CT220 Reference Design for Contactless Current Sensing

Referenced Devices
CT220
CTD221

Abstract
The objective of this reference design document is to allow the reader to understand the behavior of the CT220 linear field sensor then use it to design a contactless current sensing solution that provides infinite isolation. Specifically, it provides Printed Circuit Board (PCB) layout recommendations and examples of CT220 design implementations as well as max current and resolution of these implementations.

Introduction
The CT220 is a Tunnel Magneto-Restrictive (TMR) magnetic field sensor optimized for linearity and temperature performance. The sensor features four TMR resistive branches connected as a Wheatstone bridge along with analog front-end circuitry to tune the gain and offset.

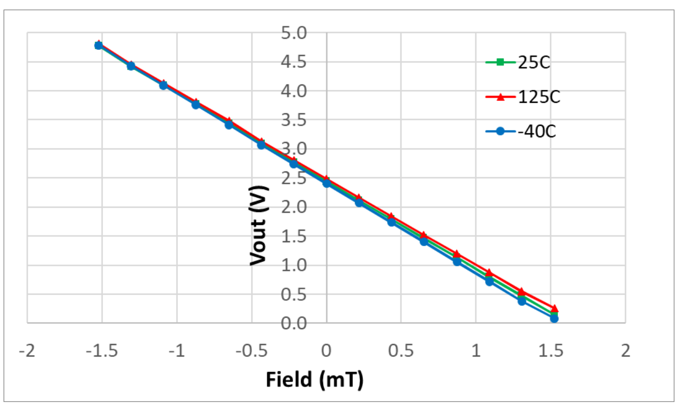

Figure 1. Voltage output vs. magnetic field under different temperature levels.

The CT220 achieves a maximum of ±0.5% linearity error over ±20 mT range magnetic field, under the full temperature range of -40°C to +125°C without any active temperature compensation circuitry.

Reference Design
Overview
To be used as a current sensor, the CT220 needs to be able to sense the magnetic field generated by the current as it flows through a conductor. This conductor is referred to as Current Carrying Conductor (CCC).

Typically, the CCC is either a bus-bar shown in Figure 2, a PCB trace Figure 3, or a cable.

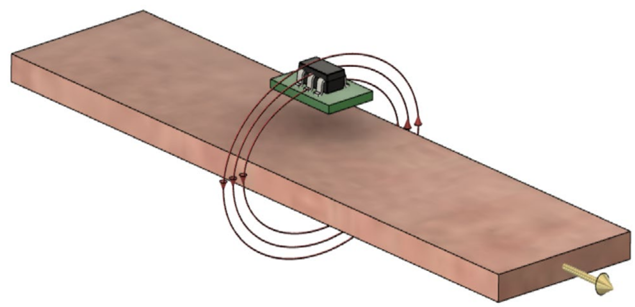

Figure 2. CT220 on a PCB (green), Current carrying bus-bar (copper).

The CT220 can measure bidirectional current and the quiescent voltage is equal to VDD/2.

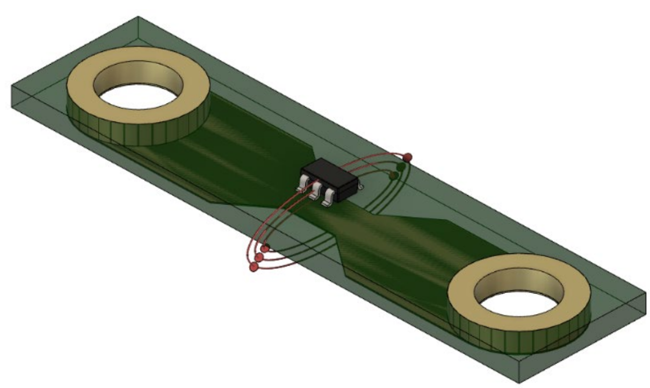

Figure 3. CT220 measuring current of a bottom PCB trace Current Carrying Conductor.

Note: Typically, Hall-effect sensors requires either internal or external magnetic field cores to amplify the signal. This is not the case with CT220 thanks to the high TMR sensitivity.

Magnetic Field Estimation

The following equations help estimate the magnetic flux generated by the current flowing on a conductor without using a shield.

