

Application Note

Space ADC Circuit Cookbook



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ABSTRACT

Electronic systems in space demand precision, reliability, and radiation tolerance across a wide range of sensing applications. From monitoring power rail health to motor position feedback, a well-designed analog signal chain is the foundation of every dependable satellite or spacecraft subsystem. Below are six distinct signal chain circuits that cover the most common measurement tasks encountered in space applications, each built around radiation-hardened or radiation-tolerant Texas Instruments devices.

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1 Introduction

There are numerous systems in satellites that require a wide variety of signal chains for different measurements. High precision temperature monitoring is important to make sure the satellite does not overheat, but it is especially critical on optical imaging payloads as the optical performance can degrade due to thermal expansion of mechanical components. General purpose telemetry is required to monitor the health of platforms, buses and payloads through voltage, current and temperature measurements. Wheatstone bridges can be used to measure strain gauges in robotic arms or mirror position feedback on laser communication terminals (LCTs). Photodiode measurements are necessary for laser positioning on LCTs, interferometers, and power beaming. Position feedback measurements from resolvers or encoders are mandatory for precise motion on LCTs, attitude and orbit control systems and robotics.

2 Multi-Channel Temperature Monitoring with ADS1278QML-SP

Temperature monitoring is one of the most fundamental housekeeping tasks in a spacecraft. This circuit implements a multi-channel temperature sensing front end using precision thermistors or thermocouple-based sensors interfaced to the [ADS1278QML-SP](#), an eight-channel, simultaneously-sampling, 24-bit delta-sigma ADC. The [LMP7704-SP](#) quad op-amp is used as an input buffer stage between the sensors and the ADC to verify that source impedance does not degrade conversion accuracy. Simultaneous sampling across all eight channels verifies that temperature gradients across a module or subsystem are captured at the same point in time.

The LMP7704-SP is an optimal choice as a unity-gain buffer in this application. The ultra-low input bias current eliminates measurement error caused by current flowing through the sensor source resistance, which is especially important when sensing with high-impedance thermistors. The rail-to-rail input/output (RRIO) characteristic of the LMP7704-SP allows the input signal to approach both supply rails, maximizing dynamic range for low-level temperature signals.

