Continued Development of a Multi-Gas Microsensor Array for the Exploration Portable Life Support System

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MAKEL ENGINEERING

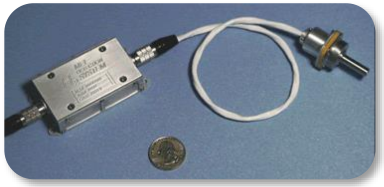
Introduction to Makel Engineering Inc.

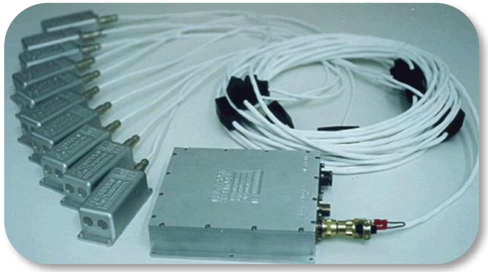
MEI Formed 1996
- HQ in Chico California

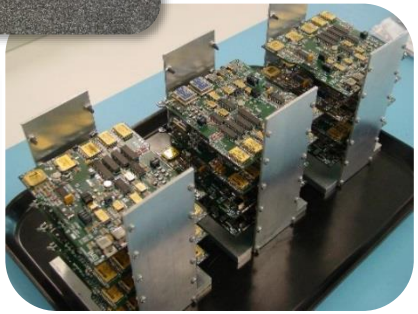
Multidisciplinary Team
- Chemical, Mechanical and Electrical Engineering
- Technicians and support staff

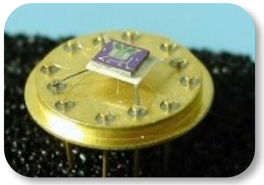
Facilities
- 16,000 ft^2
- Office, laboratories, manufacturing

www.makelengineering.com









MEI Sensing Systems

- Aerospace
  - Launch Vehicles and ISS
  - Test Facilities
  - Planetary Exploration

- Defense
  - Aircraft Life Support Systems
  - Advanced Propulsion System Sensors
  - Warfighter Physiological Monitoring

- Industrial
  - Emissions Monitoring
  - Nuclear Systems Monitoring
  - Biomedical

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Overview

- Background and Motivation
  - Need for multi-gas measurement
- Chemical Sensor Operating Principles
  - Solid-state microsensors for O_2 and CO_2
  - NDIR Sensor for CO_2
  - MEMs sensors for pressure and humidity
- M-PALSS GEN-1 Sensor Design
  - Integration of multiple sensor types
- Prototype Testing and Performance
  - Measurement accuracy and range
- Conclusions and Future Work

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Background and Motivation

Background and Motivation

- New spacesuits are being developed to support exploration objectives to the Moon and beyond
- Technology gaps have been identified during the development of these spacesuits
- There is a need to monitor multiple species in the breathing gas stream (O_2, CO_2, Humidity)
- Desirable to monitor trace contaminates
- Technology development focused on progression toward flight qualified design

Sensor Requirements

- Current PLSS design only includes nondispersive infrared (NDIR) sensors for CO_2
  - NDIR sensors outer mold is approximately 2.3 by 2.2 by 6.1 inches with 12 VDC power and digital communications
- Need to measure the major constituents of the breathing gas to provide general situational awareness
  - O_2 (20-100% ±1%)
  - CO_2 (0-30 torr ±0.3 torr)
  - H_2O (5-90% Relative Humidity ±1%)

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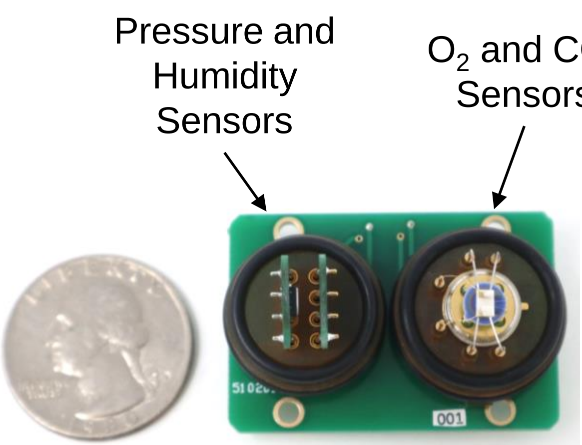
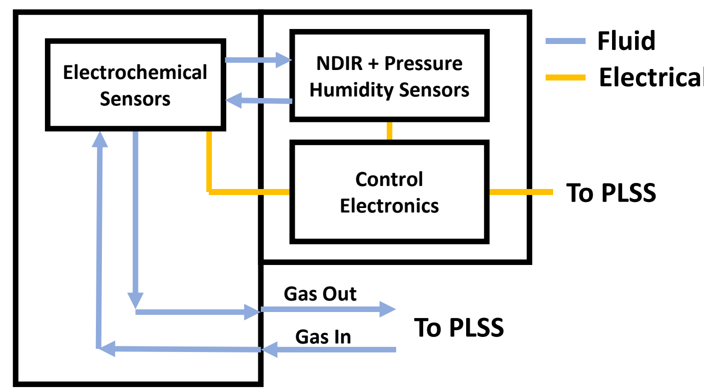
Generation 1 (GEN-1) M-PALSS

- Multi-Parameter Astronaut Life Support Sensor
  - O_2, CO_2 (electrochemical and NDIR), Humidity, and Pressure
- GEN-1 version suitable for ground testing and compatible with existing NASA test equipment
- Does not meet all requirements for space flight





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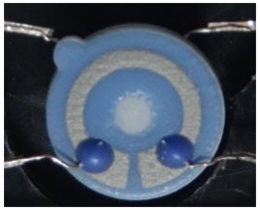
Chemical Sensor Operating Principles

Electrochemical and NDIR Sensing

Solid-State Sensing

- Directly transduces a chemical signal to an electrical signal (resistance, current, or voltage)
- Small and low power
- Good match for PLSS situational awareness requirements

Carbon Dioxide Sensor

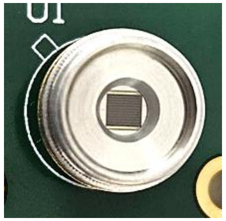


Oxygen Sensor

NDIR CO_2 Sensing

- High TRL approach currently used in PLSS

Dual Channel NDIR Detector



MEMs Blackbody Emitter

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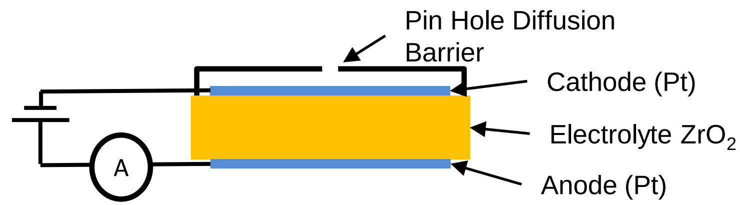
Chemical Sensing

