

Circuits from the Lab
Reference Designs

Circuits from the Lab® reference designs are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit www.analog.com/CN0365.

Devices Connected/Referenced

AD7981	High Temperature, 16-Bit, 600 kSPS PuISAR ADC
AD8634	High Temperature, Low Power, Dual Operational Amplifier
ADR225	High Temperature, Low Power Reference

16-Bit, 600 kSPS, Low Power Data Acquisition System for High Temperature Environments

EVALUATION AND DESIGN SUPPORT

Evaluation Boards

- [CN-0365 Circuit Evaluation Board \(EVAL-CN0365-PMDZ\)](#)
- [System Demonstration Platform \(EVAL-SDP-CB1Z\)](#)
- [PMOD to SDP Interposer Board \(SDP-PMD-IB1Z\)](#)

Design and Integration Files

- [Schematics, Layout Files, Bill of Materials](#)

CIRCUIT FUNCTION AND BENEFITS

A growing number of applications require data acquisition systems that must operate reliably at very high ambient temperature environments, such as downhole oil and gas drilling, avionics, and automotive. The circuit shown in Figure 1 is a 16-bit, 600 kSPS successive approximation analog-to-digital converter (ADC) system using devices rated, characterized, and guaranteed at 175°C. Because many of these harsh environment applications are battery-powered, the signal chain has been designed for low power consumption while still maintaining high performance.

This circuit uses the AD7981, a low power (4.65 mW at 600 kSPS), high temperature PuISAR® ADC, driven directly from the AD8634 high temperature, low power op amp. The AD7981 ADC requires an external voltage reference between 2.4 V and 5.1 V, and in this application, the voltage reference chosen is the micropower ADR225 precision 2.5 V reference, which is also qualified for high temperature operation and has a very low quiescent current of 60 μA maximum at 210°C.

All of the ICs in this design have packaging specially designed for high temperature environments, including monometallic wire bonds. In addition, this reference design describes the selection of the passive components, printed circuit board (PCB) materials, and construction techniques to enable operation at these extreme temperatures. A complete design support package including bill of materials, schematic, assembly, and layout files is also available.

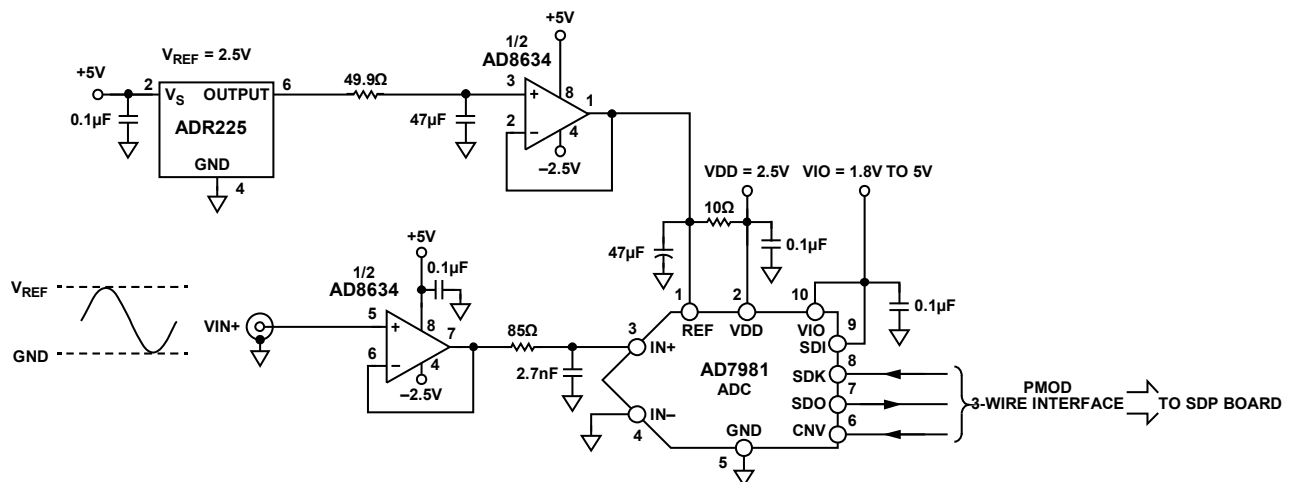


Figure 1. High Temperature Data Acquisition System (Simplified Schematic: All Connections and Decoupling Not Shown)