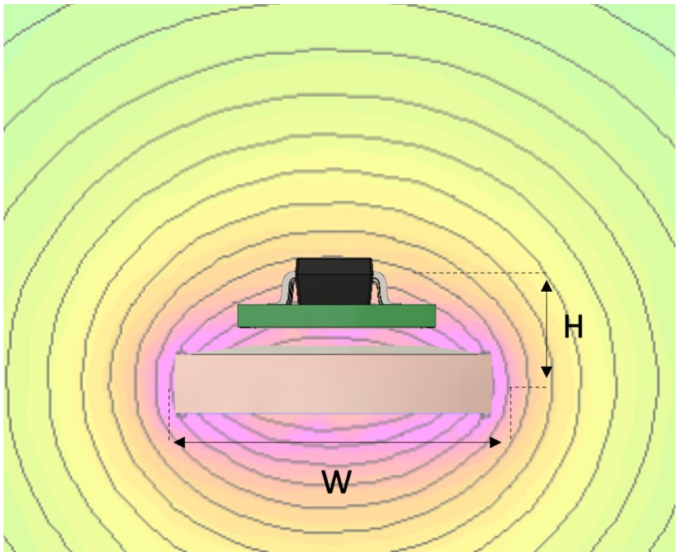

Figure 4. Magnetic field lines without a shield.

$$B\ (mT) = 1.25 \frac{I\ (A)}{2 * (W + 2H)\ (mm)}$$

Notice that the three main parameters that affect the magnetic field are the width of the current carrying conductor, W, the vertical space between the sensor and the current carrying conductor, H and the current, I.

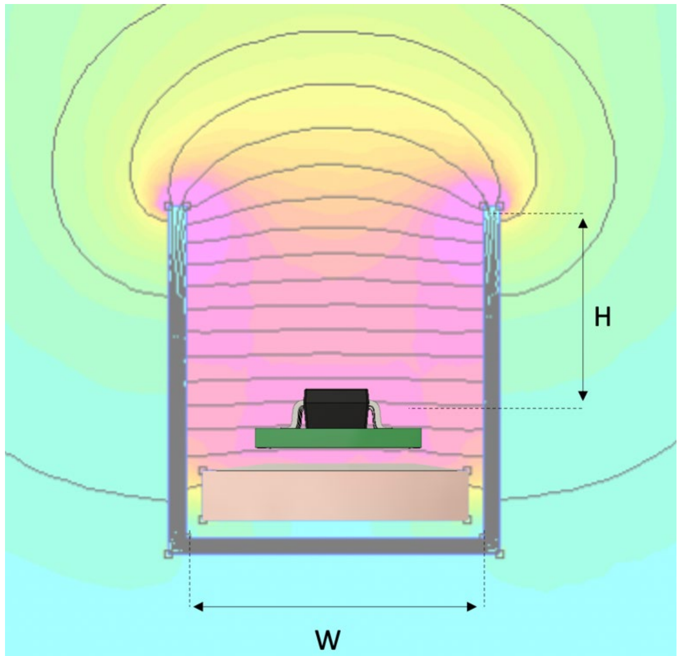

Figure 5. Magnetic field lines with a shield.

$$B\ (mT) = 1.25 \frac{I\ (A)}{W\ (mm)} \qquad (1)$$

Notice that when a shield is used the only important parameters are the inner width of the shield, W and the current, I.

The height, H is at least W/2 to generate a homogenous field across CT220.

Block Diagram

The CT220 gain and offset are factory trimmed. The device's ANA output, which is a ratiometric linear voltage output, can be directly connected to an ADC.

The CT220 also features a $\overline{\text{FLAG}}$ output, which is an active LOW digital output pin, that is factory trimmed to trigger at specific current threshold.

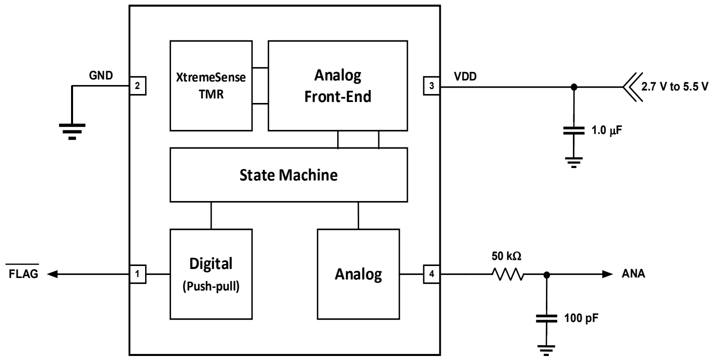

Figure 6. Complete schematics for CT220.

