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Cavity 2A Cryogenic Testing Plan at FNAL

Mohamed Awida Hassan

ADMX Collaboration Meeting

11/17/2020

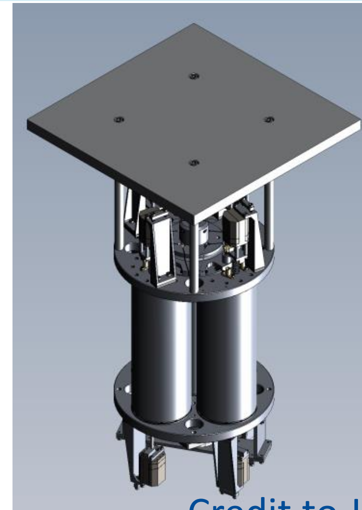
Acknowledge to FNAL, PNNL, UF and LLNL teams

Who am I?

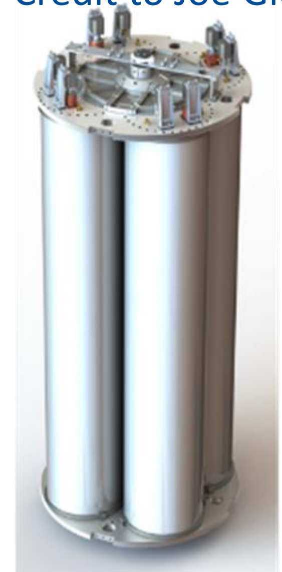
- Senior RF engineer at FNAL
- Joined ADMX a little more than a year ago
- Lead RF engineer for ADMX at FNAL site
- Wide experience in modeling, designing, and testing of various high frequency structures including;
  - microwave components (both passive and active circuits)
  - low profile antennas (microstrip, slotted waveguide, and cavity-backed structures with emphasis on the low-cost substrate-integrated waveguide “SIW” implementation)
  - cavities for particle accelerators (RFQ, re-buncher cavities, spoke resonators, elliptical cavities, twisted waveguide cavities and deflectors)
  - superconducting qubits based on Josephson junctions for quantum computing
- Skilled in multi-physics modeling that involves EM interaction with other aspect of physics including; heat transfer, solid mechanics, and particle dynamics
- Quality control of SRF cavities, tuning of SRF cavities, cryogenic testing of cavities, ultra-low temperature testing, quantum dispersive shift, qubit spectroscopy, quantum system calibration, qubit characterization, and noise analysis
- Excited to contribute to ADMX

Scaled 2A Prototype System

- It is a 4-cavity system operating in the 4-6 GHz frequency range
- A scaled version (D=55.9 mm, L=181mm, AR=3.2) of the 2A system to operate in the 1-2 GHz (D=169.2 mm, L=961.4 mm, AR=5.7)
- Was fully tested at UF (twice 11/2018--tuning wheel stuck, 4/2019--tuning wheel moved freely) in a liquid helium dunk (without linear actuators)
- Testing at FNAL with linear actuators in a crycooler

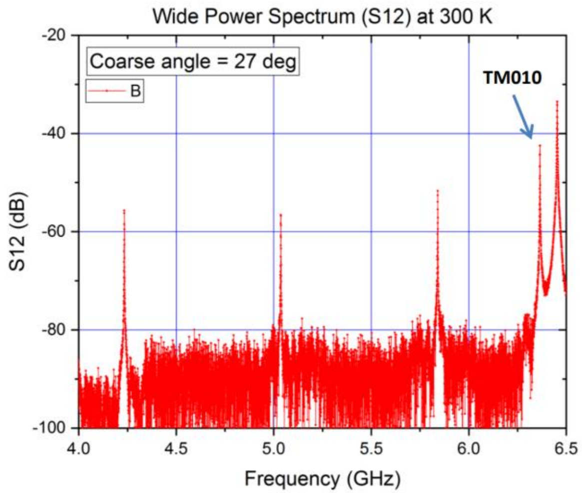


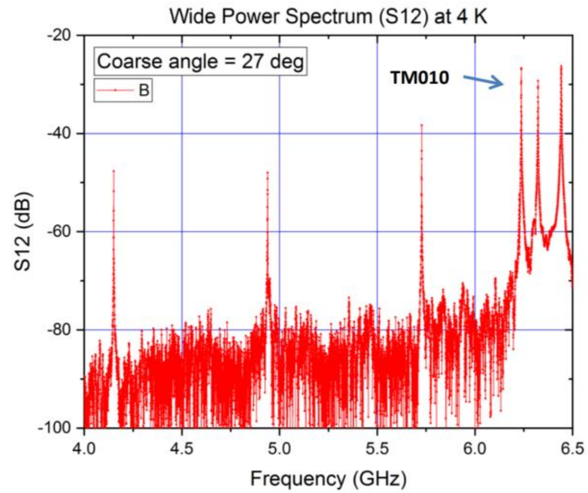

Credit to Joe Gleason

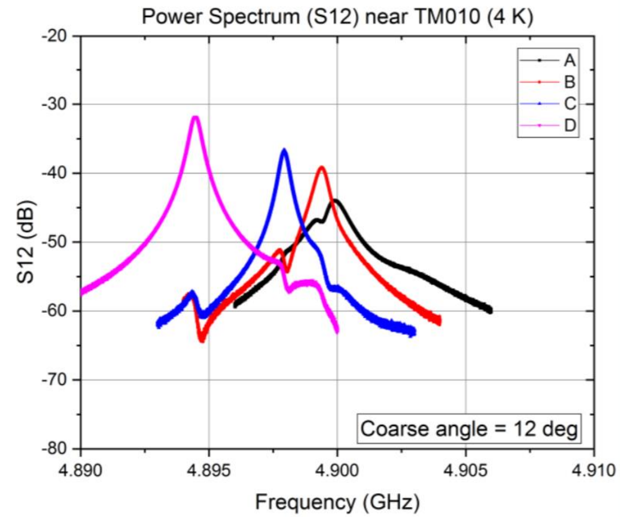


Cavity system for run 2a
4 cavity array
Sapphire (1200 – 1500 MHz)
Metal Rods (1500 – 2000 MHz)

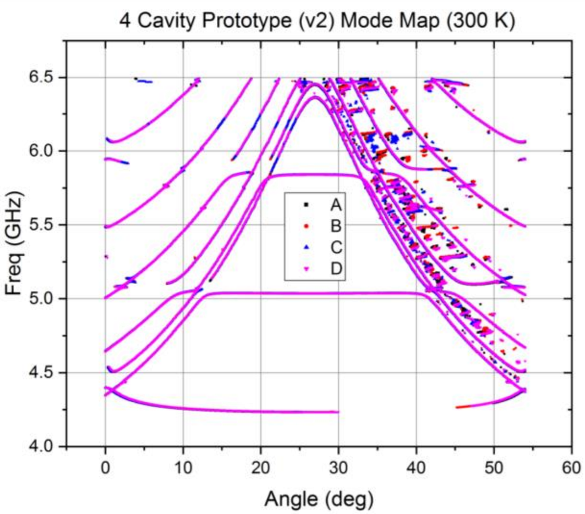
Last Cold Testing Issues of the Scaled 2A Prototype

