A Cryogenic RF Cavity BPM for the Superconducting Undulator at LCLS*

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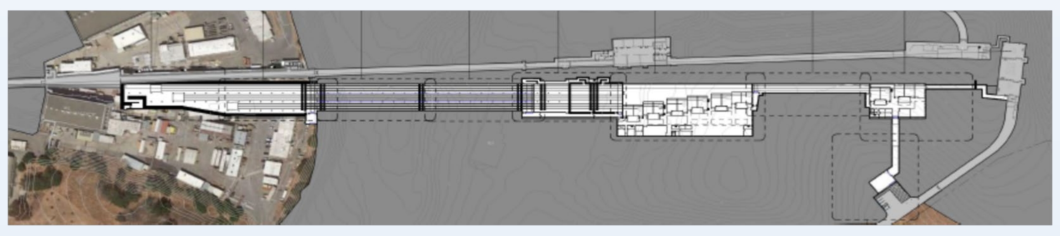
ABSTRACT

The new superconducting undulator beamline at LCLS requires the BPMs to be operated at cryogenic temperatures alongside the undulator magnets. They are used for beam-based alignment of the undulator magnets and quadrupole and require submicron resolution to achieve good FEL performance. This is to be achieved with X-band RF cavity BPMs, as is done now on the permanent undulator beamline. However, operating the cavities at cryogenic temperatures introduces significant challenges. We review the changes in RF properties of the cavities that result from cooling and how the design is changed to compensate for this. This includes a novel approach for employing a rectangular cavity with split modes to separately measure the X and Y position without coupling.

1. Project background



- LCLS long-term plans call for many new undulator beamlines, sharing the 1 MHz bunch rate from the SC linac
- Superconducting undulators provide
  - Tunability
  - Shorter period length
  - Higher fields
  - Shorter gain length
  - Multiple undulators per cryomodule

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2. Why a Cryogenic RF Cavity BPM?

- High-resolution BPMs are essential for beam-based alignment of the undulator system to achieve peak FEL performance
- Copper X-band cavity RF BPMs used in the present LCLS undulators, achieve submicron resolution @ 100pC
- A compact superconducting undulator cryomodule design requires the BPM and quadrupole to be mounted in close proximity inside the cryomodule. No space for cold to warm transitions
- Operating temperature around 40° K (not a SC BPM!)

3. Integration of the RF BPM into the SCU Cryomodule

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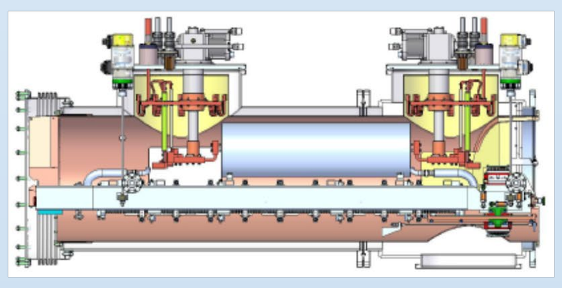
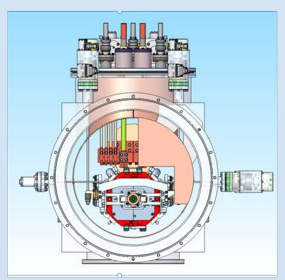
- Cutaway and end views of the cryomodule containing the SCU and quadrupole (red) and BPM (copper) at the RH downstream end.





4. Present room-temperature RF BPM at SLAC

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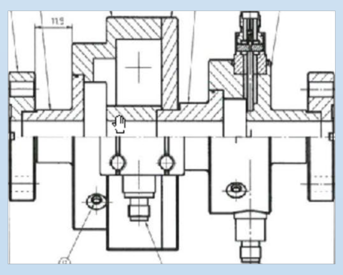
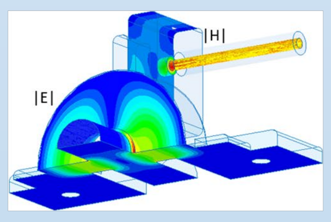
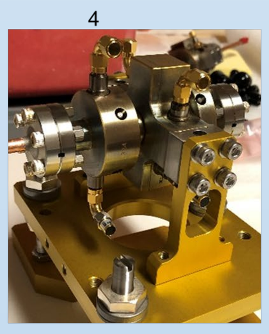


