Temperature Waves in SRF Research

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Cornell University

Outline

- Why Use Temperature Waves in Accelerator Research?
- Review of Superfluid Helium Properties
- He-II Instrumentation & Measurements
  - Oscillating Superleak Transducers
  - Quartz Tuning Fork
- Conclusions

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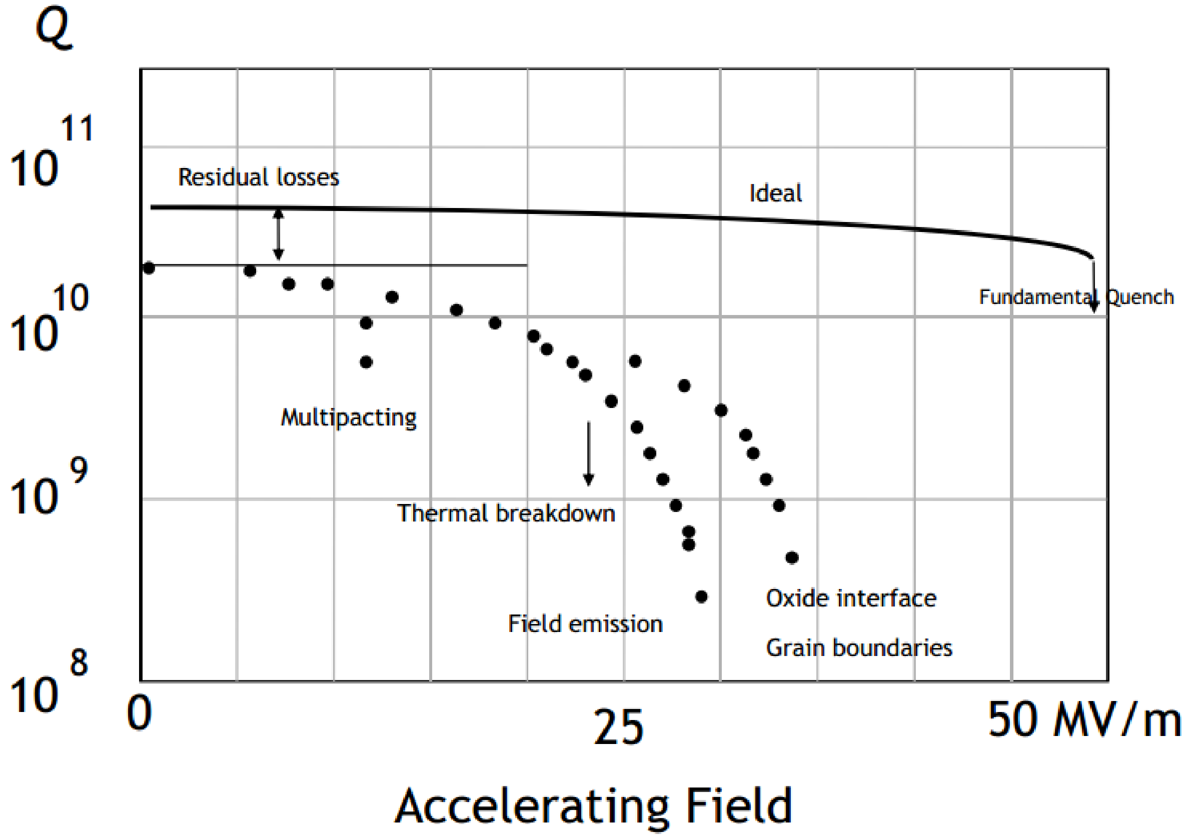
Motivation

Niobium cavity Q vs E at 1.8 K.



While testing, superconductivity can break down, initiating a sudden transition to normal state. During this quench, Joules of energy are rapidly deposited in a small region of cavity wall. Generates very large heat flux

Case Study: Defect location

- Defects occur on 10 – 100 micron length scales
- Difficult to optically identify defects
- Small/no correlation between high field quenches and visible defects

THPO009 Proceedings of SRF2011, Chicago, IL USA

QUENCH STUDIES IN LARGE AND FINE GRAIN Nb CAVITIES*

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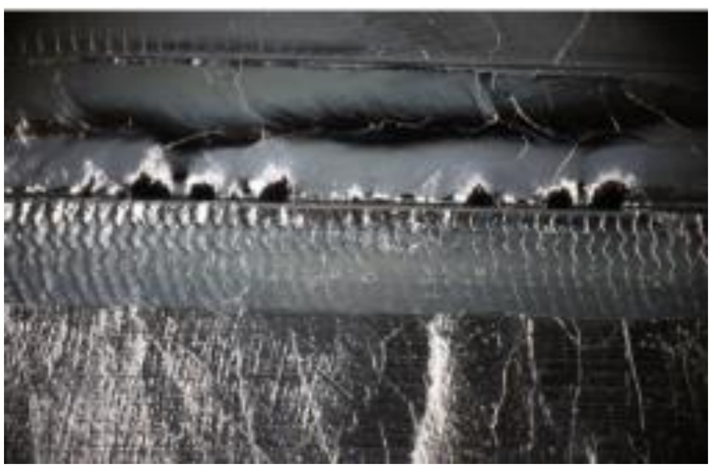
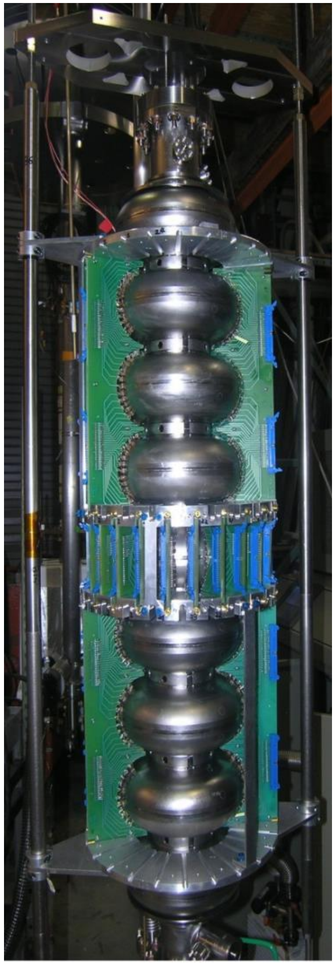
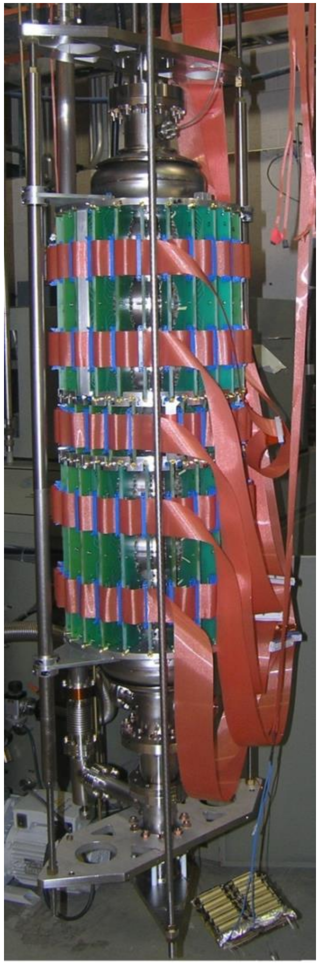


Optical inspection images of LR1-6, which quenched at 23 MV/m. Quench location on left.

