CT43x Performance Overview

Abstract

State-of-the art Hall Effect, coreless, current sensors are known to have several limitations such as offset control, temperature drift and limited bandwidth. These limitations exist because of the inherent shortcomings of Hall Effect technology. Hence, to improve current sensors, the base technology needs to be improved instead of trying to further improve the circuit design.

XtremeSense® TMR was developed by Crocus Technology to eliminate the several known compromises of designing a coreless Hall Effect current sensor.

By using a different technology in XtremeSense® TMR instead of Hall Effect, CT43x family is able to bring performance achieved only by very high cost, closed-loop current sensors to everyday current sensing.

Highlights

The bullet points below will be detailed in this application note:

- 1 MHz Bandwidth (BW)
- <0.15% Full-Scale (FS) Linearity error over temperature.
- 300 ns typical response time
- Differential Sensing for CMFR
- <15 mA_{RMS} resolution over 1 MHz BW
- <1.0% FS Maximum error versus the ideal line over the full operating temperature range.
- VREF pin

Introduction

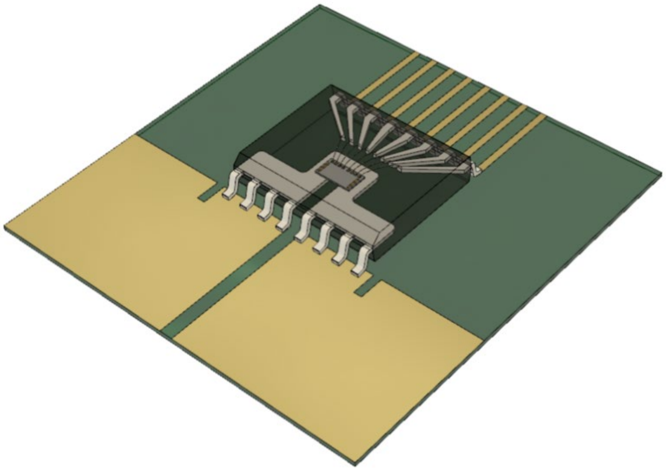


Figure 1. CT43x sensor on a PCB showing the current carrying trace and the signal traces.

XtremeSense® TMR technology enables current sensing products with industry leading performance figures. The technical benefits XtremeSense® TMR provides over Hall Effect technology were leveraged in the CT43x design to enable industry leading open-loop, core-less differential current sensor.

This document complements the datasheet to provide additional details to help the reader become more familiar with the CT43x products.

XtremeSense® TMR

For more information about XtremeSense® TMR technology, please refer to AN117.

Open-loop vs Closed-loop

Historically, designers had to make a choice, based on their application requirements, between open-loop and closed loop Hall Effect current sensors:

- High accuracy and high-speed applications needed closed-loop sensors.
- Cost sensitive application were limited to open-loop sensors.

Due to Hall Effect technical limitations in terms of offset control, temperature drift, sensitivity error… closed-loop current sensors based on Hall Effect were designed. While these sensors achieved good performance, it is at a very high cost and bulky design.

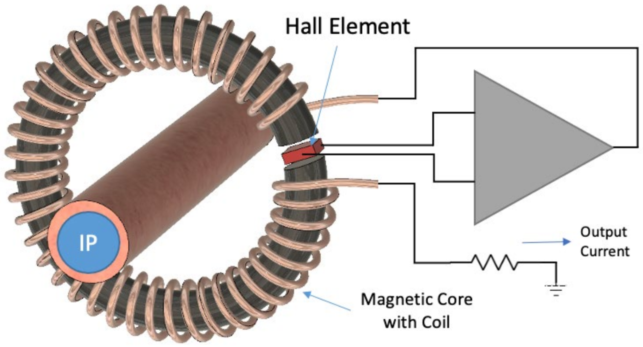


Figure 2. Hall-Effect based current sensing solution of magnetic core with coil for closed-loop system.

Open-loop Hall Effect sensors are also widely used but are relegated to lower accuracy current sensing application where cost demands have higher priority.