CT220 Variants

The CT220 is offered in four (4) variants. Each variant has a different gain setting which allows designers to optimize the full dynamic range of the sensor output to their requirements.

NOTE: the rest of this application note refers to the lowest sensitivity of the CT220.

PCB Layout Recommendations

ROUTING

Avoid any routing below the CT220 package.

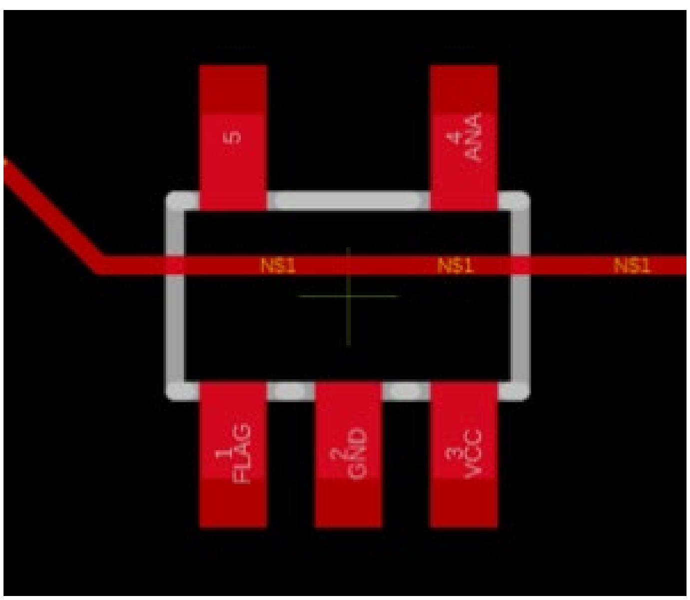

Figure 7. Poor PCB layout for CT220.

EDDY CURRENTS

Avoid power planes (GND or VDD copper plane) under the sensor.

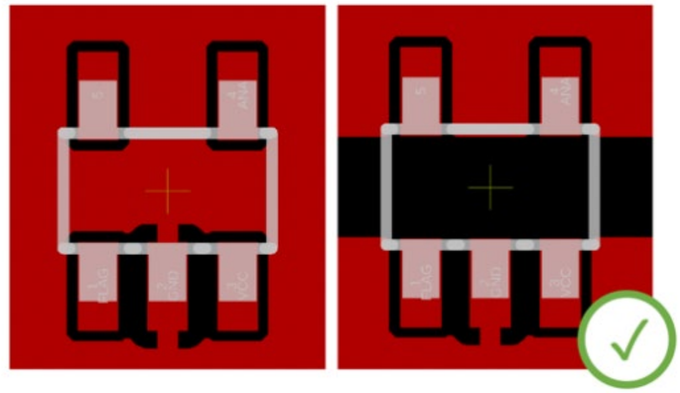

Figure 8. Recommended PCB layout for CT220.

CAPACITIVE COUPLING

Parasitic capacitive coupling appears when switching high voltages. Using a ground (GND) layer will reduce these effects.

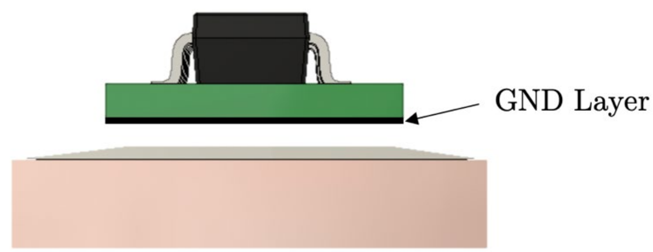

Figure 9. Illustration of PCB with GND layer to lessen parasitic capacitive coupling.

Reference Designs

The following section describes the performance of CT220 when used in two implementations:

1. The measured Current flows on the top layer
2. The measured Current flows on the bottom layer

As a reference, the figure below shows a cross-section of a standard 2-layer PCB. The top and bottom copper layers are 35 µm thick. The die is on the bottom face of the SOT23 package.

		SOT Package
200	Die	
100		Pins and solder
35	Top-Current	Cu Layer
1600		PCB
35	Bot-Current	Cu Layer

Figure 10. Stack up cross-section view of PCB and CT220 in SOT23 package

Current on Top Layer

The Current trace on the top PCB copper layer is 0.9 mm wide.