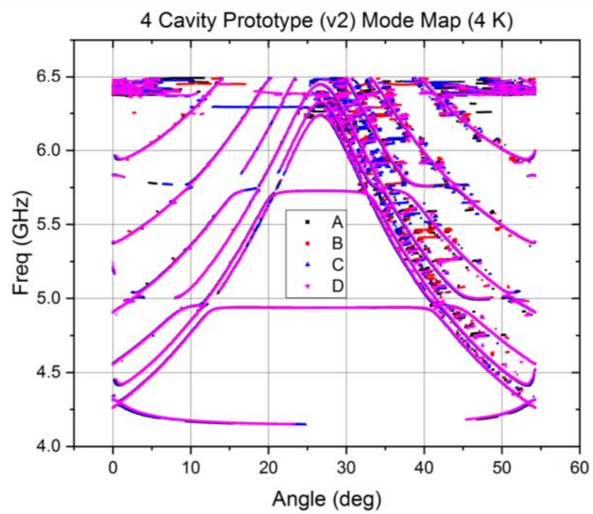


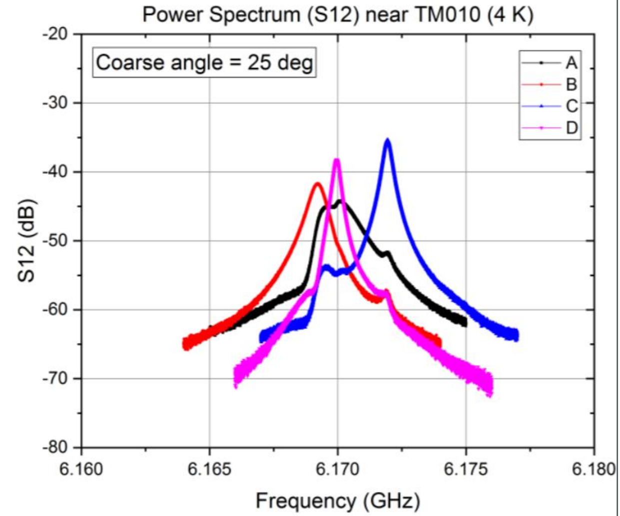




Higher Noise at 4K







Cross-Talk Issue

Reported by Jihee Yang

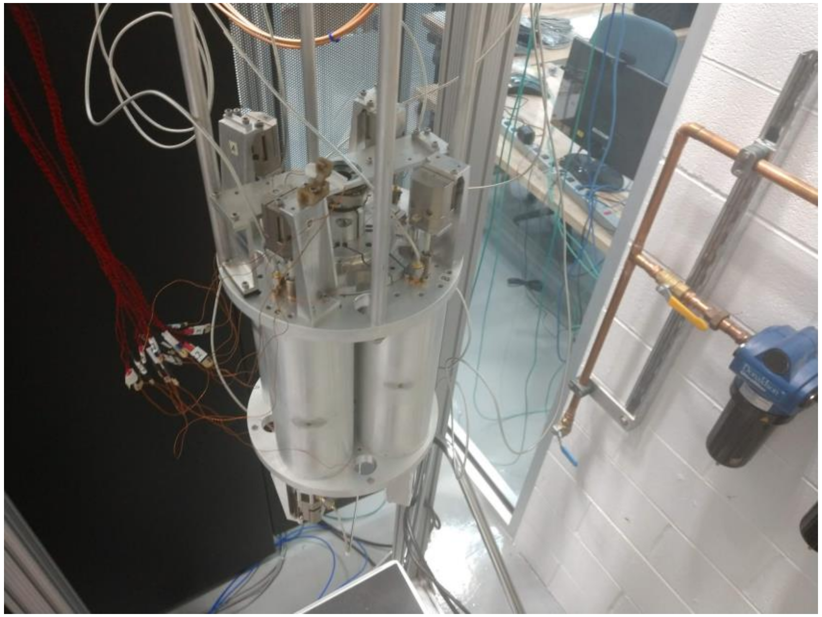
Scaled 2A Prototype Progress

- The scaled 2A prototype (4-6 GHz 4-Cavity system) is at FNAL (2019)
- The system is dressed with fine-tuning and antenna coupling piezo actuators and fully functioning as of Sep 2020
- We made progress adjusting the frequency spread between the four cavities from 23 MHz to 10 MHz
- Cavity locking work is progressing in collaboration with PNNL colleges

