# CT220 REFERENCE DESIGN FOR CONTACTLESS CURRENT SENSING

By Allegro MicroSystems

## ABSTRACT

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

## REFERENCED DEVICES

- CT220
- CTD221

## INTRODUCTION

The CT220 is a tunnel magnetoresistive (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.

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

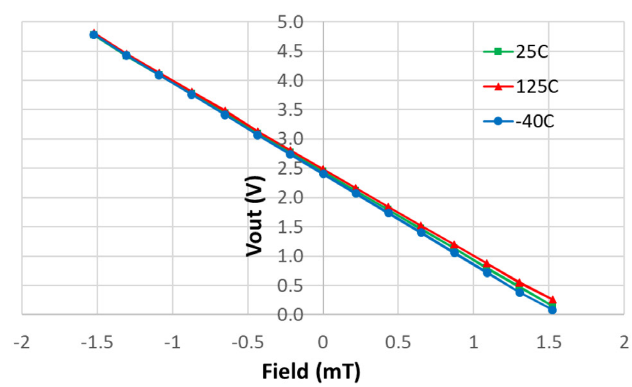


*Figure 1: Voltage Output vs. Magnetic Field Under Different Temperature Levels*

# REFERENCE DESIGN

## Overview

To be used as a current sensor, 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 a current-carrying conductor (CCC). Typically, the CCC is either a busbar as shown in Figure 2, a PCB trace as shown in Figure 3, or a cable.

The CT220 can measure bidirectional current, and the quiescent voltage is equal to $V_{DD}/2$.

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

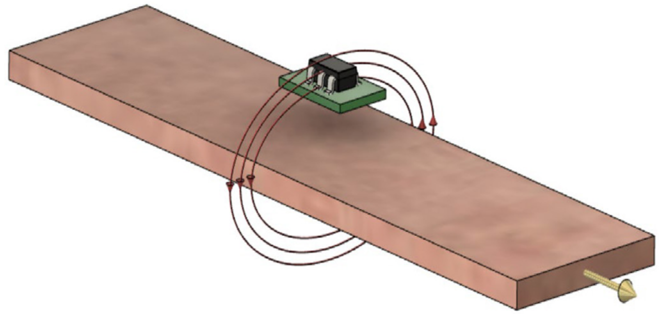

*Figure 2: CT220 on a PCB (Green), Current-Carrying Busbar (Copper)*

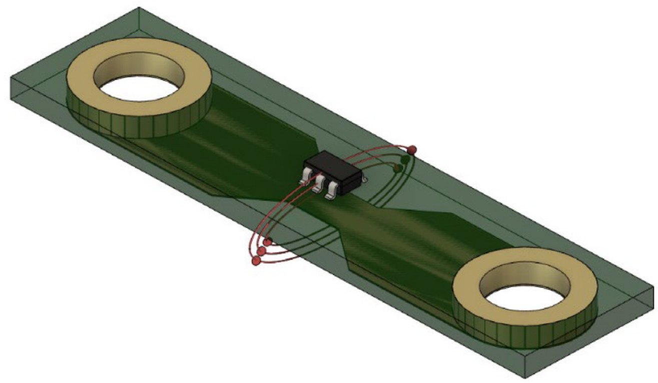

*Figure 3: CT220 Measuring Current of a Bottom-PCB-Trace, Current-Carrying Conductor.*

## Magnetic Field Estimation

To estimate the magnetic flux generated by the current flowing on a conductor without using a shield (see Figure 4):

Equation 1:

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

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.