Quench Location

- Temperature mapping systems have been used since the 1990s



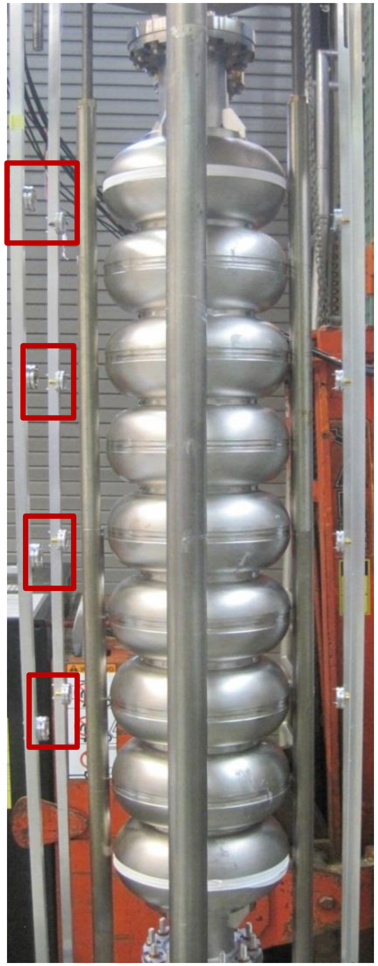


T-map system uses >3000 sensors for 7-cell cavity

New sensors must be outfitted for new cavity geometries

Temperature waves convey key information about RF surface

OST system uses 3 – 16 sensors & can be easily expandable



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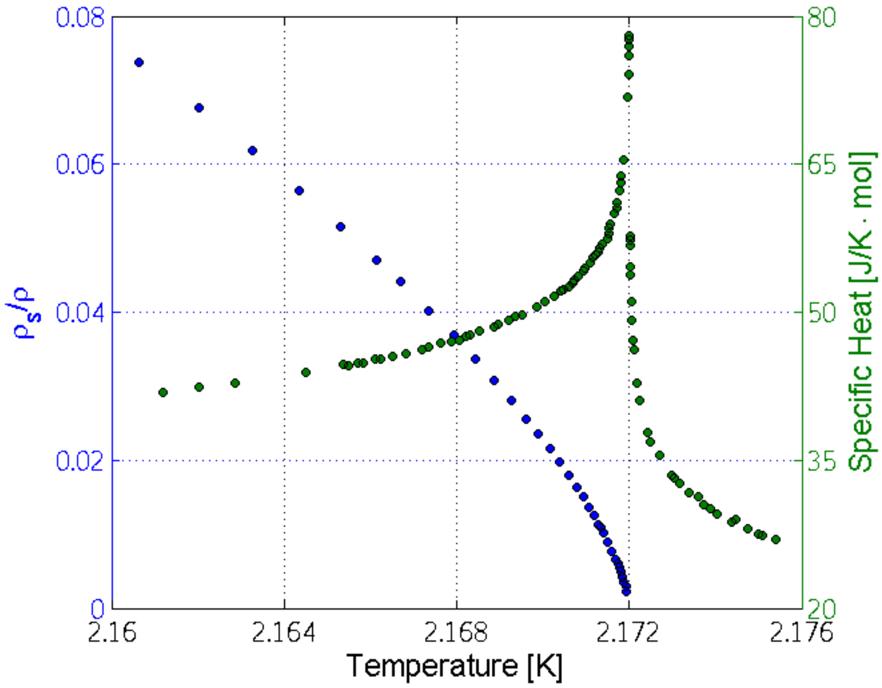
The Lambda Point

Superfluid fraction, Specific heat vs temperature



Transition named for λ shape of specific heat curve

Superfluid properties

- Broken into superfluid and normal components

$$\rho = \rho_s + \rho_n$$

- Critical point behavior

$$\frac{\rho_s}{\rho} = k_0 t^{\xi}, \qquad \xi = 0.67$$

$$t = \frac{T_\lambda - T}{T_\lambda}$$

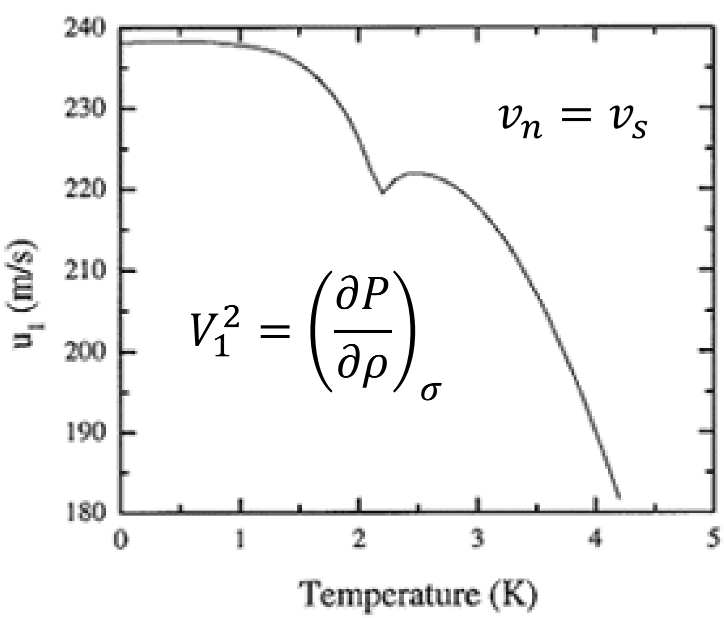
1st and 2nd Sound in Helium

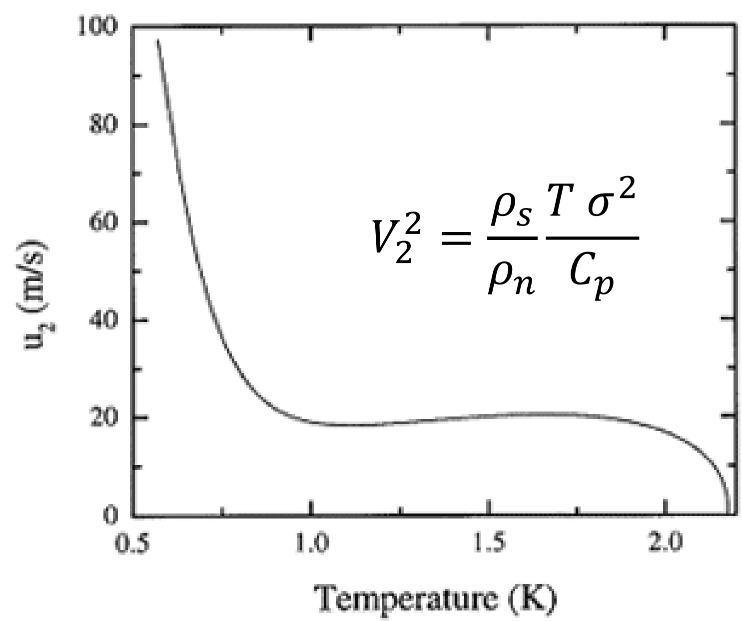
First Sound

- Longitudinal-density wave
  - Liquid, gas
- Two fluids moving together
- Fast propagation speed

Second Sound

- Temperature-entropy wave
  - Normal, superfluid
- Interpenetrating fluids with their own velocity fields
- Slow propagation speed





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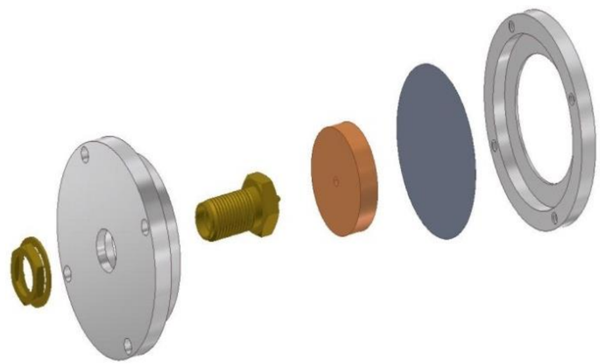
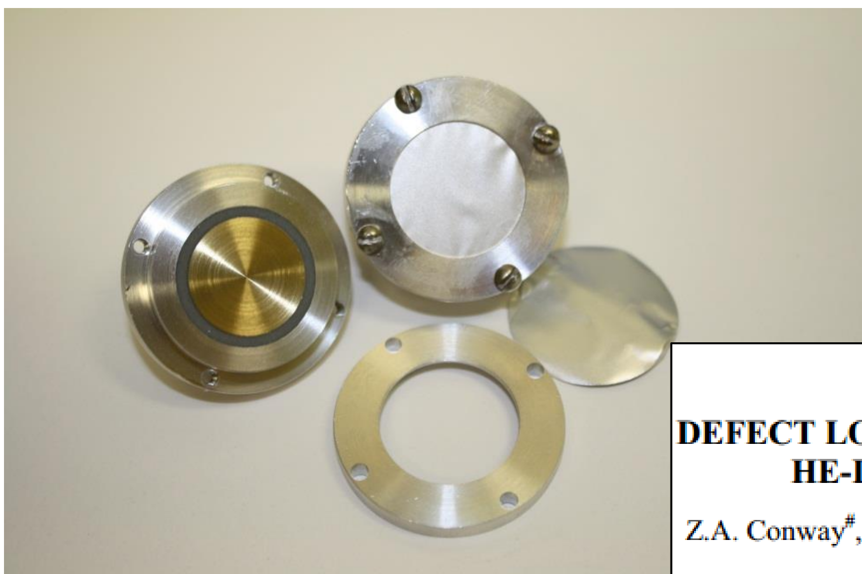
Cornell OST Hardware