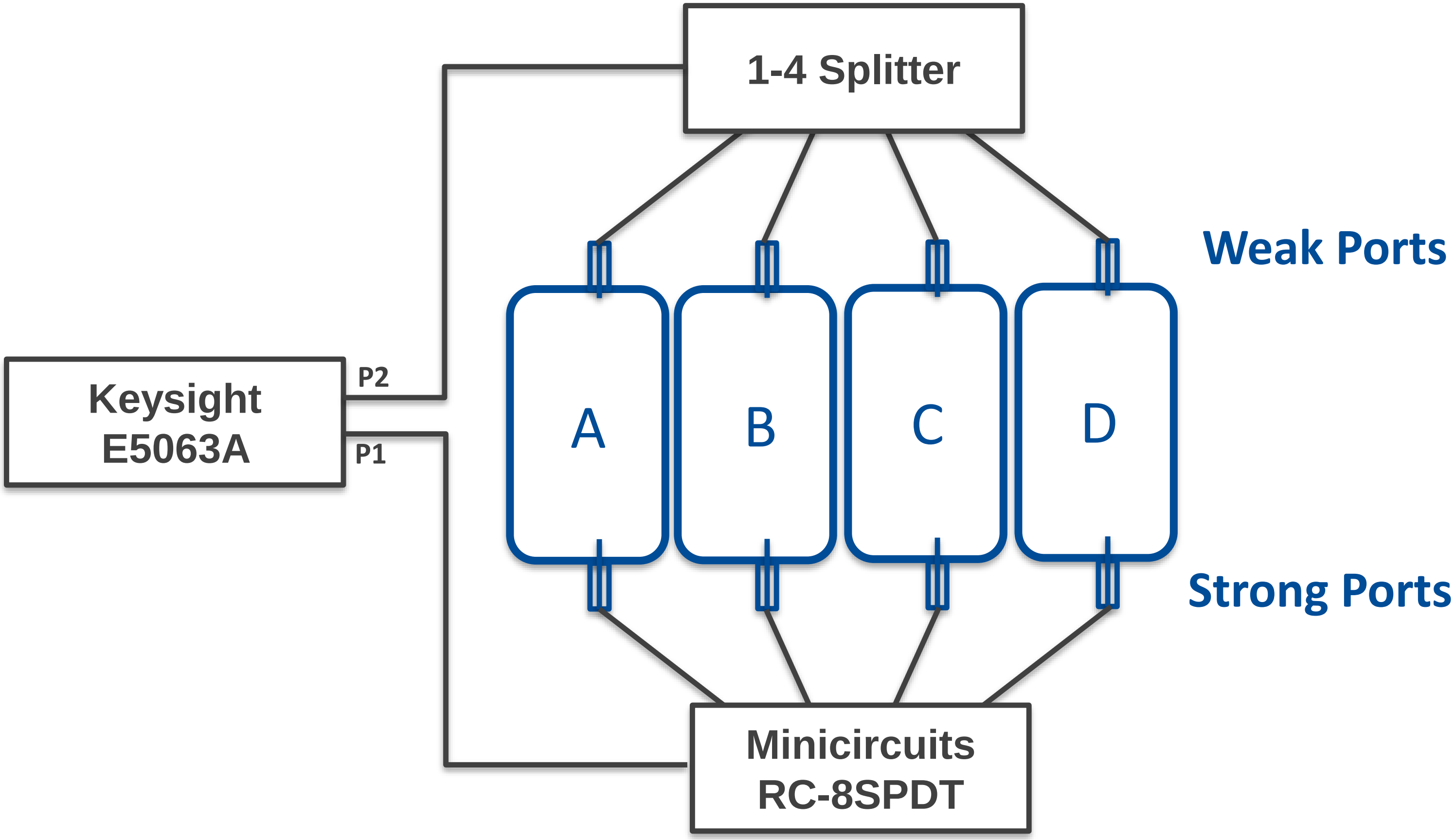
Overview of FNAL System

Scaled 2A Prototype System at FNAL

- Fully dressed with fine tuning and antenna coupling piezo actuators



Test Setup of the Cavity System at FNAL

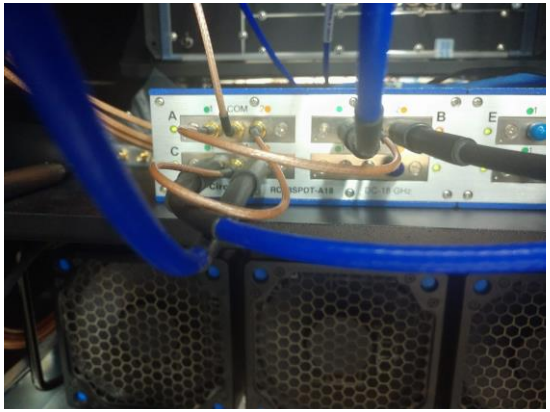


Switching Between Cavities

Case Style: LM1852

Software Package

Model No.	Description	Qty.
RC-8SPDT-A18	**USB/Ethernet RF Switch**	1
Included Accessories		
AC/DC-24-3W1	AC/DC 24V Adapter	1
CBL-3W1-XX	AC Power Cord *(see Ordering Information)*	1
USB-CBL-AB-3+	2.7 ft USB cable	1

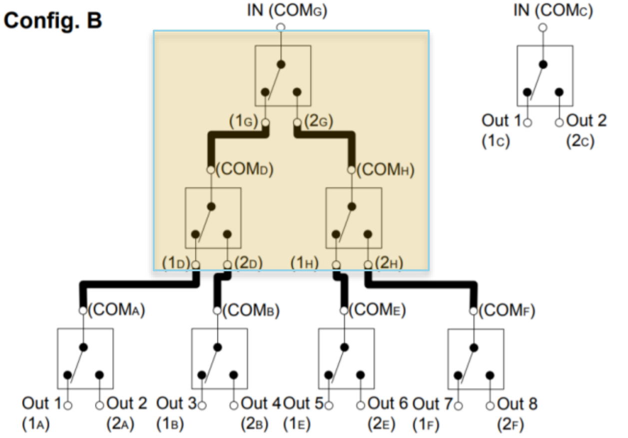


Electrical Specifications

Parameter	Port	Conditions	Min.	Typ.	Max.	Units
Frequency	All RF Ports	—	DC		18	GHz
Power On Sequence: Connect the 24V power, followed by the USB control and/or Ethernet cable before turning on the Switch Matrix.						
RF Insertion Loss (per switch)		DC to 1 GHz	–	0.10	0.15	dB
		1 GHz to 8 GHz	–	0.15	0.30	
		8 GHz to 12 GHz	–	0.25	0.40	
		12 GHz to 18 GHz	–	0.30	0.50	
RF VSWR		DC to 1 GHz	–	1.05	1.10	:1
		1 GHz to 8 GHz	–	1.20	1.30	
		8 GHz to 12 GHz	–	1.20	1.35	
		12 GHz to 18 GHz	–	1.25	1.40	
RF Isolation (per switch)		DC to 1 GHz	85	100	–	dB
		1 GHz to 8 GHz	75	90	–	
		8 GHz to 12 GHz	70	80	–	
		12 GHz to 18 GHz	60	66	–	
Switching Time		–	–	25	–	ms
RF Power (cold switching) [1,2]		–	–	–	20	W
Rated Voltage	$24V_{DC}$ IN	provided via external power adapter	23	24	25	V
	USB Port	–	–	5	–	
Rated Current	$24V_{DC}$ IN	All switches in COM -> 2 position	–	1500	2050	mA
		All switches in COM -> 1 position	–	170	220	
	USB Port	All switches in COM -> 2 position	–	10	20	
		All switches in COM -> 1 position	–	10	20	
Life (per switch)		@ 100 mW (hot switching) [3]	10	–	–	million switching cycles
		@ 1 W (hot switching) [3]	–	3	–	

[1] Power handling is specified with RF applied to the COM port and external load connected to either 1 or 2 of the respective switch.
[2] Cold switching describes switch operation where there is no significant user signal present at the moment the switch contacts open or close.

Config. B



SPDT: Switch C Logic
IN ←→Out1 : 0
IN ←→Out2 : 1

SP8T:
Switch A, B,& D - H Logic

	A	B	D	E	F	G	H
IN ←→Out1 :	0	Ø	0	Ø	Ø	0	Ø
IN ←→Out2 :	1	Ø	0	Ø	Ø	0	Ø
IN ←→Out3 :	Ø	0	1	Ø	Ø	0	Ø
IN ←→Out4 :	Ø	1	1	Ø	Ø	0	Ø
IN ←→Out5 :	Ø	Ø	Ø	0	Ø	1	0
IN ←→Out6 :	Ø	Ø	Ø	1	Ø	1	0
IN ←→Out7 :	Ø	Ø	Ø	Ø	0	1	1
IN ←→Out8 :	Ø	Ø	Ø	Ø	1	1	1

Switches A,B, D-H move together as one. Switch C moves independently

Piezo Control

- Currently using two ANC300 control boxes (one is a master, and the other is a slave)
- Both have 9 ANM150 plug in modules:-
  - 1 rotational control
  - 4 for fine tuning piezo actuators
  - 4 for antenna coupling piezo actuators
- The extra ANM300 is not currently being used

