White Paper

Gaining Precision in Space Applications: Using Voltage References for Precision Signal Paths

Introduction

Often when selecting a component in the signal path of a satellite system, it is difficult to find a device with the radiation tolerance and the accuracy required. Signal integrity is after all the key specification when designing an analog signal chain. The main causes of error to the integrity of the signal chain can be divided into two categories: inaccuracies due to noise and inaccuracies due to shifts in voltage. While it is important to consider all components in the signal path, one component is the most critical in achieving precision performance: the voltage reference.

Noise

Noise in a system can be reduced with the correct use of filters and the averaging of measurements when converting a signal from the analog domain to the digital domain. However, large or complex filters require board space and increased component count, not to mention added weight, resulting in higher costs. Large filters also increase the settling time for transient response. Averaging saves on extra component cost at the expense of sample frequency. The digital-to-analog converter requires a voltage reference with lower noise than the signal being measured to take advantage of averaging. For example, a 20-bit system requires the voltage reference to have a noise of less than 1 part per million (ppm). If the system requires higher precision than a voltage reference can deliver, averaging can still be used, but will be extremely costly as multiple analog-to-digital converters are needed. Each converter has its own voltage reference and the measurement from each is then averaged.

In the last five years, several manufacturers have offered references with noise in the single ppm peak-to-peak levels. For traditional bandgap references, about 600mV of Proportional to Absolute Temperature (PTAT) voltage is generated and added to a single transistor base-to-emitter voltage (Vbe) to produce the basic bandgap voltage of ~1.22V. An output amplifier (which may be part of the bandgap itself) gains and buffers the internal bandgap voltage up to a standard output. The 600mV of PTAT has been created from a single delta-Vbe (ΔVbe) structure made from two transistors running at different current densities generating a voltage ΔVbe=(KT/q)*ln(R) where K is Boltzmann's constant, T is absolute temperature, q is the electric charge, and R is the current density ratio between the two transistors. A common design has R=8 and ΔVbe=54mV. To bring this up to 600mV will require a gain of about 11. That gain of 11 will amplify device noises and instabilities directly.

One solution to reduce the noise in a bandgap reference is to employ cascaded ΔVbe rather than an amplified ΔVbe. That is to say, the design effectively adds 11 of those R=8 units in sequence to generate the 600mV. This has profound effects on the noise. If one adds the noise of 11 identical units, the result is only $\sqrt{11}$ noise amplification or a 3.3-fold improvement. It is better than that, though, because the mechanisms that give the gain of 11 in a standard bandgap more than double the ΔVbe noise.

When a voltage reference is exposed to radiation, the noise increases. Although the increase in noise is not large, the above solution keeps the increase even lower. Also, popcorn noise sources would only exist sparsely with perhaps one site on a die, and they would not receive the gain of 11. If ever popcorn noise is found, it will be an order of magnitude smaller than in a traditional bandgap reference.

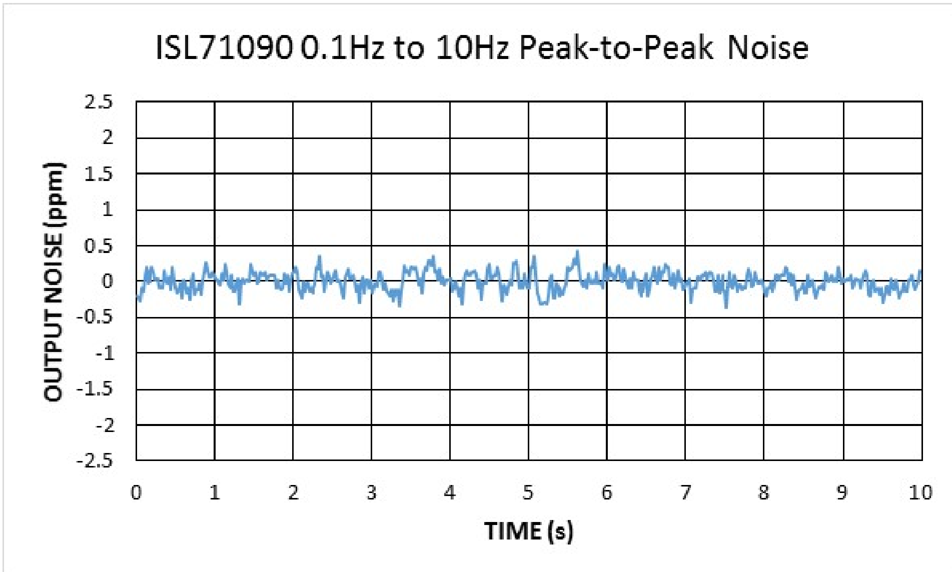

Figure 1. ISL71090SEH Voltage Reference Peak to Peak Noise Plot

Voltage Shifts

Voltage shifts in a system may be reduced with fairly simple additional circuitry, although making adjustments across a full temperature range presents added difficulty. The cost of the additional circuitry is also high. Furthermore, offset voltages can only be corrected if they are detected, meaning that there must be a fixed voltage accurate enough to use as a base for the rest of the system. Once again the critical component of the system is the voltage reference. It sets the common mode for amplifiers, can be used to trigger comparators, and may be used to provide a stable supply to sensitive sensors. Most importantly, it sets the accuracy for the analog to digital and digital to analog converters.

