CT110: REPLACEMENT FOR SHUNT RESISTOR-PLUS-ISOLATED AMPLIFIER SYSTEM

By Allegro MicroSystems

ABSTRACT

This application note reviews the challenges of implementing a shunt resistor-based system for current sensing. Then, it introduces the CT110, which bypasses the limitations and typical compromises designers make when using shunts.

REFERENCED DEVICES

- Allegro CT110
- Allegro EVB111

INTRODUCTION

Current sensing is a fundamental building block of many circuit designs in various applications. Measuring the level of current flowing through a circuit can be critical to:

- Maximize the performance and efficiency
- Protect and extend the operating lifetime
- Continuous monitoring and diagnosis

Hence, many applications benefit from accurate and precise current sensing:

- Motor control
- Battery management
- Inverters
- Switch mode power supplies
- Ground fault detectors

Designers can choose from many current-sensing technologies and even more implementation topologies to satisfy their requirements.

- Shunt resistors
- Magnetic sensors [1]
- Current transformers

Shunt resistors are typically the go-to solution because they are the most intuitive (Ohm's law $I = V/R$) and potentially the easiest to set up on a test bench. However, designers are then quickly faced with a balancing act to select the correct combination of resistor, operational amplifier, and implementation topology.

Designing an accurate and cost-effective shunt-based current-sensing solution requires a substantial engineering effort compared to the Allegro CT110.

[1] Magnetic current sensors based on Hall-effect technology are out-of-scope in this shunt-focused application note. Hall sensors are known for limitations in terms of temperature performance and cost and, hence, are not considered to be competitive solutions to shunt-based systems.

CT110 OVERVIEW

The Allegro CT110 is a tunnel-magnetoresistance (TMR) based current sensor that bypasses the usual challenges faced by designers when using shunt resistors. The CT110 is a ratiometric, linear, bidirectional, isolated current sensor with an overcurrent flag output. The sensor uses a small 3 mm × 3 mm package with an integrated current-carrying conductor (CCC) capable of carrying 15 A_{PK}. A custom material is used between the CCC and the die for enhanced galvanic isolation. When current flows in the CCC, a local magnetic field is generated on the sensor. For a detailed explanation of the CT110, refer to Allegro application note AN124.

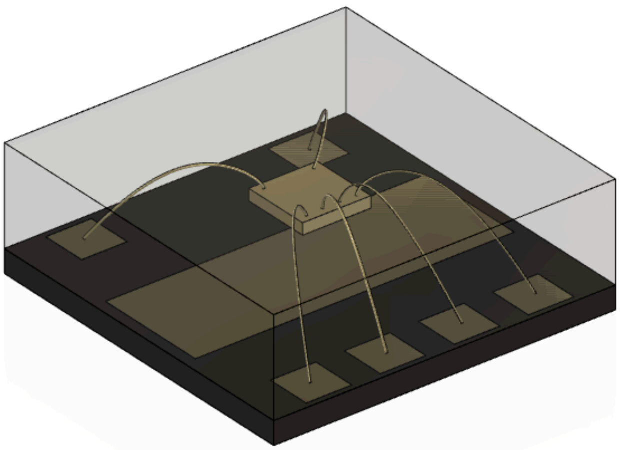

Figure 1: Three-Dimensional Representation of CT110

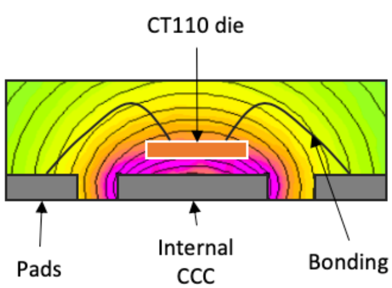

Figure 2: Representation of Magnetic Field Inside the CT110 Package

SHUNT-PLUS-AMPLIFIER SYSTEM OVERVIEW

Concept

Shunt current sensing is based on Ohm's law:

$$I = V/R$$

By placing a resistor with a known value, R, in the current path, measuring the voltage, V, gives a linear representation of the current, I.

