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QEPAS (QVR L-PAS) Based Gas Sensor Module Development

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OUTLINE

PNNL L-PAS Team Meeting

Richland, WA
February 24, 2005

- Motivation: Optimization of QEPAS (QVR L-PAS) based gas sensor technology using near-IR diode lasers
- Fundamentals of QEPAS (QVR L-PAS) Spectroscopy
  - Comparison of QEPAS (QVR L-PAS) to L-PAS
- Selected Applications of QEPAS (QVR L-PAS)
  - NH_3 Detection with 1.53 μm RT cw DFB Diode Laser
  - N_2O & CO Detection with a 4.6 μm LN_2 CW DFB Quantum Cascade Laser
- Current Status and Year 1 Research Directions

Year 1 Tasks and Deliverables (Contract # 14813)

- Development of NIR QEPAS (QVR L-PAS) based Gas Sensor Architectures:
  - Target gases: H_2O and HCN
  - Selection and implementation of near-IR high power CW fiber coupled DFB diode lasers for H_2O and HCN detection
  - Optimum TF selection and acoustic micro-resonator design
  - Laser beam coupling to Absorption Detection Module (ADM)
  - Pressure dependence
  - Development of data acquisition and processing system
  - Gas handling and calibration
- Evaluation and Optimization of NIR QEPAS (QVR L-PAS) Performance Characteristics
  - Assessment of achieved detection sensitivity (dependence on ADM design & laser power)
  - Comparison of experimental QEPAS (QVR L-PAS) sensor performance with PNNL theoretical model
- Year 1 Deliverables
  - Performance characterization of a compact HCN QEPAS (QVR L-PAS) sensor
  - Laboratory analysis of coupling efficiency of acoustic fields to TFs

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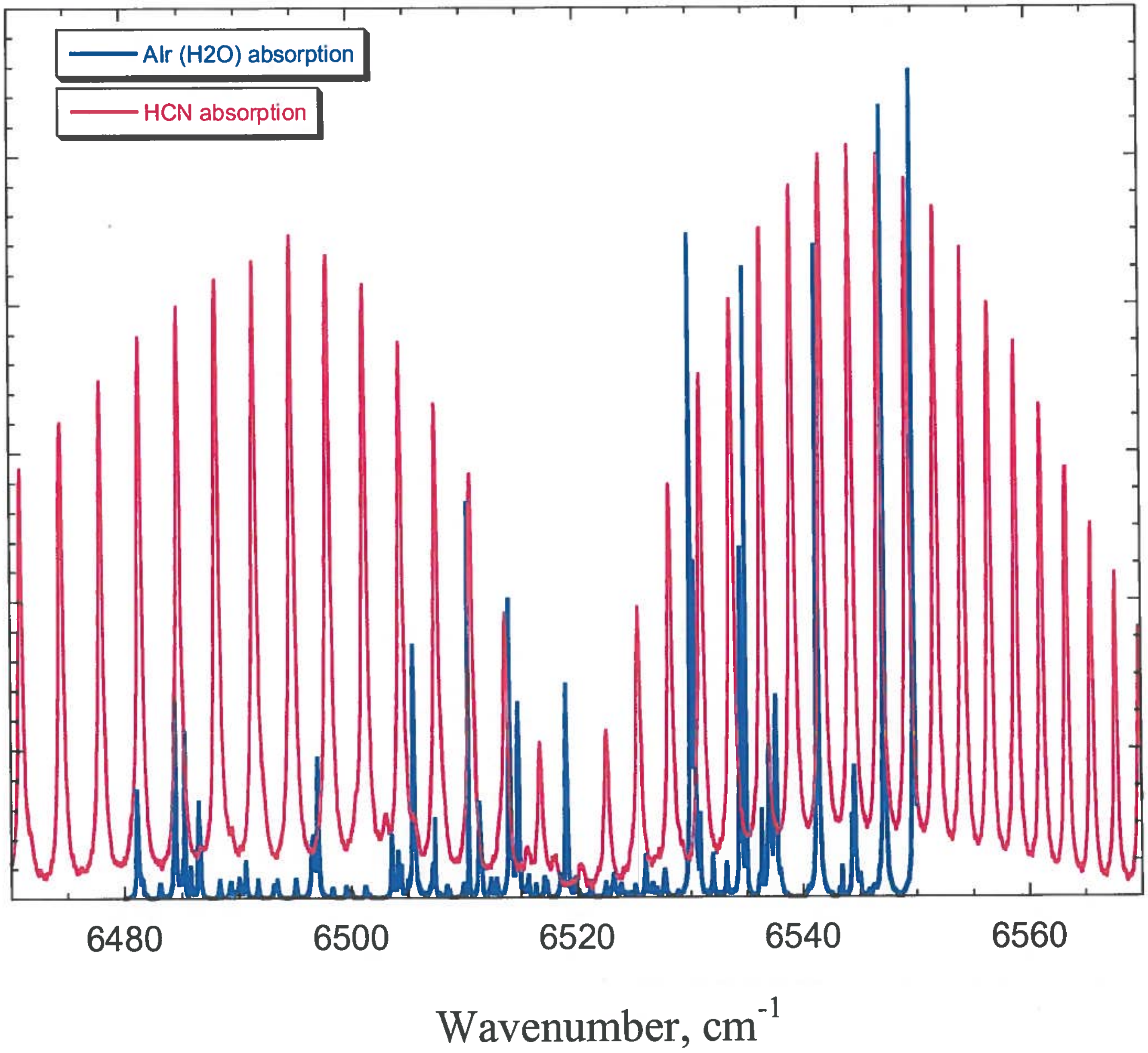
Year 2 Tasks and Deliverables (Contract # 14813)

- Development of NIR QEPAS based Gas Sensor Architectures:
  - Target test gas: broadband absorbing compound - hydrazine
  - Selection of cw broadband emitter
  - Optimum quartz resonator illumination geometry in AM-1f NIR QEPAS (QVR L-PAS) mode
  - Amplitude modulation studies to assess detection sensitivity of broadband absorbers in WM-2f and AM-1f mode of operation
  - Perform detailed investigations of the influence of gas pressure, temperature and humidity on QEPAS (QVR L-PAS) sensor performance
  - Development of data acquisition and processing system
  - Evaluate sensor sensitivity to the environmental acoustic noise sources
- Year 2 Deliverables
  - Assessment of TF fork performance as a function of environmental conditions (temperature, humidity and pressure)
  - Prototype sensor device according to PNNL specifications

