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Frequency Tuning and RF Systems for the ATLAS Energy Upgrade

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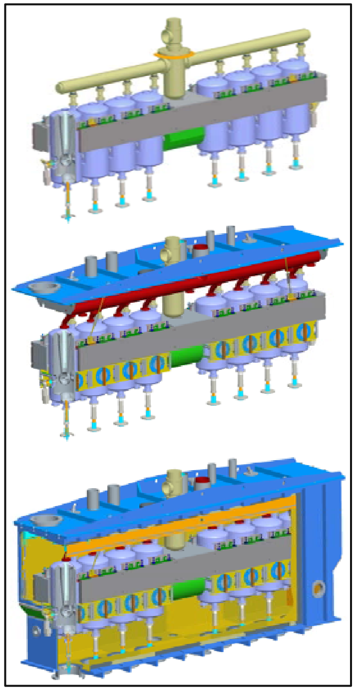
Outline

- Overview of the ATLAS Energy Upgrade
- Description of cavity
- Tuning method used during cavity construction
- Description and test results of the variable RF coupler probes
- Cold test results of quarter wave cavities

ATLAS Energy Upgrade

- The ATLAS Energy Upgrade Project at ANL includes a new cryomodule containing seven 109 MHz β=0.15 quarter-wave superconducting cavities to provide an additional 15 MV voltage to the existing linac

- Several new features have been incorporated into both the cavity and cryomodule design
  - separation of the cavity vacuum space from the insulating vacuum
  - The cavities are designed to cancel the beam steering effect due to the RF field
  - Variable RF power coupler



109.125 MHz Quarter-wave SC Cavity

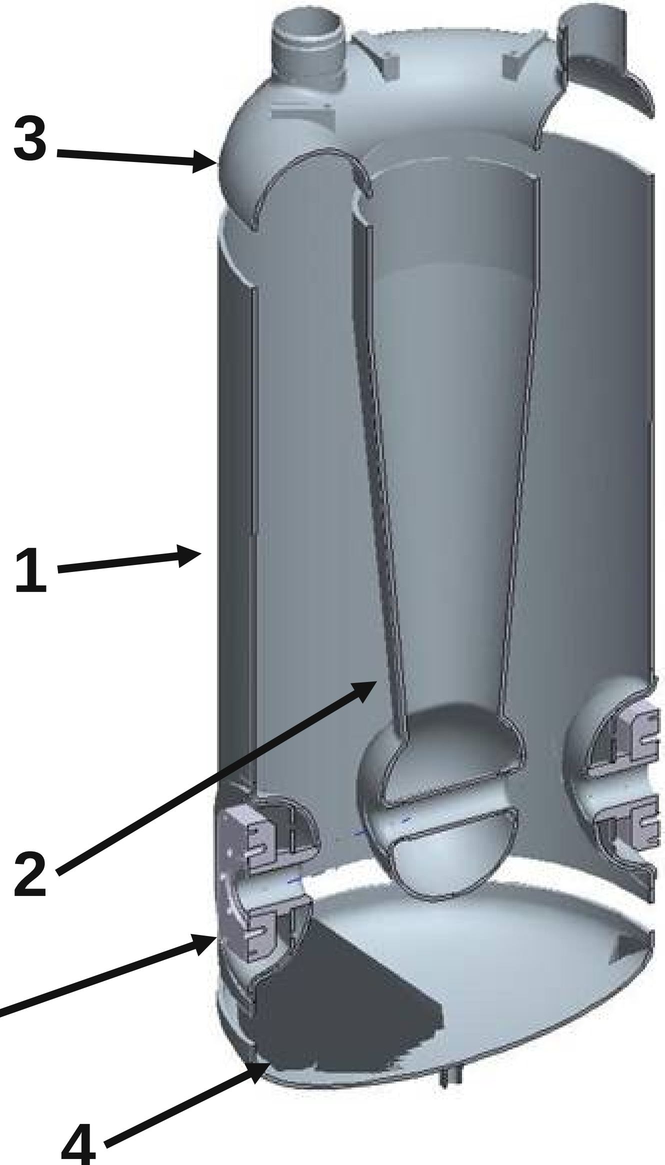
- High RRR Niobium (RRR=250)
- No demountable joints
- Jacketed in a SS vessel
- Electron beam welded
- Electro-polished interior surface
- High pressure water rinse
- Ultra-clean room assembly techniques

