http://www.analog.com/zh/circuits-from-the-lab/CN0267/vc.html

Complete 4 mA to 20 mA Loop Powered Field Instrument with HART Interface (CN0267)

具有 HART 接口的完整 4 mA 至 20 mA 环路供电现场仪器(CN0267)

Devices Connected/Referenced

连接/参考器件

ADuCM360 Low Power, Precision Analog Microcontroller

ADuCM360：低功耗、精密模拟微控制器

AD5421 16-Bit, Loop Powered, 4 mA to 20 mA DAC

AD5421：16 位、环路供电、4 mA 至 20 mA DAC

AD5700 Low Power HART Modem

AD5700：低功耗 HART 调制解调器

EVALUATION AND DESIGN SUPPORT

评估和设计支持

ircuit Evaluation Board

电路评估板

CN0267 Circuit Evaluation Board (DEMO-AD5700D2Z)

CN0267 电路评估板(DEMO-AD5700D2Z)

Design and Integration Files

设计和集成文件

Schematics, Layout Files, Bill of Materials, Code Example

原理图、布局文件、物料清单、代码示例

CIRCUIT FUNCTION AND BENEFITS

电路功能与优势

The circuit shown in Figure 1 is a complete smart industrial, loop powered field instrument with 4 mA to 20 mA analog output and a highway addressable remote transducer (HART®) interface. HART is a digital 2-way communication in which a 1 mA peakto- peak frequency-shift-keyed (FSK) signal is modulated on top of the standard 4 mA to 20 mA analog current signal. This allows features such as remote calibration, fault interrogation, and transmission of process variables, which are necessary in applications such as temperature and pressure control.

图 1 所示电路是一款完整的智能工业环路供电现场仪器，提供 4 mA 至 20 mA 模拟输出和可寻址远程传感器高速通道(HART®)接口。HART 是一种数字双向通信，可在 4 mA 至 20 mA 模拟电流信号之上调制一个 1 mA 峰峰值频移键控(FSK)信号。它可实现众多功能，例如远程校准、故障查询和过程变量传输；这些功能在诸如温度和压力控制等应用中是必须的。

This circuit has been compliance tested, verified, and registered by the HART Communication Foundation (HCF). This successful registration provides circuit designers with a high level of confidence using one or all of the components in the circuit.

该电路已通过兼容性测试和验证，并通过了 HART 通信基金会(HCF)的注册。这一成功注册可让电路设计人员极其放心地使用电路中的一个或全部元件。

The circuit uses the [ADuCM360](), an ultralow power, precision analog microcontroller, the [AD5421](), a 16-bit, 4 mA to 20 mA, loop powered digital-to-analog converter (DAC), and the [AD5700](), the industry's lowest power and smallest footprint HARTcompliant IC modem.

该电路使用了超低功耗精密模拟微控制器 ADuCM360、4 mA 至 20 mA 16 位环路供电数模转换器(DAC) AD5421，以及低功耗，小尺寸的 HART 兼容型 IC 调制解调器 AD5700。

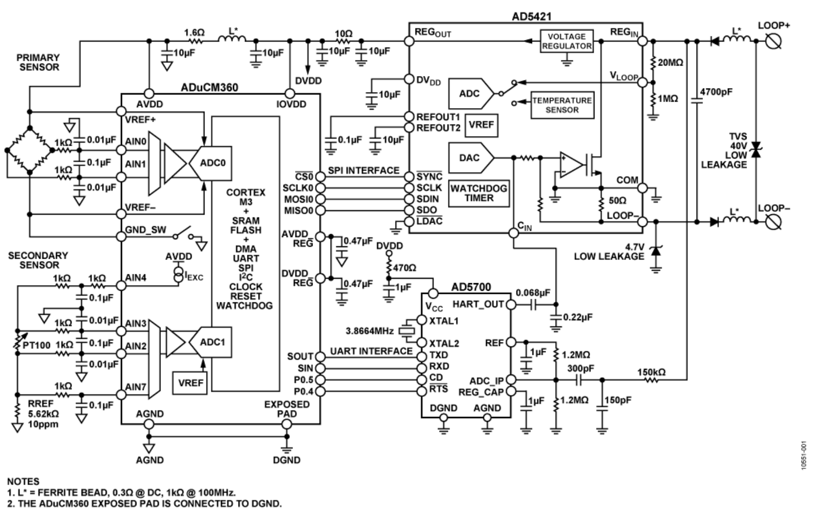

Figure 1. 4 mA to 20 mA, Loop Powered Field Instrument with HART Interface (Simplified Schematic: All Connections and Decoupling Not Shown)

图 1. 具有 HART 接口的 4 mA 至 20 mA 环路供电现场仪器（原理示意图：未显示所有连接和去耦）

Enlarge
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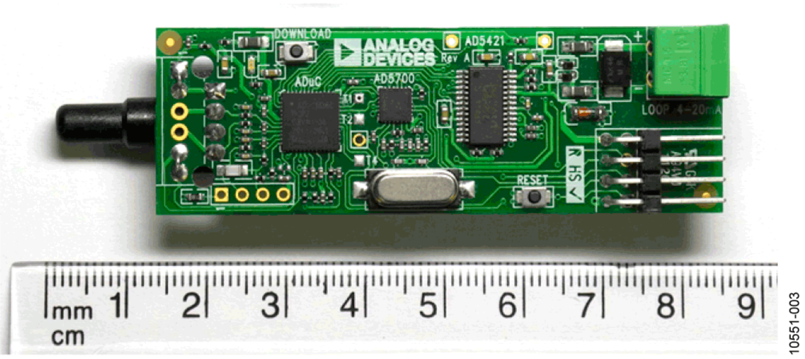

Figure 1A. DEMO-AD5700D2Z Printed Circuit Board

图 1A.DEMO-AD5700D2Z 印刷电路板

Enlarge
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back to top
返回页首

CIRCUIT DESCRIPTION

电路描述

Analog Front-End Interface

模拟前端接口

The ADuCM360 analog front-end incorporates dual, high performance 24-bit sigma-delta (Σ-Δ) analog-to-digital converters (ADCs). It also integrates programmable gain instrumentation amplifiers, a precision band-gap reference, programmable current sources, a flexible multiplexer, and many other features. It allows a direct interface to multiple analog sensors, such as pressure sensor bridges, resistive temperature sensors, thermocouples, and many other types of sensors used in the industry.

ADuCM360 模拟前端集成双通道、高性能、24 位 Σ-Δ 型模数转换器(ADC)。同时还集成了可编程增益仪表放大器、精密带隙基准电压源、可编程电流源、灵活的多路复用器以及其它许多特性。该器件允许直接与多个模拟传感器对接，如压力传感器电桥、电阻式温度传感器、热电偶以及工业用途的其它各类传感器。

The circuit in Figure 1 shows an example connection for a primary bridge type sensor and a secondary resistive temperature sensor; however the ADuCM360 flexible front-end allows many other configurations to accommodate any type of precision analog sensor application.