Rev. 0

Circuits from the Lab reference designs from Analog Devices have been designed and built by Analog Devices engineers. Standard engineering practices have been employed in the design and construction of each circuit, and their function and performance have been tested and verified in a lab environment at room temperature. However, you are solely responsible for testing the circuit and determining its suitability and applicability for your use and application. Accordingly, in no event shall Analog Devices be liable for direct, indirect, special, incidental, consequential or punitive damages due to any cause whatsoever connected to the use of any Circuits from the Lab circuits. (Continued on last page)

CIRCUIT DESCRIPTION

Analog to Digital Converter

The heart of this circuit is the [AD7981](#), a 16-bit, low power, single supply ADC that uses a successive approximation architecture (SAR) and is capable of sampling up to 600 kSPS. As shown in Figure 1, the [AD7981](#) uses two power supply pins: a core supply, VDD, and a digital input/output interface supply, VIO. The VIO pin allows a direct interface with any logic between 1.8 V and 5.0 V. The VDD and VIO pins can also be tied together to save on the number of supplies needed in the system, and they are independent of power supply sequencing.

The [AD7981](#) powers down automatically between conversions to save power. Therefore, the power consumption scales linearly with the sampling rate, making the ADC well suited for both high and low sampling rates (even as low as a few Hz) and enables very low power consumption for battery-powered systems. Additionally, oversampling techniques can be used to increase the effective resolution for low speed signals.

The [AD7981](#) has a pseudo differential analog input structure that samples the true differential signal between the IN+ and IN- inputs and rejects the signals common to both inputs. The IN+ input can accept the unipolar, single-ended input signal from 0 V to V_{REF} , and the IN- input has a restricted range of GND to 100 mV. The pseudo differential input of [AD7981](#) simplifies the ADC driver requirement and lowers power dissipation. The [AD7981](#) is available in a 10-lead MSOP rated for 175°C. A simplified connection diagram is shown in Figure 2.

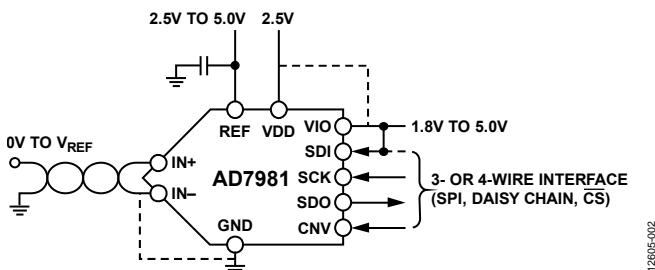


Figure 2. [AD7981](#) Connection Diagram

ADC Driver

The input of [AD7981](#) can be driven directly from low impedance sources; however, high source impedances significantly degrade the ac performance, especially total harmonic distortion (THD). Therefore, it is recommended to use an ADC driver or op amp, such as the [AD8634](#), to drive the input of the [AD7981](#) as shown in Figure 3. At the start of the acquisition time, the switch closes, and the capacitive DAC injects a voltage glitch (kickback) on the ADC input. The ADC driver helps to settle this kickback as well as to isolate it from the signal source.

The low power (1.3 mA/amplifier) [AD8634](#) dual precision op amp is suited for this task because its excellent dc and ac specifications are a good fit for sensor signal conditioning and elsewhere in the signal chain. While the [AD8634](#) has rail-to-rail outputs, the input requires 300 mV headroom from the positive and negative rails.

This headroom requirement necessitates the negative supply, which was chosen to be -2.5 V.

The [AD8634](#) is available in an 8-lead SOIC rated for 175°C and an 8-lead FLATPACK rated for 210°C.

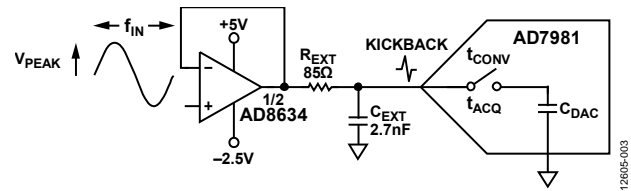


Figure 3. SAR ADC Front End Amplifier and RC Filter

The RC filter between the ADC driver and [AD7981](#) attenuates the kickback injected at the input of the [AD7981](#) and band limits the noise coming to its input. However, too much band limiting can increase settling time and distortion. The calculation of the optimum RC value is primarily based on the input frequency and throughput rate. For the example shown, $R = 85 \Omega$ and $C = 2.7 \text{ nF}$ are the optimum values yielding a cutoff frequency of 693 kHz. Details of the calculations can be found in the Analog Dialogue article, [Front-End Amplifier and RC Filter Design for a Precision SAR Analog-to-Digital Converter](#).