Construction Tuning Process

How to go from this → to this - and achieve the proper eigenfrequency at 4.5K

QWR niobium – 4 main subassemblies:

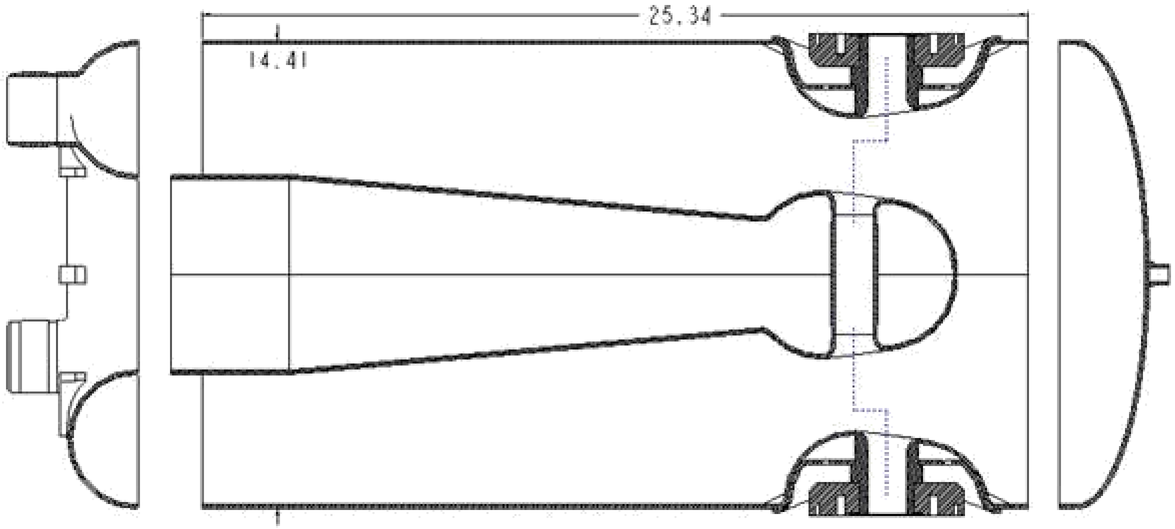
- Smaller parts are electron beam welded into 4 main subassemblies:
  - 1.) Housing with beam ports (including Nb-to-SS brazed transitions for attaching SS tank)
  - 2.) Center conductor
  - 3.) Upper (toroid) end
  - 4.) Lower (dome) end
- Parts are rolled or hydro-formed, machined, and EB welded
- Nb purity is vital – inclusions or (ultimately) any surface contaminants destroy performance



Rectangular SS flange brazed to Nb tube (QTY 2)

Frequency depends on housing & center conductor length

- Housing and center conductor are presently over-long:
  - 7/8” excess on upper (left) end
  - 1-3/4” excess on lower (right) end
- Drawing below shows nominal finished dims
- Actual final dimensions are cut to bring the cavity on frequency
- Some trimming of the toroid and dome ends also take place to ensure that the edges are squared, but our discussion will focus on the housing and center conductor