图 1 表示连接主要桥式传感器与辅助电阻式温度传感器的示例电路。而 ADuCM360 具有灵活的前端，允许进行除此之外的其它各种配置，满足各种类型的精密模拟传感器应用要求。

Primary Sensor Input

主传感器输入

The ADuCM360 on-chip ADC0 measures the field instrument primary sensor, shown as a bridge transducer in Figure 1. The sensor connects to the analog input pins, AIN0 and AIN1, via an RC filter network for improved system electromagnetic immunity. The common-mode filter bandwidth is approximately 16 kHz, and the differential-mode bandwidth is 800 Hz.

ADuCM360 的片内 ADC0 测量现场仪器的主传感器，在图 1 中表示为桥式传感器。该传感器通过一个 RC 滤波器网络连接至模拟输入引脚 AIN0 和 AIN1，以便增强系统抵抗电磁干扰的能力。共模滤波器带宽约为 16 kHz，差模带宽为 800 Hz。

The ADuCM360 VREF+ and VREF− voltage reference inputs sense the bridge excitation voltage and enable the circuit to work in a ratiometric mode, making the measurement independent of the exact value of the sensor power supply voltage. The on-chip ground switch can dynamically disconnect the bridge excitation and save power when required by the application.

ADuCM360 的 VREF+和 VREF−基准电压输入检测电桥的激励电压并启动电路的比率工作模式，使测量独立于传感器电源电压的确切值。若应用需要，则片内接地开关可动态断开电桥的激励电压，降低功耗。

Secondary Sensor Input

辅助传感器输入

The circuit uses a platinum (Pt) 100 Ω resistive temperature device (RTD) as a secondary sensor. The RTD can sense the temperature of the primary sensor and thus allow for temperature compensation of the primary sensor if required.

本电路使用 100 Ω 铂(Pt)电阻温度检测器(RTD)作为辅助传感器。RTD 能够检测主传感器的温度，因此，如果必要，可对主传感器进行温度补偿。

The ADuCM360 programmable current source supplies the RTD via the AIN4 pin. The ADC1 on the ADuCM360 measures the voltage across the RTD using the AIN3 and AIN2 pins configured as a differential input. The exact value of the current flowing through the RTD is sensed by a precision resistor (RREF) and is measured by the ADC1 using the AIN7 pin. The ADC1 uses the on-chip, band-gap voltage reference.

ADuCM360 可编程电流源通过 AIN4 引脚为 RTD 提供电源。ADuCM360 上的 ADC1 利用配置为差分输入的 AIN3 和 AIN2 引脚，测量 RTD 的电压。利用精密电阻(RREF)，对流过 RTD 的确切电流值进行检测，并使用 ADC1 的 AIN7 引脚测得。ADC1 使用片内带隙基准电压源。

Digital Data Processing, Algorithm, and Communications
数字数据处理、算法和通信

All the field instrument digital functions are provided by the ADuCM360 32-bit ARM Cortex™ M3 RISC processor, with integrated 128 k bytes of nonvolatile flash/EE memory, 8 k bytes of SRAM, and an 11-channel direct memory access (DMA) controller that supports wired (2× SPI, UART, I²C) communication peripherals.

所有现场仪器的数字功能均由 ADuCM360 32 位 ARM Cortex™ M3 RISC 处理器提供，该处理器集成 128 k 字节非易失性 flash/EE 存储器、8 k 字节 SRAM，以及一个支持有线（2× SPI、UART、I²C）通信外设的 11 通道直接存储器访问(DMA)控制器。

The demonstration software performs the initialization and configuration, processes data from the analog inputs, controls the analog output, and performs the HART communication.

演示软件可进行初始化和配置、处理来自模拟输入的数据、控制模拟输出，并进行 HART 通信。

Analog Output
模拟输出

The AD5421 integrates a low power precision 16-bit DAC with a 4 mA to 20 mA, loop powered output driver and provides all functions required for the field instrument analog output.

AD5421 集成 16 位低功耗精密 DAC，该 DAC 带 4 mA 至 20 mA 环路供电输出驱动器，可提供现场仪器模拟输出所需的全部功能。

The AD5421 interfaces with the ADuCM360 controller via the SPI interface.

AD5421 通过 SPI 接口与 ADuCM360 控制器对接。

The AD5421 also includes a range of diagnostic functions related to the 4 mA to 20 mA loop. The auxiliary ADC can measure the voltage across the instruments loop terminals via the 20 MΩ/1 MΩ resistive divider connected to the VLOOP pin. The ADC can also measure the chip temperature via the integrated sensor. The ADuCM360 controller can configure and read all the diagnostics of the AD5421, but the AD5421 can also operate autonomously.

AD5421 还集成了一系列与 4 mA 至 20 mA 环路相关的诊断功能。辅助 ADC 可通过连接至 VLOOP 引脚上的 20 MΩ/1 MΩ 电阻分压器测量仪器环路端的电压。该 ADC 还可通过集成式传感器测量芯片温度。ADuCM360 控制器可配置并读取 AD5421 的全部诊断数据，但 AD5421 也可采用自主工作方式。

As an example, if the communication between the controller and the AD5421 fails, the AD5421 automatically sets its analog output to a 3.2 mA alarm current after a defined period. This alarm current indicates to the host that the field instrument failed to operate.

例如，若控制器和 AD5421 之间的通信发生故障，AD5421 将在一段时间后自动设置其模拟输出为 3.2 mA 报警电流。此报警电流将现场仪器工作故障这一情况汇报给主机。

The software controls any change of the output current from one value to another to prevent disturbance of the HART communication. (See the Analog Rate of Change section).

输出电流值的任何改变都受到软件的控制，以防对 HART 通信产生干扰。（参见“模拟变化率”部分）。

HART Communication

HART 通信

The AD5700 integrates a complete HART FSK modem. The modem is connected to the ADuCM360 controller via a standard UART interface, complemented by request to send (RTS) and carrier detect (CD) signals.

AD5700 集成完整的 HART FSK 调制解调器。该调制解调器通过标准 UART 接口，伴随请求发送(RTS)和载波检测(CD)信号实现与 ADuCM360 控制器的连接。

The HART output is scaled to the required amplitude by the 0.068 μF/0.22 μF capacitive divider and coupled to the AD5421 CIN pin, where it is combined with the DAC output to drive and modulate the output current.

HART 输出通过 0.068 μF/0.22 μF 容性分压器调整至所需幅度，并耦合至 AD5421 的 CIN 引脚，然后与 DAC 输出一同驱动和调制输出电流。

The HART input is coupled from LOOP+ via a simple passive RC filter to the AD5700 ADC_IP pin. The RC filter works as the first stage, band-pass filter for the HART demodulator and also improves the system electromagnetic immunity, which is important for robust applications working in harsh industrial environments.

HART 输入通过一个简单的有源 RC 滤波器，从 LOOP+端耦合至 AD5700 的 ADC_IP 引脚。RC 滤波器作为第一级，用作 HART 解调器的带通滤波器，同时增强系统抵抗电磁干扰的能力——这对于稳定工作在恶劣工业环境中的应用而言非常重要。

The AD5700 low power oscillator generates the clock for the HART modem with a 3.8664 MHz external crystal connected directly to the XTAL1 and XTAL2 pins.