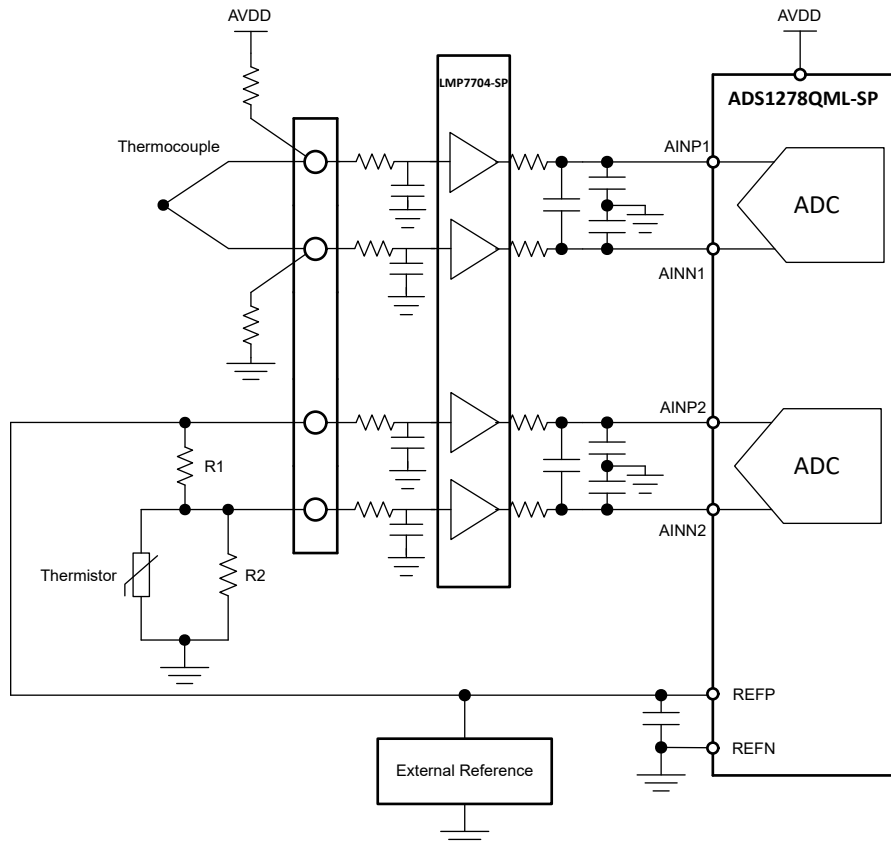


Figure 2-1. Temperature Sensing Design with ADS1278QML-SP

3 High-Speed Housekeeping with ADC128S102QML-SP

Satellite housekeeping circuits continuously monitor the health of onboard power systems, reporting voltages, currents, and temperatures to the central data handling system. This design implements a multi-parameter telemetry front end using the [ADC128S102QML-SP](#) and the [LMP7704-SP](#). The [INA901-SP](#) serves as the analog front end for high-side current and voltage measurements. Temperature measurements are taken via additional channels using thermistors or diode-based sensors buffered by the [LMP7704-SP](#).

The [ADC128S102QML-SP](#) is a QML Class V, radiation-hardened, 12-bit SAR ADC with eight multiplexed input channels and a maximum sample rate of 1MSPS. The 100 krad (Si) TID rating and SEL immunity to 120MeV·cm²/mg make it one of the most radiation-robust converters available for space housekeeping applications.

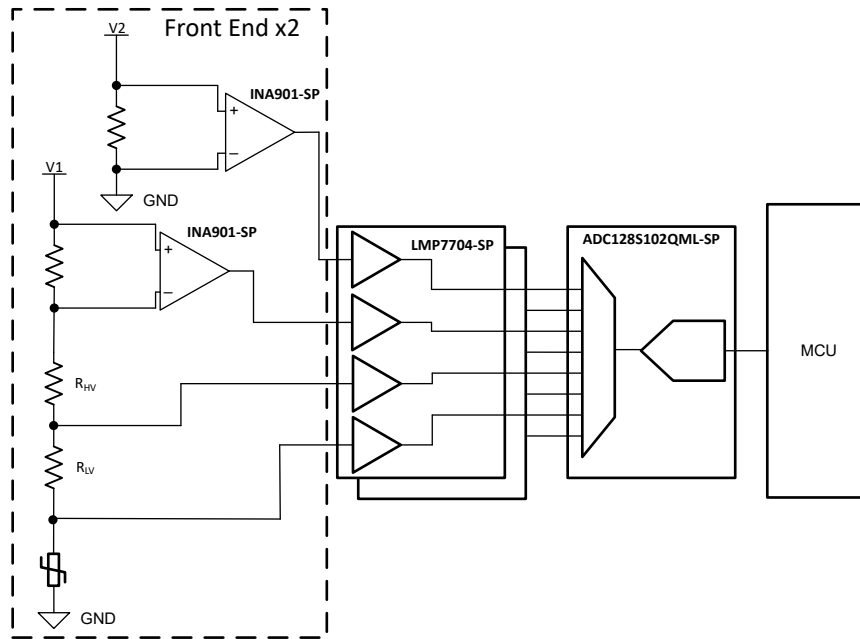


Figure 3-1. Telemetry with ADC128S102QML-SP

4 Precision Bridge Sensor Interface with ADS1282-SP

Wheatstone bridge sensors are widely used in space applications to measure strain, pressure, and force. The bridge output is a differential, low-level voltage signal whose magnitude is proportional to the applied stimulus and the excitation voltage. This design uses the [ADS1282-SP](#), a high-resolution 32-bit delta-sigma ADC, to digitize the bridge output after amplification and conditioning by the LMP7704-SP.

Bridge sensor outputs are typically in the millivolt range, requiring a precision amplifier to avoid degrading the measurement. The $\pm 60\mu\text{V}$ maximum offset voltage and low $1/f$ noise characteristics of the LMP7704-SP make this an option for amplifying these small differential signals. The internal programmable gain amplifier (PGA) of the ADS1282-SP provides additional gain, allowing the signal to be digitized at full code resolution. The ADS1282-SP provides up to 31 bits of effective resolution at lower output data rates, with an integrated PGA. The internal, two-channel multiplexer allows for differential measurements on both arms of the bridge.