Development Parameters

Master Oscillator Frequency (for *B* =.15c)	**109125**	*kHz*
Slow Tuner Half-range	+20	*kHz*
1-shot press tuning	+/-20	*kHz*
∆Freq / ∆Length(center conductor)	-132	*kHz/mm*
∆Freq / ∆Length(distance to dome)	30	*kHz/mm*
∆Freq / ∆EP(uniform)	282.8	*kHz/mm*
∆Freq / ∆EP(DT&Nose only)	1078.9	*kHz/mm*
∆Freq / ∆P(Helium Jacket)	-9	*kHz/atm*
∆Freq / ∆AIR (20C, 740 Torr, 40% Humid)	-34	*kHz*
∆Freq / ∆T(293k - 4k)	-156	*kHz*
∆Freq / ∆Indium wire .010" thk	-26	*kHz*

Working Backwards

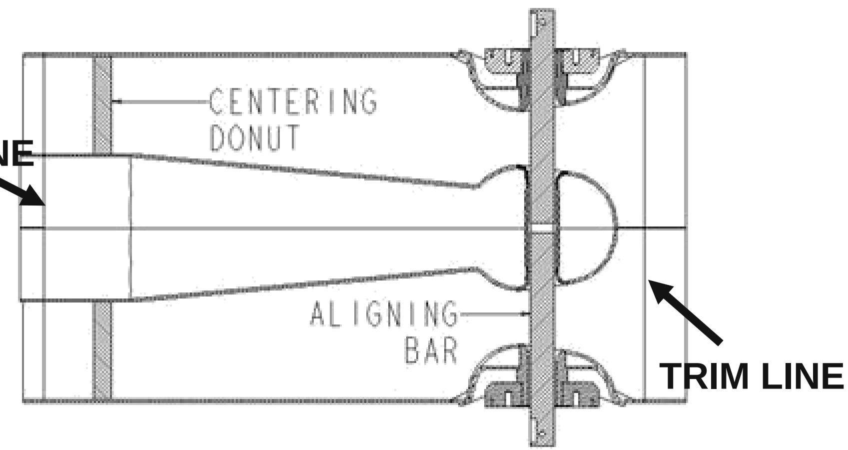
Master Oscillator Frequency (for β=.15c)	**109125**	*kHz*
Final cold frequency (4.3K) +*20 kHz for ½ Slow Tuner Range*	109145	*kHz*
At room temperature under vacuum	108989	*kHz*
Vented to air	108966	*kHz*
Before EP (125 microns base, 187 DT&Nose)	108728	*kHz*
Before welding (.58 mm shrink/weld)	108669	*kHz*
Clamp-up state (including .010 thick crushed Indium wire)	**108643**	*kHz*

Construction Tuning Process

- Clamp all parts together
  - Fixture required to align parts and hold together
  - Aluminum rings required to force parts into round and to help capture indium wire
- **Clamp-up state target frequency 108643 *kHz***
- Measure Frequency
- Using the numbers from the Development Parameters, calculate how much to trim housing and center conductor
- Transport to machine shop for EDM cutting
- NOTE: Indium wire was compressed in <u>ALL</u> of the joints. This is necessary too reduce joint losses at RF frequencies
  - The thickness of the indium had to be accounted for in the frequency calculations

Construction Tuning Process

- The dome and the toroid were only cut once to insure the faces were square
- The housing and center conductor are aligned and clamped at the beam port to insure the holes matched
- The shorted end of the center conductor was centered in the housing with an adjustable spider fixture
- A trim cut was made simultaneously on both the housing and the center conductor
  - ΔFreq / ΔLength(center conductor) -132 *kHz/mm*
  - ΔFreq / ΔLength(distance to dome) 30 *kHz/mm*



Construction Tuning Process

- Re-assemble cavity in the frequency measurement fixture (*with indium wire)*
- Measure the frequency to confirm initial trim calculations
- Calculate the amount of material to trim off
- EDM trim the housing and center conductor
- Done in small steps so as not to trim to short – *you can always cut shorter but it is difficult to add length once it is cut too short*
- Repeat process until the desired frequency is achieved
- Final Tuning processes are:
  – The proper amount of electropolishing
  – Electron Beam Welding
  – AND ………..

