CROCUS TECHNOLOGY
Intelligence in Sensing™

CT110: Replacement for Shunt Resistor + Isolated Amplifier System

Referenced Devices

CT110
EVB111

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.

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 he 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 as they are the most intuitive (Ohm's law I = V/R) and potentially the easiest to setup 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 CT110.

CT110 Overview

The CT110 is a TMR-based current sensor that bypasses the usual challenges faced by designers when using shunt resistors.

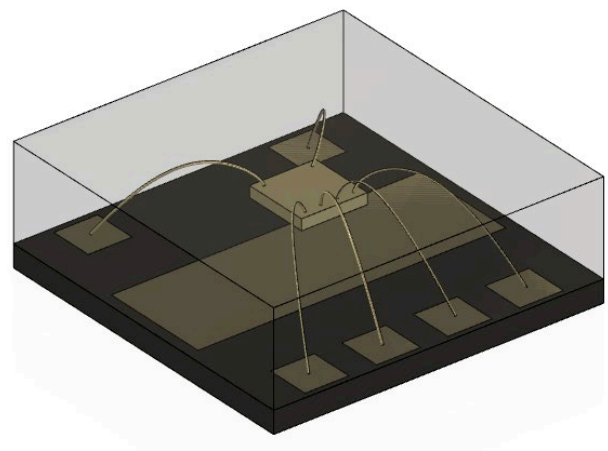

Figure 1. 3D representation of CT110.

The CT110 is a ratio-metric, linear, bidirectional, isolated current sensor with an over-current flag output.

The sensor uses a small 3 × 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 die for enhanced galvanic

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

isolation. When current flows in the CCC, a local magnetic field is generated on the sensor.

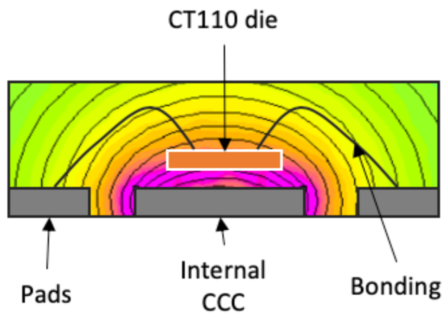

Figure 2. Representation of the magnetic field inside the CT110 package.

Please refer to AN124 for a detailed explanation of the CT110.

Shunt + Amplifier System Overview

1. 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.

2. The Shunt Resistor + Amplifier Solution

There are three main aspects to consider when designing a shunt-based current sensing solution:

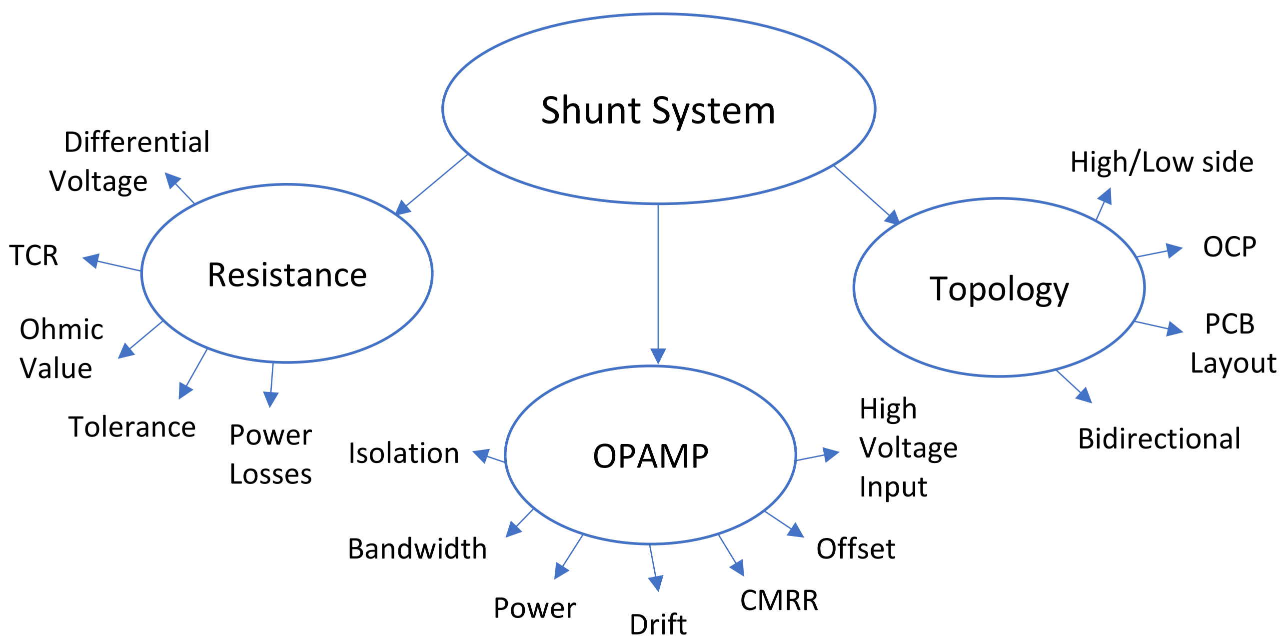

Figure 3. Shunt-based solution parameters.

Each one of the parameters highlighted in Figure 3 needs to be considered and balanced against the other parameters while keeping the total solution cost within budget.

The following section outline typical examples of the selection challenges for shunt systems.

Resistor Value

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

The CT110 completely bypasses the issues and compromises described above because it measures the magnetic field generated by the flowing current instead of the voltage across the CCC. The CT110 does use Ohm's Law but rather 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 which defines, in percentage terms, the maximum and minimum spread of the ohmic value from an ideal value. The smaller the tolerance number usually equate to more expensive shunt resistors.

The CT110's 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 regards to temperature. Typically defined in terms of ppm/°C. The shunt resistor's TCR is a critical parameter especially in high current applications where, due to heat dissipation added to the ambient temperature, the internal shunt resistor's temperature is difficult to determine, which then 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 opamp will not yield a high accuracy current sensing system.

CMRR, Offset and Drift

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

The smaller the voltage, the higher CMRR (Common-Mode Rejection Ratio) is required. The Offset of the amplifier also needs to be considered. More importantly, the temperature drift of the operational amplifiers' parameters need to be taken into account.

The CT110's die includes the analog front-end blocks that are designed by Crocus Technology 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 handle the normal operating voltage, but also, survive any voltage surge events. Typically, opamps will 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 important. 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 drawback of each topology are greatly detailed and are not in the scope of the application note, however, typically, high-side is considered to provide a more accurate representation of the current being used downstream by the load and being able to detect shorts to ground. While low-side biggest advantage is the lower cost. Figures 4 and 5 illustrate high and low-side shunt resistor plus amplifier systems, respectively.

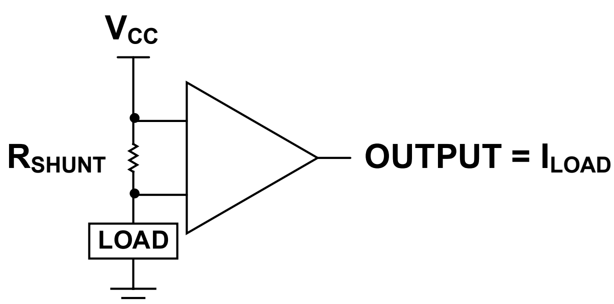

Figure 4. Simple schematic diagram of high-side shunt resistor plus amplifier system.

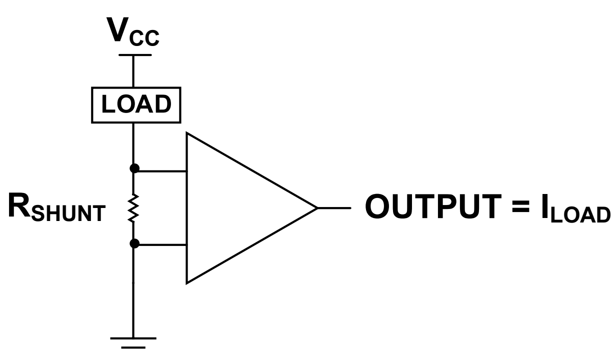

Figure 5. Simple schematic diagram of low-side shunt resistor plus amplifier system.

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

Table 1. Summary of 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

Over-Current Detection

A basic design of an Over-Current 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 opamps and voltage reference to achieve OCD.

