CKM SCRF Cavity

Microphonics Detuning Compensation and Thermometry Developments

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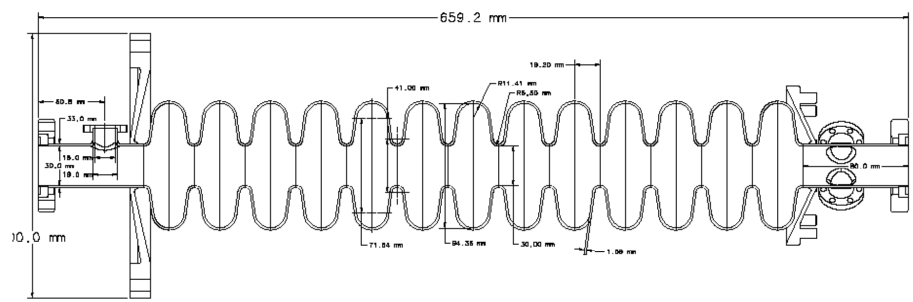
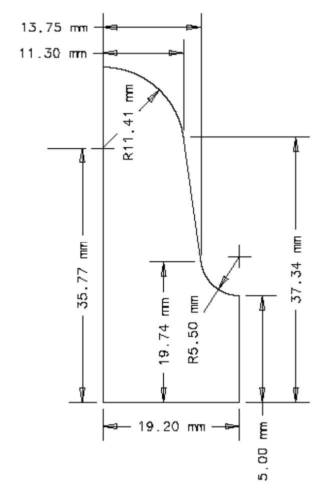
Some CKM SCRF Cavity Parameters

- Frequency: 3.9 GHz
- Cells/cavity: 13
- Cavity Length: 660 mm
- $Q_{ext} = 6 \times 10^7$
- Bandwidth (f/ Q_{ext}): 65 Hz

- Main Injector Cycle Time: 3 sec
- Extracted Beam Duration per cycle: 1 sec





Detuning Tolerance Target

- To keep RF power requirements low, it is desirable to keep the resonance frequency within ~ 1/10th of the bandwidth:

$$\frac{P_{comp}}{P_{(\Delta f=0)}} = \frac{1}{4}\left[\frac{\Delta f}{f_{1/2}}\right]^2 \qquad f = 3.9\ GHz \pm 6.5\ Hz$$

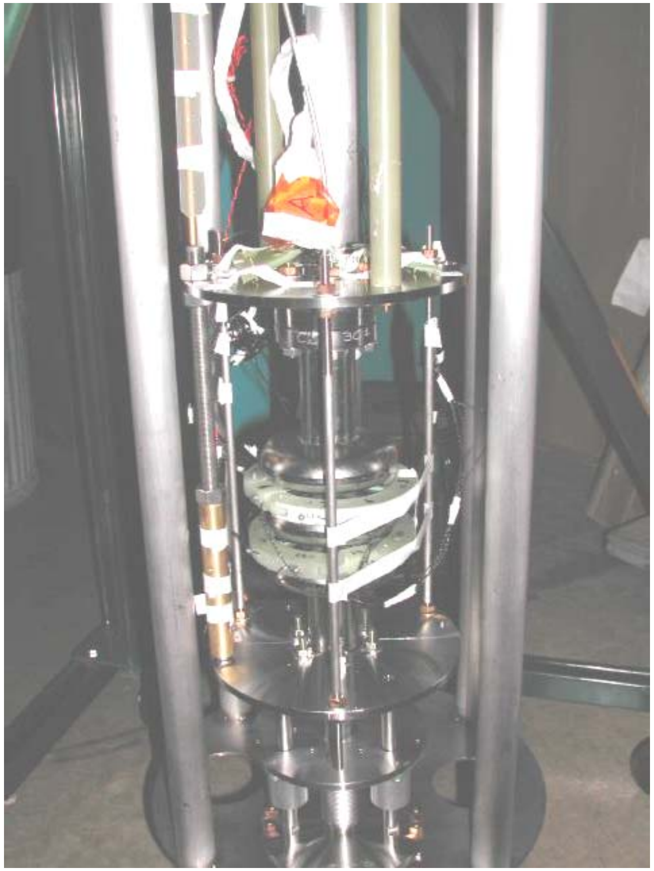
- From Finite Element Analysis models, ± 6.5 Hz corresponds to ± 3.1 nm in a 13-cell CKM cavity length.
- Failure to achieve this detuning tolerance target would require de-Qing the cavity further to increase its bandwidth, thus increasing the RF power cost.

Piezo Actuator Selection

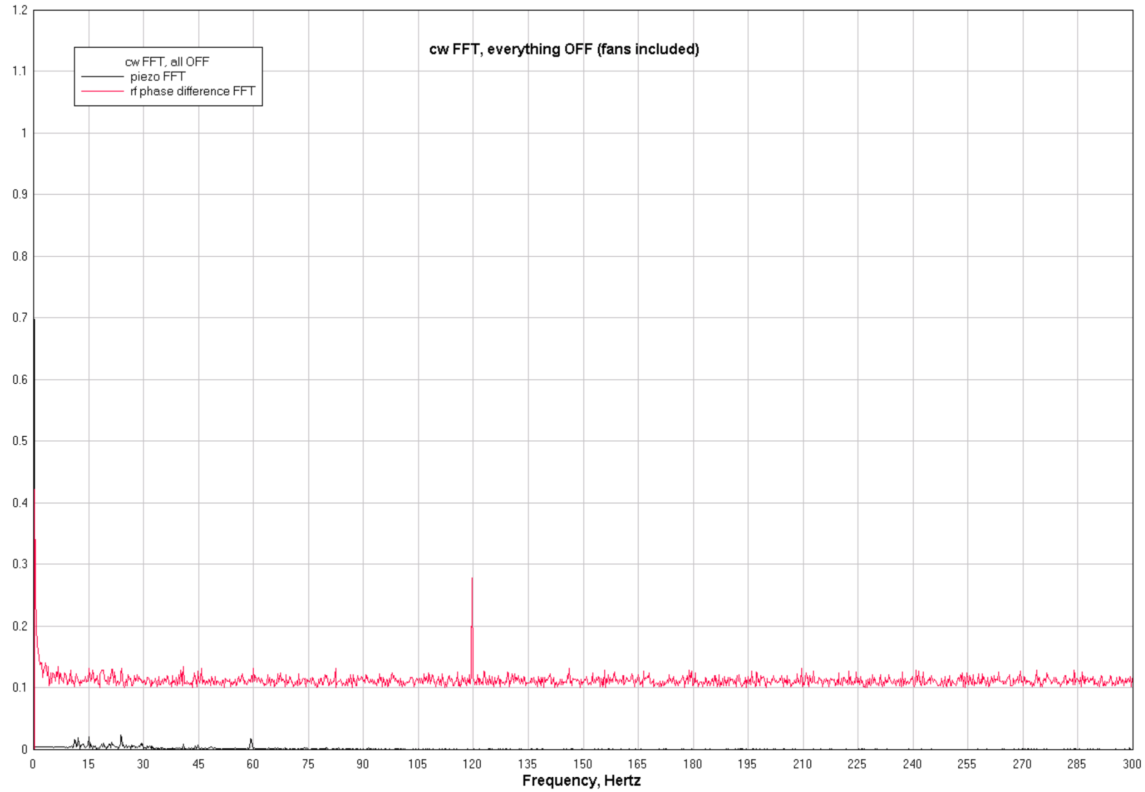
- For prototype studies, we selected the Piezo Actuator P-206-40 from Piezosystem Jena. Some of its parameters are:
  - Bare piezostack compatible with cryogenic operation in liquid helium.
  - Voltage range: -10V to 150V
  - Range of motion (room temperature): 80 µm. At 1.8 K: ~ 8 to 10 µm
  - Length: 90 mm
  - Stiffness: 12 N/µm
  - Maximum Load: 1000 N
  - Capacitance: 8500 nF