The Shunt Resistor-Plus-Amplifier Solution

There are three main aspects to consider when designing a shunt-based current sensing solution. Each parameter highlighted in Figure 3 must be considered and balanced against the other parameters while keeping the total solution cost within budget. Typical examples of the selection challenges for shunt systems are discussed in the sections that follow.

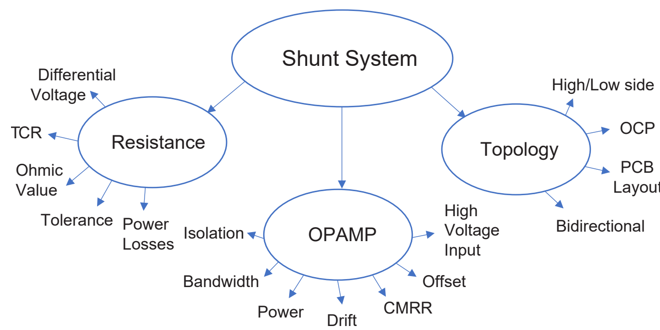

Figure 3: Shunt-Based Solution Parameters

Resistor Value

A resistor with a high ohmic value develops a higher differential voltage, which helps with the overall accuracy of a current-sensing scheme. However, a higher ohmic value dissipates more energy in the form of heat ($P = I^2R$); therefore, depending on the implementation (i.e., low-side), a higher value can generate higher levels of ground disturbance.

The CT110 completely bypasses these issues and compromises because it measures the magnetic field generated by the flowing current instead of the voltage across the CCC: Instead of Ohm's Law, the CT110 uses Ampere's Law.

Resistor Tolerance

All resistor datasheets mention two important parameters for current-sensing applications—resistor tolerance and temperature coefficient of resistance. The resistor tolerance defines, in percentage terms, the maximum and minimum spread of the ohmic value from an ideal value. A smaller-tolerance number usually equates to more-expensive shunt resistors.

The CT110 CCC has a known resistance value and tolerance; however, this ohmic value does not impact the generated magnetic field. Moreover, CT110 is factory-trimmed to adjust gain and offset.

Resistor Temperature Coefficient

The temperature coefficient of resistance (TCR) defines the change of the resistor ohmic value with regard to temperature; it is typically defined in terms of ppm/°C. The TCR of the shunt resistor is a critical parameter, especially in high-current applications, where heat dissipation adds to the ambient temperature to make it difficult to determine the temperature of the internal shunt resistor. This leads to low-accuracy systems, unless expensive shunt resistors are used.

The CT110 datasheet mentions how parameters such as gain and offset change over temperature. Instead of selecting a low-TCR shunt resistor and low-drift operational amplifier, CT110 is an all-in-one solution.

The operational amplifier (opamp) that measures and amplifies the shunt differential voltage is as important as the shunt resistor. Using an expensive shunt coupled with a low-performance operational amplifier does not yield a high-accuracy current-sensing system.

CMRR, Offset and Drift

Using an ohmic-value shunt resistor generates low voltages. This places the burden of amplifying this small voltage to a workable voltage (for example, as observed by the ADC) on the operational amplifier.

The smaller the voltage, the higher the common-mode rejection ratio (CMRR) required. The offset of the amplifier also needs to be considered. More importantly, the temperature drift of the operational amplifier parameters need to be taken into account.

The CT110 die includes the analog front-end blocks that are designed by Allegro to interface with the TMR sensor.

Voltage Input and Isolation

In some high-voltage applications, another burden is placed on the designer to correctly select an operational amplifier that can both handle the typical operating voltage and survive any voltage surge events. Typically, operational amplifiers have reduced CMRR with higher voltages. In some cases, an isolated amplifier is required. These amplifiers are costly and typically feature limitations in terms of their lifetime performance.

