

## White Paper

# Current Sensing in Space Applications

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## Abstract

Signal sensing is crucial in space applications to continuously observe the overall health of the spacecraft. In this paper, we discuss two major tradeoffs that need to be made when implementing current sensing and the device performance parameters that affect the implementation of the sense circuit. We also introduce the ISL70100SEH radiation hardened current sense amplifier and review the features that make the device ideal for the current sensing in space applications.

## Introduction

Size, Weight, Power, and Cost (SWaP- C) is the high-level analysis currently being optimized for all space applications, independent of size or mission life. As the demand for a higher functionality increases, a demand for spacecraft power consumption increases leading to a greater complexity in the spacecraft power system. To keep the power systems and spacecraft operating in an optimal condition, multiple sensors are required to read the status of the spacecraft.

It is estimated that thousands of sensors are used in a satellite to monitor spacecraft resources, health, attitude, and operation. Of the many signals that are sensed, current information is one of the more important parameters that is monitored as it can be used for motor control, current limiting, fault protection, power monitoring, line compensation, and many other functions.

## Current Sense Implementation

One of the easiest ways to monitor the current is directly with a current sense resistor ( $R_{SNS}$ ). The biggest drawback of direct current sensing is that it is invasive to the system. Think about it. Essentially a designer is cutting a PCB trace that is meant to be short and wide to carry the required amount of current. Then, the designer is adding a lossy element in series to join both sides of the cut trace. This sense resistor creates a voltage drop, or  $V_{SNS}$ , across it that is proportional to the current flowing through it.

However, the resistor increases power dissipation and reduces system efficiency. This is also where the designer encounters the first tradeoff. This trade-off is accuracy versus power dissipation. The more accurate the sensing requirement the higher the resistor value. But, the higher value resistor means more power dissipation as  $PD = I^2 \times R_{SNS}$ .

### Accuracy Tradeoff

A major part of the accuracy tradeoff study is the input offset voltage of the sense circuit. The  $V_{SNS}$  created by the sense resistor is the input to an amplifier that will gain the signal to readable levels. This amplifier will have an input offset voltage ( $V_{IO}$ ) that will add an error to the overall reading and impact the accuracy vs. power dissipation tradeoff.

As a hypothetical example, assume that one is trying to sense 5A on a power supply with an accuracy goal of  $\pm 10\text{mA}$ . Figure 1 plots the error of the sensed current versus  $V_{IO}$  for three different sense resistor values and their corresponding power dissipation. For this example, if the  $V_{IO}$  of the amplifier is  $10\mu\text{V}$  one can use a  $1\text{m}\Omega$   $R_{SNS}$  to

meet the accuracy specification and keep power dissipation at 25mW. However, if the  $V_{IO}$  is 1mV,  $R_{SNS}$  would have to be 100mΩ and  $P_D$  significantly increases to 2.5W.

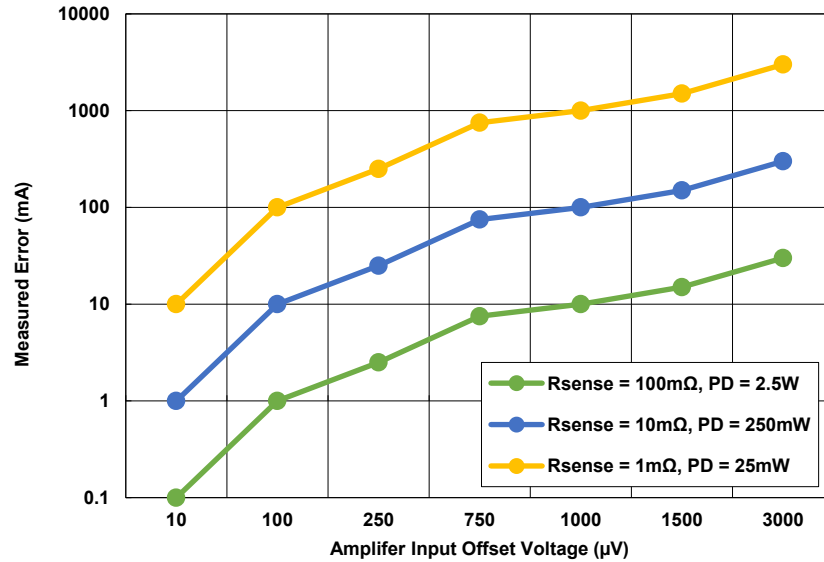


Figure 1. Sensed Current Error vs. Input Offset Voltage vs  $R_{SNS}$

### Configuration Tradeoff

Another tradeoff that needs to be made is the location of the sense resistor. In high side current sensing,  $R_{SNS}$  is placed between power source and the load. In low side current sensing  $R_{SNS}$  is placed between the load and the ground return path. Both configurations are shown in Figure 2.