AD5700 低功耗振荡器采用与 XTAL1 和 XTAL2 引脚直接相连的 3.8664 MHz 外部晶振，产生 HART 调制解调器的时钟。

Output Protection
输出保护

A transient voltage suppressor (TVS) protects the 4 mA to 20 mA HART interface from overvoltage. Its voltage rating should prevent exceeding the AD5421 absolute maximum voltage of 60 V on the REGIN pin. Note that the TVS leakage current can affect the current output accuracy; therefore, pay attention to the leakage current at a given loop voltage and temperature range when selecting this component.

瞬变电压抑制器(TVS)保护 4 mA 至 20 mA HART 接口免受过压影响。其额定电压不应超过 AD5421 在 REGIN 引脚上的 60 V 绝对最大电压。请注意，TVS 泄漏电流可能会影响电流输出精度；因此，选用此器件时，需关注一定环路电压和温度范围下的泄漏电流。

An external depletion-mode FET can be used with the AD5421 to increase the loop voltage maximum

可使用外部耗尽型 FET 与 AD5421 搭配工作，提高环路电压最大值。

The circuit is protected against reversed polarity by a pair of diodes in series with loop output.

本电路具有保护功能，通过与环路输出相串联的一对二极管保护电路免受极性反转的影响。

The ferrite beads in series with the loop together with the 4700 pF capacitor improve the system EMC performance. Do not use a higher capacitance across the loop terminals because of the HART network specifications.

铁氧体磁珠与环路串联，该串联部分与 4700 pF 电容一同提升系统的 EMC 性能。由于 HART 网络的规格限制，请勿在环路端点处使用更高数值的电容。

The 4.7 V, low leakage, Zener diode protects the AD5421 on-chip, 50 Ω loop sense resistor in the event of an accidental external voltage between the AD5421 COM pin and LOOP− pin (for example, when programming the ADuCM360 or debugging the circuit).

4.7 V 低泄露齐纳二极管保护 AD5421 的片内 50 Ω 环路检测电阻免受 AD5421 的 COM 引脚和 LOOP−引脚间意料之外的外部电压影响（例如，对 ADuCM360 编程或调试电路时）。

Power Supplies and Power Management

电源和电源管理

The complete field instrument circuitry, including the sensor drive current, must operate on the limited amount of power available from the 4 mA to 20 mA loop. This is a common challenge in any loop powered field instrument design. The circuit in Figure 1 provides an example of delivering both a low power and high performance solution. All three integrated circuits used in the application are designed for low power, and the circuit leverages their integrated features to deliver a flexible power management structure and an optimum loop-powered solution.

包括传感器驱动电流在内的完整现场仪器电路必须工作在 4 mA 至 20 mA 环路提供的限量电源下。这对所有环路供电现场仪器设计而言，都是一个普遍的难题。图 1 中的电路提供了低功耗以及高性能解决方案的一个实例。应用中用到的全部三个集成电路均针对低功耗而设计，并且电路依靠各自的集成特性提供灵活的电源管理结构和性能最优的环路供电解决方案。

The AD5421 is powered by the 4 mA to 20 mA loop voltage and provides a regulated low voltage for the rest of the circuit. The AD5421 REG_{OUT} voltage is pin programmable from 1.8 V to 12 V depending on circuit requirements. The circuit in Figure 1 uses the 3.3 V supply voltage option as an example for the input sensors used. However, the ADuCM360 and the AD5700 have a wider power supply voltage range; therefore, a different power supply voltage can be used to suit the application.

AD5421 采用 4 mA 至 20 mA 环路电压供电，为电路的其余部分提供经过调节的低电压。AD5421 的 REG_{OUT} 电压在 1.8 V 至 12 V 范围内引脚可编程，具体电压值取决于电路要求。图 1 中的电路采用 3.3 V 电源电压选项，作为所用输入传感器的一个实例。然而，由于 ADuCM360 和 AD5700 具有更宽的电源电压范围，因此可采用不同的电源电压，以满足应用要求。

The REG_{OUT} RC filter (10 µF/10 Ω/10 µF) helps to prevent any interference coming from the loop affecting the sensor analog front-end. It also prevents any interference generated by the circuit, specifically by the controller and the digital circuitry, from coupling back to the loop, which is important for a reliable HART communication.

REG_{OUT} RC 滤波器(10 µF/10 Ω/10 µF)有助于防止传感器模拟前端受到来自环路的任何干扰的影响。它还能防止电路产生的任何干扰（尤其是控制器和数字电路产生的干扰）回流耦合至环路，这对于可靠的 HART 通信而言非常重要。

The AD5700 HART modem is supplied through an additional RC filter (470 Ω/1 µF). This filter is very important in the loop powered application because it prevents current noise from the AD5700 from coupling to the 4 mA to 20 mA loop output, which would otherwise affect the HART communication. The 4 mA to 20 mA loop noise performance is specifically addressed by the HART in-band, noise during silence test. The AD5700 modem uses the external crystal with 8.2 pF capacitors to ground on the XTAL1 and XTAL2 pins, which is the option using the least possible power.

AD5700 HART 调制解调器通过一个额外的 RC 滤波器供电(470 Ω/1 µF)。该滤波器在环路供电应用中的作用非常重要，因为它可防止 AD5700 的电流噪声与 4 mA 至 20 mA 环路输出进行耦合；若非如此，将影响 HART 通信。在静默测试期间，特地通过 HART 带内噪声解决 4 mA 至 20 mA 环路噪声性能问题。AD5700 调制解调器使用外部晶振，通过将 XTAL1 和 XTAL2 上的 8.2 pF 电容接地，在可达到的功耗范围中选择最低值。

The ADuCM360 has very flexible internal power management, with many options for powering and clocking all the internal blocks and, when utilized by the software, allows an optimal balance between the required function, performance, and power for the specific instrument application. Refer to the ADuCM360 product page and the AN-1111 Application Note.

ADuCM360 具有极为灵活的内部电源管理功能，提供所有内部模块的许多供电和时钟选项，并且当软件调用时，允许针对特定的仪器应用，在要求的功能、性能和功耗之间取得最佳平衡。请参考 ADuCM360 产品页面和 AN-1111 应用指南。

The analog front-end AVDD is supplied from another filter (10 μF/ferrite bead/1.6 Ω/10 μF) to minimize power supply noise for better performance with respect to low voltage sensor signals.

模拟前端 AVDD 通过另一个滤波器（10 μF/铁氧体磁珠/1.6 Ω/10 μF）供电，以便最大程度针对低压传感器信号减少电源噪声，获得更佳性能。

The GND_SW ground switch pin of the ADuCM360 controls the excitation/power supply for the primary sensor. The switch is off as a default at the instrument power up. This default allows the system to be fully configured, including appropriate power modes, before turning on the sensor, and thus minimizes any possible power-up spikes on the 4 mA to 20 mA loop output.

ADuCM360 的 GND_SW 接地开关引脚控制主传感器的激励和电源。仪器上电时，开关默认为关闭。这一默认设定允许在开启传感器之前对系统进行全面配置，包括适当的电源模式，从而最大程度降低 4 mA 至 20 mA 环路输出上可能存在的任何上电尖峰。

Similarly, the secondary sensor is supplied from the programmable current source of the ADuCM360, and therefore, its power is fully controlled by the software.

类似地，辅助传感器采用 ADuCM360 的可编程电流源供电，因此可通过软件完全控制其电源输入。

ADuCM360 Software

ADuCM360 软件

A basic code example that demonstrates the functionality and performance of the circuit can be found in the CN-0267 Design Support Package.