The CT110 is galvanically isolated up to 2 kV per the IEC 60950-1:2005 specification and UL 2577 standard.

High-Side vs. Low-Side Current Sensing

The position of the shunt resistor relative to the load is of utmost importance. At a high level, the high-side topology places the shunt before the load, while low-side places the shunt after the load, between the load and ground. The benefits and drawbacks of each topology are greatly detailed and are not in the scope of this application note; however, typically, high-side sensing is considered to provide a more-accurate representation of the current being used downstream by the load and to be better able to detect shorts to ground. The biggest advantage of low-side sensing is the lower cost. High-side and low-side shunt resistor-plus-amplifier systems are illustrated in Figure 4 and Figure 5, respectively.

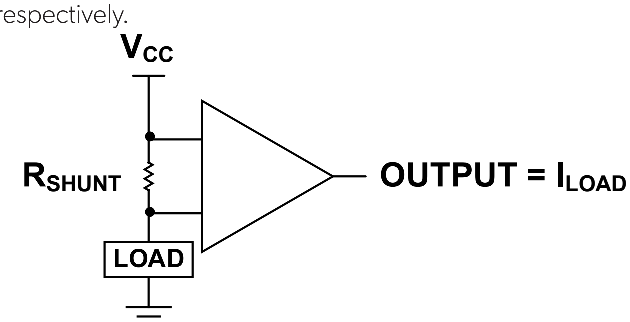

Figure 4: Simple Schematic of High-Side Shunt Resistor Plus Amplifier System

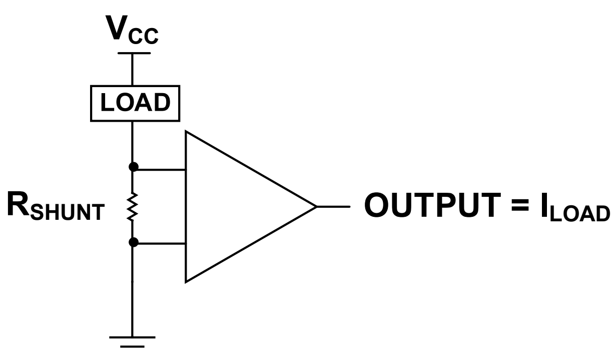

Figure 5: Simple Schematic of Low-Side Shunt Resistor Plus Amplifier System

The CT110 can be placed in any topology without the usual drawbacks of shunt-based systems. Because the CT110 is isolated, it can be placed on the high-side without CMRR and voltage input considerations. Also, because the CCC of the CT110 has a very low resistance, it can be placed on the low-side with virtually no ground disturbance. Differences between high-side and low-side implementations of current sensing are outlined in Table 1.

Table 1: High-Side vs. Low-side Current Sensing Implementation

Parameter	High-side	Low-side
Implementation	Different Input	Single or Differential Input
Ground Disturbance	No	Yes
Common Voltage	Close to Supply	Close to Ground
CMRR Requirements	Higher	Lower
Detects Short Circuit	Yes	No
Accuracy	Higher	Lower
Cost	Higher	Lower

Overcurrent Detection

A basic design of an overcurrent detection (OCD) circuit requires a comparator and a voltage reference in addition to the shunt resistor and operational amplifier.

The CT110 includes the necessary circuitry to provide the user with an active LOW digital FLAG output. Thus, it removes the need for additional external operational amplifiers and voltage reference to achieve OCD.

Common-Mode Rejection and Crosstalk

The CT110 measures the magnetic field generated by the internal busbar of its package. The sensor is then susceptible to adjacent magnetic fields.

An external magnetic field of 0.5 mT generates an offset on the CT110 output voltage as shown in Figure 6. This offset amplitude is related to the amplitude of the external magnetic field.

To eliminate the effects of this external magnetic field, a U-shaped shield is used around the CT110 sensor, as shown in Figure 7.

The performance of the EVB111 evaluation board with a U-shaped shield under 0.5 mT external magnetic field is shown in Figure 8, comparing it to a reference ±10 A sweep.