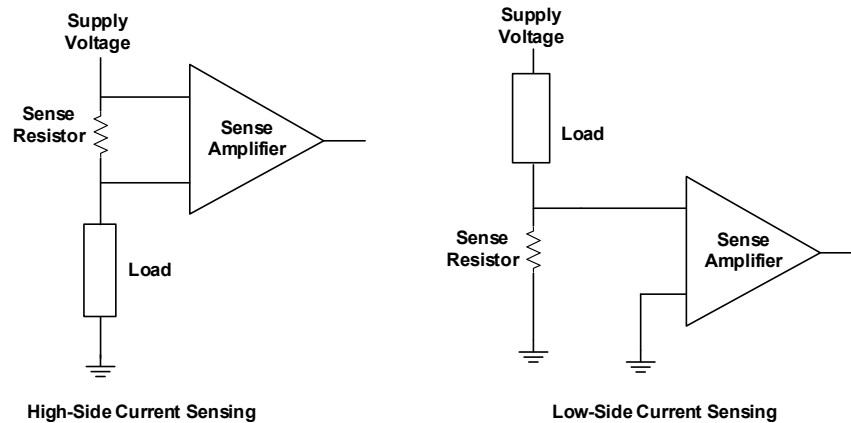


Figure 2 High-Side and Low-Side Current Sensing Configurations

While each configuration has its own pros and cons, one important parameter can determine which configuration is used. This parameter is the input common-mode voltage range of the sense amplifier,  $V_{CMIR}$ . If the  $V_{CMIR}$  is wide enough to include the power bus being monitored, high-side current sensing can be implemented. However, if the  $V_{CMIR}$  does not include the monitored supply, low-side current sensing must be used.

The sense amplifier can be realized multiple ways including using a general-purpose operational amplifier (op amp); instrumentation amplifiers or even chopper op amps. However, implementing these devices in current sensing applications has drawbacks. One of the drawbacks is the input common-mode voltage range is limited by the power

rail voltage. If the amplifier is not capable of input rail-to-rail, the  $V_{CMIR}$  is even more limited. Chopper amps have low  $V_{IO}$  sub- $10\mu V$ , but they typically have low bandwidth and operate from 5V and below.

## The ISL70100SEH Current Sense Amplifier

A better alternative is to use an amplifier specifically designed for current sensing applications. One such device is the ISL70100SEH. This Current Sense Amplifier (CSA) has an ultra-low input offset voltage specification of  $10\mu V$  (typical) at  $25^\circ C$ , allowing designers to achieve their required accuracy without increasing the sense resistor value and wasting unnecessary power.

Also, the input common-mode voltage range is  $-0.3V$  to  $40V$  independent of the power supply used to bias the CSA. This allows you to power the CSA from  $3.3V$ , but monitor currents from a  $28V$  bus voltage.

Finally, ISL70100SEH is simple to use. Besides the sense resistor, only one additional resistor on the output is required to set the overall gain of CSA. This eliminates the need for external output-to-input gain resistors, therefore, reducing component count and board space. Figure 3 compares a low-side current sensing application with the ISL70218SEH op amp versus a high-side sensing application using the ISL70100SEH.