HCN NIR line selection



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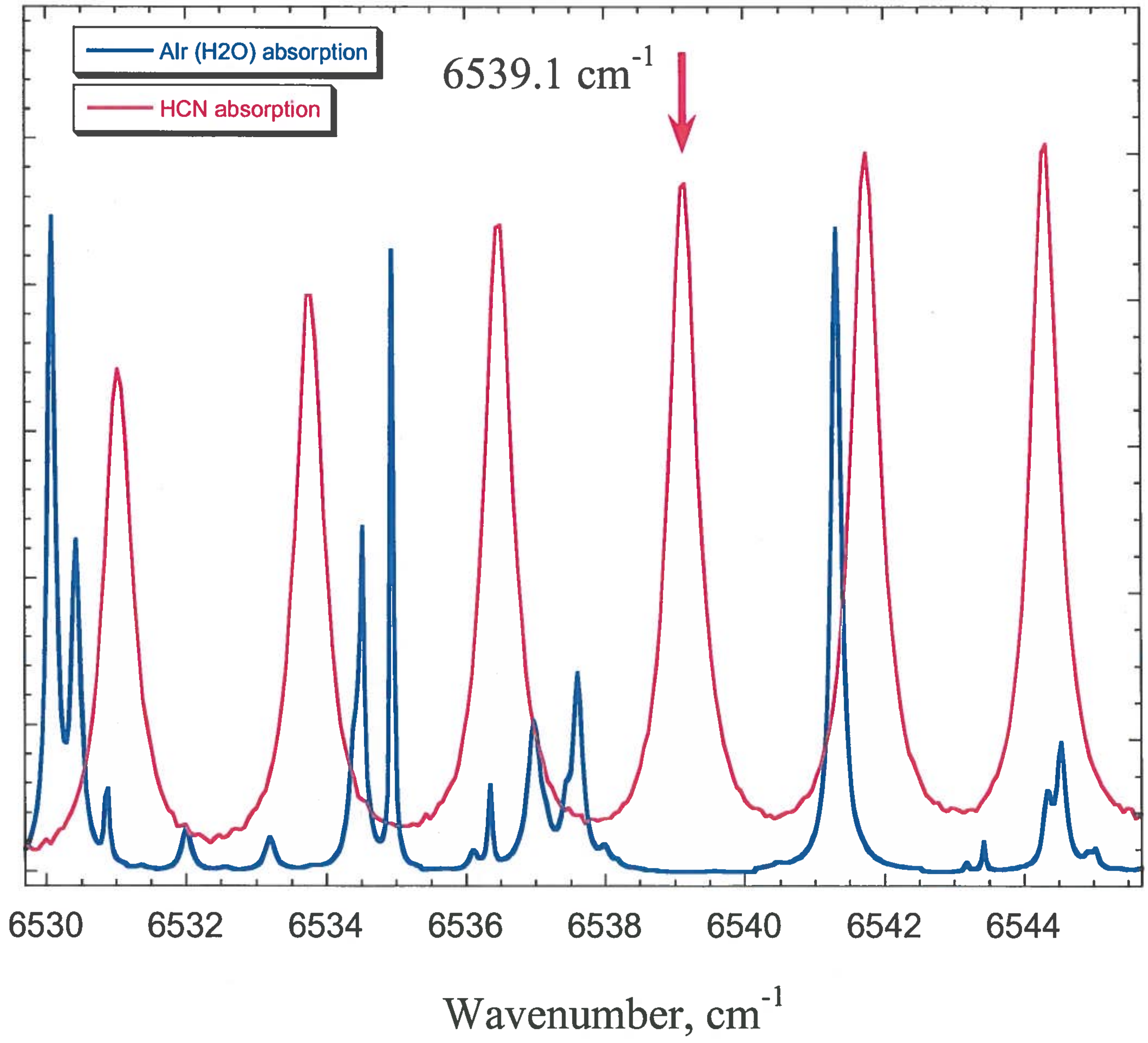
HCN NIR line selection - zoom



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Year 1 tasks (SOW)

63 mW 1550 nm CW DFB Lasers with PM Fiber for WDM Applications
CQF935/908 Series

The JDS Uniphase CQF935/908 series laser is specifically developed for wavelength division multiplexing (WDM) systems, where it is used in combination with an external modulator, such as the LiNbO3-based Mach-Zehnder.

Selected wavelengths comply with ITU recommendations, both in range (1527.61 to 1610.06 nm) and in channel definition, thus adhering to the 100 GHz grid (0.8 nm) relative to a frequency of 193.1 THz (i.e., a wavelength of 1552.52 nm). It is possible to customize the wavelength spacing to a 50 GHz grid (0.4 nm).

Each laser's wavelength is accurately measured, and the laser itself is accompanied by a datasheet with the laser performance at the temperature T, where the required wavelength channel is reached.

The CQF935/908 shows high side mode suppression ratios, very low relative intensity noise, and small linewidths. It is available in a standard 14-pin butterfly package equipped with a polarization maintaining fiber to facilitate coupling to the modulator, and shows superb thermal stability.

Key Features
- 1550 nm WDM distributed feedback laser diode
- High power (>63 mW)
- Polarization maintaining fiber
- Built-in thermoelectric cooler
- Cooled, built-in optical isolator
- 1527 - 1610 nm wavelength range
- 0.8 nm (100 GHz) spacing
- 0.4 nm (50 GHz) spacing optional

Applications
- Hybrid fiber-coax (HFC) networks, cable-television (CATV) networks, and metro architectures where high power, low RIN, and narrow linewidths are required
- Long haul for compensation of high-loss passive or active components