Copper body with a cylindrical X-band TM011 dipole mode cavity plus a cylindrical 0-mode reference cavity



Dipole cavity has two orthogonal coupling slots to selectively measure X and Y position



80 units of the SLAC-PAL design were manufactured by Vitzrotech and installed on the SXR and HXR undulator beamlines

5. Design challenges for a cryogenic RF BPM

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- Cooling to 40° K makes a large dimensional change, shifting the resonant frequency of the cavity
- The conductivity of copper is lowered, making changes in cavity Q and coupling ratio, β.
- Dimple tuning can't be performed once the cavity is mounted inside the cryomodule
- Coaxial vacuum feedthroughs don't survive temperature cycling to 40° K

6. Thermal expansion issues

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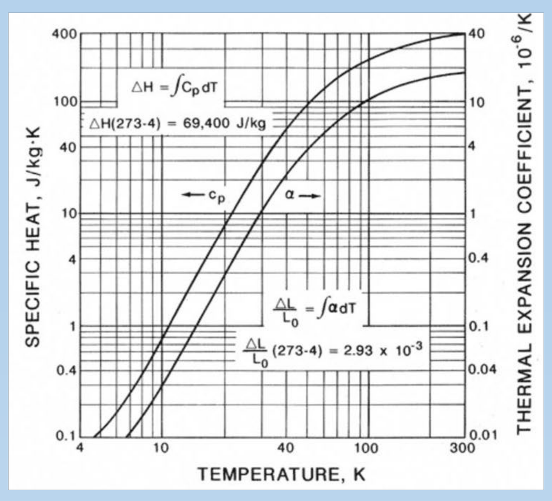
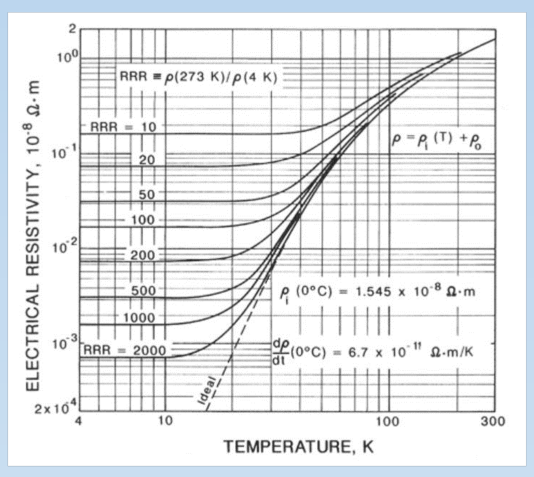
- The expansion coefficient also decreases exponentially with temperature.
- The coefficient is so small below about 40° K that contraction effectively stops below that temperature
- Predicted contraction factor of ~0.99673, increasing frequency by a factor of ~1.00328 at 40° K



7. Changes in copper resistivity

- conductivity of the copper decreases significantly at cryogenic temperatures
- Cavity Q factor, and the cavity coupling must be recalculated for the new design so the loaded Q_L factor is within design requirements.
- Resistivity of copper is seen to plateau below about 20° K.
- The residual resistance ratio (RRR) equal to the ratio of its resistivity at 293° K to the resistivity at 4.2° K depends on the composition and purity of the copper used.