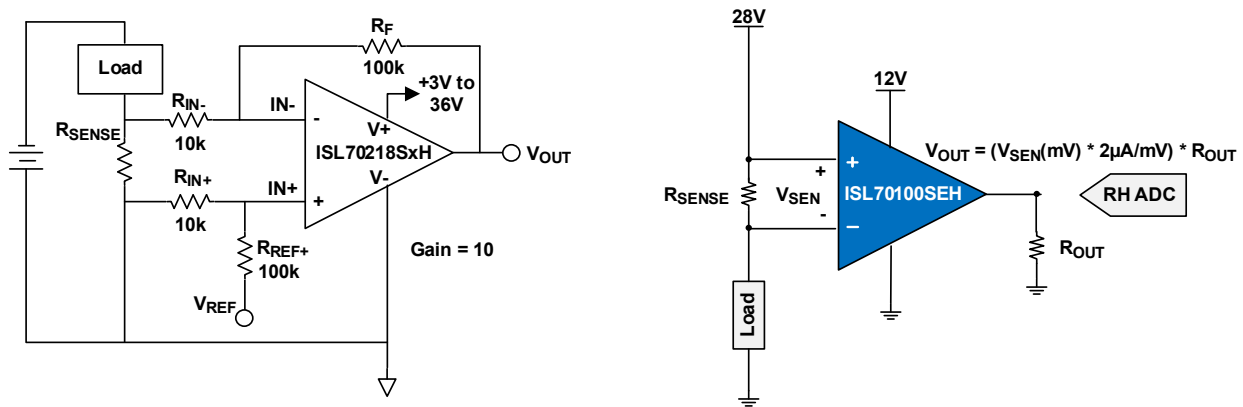


Figure 3 Current Sense Application Schematic for an Op Amp vs ISL70100SEH

Differential current sensing with the ISL70218SH requires four external resistors, and the  $V_{CMIR}$  is limited by the power supply voltage and the fact that the device is not capable of input rail-to-rail operation. The ISL70100SEH has an internal transconductance gain stage with a gain =  $2\mu A/mV$ , and a single resistor on the output is used to set the overall gain and convert the output current into a voltage.

## Robust Operation in Space

For space applications, the designer must ensure that the solution also operates correctly in the harsh space environment. The ISL70100SEH is built on a silicon-on-insulator bipolar process to eliminate single event latch-up. The device is also rated at  $100krad(Si)$  at HDR ( $50 - 300rad(Si)/s$ ) and at  $75krad(Si)$  at LDR ( $0.01rad(Si)/s$ ). Figure 4 shows the internal transconductance gain, and the input offset voltage as a function of total dose radiation plus post anneal. The graphs show how stable each parameter is over radiation and how they are well within the limits specified in the standard microcircuit drawing.

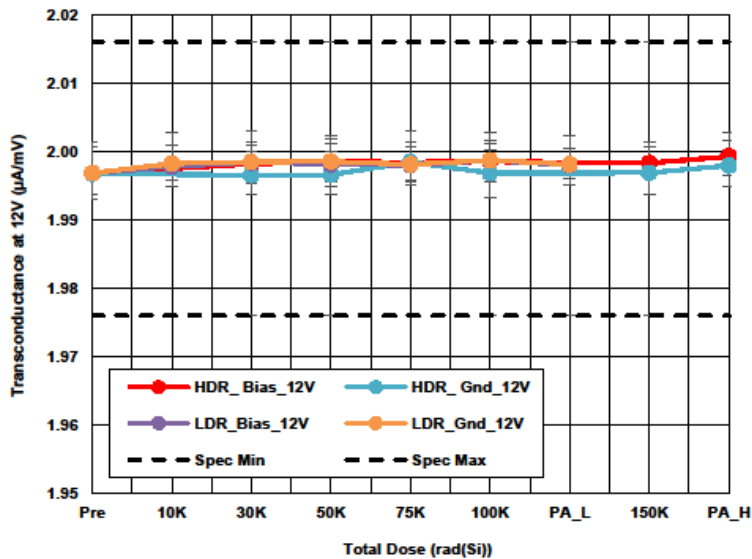
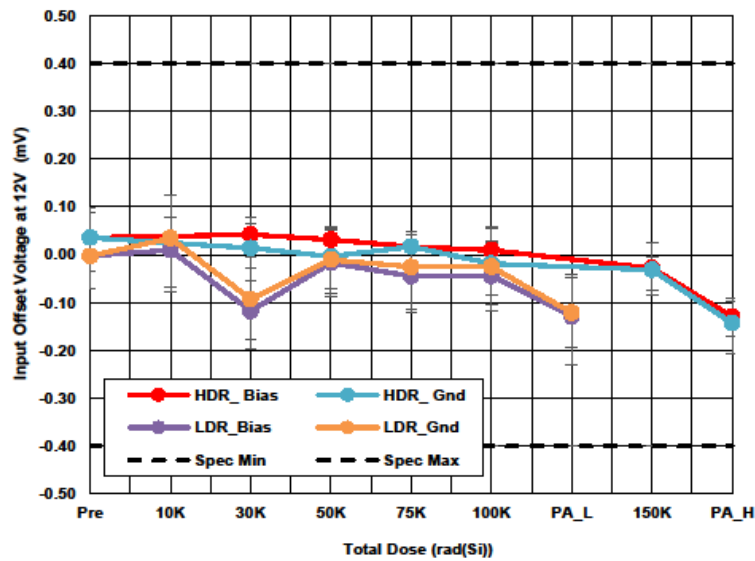


Figure 4 Transconductance Gain and Input Offset Voltage as a Function of Total Dose Radiation

## Summary

With the arrival of the QML-V qualified ISL70100SEH radiation hardened current-sense amplifier ICs by Renesas, space power engineers are able to quickly implement accurate and reliable current sensing in space applications. This device simplifies the overall implementation allowing engineers to replace older, more complex designs that use discrete components or general op amps with a simpler solution.

### Next Steps

- [Visit the ISL70100SEH web page](#)

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