



Development of a Low-Cost Non-Dispersive Infrared Spectrometer for Real-Time Nitrous Oxide Detection

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Introduction

- Nitrous oxide (N₂O) is the third-most problematic greenhouse gas [1]
- N₂O is a dominant ozone-depleting gas [2]
- Agricultural soils are responsible for 75% of U.S. N₂O emissions, primarily from fertilizer use [1], [3]
- Monitoring soil N₂O emissions is vital to modeling climate change and for sustainable agriculture [4]
- N₂O emissions are highly variable, sometimes changing within hours and across single fields [3]
- Current N₂O measurement devices are costly and limited in spatial and temporal resolution [3]

Project Motivation

This project has two distinct goals:

- To enable real-time, *in-situ* N₂O flux measurement for soils and watersheds, enhancing understanding of emissions
- For integration in a nitrogen sensor suite for combustion-based soil total N measurement tool for precision fertilizer application

Sensor Design

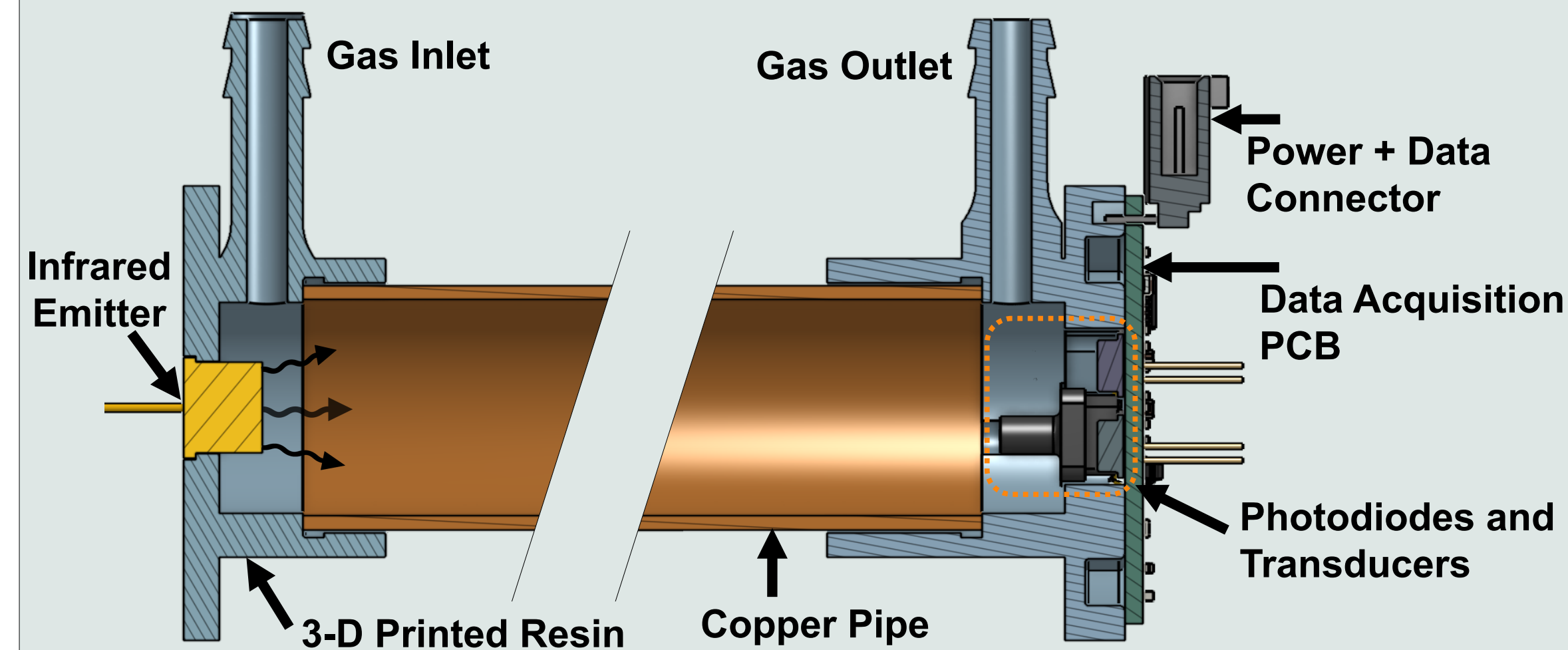


Figure 2: A cross-sectional view of the NDIR sensor. A custom copper gas cell reduces cost and while retaining high MIR reflectivity.

