

## **Harsh Environments Conquered—Low Power, Precision, High Temperature Components for Extreme High Temperature Applications**

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### **INTRODUCTION**

When we think of harsh environments, there is no doubt that one of the most challenging applications on this planet is downhole drilling. Oil field service companies are pushing the limits of technology to design precision equipment that must survive extreme pressure, shock, and vibration, while at the same time have a long battery life and fit in very small form factors. However, perhaps the biggest challenge for electronics used in this environment is the extreme temperature. These high temperatures are a function of depth; while on average the geothermal gradient is about 25°C/km, in some regions it can be higher. Due to increasing global energy demands, there is motivation to drill and develop these hotter wells where it has not been feasible to do so before. Unfortunately, cooling the electronics in this environment is not an option. Because of this, the industry is calling for precision instrumentation that must operate reliably above 200°C. Indeed, the importance of reliability is underscored by the high cost of a failure. An electronics assembly on a drill string operating miles underground can take more than a day to retrieve and replace—and the rate for operating a complex deepwater offshore rig can be more than \$500k per day.

In addition to oil and gas exploration, there are other emerging applications for high temperature electronics. The aviation industry has a growing movement toward the “more electric aircraft.” Part of this initiative seeks to replace traditional centralized engine controllers with distributed control systems, which places the engine controls closer to the engine, greatly reducing the complexity of the interconnections and saving hundreds of pounds of aircraft weight. Another aspect of the initiative is to replace hydraulic systems with power electronics and electronic

controls to improve reliability and reduce maintenance costs. The control electronics ideally need to be very close to the actuators, which again produce a high ambient temperature environment. Similar to avionics jet engines, control systems and instrumentation are required for heavy industrial gas turbines used for power generation.

### **HIGH TEMPERATURE RATED ICs**

In the past, high temperature electronics designers were forced to use components above their rated specification due to the unavailability of high temperature ICs. While some standard temperature ICs may have limited functionality above specification, it is an arduous and risky endeavor and there is no guarantee of reliability or performance. For example, engineers must identify potential candidates, completely test and characterize performance over temperature, and qualify the reliability of the part over a long period of time. Performance and lifetime of the part are often substantially derated and could vary substantially between manufacturing lots. This is a challenging, expensive, and time consuming process that designers would prefer to avoid. Additionally, target design temperatures are transitioning to 175°C and higher advanced packaging is necessary to enable reliability even for short durations of time.

Fortunately, advances in recent years have led to high temperature rated ICs being available off the shelf. Products in the Analog Devices high temperature portfolio use specialized process technology, circuit design, and packaging along with a comprehensive characterization, qualification, and production test program to enable reliable performance at high temperature with guaranteed data sheet specifications.

### **HIGH TEMPERATURE SIGNAL CHAIN**

While we have presented some varying end applications for high temperature electronics, from oil exploration to avionics to heavy industrial fields, there are several common requirements in their signal chains. The majority of these systems require precision data acquisition from multiple sensors or require high throughput rates. Furthermore, many of these applications have stringent power budgets because they are running from batteries or cannot tolerate additional temperature increases from the self heating of the electronics. Therefore, a low power data acquisition signal

chain is required, consisting of sensors, precision analog components, and a high throughput ADC.

Even though there are now commercially available HT rated ICs, there is still a limited selection of circuit building blocks today. In particular, there are no commercially available precision ADCs that are low power, have a sample rate higher than 100 kSPS, and are rated for operation above 200°C. This is a major pain point for circuit designers who need to acquire and process wider bandwidth signals or want to multiplex channels. To meet this need, ADI has recently released the [AD7981](#) ADC, capable of samples rates up to 600 kSPS with 16-bit resolution while maintaining low power and a very small footprint. It is available today in a 10-lead MSOP package rated for 175°C, with a 210°C rated ceramic flatpack, and known good die versions are to follow soon. As a case study we will examine in further detail the features of this ADC that enable its breakthrough performance and reliability at extreme temperatures.