3-cell prototype instrumentation

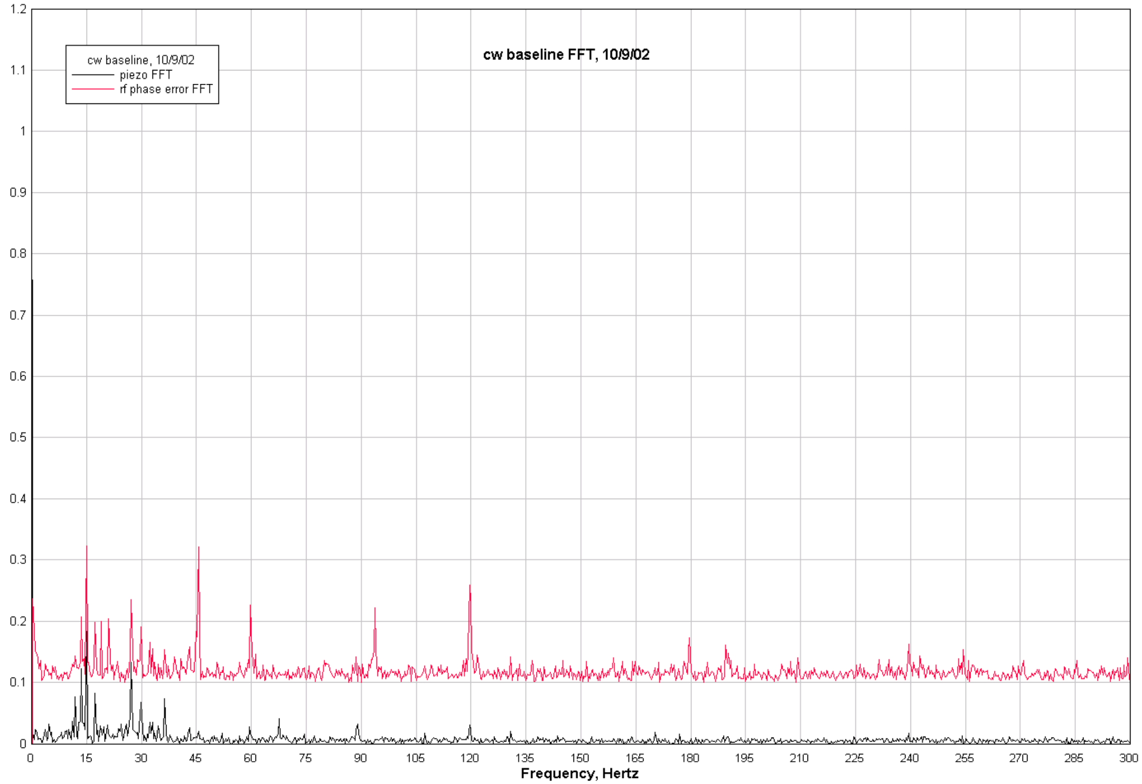
- 3-cell prototype showing location of piezo element plus thermometry rings.
- Piezo element was used both as a sensor and as an actuator.



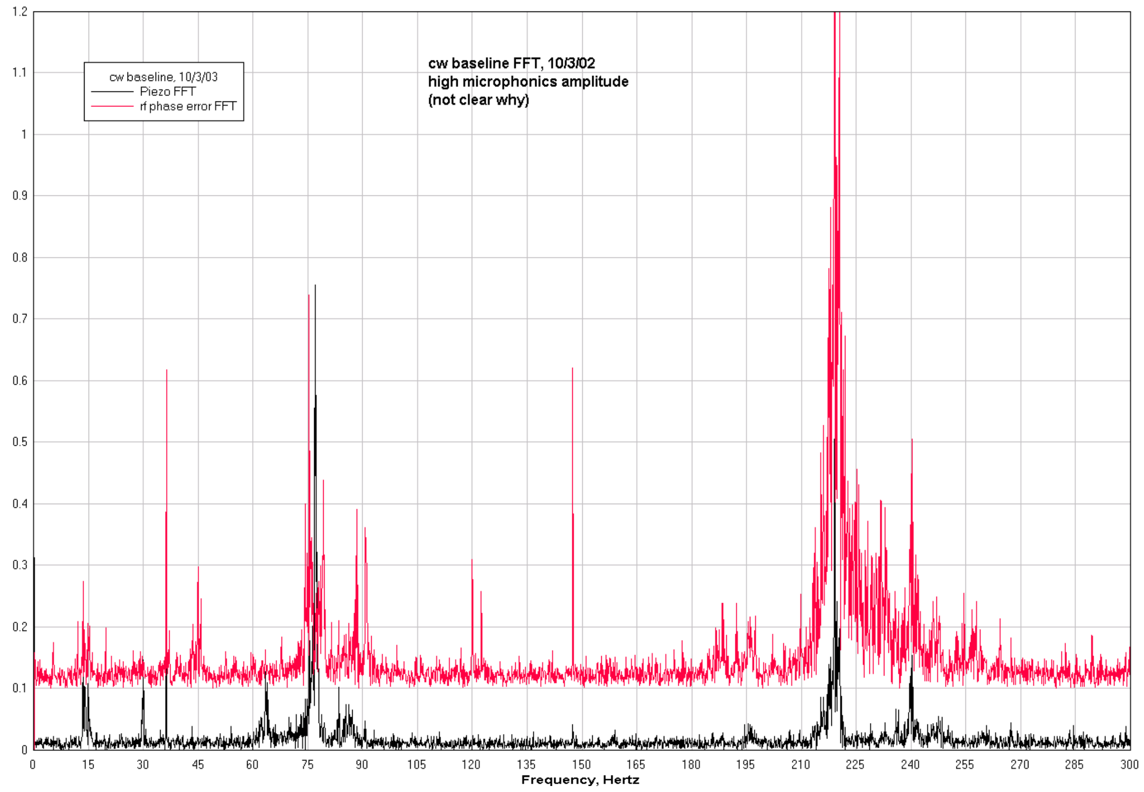
Microphonics FFT – All Pumps OFF



Microphonics FFT – Low Amplitude (~ ± 100 Hz)