A number of open-loop Hall Effect based sensors try to mitigate the technology limitations by adding complex compensation algorithms and heavy calibration. While these sensors provide better performance, it is still sub-par to closed-loop systems.

Open-loop current sensors

Integrated Core

Some Hall Effect current sensors include a ferromagnetic core without the coil around it to achieve the closed-loop feedback circuit.

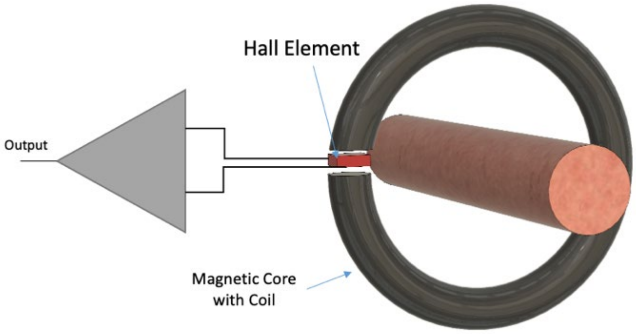


Figure 3. Hall-Effect based current sensing solution of magnetic core with coil for open-loop system.

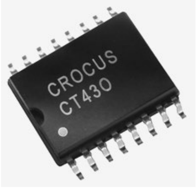
The ferromagnetic core serves as a concentrator that focuses the magnetic field on the Hall Effect sensor. Due to the low sensitivity of Hall, this improves the overall SNR and shields against external magnetic fields. But is susceptible to magnetic hysteresis, saturation, and bandwidth limitations. Temperature performance was also limited along with offset control.

These sensors are typically bulky and provide mid-range performance for a mid-range cost.

Coreless

Coreless current sensors do not include the usual ferromagnetic concentrator. Historically, these sensors were selected in cost-driven designs.

These current sensors struggled with Hall Effect limitations: low SNR, substantial gain, and offset temperature drift.



CT43x is based on XtremeSense® TMR Technology is an open-loop, coreless current sensor with closed-loop performance figures.

Linearity and Accuracy

Linearity Error

XtremeSense® TMR technology is inherently highly linear. This behavior benefits all of Crocus Technology products including the CT43x.

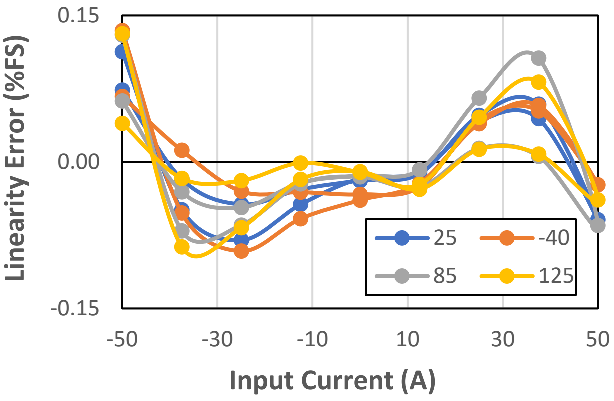


Figure 4. Linearity error over full temperature.

Total Accuracy

The CT43x is intended to be used without any end of line calibration from the customer. The sensor is calibrated by Crocus Technology to match the figures of gain and offset found on the datasheet.

The figure below shows the percentage full scale (FS) error of V_{OUT} compared to the ideal line.

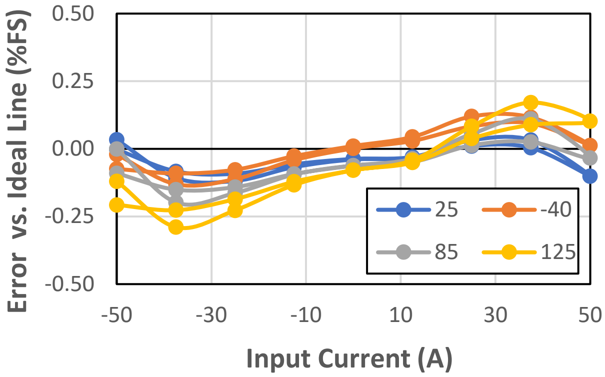


Figure 5. Accuracy versus the Ideal transfer line.