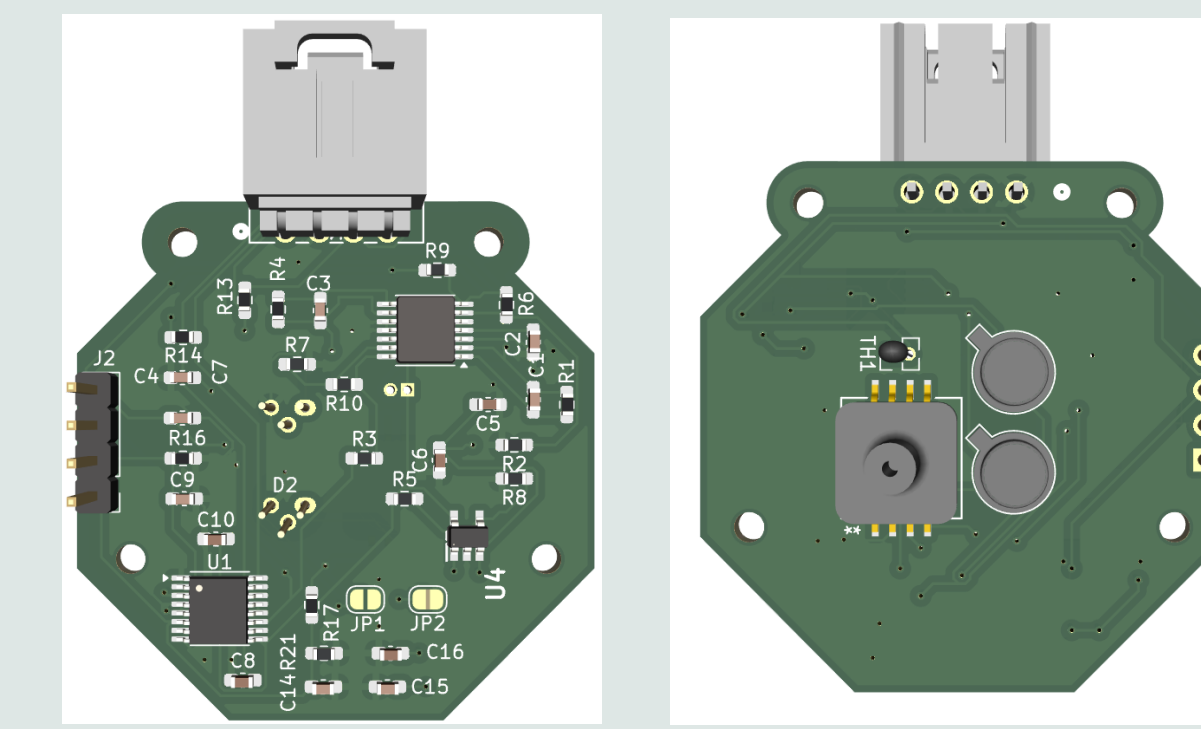


Figure 3: The data acquisition board. The left image shows the signal conditioning circuitry, while the right shows the sensor array.

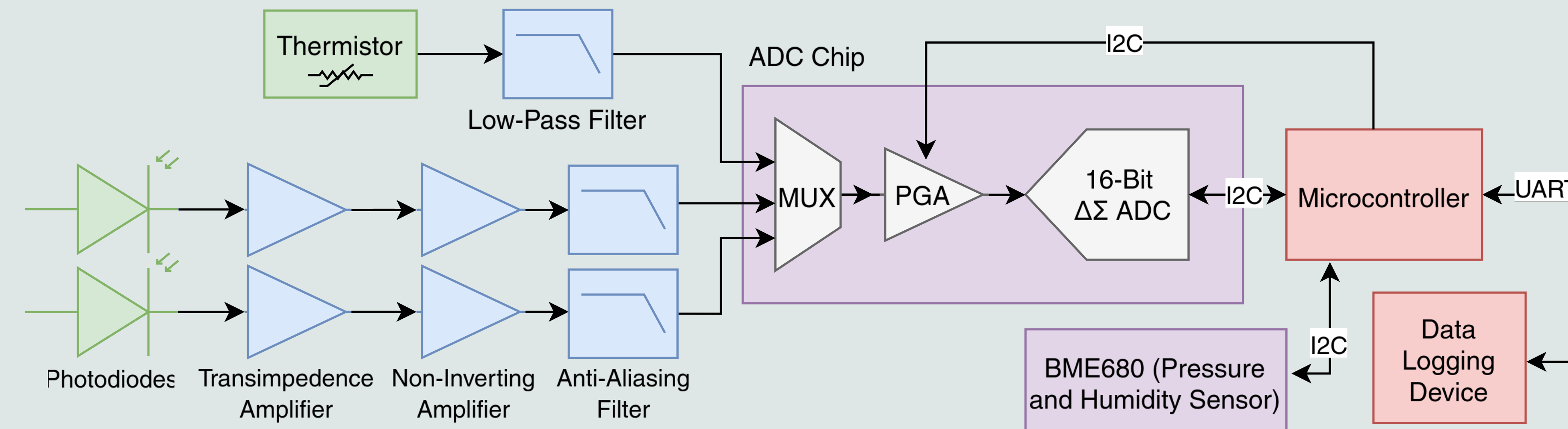


Figure 4: The block diagram of the signal conditioning circuitry. Green = transducers; blue = analog front-end; purple = analog/digital devices, red = digital devices.

Discussion

- Despite best sealing efforts, the system exhibited a 15-20 Pascal/sec leak
- Gas leakage may cause actual N₂O concentrations to be lower than theoretical, explaining sensor response
- The reference signal increase with each gas injection may be due to interference between the channels, but is unclear
- Significant noise limiting detection limits without time-domain filtering
- Calculations assume ideal Beer-Lambert law

Future Work

- Develop a new gas mixing system using flow controllers to eliminate pressure requirement
- Use a pulsed IR emitter to reduce the impact of 1/f noise and increase power efficiency
- Investigate behavior of reference channel
- Conduct field tests to determine real-world performance for flux measurements

Technical Background

- N₂O uniquely absorbs IR light at 4.5 μm
- The absorption of 4.5μm in a cell is proportional to the concentration of N₂O