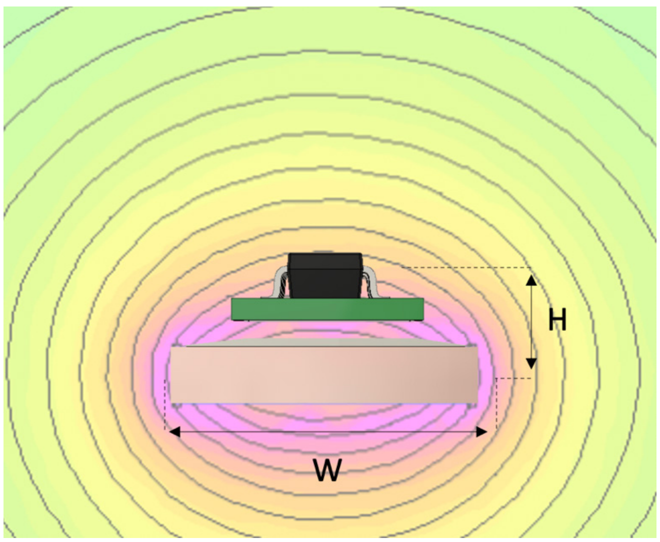


*Figure 4: Magnetic Field Lines Without a Shield*

To estimate the magnetic flux generated by the current flowing on a conductor using a shield (see Figure 5):

Equation 2:

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

Notice that, when a shield is used, the only important parameters are the inner width of the shield, W, and the current, I. To generate a homogenous field across the CT220, the height, H, must be at least W/2.

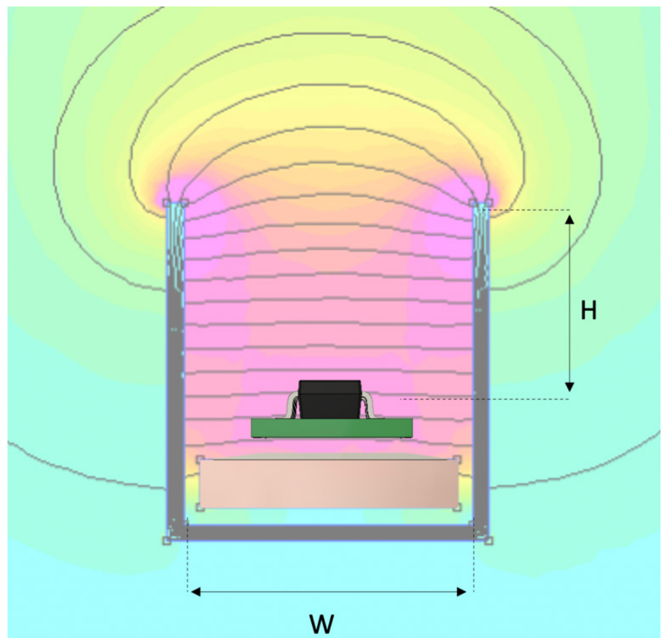


*Figure 5: Magnetic Field Lines With a Shield*

## Block Diagram

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

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

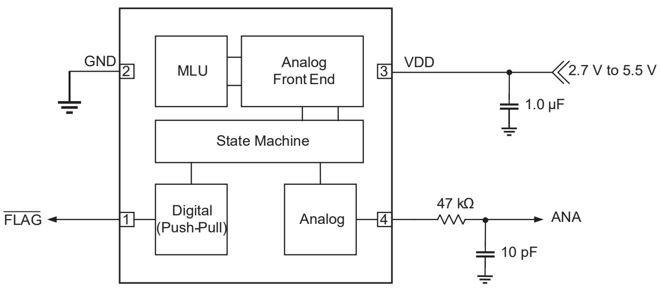


*Figure 6: Complete Schematics for CT220*

# CT220 VARIANTS

CT220 is offered in five 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.