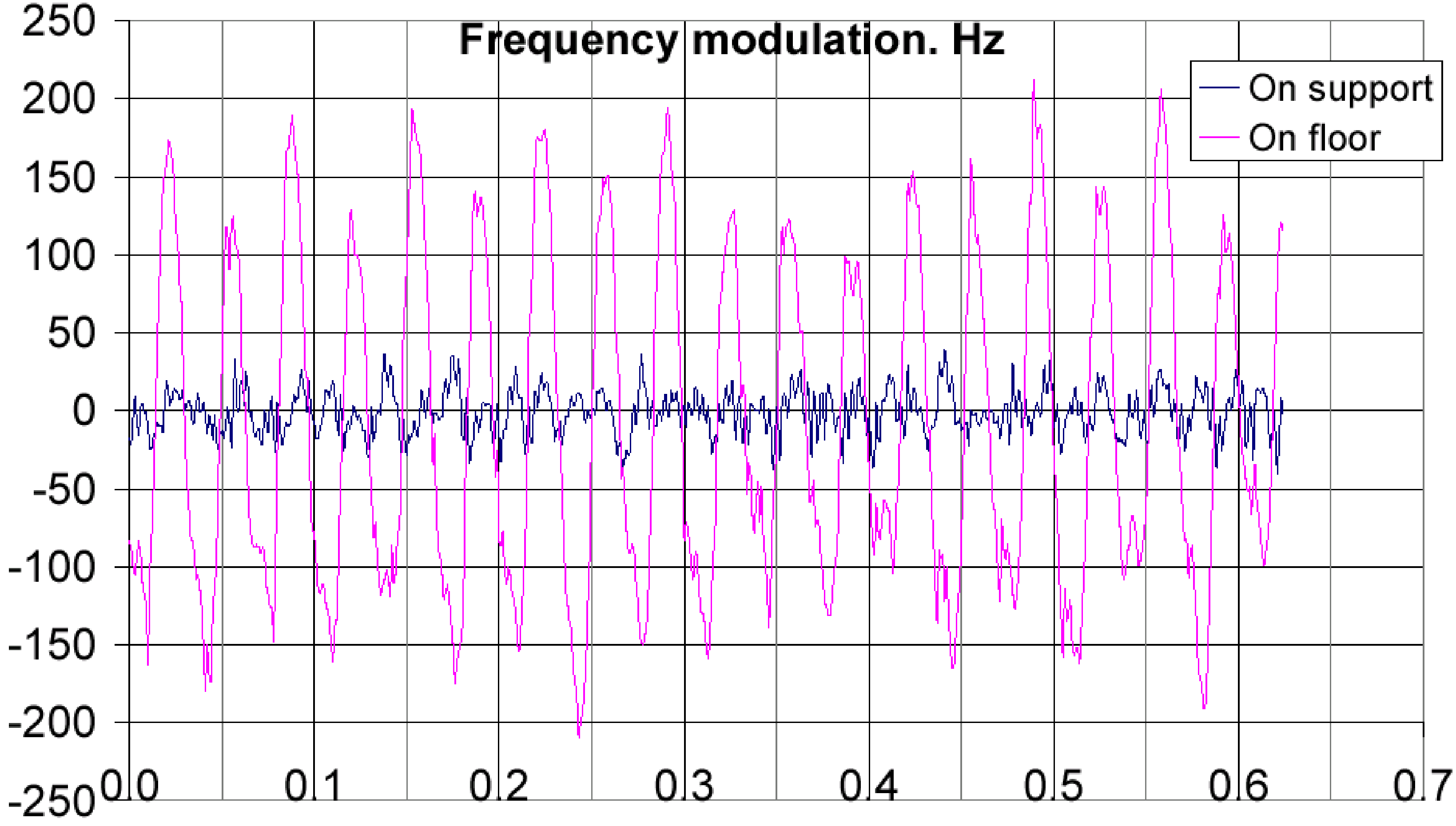


Microphonics FFT - High Amplitude (~ ± 550 Hz)