Common Mode Field Rejection

While other Hall Effect based current sensors already achieve common mode field rejection to different extents. XtremeSense® TMR, brings key advantages that the CT43x benefits from as a current sensor that will be described below.

Overview

To achieve a good Common Mode Field Rejection ratio, the current sensors need to be based on two (2) near-identical magnetic sensors. This paragraph illustrates how XtremeSense® TMR allows for a near-perfect matching.

How CMFR works

When an external field is applied the two full bridges TMR sensors' outputs behave similarly in amplitude and sign.

For example:

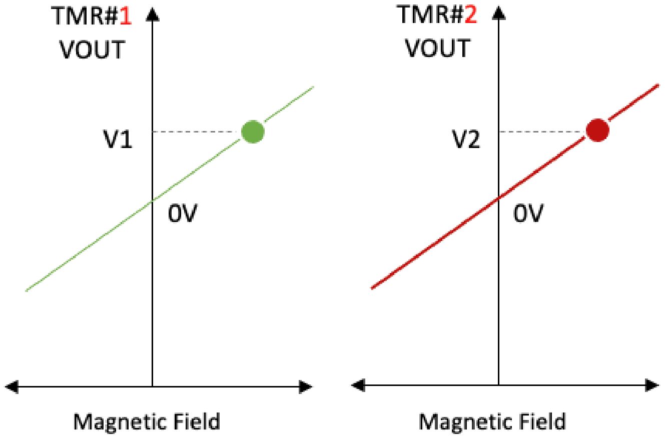


Figure 6. The XtremeSense® TMR Full-bridge outputs under an external magnetic field.

The figure above shows that the voltage output of the two bridges is identical, hence, the differential voltage output of V1-V2 will be 0 V eliminating the external magnetic field influence.

Conversely, when current flows on the internal U-shaped lead frame. The two full-bridge TMR sensors’ outputs behave with the same amplitude but different sign.

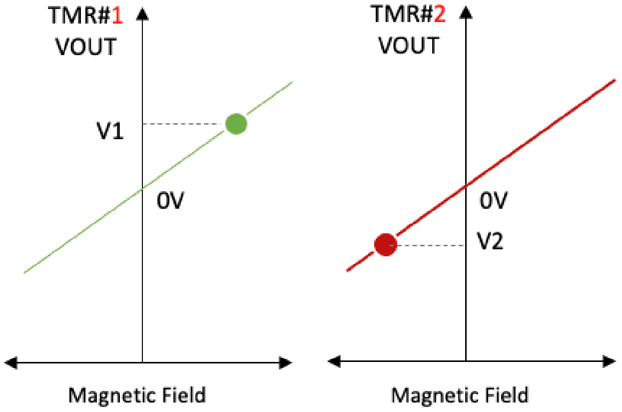


Figure 7. The XtremeSense® TMR Full-bridge outputs under the magnetic field generated by the U-shape internal lead frame.

Hence, the differential voltage output V1-V2 ≠ 0 which then leads to the voltage on the OUT pin to change.

Differential Sensing

The CT43x uses two full-bridge XtremeSense® TMR sensors to achieve differential magnetic sensing capability, which allows CT43x to greatly attenuate external magnetic fields and only capture the magnetic field generated by current flowing on the internal lead frame current carrying conductor.

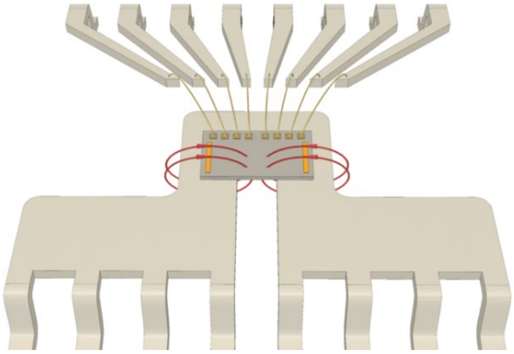


Figure 8. General representation of the internal lead frame.