Mechanical Design





Specifications

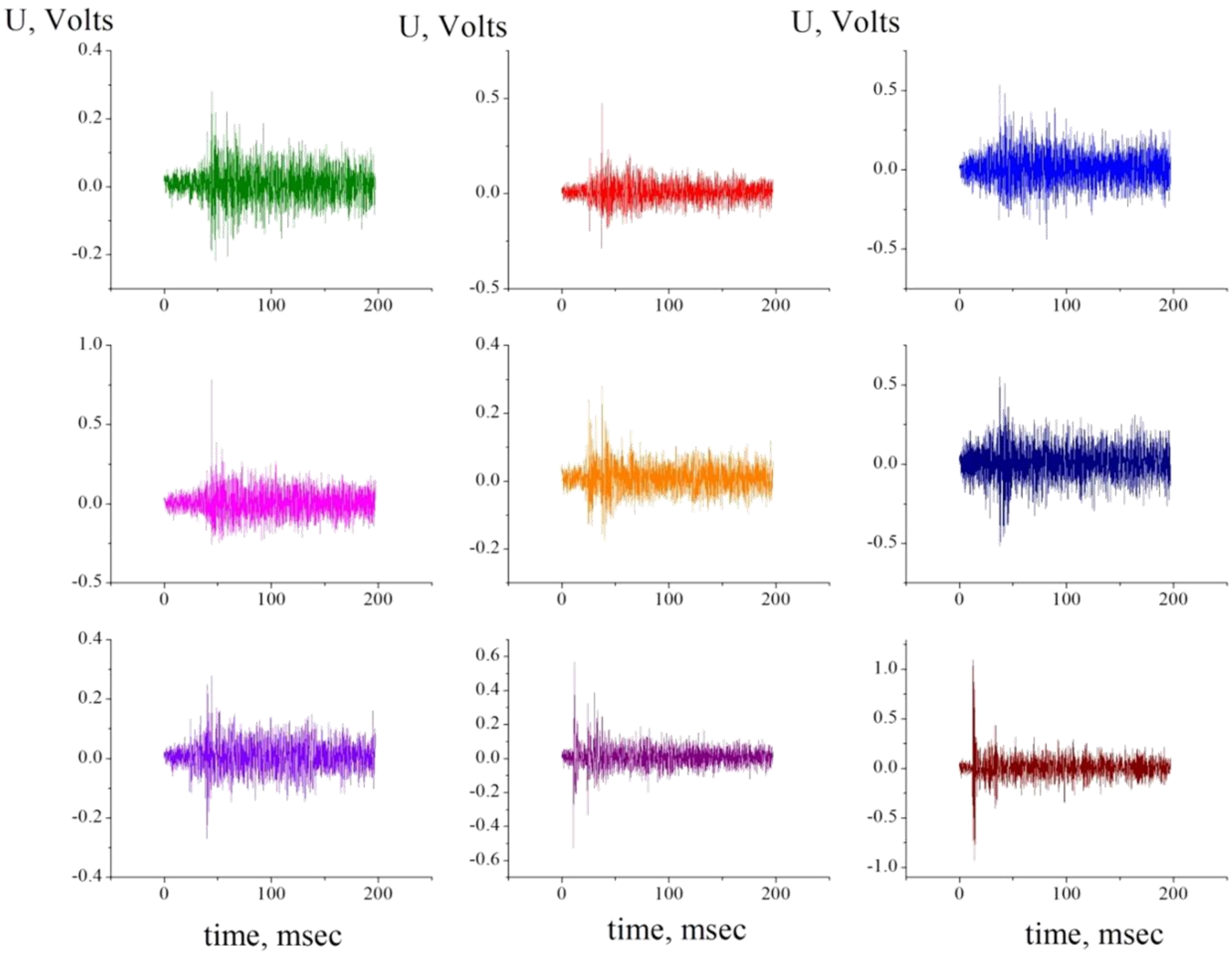
- Membrane
  - Polycarbonate track-etch membrane with 0.2 mm holes
  - 20–50 nm layer evaporated Al
- Brass disk
- Aluminum body
- Aluminum end cap
- SMA bulkhead jack

Proceedings of SRF2009, Berlin, Germany TUOAAU05

DEFECT LOCATION IN SUPERCONDUCTING CAVITIES COOLED WITH HE-II USING OSCILLATING SUPERLEAK TRANSDUCERS*

Z.A. Conway#, D.L. Hartill, H.S. Padamsee, and E.N. Smith, CLASSE, Cornell University, Ithaca, NY, U.S.A.