可在 CN-0267 设计支持包中找到演示本电路功能和性能的基本代码示例。

The code example includes a basic HART slave command response to demonstrate the hardware function and capability. However, the code example does not include the protocol layers of the HART communication.

代码示例包括基本 HART 从机命令响应，用于演示硬件的功能和特性。代码示例不包括 HART 通信的协议层。

back to top
返回页首

COMMON VARIATIONS

常见变化

The ADuCM360 has a high performance and very flexible analog front-end, with 12 analog input pins and extra pins for voltage reference and ground switch. It allows direct interface to multiple analog sensors of varying types, such as any resistive bridge sensors, resistive temperature sensors, or thermocouples. Therefore, do not limit the field instrument solution to temperature-compensated pressure measurement only because it can be used for almost any sensor field instrument.

ADuCM360 具有一个高性能且非常灵活的模拟前端，提供 12 个模拟输入引脚以及供基准电压源和接地开关使用的额外引脚。它允许与多个各类模拟传感器直接接口，比如任意的阻性桥式传感器、电阻式温度传感器或热电偶。由于可用于几乎所有的传感器现场仪器，这款现场仪器解决方案并不局限于温度补偿型压力测量。

The ADuCM361 can be used as an alternative to the ADuCM360 in applications that need only one Σ-Δ ADC in the analog front-end. Aside from the second ADC, the ADuCM361 contains all the features of the ADuCM360.

在模拟前端只需一个 Σ-Δ 型 ADC 的应用中，可使用 ADuCM361 替换 ADuCM360。除了备用 ADC，ADuCM361 提供 ADuCM360 的所有特性。

The ADuCM361 on-chip DAC with an external transistor can be used to control the 4 mA to 20 mA loop, refer to CN-0300 for details.

ADuCM361 片内 DAC 和外部晶体管可用于控制 4 mA 至 20 mA 环路，详情请参见 CN-0300。

The AD5421 can be connected via the protection directly to the loop. Alternatively, a depletion mode N-channel MOSFET can be connected between the AD5421 and the loop power supply, as shown in Figure 2. The use of the additional MOSEFT in this configuration keeps the voltage drop across the AD5421 at approximately 12 V, lowers the power dissipated in the AD5421 package, and therefore improves the 4 mA to 20 mA analog output accuracy. It also increases the maximum voltage allowed in the loop to the level of the MOSFET rating. The additional MOSFET has no effect on the HART communication.

AD5421 可通过保护电路直接与环路相连。也可在 AD5421 和环路电源之间连接一个耗尽型 N 沟道 MOSFET，如图 2 所示。由于在本配置中使用额外 MOSFET，因此可将 AD5421 上的电压降保持在 12 V 左右，降低 AD5421 封装的功耗，并增加 4 mA 至 20 mA 模拟输出精度。它还可将环路允许的最大电压提升至 MOSFET 的额定电平值。额外的 MOSFET 对 HART 通信无影响。

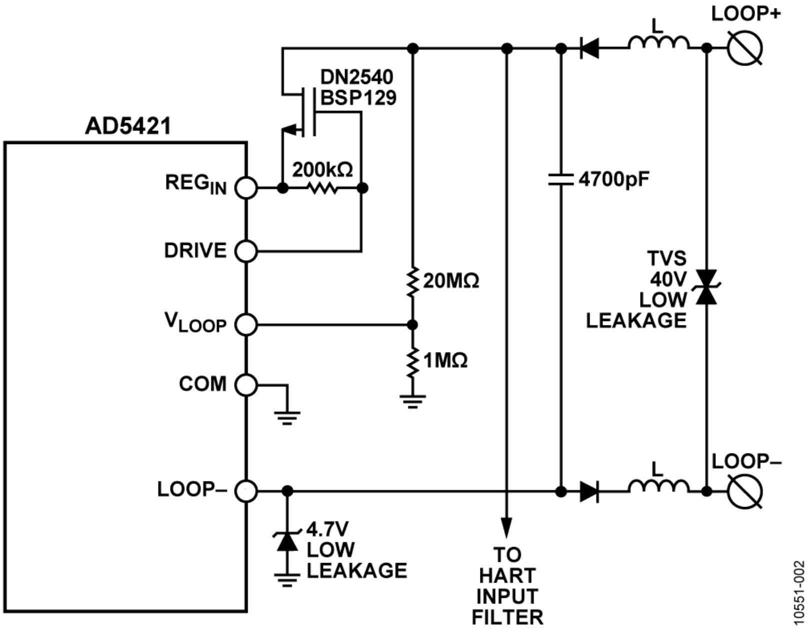

Figure 2. MOSEFT Connected to the AD5421 Loop Power Supply

图 2. MOSEFT 连接至 AD5421 环路电源

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The AD5700 is used with a 3.8664 MHz crystal in this circuit, which is the configuration achieving the lowest power consumption. Alternatively, the AD5700-1, with an integrated 0.5 %precision internal oscillator, can be used. The internal oscillator increases the modem power supply current by 225 µA maximum, compared to the crystal oscillator, but because no external crystal is needed, this option provides both cost savings and reduced board area requirements.

本电路中，AD5700 与 3.8664 MHz 晶振共同使用，形成具有最低功耗的配置。作为替代方案，AD5700-1 可配合 0.5 %精度的集成式内部振荡器使用。与晶体振荡器相比，内部振荡器最多可提升 225 µA 调制解调器电源电流，但因为无需使用外部晶体，因此该方案同时节省了成本，降低了所需的电路板面积。

For the applications that are not loop powered, the AD5410, AD5420, AD5422, or AD5755 are good choices for the 4 mA to 20 mA DAC.

对于非环路供电的应用，则 AD5410、AD5420、AD5422 或 AD5755 是针对 4 mA 至 20 mA DAC 不错的选择。

back to top
返回页首

CIRCUIT EVALUATION AND TEST

电路评估与测试

Circuit Hardware

电路硬件

The circuit shown in Figure 1 is built on the DEMO-AD5700D2Z printed circuit board shown in Figure 3.

图 1 中的电路基于图 3 中的 DEMO-AD5700D2Z 印刷电路板构建。

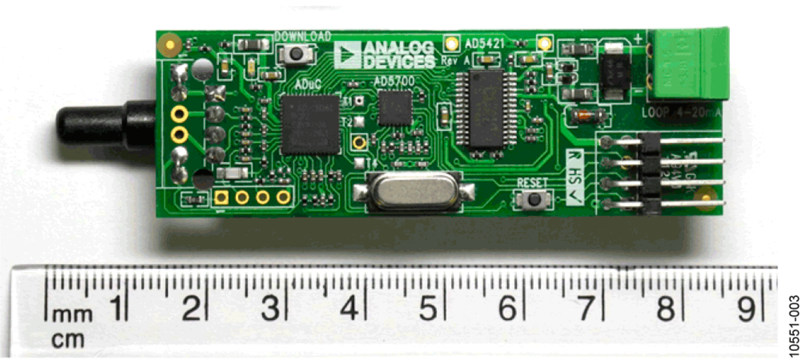

Figure 3. DEMO-AD5700D2Z Printed Circuit Board

图 3. DEMO-AD5700D2Z 印刷电路板

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The DEMO-AD5700D2Z circuit board includes some additional features for easy system evaluation. The 0.1 inch-pitch connector footprints allow optional primary and secondary sensor connections. There are test points for HART RTS and CD signals, which may be needed for HART compliance tests.