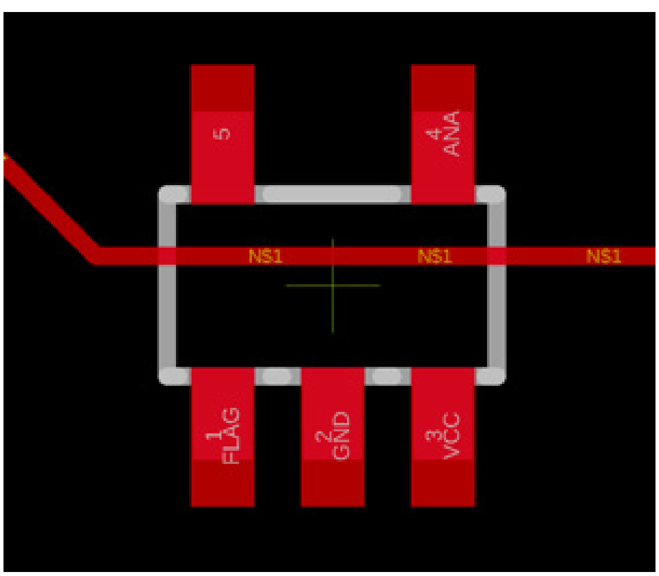


*Figure 7: Poor PCB Layout for CT220*

## Eddy Currents

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

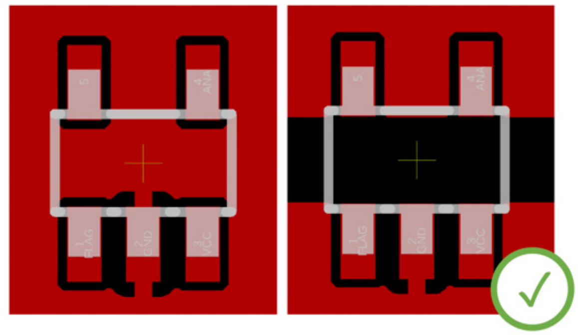

*Figure 8: Recommended PCB Layout for CT220*

## Capacitive Coupling

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

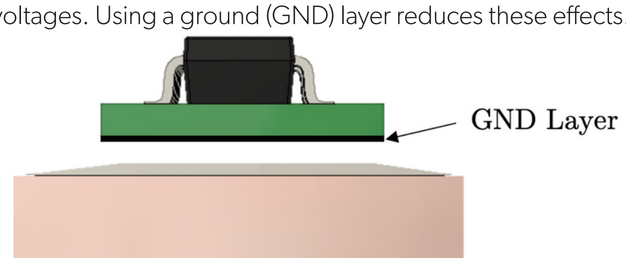


*Figure 9: Illustration of PCB with GND Layer to Lessen Parasitic Capacitive Coupling*

# REFERENCE DESIGNS

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

- The measured current flows on the top layer.
- The measured current flows on the bottom layer.

As a reference, a cross section of a standard two-layer PCB is shown in Figure 10. 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 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.
- Excellent resolution observed: 10 mA steps resolved very easily, but output becomes nonmonotonous at 2 mA steps.