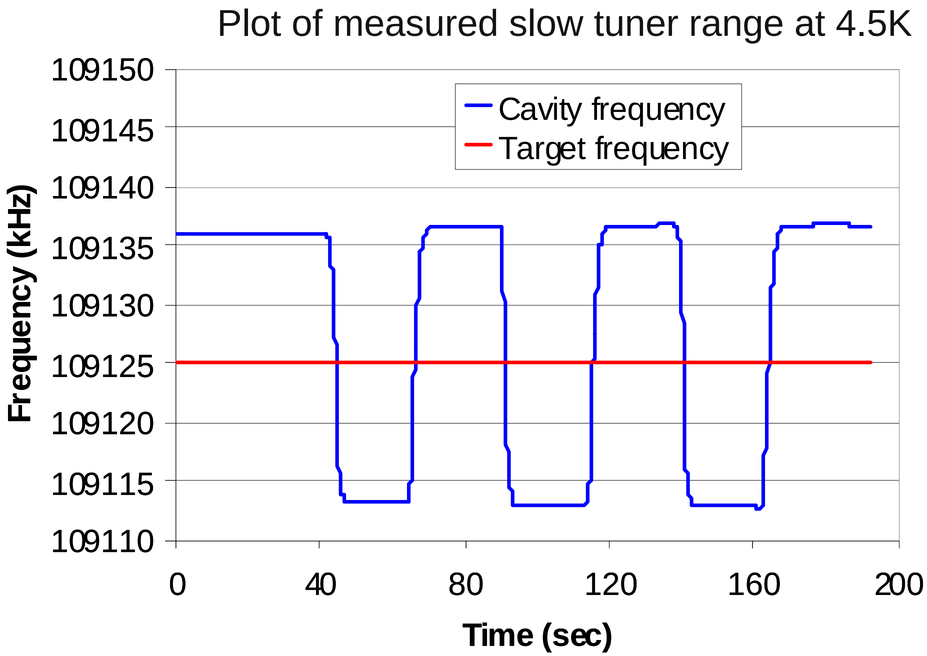
The Final (limited) Tuning Adjustment

- Squeezing or stretching the cavity with hydraulic jacks
  - Limited to ~20 kHz

The Tuning Results for Seven Cavities

	293K	4.5K
1 *	**109016.0**	**109165.9**
2	**108953.1**	**109137.0**
3	**108952.0**	**109137.7**
4	**108952.5**	**109142.9**
5	**108954.6**	**109137.2**
6	**108952.0**	**109136.3**
7	**108955.1**	**109140.8**