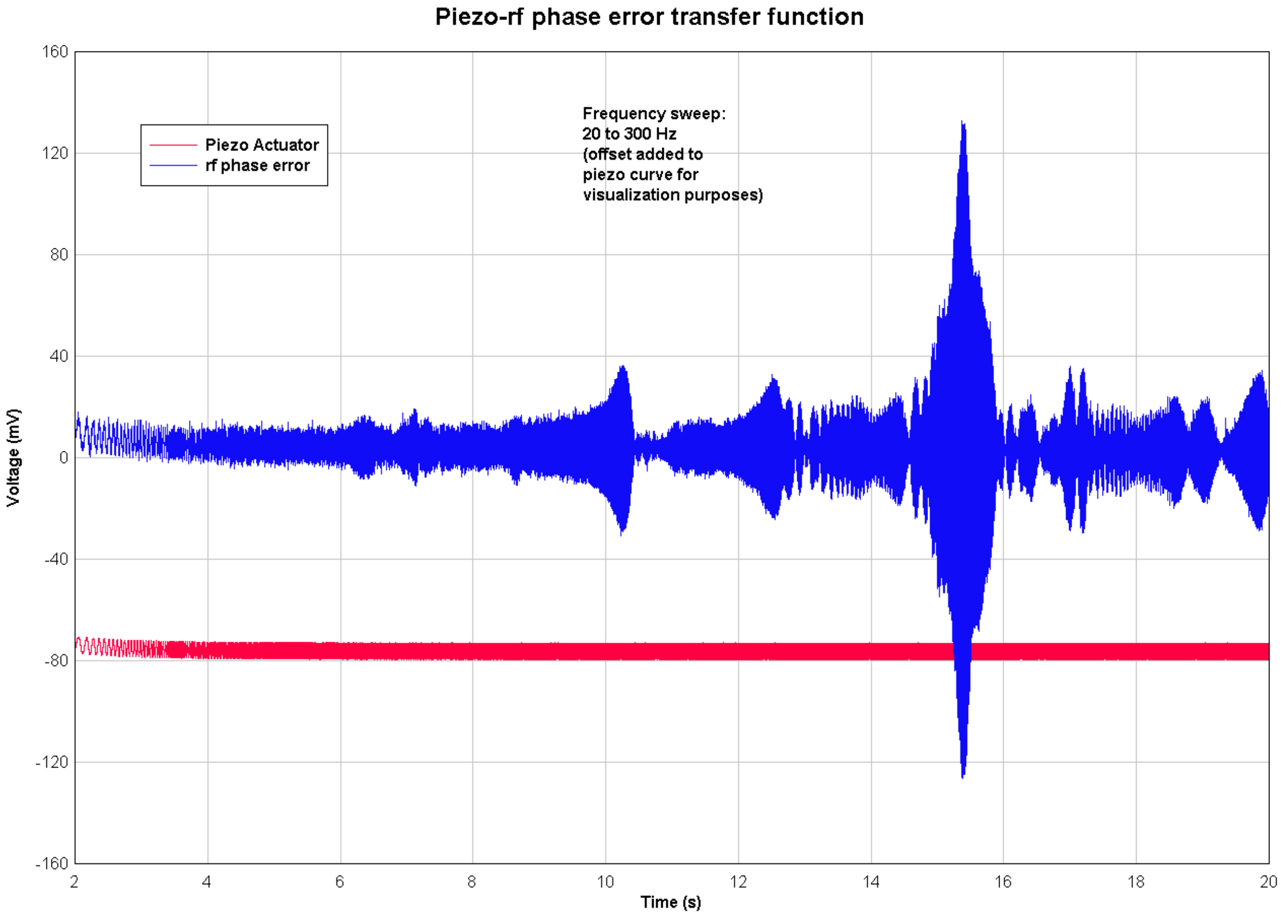


Microphonics – Dewar Support Modifications

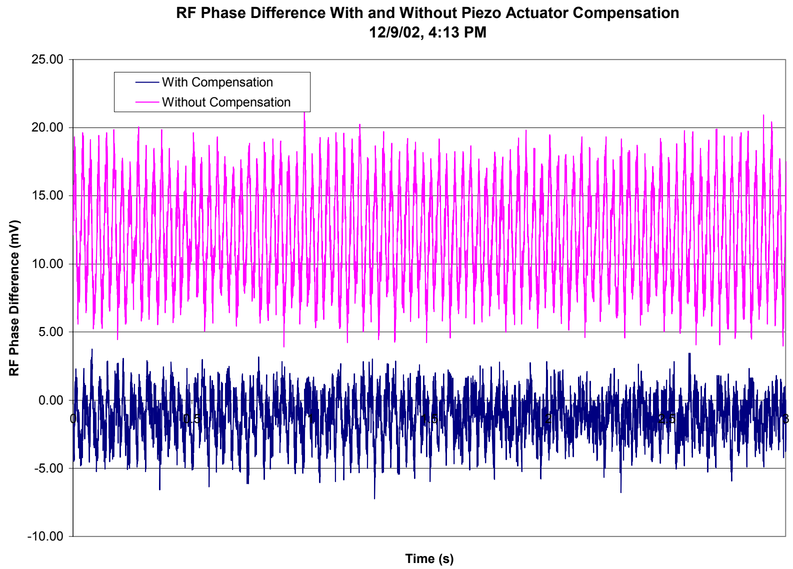
(Measurements by T. Khabiboulline, April 2003)

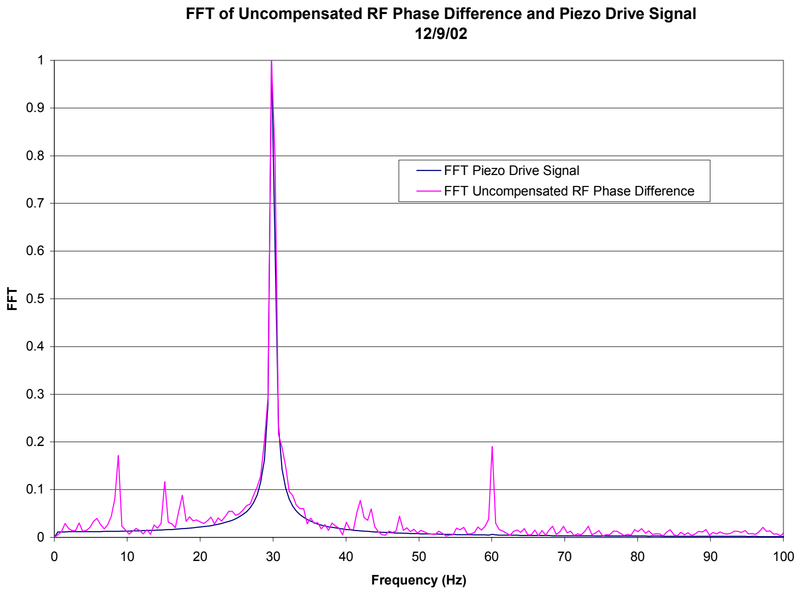


Piezo-RF Phase Error Transfer Function



Manual Detuning Compensation

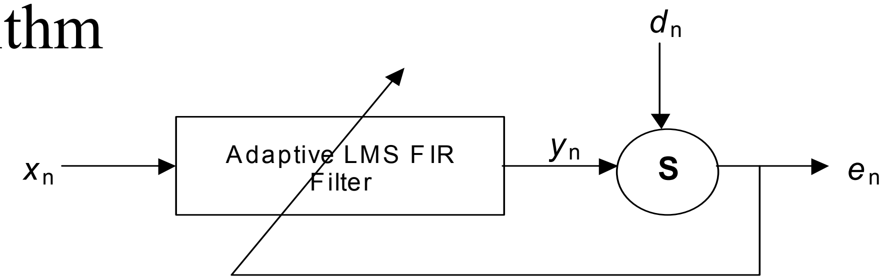




Microphonics detuning was reduced from ± 375 Hz to ± 175 Hz. Manual compensation is difficult because frequency, amplitude, and phase must be adjusted. In addition, only one sine frequency was used to drive the piezo actuator.