Second sound wave signals



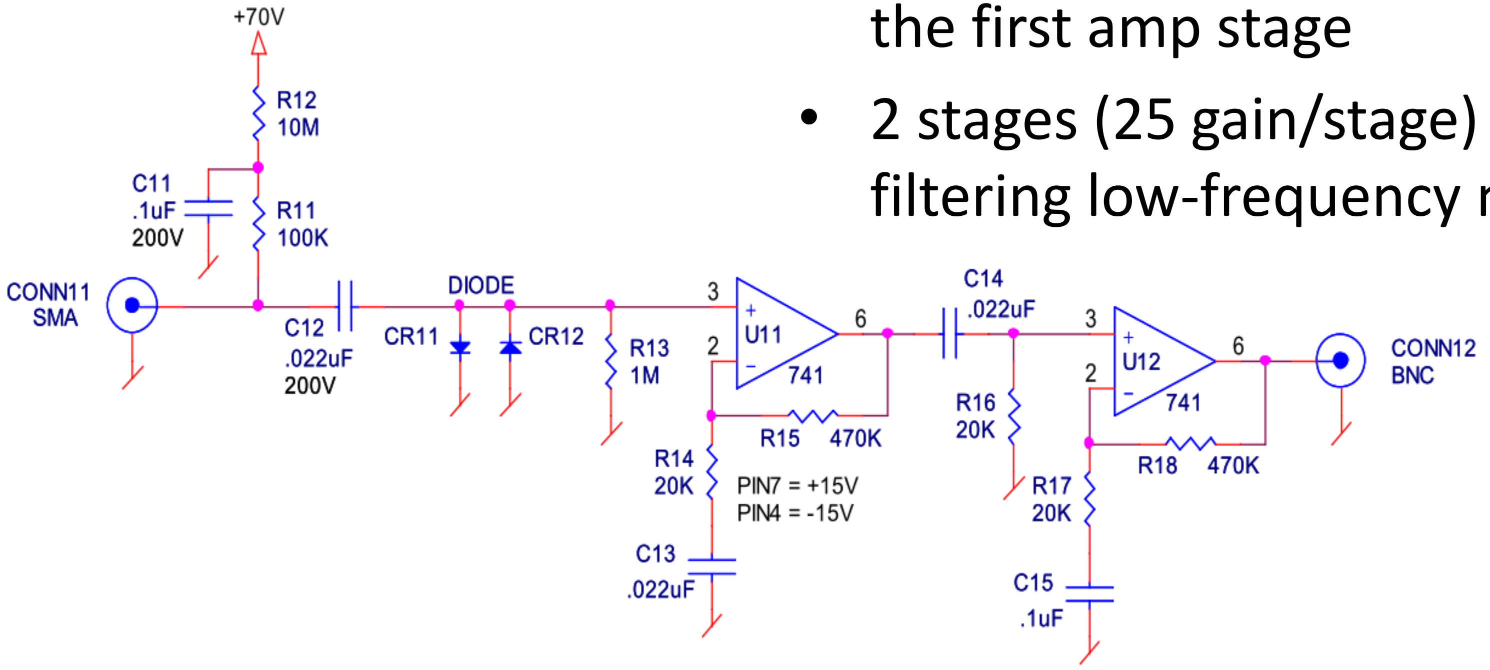
Preamplifier Circuit

Requirements

- Low noise
- Output voltage signals on the scale of ~ 1 V
- One amp circuit/OST

Circuit

- Membrane is biased +70 V
- Current limited to prevent short-circuit heating
- OST capacitively coupled to the first amp stage
- 2 stages (25 gain/stage) , each filtering low-frequency noise



OST Hardware

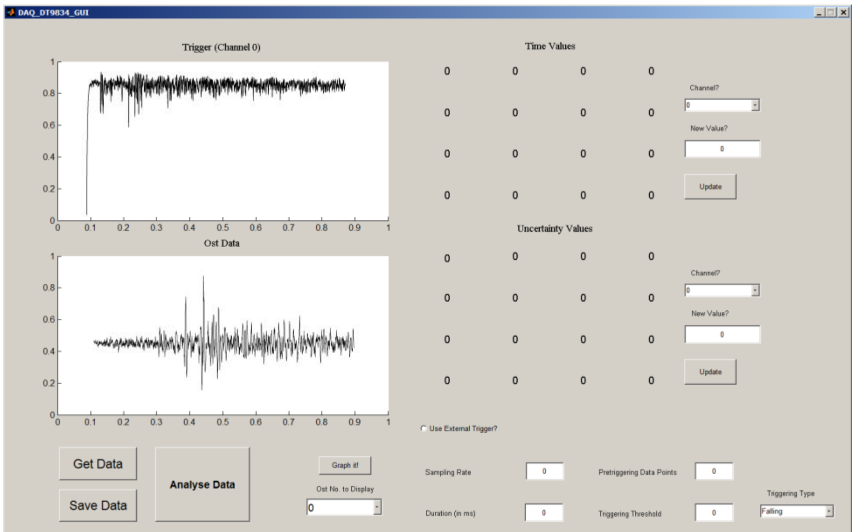
OST → Preamplifier → DAQ Card → Computer

- OST preamplifier designed at Cornell
- SMA input, BNC output

- DT 9834 DAQ Card
- Number of Channels easily extensible via adding additional units

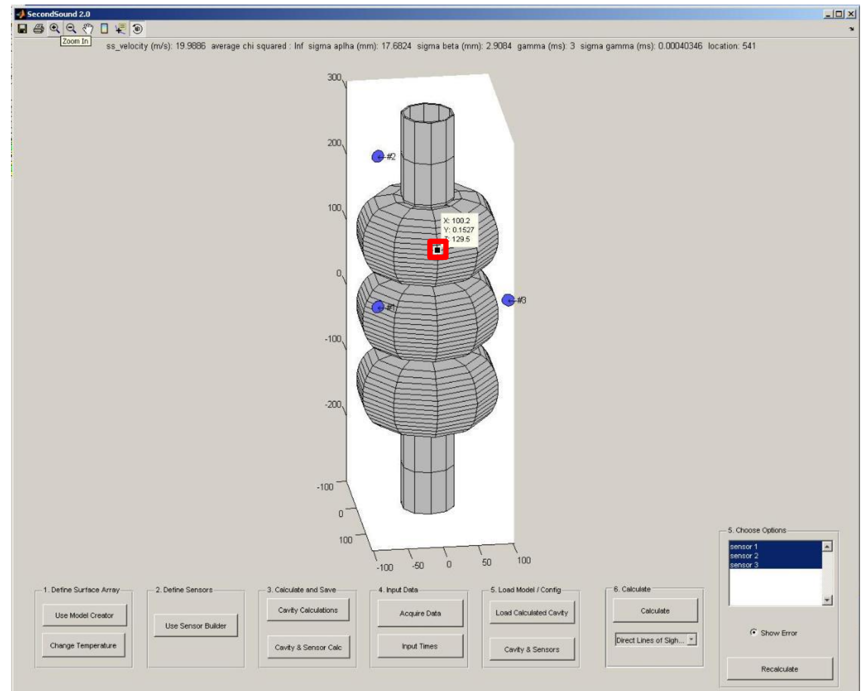
Second Sound software performs two main functions

Data Acquisition



- Interfaces with DAQ card and field probe
- Performs quench time of flight calculations
- Passes results to quench location program.