Cavity Frequencies: Target frequency (cold) is 109135 kHz

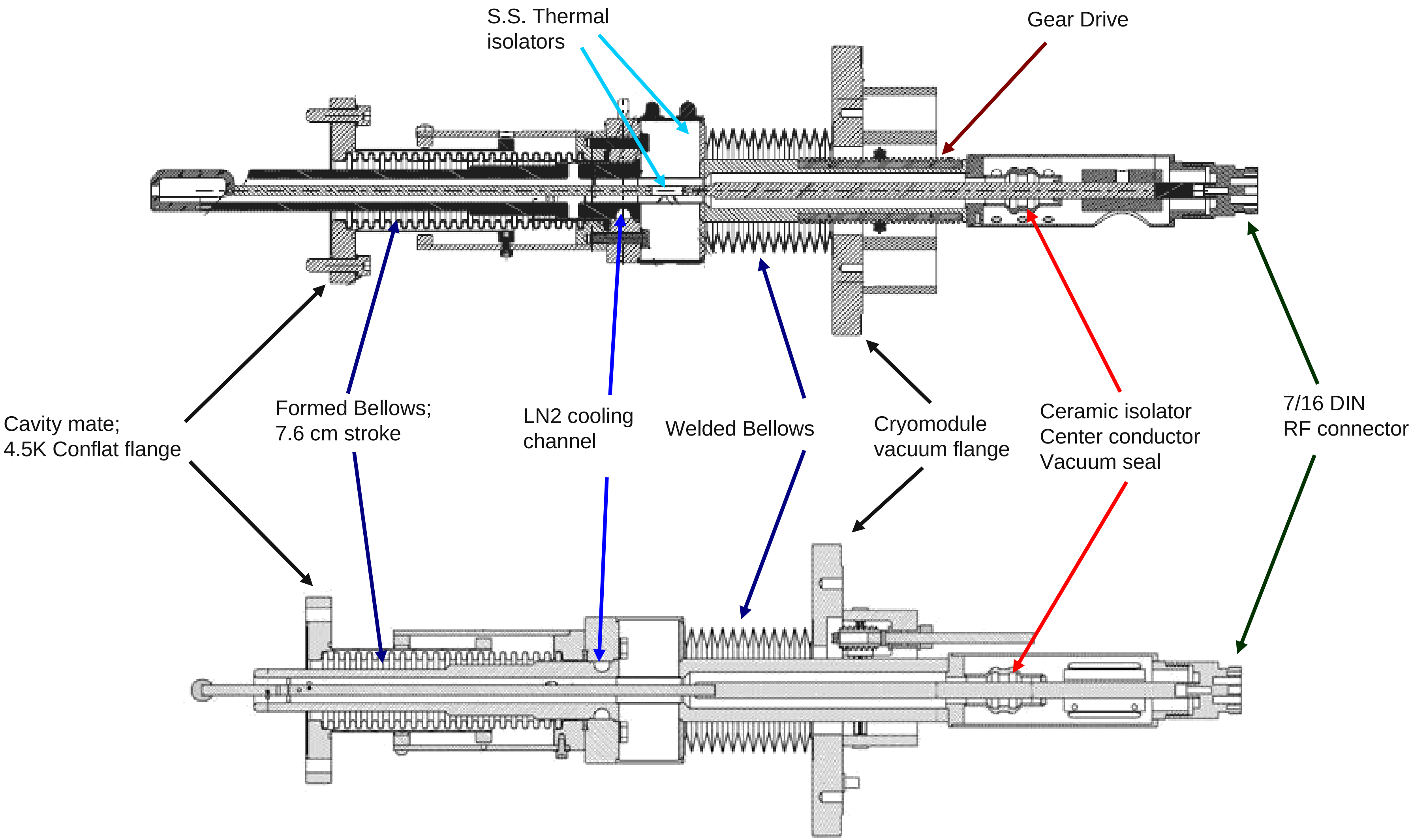


* Different cavity design

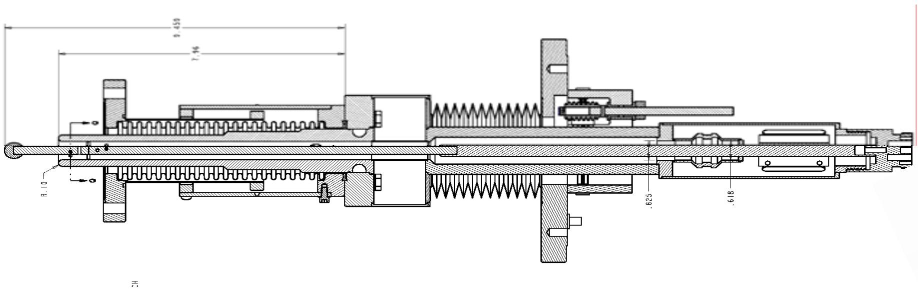
Variable RF Power Coupler

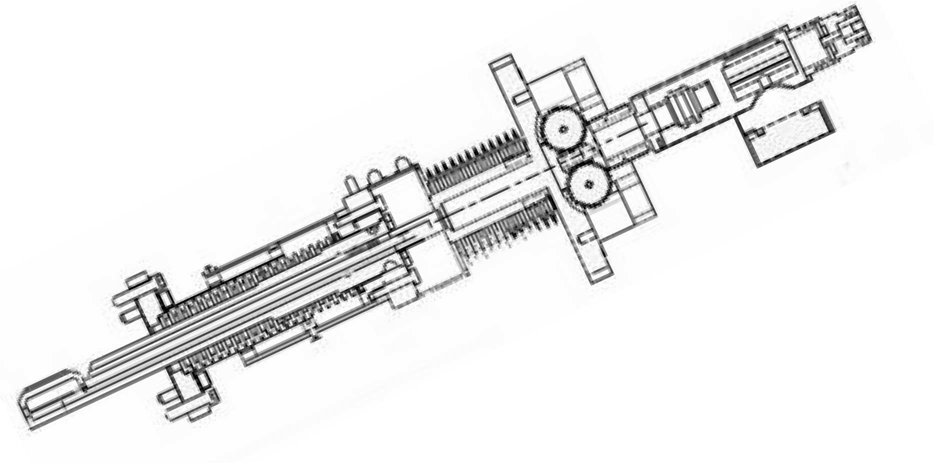
- As development work for the Facility for Rare Isotope Beams (FRIB) two types of RF Power Couplers were designed, constructed and tested
  - An Inductive RF power coupler for magnetic field coupling
  - A Capacitive RF power coupler for electric field coupling
- Three inches of stroke
- Vacuum break at room temperature
- Liquid nitrogen cooled
- Stepper motor actuator outside of cryostat at room temperature
- Tested up to 600 Watts