DEMO-AD5700D2Z 电路板具有一些额外的特性，方便进行系统评估。连接器具有 0.1 英寸的引脚间距，允许使用可选的主级和次级传感器连接。HART 兼容性测试可能需要用到 HART RTS 和 DC 信号的测试点。

A connector on the edge of the DEMO-AD5700D2Z makes the ADuCM360 single wire and UART download/debug signals accessible allowing easy software development, code download and in-circuit debugging and emulation. The connector—with a small header extender included with the DEMO-AD5700D2Z board—is compatible with all the Analog Devices, Inc., Cortex-M3 based development tools, such as the EVAL-ADuCM360QSPZ evaluation kit (the evaluation kit is not included with the DEMO-AD5700D2Z board).

DEMO-AD5700D2Z 边沿上的连接器使 ADuCM360 信号线和 UART 下载/调试信号可被访问，让软件开发、代码下载和在线调试与仿真更为便捷。连接器带有小型的连接头扩展器（随 DEMO-AD5700D2Z 板一同提供），兼容 ADI 的所有基于 Cortex-M3 的开发工具，例如 EVAL-ADuCM360QSPZ 评估套件（该评估套件不随 DEMO-AD5700D2Z 板提供）。

These features are not shown in the simplified diagram in Figure 1; however, they can be seen in the complete circuit schematic in the CN-0267 Design Support Package. The design support package also includes a full field instrument C-code example, which enables complete verification and evaluation of all hardware blocks and features of the circuit, and a limited verification of the HART interface functionality. For detailed information about HART interface specifications and resources, please contact the Hart Communication Foundation.

图 1 的简化框图中未显示这些特性；然而，可在 CN-0267 设计支持包中的完整电路图上看到它们。设计支持包还包括完整的现场仪器 C 语言代码示例，可用来对全部硬件模块和电路特性进行完整的验证与评估，并对 HARt 接口的功能性提供一定程度的验证。有关 HART 接口规格和资源的详细信息，请联系 HART 通信基金会。

HART Compliance The DEMO-AD5700D2Z has been verified to be compliant with HART FSK Physical Layer Specification (HCF_SPEC-054, Revision 8.1), using methods and equipment specified in the HART Physical Layer Test Specification (HCF_TEST-2, Revision 2.2). The board was submitted to the Hart Communication Foundation and was successfully registered.

HART 兼容性 DEMO-AD5700D2Z 已通过 HART FSK 物理层规范（HCF_SPEC-054，修订版 8.1）的兼容性验证，该验证采用 HART 物理层测试规范（HCF_TEST-2，修订版 2.2）中的方法和设备。本电路板已提交 HART 通信基金会，并成功注册。

The registered circuit can be found on the HART Communication Foundation (HFC) web site in the product catalog as DEMO-AD5700D2Z.

可在 HART 通信基金会(HFC)网站上找到该注册电路，产品目录为：DEMO-AD5700D2Z。

The results of two of the tests involved the output noise during silence and the analog rate of change.

涉及的两项测试为：静默期间的输出噪声和模拟变化率。

Output Noise During Silence Test
静默期间的输出噪声测试

When a HART device is not transmitting (silence), do not couple noise onto the network. Excessive noise may interfere with reception of HART signals by the device itself or other devices on the network.

当 HART 设备没有进行传输（静默）时，噪声不应耦合至网络上。噪声过高可能会干扰设备本身或网络上的其它设备对 HART 信号的接收。

The voltage noise measured across a 500 Ω load in the loop must contain no more than 2.2 mV rms of combined broadband and correlated noise in the HART extended frequency band. In addition, the noise should not exceed 138 mV rms outside the HART extended frequency band.

对于在环路中的 500 Ω 负载上测得的电压噪声，其包含的宽带噪声和 HART 扩展频带中的相关噪声总和不能超过 2.2 mV rms。此外，HART 扩展频带外的噪声不应超过 138 mV rms。

This noise was measured by a true rms meter across the 500 Ω load. This noise was measured directly for the out-of-band noise and measured through the HCF_TOOL-31 filter for the in-band noise. An oscilloscope was also used to examine the noise waveform.

500 Ω 负载上的噪声采用真均方根测量仪测得。此噪声作为带外噪声直接进行测量，作为带内噪声通过 HCF_TOOL-31 滤波器测量。也可使用示波器来检查噪声波形。

The noise was measured at the worse condition, which was 4 mA output current. The captured noise waveform is shown in Figure 4, and the results are summarized in Table 1.

在最差情况下进行噪声测量，即 4 mA 输出电流。图 4 显示捕获的噪声波形，结果总结在表 1 中。

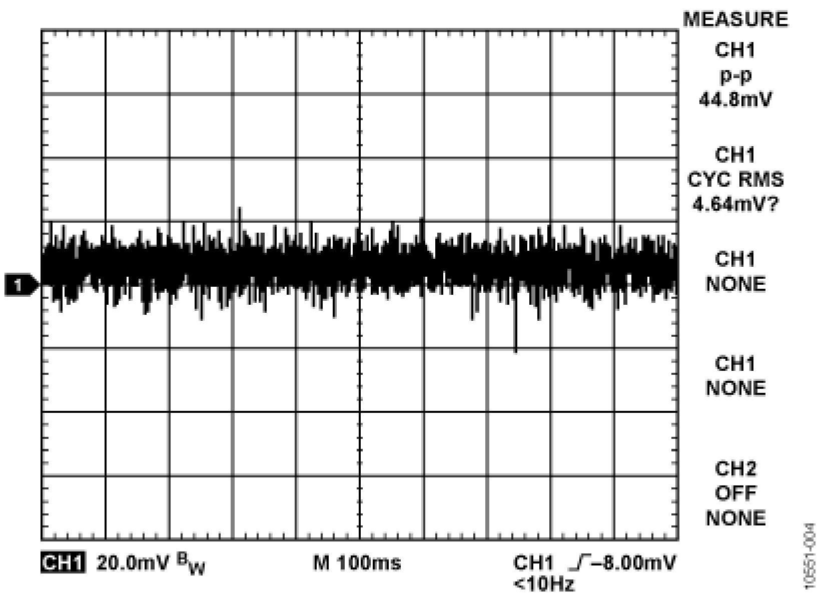

Figure 4. Output Noise During Silence Waveform

图 **4.** 静默波形下的输出噪声

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Table 1. Output Noise During Silence
表 1. 静默时的输出噪声

Output Noise 输出噪声	Measured (mV) 测得值(mV)	Measured (mV) 测得值(mV)
Outside Extended Frequency Range 扩展频率范围以外	4.13 4.13	<138 <138
Inside Extended Frequency Range 扩展频率范围以内	1.03 1.03	<2.2 <2.2

Analog Rate of Change Test This specification ensures that when a device regulates the analog output current, the maximum rate of change of analog current does not interfere with HART communications. Step changes in current disrupt HART signaling.