Common Mode Rejection & Crosstalk

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

The figure below shows how an external magnetic field of 0.5mT generates an offset on the CT110 output voltage. This offset amplitude is related to the amplitude of the external magnetic field.

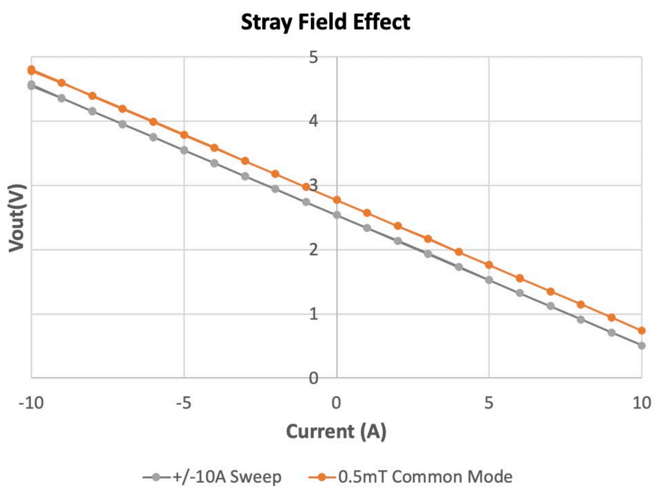

Figure 6. Effects of external magnetic field.

To eliminate the effects of this external magnetic field, a U-shape shield is used around the CT110 sensor.

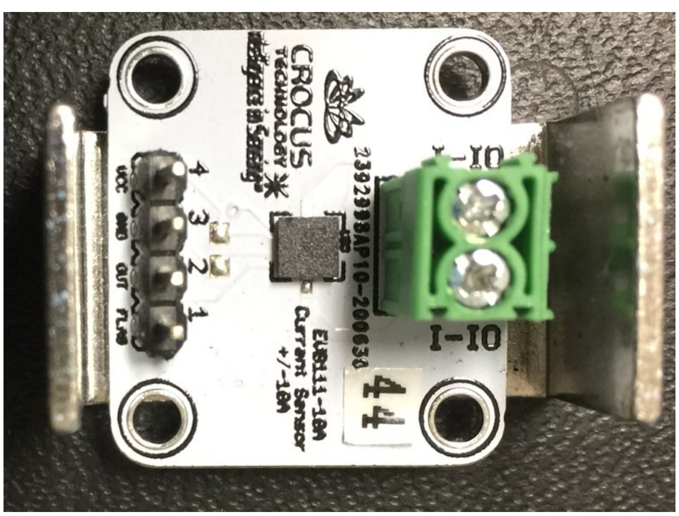

Figure 7. EVB111 with a U-shape shield.

The figure below shows the performance of the EVB111 evaluation board with a U-shape shield under 0.5 mT external magnetic field. Comparing it to a reference ±10 A sweep.

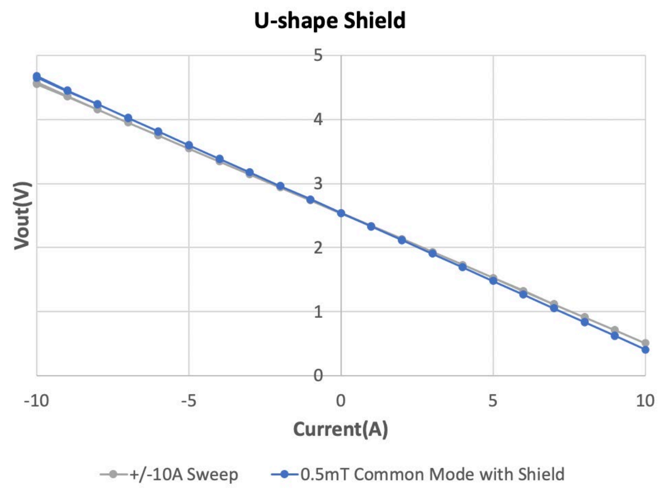

Figure 8. U-shape shield performance against external magnetic fields.

Please refer to AN122 for additional discussion about using Crocus Technology's sensors in magnetically noisy environments.

Conclusion

Compares 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.