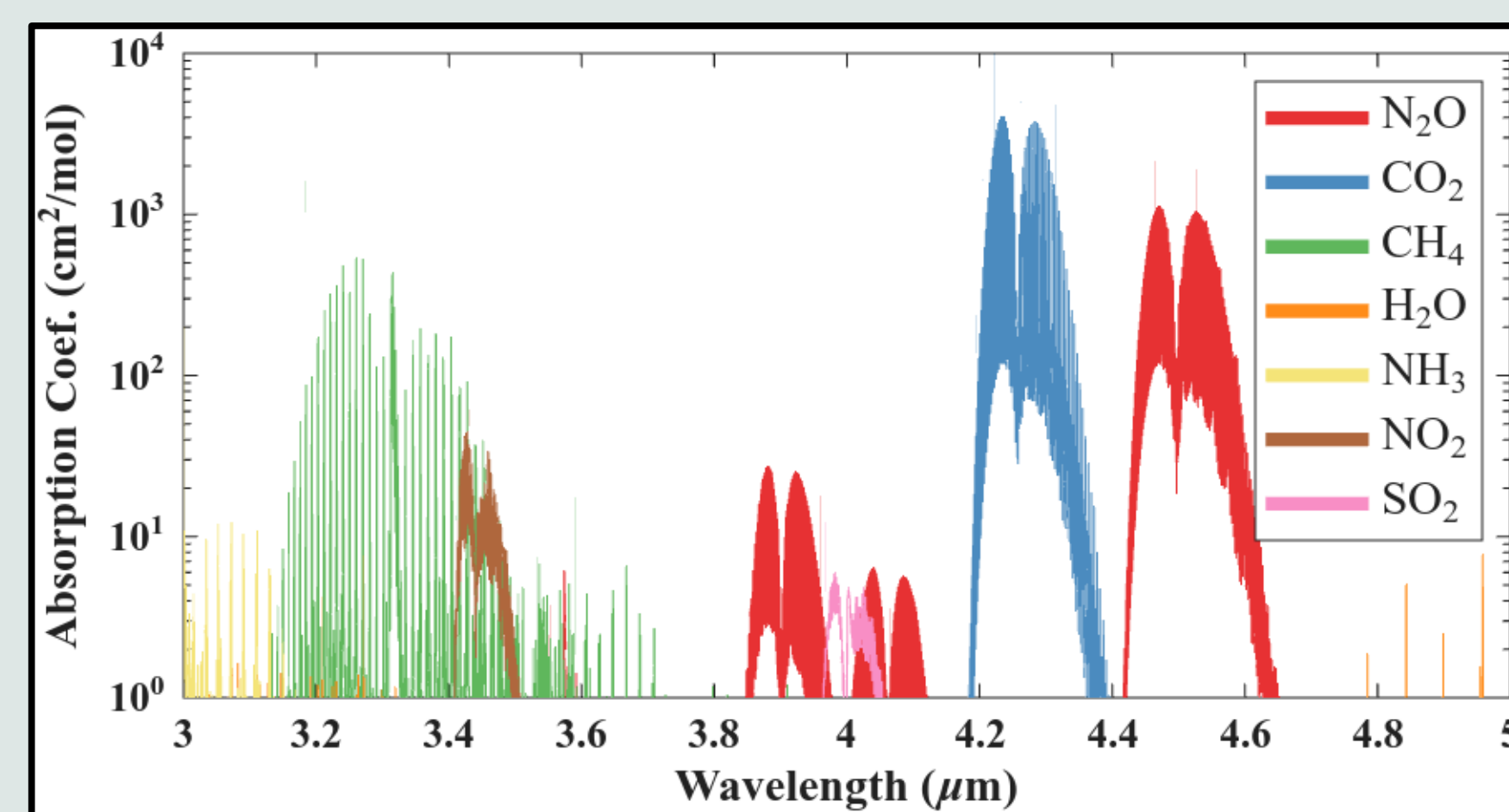


Figure 1: The log absorption spectra of common gases in the Mid-IR range.

The Beer-Lambert Law relates the absorption of light to the concentration of gas, given by:

$$I_o / I = \epsilon lc$$

where I = absorbed light intensity, I_o = reference intensity, ϵ = molar extinction coefficient, l = path length, c = gas concentration

In a dual-channel system (N₂O and Reference), the concentration is given as:

$$c = \frac{T}{T_{cal}} \frac{P_{cal}}{P} \left[\frac{\ln \left(\frac{(N_2O)}{(Ref)*Zero} \right)}{\epsilon l} \right]$$

where T_{cal} and P_{cal} are the temp. and pressure when ϵ was calculated and $Zero$ is the zero-gas ratio between the channels [5].

Test Methods and Results

- A mixing system was built to create known N₂O concentrations
- 100 ppm N₂O gas is injected using a syringe
- The gas is mixed and circulated through the NDIR sensor
- Sensor output is captured and analyzed
- A 1st order IIR filter was used to filter photodiode signals
- ϵ was determined empirically from the first concentration step