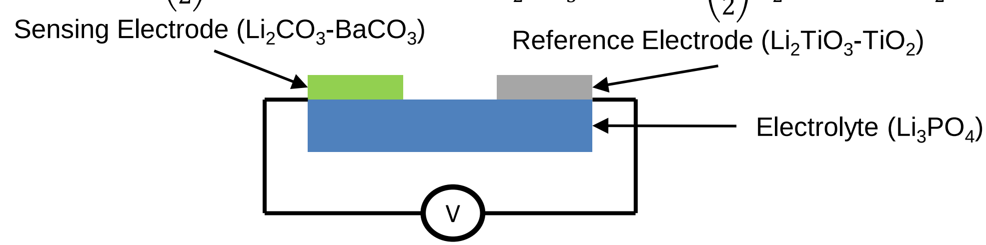
Amperometric Oxygen Sensor



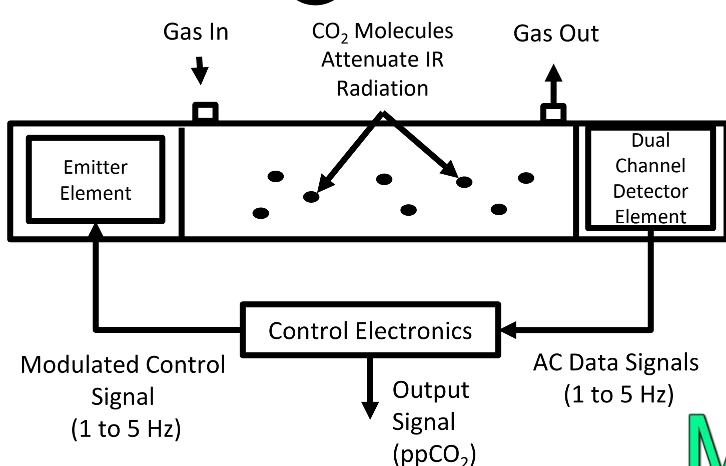
Potentiometric Carbon Dioxide Sensor

$$2Li^{+} + CO_2 + \left(\frac{1}{2}\right) O_2 + 2e^{-} \leftrightarrow Li_2CO_3$$

$$Li_2TiO_3 \leftrightarrow 2Li^{+} + \left(\frac{1}{2}\right) O_2 + 2e^{-} + TiO_2$$



Nondispersive Infrared (NDIR) CO_2 Sensor



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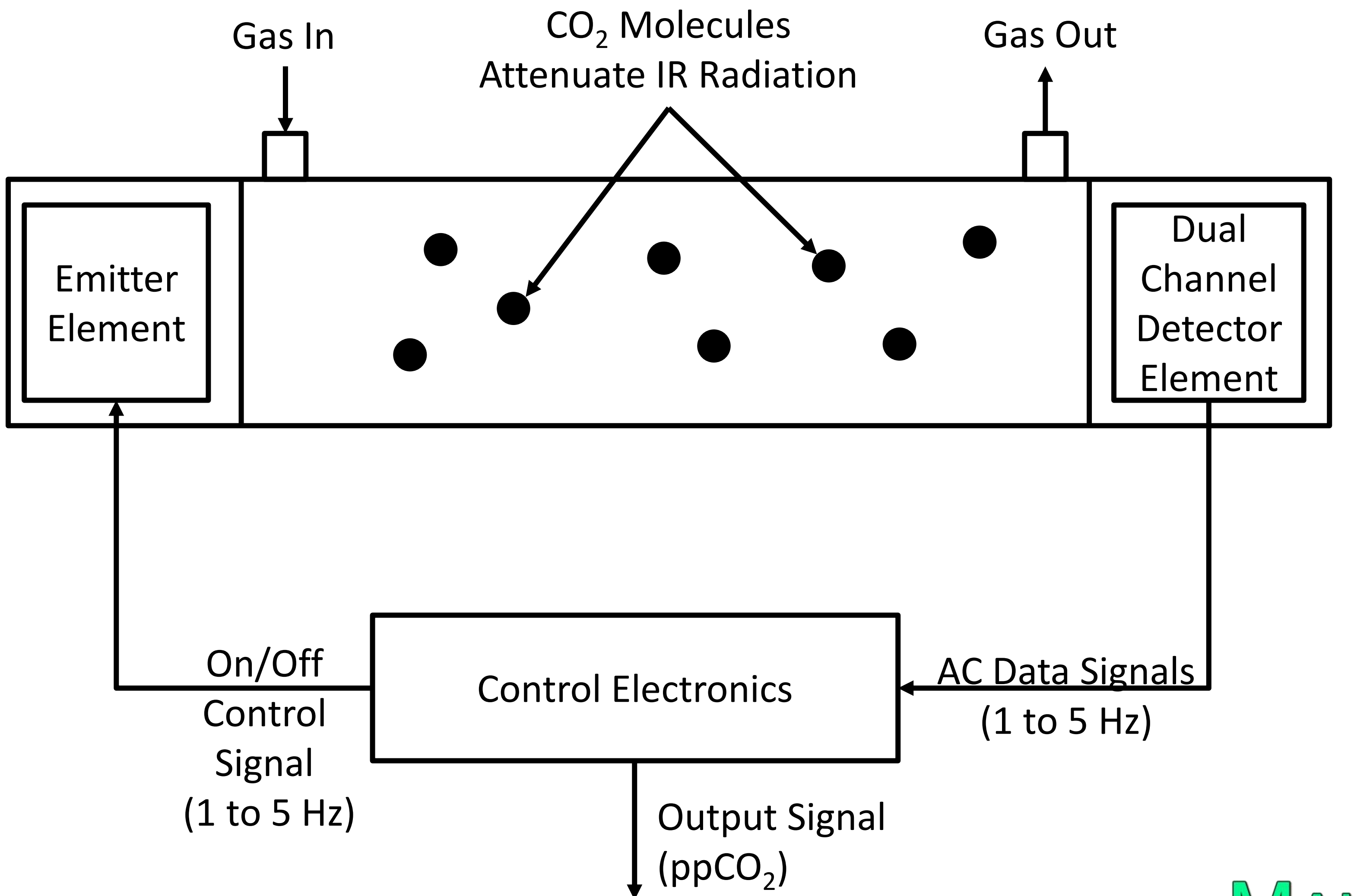
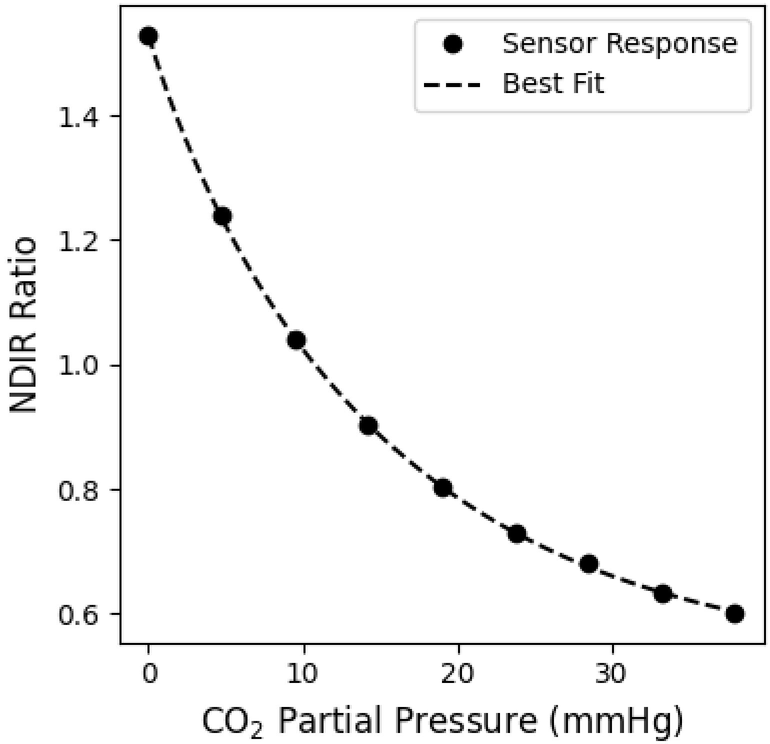


