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Devices Connected/Referenced	
ADuC7060/ ADuC7061	ARM7-Based Microcontroller with Dual 24-Bit Σ - Δ ADCs, VDAC, and PWM
ADP1720	2.5 V Output Linear Regulator
OP193/OP293	Low Power Op Amp
ADR280	Low Power 1.2 V Reference Source

4 mA-to-20 mA Loop-Powered Temperature Monitor Using the ADuC7060/ADuC7061 Precision Analog Microcontroller

CIRCUIT FUNCTION AND BENEFITS

This circuit provides a simple highly integrated temperature monitor solution that can interface to a 4 mA-to-20 mA host controller. This circuit provides a very low cost solution to temperature monitoring because so much of the circuit functionality is integrated on the ADuC7060/ADuC7061 precision analog microcontroller, including dual 24-bit Σ - Δ ADCs, the ARM7 processor core, and the DAC/PWM features for controlling the 4 mA-to-20 mA feedback circuit.

The performance of the ADCs and other analog circuits within the ADuC7060/ADuC7061 is superior to competitive

microcontrollers that have integrated analog circuits. The circuit presented here represents the most cost-effective, lowest power, lowest board area solution compared to using discrete ADCs and a separate microcontroller. Because of its high level of integration and low power, the ADuC7060/ADuC7061 can operate directly from the loop power in the 4 mA-to-20 mA application. With the ARM7 core running at 640 kHz, the primary ADC active and measuring the external RTD temperature sensor, and the PWM controlling the 4 mA-to-20 mA feedback circuit, the entire circuit typically consumes 3.15 mA. Further details on the power consumption are provided in the Circuit Description section.

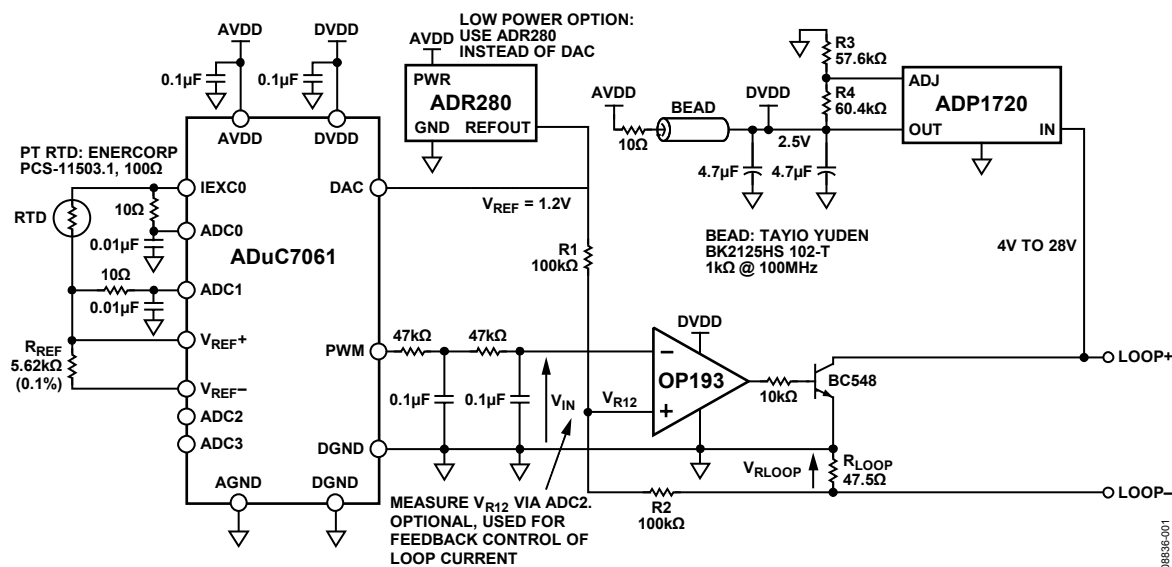


Figure 1. ADuC7061 Controlling 4 mA-to-20 mA Loop-Based Temperature Monitor Circuit. (Simplified Schematic: All Connections and Decoupling Not Shown)

Rev. 0

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During the intervals between temperature measurements, the ADC and the RTD excitation current sources can be turned off to further reduce power.

The 100 Ω Pt RTD is an Enercorp #PCS11503.1. The complete circuit meets a better than $\pm 1^\circ\text{C}$ specification. The temperature range of this RTD is -50°C to $+130^\circ\text{C}$. The RTD is available in a 1206 size SMD package and has a temperature coefficient of $0.385 \Omega/^\circ\text{C}$.