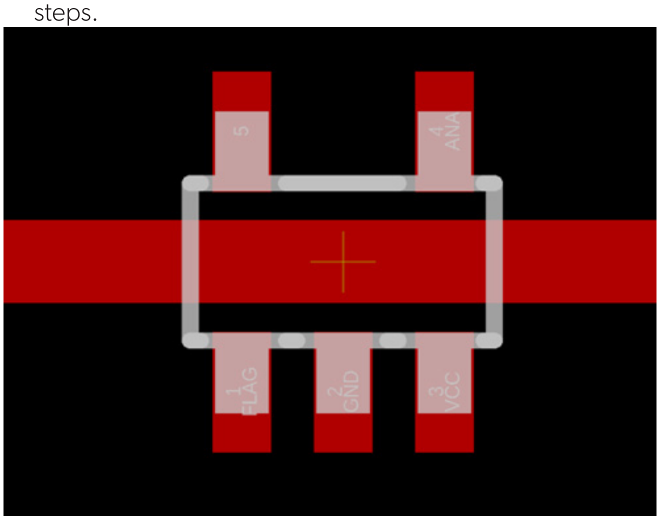


*Figure 11: Current Flowing on Top Layer*

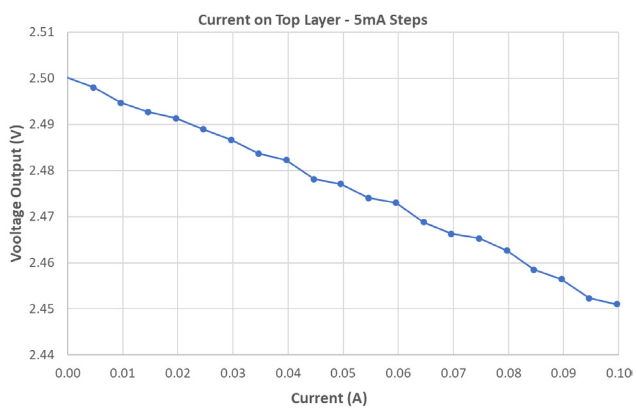


*Figure 12: Resolution Achieved Using Top Copper Layer*

## Current on Bottom Layer

- The current trace on the bottom PCB copper layer is 2 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.
- 10 mA steps can be resolved despite distance between trace and TMR sensor.

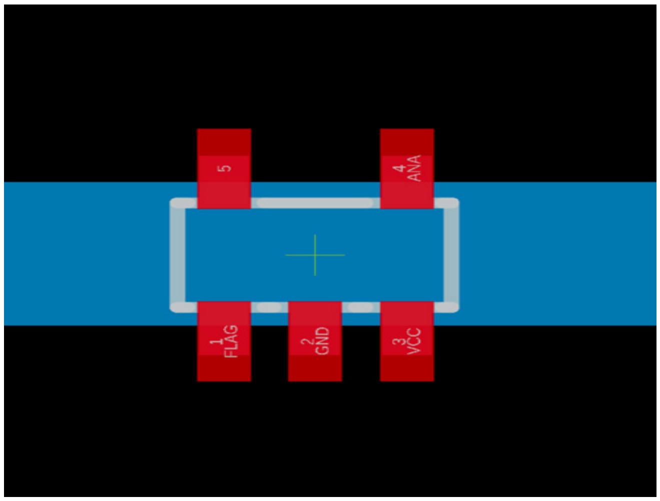


*Figure 13: Current Flowing on the Bottom Layer*

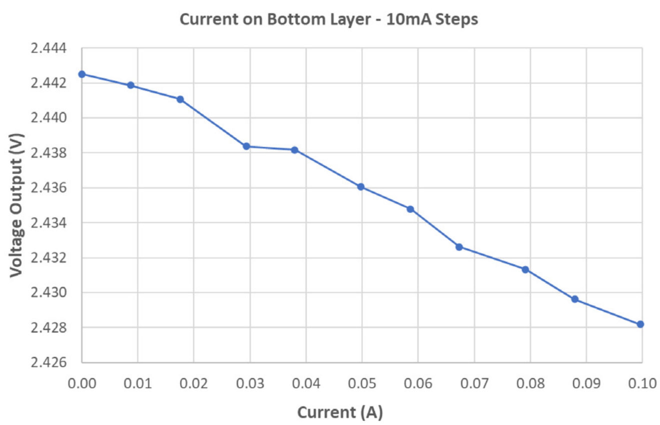


*Figure 14: Resolution Achieved Using Bottom Copper Layer*

## Copper Busbar

- The current flows in a current-carrying copper busbar 4 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.