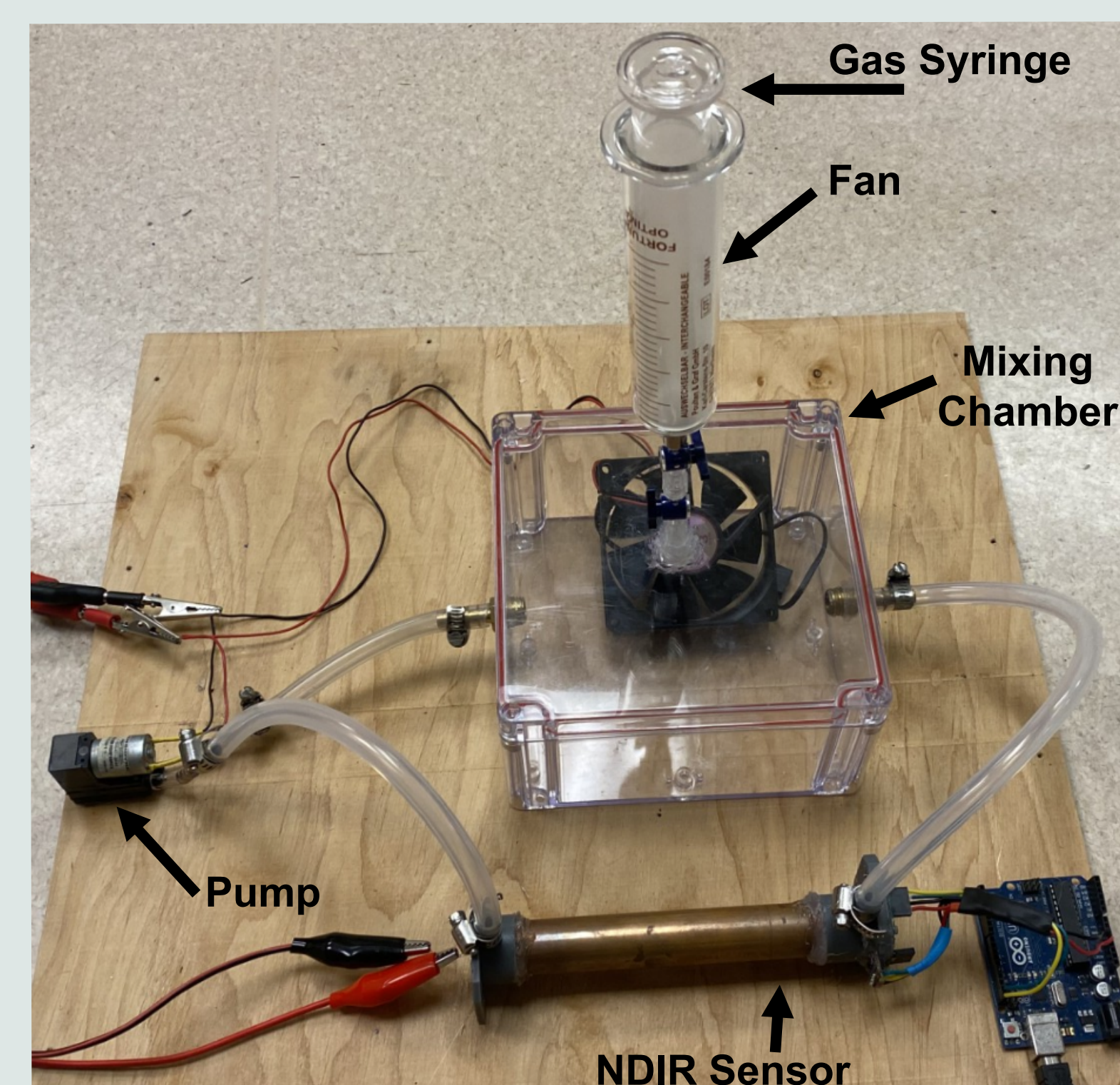


Figure 5: The N₂O mixing and test system.