#### AD7981 HIGH TEMPERATURE ADC

The AD7981 is a 16-bit, low power, single-supply ADC that uses a successive approximation architecture (SAR) capable of sampling up to 600 kSPS. It is based on ADI's proven SAR core that has been designed into a high volume of industrial and instrumentation systems. The architecture is based on ADI's proprietary charge redistribution capacitive DAC technology. The CMOS fabrication process enables excellent performance at elevated temperature partly due to the matching and tracking of these capacitors over temperature. In addition, optimizations were made to the acquisition circuit to improve precision at high temperature.

The AD7981's typical application signal chain is shown in Figure 1, where the high temperature qualified rail-to-rail output, precision, low power, dual amplifier [AD8634](#) is used for driving the input of the AD7981 and as a reference buffer in conjunction with the high temperature qualified, low temperature drift [ADR225](#) 2.5 V reference. The AD7981 requires two supplies: an analog and digital core supply (VDD), and a digital input/output interface supply (VIO) for a direct interface with any logic between 1.8 V and 5 V. The VIO and VDD pins can be tied together to reduce the number of supplies needed.

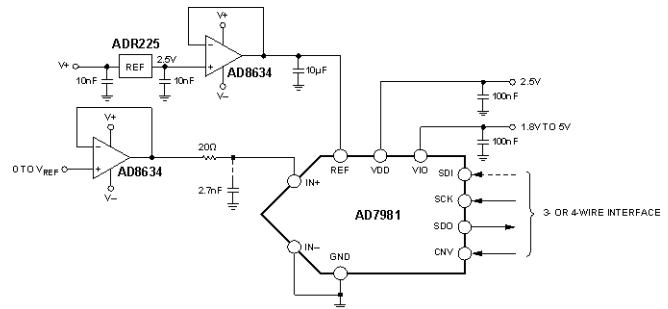


Figure 1. AD7981 Application Signal Chain

The AD7981 achieves excellent ac and dc performance with typical  $\pm 0.7$  LSB INL,  $-102$  dB THD, and 91 dB SNR, enabling a high dynamic range with better accuracy and precision even at a high temperature of 175°C. The AD7981 typical INL vs. code plot is shown in Figure 2.

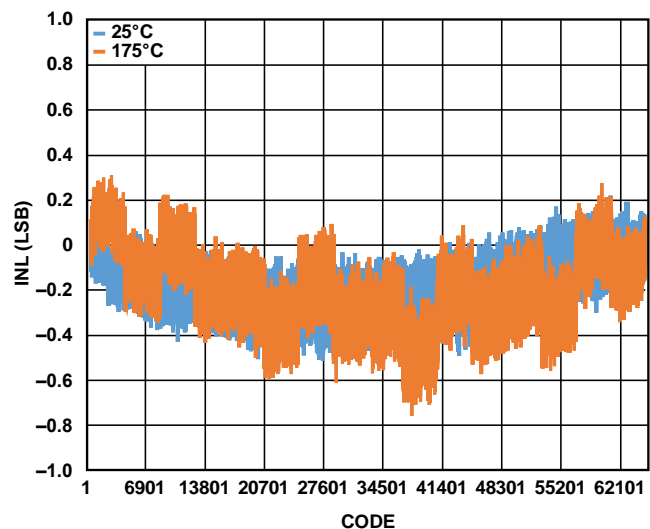


Figure 2. AD7981 Nonlinearity Error vs. Temperature

The AD7981 signal-to-noise and distortion (SINAD) performance for a wide input frequency range over various temperatures is shown in Figure 3.

