All your base are belong to us: Creating a field-durable pH measurement circuit

Many traditional circuits for sensing pH via ion selective electrodes are not field-durable and are subject to disruption when contaminated or operated outside the lab. The authors set out to create a less orthodox but more robust circuit, with positive results.

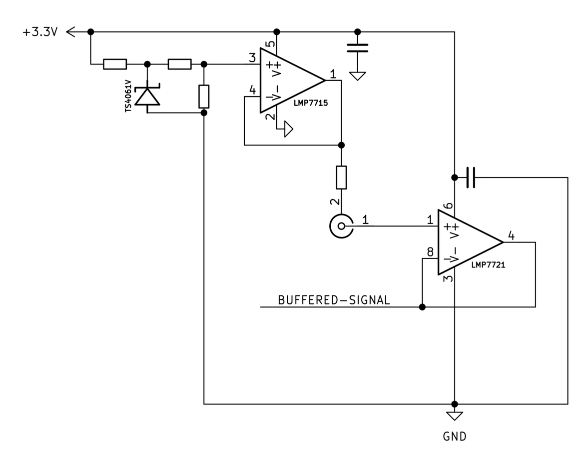
Introduction

The physics of ion selective electrodes dictate that the current they can provide to sensing circuits is minute, on the order of 1nA[1]. These faint electrical forces make normally ignorable current leakage paths like skin oils and soldermask on circuit boards produce wildly unreliable results when traditional circuits given in many textbooks and app notes are taken outside of the sterile world of the engineering lab.

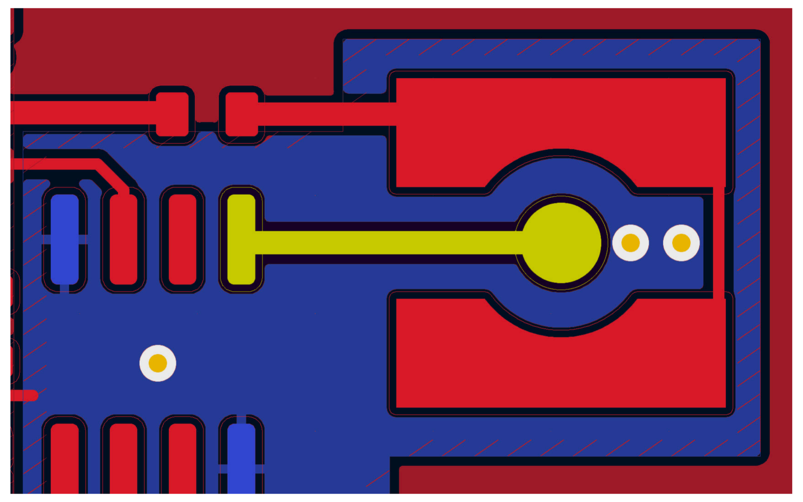
Materials and Methods

The circuit runs from a single-ended power supply at 3.3V. A reference voltage of 1.024V is created by a precision shunt voltage reference TS4061V (STMicroelectronics, Geneva, Switzerland) and buffered by a precision amplifier LMP7715 (Texas Instruments, Dallas, TX, USA) in a unity gain configuration. This creates a stable bias voltage which is connected to the probe shield. A second precision amplifier LMP7721 (Texas Instruments, Dallas, TX, USA) also in unity gain configuration, is connected to the pin of the electrode. The output of this amplifier is a buffered version of the delicate signal from the probe, which is then used to surround the original signal path on the circuit board on both layers. This area of buffered similar potential prevents current leakage.This output signal is also the one we use for sensing, in this case with a 24-bit general purpose delta-sigma ADC ADS1219 (Texas Instruments, Dallas, TX, USA).

Once calibrated we exposed the surface of the PCB to a variety of contaminants including water, Human Skin Oils (Evolution, Earth) and Blueberry Preserves (Polaner Spreads, Roseland, NJ, USA) in the interest of thoroughness.



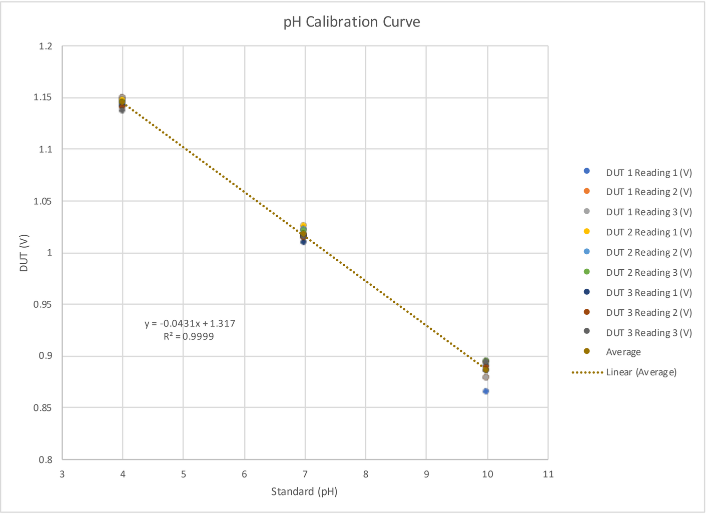
Partial schematic of the pH sensing circuit. This shows the amplifier and power topology. The ADC and implementation details are omitted for clarity.