Automatic Detuning Compensation Adaptive Feedforward Control

- LMS Algorithm



The output of the filter is:

$$y(n)=w^T(n)\,x(n)$$

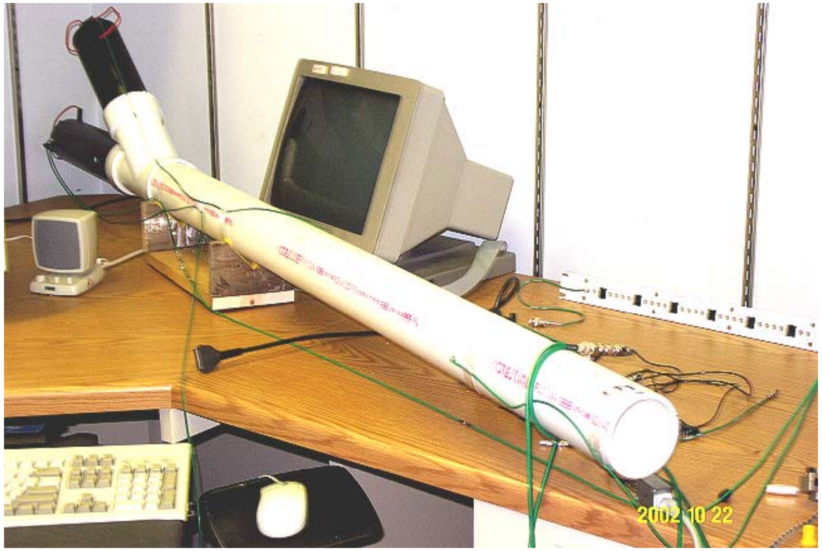
Where w*(n)* = [$w_0\ w_1 \ldots w_{M-1}$]^T is the *weight vector* at time index *n* and x*(n)* = [$x(n)\ x(n-1) \ldots x(n-M+1)$]^T is the data vector of the *M* most recent input samples. The weight vector is adjusted each iteration according to equation:

$$w(n+1)=w(n) + 2u\ x(n)e(n)$$

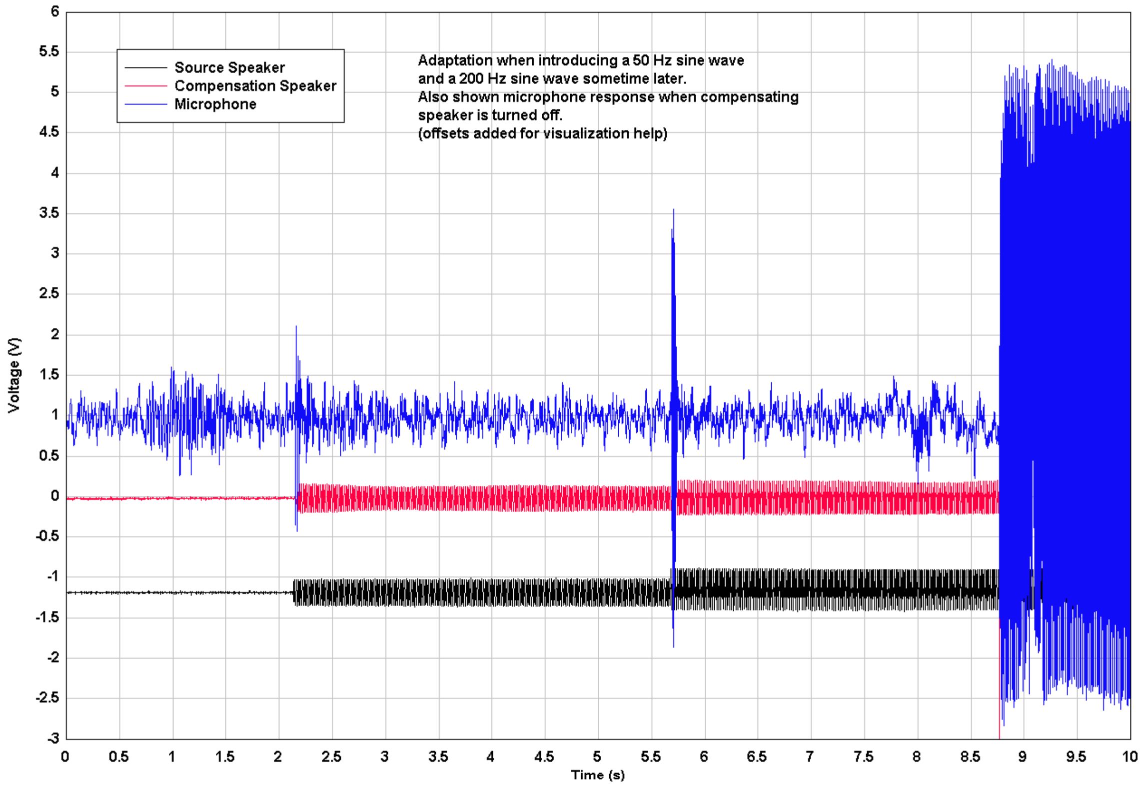
Where u is a *convergence factor* the value of which affects the amount the weight vector is altered on each iteration.

Active Noise Cancellation with Adaptive LMS Filter Concept Demonstration

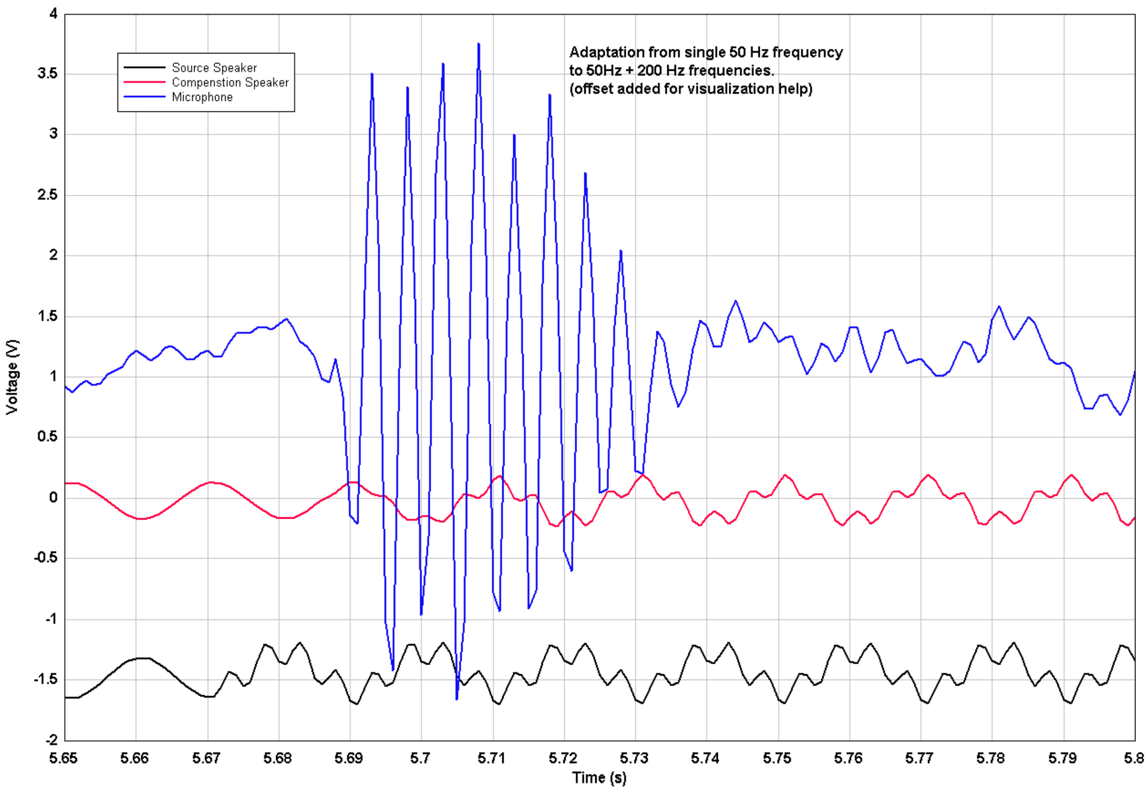
- The LMS filter was implemented to cancel noise from a source speaker in a duct using a compensating speaker.
- The algorithm was programmed in a real-time VxWorks operating system. The signals were acquired with a VME-based data acquisition hardware.