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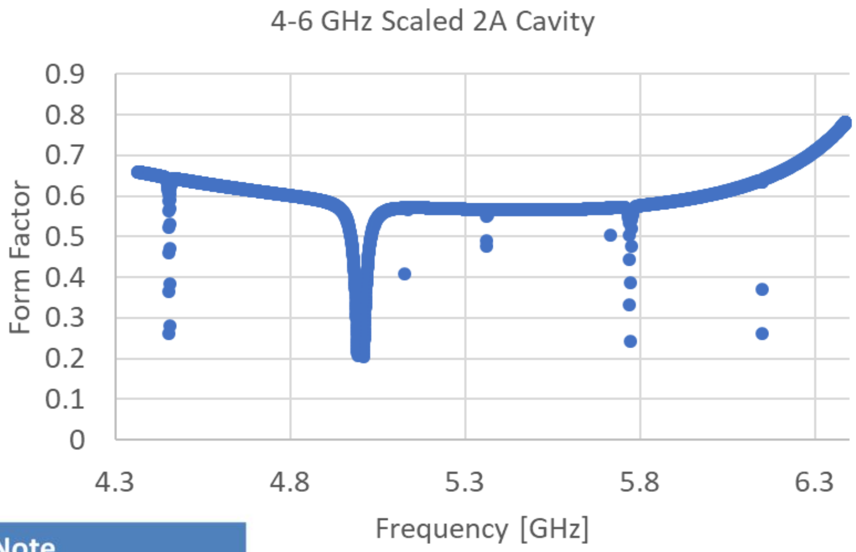
Electromagnetic Simulation of Scaled 2A Prototype

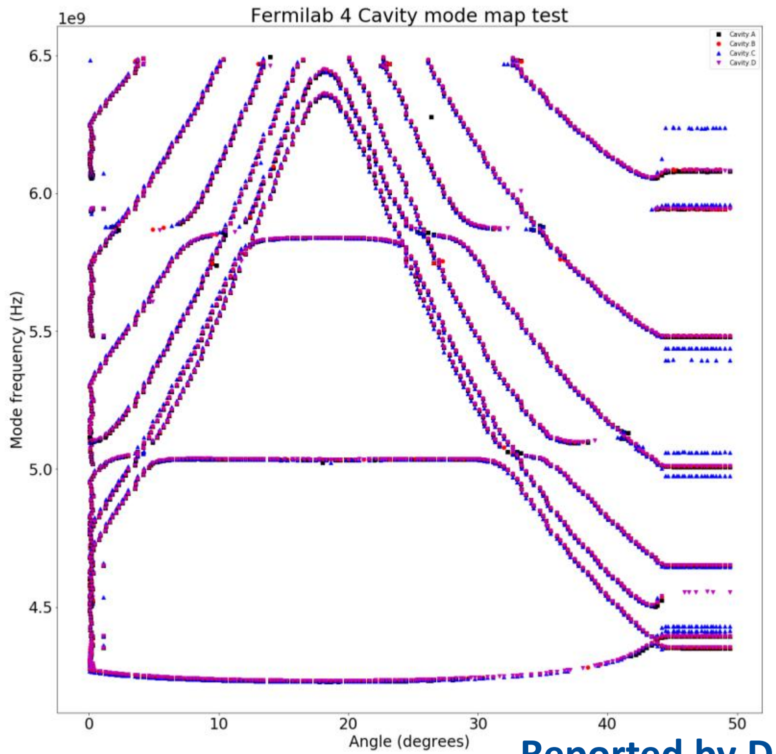


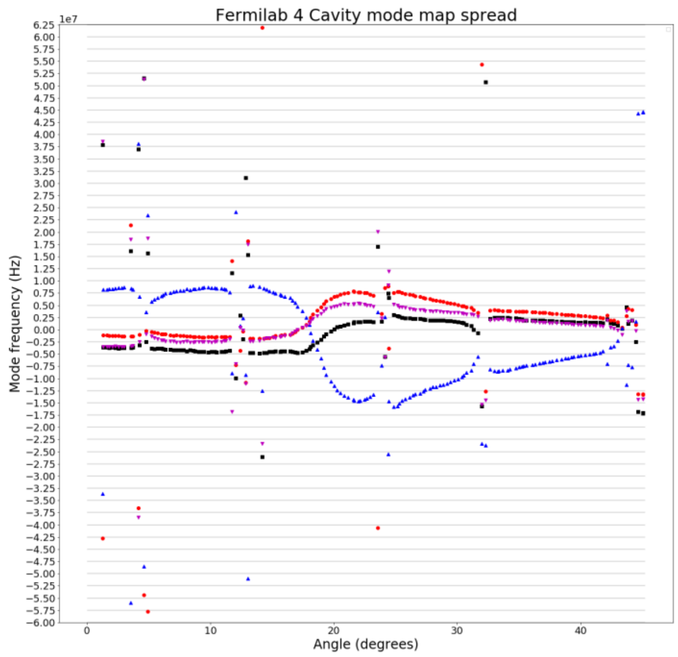
Index	Freq_300 K (GHz)	Freq_4 K (GHz)	Angle (deg)	Note
Overall Range	4.35 – 6.36	4.26 – 6.24	0 – 27	
Crossing (1)	4.38	4.30	0.9	Major
Crossing (2)	4.44	4.35	2.3	
Crossing (3)	5.01 – 5.12	4.92 – 5.03	12.6 – 13.4	Major, avoided
Crossing (4)	5.75	5.64	20.3	
Crossing (5)	5.81	5.70	21.0	Major