For additional discussion about using Allegro TMR sensors in magnetically noisy environments, refer to AN122.

CONCLUSION

Compared to shunt-based current-sensing solutions, the CT110 is an all-in-one current sensor that bypasses the usual challenges faced by designers when using shunt resistors.

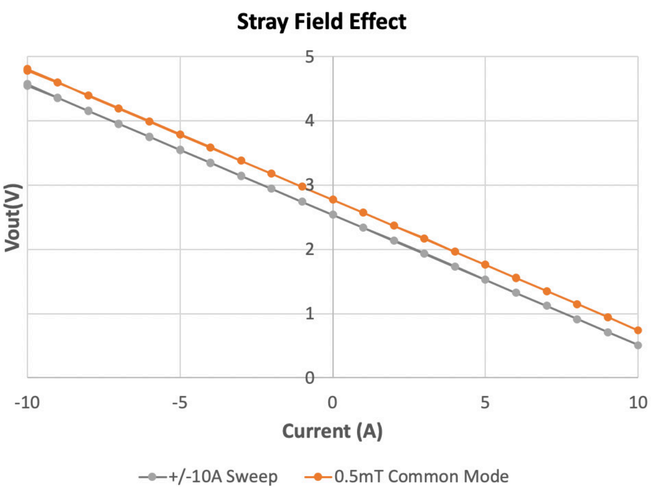

Figure 6: Effects of External Magnetic Field

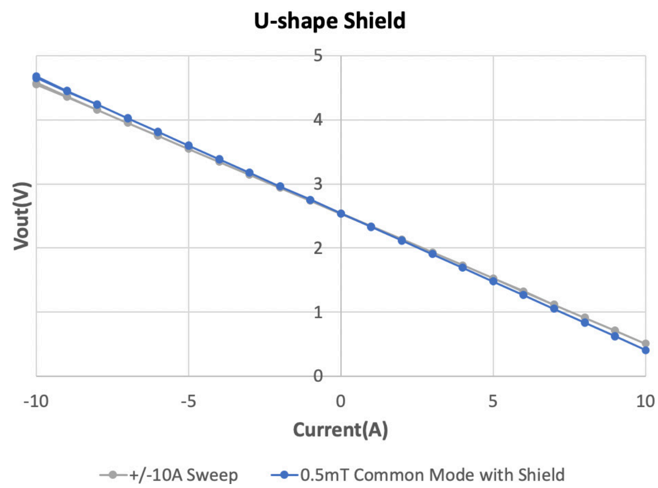

Figure 8: U-shaped Shield Performance Against External Magnetic Fields

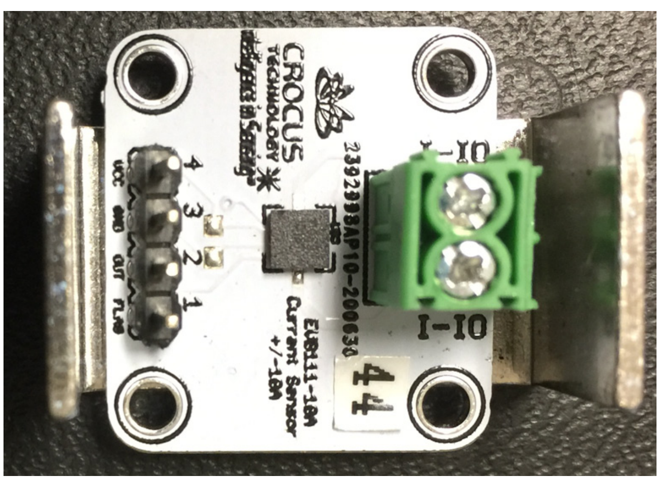
Figure 7: EVB111 with U-Shaped Shield

Revision History

Number	Date	Description	Responsibility
1	November 14, 2023	Document rebrand and minor editorial corrections	J. Henry