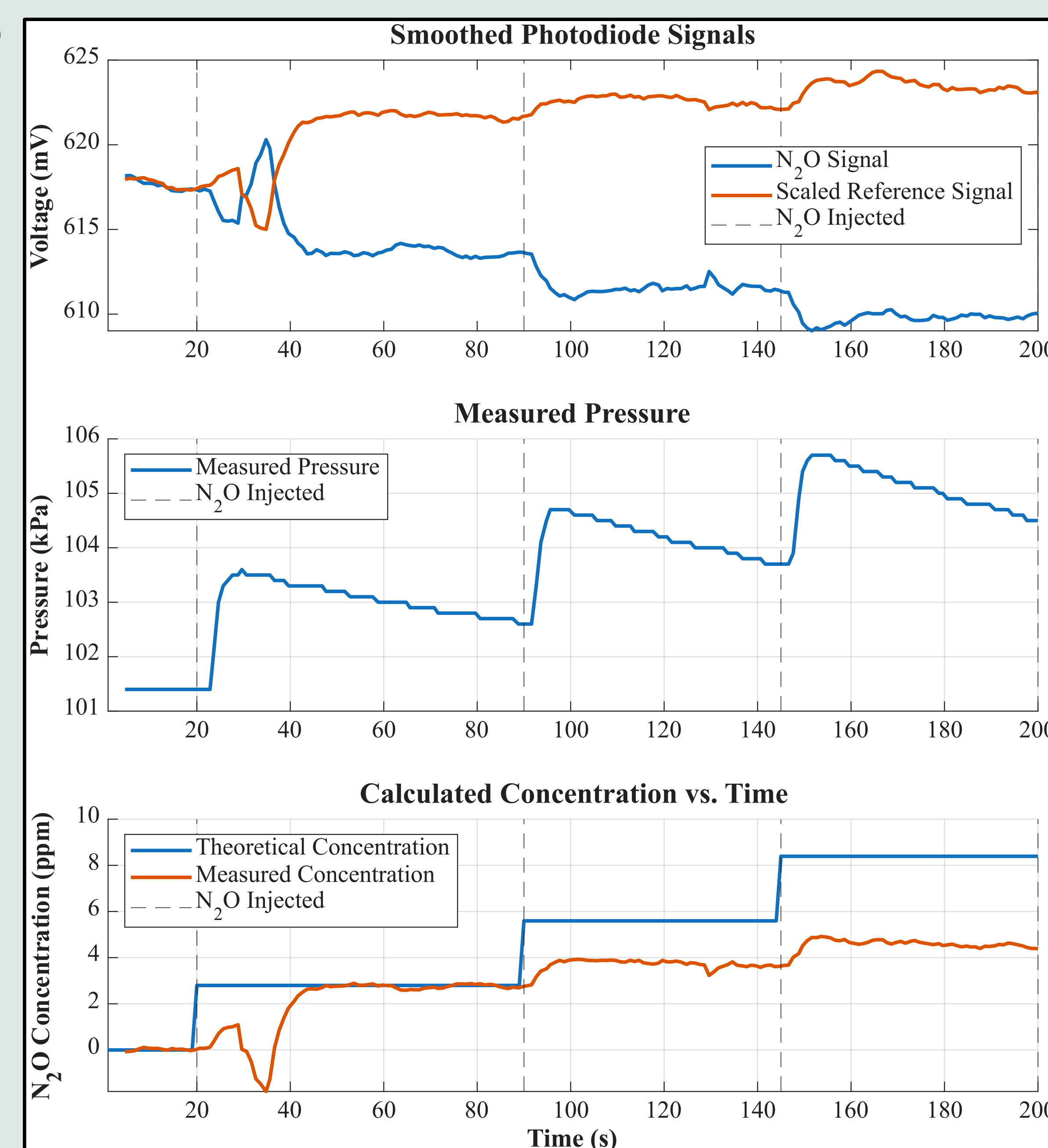


Figure 6: The results of the closed-system calibration tests.

Key Contributions

- Portable, low power (1.2 W continuous) N₂O sensor enables remote field measurements
- Sensor cost under \$300, significantly less than than commercially available sensors
- Demonstrated sensitivity to sub-five ppm N₂O concentration
- Reference channel enables calibration-free measurements and eliminates drift
- Alternate designs using an adjustable path length maximize sensor measurement range
- Easily integrated into flux measurement systems

References

- [1] US EPA, "Overview of Greenhouse Gases," Greenhouse Gas Emissions. Accessed: Dec. 28, 2024. [Online]. Available: <https://www.epa.gov/ghgemissions/overview-greenhouse-gases>
- [2] A. R. Ravishankara, J. S. Daniel, and R. W. Portmann, "Nitrous Oxide (N₂O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century," *Science*, vol. 326, no. 5949, pp. 123-125, Oct. 2009, doi: 10.1126/science.1176985.
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Acknowledgments

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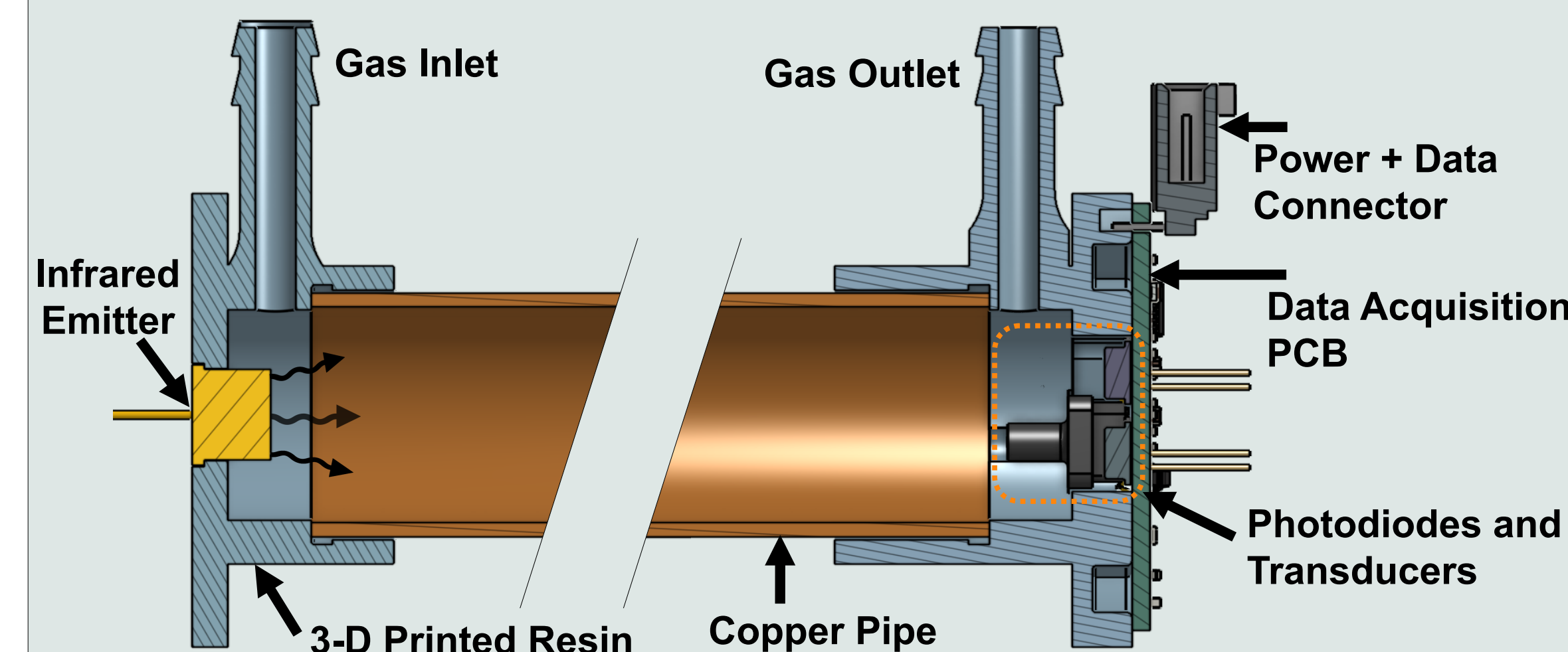