- Overall range and mode crossing frequencies are shifted down to ~ 98% as well

Reported by Jihee Yang

Initial Mode Map and Frequency Spread

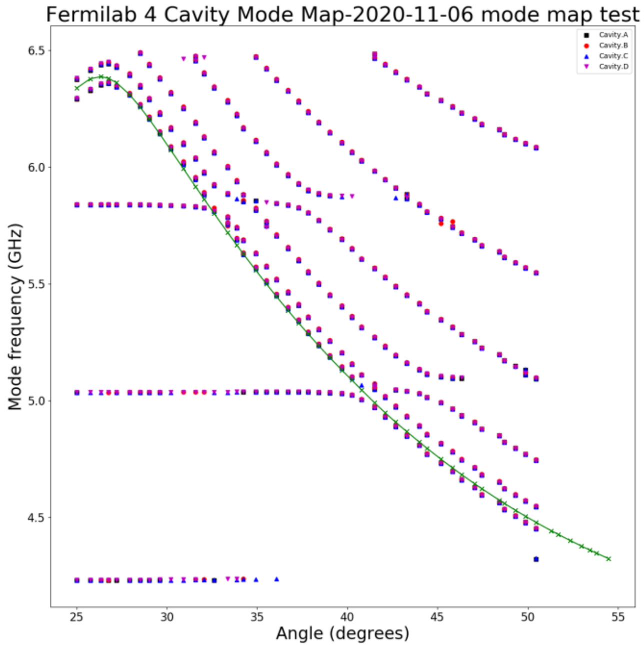


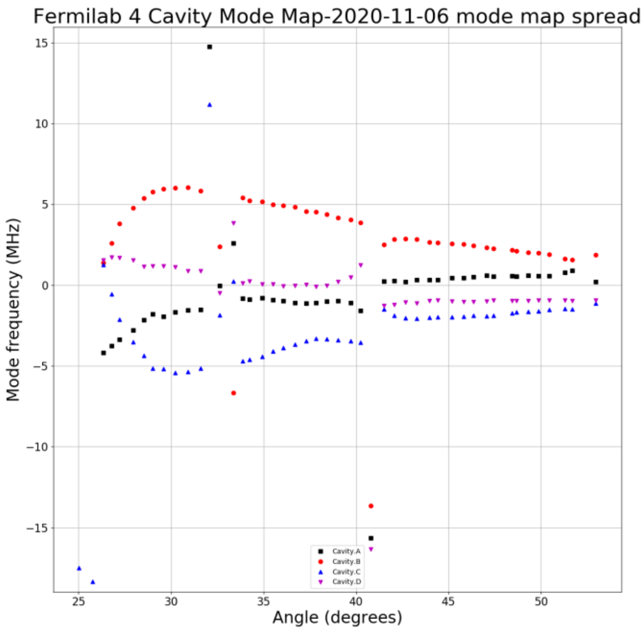


Reported by Daniel Cain

- Daniel Cain developed to some extent an algorithm that can clean up them mode map
- Frequency spread of about 22 MHz
- Flexure adjustment was needed

Frequency Spread after Some Flexure Adjustment

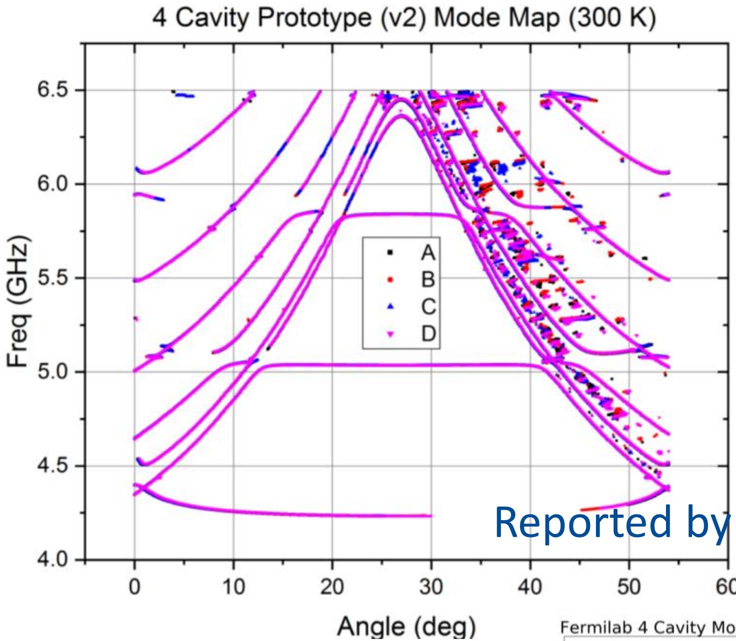


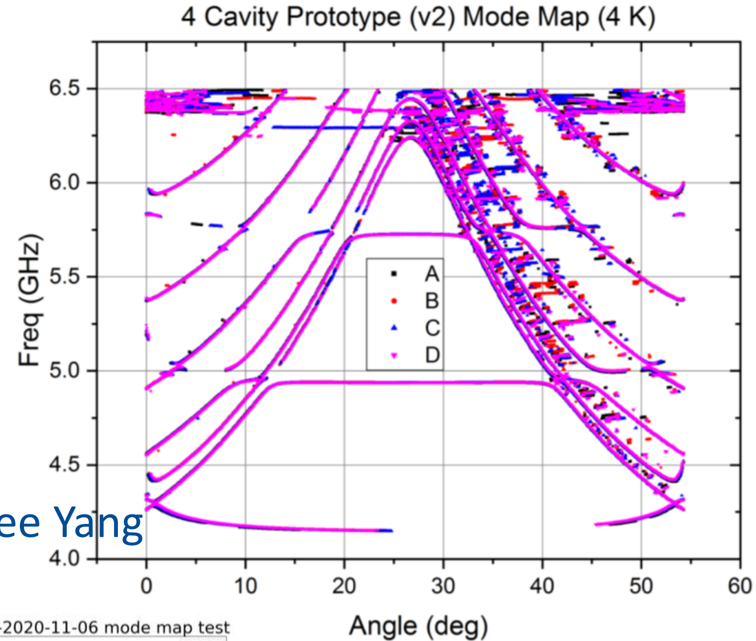


Reported by Daniel Cain

- Frequency spread of about 10 MHz after relaxing the flexure of cavity C (by Tyler Funk)
- Som additional flexure adjustment is needed

Mode Map Comparison





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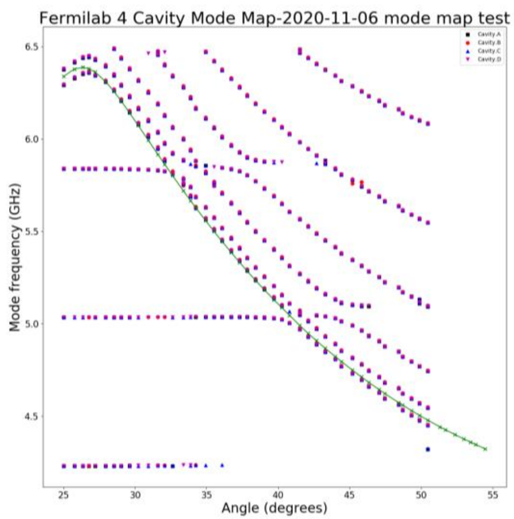

Reported by Daniel Cainc

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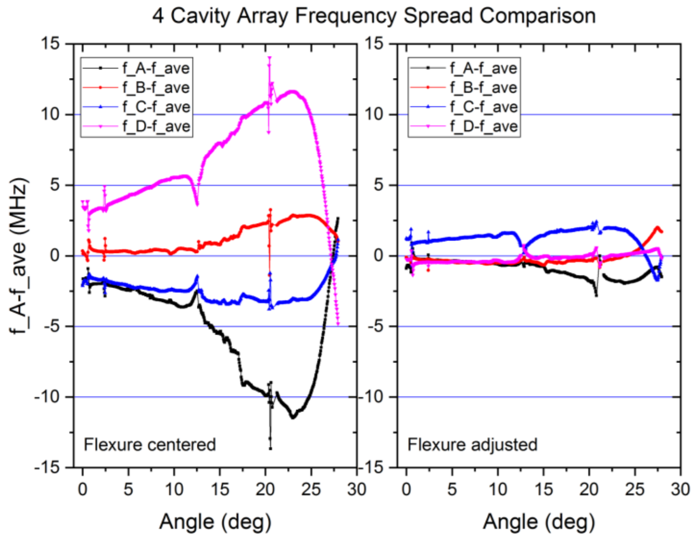
Frequency Spread Comparison