模拟变化率测试 这一技术规范可确保当设备调节模拟输出电流时，模拟电流的最大变化率不会干扰 HART 通信。电流的阶跃变化会扰乱 HART 信号传输。

The worst-case change in the analog output current must not produce a disturbance higher than 15 mV peak, measured across a 500 Ω load in the HART extended frequency band.

最差情况下的模拟输出电流变化一定不能产生高于 15 mV 峰值电压的干扰，此数值在 HART 扩展频带下，通过对 500 Ω 负载进行测量得到。

The AD5421 DAC and output driver are relatively fast. Therefore, to meet the required system specification, the output current change is controlled by combining hardware slew-rate limiting implemented at the AD5421 and a digital filter implemented in the ADuCM360 software.

AD5421 DAC 和输出驱动器相对较快。因此，为了满足所需的系统规格，可将 AD5421 的硬件压摆率限值与 ADuCM360 软件中的数字滤波器相结合，控制输出电流的变化。

The hardware slew-rate limit is set by the capacitance connected to the AD5421 C_{IN} pin. When a large step change is required in the analog output current value, the ADuCM360 software splits the output current change sent to the AD5421 DAC into a number of smaller subsequent steps.

通过与 AD5421 的 C_{IN} 引脚相连的电容，设置硬件压摆率限值。当模拟输出电流值需要改变较大的步进时，ADuCM360 软件将发送到 AD5421 DAC 的输出电流变化分割成数个较小的步进。

This test was performed using an oscilloscope coupled to the 500 Ω load through the HCF_TOOL-31 filter.

使用一个示波器执行该测试，并通过 HCF_TOOL-31 滤波器耦合至 500 Ω 负载。

The result is shown in Figure 5. Waveform CH1 shows the periodic steps between 4 mA and 20 mA, sensed directly across the 500 Ω load. Waveform CH2 is the signal captured on the HCF_TOOL-31 filter output, amplified 10×, within the 150 mV peak limits.

结果如图 5 所示。波形 CH1 显示 4 mA 和 20 mA 之间的周期性步进，直接在 500 Ω 负载上测得。波形 CH2 是 HCF_TOOL-31 滤波器输出端捕获的信号，将其放大 10 倍，并处于 150 mV 峰值限制之内。

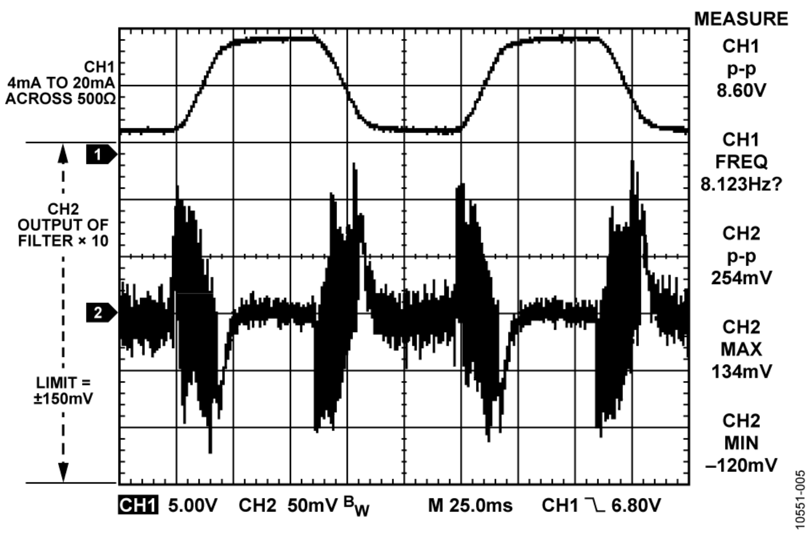

Figure 5. Analog Rate of Change Waveform

图 5. 模拟变化率波形

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Circuit Power Consumption Two methods were used to evaluate the circuit power consumption performance.

电路功耗 使用两种方法来评估电路的功耗性能。

In the first method, the current from the AD5421 integrated voltage regulator output was measured.

在第一种方法中，测量来自 AD5421 集成式电压调节器的输出电流。

Considering the minimum analog output current of 4 mA and HART output ac modulation of 0.5 mA peak, the maximum current consumed by the circuit in normal mode operation must be less than 3.5 mA. The AD5421 requires a 0.3 mA maximum for its own operation, which leaves approximately 3.2 mA maximum current for the AD5421 REG_{OUT} output.

考虑到最小模拟输出电流为 4 mA，并且 HART 输出直流调制峰值为 0.5 mA，则电路在正常工作模式下消耗的最大电流必须低于 3.5 mA。AD5421 自身工作需消耗 0.3 mA 的最大电流，因此留给 AD5421 REG_{OUT} 输出的最大电流约为 3.2 mA。

For ease of in-circuit measurement, the DEMO-AD5700D2Z has test points (T5, T6) on each side of the 10 Ω resistor in the REG_{OUT} output filter, as shown in Figure 6. This setup allows the voltage drop across the resistor to be measured, and the current to be calculated without interrupting the supply current or disturbing the circuit.

为了便于进行在线测量，DEMO-AD5700D2Z 在 10 Ω 电阻两侧的 REG_{OUT} 输出滤波器中均有测试点（T5，T6），如图 6 所示。此设置允许对电阻上的压降进行测量，并对电流进行计算，而无需打断电源电流或干扰电路。

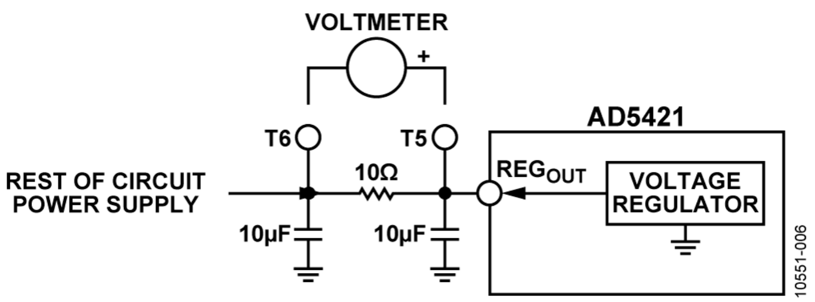

Figure 6. Measuring the AD5421 REGOUT Current Using Test Points

图 6. 使用测试点测量 AD5421 REGOUT 电流

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The results are shown in Table 2 and were measured at the following conditions:

结果显示在表 2 中，测量条件如下：

- REG$_{OUT}$ = 3.3 V
- REG$_{OUT}$ = 3.3 V
- ADuCM360 M3 core clock = 2 MHz
- ADuCM360 M3 内核时钟 = 2 MHz
- Both ADCs converting at 50 samples per second
- 两个 ADC 每秒均转换 50 个样本
- ADC0 has both buffers on and gain = 8
- ADC0 的两个缓冲器均开启，增益 = 8
- ADC1 has both buffers on and gain = 16
- ADC1 的两个缓冲器均开启，增益 = 16
- RTD excitation current = 200 μA
- RTD 激励电流 = 200 μA
- SPI communicating to AD5421 with serial clock = 100 kHz
- SPI 与 AD5421 通信的串行时钟 = 100 kHz
- HART communicating
- HART 通信

The circuit with all relevant analog and digital blocks, including the input sensor, consumes power supply current within the budget allowed at the minimum 4 mA loop current.