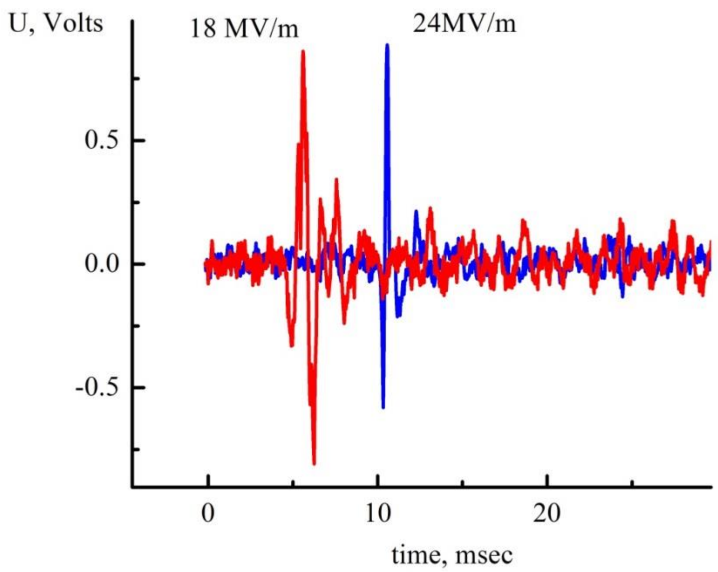
Quench Location

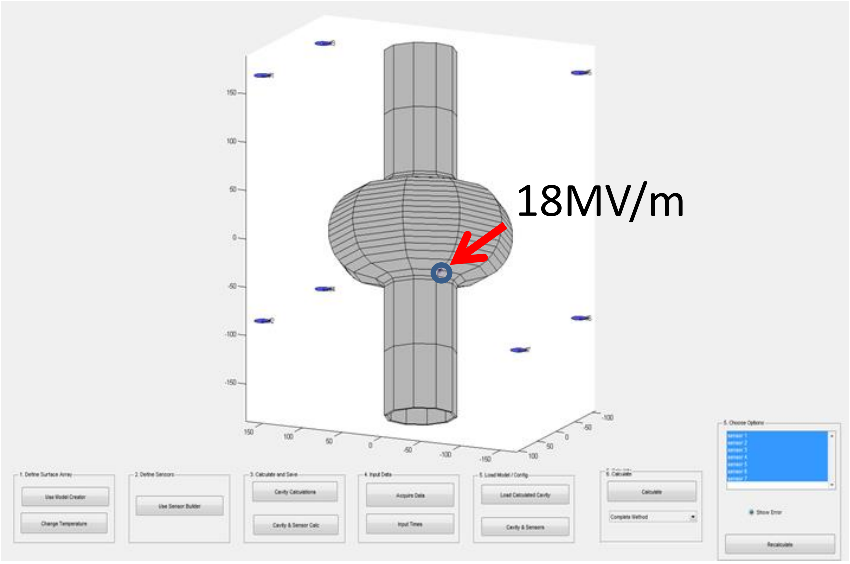


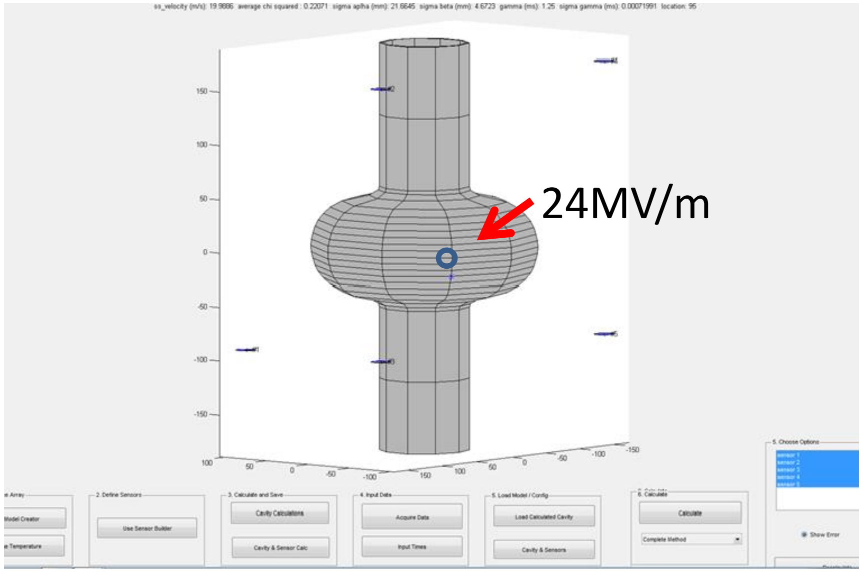
- Generates geometry mesh
- Solves for quench location from time of flight data

Quench Drift Measurements

- Initial quenching near cavity's iris at 18 MV/m
- After processing field emitter, quench field remained at 24 MV/m at equator
- OSTs quickly pinpoint variation in quench location during test.

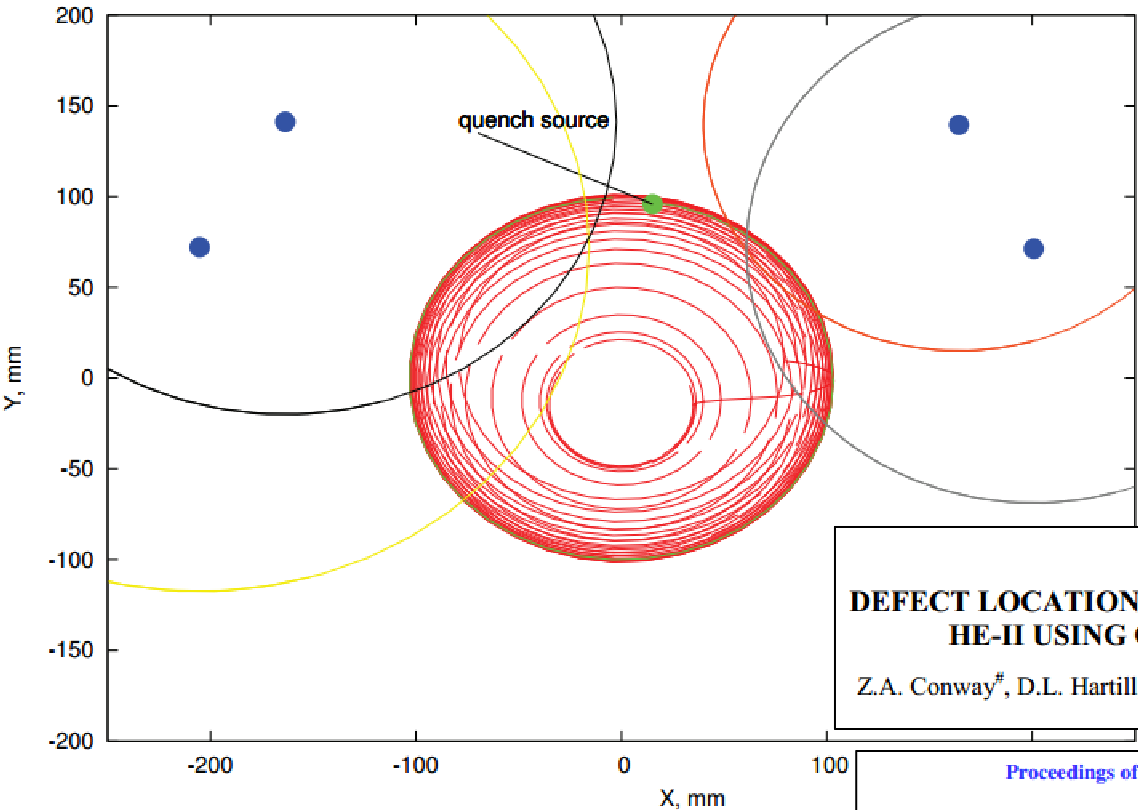






Quench location precision

Widely observed phenomena: Second sound transit times are too short. Quench source is localized to within ~1 cm



Attempted solutions:

- Use velocity as parameter
- Adopt a ‘circle of confusion’
- Model quench dynamics
- Coupling of 1st/2nd sound

Proceedings of SRF2009, Berlin, Germany TUOAAU05

DEFECT LOCATION IN SUPERCONDUCTING CAVITIES COOLED WITH HE-II USING OSCILLATING SUPERLEAK TRANSDUCERS*

Z.A. Conway#, D.L. Hartill, H.S. Padamsee, and E.N. Smith, CLASSE, Cornell University, Ithaca, NY, U.S.A.

Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA TUP041

QUENCH DYNAMICS IN SRF CAVITIES: CAN WE LOCATE THE QUENCH ORIGIN WITH 2ND SOUND?*

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Dmitri A. Sergatskov, Fermilab, Batavia, IL, USA

Pulsed Heater Measurement

- Observation: In cavity walls, for large heat flux (1 – 10 W/cm^2), film boiling occurs
- Postulate: Quench signal propagates some time through normal fluid, then couples to superfluid when heat flux is low enough.

Pulsed Resistor Measurement

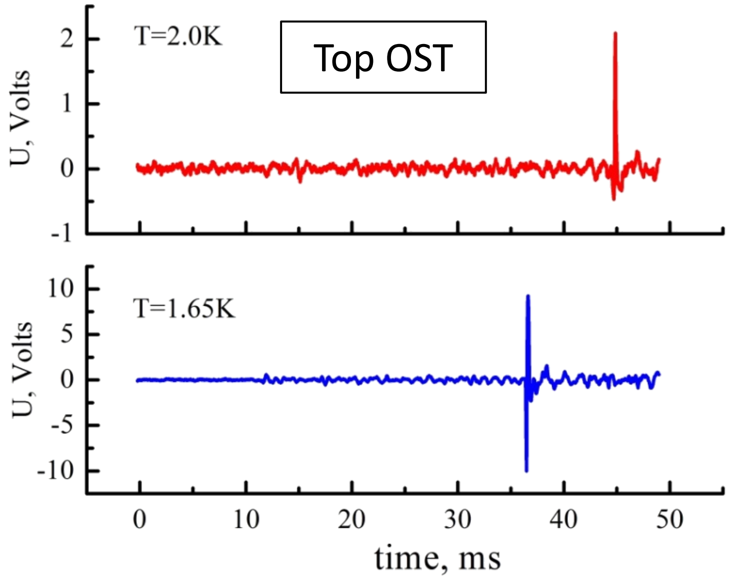
- 25 Ω heater, pulsed @ 500 V for 100 us
- Surface area ~2 mm^2
- Heat flux is ~5 kW/cm^2
- Measured at 1.65 K, 2.00 K