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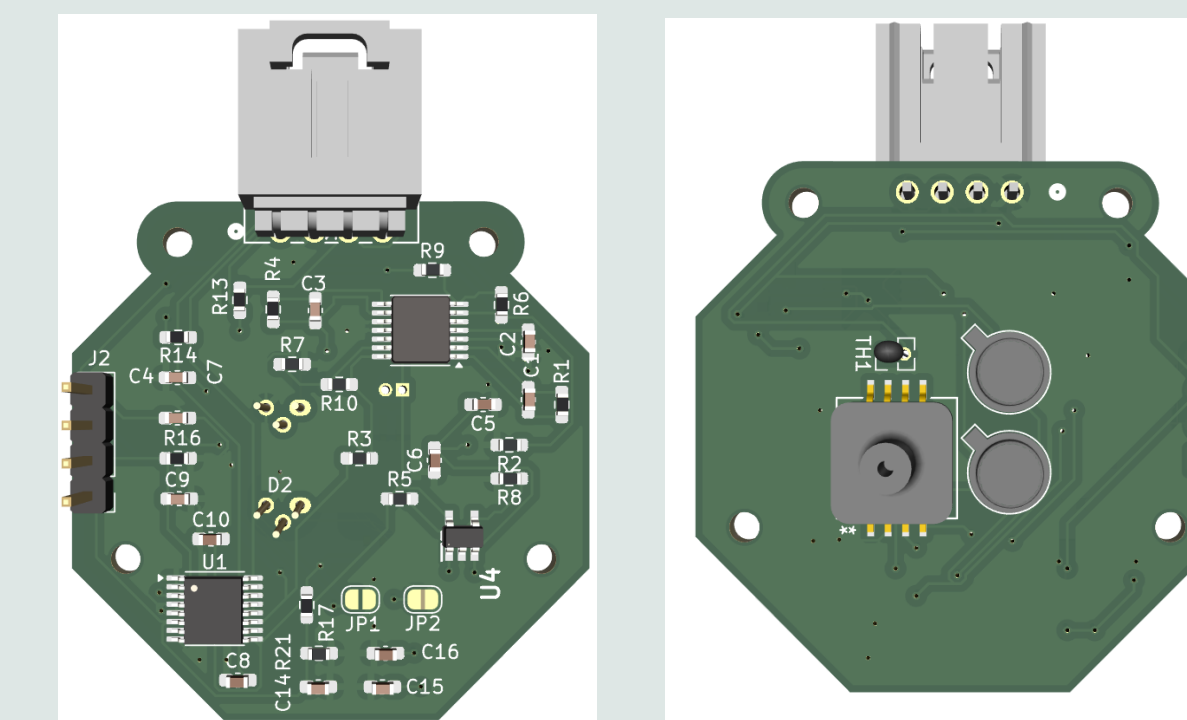


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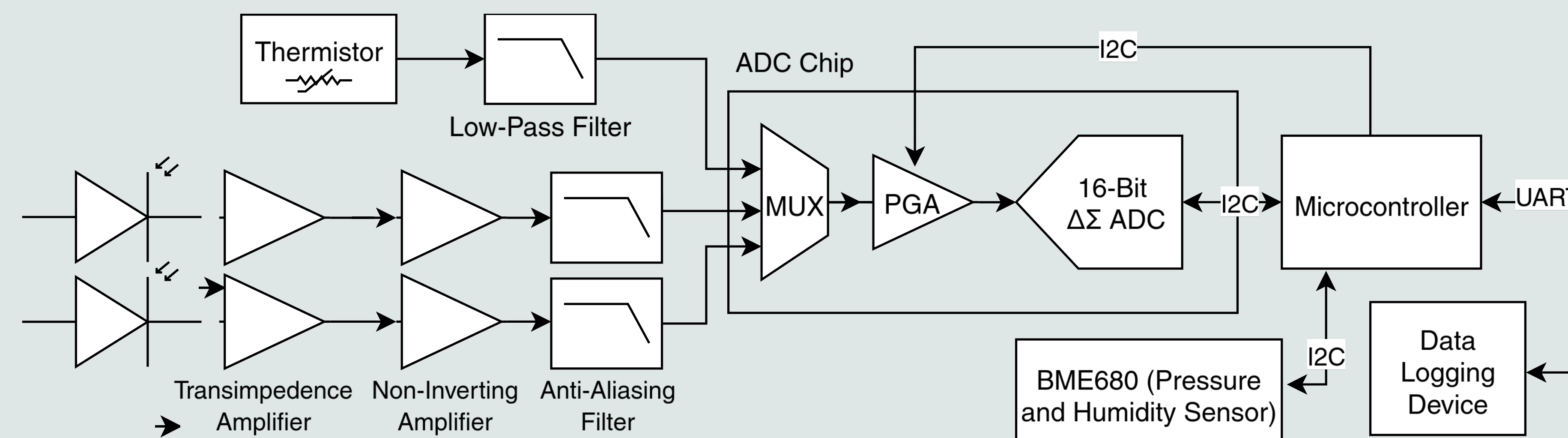


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- Investigate behavior of reference channel
- Incorporate non-ideal Beer-Lambert law factors