电路及所有相关模拟和数字模块（包括输入传感器）的功耗在环路电流最小值为 4 mA 时，许可的预算之内。

Table 2. Power Supply Current from AD5421, REG$_{OUT}$ = 3.3V
表 2. AD5421 的电源电流（REG$_{OUT}$ = 3.3V）

Input Sensor 输入传感器	Voltage T5 to T6 Maximum (mV) T5 至 T6 电压最大值(mV)	Current REG$_{OUT}$ Maximum (mA) REG$_{OUT}$ 电流最大值(mA)
无	24.4 24.4	2.44 2.44
24PCDFA6D (5 kΩ, 0.66 mA at 3.3 V) 24PCDFA6D（3.3 V 时为 5 kΩ、0.66 mA）	31.0 31.0	3.10 3.10

In the second method for assessing the circuit power consumption, the circuit was verified to function as expected with the analog output current set to the minimum of 4 mA while performing HART communication. The result showed that the circuit delivered the 4 mA current and showed no distortion of the HART output signal.

在评估电路功耗的第二种方法中，电路经验证正常工作，执行 HART 通信任务时的模拟输出电流设置为 4 mA 最小值。结果显示电路提供 4 mA 电流，且 HART 输出信号不失真。

Primary Sensor Input Performance<

主传感器输入性能<

The ADuCM360 integrates most of the analog front-end on chip; therefore, the performance of the analog input is primarily determined by the specifications of the ADuCM360.

ADuCM360 片内集成大部分模拟前端，因此模拟输入的性能主要由 ADuCM360 的规格决定。

The level of noise is the main factor that can be influenced by the interaction of the analog front-end with the rest of the circuitry on the board. Thus, tests were carried out to focus on the noise and related resolution performance of the system.

噪声电平是受模拟前端与板上其余电路部分交互干扰的主要因素。因此，测试主要针对噪声以及相关的系统分辨率性能。

The demonstration was configured to transmit data from the primary analog input, expressed as pressure in kPa, over the HART communication. One hundred samples were captured, and a basic data analysis to quantify the performance was completed. Two of the tests involved the following:

该演示配置为从主模拟输入通过 HART 通信发送数据，数值以压力表示，单位为 kPa。捕获 100 个样本，完成基本数据分析以便量化性能。两项测试包括：

- The first test was performed with a standard pressure sensor (Honeywell 24PCDFA6D) soldered directly on the board.
- 第一项测试将标准压力传感器(Honeywell 24PCDFA6D)直接焊接至电路板上。
- A second test was performed with the primary input signal generated by a set of fixed and variable resistors, as shown in Figure 7.
- 第二项测试采用由一组固定和可变电阻生成的主输入信号执行，如图 7 所示。

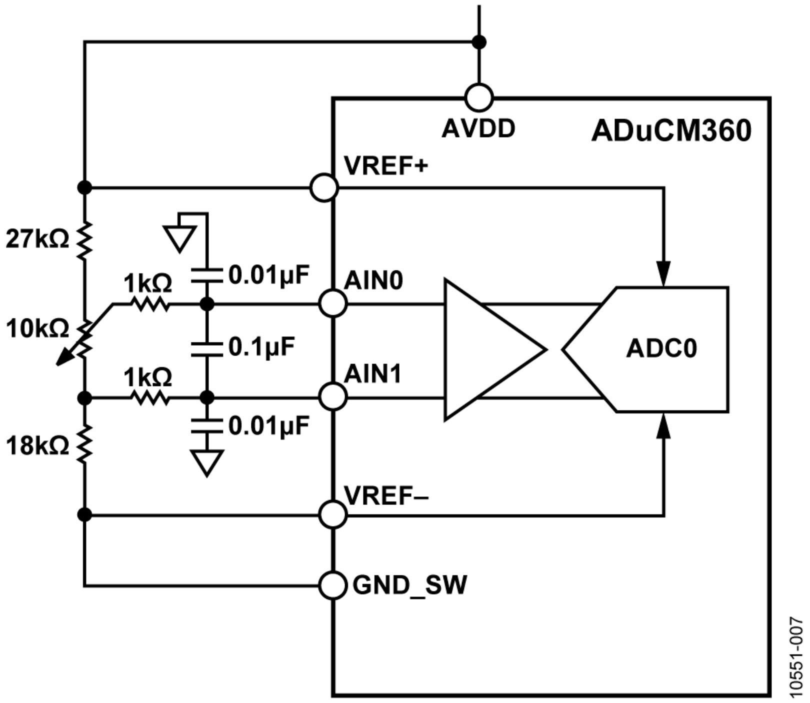

Figure 7. Primary Input Signal Generated by a Set of Resistors

图 7. 由一组电阻生成的主输入信号

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The performance summary can be seen in Table 3, and the signal plots are shown in Figure 8 and Figure 9.

性能总结见表 3，图 8 和图 9 显示信号曲线图。

Table 3. Primary Sensor Input Noise and Resolution
表 3. 主传感器输入噪声和分辨率

Parameter 参数	Pressure Sensor 压力传感器	Resistive Network 阻性网络
Full Scale 满量程	207 kPa 207 kPa	246 kPa 246 kPa
Noise RMS	1.3 Pa	0.68 Pa

均方根噪声	1.3 Pa	0.68 Pa
Peak-to-Peak Noise 峰峰值噪声	6.8 Pa 6.8 Pa	3.6 Pa 3.6 Pa
Resolution Effective (rms) 有效分辨率(rms)	17.2 bit 17.2 位	18.5 bit 18.5 位
Noise-Free Resolution (p-p) 无噪声分辨率(p-p)	14.9 bit 14.9 位	16.1 bit 16.1 位