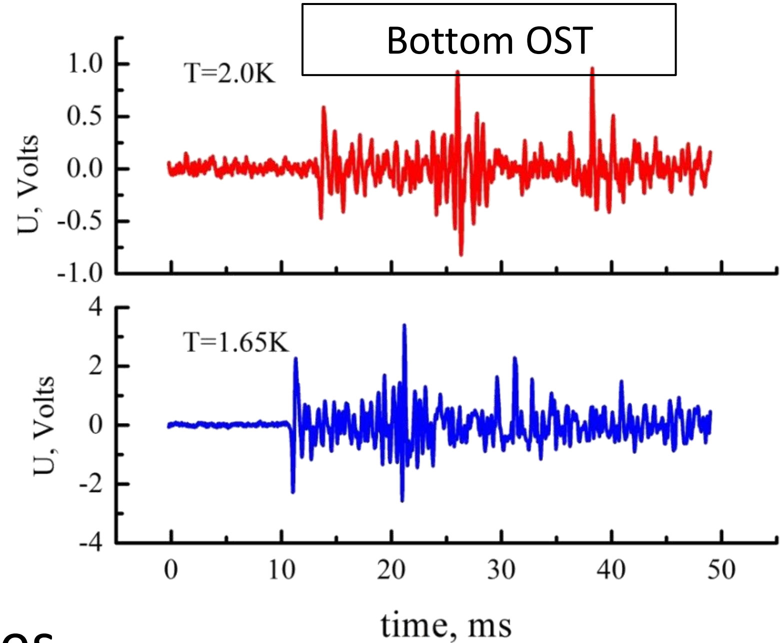
Second sound velocities

$$v_{1.65\ \mathrm{K}} = 16.68\frac{\mathrm{m}}{\mathrm{s}}, v_{2.00\ \mathrm{K}} = 20.36\frac{\mathrm{m}}{\mathrm{s}}$$

If quench only propagates via 2nd sound, then $d = v_s(T) \cdot t_T$

Coupling 1st & 2nd Sound?





No 1st and 2nd sound coupling implies

$$\frac{t_{1.65\ K}}{t_{2.00\ K}} = \frac{v_{2.00\ K}}{v_{1.65\ K}} = 1.220$$

$$\mathrm{v}_{1.65\ \mathrm{K}} = 16.68\,\frac{\mathrm{m}}{\mathrm{s}}\ ,\ \mathrm{v}_{2.00\ \mathrm{K}} = 20.36\,\frac{\mathrm{m}}{\mathrm{s}}$$

Measurement:

$$\frac{t_{1top}}{t_{2top}} = \frac{44.5\ ms}{36.3\ ms} = 1.22 \pm 0.01$$

$$\frac{t_{1bt}}{t_{2bt}} = \frac{13.1\ \ ms}{10.7\ \ ms} = 1.22 \pm 0.01$$

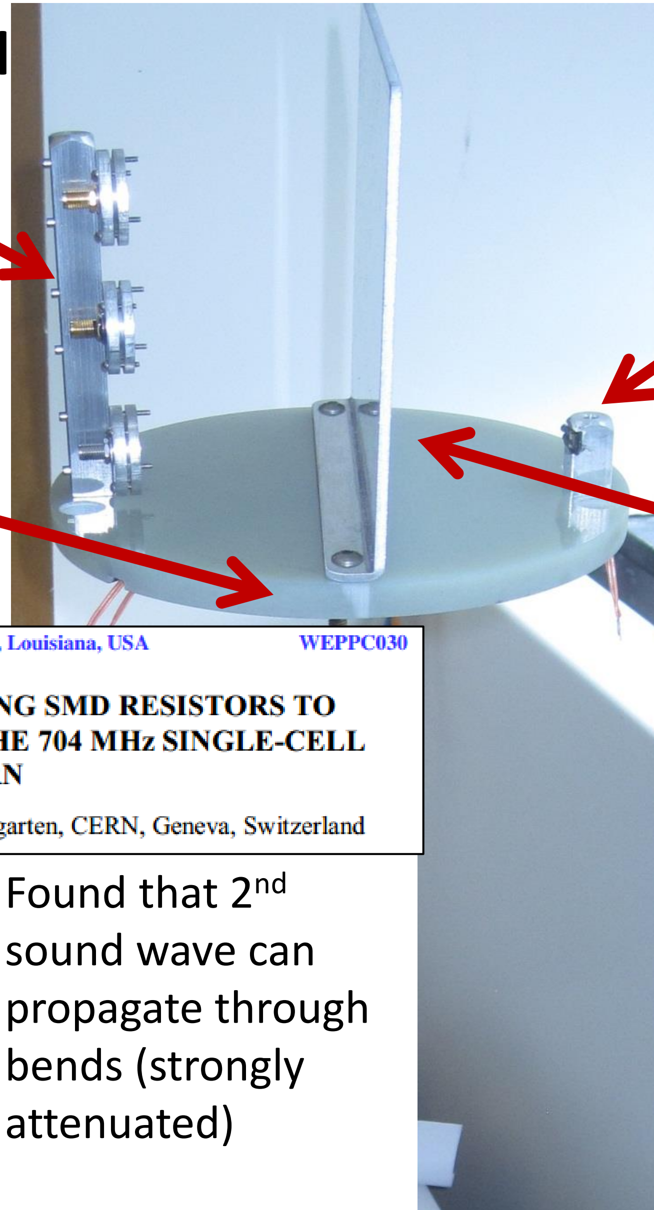
Consistent with quench heat flux carried only by 2nd sound component.

Second Sound Diffraction Measurements

Investigation at Cornell

OST array

Stage-mounted heater controls temperature



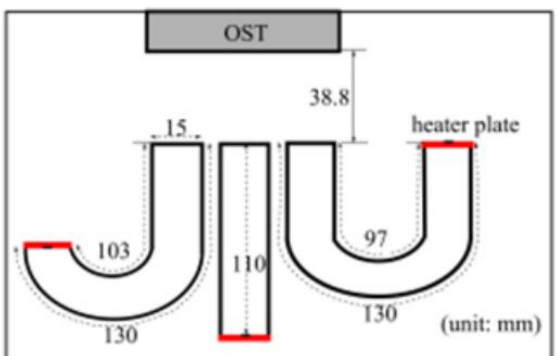
Pulsed heater generates second sound waves

Aluminum wall is screen for various diffraction pattern measurements

Proceedings of IPAC2012, New Orleans, Louisiana, USA WEPPC030

SECOND SOUND MEASUREMENT USING SMD RESISTORS TO SIMULATE QUENCH LOCATIONS ON THE 704 MHz SINGLE-CELL CAVITY AT CERN

K. Liao*, O. Brunner, E. Ciapala, T. Junginger, W. Weingarten, CERN, Geneva, Switzerland



Found that 2nd sound wave can propagate through bends (strongly attenuated)

Experimental Goals:

- Reflections off dewar
- Single and double slit diffraction studies
- Diffraction around cylindrical pipes (cavities)