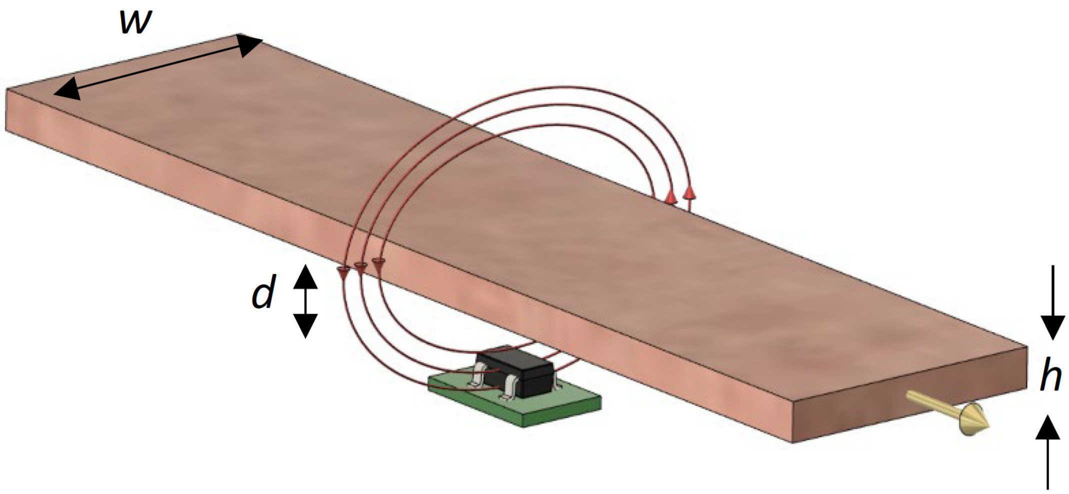


*Figure 15: Current Flowing on the Busbar (d = 4.0 mm, w = 12.7 mm, and h = 1.59 mm)*

Full ±50 A range is shown in Figure 16. The CT220 is able to resolve 50 mA steps, as shown in Figure 17, which means CT220 has a dynamic range of 1:1000

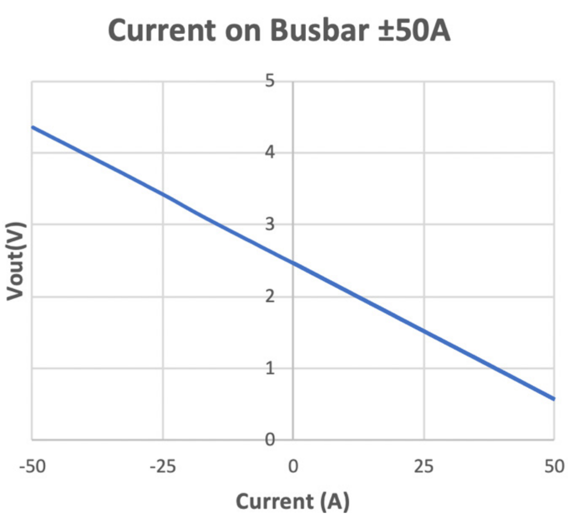


*Figure 16: Resolution Achieved Using Busbar*

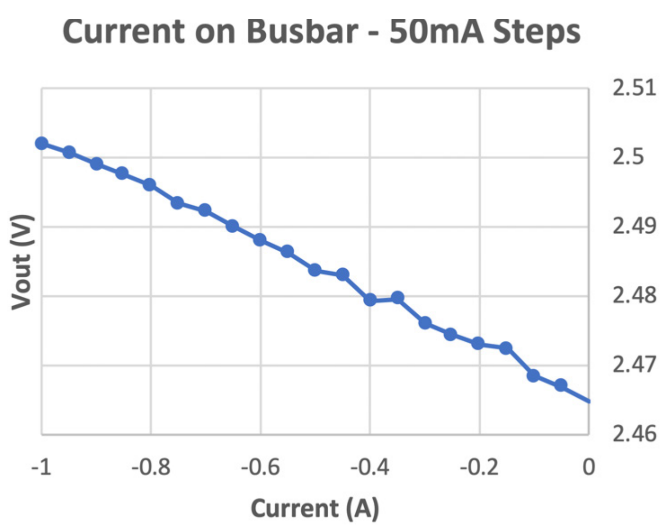


*Figure 17: Resolution Achieved Using Busbar*

## COMMON-MODE REJECTION AND 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, in a three-phase system.

The offset generated by an external stray field is shown in Figure 18: The gray curve represents a sweep of ±0 A on the CTD221 evaluation board without an external magnetic field; and the orange curve represents a sweep of ±0 A under a 0.5 mT external stray magnetic field. When an external magnetic field is applied, an offset shift is observed.

To eliminate this susceptibility to external magnetic fields, a U-shaped shield is used, as shown in Figure 19.

