

basic solution, it is less than 0. The output value can be calculated using the following equation:

$$E_R = E_0 - \frac{2.303 RT}{nF} (pH - pH_{REF}) \quad (2)$$

where:

E is the output voltage of the probe.

E₀ is the standard electrode potential (typically 0 V), dependent on the probe.

R is the universal gas constant. R = 8.31447 J mol⁻¹ K⁻¹.

T is the temperature in Kelvin.

n is the number of transferred electrons (or equivalent number).

F is the Faraday constant. F = 96485.34 C mol⁻¹.

pH is the hydrogen ion concentration of unknown solution.

pH_{REF} = 7, reference value of reference electrode.

The Circuit

The three main elements of the circuit are the buffer for the probe, the ADC, and the isolator with the voltage transmission. The buffer op amp **AD8603** was selected because it has low power consumption, low noise, and extremely low input bias current. The low input bias current of typically 200 fA ensures that the voltage drop due to current flow across the internal resistor of the probe is minimized. Another important component is the ADC, represented here by the **AD7793**, a 24-bit Σ - Δ converter with an integrated power source and programmable amplifier. The integrated current source generates the current that flows through the Pt1000. With this, the temperature measurement needed for compensation in the processor is performed. The same current also flows through the 5 k Ω resistor (0.1% tolerance), which thereby generates the reference voltage of 1.05 V. As a second function, the resistor boosts the common-mode voltage. Through this and through selection of the reference voltage, the input range of the ADC is fully utilized: the probe outputs ± 414 mV—a maximum ± 490 mV. The isolator is the **ADuM5411**, an isolated dc-to-dc converter that simultaneously provides for isolation of the SPI interface of the ADC.

Circuit Characteristics

To achieve high accuracy, the op amp was selected with a typical input bias current of 200 fA, which leads to a maximum voltage offset of 0.2 mV at the probe impedance of 1 G Ω . This corresponds to an error of 0.0037 units of pH at 25°C. Even with a maximum input bias current of 1 pA, the maximum offset error is very low, at 1 mV. In order not to give away this good starting position, it is advisable to take suitable layout measurements by using, for example, a guard ring, shielding, and other techniques that are

not affected by very low currents. At the selected data rate of 16.7 Hz and a gain of 1, the noise generated by the ADC is approximately 2 μ V rms. If the calculation is done with a peak-to-peak noise of 13 μ V, the accuracy of the pH value is 0.00022 units of pH. If the noise from the amplifier and the noise from the ADC are taken together, this yields 0.00053 units of pH—and, hence, the offset error is much more significant.

Conclusion

The circuit shown here is a simple, very precise, and power-saving variant for pH sensor readings. Once the circuit has been calibrated, an accuracy of 0.5%, corresponding to 0.005 units of pH can be achieved. Thanks to the isolation, it is suitable for numerous applications.

About the Author

Thomas Tzscheetzsch joined Analog Devices in 2010, working as a senior field applications engineer. From 2010 to 2012, he covered the regional customer base in the middle of Germany and, since 2012, has been working in a key account team with a smaller customer base. After the reorganization in 2017, he's leading a team of FAEs in the IHC cluster in CE countries as FAE manager.

At the beginning of his career, he was working as an electronics engineer in a machine building company from 1992 to 1998, as head of the department. After his study of electrical engineering at the University of Applied Sciences in Göttingen, he worked at the Max Planck Institutes for solar system research as a hardware design engineer. From 2004 to 2010, he worked as an FAE in distribution and worked with Analog Devices' products. He can be reached at thomas.tzscheetzsch@analog.com.

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