Low Temperature Drift Integrated Shunt vs Active Temperature Compensation of Shunt

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Current sensing applications typically use a shunt as a sensing element. A shunt is a resistive material that is designed such that the maximum current flow is diverted across the shunt in the system. The current flowing through the shunt develops a differential voltage across its terminals which is then measured using a current sense amplifier. The selection of the shunt depends on the maximum current rating and the permissible power dissipation across the shunt in the system. To minimize power dissipation across the shunt often a low ohmic value shunt is preferred. For smaller currents, the differential voltage developed across the low ohmic shunt can be relatively small, a current sense amplifier with a high gain can amplify the signal across the shunt which can then be connected to ADC for further processing. As a lower shunt value is preferred in an application for lower power dissipation, at lower currents the signal generated across the shunt can be comparable to the noise in the system, a current sense amplifier with high gain, low offset and lower noise is required to measure the full dynamic range across the shunt. Often the offset error, bias currents and input referred noise of the current sense amplifier limits the least current that can be measured across a low ohmic shunt.

The INA240 is a current sensing product from Texas Instruments that has the lowest offset voltage of 25 µV with a offset drift of 0.25 µV/°C. Advancements in current sense amplifier specifications has lead to highest absolute accuracy with stable measurement across full temperature range with an max drift accuracy of 2.5 ppm/°C. However, to realize accurate stable measurements across the shunt the limitation is still in the maximum temperature error drift of the shunt. In a current sensing system the total error of a solution is the sum of squares of root (RSS) of error sources of shunt and the current sense amplifier. In a system with a discrete shunt and INA240, the overall system error is limited by the precision and the type of the shunt. One methodology to minimize errors due to the shunt placement and layout is to implement a 4-wire kelvin connection to the amplifier. However, best layout and 4-wire kelvin connection can only address the accuracy at 25 °C, the temperature drift of the shunt is unaccounted for. In order to address the temperature drift measurements a full temperature calibration is performed in the system and look up values are stored in the micro controller. An active temperature compensation can be performed using a temperature sensor, the shunt variation due to temperature drift can now be accounted for. However, the extent of temperature calibration is limited due to placement of temperature, time to reach steady state, temperature gradient across the shunt etc, this is unpredictable often impracticable to be implemented in large scale production.

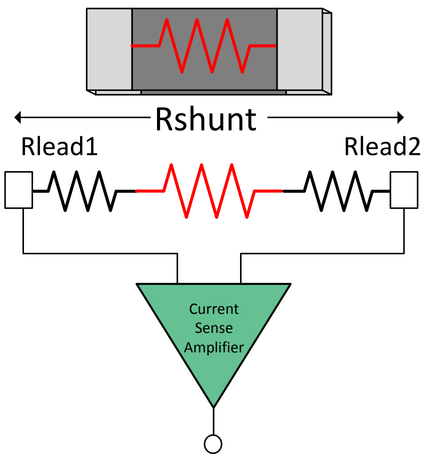

Figure 1. Shunt electrical resistance representation

Figure 1 describes a common breakdown of the shunt resistance. For low ohmic shunts, the lead resistance can be unpredictable and often varies forcing the system to perform on board calibration. If the shunt leads are material based of copper then the accuracy of the shunt will worsen as copper has a temperature drift of 3900 ppm/°C. For applications that require precision measurement across temperature the solution to get higher accuracy is to use 4-wire kelvin connected shunts. Kelvin connected shunt ensures that even if the leads are constructed using copper the kelvin leads are connected across the shunt ensuring the current measurement is measured directly across the shunt and not influenced by changes in the lead resistance and immune to any application errors sources like placement and trace layout. Figure 2 describes an electrical representation of a 4-wire kelvin shunt.