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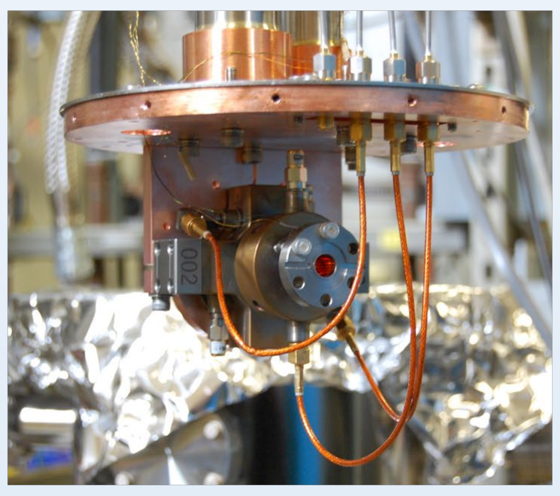
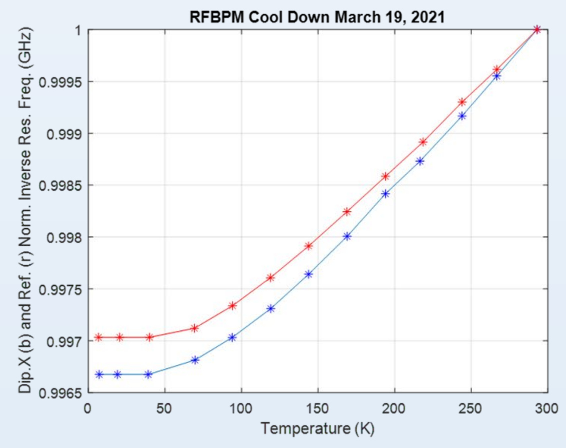
8. Cryogenic RF testing

- RF BPM mounted in test cryostat



- Reproducible frequency change of 34.3 MHz to the dipole mode frequency



9. X-Y Coupling and Cavity Tuning

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- Dimple tuners adjust the X&Y resonant frequencies of the dipole modes
- But dimple tuners introduce asymmetry in the cylindrical dipole cavity which creates X-Y coupling
- Tuning therefore requires iterations to optimize
- Tuners are inaccessible inside the cryomodule
- Abandon single cylindrical dipole cavity in favor of two, independent X and Y rectangular dipole cavities

10. Features of the dual rectangular dipole cavity approach

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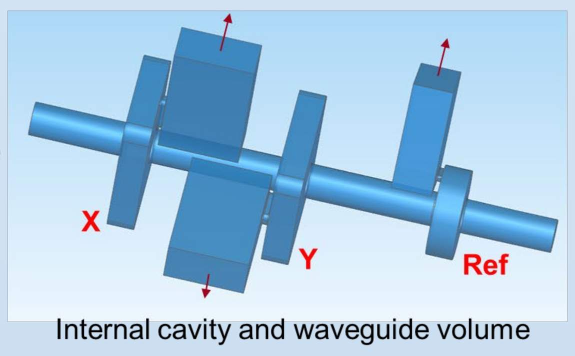
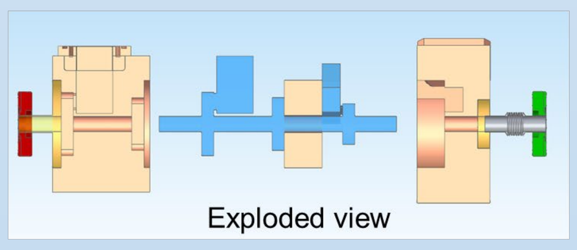
- Rectangular shape ensures the two dipole modes in each cavity are widely separated in frequency, so only one dipole mode in each plane is at 11.424 GHz
- Only one tuning screw per cavity, and no X-Y coupling
- Procedure is to tune the cavity frequency to a prescribed Δf = 34.3 MHz below 11.424 GHz at room temperature that gives correct frequency at 40K



Internal cavity and waveguide volume



Exploded view

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11. 1-Port Dipole Cavity Analysis

Frequency (GHz)	Q	
11.4239 +j 0.000112502	50772.1	Q_0

w/ 20K Cu — Conductivity: 3200000000

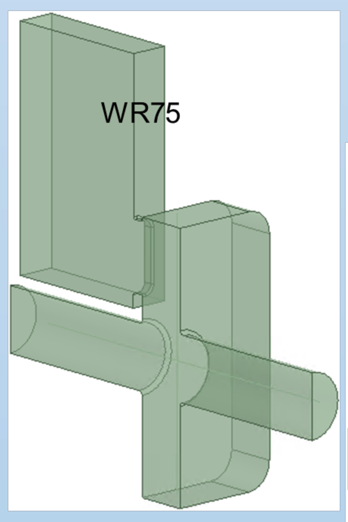
Frequency (GHz)	Q	
11.4241 +j 0.00244901	2332.39	Q_e

