbar, and infinitesimally thin busbars are difficult to procure. Similarly, a mismatch in the field observed by the two sensors reduces the error due to external field, but it does not cancel it. Such a mismatch can occur when the two sensors are not placed symmetrically around the busbar.

Magnetic Shields to Block Common-Mode Fields

This approach relies on using commercially available magnetic shields to block the common-mode field, as illustrated in Figure 5. Soft magnetic materials are often used to shield electronics from quasi-static magnetic fields. One such commonly used shielding material is Mu-metal. With a relative permeability >80,000, Mu-metal acts like a magnetic sponge, absorbing the interfering common-mode magnetic field, diverting it away from the area to be shielded.

The efficacy of this approach is dependent on the magnetic shield material and dimensions and has been tested by Allegro using the shield U12-13-12.5-1.5 made by PML India [1] with the CTD103 PCB. This PCB has specially designed slots to insert the magnetic shield around the CT100 sensor.

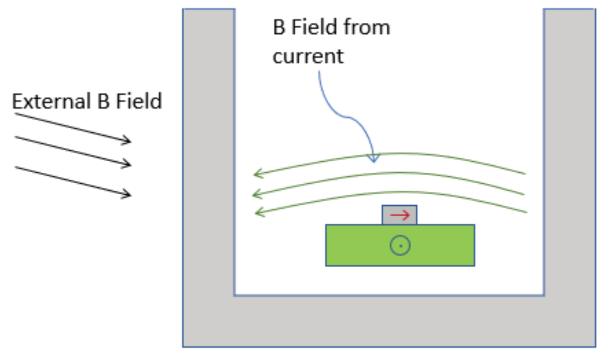

Figure 5: Magnetic Shields Used to Mitigate Common-Mode Error

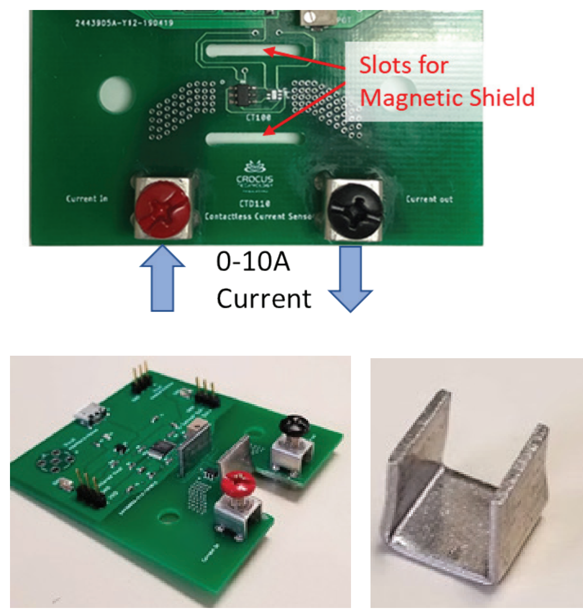

Figure 6: CTD103 PCB with Magnetic Shield Around CT100

The impact of common-mode field on sensor output was characterized while sweeping the trace current (see Figure 7 and Figure 8. The effect of common-mode field on the sensor output is compared in Table 1.

[1] https://www.pmlindia.com/pages/u-shield?srsltid=AfmBOor1I1T_8GSSUrP7y3NWvkgbATxeOJVxseCw08I6U5aNE73FGg8f

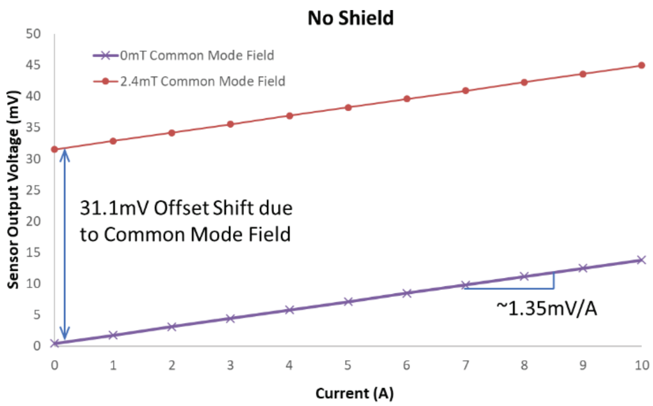

Figure 7: Change in Sensor Offset Due to Common-Mode Field

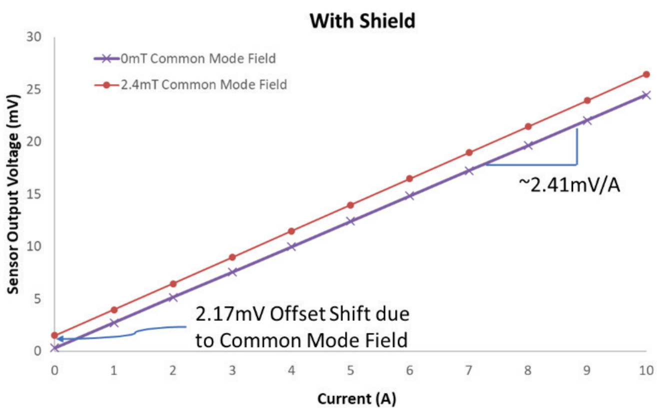

Figure 8: Common-Mode Rejection Due to Shield

Table 1: Comparison of Sensitivity and Common-Mode Error With and Without Shield

	Sensitivity (mV/A)	Common-Mode Error (mV)
Unshielded	1.35	31.1
With Shield	2.41	2.17

Not only does the shield lead to a ~15× reduction in the impact of common-mode field, it also increases the sensitivity of the system from 1.35 mV/A to 2.41 mV/A, without impacting the linearity of the system.