The primary ADC within the ADuC7060/ADuC7061 has a peak-to-peak noise-free code resolution of greater than 18 bits. The PWM based DAC output provides 12 effective bits of resolution. The performance of the overall circuit is discussed in the Circuit Description section.

Due to the small form factor of the ADuC7061, a $5 \text{ mm} \times 5 \text{ mm}$ 32-LFCSP package, the entire circuit will fit on an extremely small PCB thus further reducing cost.

The focus here is primarily the 4 mA-to-20 mA interface aspect of the circuit. For details on the RTD sensor interface to the ADC and on linearization techniques of the RTD measurements, see [Application Note AN-0970](#) and [Circuit Note CN-0075](#).

CIRCUIT DESCRIPTION

The circuit is powered via the [ADP1720](#) linear regulator (adjustable version), which regulates the Loop+ supply to 2.5 V for the ADuC7060/ADuC7061, the [OP193](#) op amp, and the optional [ADR280](#) reference.

The 4 mA-20 mA feedback circuit is primarily controlled by the ADuC7060's on-chip 16-bit PWM (pulse width modulator). The duty cycle of the PWM is configured in software to control the voltage across the 47.5Ω R_{LOOP} resistor, which in turn sets the loop current. Note the top of R_{LOOP} connects to the ADuC7060 ground. The bottom of R_{LOOP} connects to the loop ground. Because of this, the current due to the ADuC7060/ADuC7061, ADP1720, ADR280, and OP193, plus the current set by the filtered PWM output, flows across R_{LOOP} .

V_{REF} is supplied by the ADR280, a 1.2 V precision reference. Alternatively, the on-chip DAC of the ADuC7060/ADuC7061 could be configured to provide the 1.2 V reference, but this would consume extra power by enabling the internal DAC.

The voltage at the junction of R1 and R2 can be expressed:

$$V_{R12} = (V_{R_{\text{LOOP}}} + V_{\text{REF}}) \times R2 / (R1 + R2) - V_{R_{\text{LOOP}}}$$

After the loop settles:

$$V_{\text{IN}} = V_{R12}$$

Since $R1 = R2$:

$$V_{\text{IN}} = (V_{R_{\text{LOOP}}} + V_{\text{REF}}) / 2 - V_{R_{\text{LOOP}}} = V_{\text{REF}} / 2 - V_{R_{\text{LOOP}}} / 2$$

$$V_{R_{\text{LOOP}}} = V_{\text{REF}} - 2V_{\text{IN}}$$

Full-scale current will flow when $V_{\text{IN}} = 0$, at which point $V_{R_{\text{LOOP}}} = V_{\text{REF}}$. Hence, full-scale current is $V_{\text{REF}} / R_{\text{LOOP}}$, or $\approx 24 \text{ mA}$. When $V_{\text{IN}} = V_{\text{REF}} / 2$, no current will flow.

The OP193 amplifier impedance at V_{IN} is high and will not load the PWM filtered output. The amplifier output varies only a small amount around 0.7 V.

Performance at the range extremes, 0 mA to 4 mA, and 20 mA to 24 mA, is not critical; therefore, the op amp does not require good performance at the supply rails.

Absolute values of R1 and R2 are not critical. However, note that matching of R1 and R2 is important.

Also note the possibility of measuring the voltage at the point marked V_{R12} by using an input channel of ADC0 on the ADuC7060/ADuC7061. This ADC measurement can be used as feedback for the PWM control software to adjust the 4 mA-to-20 mA current setting.

The primary ADC of the ADuC7060/ADuC7061 measures the voltage across the RTD. The RTD is excited by the on-chip excitation current source, IEXC0. It is recommended that the excitation current is configured for 200 μA to conserve power, and it should be switched off between measurements. The internal PGA on the front end of the primary ADC is configured for either a gain of 16 or 32. The reference source for the RTD measurement may be either the internal reference or the external 5.62 k Ω reference resistor. Selecting the external resistor will conserve further power. For further details on the RTD to ADC interface and on linearization techniques for the ADC results see [Application Note AN-0970](#) and [Circuit Note CN-0075](#).

Power requirements for the circuit depend on whether the module is powered directly from the 4 mA-to-20 mA loop supply or actively from a 4-wire loop where the module is powered separately. For this document, we will assume the temperature monitor module is loop powered, therefore the total current consumption of the module should not exceed approximately 3.6 mA.