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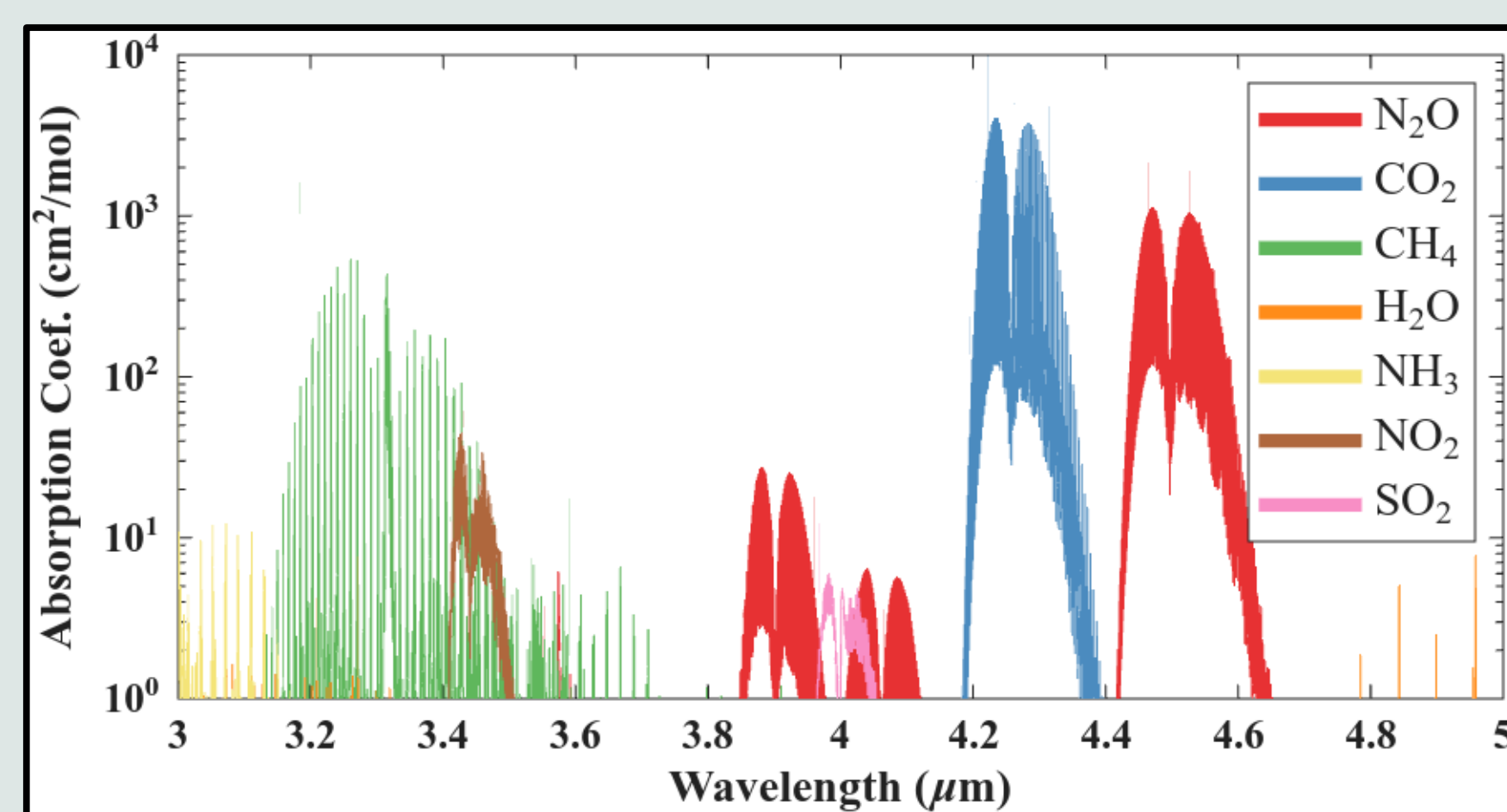


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Where I = experimental light intensity, I_o = reference light intensity

