Reducing the Influence of External Fields & Crosstalk for Contactless Current Sensing

1. 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 in this application is the influence of stray magnetic fields, that is, fields that are not generated by the current that is intended to be measured. It is necessary to remove the influence of stray fields in order to measure the current in the conductor accurately.

The stray magnetic field can come from following two sources: Common Mode fields from external magnets in the proximity of the current sensor (Figure 1) and current carrying busbars adjacent to the sensor (Figure 2). This Application Note will present techniques to minimize the errors due to external fields on the current measurement.

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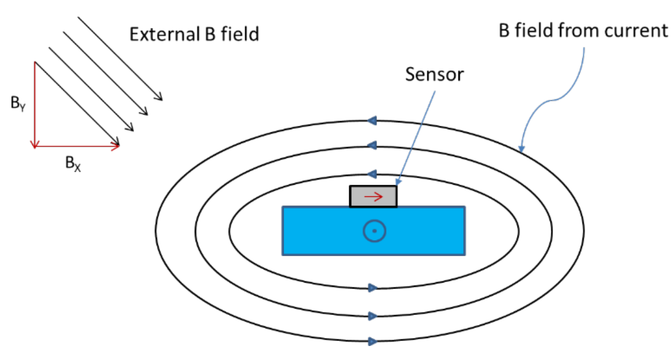

Figure 1: External common mode field superimposed on field being measured

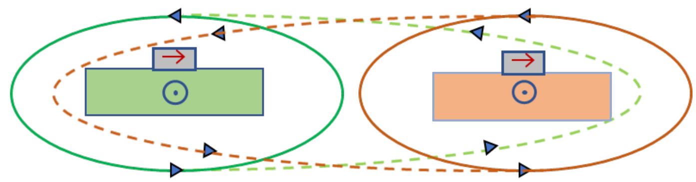

Figure 2: Magnetic crosstalk between multiple busbars

2. Common Mode Field Correction

Consider a magnetic sensor that is placed above a bus bar to measure the current flowing through it. Figure 1 shows such an arrangement with a stray external field is superimposed on the field generated by the bus bar current. 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 bus bar 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 bus bar accurately.

2.1. 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 their axes of sensitivity antiparallel, as shown in Figure 3.

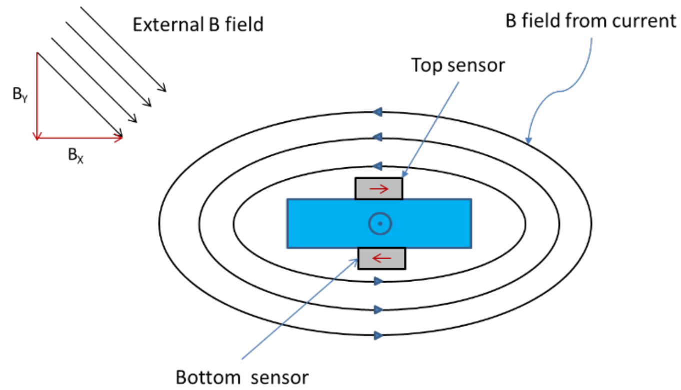

Figure 3: Using two sensors to cancel common mode field

The outputs of the two sensors should be combined using a difference amplifier, as shown in Figure 4.

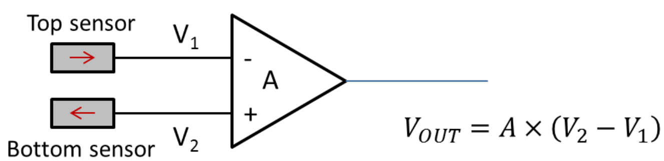

Figure 4: Difference amplifier on output of both sensors

Assuming equal magnitudes of the B field on opposite sides of the bus bar, each would see the same field magnitude, but with opposite polarities. Taking the output of the top sensor as V_1, and that 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:

$$V_{OUT} = A \times \Big(\big(k \times B_X(Current) + k \times B_X(External)\big) - \big(-k \times B_X(Current) + k \times B_X(External)\big) \Big),$$

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 sensors' outputs is eliminated.

If there is a gradient in the external B field between the two sensors, the effect of the external field will be 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 bus bar, and infinitesimally thin bus bars are difficult to procure. Similarly, a mismatch in the field seen by the two sensors will reduce the error due to external field, but not cancel it. Such a mismatch can occur when the two sensors are not placed symmetrically around the bus bar.

2.2. Magnetic Shields to Block Common Mode Fields

This approach relies on using commercially available magnetic shields to block the common-mode field and is 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.