Reported by Jihee Yang



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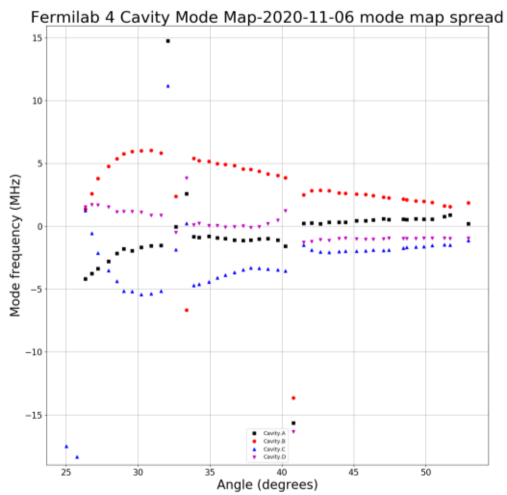
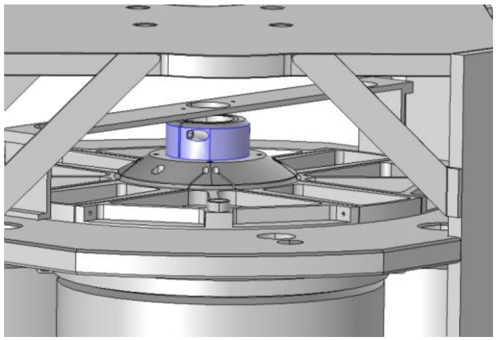
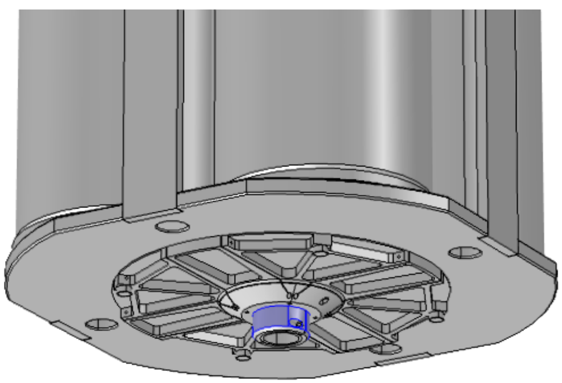


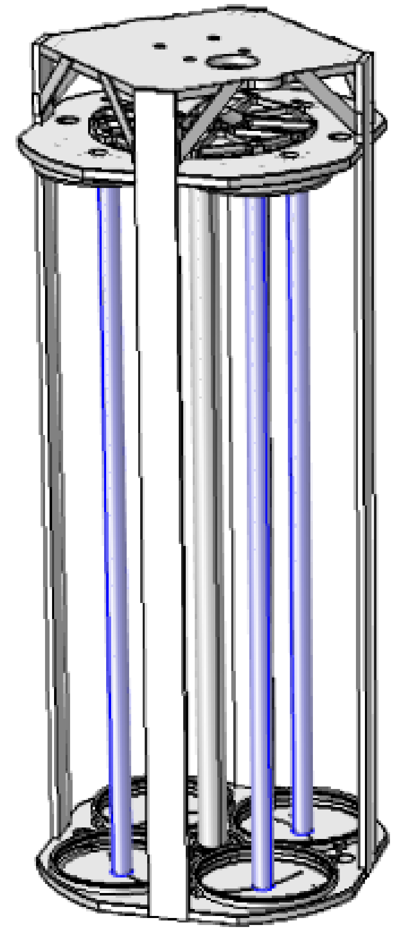
- Looks like we can bring the frequency spread to ~6MHz