NDIR CO_2 Sensor Response Characteristic



Modified Beer-Lambert Law

$$\boldsymbol{FA = SPAN(1 - e^{-bx^c})}$$

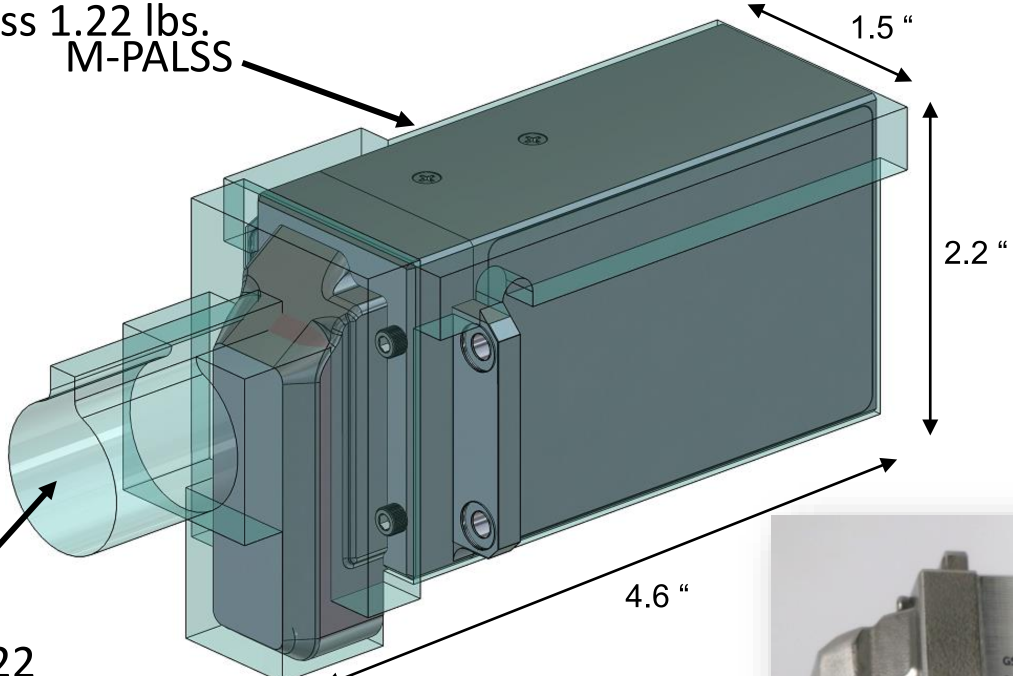
$$\boldsymbol{R = R_0\left(1 - SPAN\left(1 - e^{-bx^c}\right)\right)}$$

$FA \coloneqq Fractional\ Absorbance$
$R \coloneqq NDIR\ Ratio$
$R_0 \coloneqq NDIR\ Zero$
$SPAN \coloneqq Response\ Span$
$b \coloneqq Effective\ Path\ Length$
$c \coloneqq Nonideality\ Term$

M-PALSS GEN-1 Sensor Design

GEN-1 Mechanical Design

- GEN-1 M-PALSS included both and NDIR CO_2 sensor and electrochemical CO_2 sensor
- GEN-1 Package fits within GS-300/GS-322 enveloped and conforms to existing interfaces
- Mass 1.22 lbs.



Rear View

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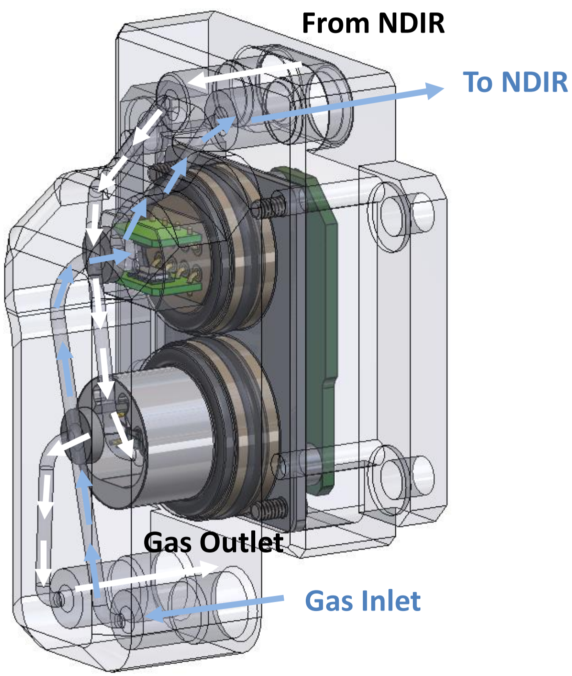
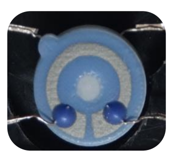
GEN-1 Sensor Detailed Design