In this circuit, the ADC driver is in unity gain buffer configuration. Adding gain to the ADC driver reduces the bandwidth of the driver and lengthens the settling time. In this case, the throughput of the ADC may need to be reduced or an additional buffer as a driver can be used after the gain stage.

Voltage Reference

The [ADR225](#) 2.5 V voltage reference uses only 60 μA maximum of quiescent current at 210°C and has very low drift of 40 ppm/°C typical, making it an ideal device for this low power data acquisition circuit. The [ADR225](#) has an initial accuracy of $\pm 0.4\%$ and can operate over a wide supply range of 3.3 V to 16 V.

The voltage reference input of the [AD7981](#), like other SAR ADCs, has a dynamic input impedance and must therefore be driven by a low impedance source with efficient decoupling between the REF pin and GND, as shown in Figure 4. The [AD8634](#) is well suited as a reference buffer in addition to its ADC driver application.

Another advantage of using a reference buffer is that the noise on the voltage reference output can be further reduced by adding a low pass RC filter. In this circuit, a 49.9 Ω resistor and 47 μF capacitor give a cutoff frequency of approximately 67 Hz.

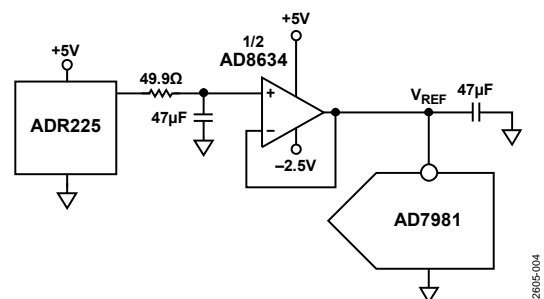


Figure 4. SAR ADC Reference Buffer and RC Filter

During conversions, current spikes as high as 2.5 mA can occur on the [AD7981](#) reference input. A high value reservoir capacitor is placed as close as possible to the reference input to supply that current and to keep the reference input noise low. Typically, a low ESR, 10 μF or more, ceramic capacitor is used; however, for high temperature applications, ceramic capacitors are not available. For this reason, a low ESR, 47 μF tantalum capacitor was chosen that has minimal impact on the performance of the circuit.

Digital Interface

The [AD7981](#) offers a flexible serial digital interface compatible with SPI, QSPI, and other digital hosts. The interface can be configured for a simple 3-wire mode for the lowest input/output count, or 4-wire mode that allows options for the daisy-chained readback and busy indication. The 4-wire mode also allows independent readback timing from the CNV (convert input), which enables simultaneous sampling with multiple converters.

The PMOD interface used on this reference design implements the simple 3-wire mode with SDI tied high to VIO. The VIO voltage is supplied externally from the SDP-PMOD interposer board.

Power Supplies

This reference design requires external, low noise power supplies for the +5 V and -2.5 V rails. Because the [AD7981](#) is low power, it can be supplied directly from the reference buffer, as shown in Figure 5, thereby eliminating the need for an additional power supply rail, saving power and board space.

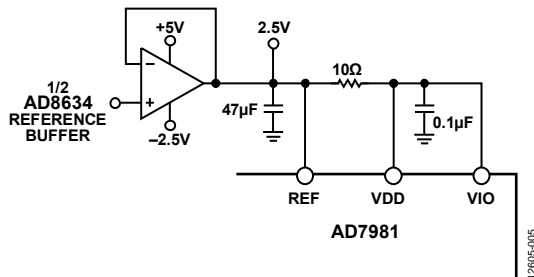


Figure 5. Supplying ADC Reference from Reference Buffer

IC Packaging and Reliability

Devices in the Analog Devices high temperature portfolio go through a special process flow that includes design, characterization, reliability qualification, and production test. Part of this process is special packaging designed specifically for extreme temperatures. A special material is used for the 175°C plastic packages in this circuit.