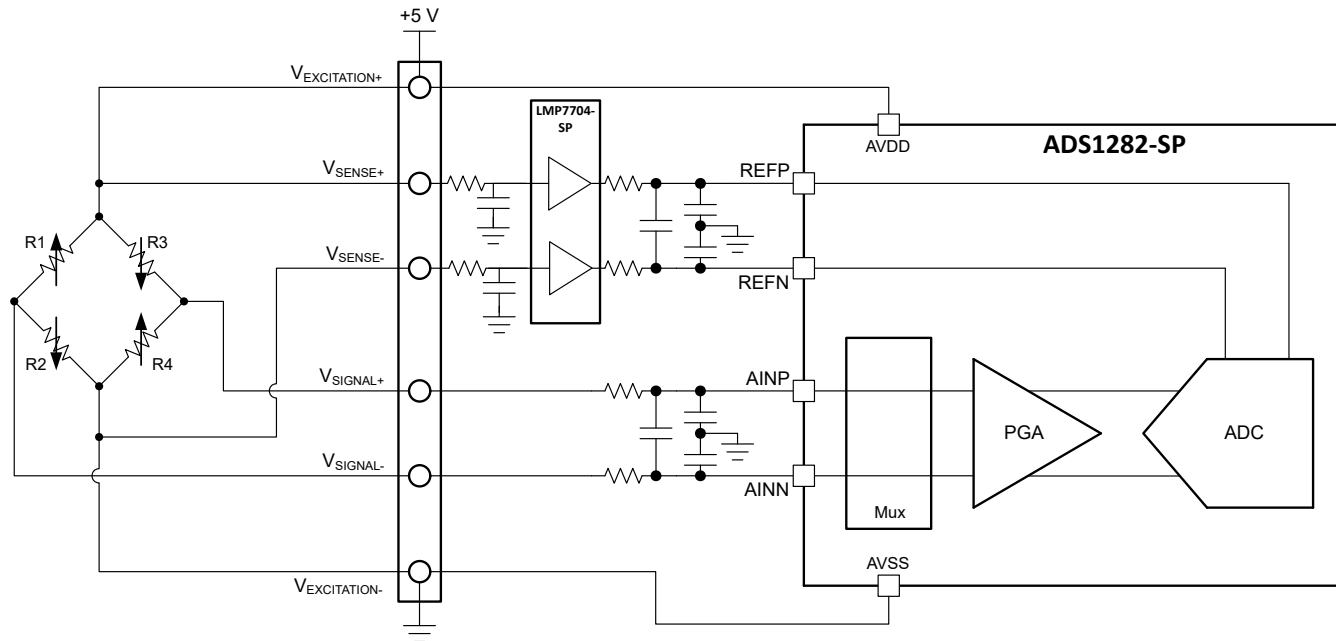


Figure 4-1. Bridge Measurement with ADS1282-SP

5 Photodiode Signal Measurement with ADC168M102R-SEP

Optical sensors and photodiodes are used in space applications for optical inter-satellite link (OISL) communications, power beaming, and laser ranging. The photodiode generates a current proportional to incident light intensity. This current must be converted to a voltage and amplified before it can be digitized. This design implements the [OPA4H014-SEP](#) as a transimpedance amplifier (TIA) and ADC driver, followed by the [ADC168M102R-SEP](#) for high-speed, multichannel digitization.

The OPA4H014-SEP is a radiation-tolerant, JFET-input quad op-amp with an extremely low input bias current. The low input bias current is essential in TIA applications, where the op-amp input bias current adds directly to the photodiode dark current, creating a measurement offset. The ADC168M102R-SEP is a radiation-tolerant, 16-bit, 8-channel, 1 MSPS simultaneous-sampling SAR ADC. The dual simultaneous sampling architecture allows multiple photodiode channels to be captured at the same instant, which is critical in laser position-sensing applications where relative signal levels are measured across channels.