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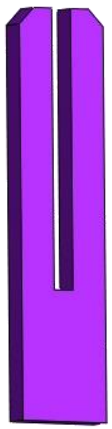
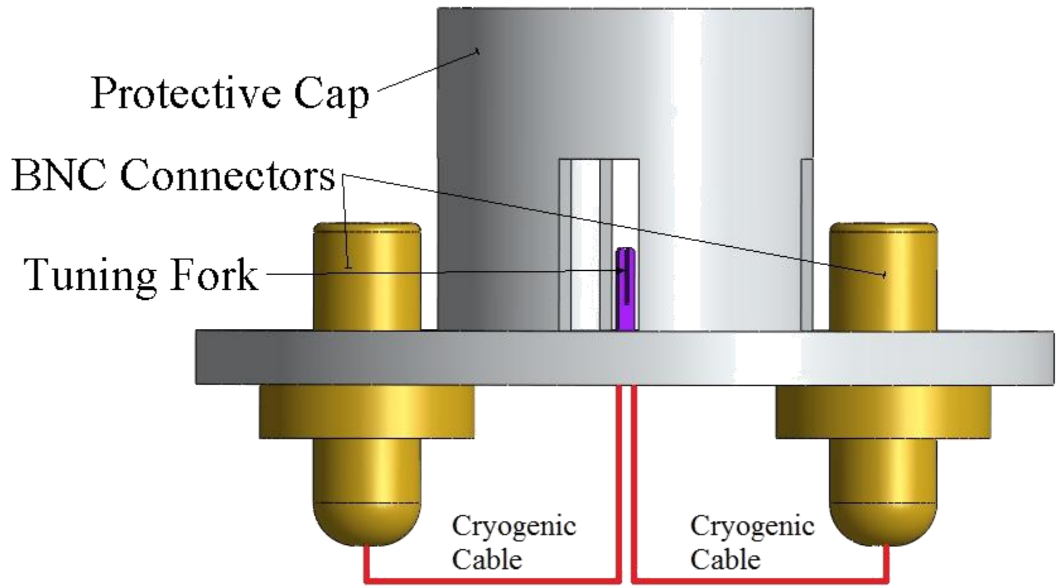
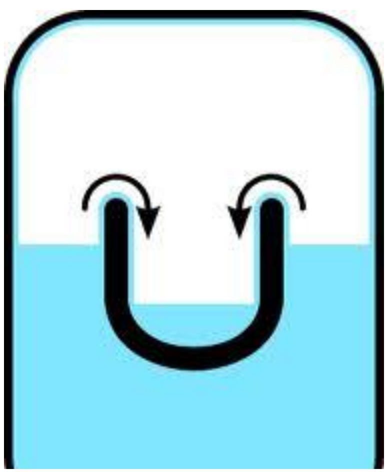
Tuning fork as level meter

- Piezo electric tuning fork used in digital watches
- Acts as density probe/viscometer
- Oscillation frequency determined by using a lock-in amplifier.





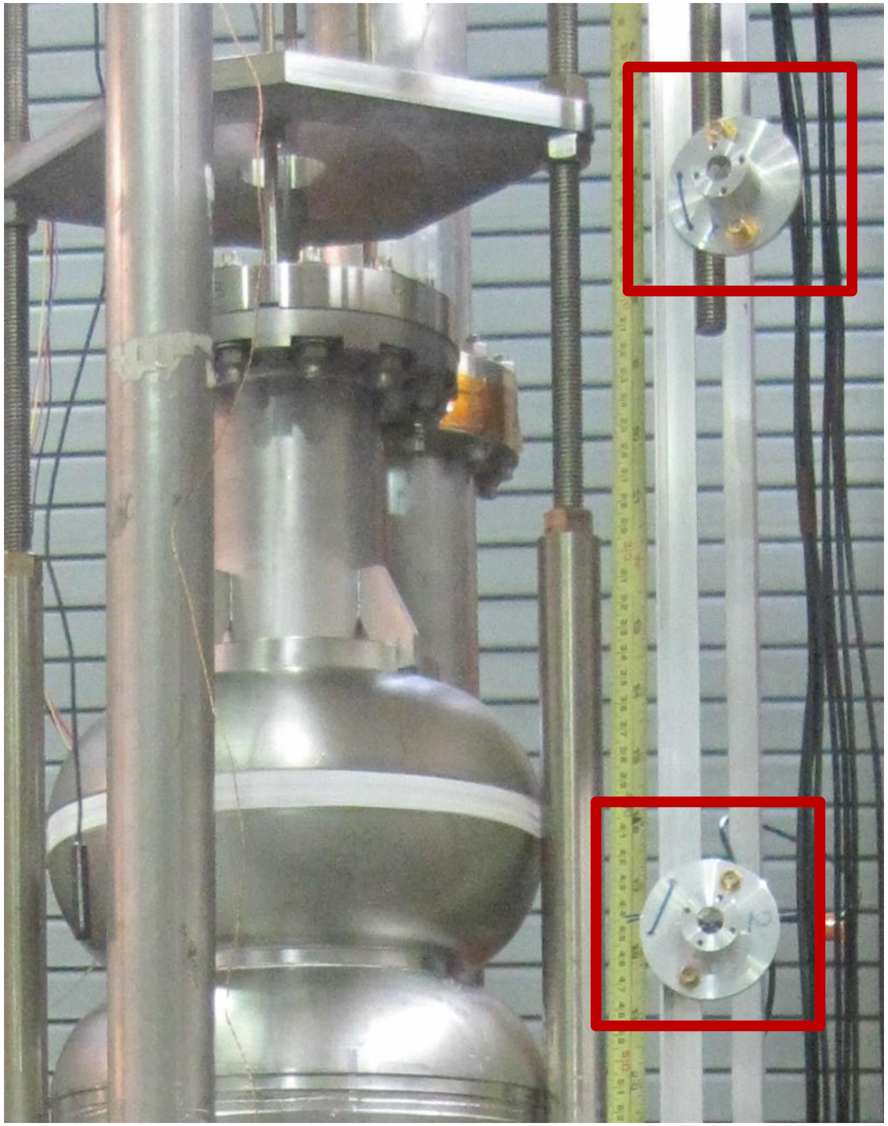


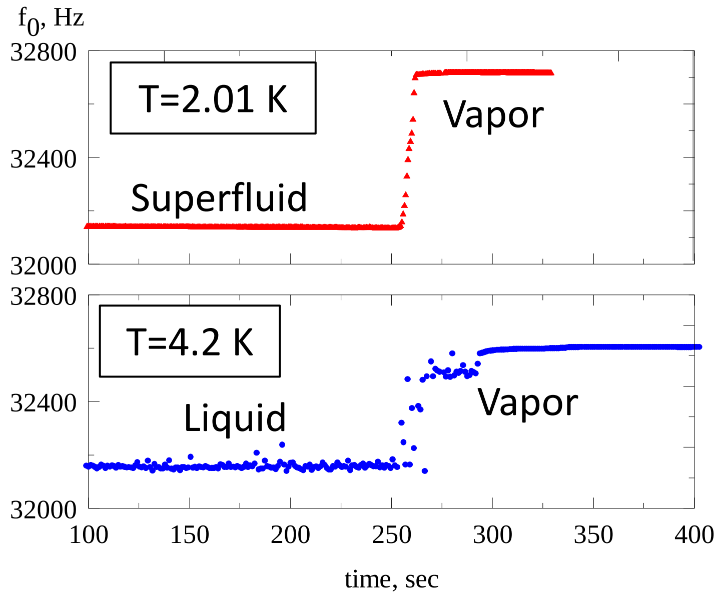
He-II creeping into basin

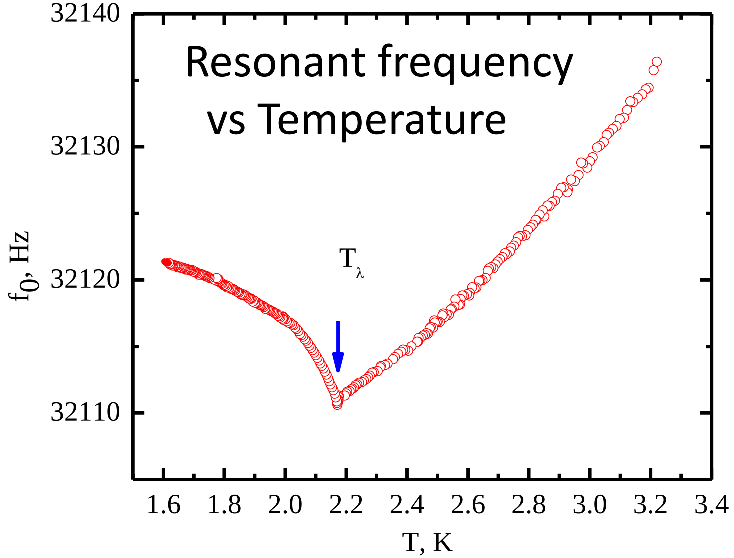
Use of Quartz Tuning Forks for sensitive, *in-situ* measurements of helium properties during SRF cavity tests