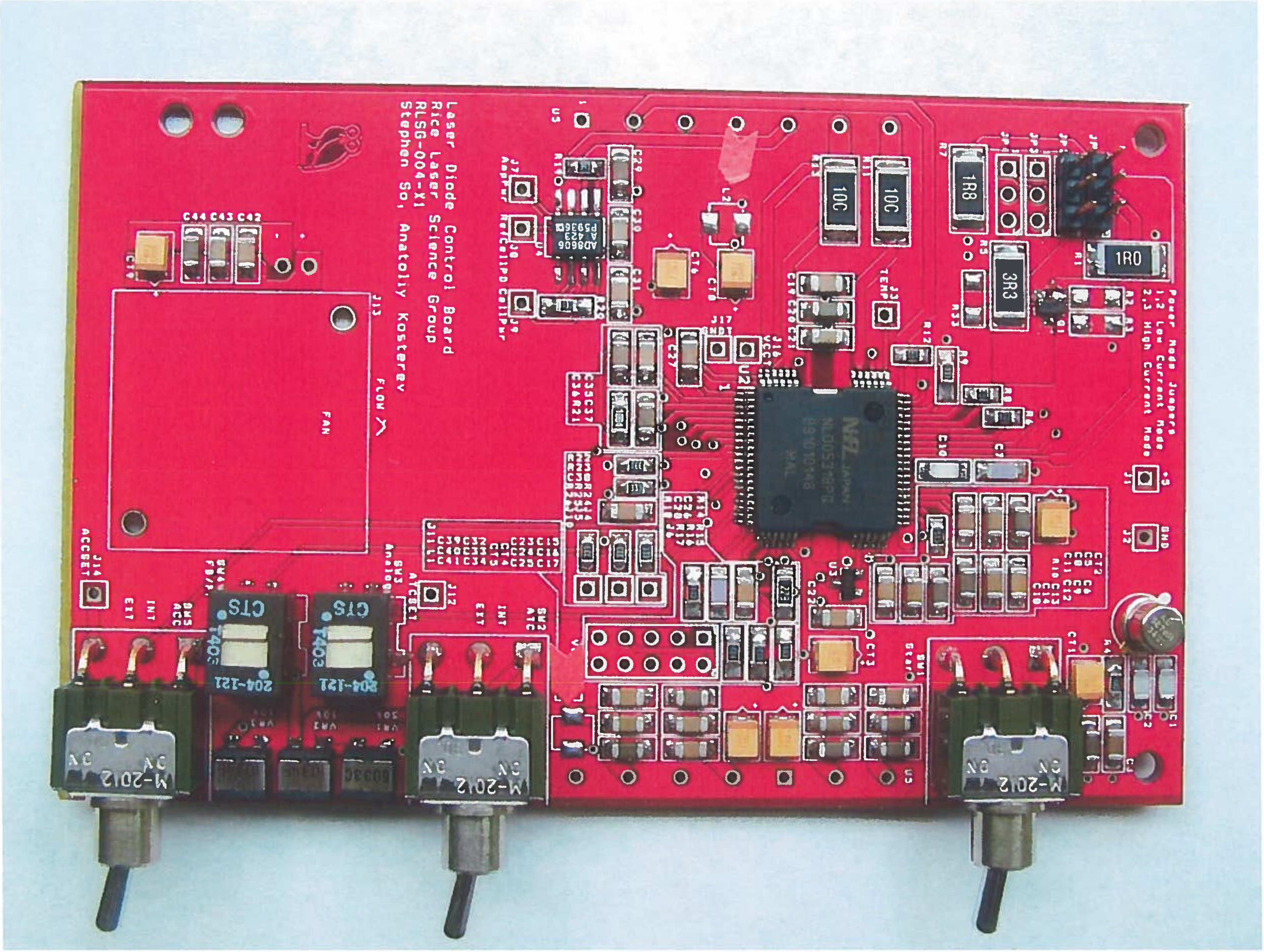
Channel 19600

1529.56 nm

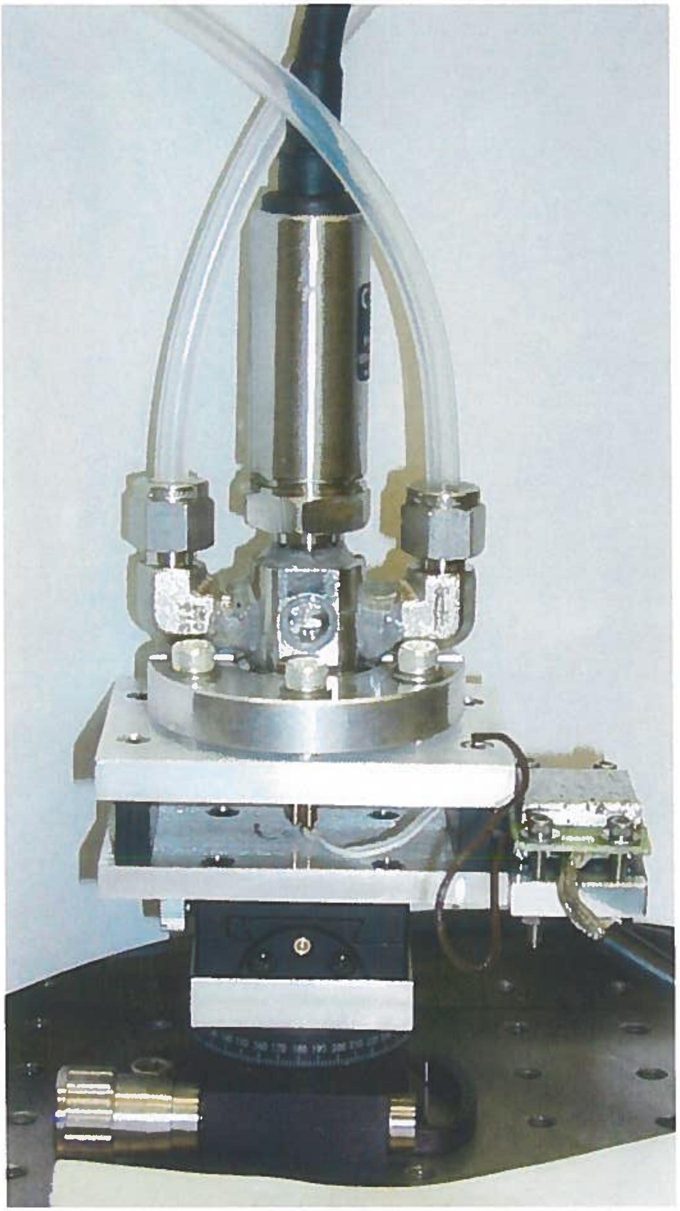
6537.8 cm^{-1} (+25°C)

0.1 nm/°C$\Rightarrow$0.4 cm^{-1}/ °C

One-chip TEC/DL driver



TF gas cell upgrade



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Quest for a low-frequency TF: Why?