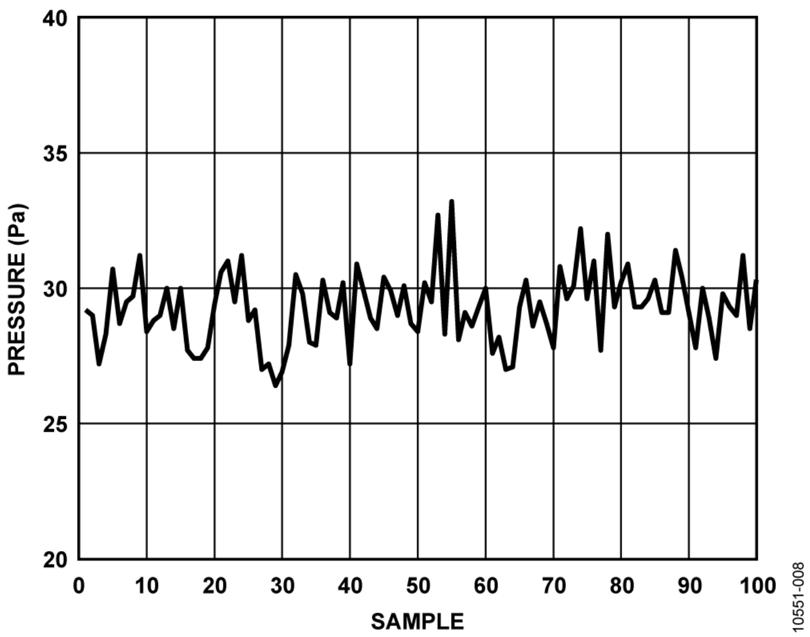

Figure 8. Pressure Sensor Input Signal Plot

图 8. 压力传感器输入信号曲线图

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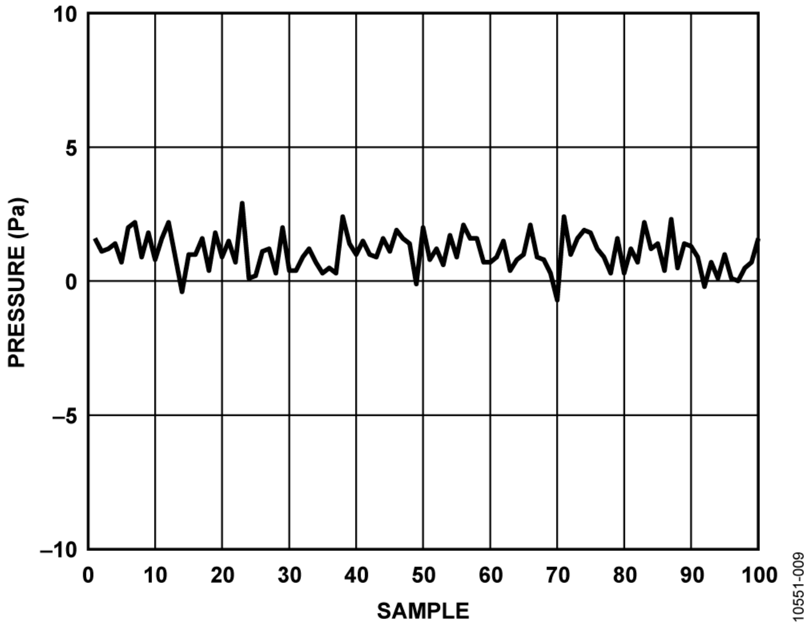

Figure 9. Resistive Network as Primary Input Signal Plot

图 9. 阻性网络作为主输入信号的曲线图

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Secondary Sensor Input Performance Similar to the primary sensor, the performance of the secondary sensor input is mainly determined by the analog front-end of the ADuCM360 with the exception of noise performance.

辅助传感器输入性能 与主传感器类似，辅助传感器输入的性能主要由 ADuCM360 的模拟前端决定（噪声性能除外）。

The analog input was configured to transmit temperature in degrees Celsius (°C) to a master over the HART communication path. Analysis was performed on two tests of 100 samples to quantify the performance.

模拟输入配置为通过 HART 通信路径向主机发送温度数据（以°C 表示）。对 100 个样本执行两项测试，以便进行性能的量化分析。

The first test was performed using the platinum 100 Ω sensor on the board, and the second test was performed with the sensor replaced on the board by a standard (fixed) 100 Ω ± 1% resistor.

第一项测试采用板载 100 Ω 铂电阻传感器进行，第二项测试则采用标准（固定）100 Ω ± 1%电阻代替板载传感器进行。

The performance summary is shown in Table 4, and the signal plots are shown in Figure 10 and Figure 11.

性能总结见表 4，图 10 和图 11 显示信号曲线图。

Table 4. Secondary Sensor Input Noise Performance
表 4. 辅助传感器输入噪声性能

Parameter 参数	Pressure Sensor 压力传感器	Resistive Network 阻性网络
Noise RMS 均方根噪声	0.037°C 0.037°C	0.033°C 0.033°C
Noise P-P 峰峰值噪声	0.19°C 0.19°C	0.16°C 0.16°C

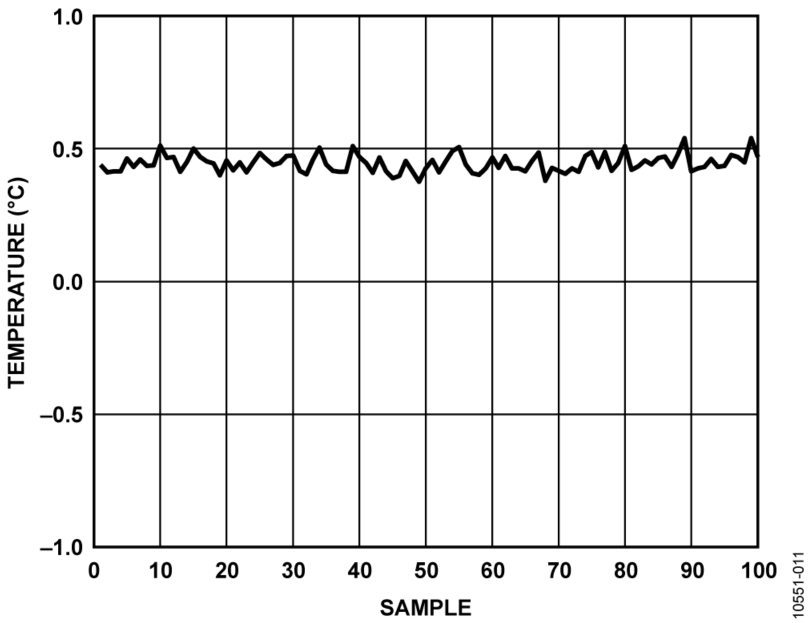

Figure 11. Fixed 100 Ω ± 1% Resistor as the Secondary Input Signal Plot

图 11. 固定 100 Ω ± 1%电阻用作辅助输入的信号曲线图

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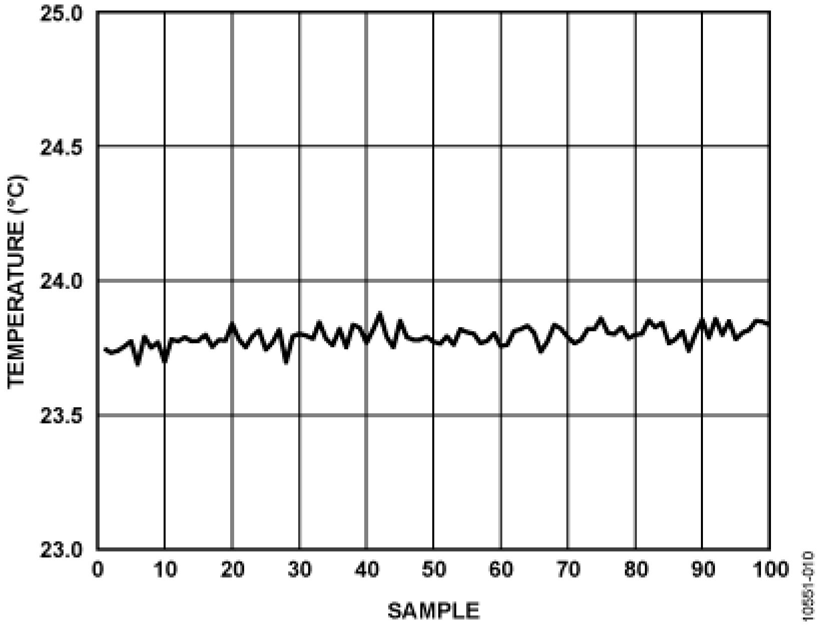

Figure 10. RTD (Platinum 100 Ω) Sensor Input Signal Plot

图 10. RTD（100 Ω 铂电阻）传感器输入信号曲线图

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back to top

返回页首