Monolithic Design

CT43x is a single chip design that contains two full-bridge XtremeSense® TMR current sensors along with the analog circuit. The monolithic nature of CT43x allows impeccable matching between the two full bridges.

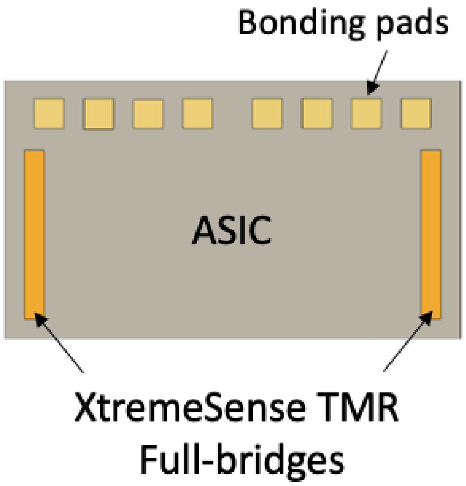


Figure 9. Representation of the CT43x die layout.

The figure above shows a global view of the CT43x die. The two vertical elements on the edges of the die represent the location of the two full-bridge XtremeSense® TMR sensors.

Gain Matching

To eliminate external fields, the two TMR sensors’ gain needs to be the same. This helps the two sensors to react the exact same way to an external field. Many parameters contribute to the great matching achieved in CT43x family

1. CT43x is monolithic, the matching between the two sensors is inherently great,
2. The CT43x includes additional fine gain adjustment to further eliminate any gain mismatch.
3. XtremeSense® TMR temperature performance maintains the gain matching over the operating temperature range.

Axis of Sensitivity

XtremeSense® TMR has a planar axis of sensitivity which is perpendicular to the out-of-plan sensitivity axis of Hall Effect sensors.

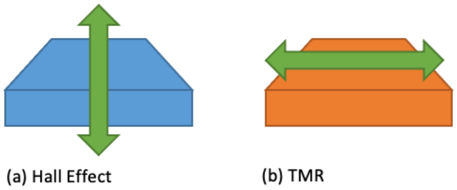


Figure 10. Magnetic axis of sensitivity for Hall Effect and TMR.

The different axis of sensitivity of TMR provides two substantial benefits:

1. Alignment

Ideally, the two sensors in a differential sensing system should see the exact same magnetic field amplitude with opposite signs. Because both sensors see the same amplitude, the gain adjustment required is minor. Whereas if the sensors see different fields, then the sensor circuitry needs to adjust very different gains, which can require complex and larger circuitry.

Hall Effect sensors, due to their vertical axis of sensitivity, sense the magnetic field inside the U-shape and outside. The amplitudes between the inside and outside of the U-shape are substantially different.

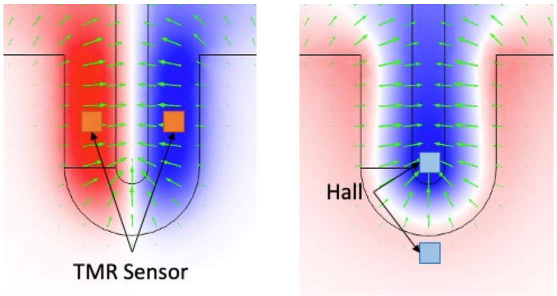


Figure 11. the magnetic field relative amplitude generated by the Internal current carrying lead frame.

XtremeSense® TMR senses the magnetic field generated on top of the U-shape, simply by placing the die at the center of the lead frame, the two sensors see a substantially similar magnetic field.

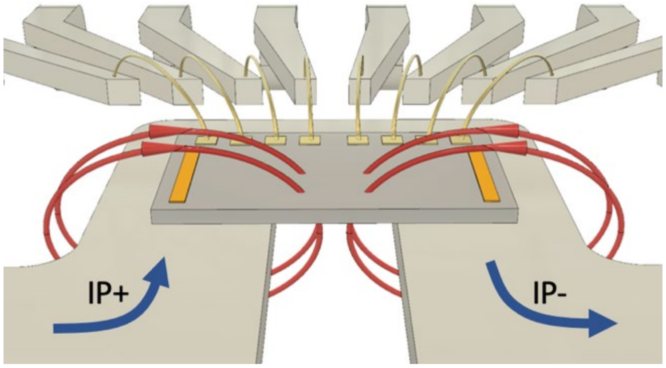


Figure 12. The differential magnetic field generated by current flowing in the lead frame.