One of the major failure mechanisms in high temperature packaging is the bond wire-to-bond pad interface, particularly when gold (Au) and aluminum (Al) metals are mixed, as is typical in plastic packages. Elevated temperature accelerates the growth of AuAl intermetallic compounds. It is these intermetallics that are associated with bond failures, such as brittle bonds and voiding, which can occur in a few hundred hours, as shown in Figure 6.

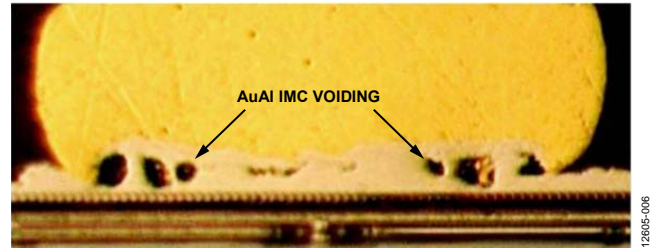


Figure 6. Au Ball Bond on Al Pad, After 500 Hours at 195°C

To avoid these failures, Analog Devices 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 qualification testing with over 6000 hours soak at 195°C, as shown in Figure 7.

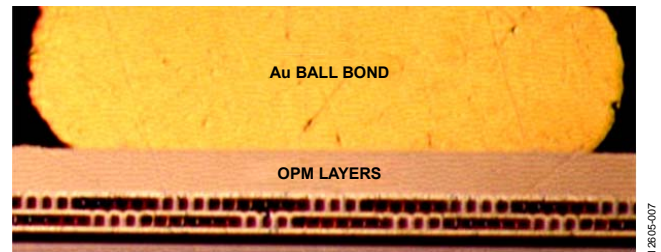


Figure 7. Au Ball Bond on OPM Pad, After 6000 Hours at 195°C

Although Analog Devices 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 molding compound.

In addition to the 175°C rated products used on this circuit, 210°C rated models are also available in a ceramic FLATPACK package. Known good die (KGD) are also available for systems that require custom packaging.

Analog Devices has a comprehensive reliability qualification program for high temperature products that includes high temperature operating life (HTOL), with the devices biased at the maximum operating temperature. High temperature products are data sheet specified for a minimum of 1000 hours at the maximum rated temperature. Full production testing is the last step required to guarantee performance for each device that is manufactured. Each device in the Analog Devices high temperature portfolio is production tested at elevated temperature to ensure that performance is met.

Passive Components

Passive components chosen must be rated for high temperatures. For this design, 175°C+ thin film, low TCR resistors were used. COG/NPO capacitors were used for low value filter and decoupling applications and have a very flat coefficient over temperature. High temperature rated tantalum capacitors are available in larger values than ceramic capacitors and are commonly used for power supply filtering. The SMA connector used on this board is rated for 165°C; therefore, it must be removed for long duration testing at elevated temperatures. Similarly, the insulation material on the 0.1" header connectors (J2 and P3) is only rated for short durations at high temperature and must also be removed for prolonged high temperature testing.

PCB Layout and Assembly

The PCB for this circuit is designed so that the analog signals and digital interface are on opposite sides of the ADC, with no switching signals running under the IC or near analog signal paths. This design minimizes the amount of noise that is coupled into the ADC die and supporting analog signal chain. The pinout of the [AD7981](#), with all its analog signals on the left side and all its digital signals on the right side, eases this task. The voltage reference input, REF, has a dynamic input impedance and must be decoupled with minimal parasitic inductances, which is achieved by placing the reference decoupling capacitor as close as possible to the REF and GND pin and making the connection to the pin with a wide, low impedance trace. The layout of this board was purposely designed with components only on the top side of the board, to facilitate testing over temperature where heat is applied from the bottom of the board. For further layout recommendations, see the [AD7981](#) data sheet.

For high temperature circuits, special circuit materials and assembly techniques must be used to ensure reliability. FR4 is a common material used for PCB laminates; however, commercial grade FR4 has a typical glass transition temperature of approximately 140°C. Above 140°C, the PCB begins to break down, delaminate, and cause stress on components. A widely used alternative for high temperature assemblies is polyimide, which typically has a glass transition temperature of greater than 240°C. A 4-layer polyimide PCB was used in this design.

The PCB surface is also a concern, especially when used with solders containing tin, because of the tendency of the solder to form intermetallics with copper traces. A nickel-gold surface finish is commonly used, where the nickel provides a barrier, and the gold provides a good surface for the solder joint bonding. High melting point solder must also be used with a good margin between the melting point and maximum operating temperature of the system. SAC305 lead free solder was chosen for this assembly. With a melting point of 217°C, there is a margin of 42°C from the highest operational temperature of 175°C.

