A Fiber-Optic Sensor for Leak Detection in a Space Environment

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There are many sensors that can provide leak detection:

- Thermocouple/Pressure
- Ionization gauge
- Capacitive
- Silicon carbide
- Chemical leak sensing
- Mass spectrometer

Certain limitations may restrict their applicability in certain applications:

- Environmental vulnerability (e.g. pressure spikes)
- Electromagnetic interference (EMI)
- Pressure range limitations
- One time use
- High vacuum environment limits (on-orbit applications)
- Size and cost

No solution was able to detect and quantify slow leaks that would pose a significant hazard in planned Ares on-orbit crew/fuel transfer missions.

- Fuel/Oxidizer detection
- Vacuum environment
- No EMI susceptibility
- Small/lightweight

A fiber optic coupled interferometer would be able to meet these needs and requirements!

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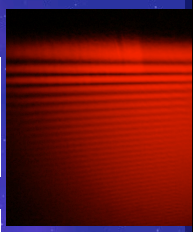
- Background.
- Concept.
- Design.
- Measured Data.
- Conclusion.

An established relationship exists between the observed fringe shift/spacing and the gas density/pressure.



Single-pass interference condition

$$\Delta m = \frac{\Delta\phi}{2\pi} = \frac{l\,\Delta n}{\lambda}$$

Lorentz-Lorenz equation

$$P = \frac{3}{4\pi}\frac{RT}{\alpha N_A}\frac{n^2-1}{n^2+2}$$

Rate of pressure change with respect to the order

$$\mu \equiv \frac{\partial P}{\partial m} \approx \frac{2RT\lambda}{3A\,l}$$

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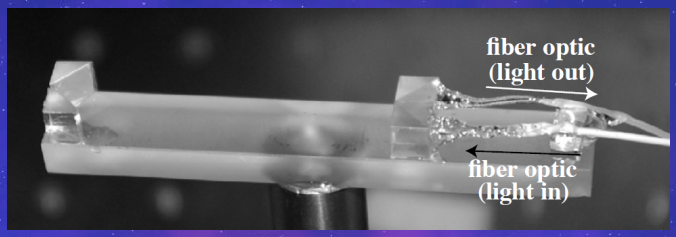
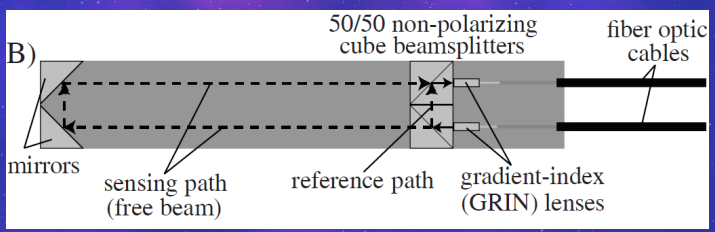


gas sensing interferometer



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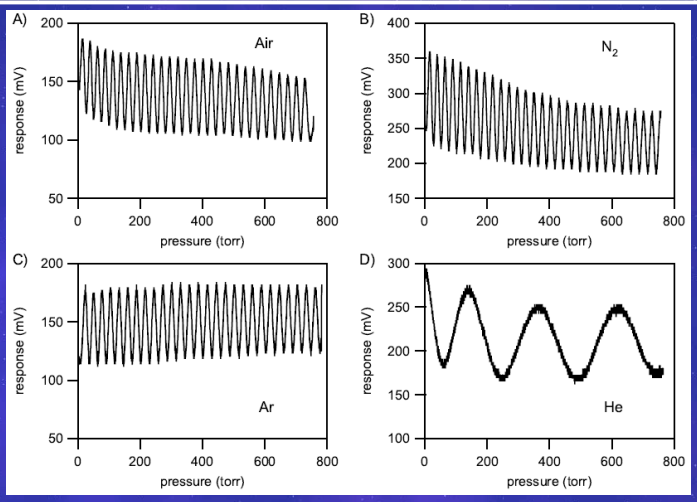

- Constant 1500 sccm gas injection rate
- Fringe spacings compare favorably with theory for air, N_2, Ar
- Non-uniform spacing for He (large difference in Molar refractivity (A))

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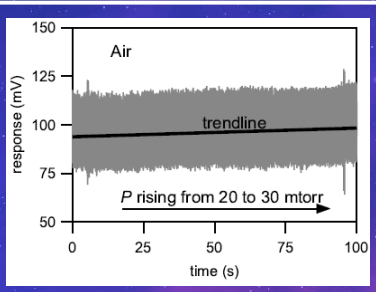
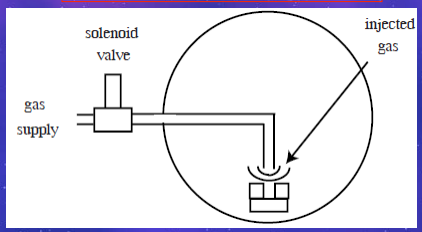


- Slow leak data
- Pressure resolution on air below 10 mtorr

Fast gas injection setup



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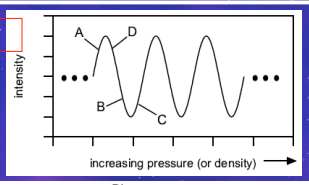
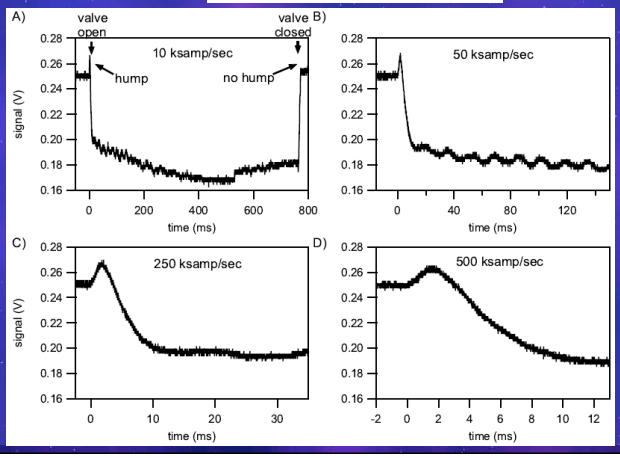
Notional response



- Fast, transient gasdynamic events and waves are captured.
- Measurements are in-line with the notional response
- Measurements on order of photodiode response time



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- Exists a need to detect and quantify slow leaks on-orbit that might endanger a mission or crew.
- No solution to this problem that was capable of
  - Fuel/Oxidizer detection
  - Vacuum environment
  - No EMI susceptibility
  - Small/lightweight
- A fiber-coupled, solid body interferometer was demonstration tested as a possible solution
- Results
  - General agreement between predicted and measured interferometer response
  - Sensor resolution demonstrated at under 10 mtorr pressure change
  - Showed capability to acquire time-resolved, transient data that resolved bulk pressure variations and much faster gasdynamic pressure oscillations
- Theory shows that much higher levels of resolution are possible using a combination of present solid-body optics / MOEMS manufacturing techniques