To facilitate low power operation, the ADuC7060/ADuC7061 core operating speed can be reduced by programming the internal POWCON0 register. This allows the top frequency of 10.28 MHz to be divided in binary multiples of 2 to 128. During the tests, a clock divide value of 16 was used, giving a core speed of 640 kHz. The primary ADC was enabled with a gain of 32. The PWM was also enabled. All other peripherals were disabled.

For our circuit and test setup, Table 1 gives a breakdown of the I_{DD} current consumption, and Table 2 gives the currents for the various peripherals.

Table 1. Typical I_{DD} Values for Components of Temperature Monitor Circuit

Component	I _{DD} Value at 25°C	I _{DD} Value at 85°C
ADuC7060/ADuC7061 ADC0 On, Gain = 32, FADC = 100 Hz CPU speed = 640 kHz (POWCON0 = 0x7C) PWM On. PWMCON1 = 0x100 External reference selected by ADC0. All other peripherals off. Note: Add excitation current value to this figure. Typical value is 200 µA.	2.45 mA	2.74 mA
ADR280, 1.2 V Reference	12 µA	15 µA
ADP1720, 2.5 V Output Linear Regulator	200 µA	300 µA
OP193, Low Power Op Amp	15 µA	25 µA
Remaining Circuitry	50 µA	50 µA
Total Current Less Excitation Current	2.73 mA	3.13 mA

The DNL graph in Figure 2 shows a better than 0.6 LSB typical performance in the critical 4 mA-to-20 mA range. These tests were conducted with a second order filter on the PWM output. Two 47 kΩ resistors and two 100 nF capacitors were used as shown in Figure 1.

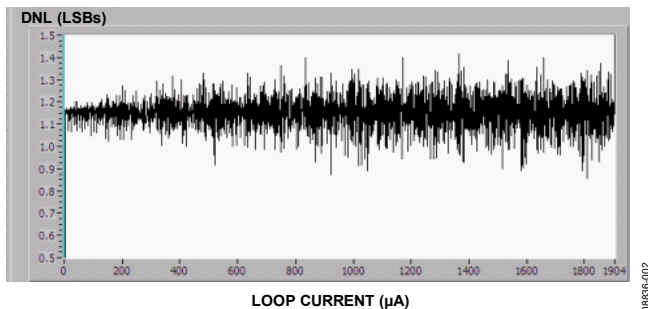


Figure 2. Typical DNL performance of circuit

The performance of the PWM based output could be enhanced by using the ADC to measure the voltage point V_{R12} and other points on the circuit. This method of feedback could be used to calibrate the PWM output for greater precision.

Note that the PWM circuit was only used to set the output voltage between 0 V and 600 mV, hence the reduced number of codes. Code 0 above is not important as it represents a value greater than 24 mA.

For ADC measurement performance, see [AN-970](#) and [CN-0075](#) and the [ADuC7060/ADuC7061 data sheet](#).

Table 2. Typical I_{DD} Values for Different Peripherals on the ADuC7060/ADuC7061

Peripheral of ADuC7060/61	I _{DD} Value, Typical, 25°C
ARM7 Core @ 10.24 MHz	5.22 mA
5.12 MHz	4.04 mA
2.56 MHz	2.7 mA
1.28 MHz	2 mA
640 kHz	1.674 mA
320 kHz	1.5 mA
160 kHz	1.42 mA
80 kHz	1.38 mA
Primary ADC, G = 1	30 µA
G = 4	440 µA
G ≥ 128	630 µA
Auxiliary ADC	350 µA
DAC	330 µA
PWM	340 µA
SPI	40 µA
UART	200 µA

COMMON VARIATIONS

Instead of using the PWM, the on-chip DAC could be used for the same function. The advantage would be quicker response time and a cheaper solution. The ADR280 reference would not be required in this case.

The OP90 can be used instead of the OP193.

LEARN MORE

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Data Sheets and Evaluation Boards[ADP1720 Data Sheet](#)[ADR280 Data Sheet](#)[ADuC7060 Data Sheet](#)[ADuC7060 Evaluation Board and Software](#)[ADuC7061 Data Sheet](#)[ADuC7061 Evaluation Board and Software](#)[OP193 Data Sheet](#)[OP293 Data Sheet](#)[OP90 Data Sheet](#)**REVISION HISTORY**

2/10—Revision 0: Initial Version

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