Coupling coefficient: 3.45 G/A
DC current measurement range: ±3.85 A

Clearance between the trace and IC pads is 0.35 mm. Which provides isolation of 1 kV between current trace and SOT23 pins.

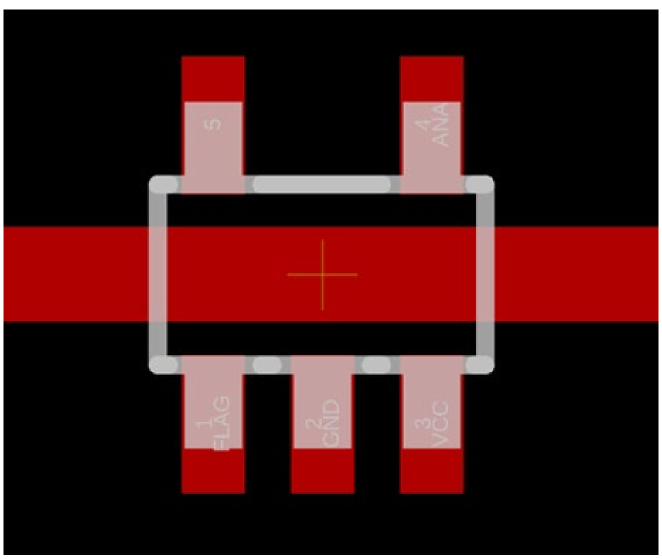

Figure 11. Current Flowing on the top layer

Excellent resolution observed: 10 mA steps resolved very easily, but output becomes non-monotonous at 2 mA steps.

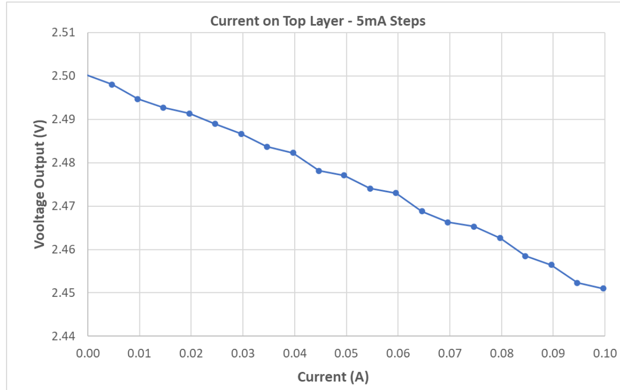

Figure 12. Resolution achieved using top copper layer.

Current on Bottom Layer

The Current trace on the bottom PCB copper layer is 2.0 mm wide.

Coupling coefficient: 0.98 G/A
DC current measurement range: ±13.4 A

High isolation. No breakdown observed for 5.1 kV_{RMS} isolation.

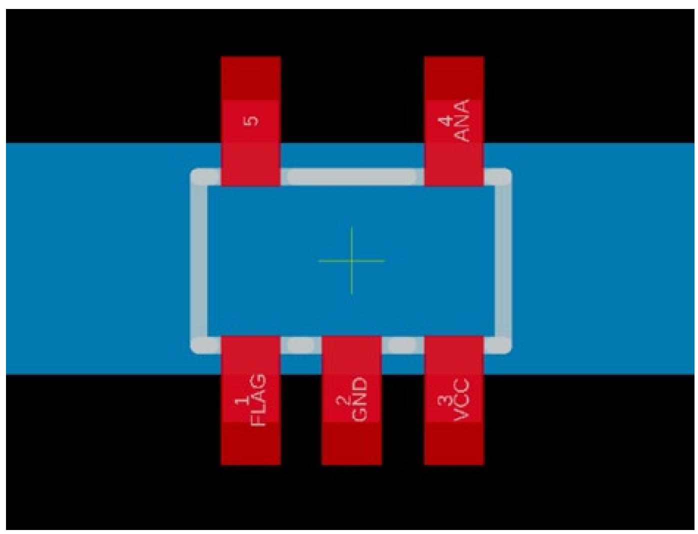

Figure 13. Current Flowing on the bottom layer.

10 mA steps can be resolved despite distance between the PCB trace and TMR sensor.