CROSSTALK MITIGATION FROM ADJACENT CONDUCTORS

It is common to have multiple busbars carrying currents in power distribution units (PDUs), smart meters, and motor controllers. These busbars are typically placed parallel to each other, which causes crosstalk error in the magnetic field measurement. The crosstalk field above and below the busbars are in the same direction as the primary field being measured, as shown in Figure 2. Thus, the method outlined in the Using Multiple Sensors per Conductor section cannot be used to reduce crosstalk error.

However, it is possible to use magnetic shields to reduce crosstalk. A specially designed PCB was used to demonstrate this method. The PCB design with two sets of CT100 sensors on current-carrying trace is shown in Figure 9 . This configuration exhibits crosstalk between trace current and adjacent CT100 sensor. With proper placement of the U12-13-12.5-1.5 shield, each of the traces attenuates the crosstalk and increases the accuracy of the measurement. The magnetic field around both the channels with and without the shield are illustrated in Figure 10.

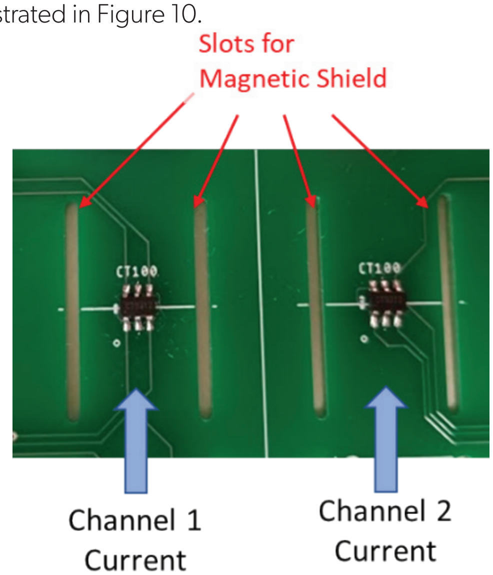

Figure 9: Test PCB Used to Characterize Crosstalk Between Adjacent Busbars

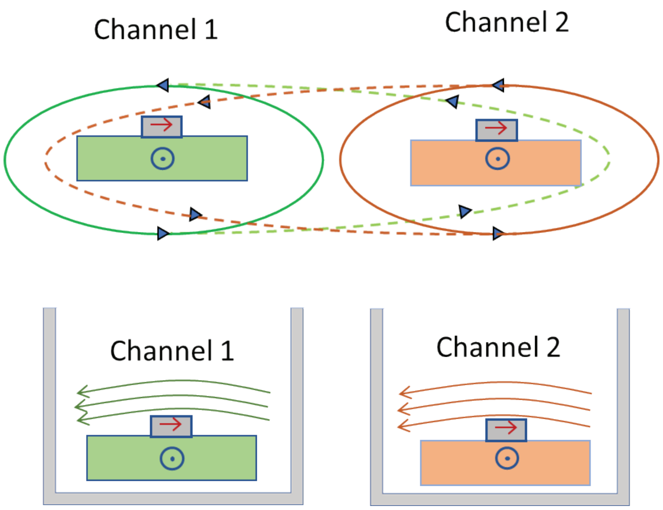

Figure 10: Multiple Busbar/Sensor Systems With and Without Magnetic Shields

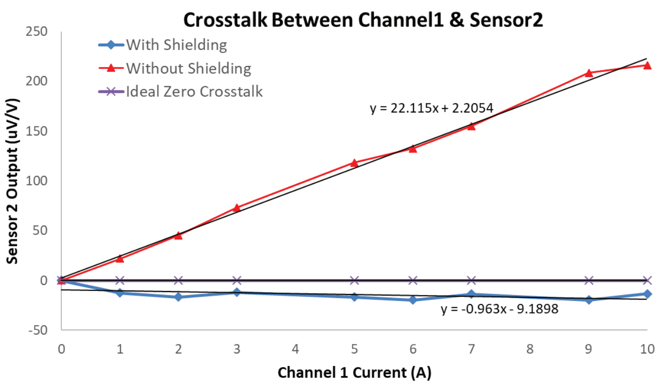

Figure 11: Crosstalk Reduction Due to Shielding Between Channels

The crosstalk between the current flowing in a channel and the adjacent sensor was measured to be ~22.1 μV/A without any shields. In the presence of magnetic shields, the crosstalk is significantly lower at –0.96 μV/A.

SUMMARY

Magnetic sensors are useful for measuring current in an electrical conductor without physical contact with the conductor, but they are unable to discriminate between the field generated by current flow within the conductor and external fields.

Using two sensors placed on either side of a conductor, with the axes of sensitivity antiparallel and combining the outputs with a difference amplifier can substantially reduce the influence of external fields on the magnetic sensors.

Alternatively, deploying soft magnetic material shields to divert the common-mode field without making any changes to the readout circuitry can also be effective in reducing the errors due to common-mode external fields. These magnetic shields can also be used to minimize crosstalk error in systems with multiple channels.

Revision History

Number	Date	Description	Responsibility
1	November 14, 2023	Document rebrand and minor editorial corrections	J. Henry
2	December 10, 2024	Fixed broken link (page 2)	J. Henry

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