Electrochemical Sensor Manifold



Carbon Dioxide Sensor

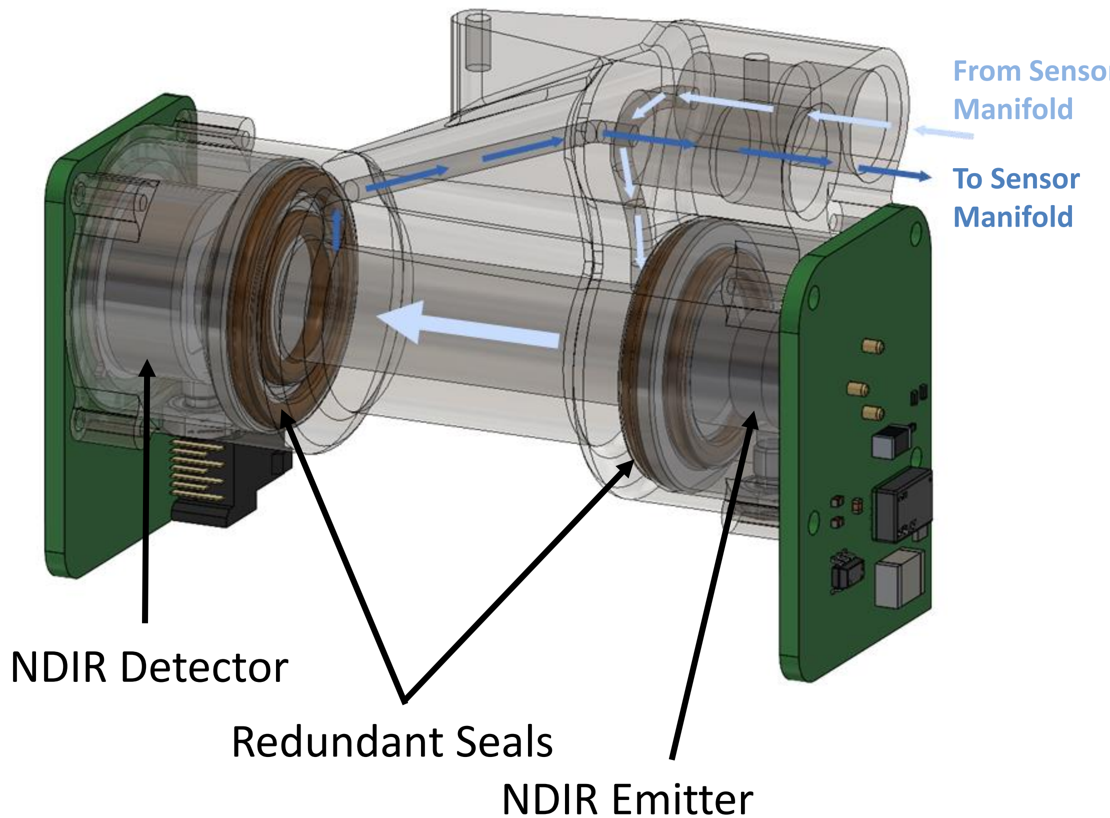


Oxygen Sensor

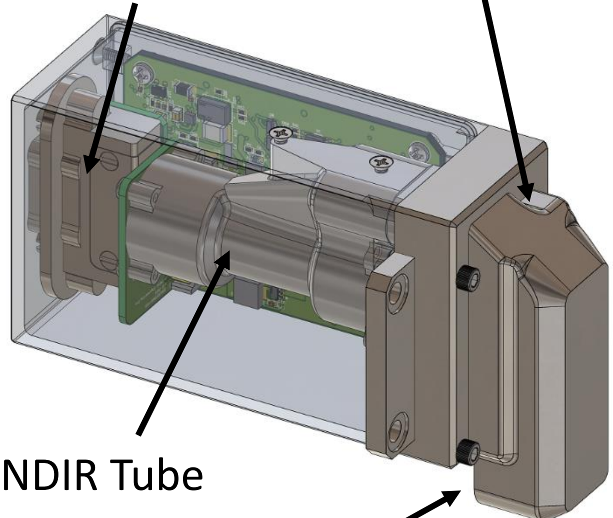
Pressure Sensor

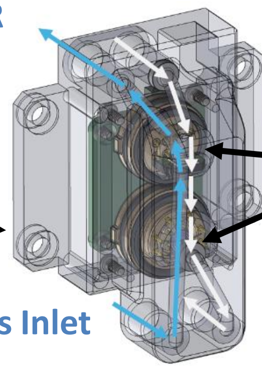
Humidity Sensor

NDIR Sensor

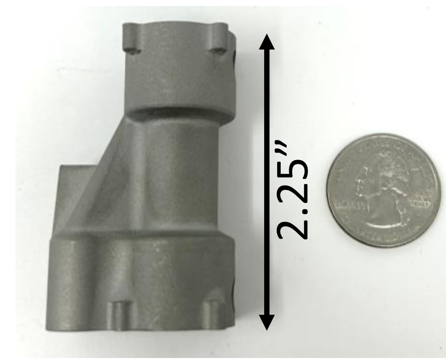


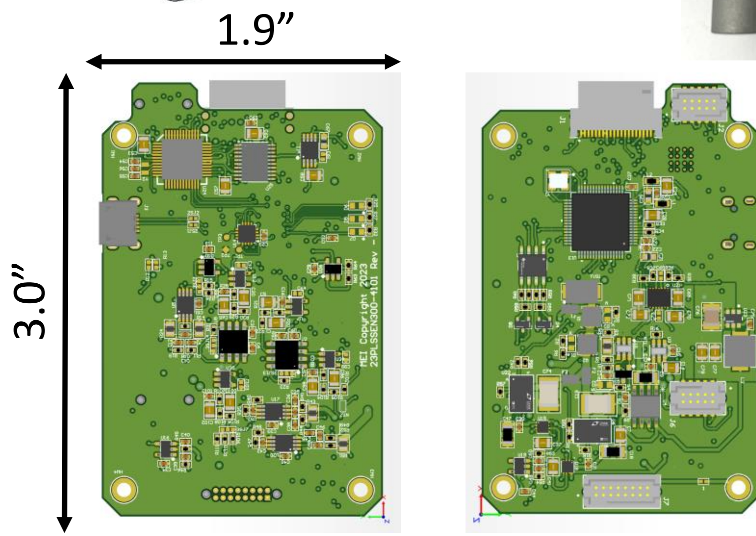
GEN-1 M-PALSS Design





3D Printed Steel NDIR Tube





Primary
Electronics

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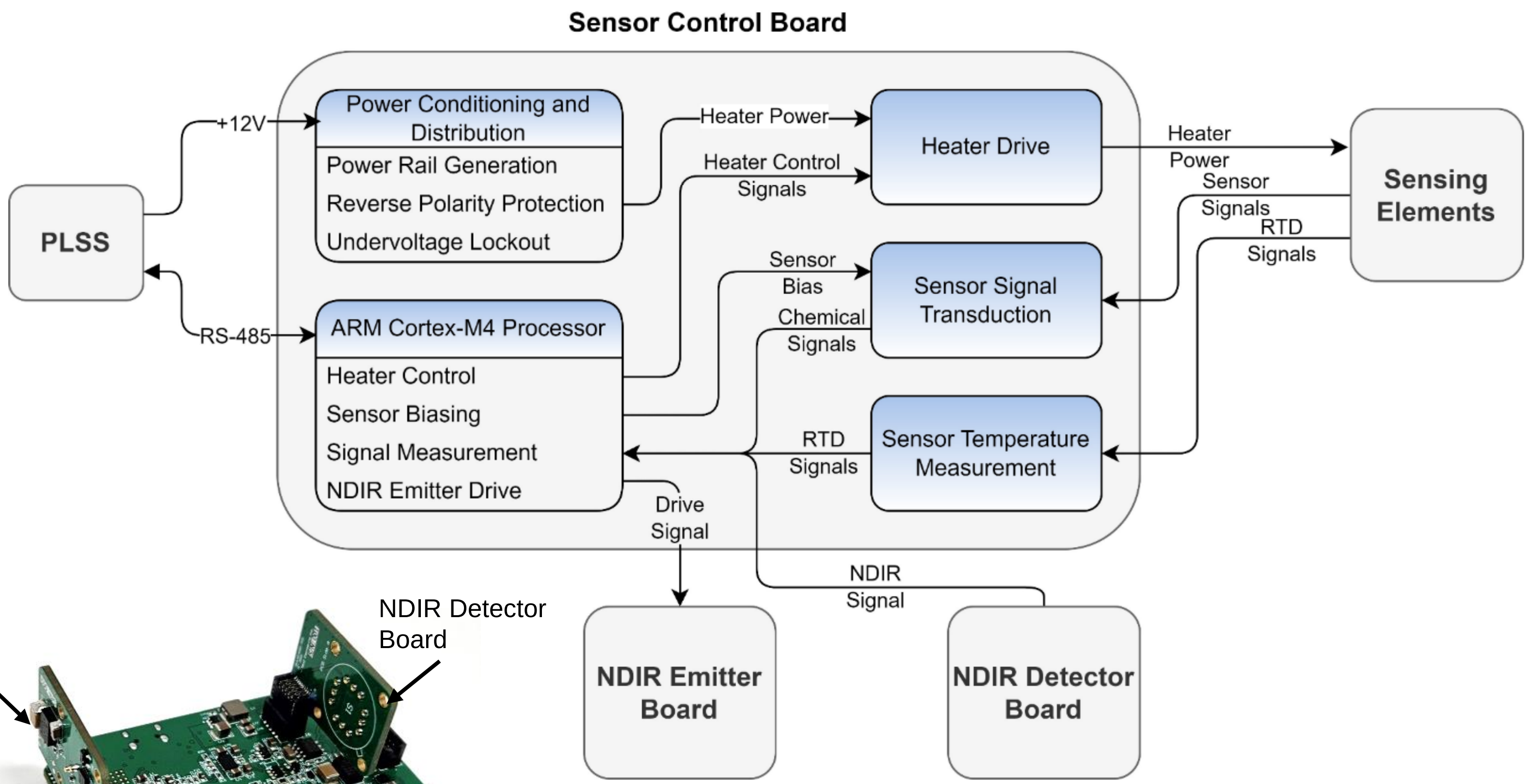
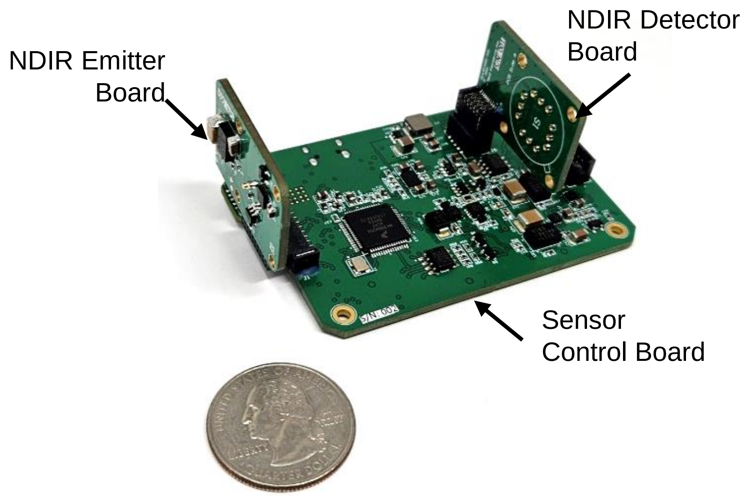
GEN-1 Sensor Control and NDIR Electronics