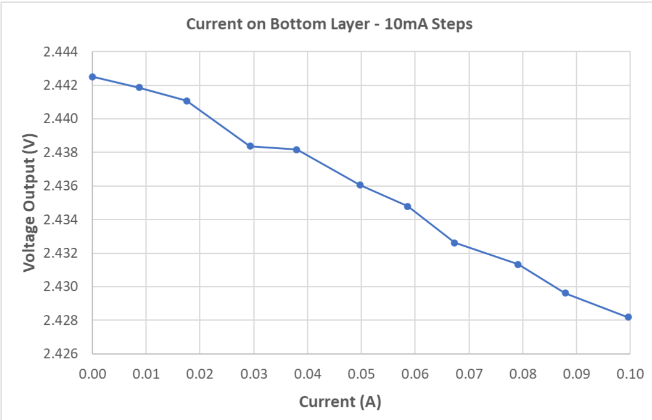

Figure 14. Resolution achieved using bottom copper layer.

Copper Busbar

The current flows in a current carrying copper busbar 4.0 mm on top of the CT220.

Coupling coefficient: 0.25 G/A
DC current measurement range: ±50 A

High isolation. No breakdown observed for 5.1 kV_{RMS} isolation.

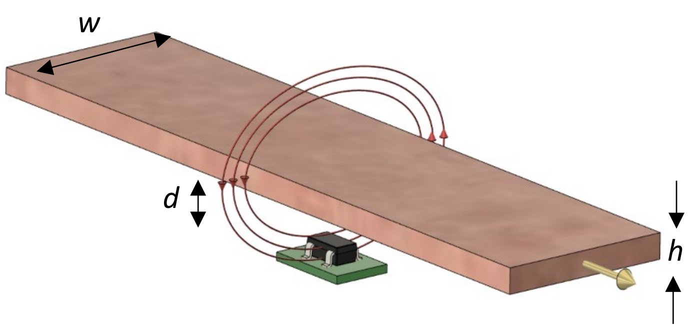

Figure 15. Current Flowing on the busbar where d = 4.0 mm, w = 12.7 mm and h = 1.59 mm.

Figure 16 below shows the full range ±50 A.

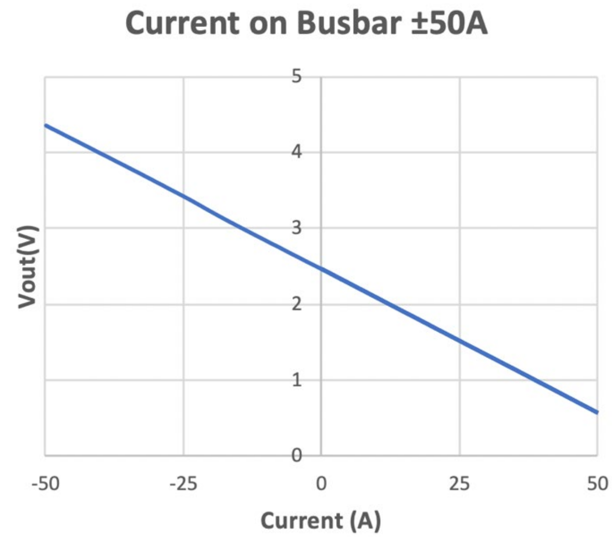

Figure 16. Resolution achieved using busbar.

The figure below shows CT220 is able to resolve 50 mA steps which is means CT220 has a dynamic range of 1000:1.

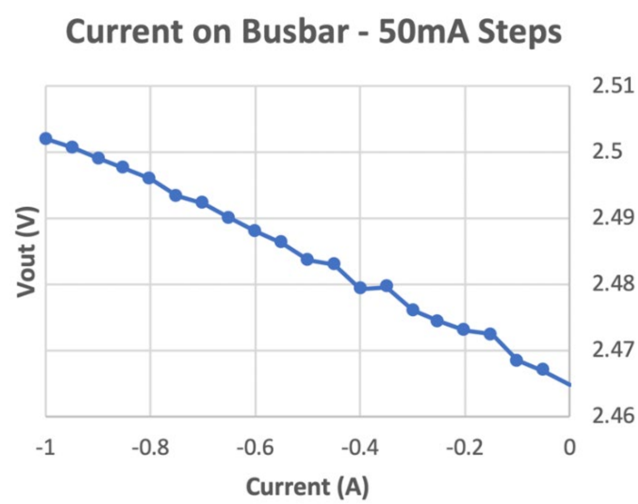

Figure 17. Resolution achieved using busbar.

Common Mode Rejection & Crosstalk

CT220 measures the magnetic field generated by the current as it travels a current carrying conductor (PCB trace or Busbar). The sensor is then susceptible to measure stray magnetic fields either generated by other components on the vicinity of the sensor, or by other adjacent current carrying conductors.