$$S = k\frac{\alpha lCPQ}{fV} = k\frac{\alpha CPQ}{fA}$$

$$m' = nm$$

$$f_0' = \frac{f_0}{\sqrt{n}}, \quad Q' = Q\sqrt{n}$$

$$\boxed{S' = nS = \left(\frac{f_0}{f_0'}\right)^2}$$

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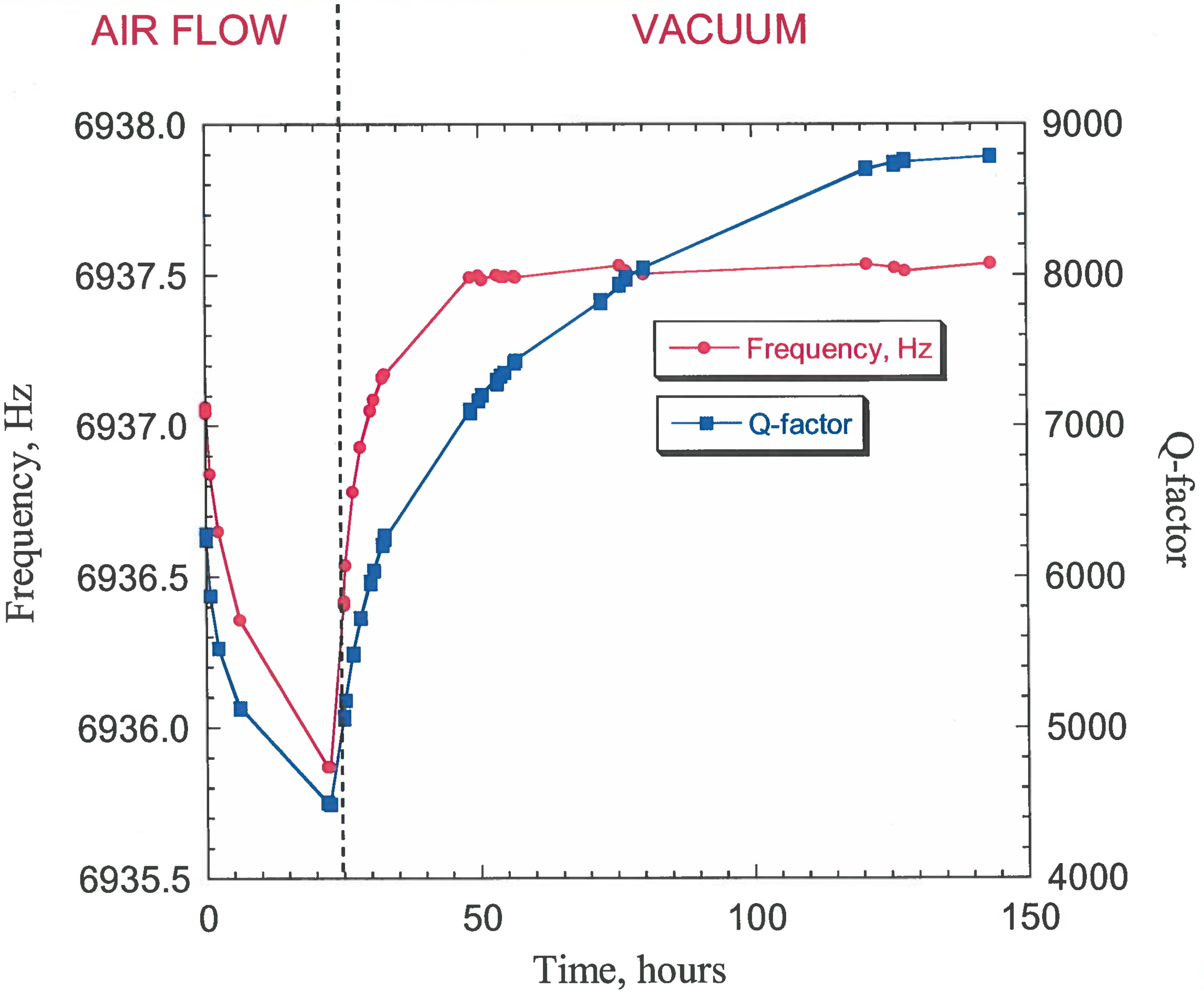
TF with weights

Tungsten carbide

ρ=14.95, d=1 mm

Heavy TF: air and vacuum



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Next "heavy steps" (in progress)

- Try different adhesives (preferably hydrophobic)
- Fabricate a few more samples
- Order factory-made low-frequency heavy TFs