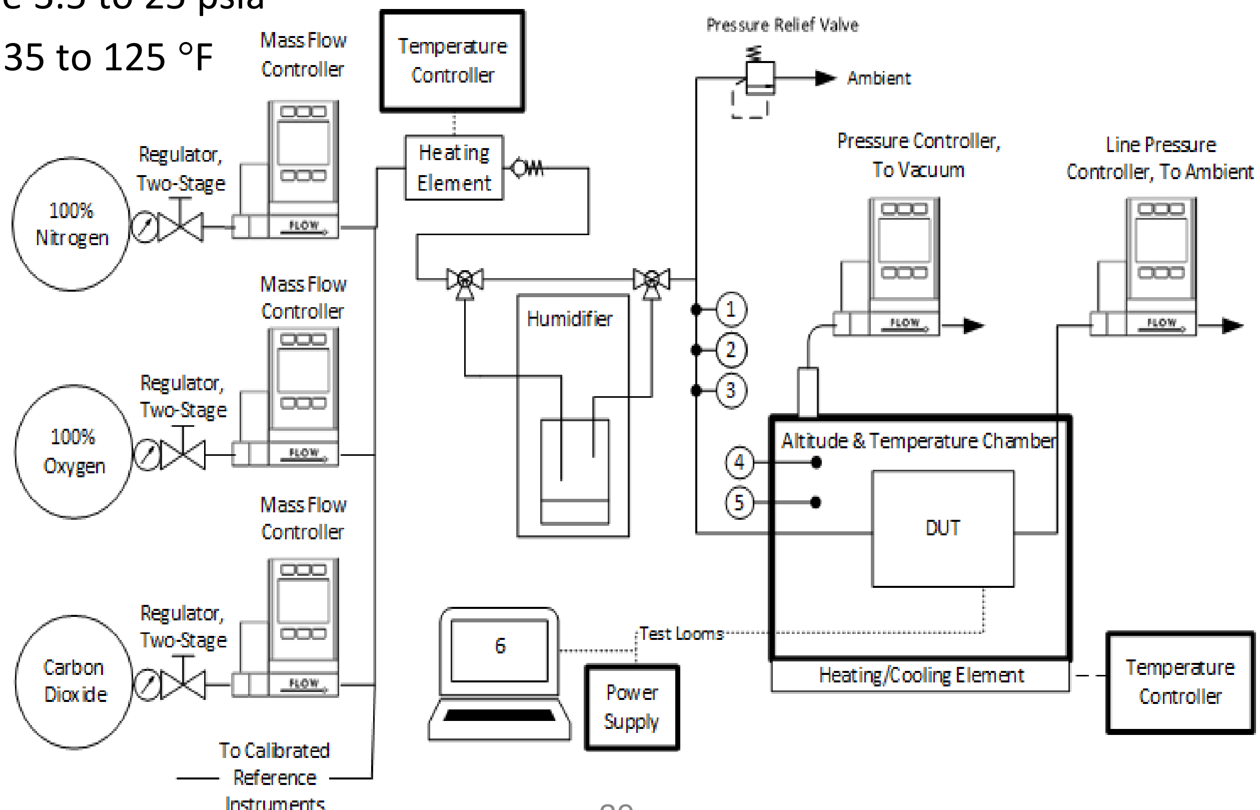




Prototype Testing and Performance

Reduced Pressure and Thermal Test System

- Ranges for gas testing:
  - O_2 0 to 100%
  - CO_2 0 to 30 mmHg
  - Relative Humidity 0 to 95% (Dew Point 40 to 90 °F)
  - Pressure 3.5 to 25 psia
- Temperature 35 to 125 °F