Common Mode Rejection refers to the ability of the sensor to minimize or completely eliminate the effects of external magnetic fields.

Crosstalk refers to the magnetic field generated by adjacent current carrying conductors, for example, is a 3-phase system.

The graph below shows two curves, the first (grey) is sweep of ±10 A on the CTD221 evaluation board without an external magnetic field. The second (orange) is also a sweep of ±10 A however under a 0.5 mT external stray magnetic field.

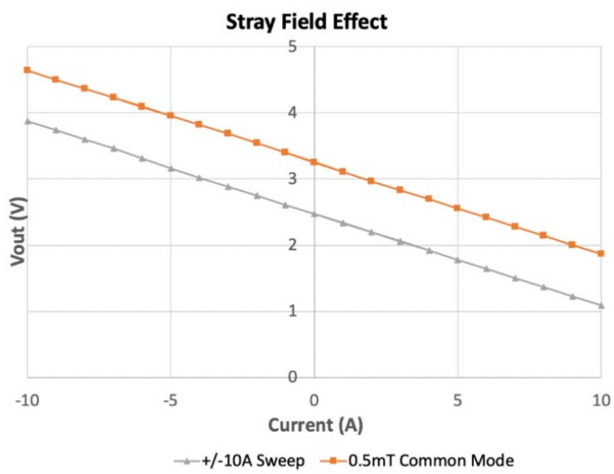

Figure 18. Offset generated by External Stray Field.

When an external magnetic field is applied, an offset shift is observed. To eliminate this susceptibility to external magnetic fields, a U-shape shield is used.

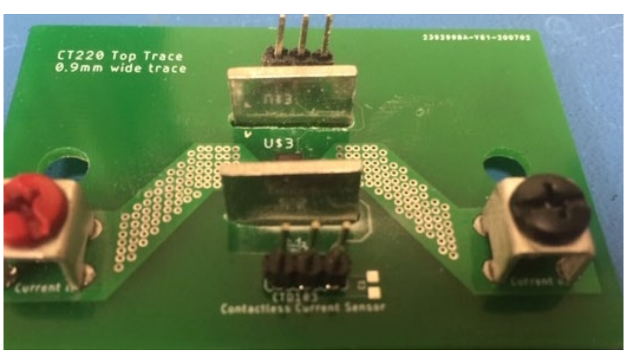

Figure 19. U-shield on CTD221 evaluation board.

	Offset (V)	Gain (V/A)	Non-Linearity (%FS)	Hysteresis (% FS)
Bottom Trace	2.48	-0.14	0.41	0.038
With 0.5mT CM Field	3.25	-0.14	0.47	0.02
With Shield	2.50	-0.24	0.69	0.85

Figure 20. Summary of results

The graph below compares the performance of CTD221 under an external stray field when using a shield (blue curve).

When compared to the previous graph, the shield eliminates the effect of the external stray field while increasing the sensitivity of the sensor because it also acts as a concentrator.

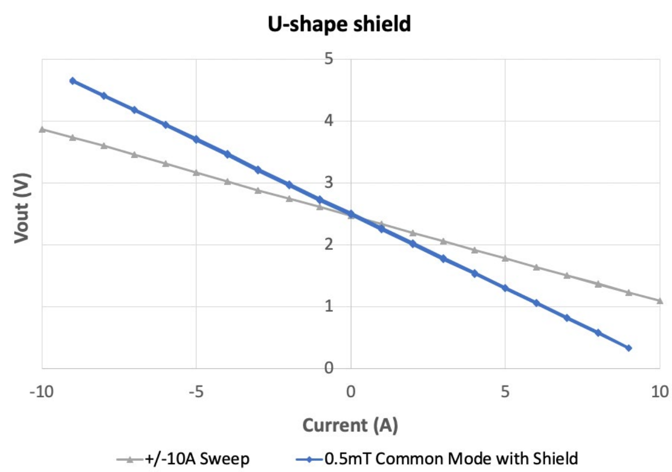

Figure 21. U-shield performance against external magnetic fields

Please refer to AN122 for additional discussion about using CT220 in magnetically noisy environments.

Conclusion

The CT220 is a linear ratiometric TMR sensor from Crocus Technology that is an ideal current sensor for contactless, isolated current sensing applications.