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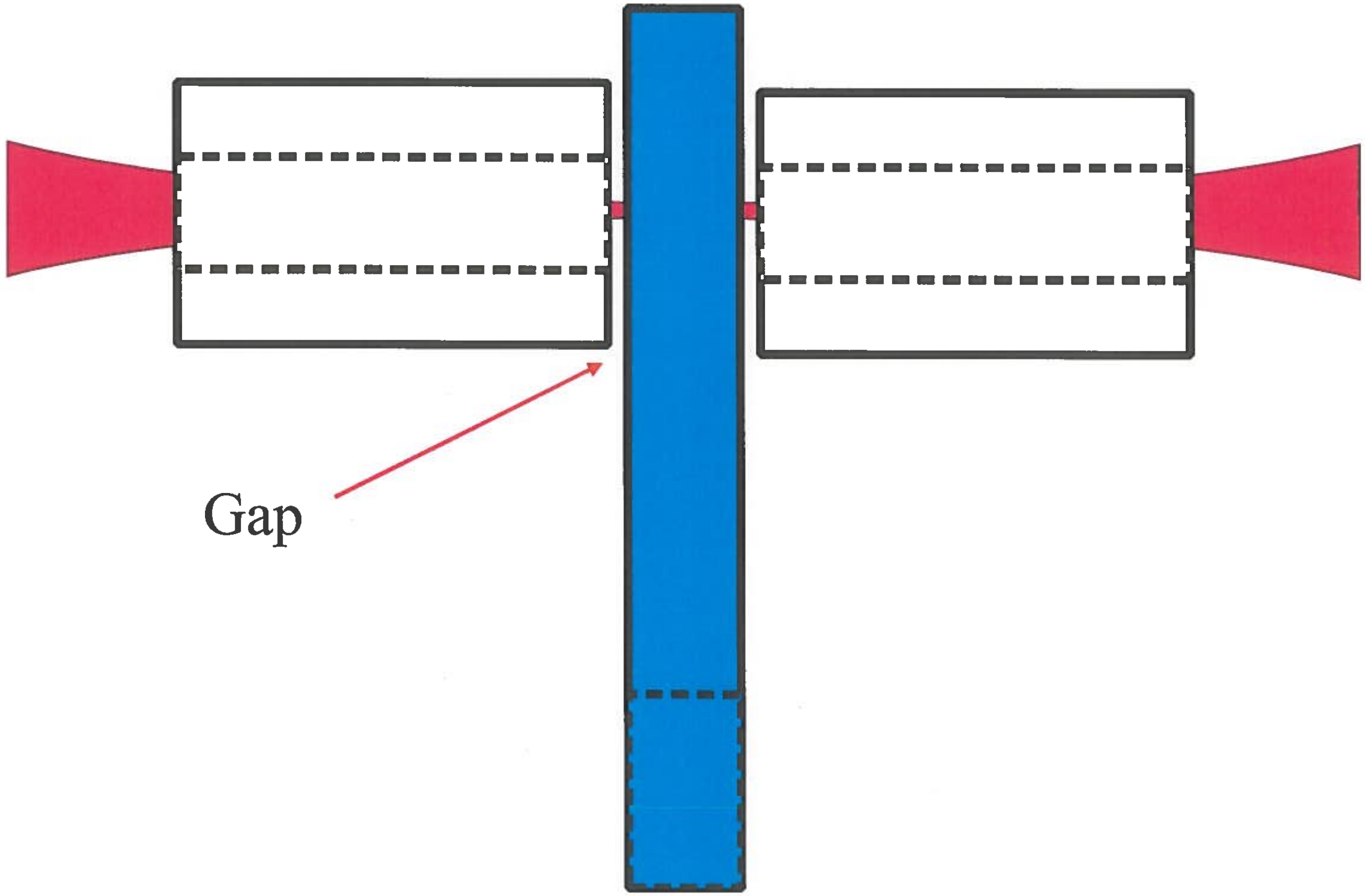
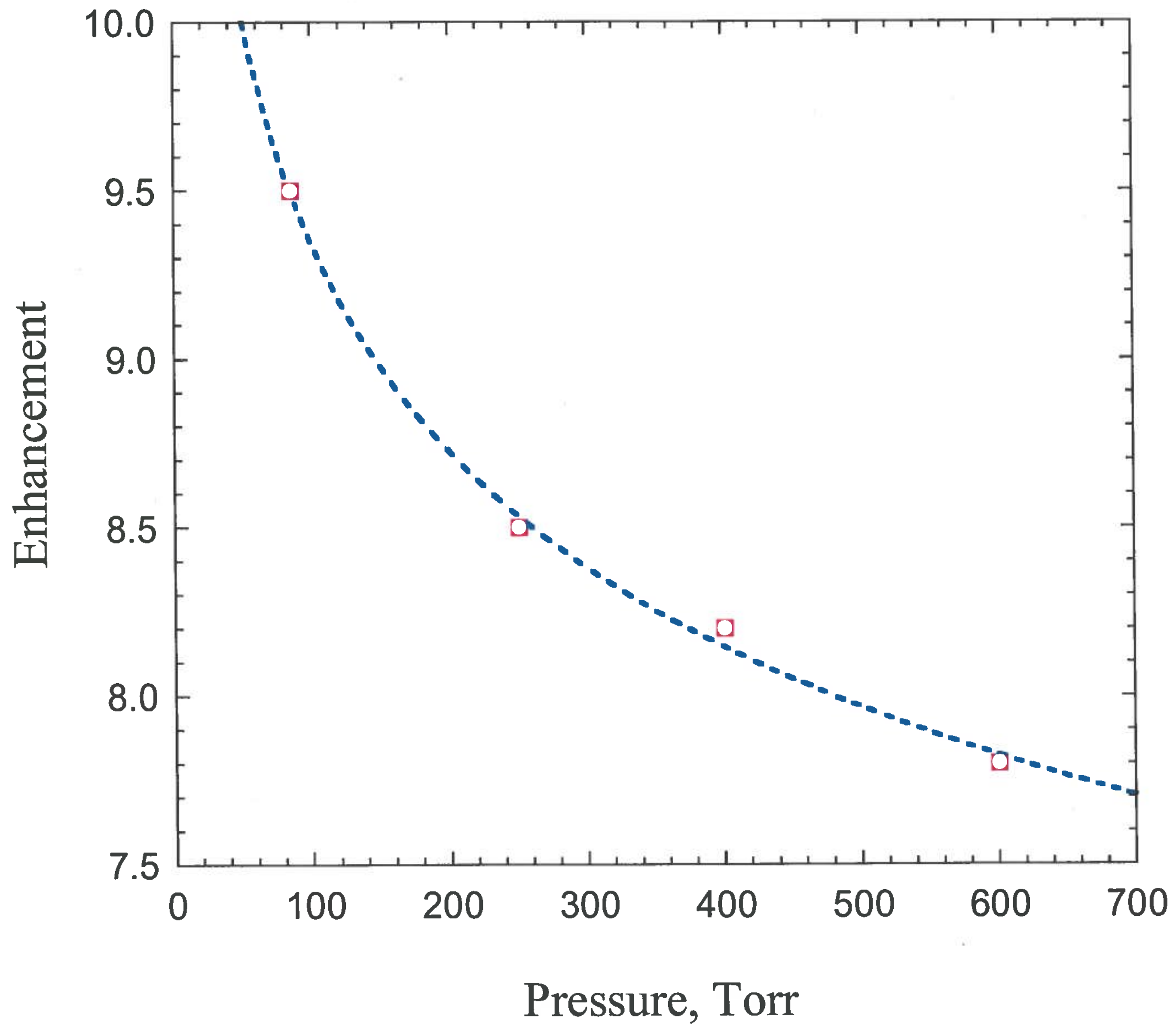
Existing configuration