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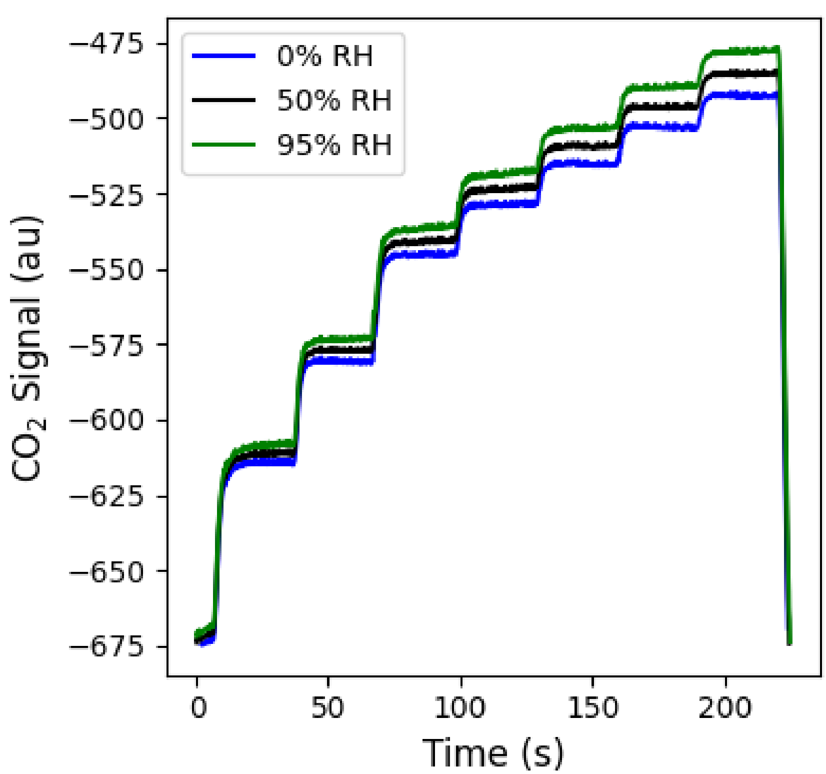
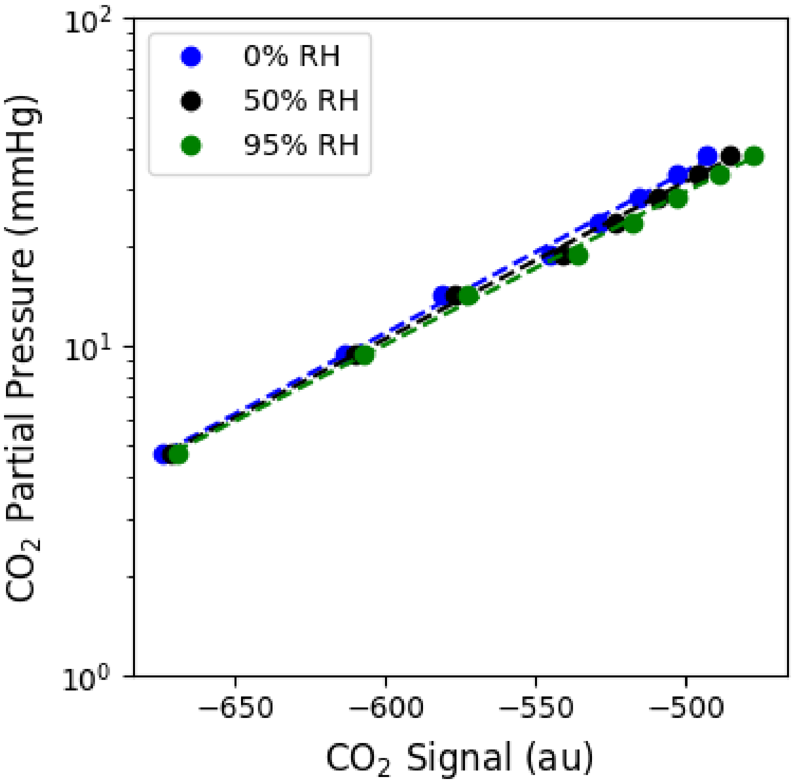
Electrochemical CO_2 Sensor Response





- Humidity compensation required to achieve accuracy requirements
- Time response approximately 12 s
- Ongoing work is characterizing long term stability and calibration

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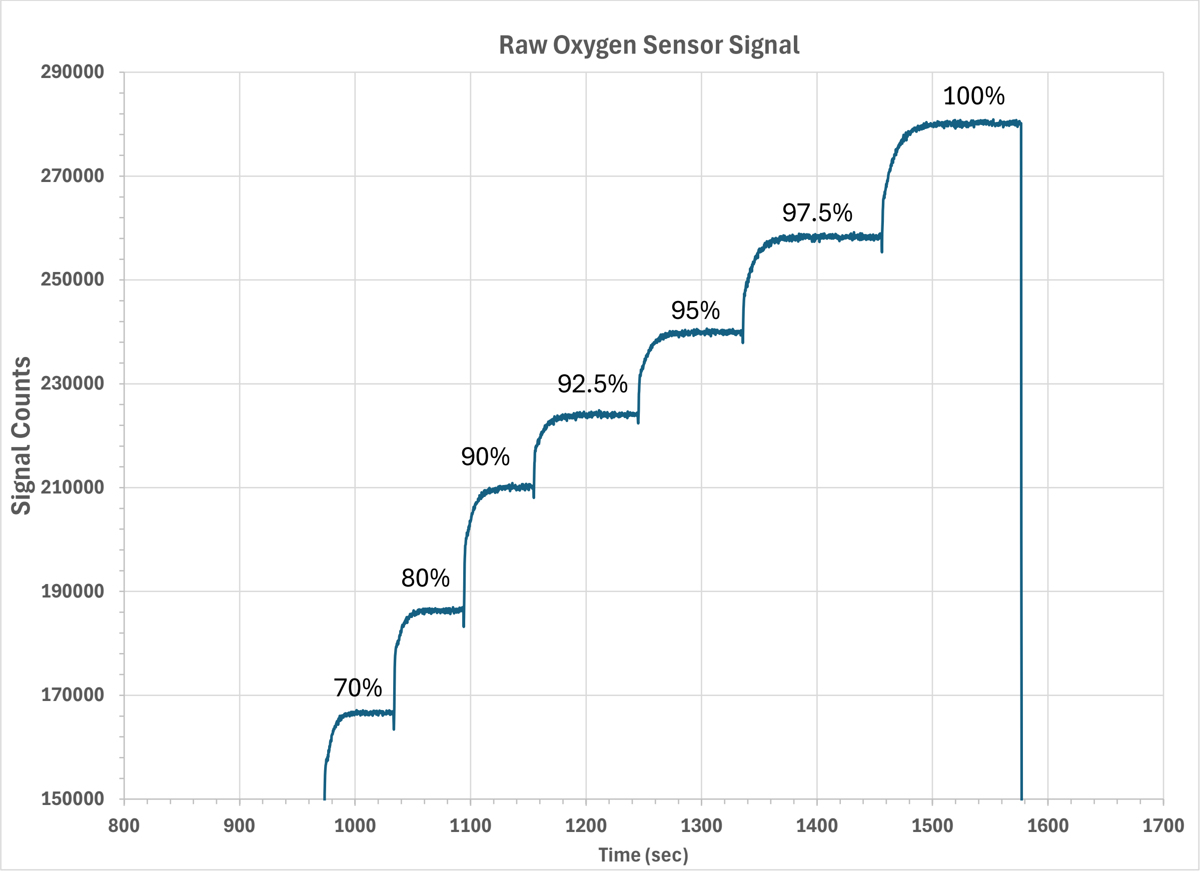
Electrochemical Oxygen High End Sensitivity



- +/-1% oxygen sensor accuracy required in the high range from 90 to 100%
- Improved bias circuit to maintain constant bias over full oxygen range
- Improved sensitivity at high oxygen concentration compared to earlier version