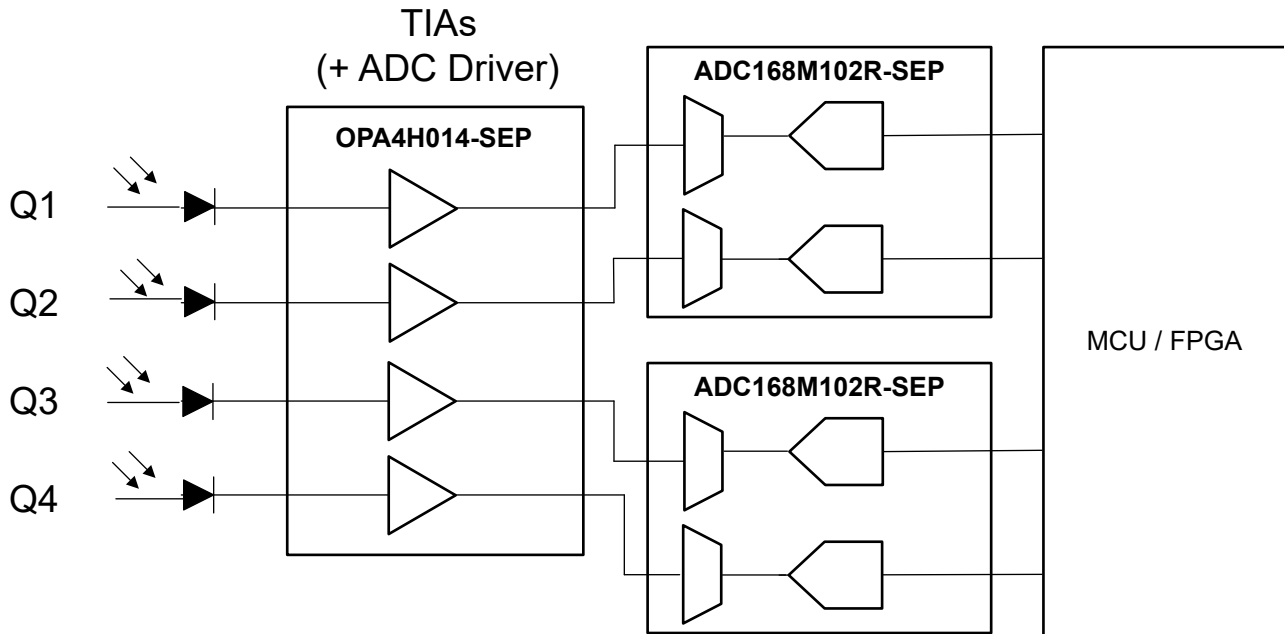


Figure 5-1. Laser Positioning with ADC168M102R-SEP

6 Precision RTD Measurement with ADS1282-SP

Resistance Temperature Detectors (RTDs), such as the PT100 or PT1000, offer exceptional linearity and long-term stability compared to thermocouples, making them the preferred sensor for precision temperature metrology in space payloads. This design uses the ADS1282-SP's high resolution and internal PGA to directly digitize the small differential voltage developed across the RTD when a precision excitation current is applied, which can achieve a temperature accuracy of less than 1mKelvin. The LMP7704-SP creates a constant current source to bias the RTD. Additional LMP7704-SP amplifiers can be used to buffer the reference inputs.

RTD resistance changes are small, so minimizing offset and drift errors across the signal chain is paramount. The $\pm 60 \mu\text{V}$ offset and low drift of the LMP7704-SP, combined with the 32-bit resolution and internal calibration of the ADS1282-SP, provide the performance needed to resolve sub-degree temperature changes. To measure more than 2 channels, an external MUX, such as the [TMUX182-SEP](#), is required.