A.N. Ganshin,* X. Mi, E.N. Smith and G. H. Hoffstaetter
2013 JINST 8 P04007 doi:10.1088/1748-0221/8/04/P04007

He characterization with Tuning Fork





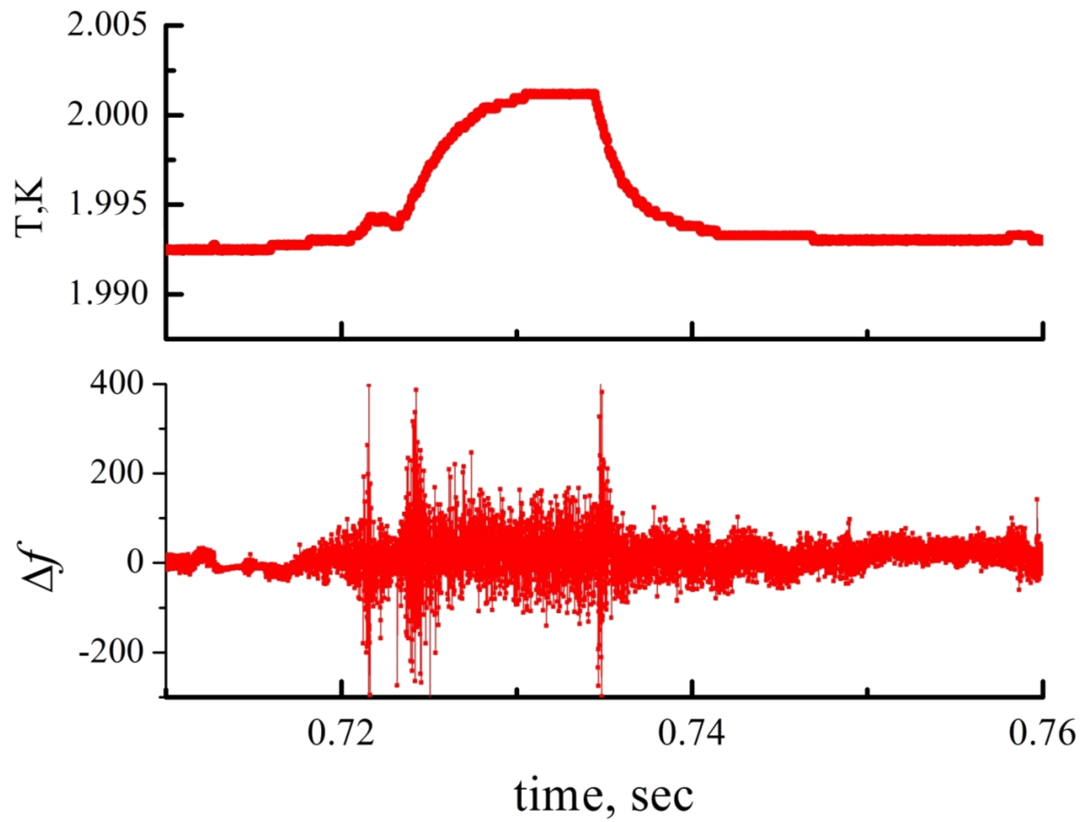


Tuning Fork: Cavity heating

During cavity tests we generate significant amount of heat radiating from the cavity surface.

Top: Bath temperature rises by 10 mK

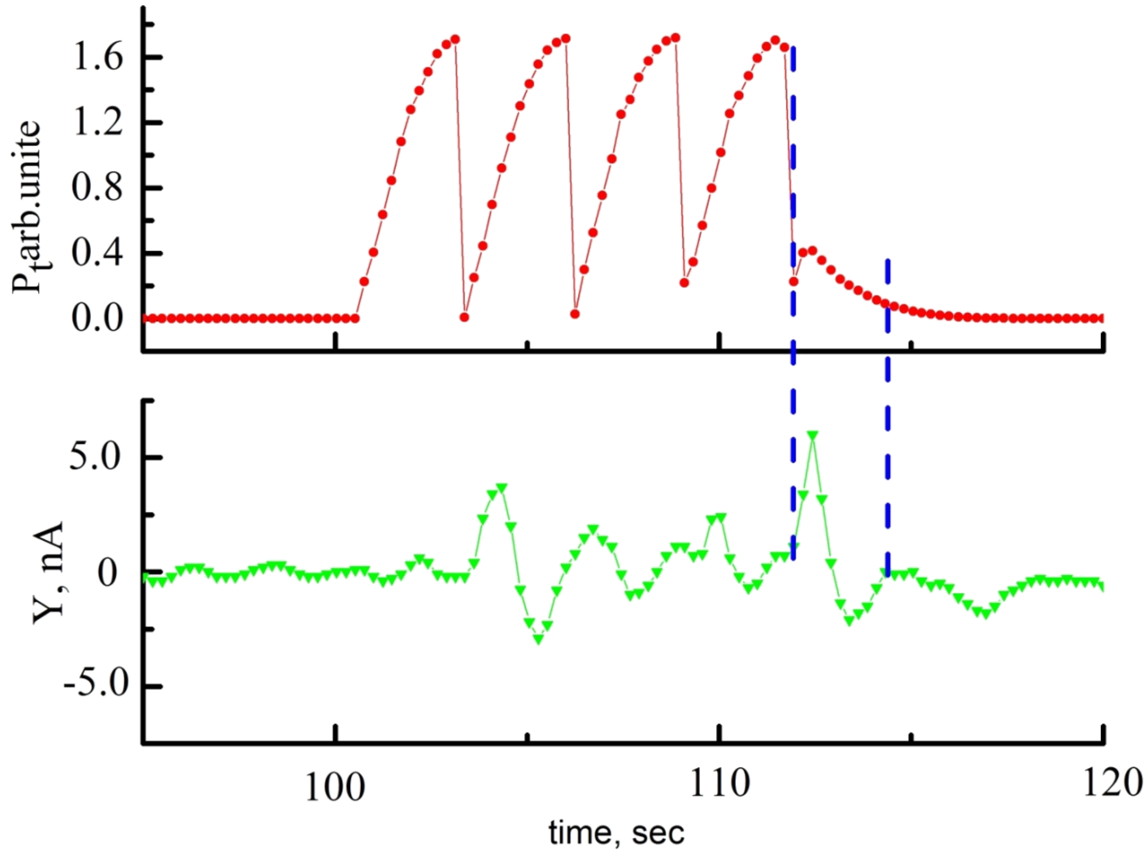
Bottom: Despite small temperature rise, tuning fork is very sensitive to heating changes.



Tuning Fork: Quench Events

Top: Quenching of top cell of 9 cell cavity.

Bottom: Out-of-phase component of tuning fork signal (more sensitive to outside perturbations)



Quantum Turbulence

- During SRF cavity operation in superfluid, heat flux generates vortices in quantum fluid
- Theoretical possibility of QT in superfluid He first discussed by Feynman (1955)
  - Should be a random tangle of vortices
- Vortices have fixed cross-sectional area and quantized circulation given by

$$\oint_C v \cdot dl = \frac{2\pi h}{m} n$$

C: Contour around fluxoid, v: velocity field

- Vortices carry heat flux information which is related to surface resistance.
- Viscosity consists of phonon and roton components

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Conclusions

- OSTs used for temperature wave detection at laboratories worldwide
- Automated software to acquire time of flight data and locate quench origin have been developed
  - Quench location determined on-the-fly
  - Cavity test data show “too fast” second sound signals
  - Pulsed heater measurements show propagation at predicted velocity of second sound.
  - Experimental plan to characterize the propagation of 2^{nd} sound waves is underway
- Quartz tuning fork viscometer has been developed
  - Accurately measures phase transitions between liquid/superfluid and liquid/gas states
  - In addition, allows vortex behavior, time scale of quantum turbulence dissipation to be characterized