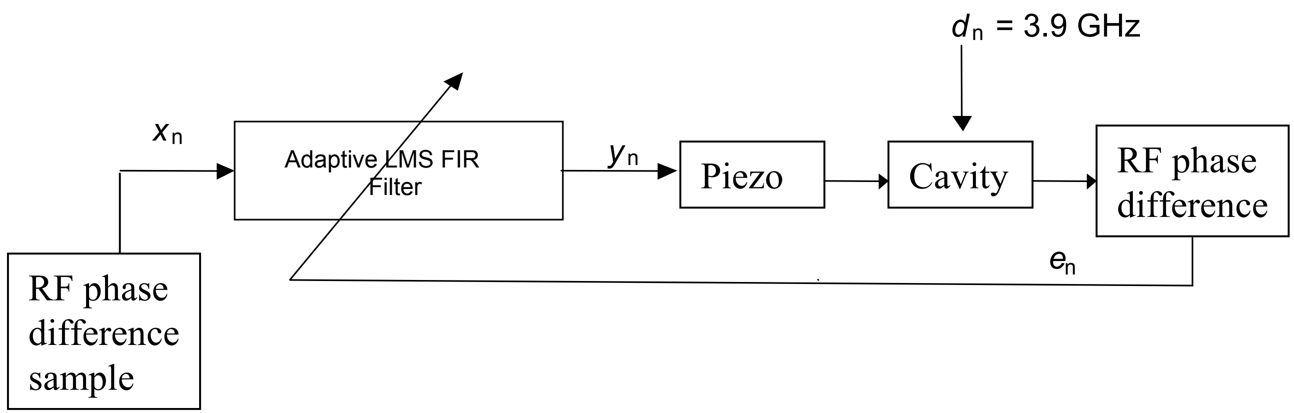
Noise Cancellation Results



Noise Cancellation Adaptation Details



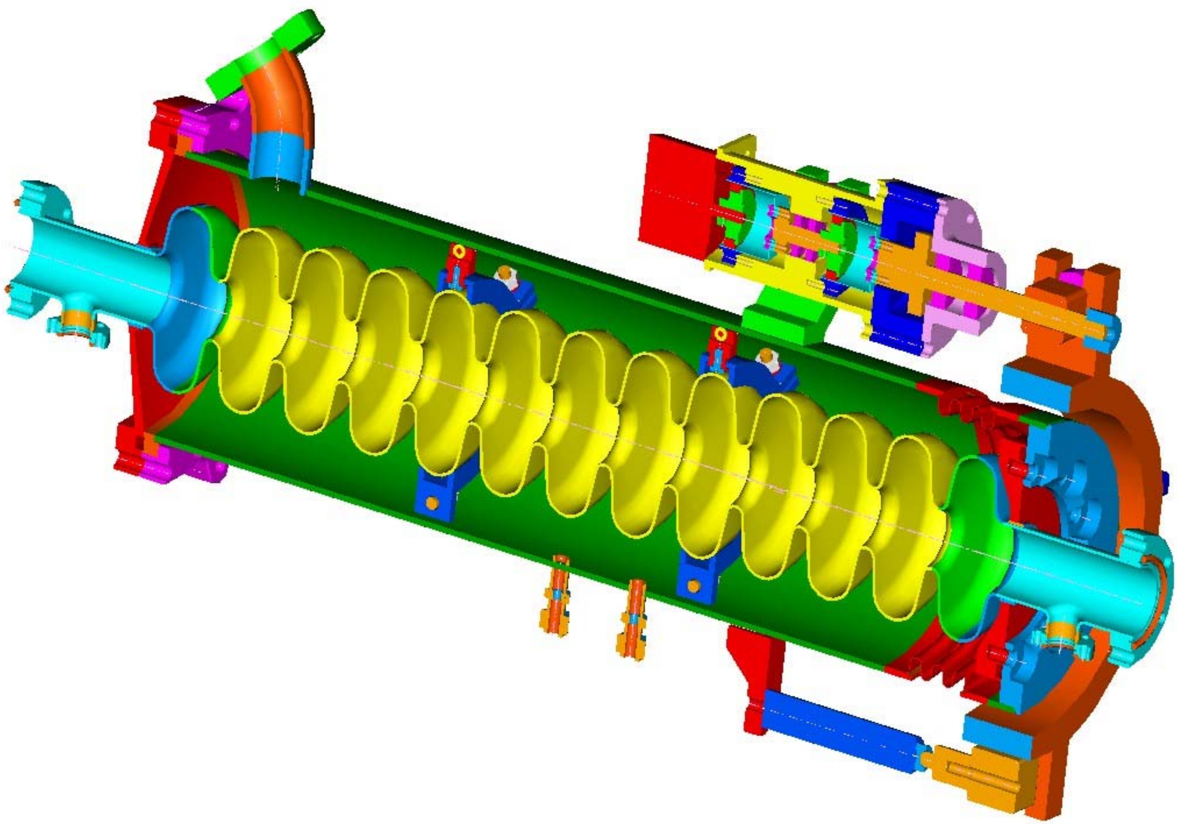
LMS applied to CKM cavity (preliminary)



(taken while LMS is OFF and "replayed")

- This approach assumes the microphonics spectrum remains more or less constant between samples.
- Samples of the microphonics spectrum can be taken while the beam is OFF and then replayed to provide Xn. However, RF power is required for this measurement.