Performance Expectations

The [AD7981](#) is specified for 91 dB SNR typical with a 1 kHz input tone and a 5 V reference. However, when using low reference voltages, as is common in low power/low voltage systems, some degradation in SNR is expected. From the [AD7981](#) data sheet typical performance curves, approximately 86 dB of SNR is expected at room temperature with a 2.5 V reference. This SNR value compares well with the performance achieved when the circuit was tested at room temperature with approximately 86 dB SNR, as shown in Figure 8.

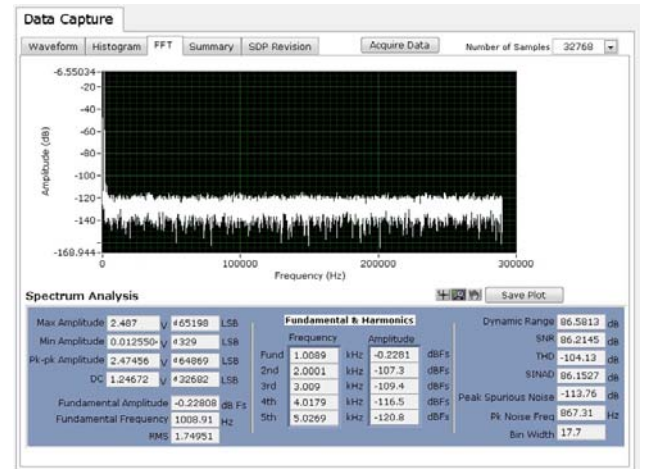


Figure 8. AC Performance with 1 kHz Input Tone, 580 kSPS, 25°C

When this circuit is evaluated over temperature, SNR performance only degrades to approximately 84 dB at 175°C, as shown in Figure 9. THD remains better than -100 dB, as shown in Figure 10. The FFT summary for the circuit at 175°C is shown in Figure 11.