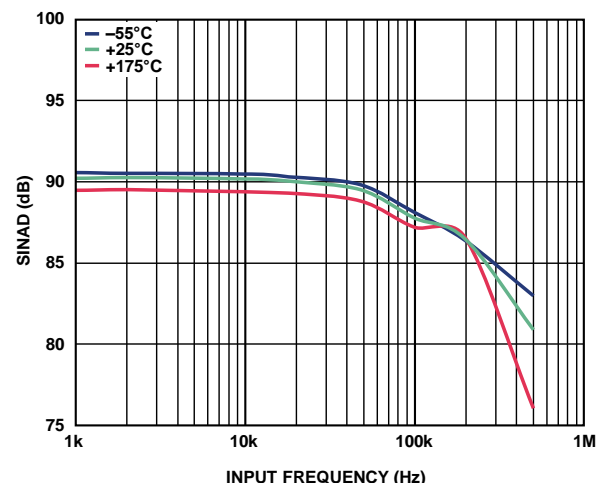


Figure 3. SINAD vs. Frequency Over Temperature

The AD7981 maximizes battery life in harsh environments by scaling power linearly with throughput rate, dissipating typically around 4 mW at full throughput of 600 kSPS, and 70  $\mu$ W at 10 kSPS, as shown in Figure 4. The AD7981 powers down automatically between conversions in order to save power. This makes the part dually suited for low sampling rate applications, even of a few Hz, and enables very low power consumption for battery-powered portable systems.

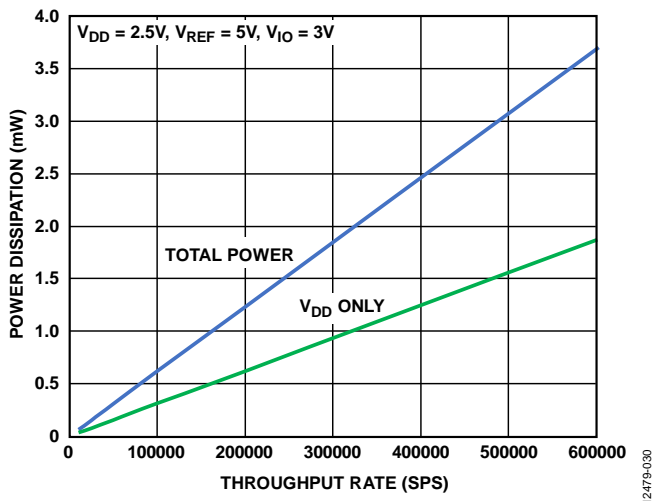


Figure 4. AD7981 Power Dissipation vs. Throughput Rate

The AD7981 offers a flexible serial digital interface compatible with SPI and other digital hosts. It can be configured for a simple 3-wire mode for the lowest I/O count, or 4-wire mode that allows options for the daisy-chained readback and simultaneous sampling. For multichannel data acquisition systems, the AD7981 can easily be used with a multiplexer because it integrates an on-chip, track-and-hold circuit, and the SAR architecture does not exhibit any pipeline delay or latency.

#### HIGH TEMPERATURE PACKAGING

Once we have high performance silicon that operates at high temperature, only half the battle is won. Robust packaging is critical for integrated circuits that must survive harsh high temperature environments. The package must provide adequate protection from the environment and reliable interconnect to the PCB while having a form factor appropriate for the mission profile of the system.

While there are many considerations to reliable packaging, one of the major failure points at high temperature is the wire bond. This failure has been particularly problematic in plastic packaging commonly found in the industry, where gold bond wires and aluminum bond pads are the standard. Elevated temperature accelerates the growth of AuAl intermetallic compounds. These intermetallics are associated

with bond failures such as brittle bonds and voiding, which can happen as quickly as hundreds of hours, as shown in Figure 5. In order to avoid these failures, ADI uses an over pad metallization (OPM) process to create a gold bond pad surface for the gold bond wire to attach. This monometallic system does not form intermetallics and has been proven reliable in our qualification testing with over 6000 hours soak at 195°C, as shown in Figure 6. Although ADI has shown reliable bonding at 195°C, the plastic package is rated for operation only up to 175°C due to the glass transition temperature of the moulding compound.