Key aspects to consider on a voltage reference include initial accuracy, drift over temperature, drift over time and shift over radiation. Many voltage references provide trim options to adjust initial accuracy; however, the process requires external circuitry and may adversely affect the other specifications. A much simpler approach is to calibrate out the error on the digital side. Note that digital calibration reduces the total input signal voltage range by the amount of the error. Bandgap references can be found with an initial accuracy within hundredths of a percent before radiation.

Drift over temperature in precision voltage references is caused by imperfections in the elements making up the device and is not linear. The uncompensated curve of a bandgap reference is about 20ppm. One solution to improve the temperature coefficient of the device is to use translinear circuitry to compensate for the curve by adding an exponential term to the current summation. With curve compensation, one is able to achieve a temperature coefficient lower than 3ppm.

Drift over time is independent of other shifts and occurs predominantly toward the beginning of the life of the reference. Thus, initial calibration does not help correct for this drift. Calibration after an initial burn in period is an option at the expense of the burn in time. Also, the cascade design for creating a bandgap reference does not just help reduce noise, it has been found to reduce the long-term drift as well.

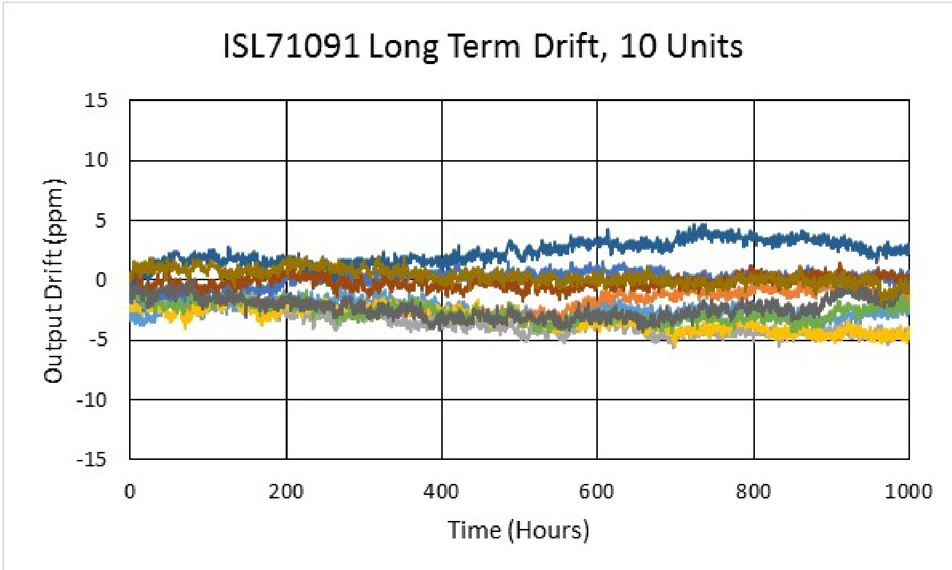

Figure 2: ISL71091SEH Voltage Reference Long-Term Drift

Finally, shifts due to radiation are critical in space applications. Many voltage references provide excellent accuracy in industrial environments but have large shifts when exposed to radiation. Research has shown that low dose rate radiation best mimics the actual conditions in space. Low dose rate used in testing is typically 10mrad(Si)/s. While this is a higher rate compared to the natural occurring radiation in space, it is a compromise between the time needed to complete the radiation testing and the dose rate chosen. Testing at high dose rates (50-300rad(Si)/s) can produce secondary effects due to the accelerated nature of the dose rate. It is highly recommended to select devices that have undergone both low dose and high dose rate radiation testing on a wafer by wafer basis. Radiation hardening is achieved both through design and through the process used in creating the device. A good solution for a radiation-tolerant process is to have the transistors oxide-isolated and diffused neither too shallow so as to be sensitive to radiation-damaged oxides, and not diffused so deeply as to increase layout size and lower frequency responses.

Table 1 shows a comparison of key specifications over radiation of three of the top competing voltage references.

Table 1. Comparison of Top Voltage References for Space Applications

Device	ISL71090SEH	ISL71091SEH	Competitor A	Competitor B
Radiation Testing	Low dose and high dose rate tested on each wafer	Low dose and high dose rate tested on each wafer	High dose rate tested	Low dose and high dose rate tested
0.1Hz to 10Hz Peak-to-Peak Noise	0.8 ppm typical	1.6 ppm typical	1.6 ppm typical	Not specified

Initial Accuracy	±0.175% Max (2.5V option)	±0.25% Max	±0.2% Max	±0.2% Max
Temperature Coefficient	10 ppm/°C Max	6 ppm/°C Max	15 ppm/°C Max	33 ppm/°C Max
Long-Term Drift	15 ppm/kHr typical	20 ppm/kHr typical	Not specified	20 ppm/kHr typical

Conclusion

In summary, voltage references directly affect signal integrity because they are used as the standard by which the signal is compared to when it is converted from the analog domain to the digital domain. Calibration and compensation methods exist, but are often expensive and may consume significant board space. New designs, testing and wafer process techniques, like those used in Intersil's ISL71090SEH and ISL71091SEH rad hard voltage references, are improving specifications and minimizing or even eliminating the need for calibration.

Next Steps

- Learn more about the ISL71091SEH rad hard voltage reference family
- Check out the ISL71091SEH evaluation boards
- Get the ISL71091SEH33 datasheet
- Find rad hard parts using our parametric search

# # #