Performance of the CTD221 under an external stray field is shown in Figure 20 when not using a shield (gray curve) and when using a shield (blue curve). Compared to Figure 18, the shield eliminates the effect of the external stray field while increasing the sensitivity of the sensor because it also acts as a concentrator.

For additional discussion about using the CT220 in magnetically noisy environments, refer to Allegro application note AN122.

*Table 1: Summary of Results*

| | Offset (V) | Gain (V/A) | Nonlinearity (%FS) | Hysteresis (%FS) |
|---|---|---|---|---|
| Bottom Trace | 2.48 | –0.14 | 0.14 | 0.038 |
| With 0.5 mT CM Field | 3.25 | –0.14 | 0.47 | 0.02 |
| With Shield | 2.5 | –0.24 | 0.69 | 0.85 |

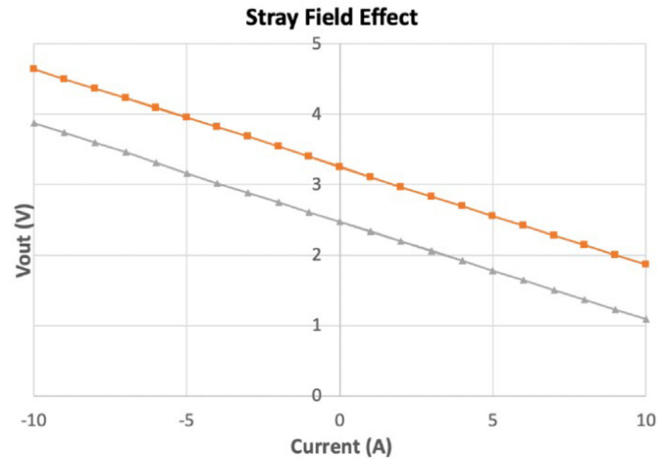


*Figure 18: Offset Generated by External Stray Field*

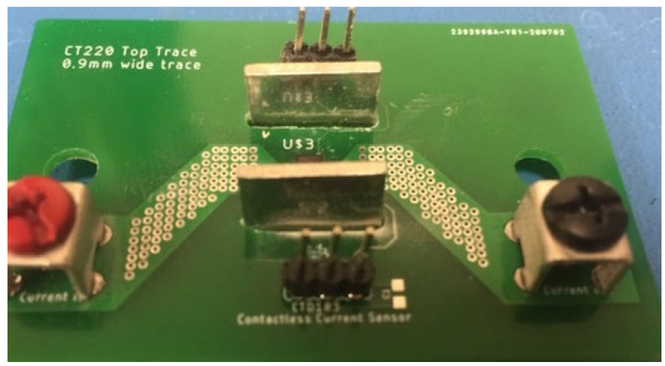


*Figure 19: U-Shield on CTD221 Evaluation Board*

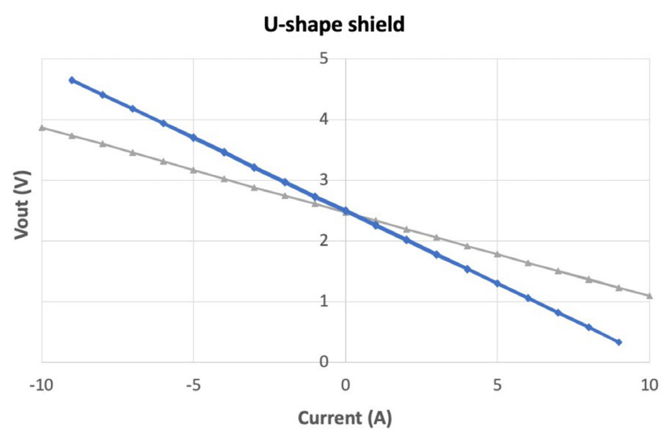


*Figure 20: U-Shield Performance Against External Magnetic Fields.*

## CONCLUSION

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

*Revision History*

| Number | Date | Description | Responsibility |
|---|---|---|---|
| 1 | November 15, 2023 | Document rebrand and minor editorial corrections | J. Henry |