Temperature Cooling Surfaces at 100 mk

Temperature Cooling Surfaces at 100 mk

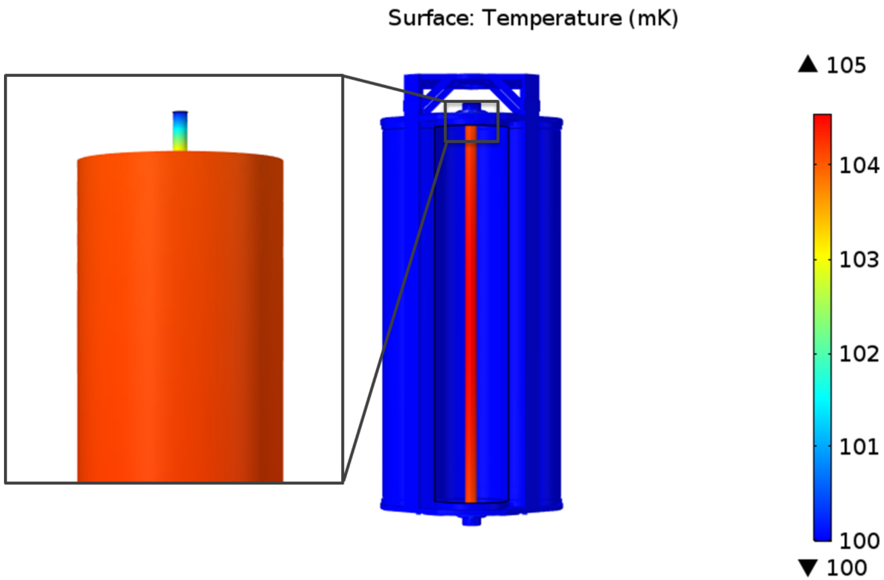


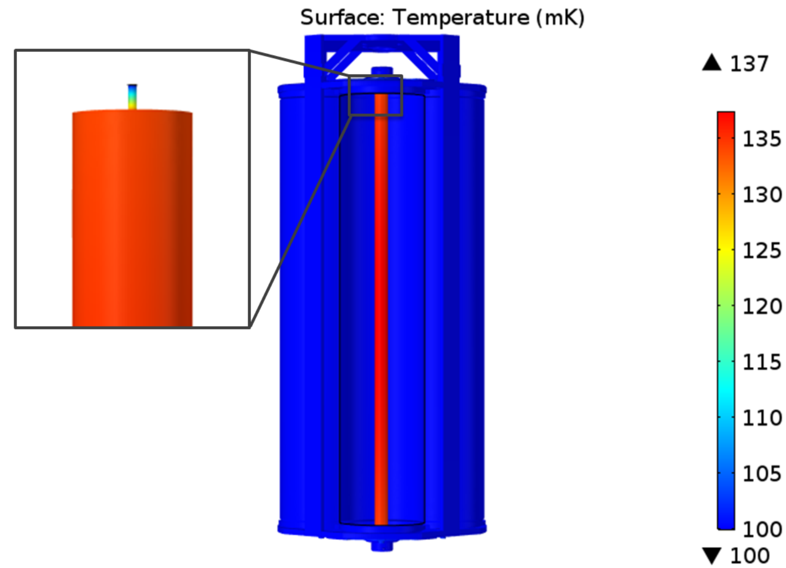




Uniform Heat Flux Deposition

Preliminary Thermal Profile of Tuning Rods





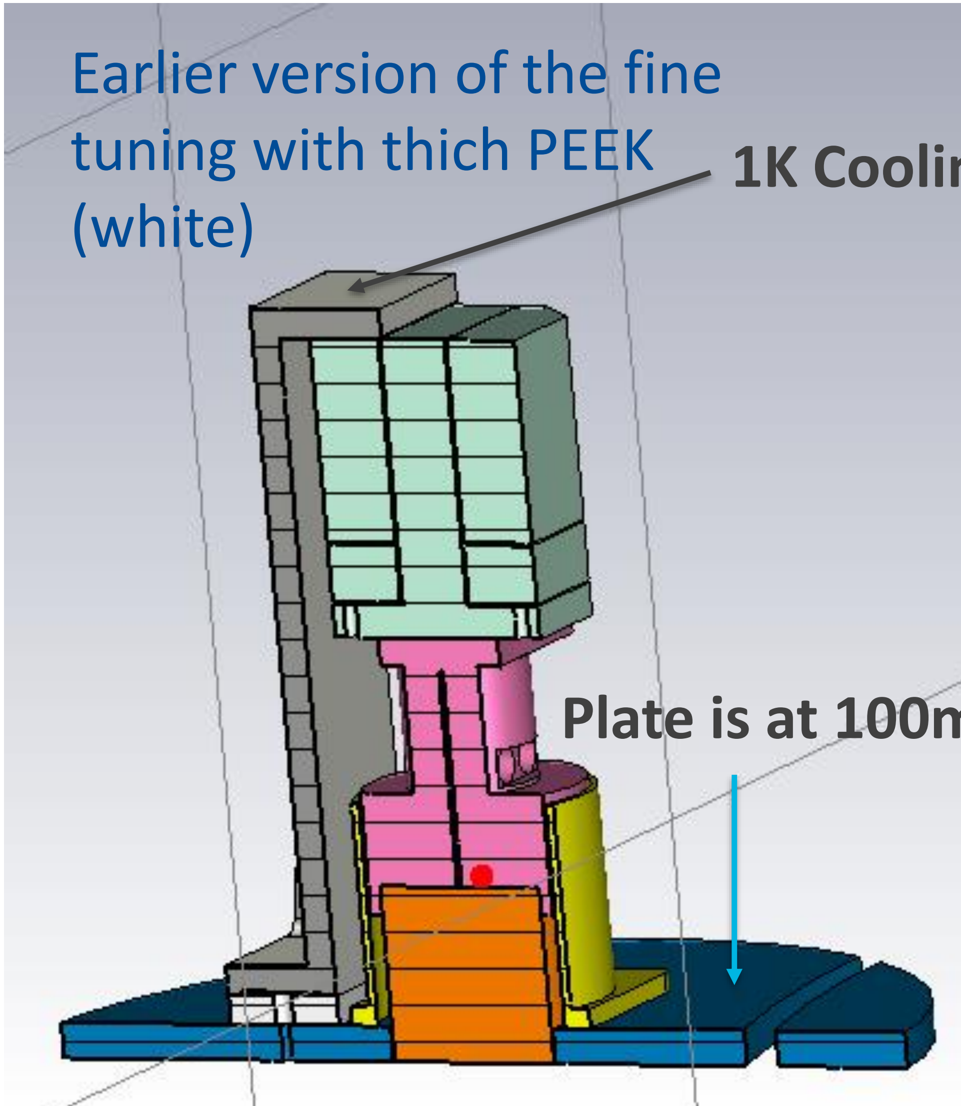
2.5 uW Uniform Heat Deposition Per Each Rod

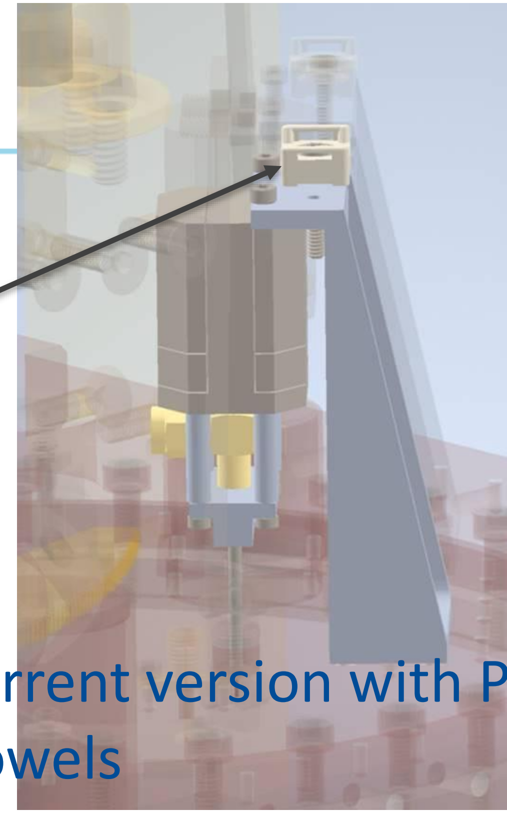
25 uW Uniform Heat Deposition Per Each Rod

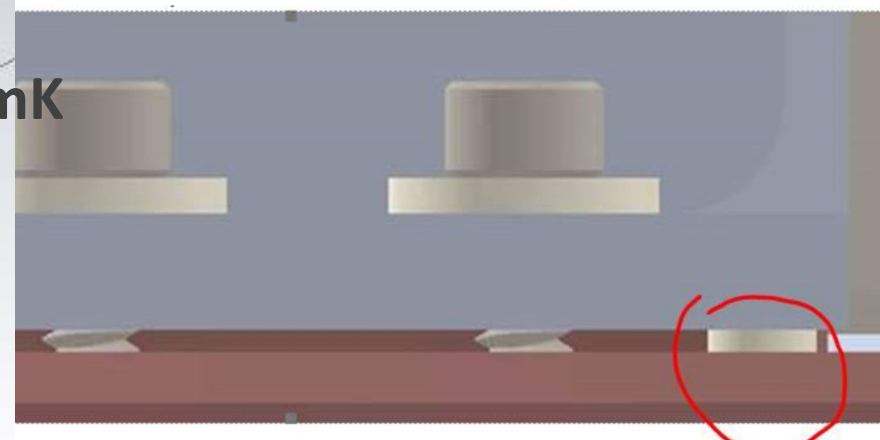
Kapitza resistance is not yet included in these results

For how to add the effect of Kapitza resistance in the thermal analysis of quench in superconducting cavities, please refer to Awida, M. H., Gonin, I., Khabiboulline, T., & Yakovlev, V. P. (2020). Modeling of Thermal Quench in Superconducting RF Cavities. *IEEE Transactions on Applied Superconductivity*, *30*(6), 1-8.