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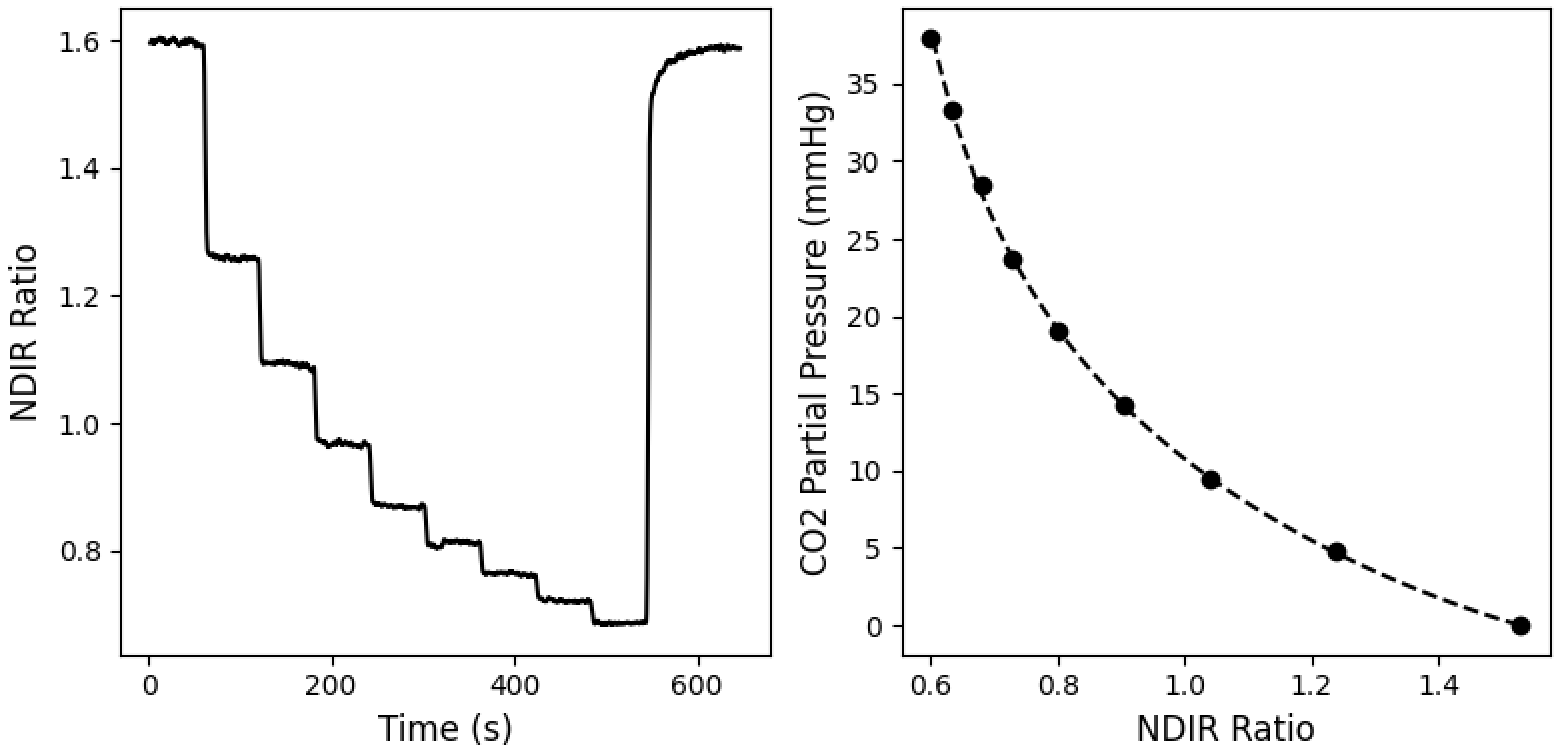
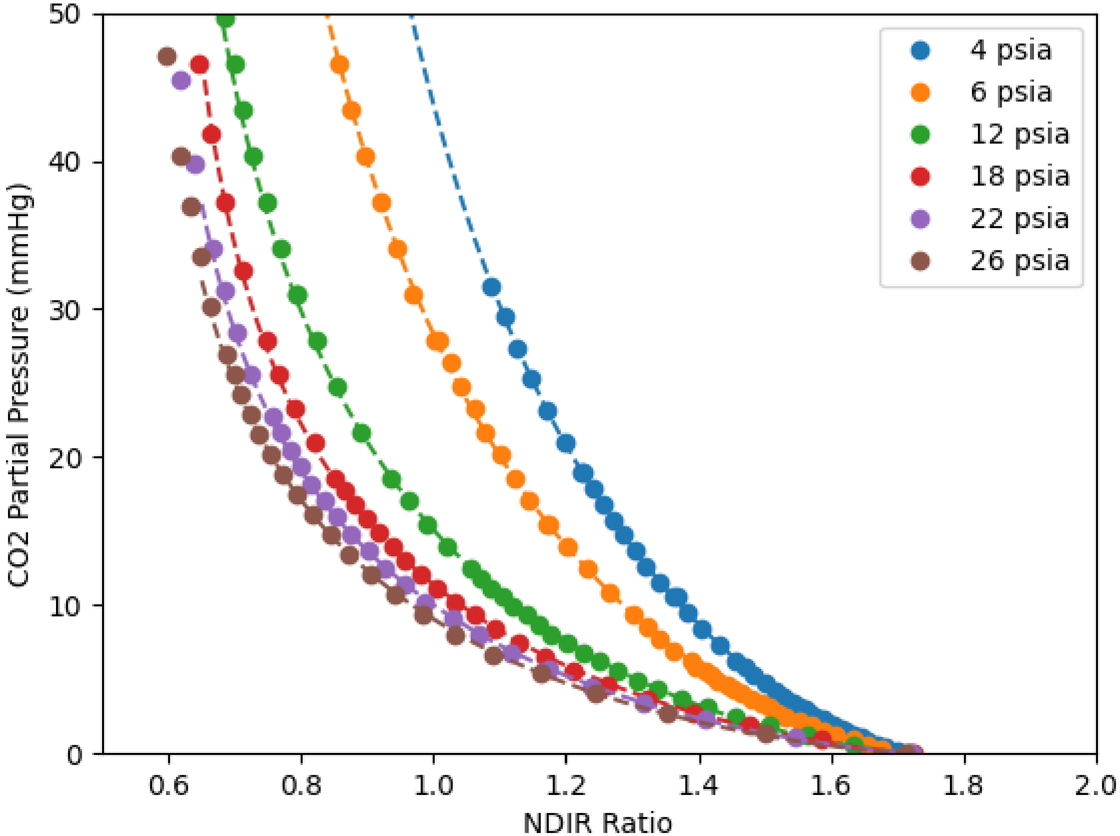
NDIR CO_2 Sensor



- Ratio of amplitude of the of the signal to reference channel is proportional to CO_2 partial pressure
- Sensitivity is highest in lower CO_2 partial pressure range

Sensor Signal (NDIR Ratio) vs CO_2 Partial Pressure at Different Sensed Gas Total Pressures