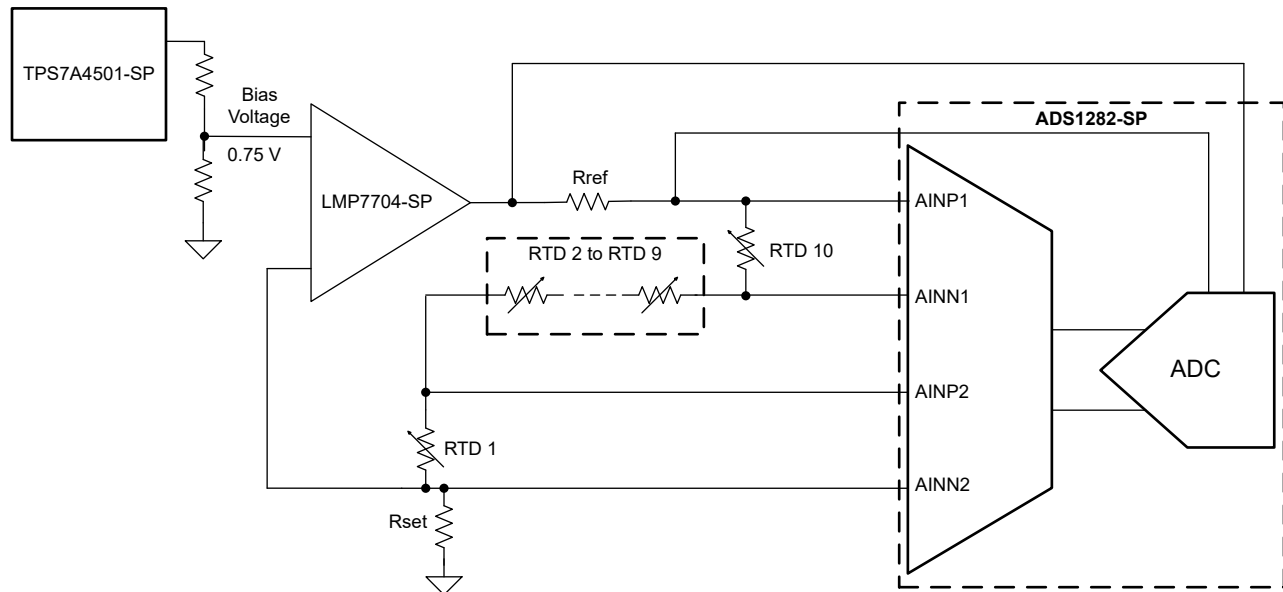


Figure 6-1. RTD Measurement with ADS1282-SP

7 Motor Position Feedback Measurement Using ADC168M102R-SEP

Precise motor position control is essential in spacecraft attitude control systems, solar array drive assemblies, antenna pointing mechanisms, and laser communication terminals. Position feedback is commonly derived from resolvers or sine/cosine encoders, which produce two sinusoidal analog signals with 90° phase offset. This design uses the ADC168M102R-SEP’s simultaneous-sampling capability to digitize the sine and cosine output signals at the same instant, enabling accurate angle computation via an arctangent function. The OPA4H014-SEP provides signal conditioning and drive capability for the ADC input.

Simultaneous sampling is critical in this application. If the two channels are sampled at different times, the phase error between them introduces an angular error in the computed position. The dual-ADC architecture of the ADC168M102R-SEP captures both signal channels in the same conversion cycle, eliminating this source of dynamic error.