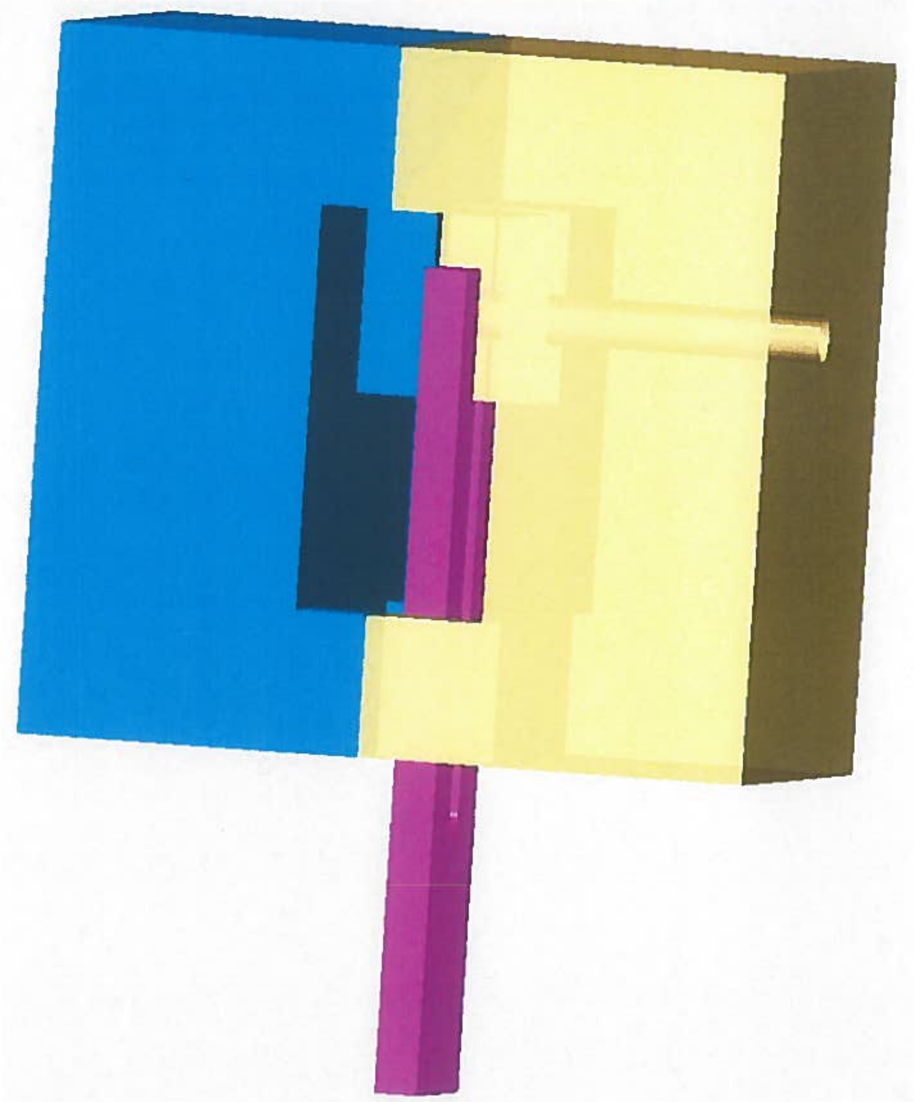
Q at 760 Torr air: ~12000 (practically unchanged)

Signal gain



10.0
9.5
9.0
8.5
8.0
7.5
Enhancement
0
100
200
300
400
500
600
700
Pressure, Torr