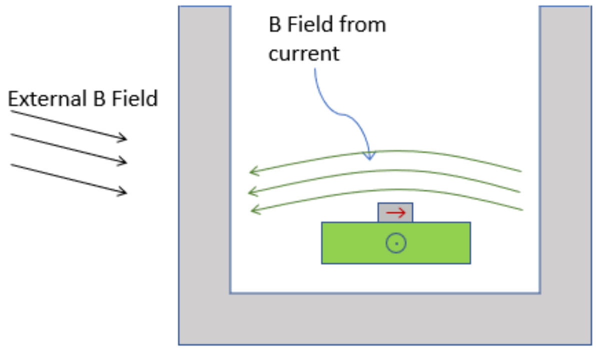

Figure 5: Using magnetic shields to mitigate common mode error

The efficacy of this approach is dependent on the magnetic shield material and dimensions and has been tested at Crocus Technology by using the shield U12-13-12.5-1.5 made by PML India (https://www.pmlindia.com/collections/magnetic-shielding/products/u-shields) with the CTD103 PCB. This PCB has specially designed slots to insert the magnetic shield around the CT100 Sensor.

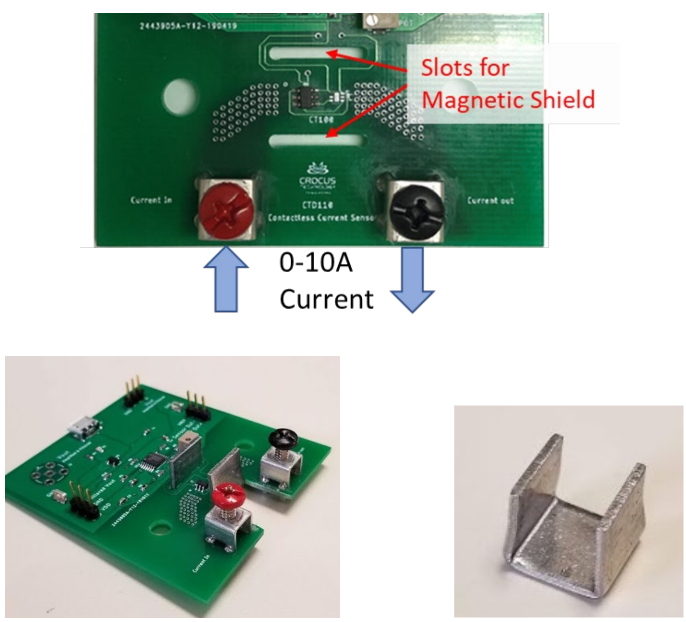

Figure 6: CTD103 PCB with magnetic shield around CT100

The impact of common-mode field on sensor output was characterized while sweeping the trace current. Figure 7 and Figure 8.

Table 1 contrast the effect of common mode field on the sensor output.

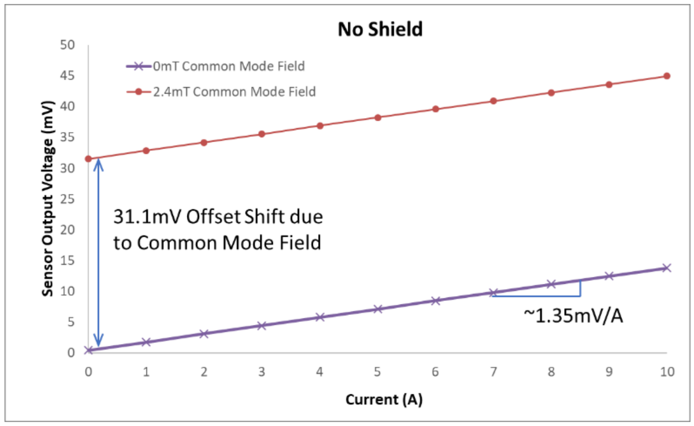

Figure 7: Change in sensor offset due to common mode field

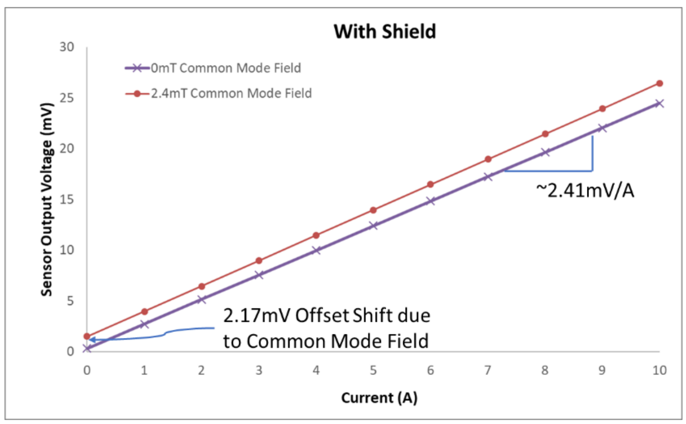

Figure 8: Common mode rejection due to shield

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

Table 1: Comparison of sensitivity and common-mode error with and without shield

Not only does the shield lead to a ~15x 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.