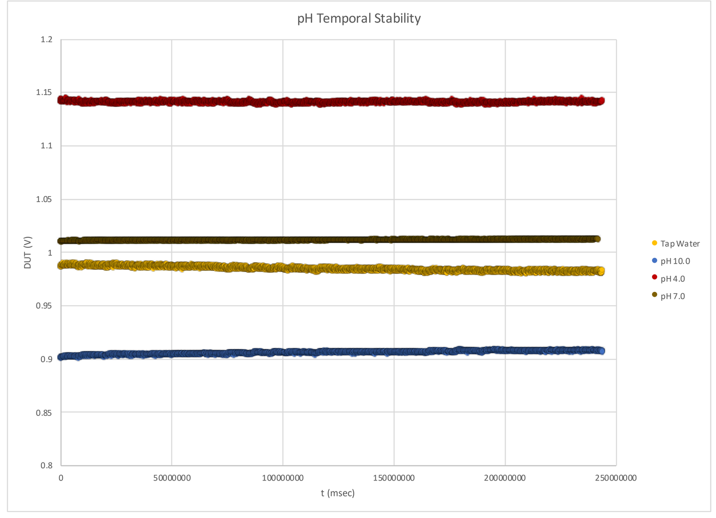
PCB Layout. Observe how the fragile electrode signal chain (yellow) enters the amplifier at left and emerges as a buffered signal (blue) which surrounds the electrode's signal chain completely, preventing current leakage. This buffered signal is also brought onto the back surface of the PCB to prevent current leaks through the substrate.

Results

Being single-ended with a positive bias voltage, the voltages sensed at the ADC are obviously transposed up from the conventional arrangement. Once calibrated, the results in normal operation were precise and repeatable. Distortions to the signal due to various applications of contaminants were not distinguishable from noise. Power supply disruptions of up to 0.5V from nominal were similarly shrugged off.



Calibration curve of the pH measurement circuit. This curve was compiled from three separate devices tested three separate times each with NIST-traceable pH standards at pH 4.0, 7.0, and 10.0.



Temporal stability plot of pH measurements by circuits over the course of just under three days. While the pH 7.0 standard stays very flat, the other two and tap water can be seen to creep in different directions. In the case of the tap water, it becomes slightly more basic as the dissolved carbon dioxide and oxygen come out of solution, while in the case of the basic pH 10.0 standard, it acidifies by absorbing atmospheric carbon dioxide. The fact that the circuits are sufficiently stable to see this behavior over this long of a time period speaks to their quality and precision.

Discussion

Creating a biased signal of the same potential to the one being sensed and surrounding the signal path with it is very effective at preventing current leakage, giving the current effectively no place to go of dissimilar potential. The trade-off of unity gain is, of course, reduced voltage bandwidth, but with a high precision ADC, this need not be a serious obstacle.

The single-ended power and sensing arrangement, while slightly unorthodox, simplifies the circuit and reduces cost significantly. It should be noted that when used in a shared power domain with other sensor modalities which involve electrically coupling the system ground to the fluid being measured signal disruptions were observed, which can be effectively ameliorated by galvanically isolating all sensor modalities from each other.

Conclusion

The demonstrated circuit is robust, moderately priced, and precise. It provides a good alternative to many textbook/app note circuits and pre-packaged pH sensing solutions sold as drop-in castellated modules. Aspects of the design may be instructive even in other modalities which face similar challenges.

Bradley Gawthrop; FieldKit

Author & Affiliates

Bradley Gawthrop[1], Peter Marchetto[1,2], Shah Selbe[1,3,4], Jacob Lewallen[1], Lindsay Starke[1], Sara Clements-Tiberio[1], Sarah Koons[1], Susan Allen[1], Jer Thorp[1,5], Kate Kuehl[1], Erin Kennedy[1]

[1]FieldKit, Los Angeles, CA, USA
[2]Graduate School and Institute on the Environment, University of Minnesota-Duluth, Duluth, MN, USA
[3]Nelson Institute for Environmental Studies, University of Wisconsin-Madison, Madison, WI, USA
[4]New England Aquarium, Boston, MA, USA
[5]Tisch School of the Arts, New York University, New York, NY, USA

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References

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