2. Crosstalk

When a current carrying conductor, pictured in red below, is adjacent to the CT43x, the magnetic field generated is substantially perpendicular to the axis of sensitivity of the sensor. Making this field all but null from the sensors' perspective.

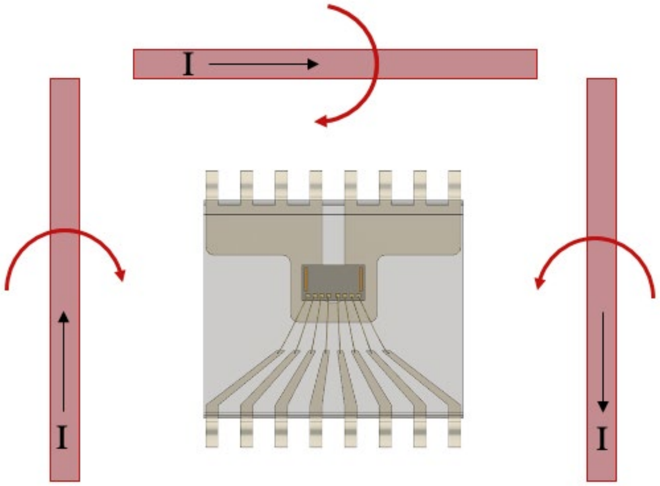


Figure 13. CT43x along with 3 adjacent current carrying conductors pictured in red.

Noise, Resolution and SNR

Signal-to-Noise ratio (SNR) is one of the most important parameters when considering a current sensing solution. To evaluate this parameter, both the sensor's noise and sensitivity need to be evaluated.

Resolution

The CT43x family resolves down to 15 mA over its entire 1 MHz bandwidth. This industry leading figure is due to the benefits of using XtremeSense® TMR.

While in a Hall Effect based current sensor, both the Hall Plate and the amplification circuit are major contributors to the final SNR figure, forcing designers to use integrated Low-Noise Amplifiers with relatively bigger gain factors (that can limit the bandwidth).

XtremeSense® TMR features a higher SNR while also providing a higher sensitivity allowing a simpler amplification circuit design.

Noise

Contrary to a majority of Hall Effect based sensors, the CT43x does not include a "chopper circuit" to mitigate the high offsets and eliminate the 1/f noise characteristic of Hall Effect technology. Hence, the voltage noise spectral density of the CT43x shows a 1/f noise characteristic.

The integrated noise over a 100 kHz bandwidth is 9.8 mA. These results were measured on the CT430-HSWF50MR which can handle current from -50 A to +50 A providing an SNR figure of 80 dB.

$$SNR = 20 * \log\left(\frac{0.0098}{100}\right) = 80.02$$

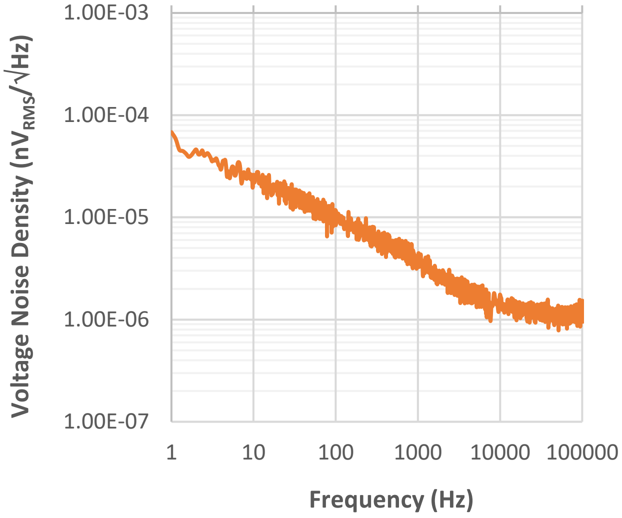


Figure 14. CT43x noise density performance.