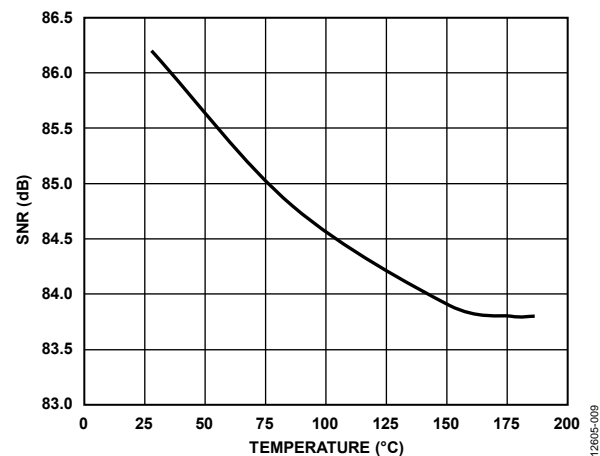


Figure 9. SNR over Temperature, 1 kHz Input Tone, 580 kSPS

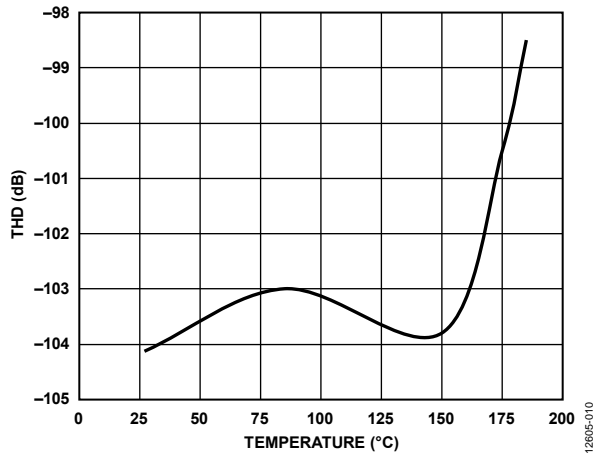


Figure 10. THD over Temperature, 1 kHz Input Tone, 580 kSPS

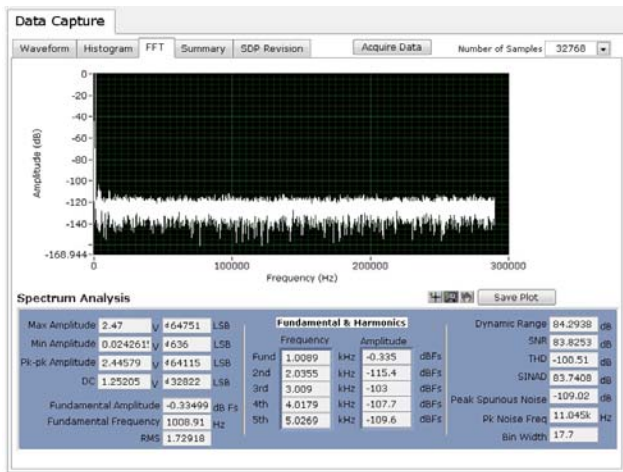


Figure 11. AC Performance with 1 kHz Input Tone, 580 kSPS, 175°C

CIRCUIT EVALUATION AND TEST

This circuit uses the [EVAL-CN0365-PMDZ](#) circuit board, the [SDP-PMD-IB1Z](#) interposer board, and the [EVAL-SDP-CB1Z](#) system demonstration platform (SDP) board. The interposer board and the SDP board have 120-pin mating connectors. The interposer board and the [EVAL-CN0365-PMDZ](#) board have 12-pin PMOD matching connectors, allowing quick setup and evaluation of the circuit performance. The [EVAL-CN0365-PMDZ](#) board contains the circuit to be evaluated, as described in the [CN-0365](#), and the SDP evaluation board is used with the [CN-0365 Evaluation Software](#).

Equipment Needed

The following equipment is needed:

- [EVAL-CN0365-PMDZ](#) board
- System Demonstration Platform ([EVAL-SDP-CB1Z](#))
- PMOD to SDP Interposer Board ([SDP-PMD-IB1Z](#))
- [CN-0365 Evaluation Software](#)
- Function generator/signal source, such as the Audio Precision SYS-2522 used in these tests
- Power supplies: +5 V and -2.5 V
- Power supply: +6 V wall wart ([EVAL-CFTL-6V-PWRZ](#))
- PC operating Windows® XP (SP2), Windows Vista or Windows 7 Business/Enterprise/Ultimate editions (32-bit/64-bit systems) with USB port and USB cable

Getting Started

To get started, take the following steps:

1. Download the [CN-0365 Evaluation Software](#) to the PC from <ftp://ftp.analog.com/pub/cftl/CN0365>.
2. Install the software prior to connecting the SDP board to the USB port of the PC, to ensure that the SDP board is recognized when it connects to the PC.
3. Unzip the downloaded file.
4. Run the **setup.exe** file.
5. Follow the on-screen prompts to finish the installation. It is recommended to install all software components to the default locations.

Functional Block Diagram

Figure 12 shows the functional diagram of the test setup.

Setup

To set up the circuit, take the following steps:

1. Connect the [EVAL-CFTL-6V-PWRZ](#) (+6 V dc power supply) to the [SDP-PMD-IB1Z](#) interposer board via the dc barrel jack.
2. Connect the [SDP-PMD-IB1Z](#) interposer board to the [EVAL-SDP-CB1Z](#) SDP board via the 120-pin CON A connector.
3. Connect the [EVAL-SDP-CB1Z](#) SDP board to the PC via the USB cable.
4. Connect the [EVAL-CN0365-PMDZ](#) evaluation board to the [SDP-PMD-IB1Z](#) interposer board via the 12-pin header PMOD connector.
5. Connect the +5 V (V_{S+}) and -2.5 V (V_{S-}) power supplies to the [EVAL-CN0365-PMDZ](#) P3 header. The VDD voltage (2.5 V) does not need an external connection in the default configuration because it is generated on-board.
6. Connect the signal source to the [EVAL-CN0365-PMDZ](#) via the SMA connector.
7. Set the Audio Precision SYS-2522 (or equivalent signal generator) for a 1 kHz frequency and a 2.5 V p-p sine wave with a 1.25 V dc offset.

Test

Launch the evaluation software. The software communicates to the SDP board if the Analog Devices System Development Platform drivers are listed in Windows Device Manager. After USB communications are established, the evaluation software can be used to test, view, and save circuit performance metrics.

Further details on the operation of the software can be found in the [UG-340](#) and at the [Evaluating 14-/16-/18-Bit ADCs from the 8/10 LEAD PulSAR® Family](#) wiki page.