13-cell cavity tuner cross section



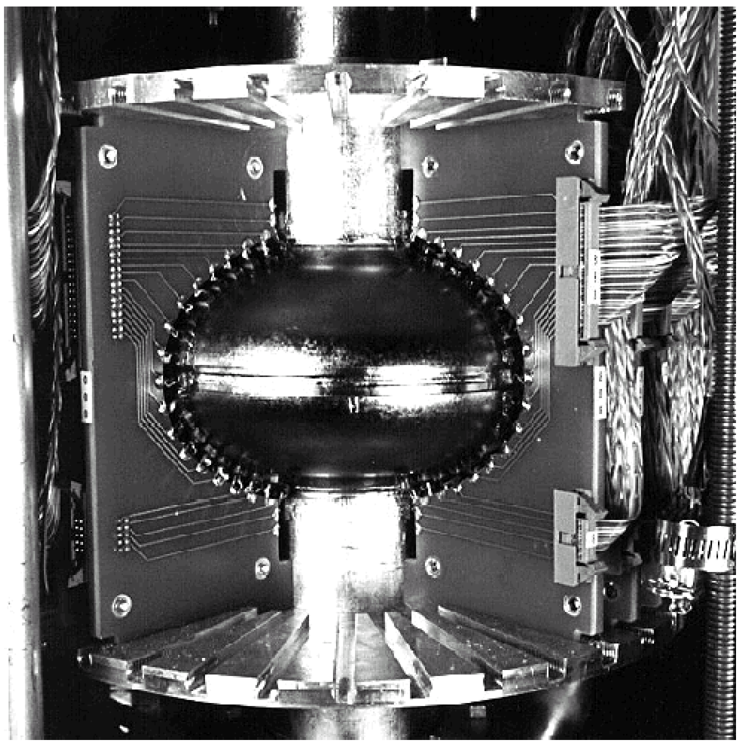
Path Forward

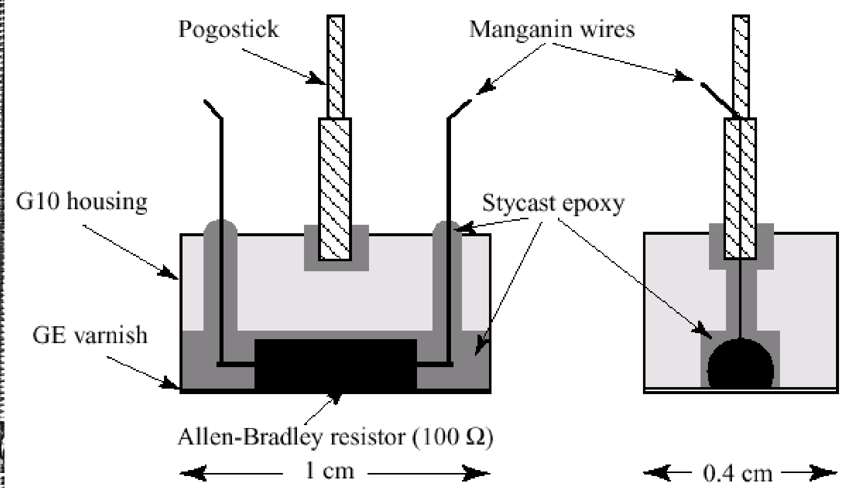
- Demonstrate automatic microphonics detuning compensation in the 3-cell prototype using an FPGA board programmed with the adaptive feedforward LMS algorithm.
- 13-cell cavity measurements in operating conditions (e.g., mechanical resonances, piezo-rf transfer function, uncompensated microphonics)
- Characterization of the high-load piezo actuator to be used in the 13-cell cavity.
- 13-cell cavity measurements automatic compensation: strategy, fine-tune algorithm, etc.
- Packaging for production.

Cavity Thermometry - General

- Cavity surface thermometry is used to study local distribution of various types of energy losses and identify defects.
- Main types of cavity loss mechanisms:
  - Thermal breakdown (related to surface magnetic field)
  - Field emission (related to surface electric field)
- The temperature sensing element is usually Allen-Bradley carbon resistors encased in epoxy to prevent excessive cooling of the thermometer by the helium bath.
- Fixed or rotating arrays of thermometers have been used.

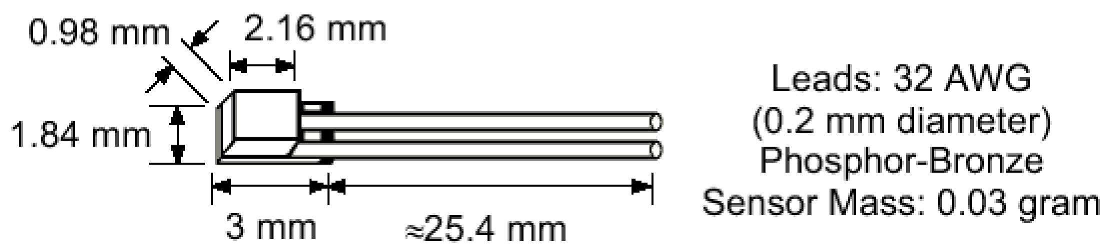
Example: 1.5 GHz Cavity (Cornell)





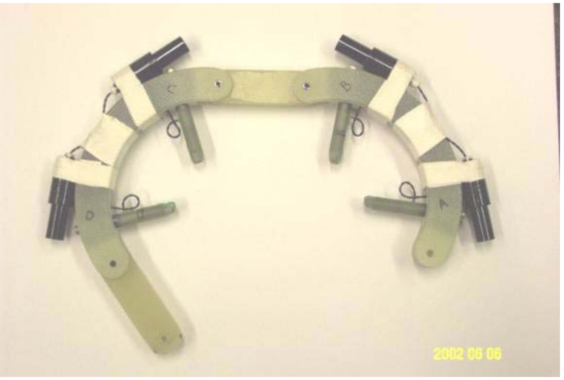
CKM Cavity Thermometry

- Small Iris size (30 mm) makes it difficult to use the general approach used in other cavities with Allen-Bradley carbon sensors. A smaller CERNOX sensor was used instead.