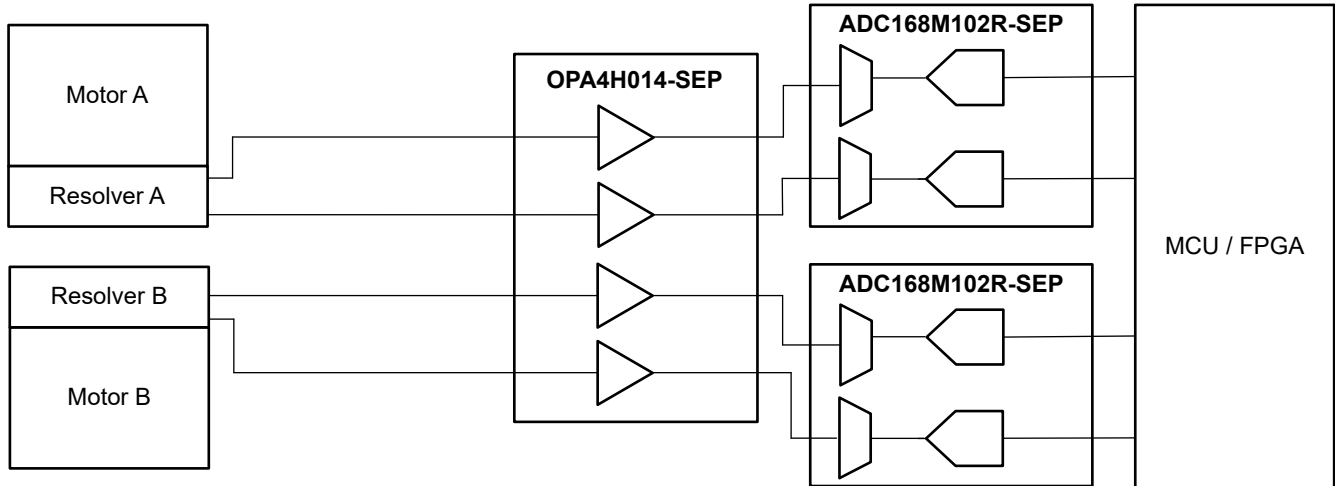


Figure 7-1. Motor Position Feedback with ADC168M102R-SEP

8 Summary

These six space-grade analog signal chains, using Texas Instruments' precision ADC families, cover the full spectrum of applications in space, from basic housekeeping to precise temperature control. The ADC128S102 family has a lot of flight heritage and is great for basic telemetry on space buses and payloads. The ADC168M102R-SEP is optimal for control loop applications that require higher precision and faster sampling rates, such as laser positioning and motor control. The ADS1278QML-SP and ADS1282-SP are desirable for space systems that require the highest levels of precision such as vibration monitoring or temperature control.

Device Summary

Table 8-1 summarizes all devices used across the six designs presented.

Table 8-1. Device Summary

Device	Description	TID (krad (Si))	SEL (MeV·cm ² /mg)
ADC128S102QML-SP	12-Bit, 8-Ch, 1-MSPS, SAR ADC	100	120
ADC128S102-SEP	12-Bit, 8-Ch, 1-MSPS, SAR ADC	30	43
ADC168M102R-SEP	16-Bit, 8-Ch, dual simultaneous sampling, 1-MSPS, SAR ADC	30	43
ADS1278QML-SP	24-bit, octal simultaneous sampling, 128-kSPS, Delta-Sigma ADC	50	51
ADS1282-SP	31-bit, 2-Ch, 4-kSPS, Delta-Sigma ADC with PGA	50	60
LMP7704-SP	Precision low-input-bias wide-supply-range amplifier with RRIO	100	85
OPA4H014-SEP	11MHz, low-noise, precision rail-to-rail output JFET amplifier	30	43
OPA4H199-SEP	Quad, 40V 4.5MHz rail-to-rail input and output operational amplifier	30	43
OPA4H199-SP	Quad, 40V 4.5MHz rail-to-rail input and output operational amplifier	100	65
INA901-SP	-15V to 65V, split-stage current sense amplifier with in-line filter option	50	75
TMUX182-SEP	8:1, one-channel multiplexer with 1.8V logic	30	43

9 References

- Texas Instruments, [TI's Space Grade Precision ADCs in Laser Communication Terminals](#), application brief.
- Texas Instruments, [Radiation-Tolerant, 30-krad, Comparing Current Sensing Amplifier With Second Stage Buffer to ADC](#), application brief.
- Texas Instruments, [Radiation-Tolerant, 30-krad, Voltage-Sensing ADC Circuits](#), application brief.
- Texas Instruments, [Reduce Cost, Size, and Weight of Telemetry Circuits in Low-Earth-Orbit Satellites](#), application brief.
- Texas Instruments, [Precision High-Voltage Current Sensing Using Zener-Shifted Floating Ground and Isolated Digital Interface](#), application brief.
- Texas Instruments, [Radiation-Hardened Space Battery Management System \(BMS\) Reference Design](#), design guide.
- Texas Instruments, [Series Resistance Temperature Detector \(RTD\) Sensing Reference Design](#), design guide.
- Texas Instruments, [A Basic Guide to RTD Measurements](#), application note.
- Texas Instruments, [A Basic Guide to Bridge Measurements](#), application note.
- Texas Instruments, [A Basic Guide to Thermocouple Measurements](#), application note.

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