Bandwidth

While XtremeSense® TMR can reach higher bandwidths, the CT43x is optimized for an operational bandwidth of 1 MHz.

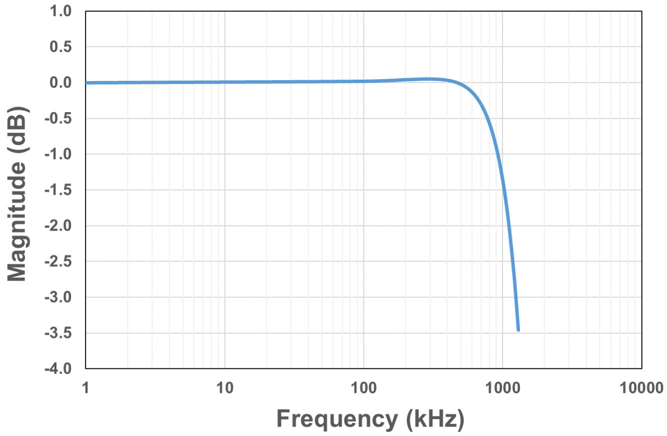


Figure 15. CT43x frequency response curve (bandwidth).

Response Time

The graph in Figure 16 shows the typical pulse response of CT43x to a step current input. The Rise and Fall response time is less than 300 ns (typical).

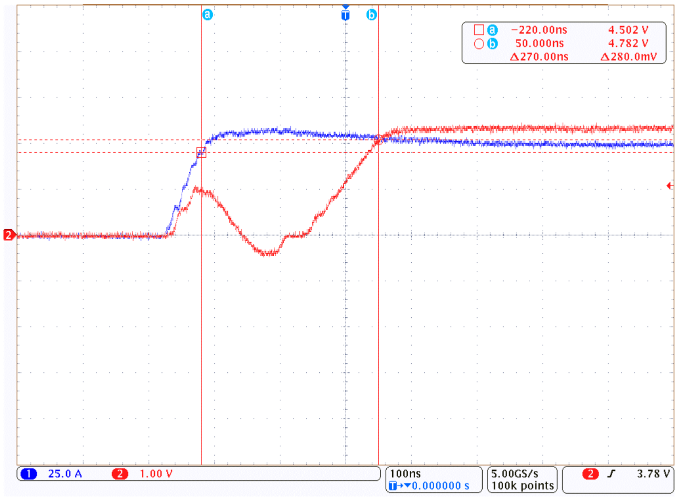


Figure 16. CT43x response time to step current input.

High Voltage Isolation

The CT43x is able to achieve at least 5 kV isolation during 60 seconds in accordance with IEC/UL 62368-1 and UL1577. To achieve this figure, XtremeSense® TMR technology and advanced packaging technology are used.

The high XtremeSense® TMR Signal-to-Noise ratio combined with its planar axis of sensitivity allows for an easier die placement on top of the lead frame and a greater distance between die and the current carrying lead frame. Contrary to Hall Effect technology where, due to lower SNR and a perpendicular axis of sensitivity renders the die placement harder.

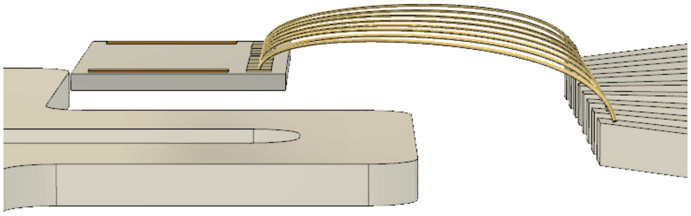


Figure 17. Exaggerated representation of the die on top of the lead frame.

Crocus Technology developed with its packaging partners a custom lead frame for the 16-lead SOIC-Wide package along with proprietary isolation materials.

Other Information

Please check our website www.crocus-technology.com for additional documentation or contact support@crocus-technology.com.