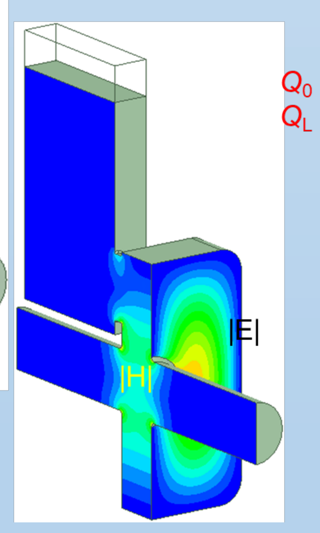
Frequency (GHz)	Q	
11.4240 +j 0.00256510	2226.82	Q_L

Other Modes:

	Frequency (GHz)	Q
TM_{11}	7.25799 +j 8.62302e-05	42085.0
TM_{12}	10.3277 +j 0.000103433	49924.6
TM_{13}	14.8850 +j 0.000119279	62395.6

- Undamped modes will decay much more slowly.
- Make sure not resonant with bunch spacing

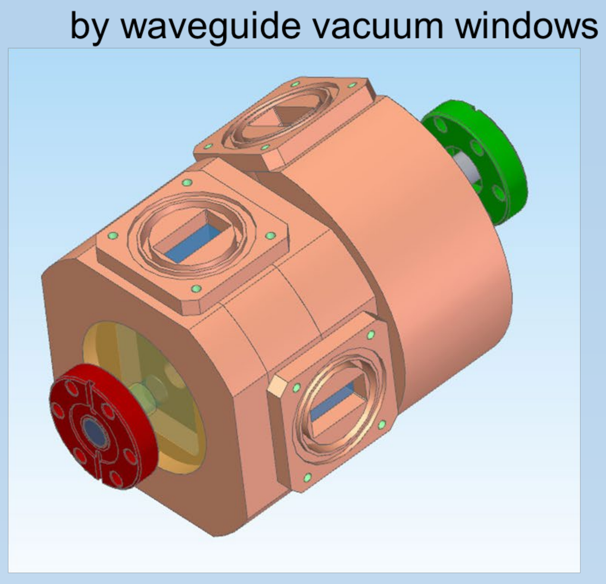




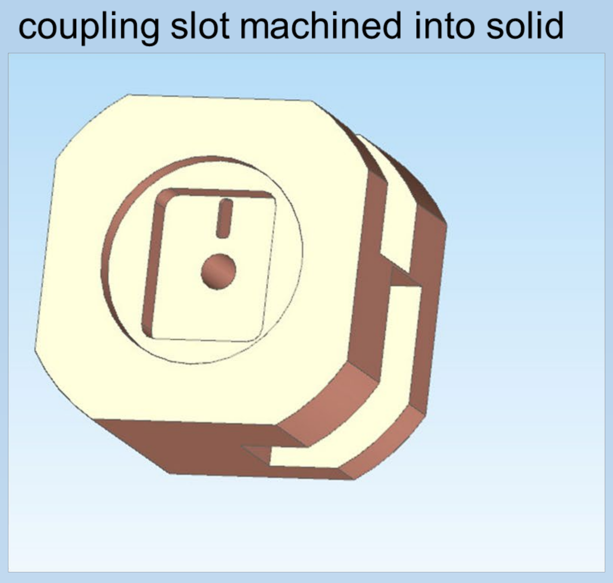
Q_0 = 50,770
Q_L = 2,227

12. Complete RF BPM Cavity Body

- Coax feedthroughs are replaced by waveguide vacuum windows



- Rectangular dipole cavity and coupling slot machined into solid



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