Micro Aluminum resonator



Q at 760 Torr air:
13000→ 5200

Q at 60 Torr:
26000→ 10200

But:
<u>Signal is UP 1.3 times!</u>

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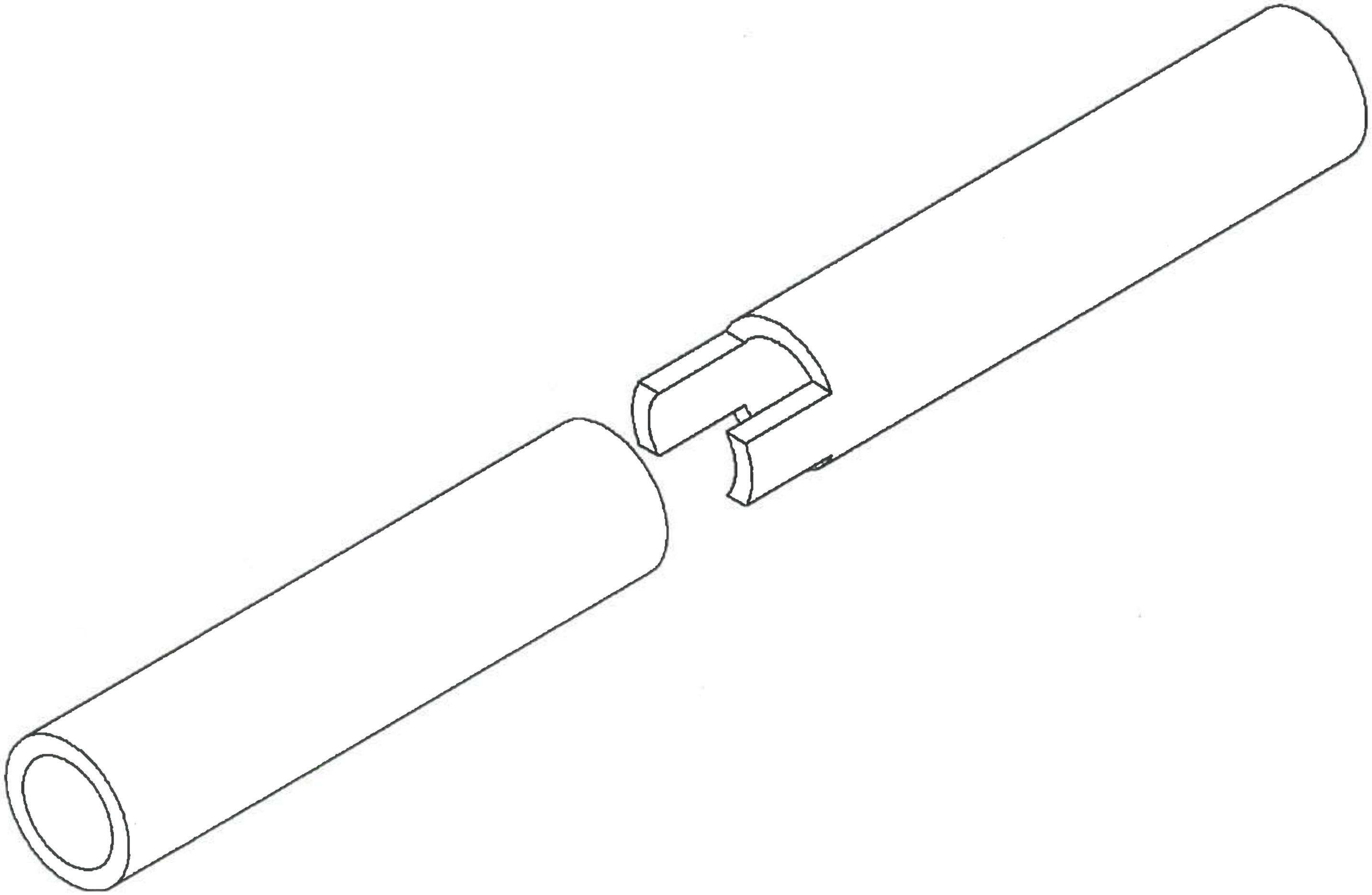
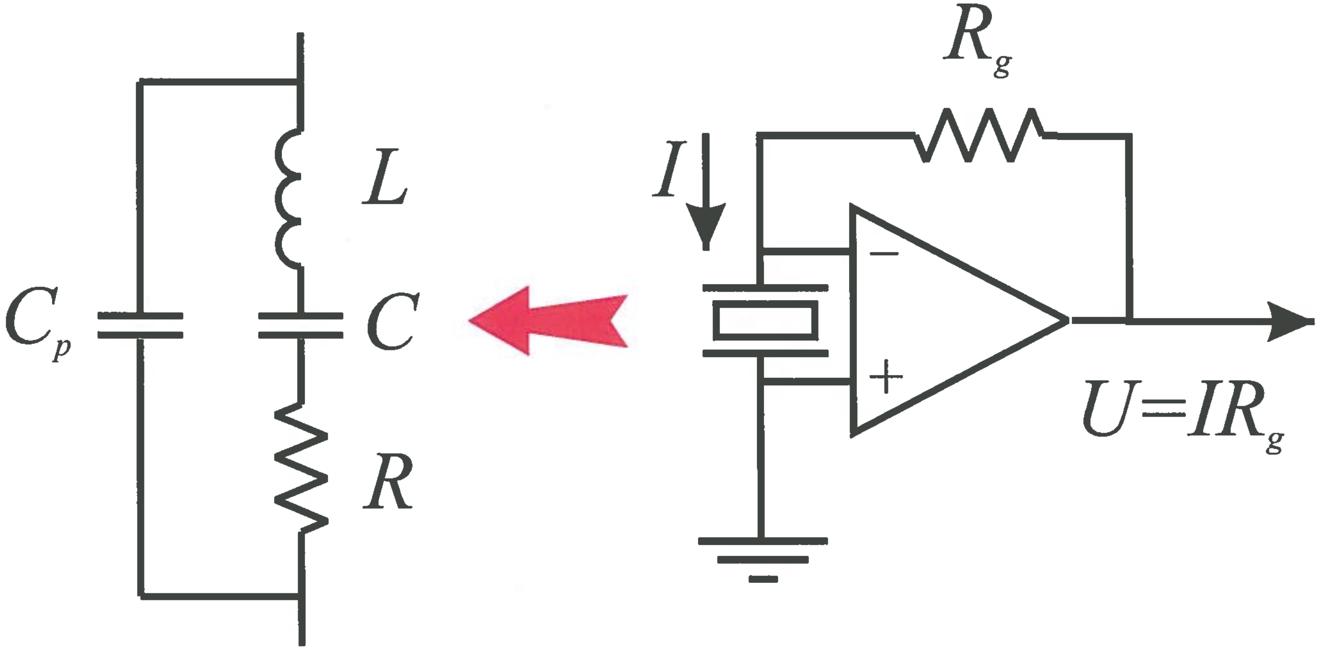
micro

Next generation resonator



Noise analysis



$$S_1=\sqrt{4k_BTR_g};\quad R_g=10\ \mathrm{M\Omega}\Rightarrow S_1=4.1\cdot10^{-7}\ \frac{\mathrm{V}}{\sqrt{\mathrm{Hz}}}$$

$$S_2=\sqrt{\frac{4k_BT}{R}R_g};\quad R=100\mathrm{k\Omega}\Rightarrow S_2=4.1\cdot10^{-6}\ \frac{\mathrm{V}}{\sqrt{\mathrm{Hz}}}\ \text{(at 760 Torr)}$$

$$S=\sqrt{S_1^2+S_2^2}\approx S_2\quad\text{(at resonance)}$$

Noise goes up as $\sqrt{\mathrm{Q}}$.