For testing over temperature in an environmental chamber, extension harnesses (not supplied) can be used for the analog input, power supply, and PMOD connections. These harnesses must be as short as possible, and best practices must be used to avoid noise. The SMA connector used on this board is rated for 165°C; therefore, it must be removed for long duration testing at elevated temperatures. Similarly, the insulation material on the 0.1" header connectors (J2 and P3) is only rated for short durations at high temperature and must also be removed for prolonged high temperature testing.

A photo of the [EVAL-CN0365-PMDZ](#) board is shown in Figure 13.

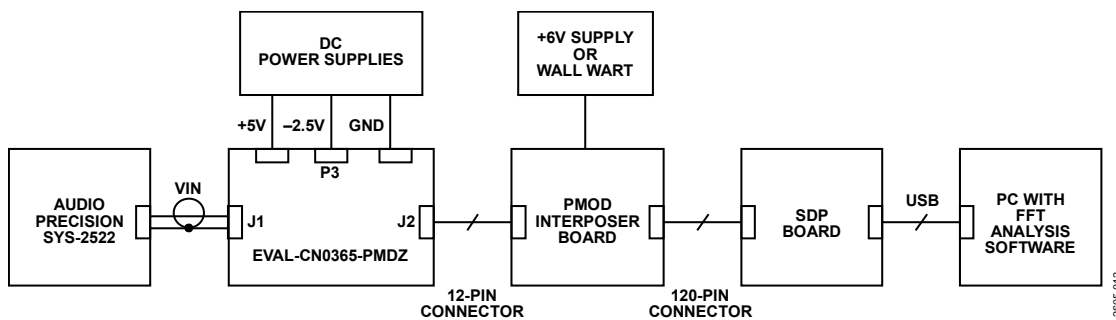


Figure 12. Circuit Test Setup for Measuring AC Performance

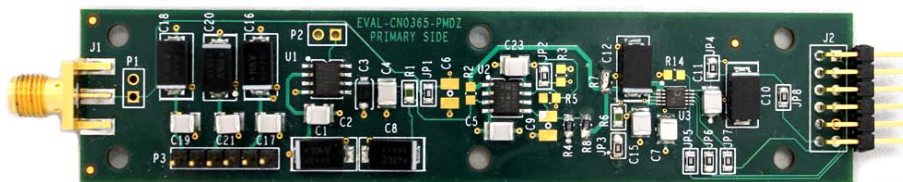


Figure 13. Photo of [EVAL-CN0365-PMDZ](#) Circuit Board

LEARN MORE

CN-0365 Design Support Package:

www.analog.com/CN0365-DesignSupport

[System Demonstration Platform \(SDP\)](#)

[UG-340 User Guide](#)

[Evaluating 14-/16-/18-Bit ADCs from the 8/10 LEAD PulSAR® Family Wiki Page](#)

[High Temperature Products from Analog Devices](#)

[Watson, Jeff and Gustavo Castro, “High Temperature Electronics Pose Design and Reliability Challenges,” Analog Dialogue, Volume 46, April 2012.](#)

[Watson, Jeff and Maithil Pachchigar, “Harsh Environments Conquered—Lower Power, Precision, High Temperature Components for Extreme Temperature Applications,” MS-2707, Analog Devices.](#)

[Walsh, Alan, “Front-End Amplifier and RC Filter Design for a Precision SAR Analog-to-Digital Converter,” Analog Dialogue, Vol. 46, December 2012.](#)

[Walsh, Alan “Voltage Reference Design for Precision Successive-Approximation ADCs,” Analog Dialogue, Vol. 47, June 2013.](#)

[MT-021 Tutorial, *Successive Approximation ADCs*, Analog Devices](#)

[MT-031 Tutorial, *Grounding Data Converters and Solving the Mystery of “AGND” and “DGND,”* Analog Devices.](#)

Data Sheets and Evaluation Boards

[CN-0365 Circuit Evaluation Board \(EVAL-CN0365-PMDZ\)](#)

[System Demonstration Platform \(EVAL-SDP-CB1Z\)](#)

[SDP-PMOD Interposer Board \(SDP-PMD-IB1Z\)](#)

[AD7981 Data Sheet](#)

[AD8634 Data Sheet](#)

[ADR225 Data Sheet](#)

REVISION HISTORY

6/15—Revision 0: Initial Version

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