3. Crosstalk Mitigation from Adjacent Conductors

It is common to have multiple busbars carrying currents in PDUs (Power Distribution Units), Smart Meters, and Motor Controllers. These busbars are typically placed parallel to each other with causing crosstalk error in the magnetic field measurement. As shown in Figure 2, the crosstalk field above and below the busbars are in the same direction as the primary field being measured. Thus, the method outlined in 2.1 cannot be used to reduce crosstalk error.

However, it is possible to used magnetic shields to reduce crosstalk and a specially designed PCB was used to demonstrate this method.

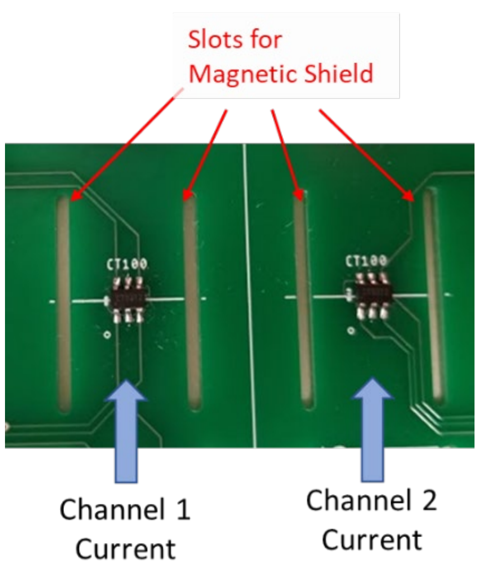

Figure 9: Test PCB used to characterize crosstalk between adjacent busbars

Figure 9 shows the PCB design with two sets of CT100 sensors on current carrying trace. This configuration will have crosstalk between trace current and adjacent CT100 sensor. Placing the U12-13-12.5-1.5 shield each of the traces will attenuate the crosstalk and increase the accuracy of the measurement. The magnetic field around both the channels with and without the shield are illustrated in Figure 10.

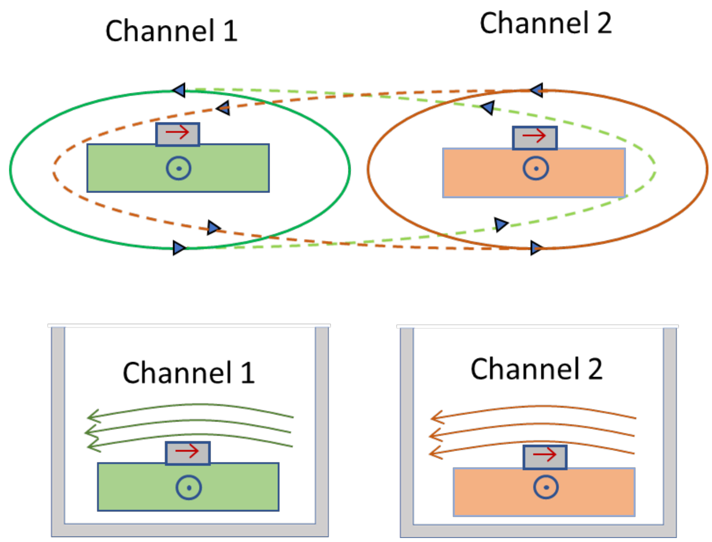

Figure 10: Multiple busbar/sensor systems with and without magnetic shields

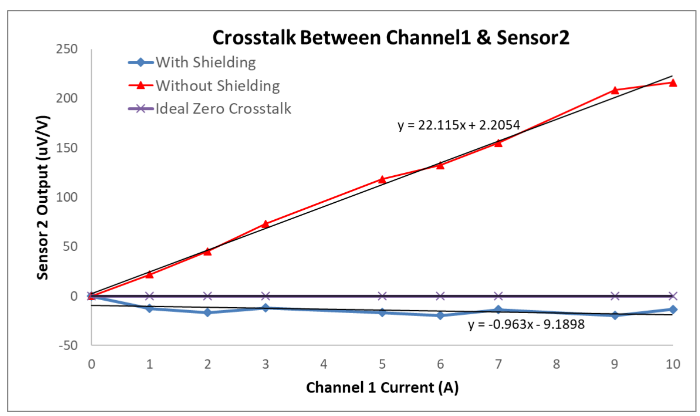

Figure 11: Crosstalk reduction due to shielding between channels

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.

4. Summary

Magnetic sensors are useful for measuring current in an electrical conductor without physical contact with the conductor but 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 their axes of sensitivity antiparallel, and combining their 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 read-out circuitry can also be effective in reducing the errors due to common-mode external fields. These magnetic shields can also be used to minimize the crosstalk error in systems with multiple channels.