NDIR ratio vs partial pressure data agrees with the Modified Beer-Lambert Law

$$FA = SPAN\left(1 - e^{-bx^{c}}\right)$$

$$FA \coloneqq Fractional\ Absorbance$$
$$b \coloneqq Effective\ Path\ Length$$
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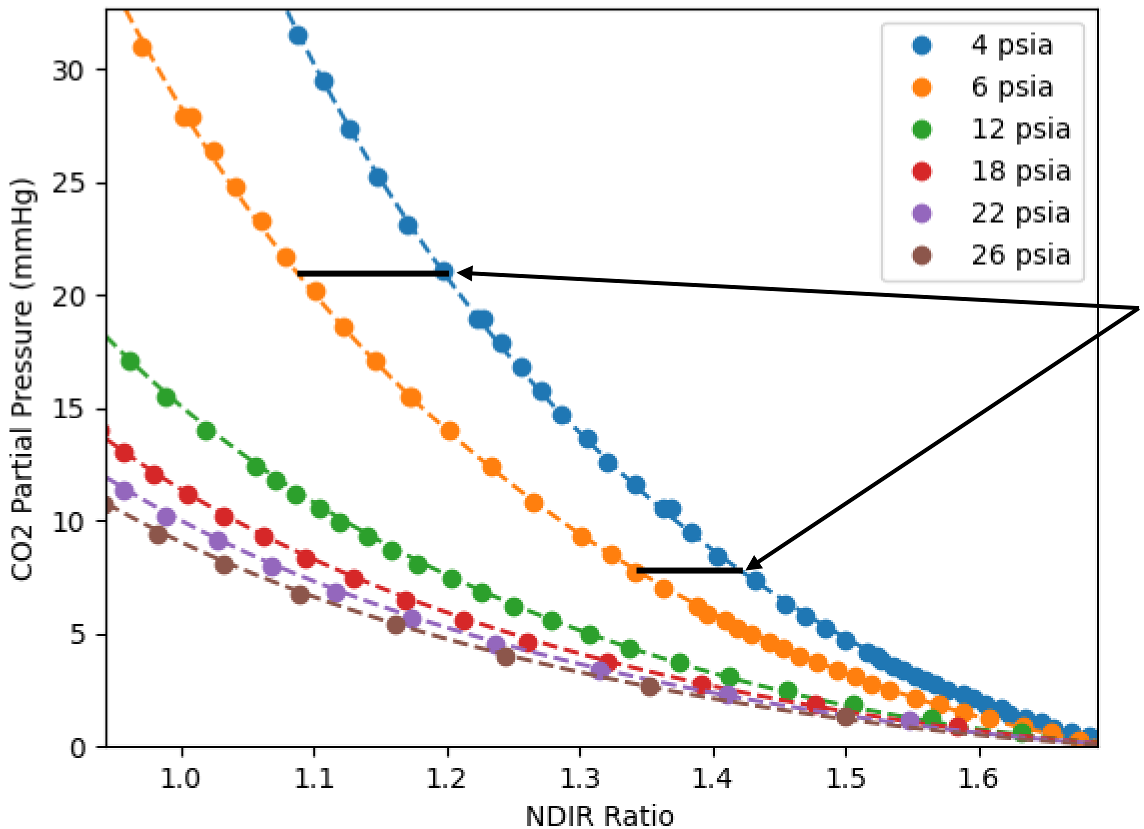
Pressure Broadening Effect is Compensated Using Independent Pressure Sensor



- Magnitude of pressure broadening effect depends on both total pressure and CO_2 partial pressure
- Correction performed in firmware over full PLSS operating pressure range

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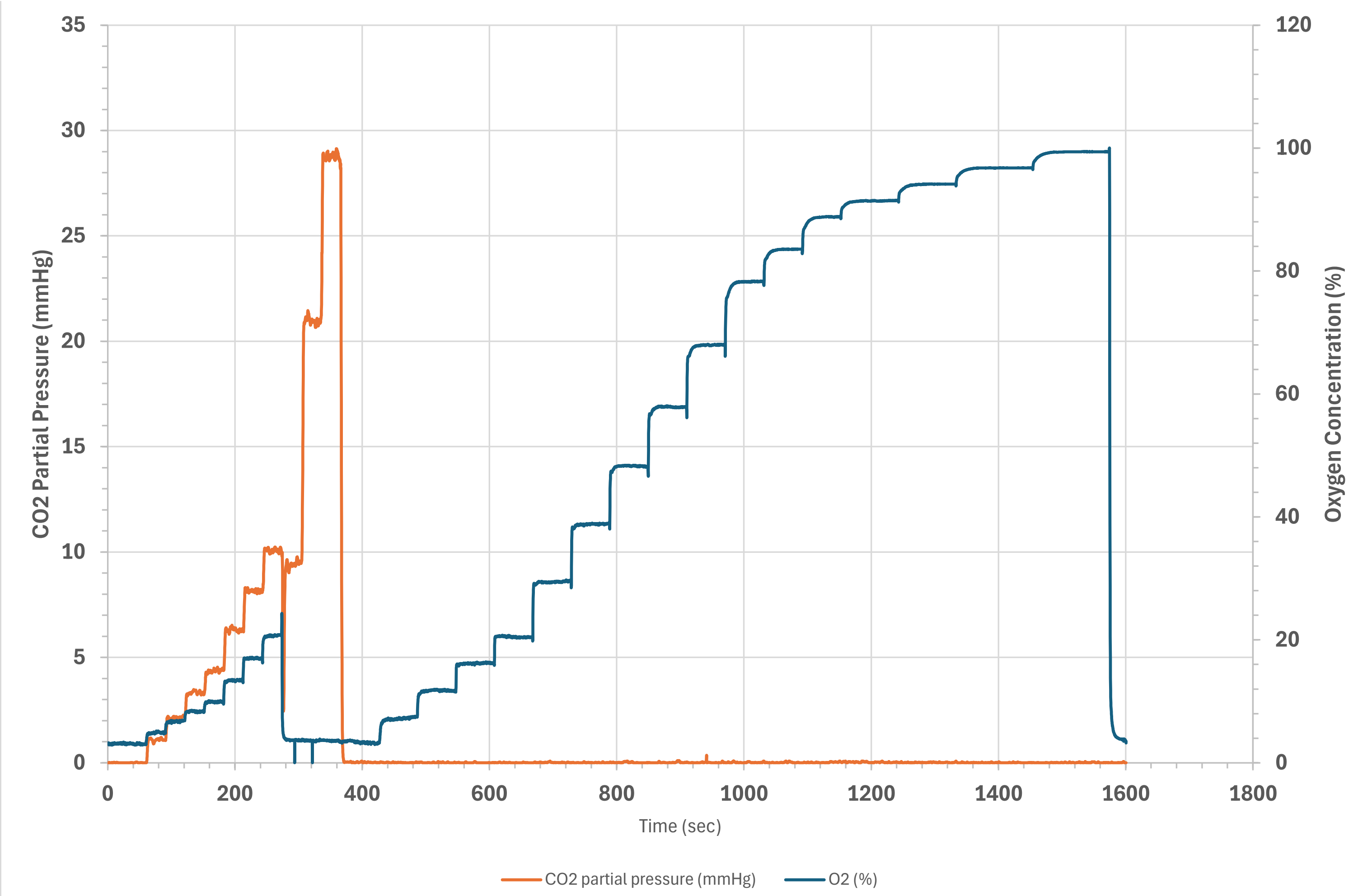
Typical Test Profile Used at Different Pressures and Humidity Levels



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Enhanced Sensing Capability Under Development For Next Generation M-PALSS

SMACs (Spacecraft Maximum Allowable Concentrations)

Chemical	24 hr (ppm)	Sensing Technology	Status/Issue	Risk
Ammonia	20	Potentiometric, Chemiresitive (WO_3)	Under development	Med/High
Carbon Monoxide	**100**	**Chemiresistive (TiO_2)**	**Selected for GEN-2**	**Low**
Formaldehyde	0.5	Photoionization	Under development	**Medium**
Methanethiol	(10 to 20)*	Photoionization	Under development	**Low/Med**

*Estimated based on OSHA limits

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Conclusion and Future Work

- Work presented here completed as part of NASA Phase II SBIR Contact 80NSSC23CA117.
- Solid-state microsensors and NDIR CO_2 packaged into a prototype that preserves interfaces of current NDIR CO_2 sensors and meets target measurement accuracy.
- On-going work to establish long term stability of electrochemical sensors.
- GEN-2 development is underway including transitioning design to meet NASA ionizing environment requirements and spaceflight integration into PLSS.