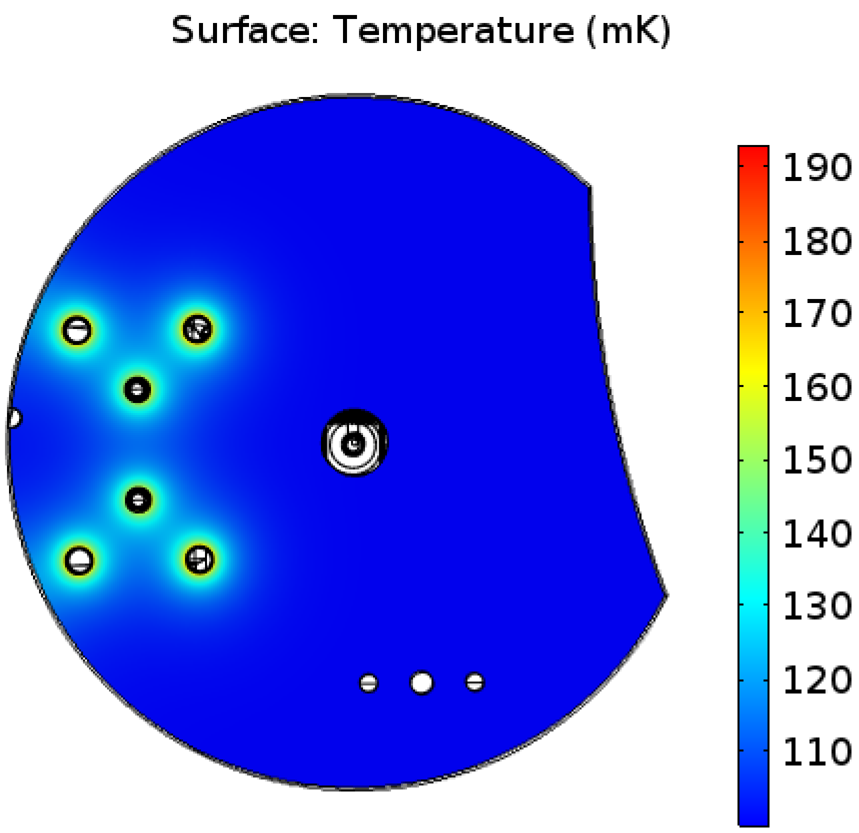
Piezo Support Geometry

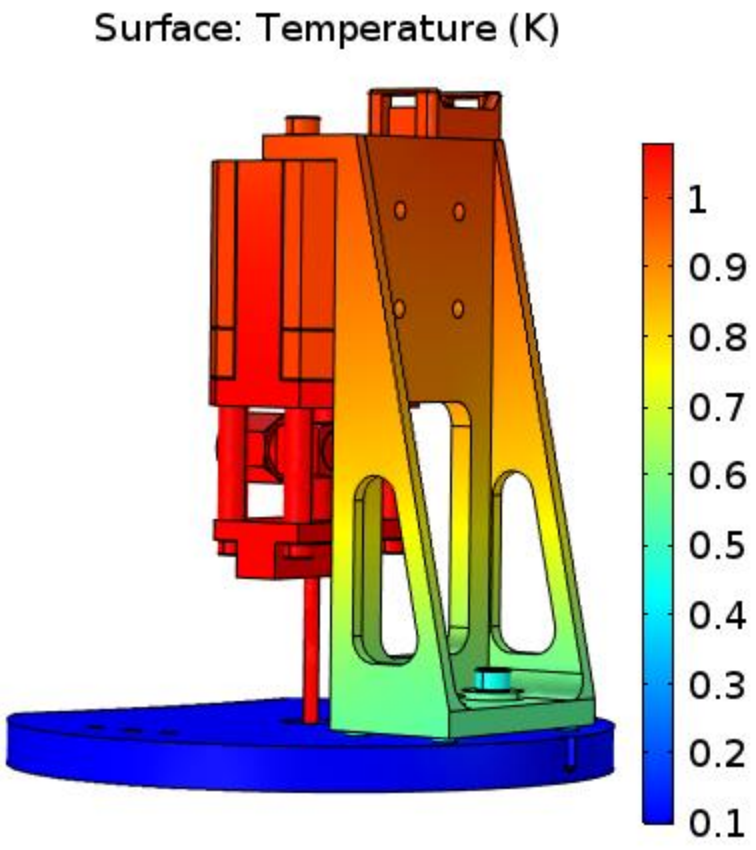






Modified Design with Thin Wall Carbon Fiber Dowels and SS Bracket with Cutout

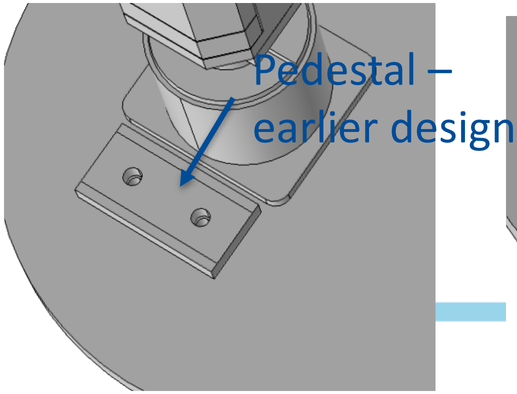


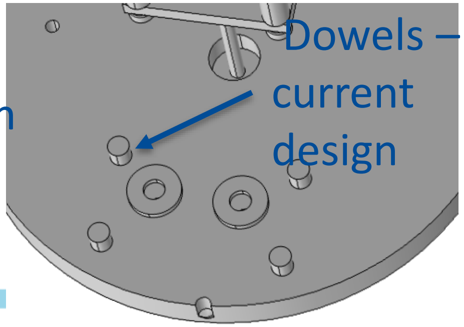


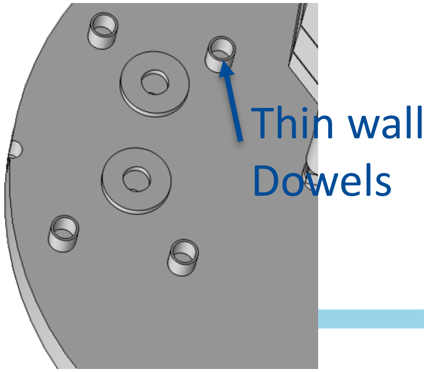
~8uW thru the 4 Carbon Fiber Dowels

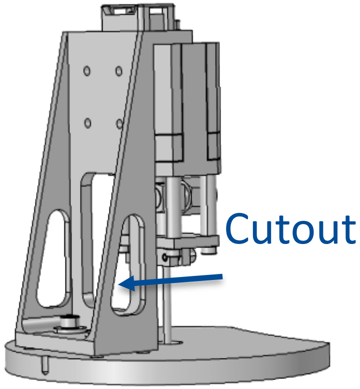
Summary of Thermal Analysis for Piezo Support

	Heat Leakage per Piezo [uW]
Earlier design (aluminum bracket, PEEK pedestal)	58
Current Design (aluminum bracket, PEEK dowels)	38
aluminum bracket with thin wall carbon fiber dowels	26
stainless steel bracket with thin wall carbon fiber dowels	11
stainless steel bracket with cutout and thin wall carbon fiber dowels	8









Conclusion

- Additional fine flexure adjustment is to be done to get the spread to 6MHz
- System is fully functioning and can be used for room temperature locking development
- Bringing the frequency spread to 6MHz could enable faster locking
- Cool-down is subject to approval withing new stricter rules for COVID mitigation
- A full test at 4K will enable
  – Cavity characterization cold (mode map, frequency spread)
  – Cold locking studies
  – Some thermal studies for the effect of piezo potential heating
- Switch to the 2A cavity system once received from LLNL