ϵ = molar extinction coefficient

l = gas cell path length

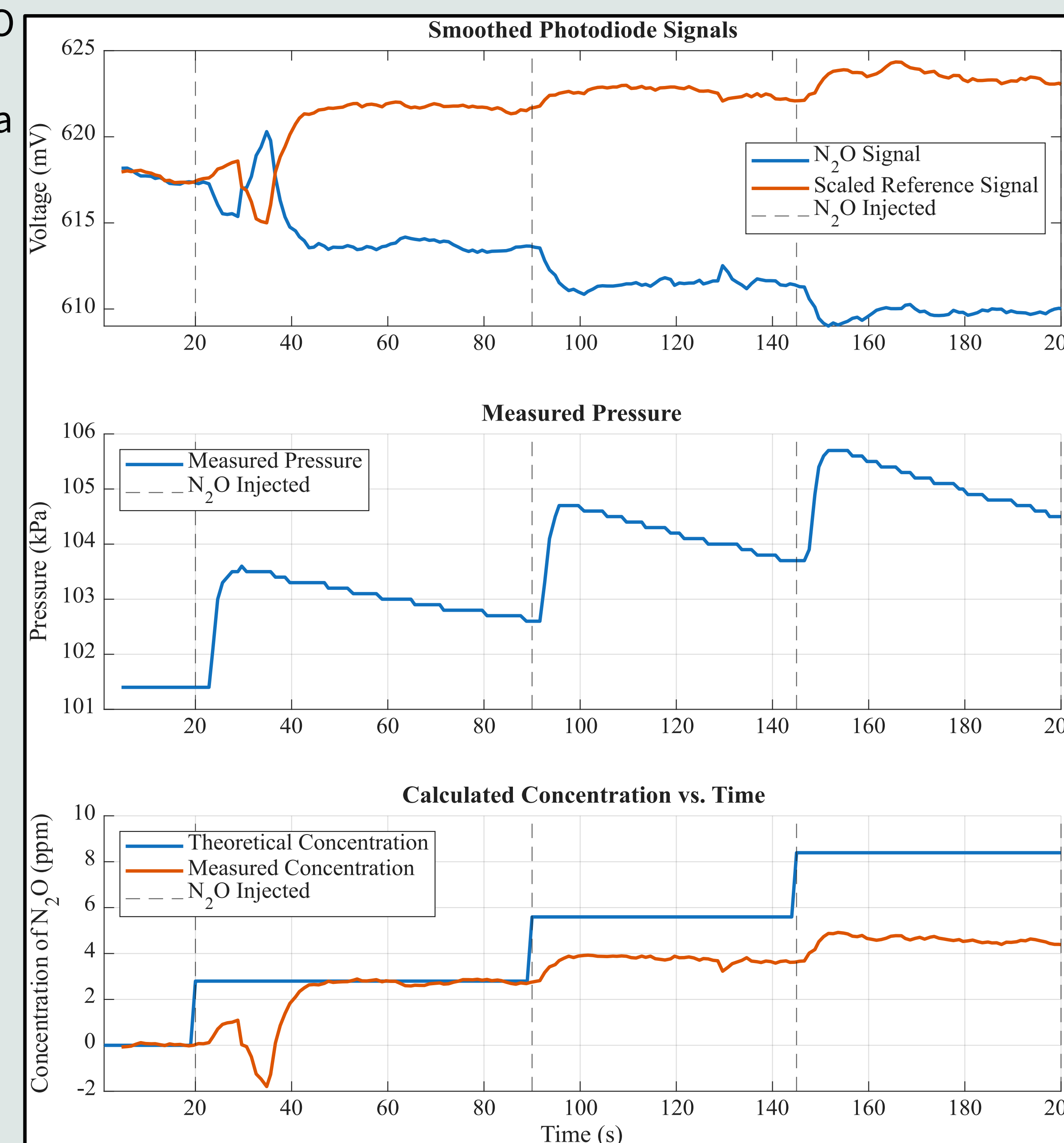
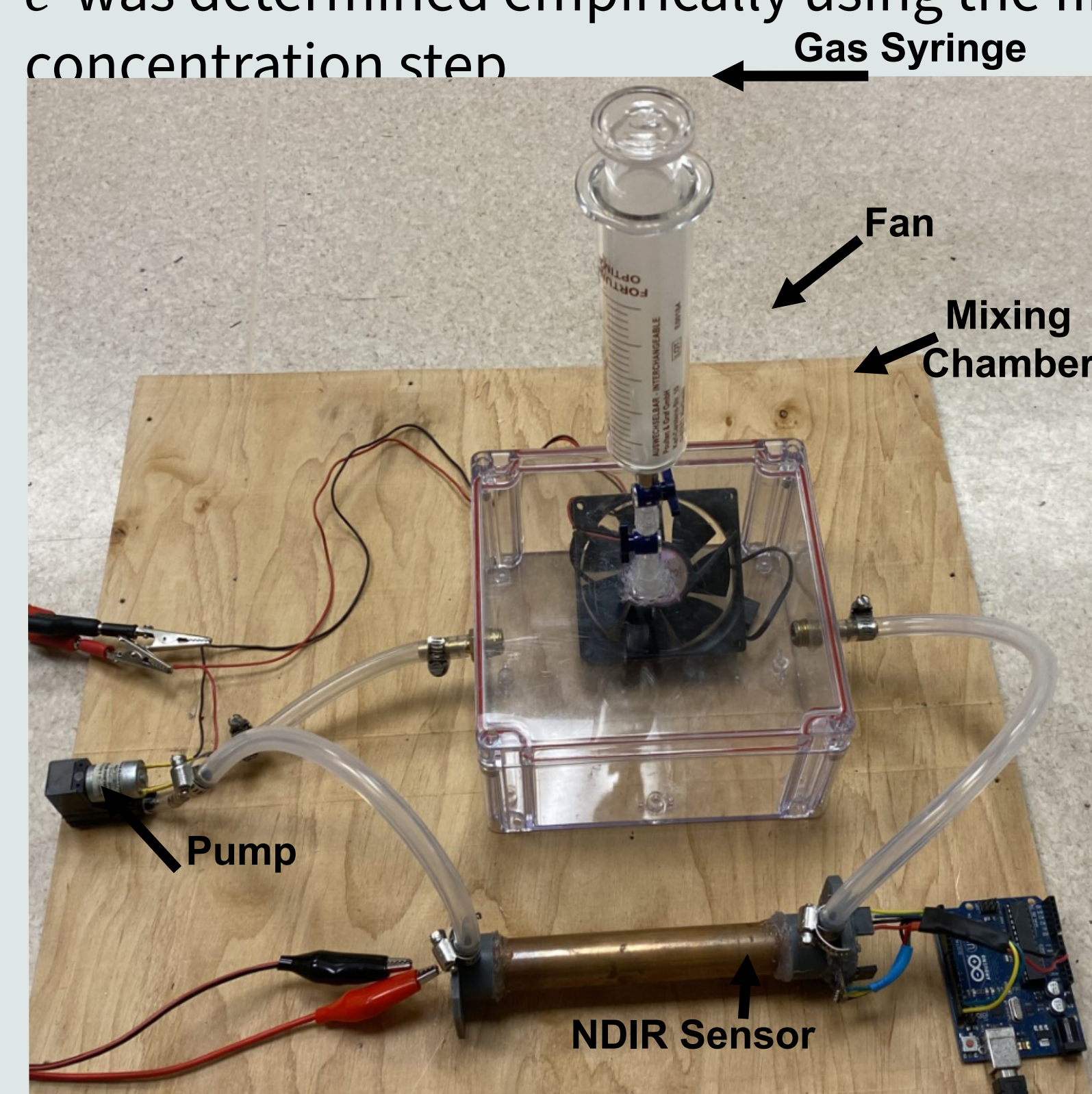
c = concentration of target gas

Solving for c and using the Ideal Gas Law in a dual-channel system yields:

$$c = \frac{T}{T_{cal}} \frac{P_{cal}}{P} \left[\frac{\ln \frac{(N_2O)}{(Ref)*Zero}}{\epsilon l} \right]$$

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- K. M. T. S. Band

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