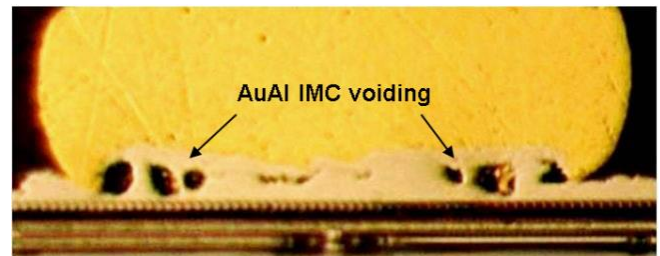


Figure 5. Au Ball Bond on Al Pad, Post 500 Hours at 195°C

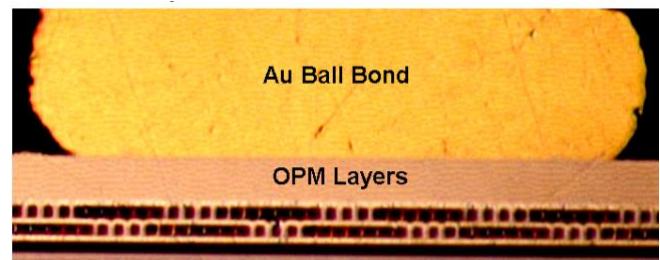


Figure 6. Au Ball Bond on OPM, Post 6000 Hours at 195°C

#### APPLICATION EXAMPLE

The above combination of the AD7981 key features such as high performance, robustness, low power, and flexible configuration addresses critical performance criteria for precision measurement applications in harsh, high temperature environments, such as downhole oil and gas drilling, as well as industrial, instrumentation, and avionics applications.

The AD7981 is a member of a growing portfolio of high temperature products that enable precision analog signal processing from the sensor up to the processor. The AD7981 is complemented by the ADR225 2.5 V output voltage reference and AD8634/AD8229 amplifiers for signal conditioning. High temperature rated MEMS inertial sensors such as the ADXL206 accelerometer and ADXRS645 gyroscope provide designers with information about the orientation and motion of the system. A simplified signal chain of downhole drilling instrument using these components is shown in Figure 7.

In this application, signals from various downhole sensors are sampled in order to collect information about the surrounding geologic formations. These sensors could take the form of electrodes, coils, piezo, or other transducers. Accelerometers, magnetometers, and gyroscopes provide information about the inclination, azimuth, rotation rate, shock, and vibration of the drill string. Some of these sensors are very low bandwidth, while others could have information in the audio frequency range and higher. The AD7981 is able to sample data from sensors with varying bandwidth requirements while maintaining power efficiency. The small footprint makes it easy to include multiple channels even in space constrained layouts, such as the very narrow board widths prevalent in downhole tools. In addition, the flexible digital interface allows for simultaneous sampling in more demanding applications, while also allowing simple daisy-chained readout for low pin count systems.

### SUMMARY

In summary, extreme high temperatures provide one of the biggest challenges in harsh environment systems. However, new high temperature rated ICs, such as the AD7981, are allowing designers to conquer this challenge with off the shelf components that are high precision, low power, and have well qualified reliability.

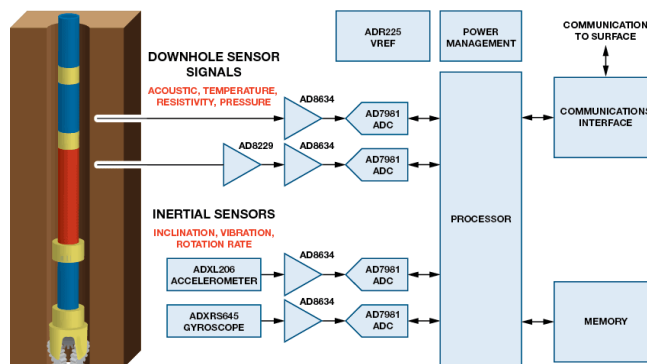


Figure 7. Simplified Signal Chain of Downhole Drilling Instrument

### RESOURCES

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