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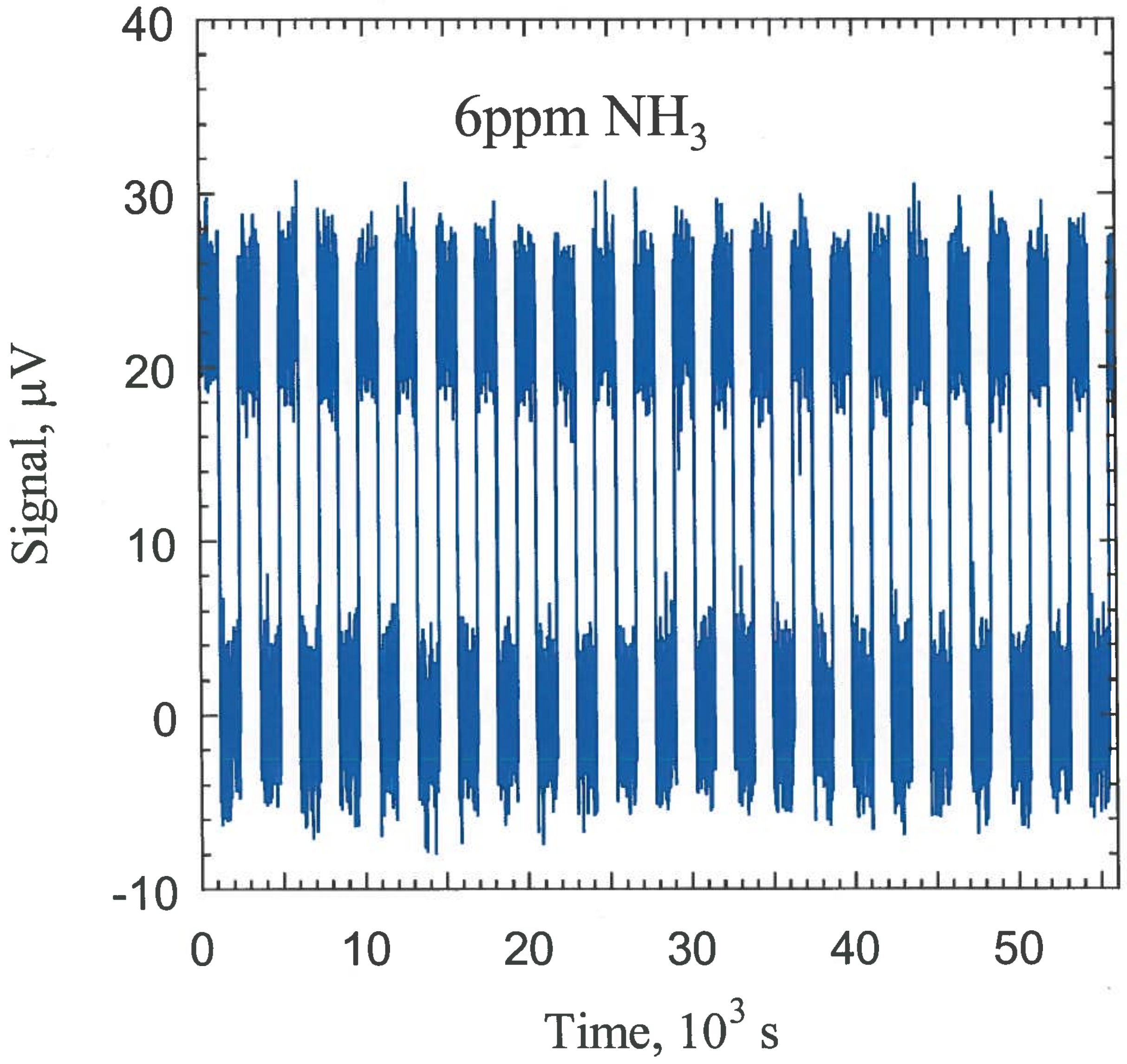
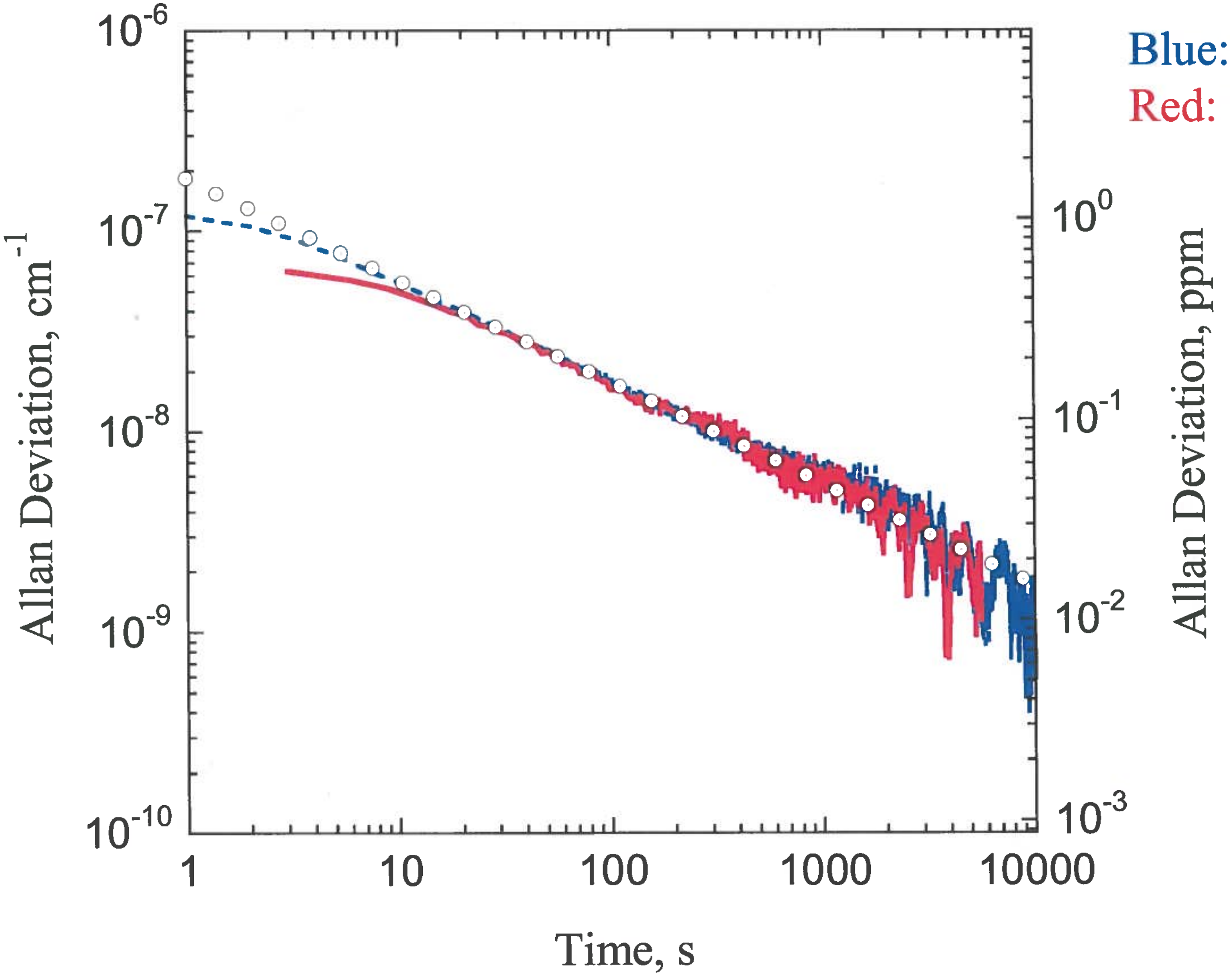
How long can we average?



Allan deviation



Blue: t=0.3 s, laser blocked

Red: t=1 s, NH_3 signal

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