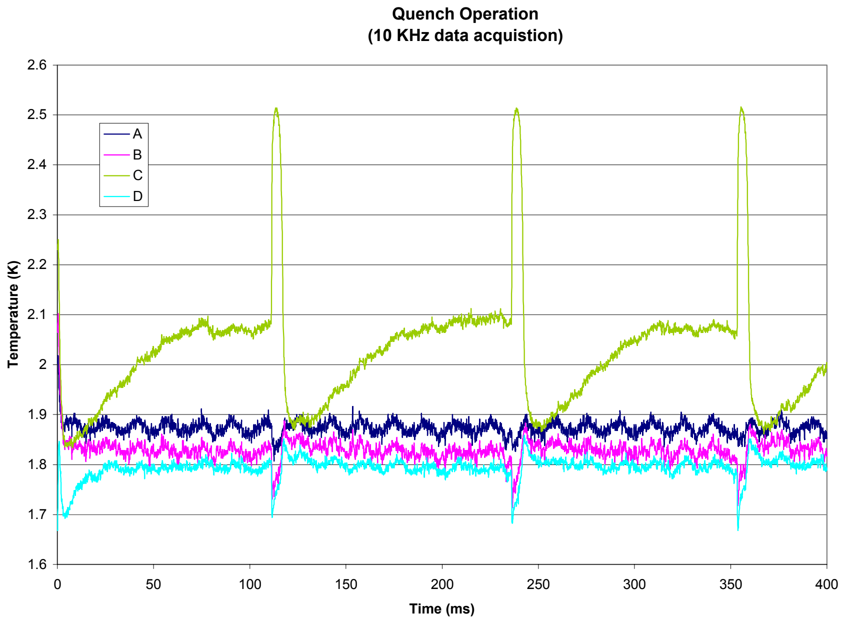


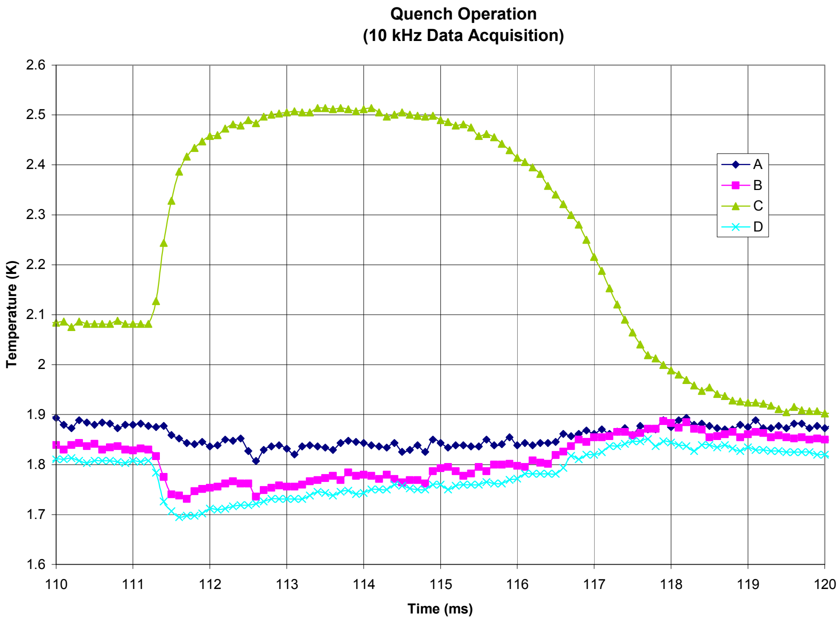
- The sensor was attached with epoxy to a spring-loaded G-10 stick, and an Indium half-sphere was glued to the tip of the CERNOX sensor and covered with Apiezon grease prior to installation to improve thermal contact.

CKM Cavity Thermometry

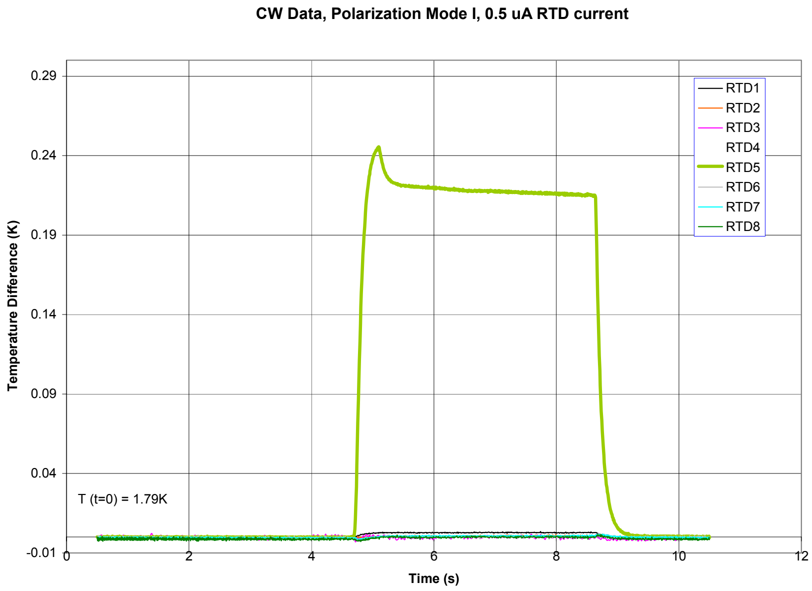


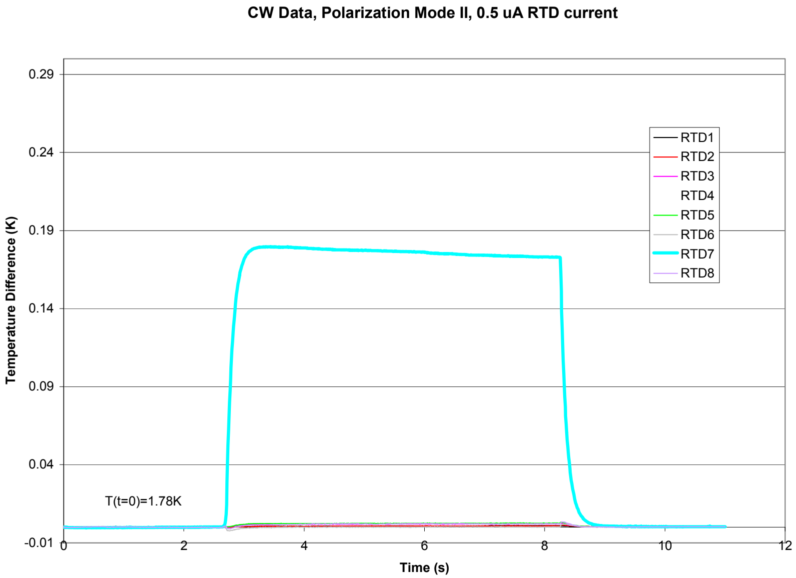
Cavity Quench Thermometry





Cavity cw thermometry at two different polarizations





Path Forward

- We need to scale up the thermometry system for the 13-cell cavity.
- Software for automatic data reduction and analysis has to be written.