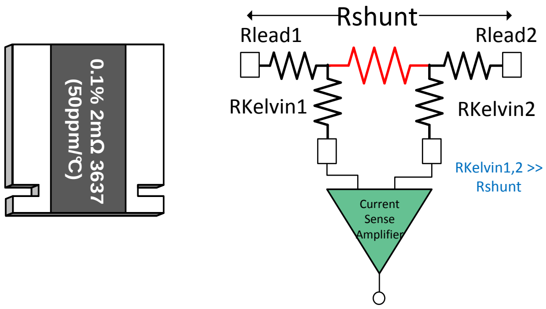

Figure 2. 4-wire Kelvin Shunt electrical resistance representation

One of the drawbacks of using low drift shunt material as a shunt is the cost associated with the manufacturing of the shunt and also its integration with the package leadframe. There has been other techniques in the industry to integrate copper leadframe as a shunt material due to its cost advantage. However, copper shunt metal has a temperature drift of 3900 ppm/°C that needs to be compensated. The compensation techniques has only been successful in achieving sub 100 ppm/°C of error correction. The solutions that can achieve <50 ppm/°C error correction tends to be performed in digital domain using an ADC. The absolute shunt error of copper at ambient temperature of 25°C can always be corrected using factory trim. The challenge lies in the temperature drift compensation. The error correction however is dependent on the accuracy of the temperature sensor and also its placement of the sensor inside the package. As the current flows through the copper shunt, the self heating of the shunt creates a temperature gradient within the shunt, this temperature gradient can be off by 5°C to 10°C. If the placement of the temperature sensor is offset by 10°C the drift error specification can see a change in 2% - 4%.

The challenge still lies ahead to use copper as a shunt material to achieve the drift specification accuracy levels of low drift metal shunt. The error correction technique requires temperature sensor, current sensor feedback loop to be operated in servo. This often adds complexity to the design if a current sense amplifier with analog output is desired. To address this feedback loop complexity the temperature sensor and current sense amplifier are error corrected in digital domain using ADCs and microcontroller. This techniques address the complexity but however adds latency and the application is restricted to current measurements with digital output domain. for fast feedback control applications like EPS systems, 3-Ph motor control systems and power supply loop control a digital output current sense amplifier can add too much latency for the system to perform any type compensation often compromising on the speed and control of the system.

Figure 3 illustrates a graphical representation of error of a shunt using calibrated copper metal and compared with using low drift metal alloy. The low drift metal alloy virtually has constant electrical resistance across temperature eliminating the need for drift correction for integrated shunts. Temperature compensation elimination saves valuable manufacturing costs and enables accurate precision solutions to be available in the market at a lower cost.

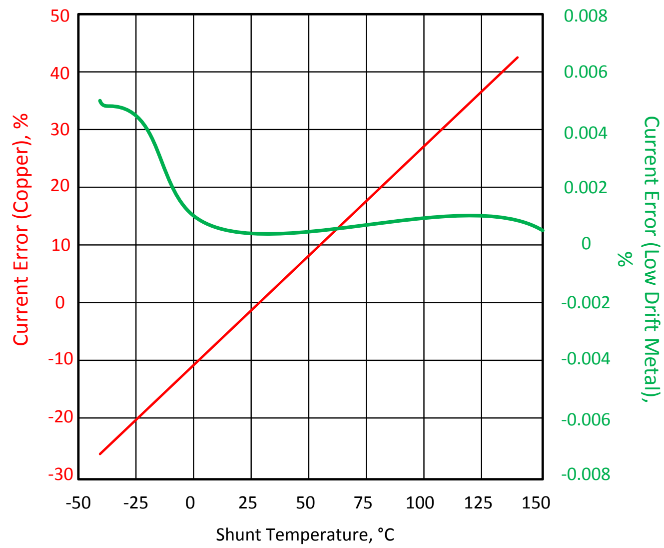

Figure 3. Current error output

The INA250 was designed to address the system accuracy challenge by integrating a 4-wire kelvin 2mΩ shunt inside a package. The INA250 provides a total system accuracy of <0.3% with a temperature drift of 45 ppm/°C. The INA260, a digital output solution with 2mΩ integrated shunt provides a gain error accuracy of 0.15% with a gain error drift of 35 ppm/°C. The 2mΩ integrated shunt is built using a low temperature drift temperature shunt. he thermal coefficient of integrated shunt is ±15 ppm/°C.

Table 1. Alternate Device Recommendations

Device	Optimized Parameter	System Performance Trade-Off
INA240	25 µV offset, 0.2% gain error, 2.5 ppm/°C error drift	Discrete Shunt
INA282	DC CMRR: 140dB	Bandwidth: 10kHz, Discrete Shunt

Table 2. Related TI TechNotes

SBOA202	Benefits of Intergated Low Inductive Shunt for PWM Applications
SBOA170	Integrating the Current Sensing Resistor

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