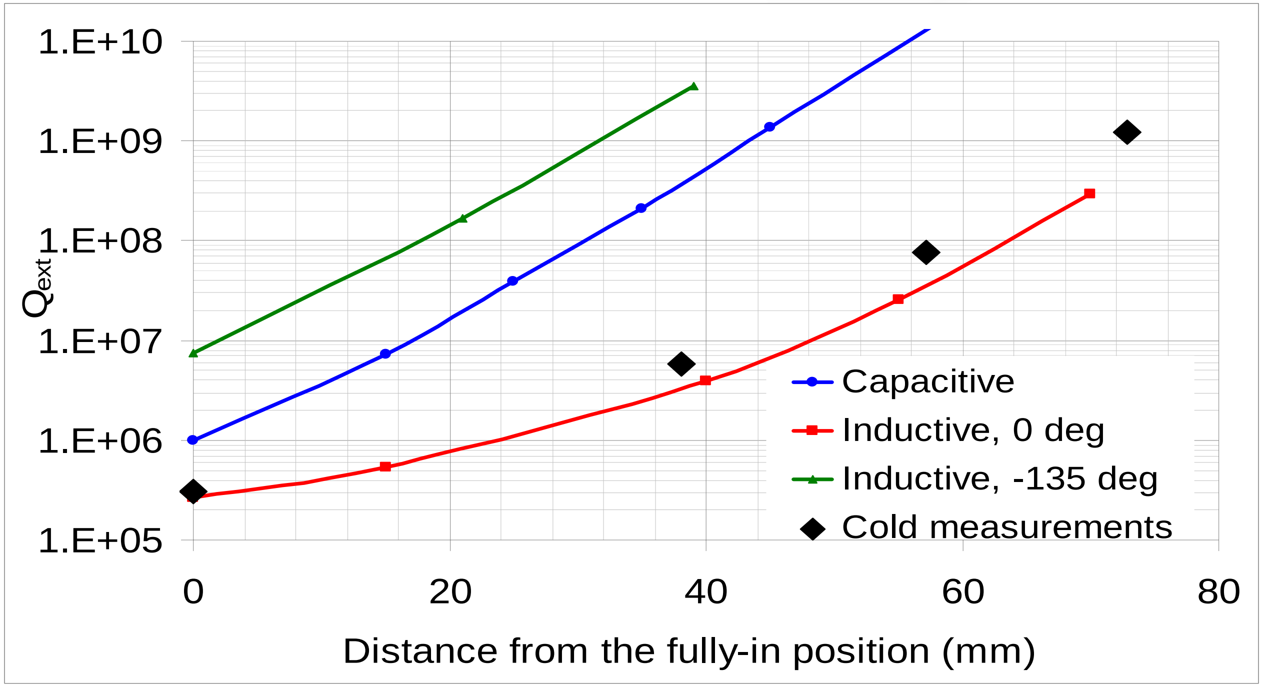
Variable RF Power Couplers



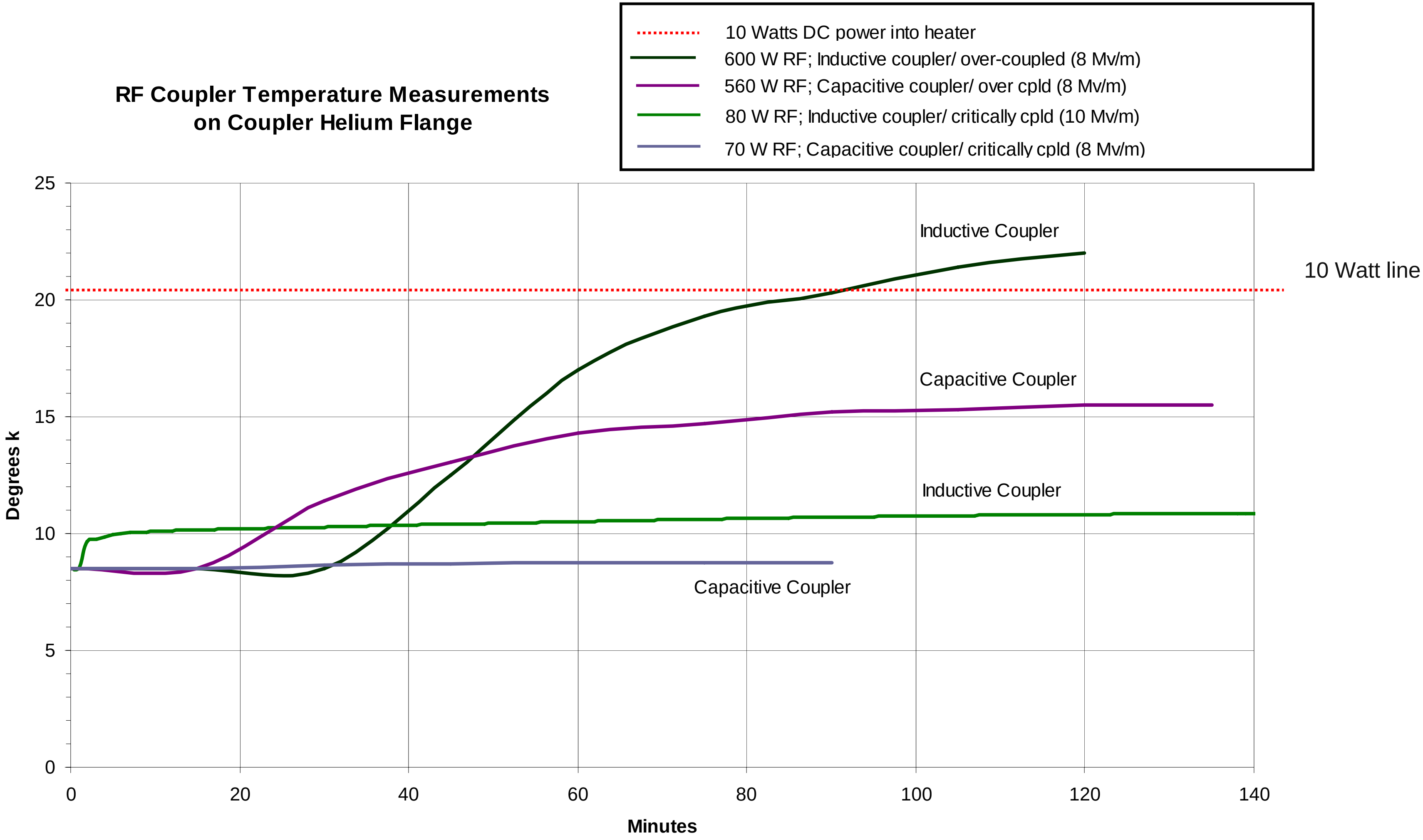
RF Power Coupler Design





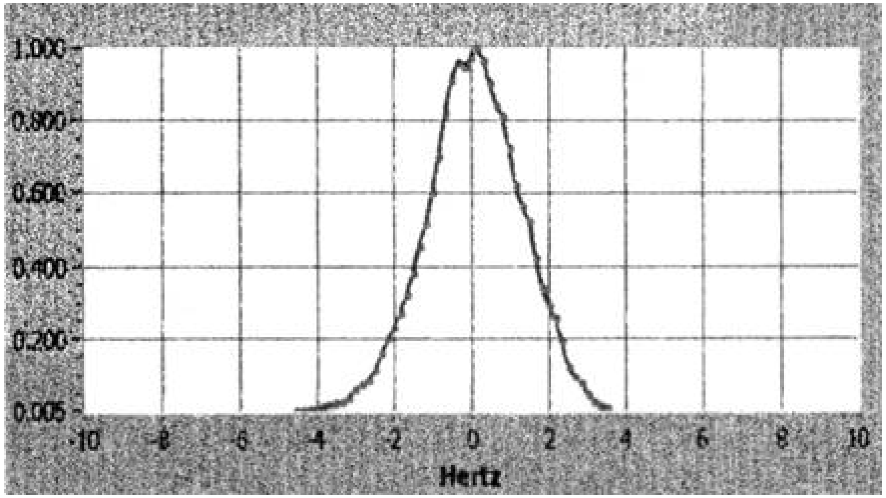


Thermometry Data on the Capacitive and Inductive RF Couplers

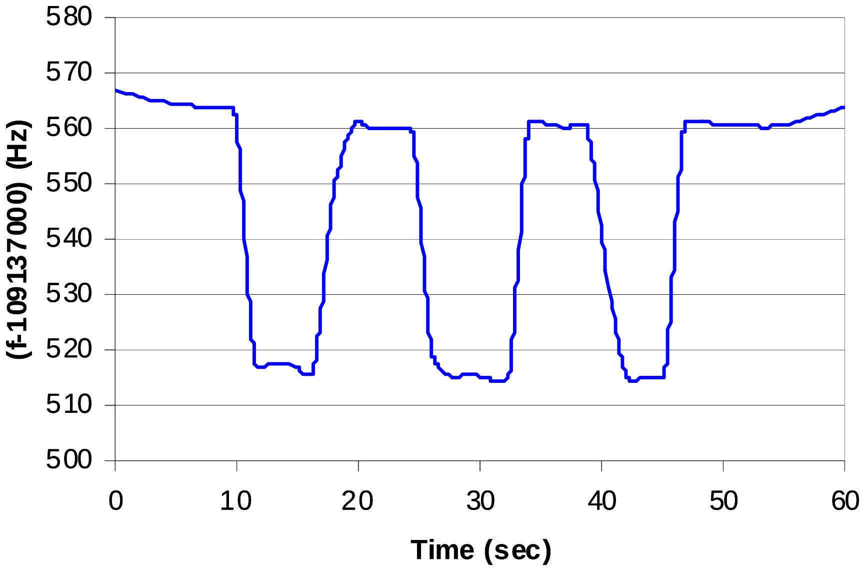


Cold Results in the Final Cryomodule Assembly

- We measured the microphonics of each cavity while connected to the cryogenic system; largest excursion is about +/- 4 to 6 Hz
- The fast tuner window is capable of compensating for frequency deviations from microphonics up to ~40 to 45 Hz



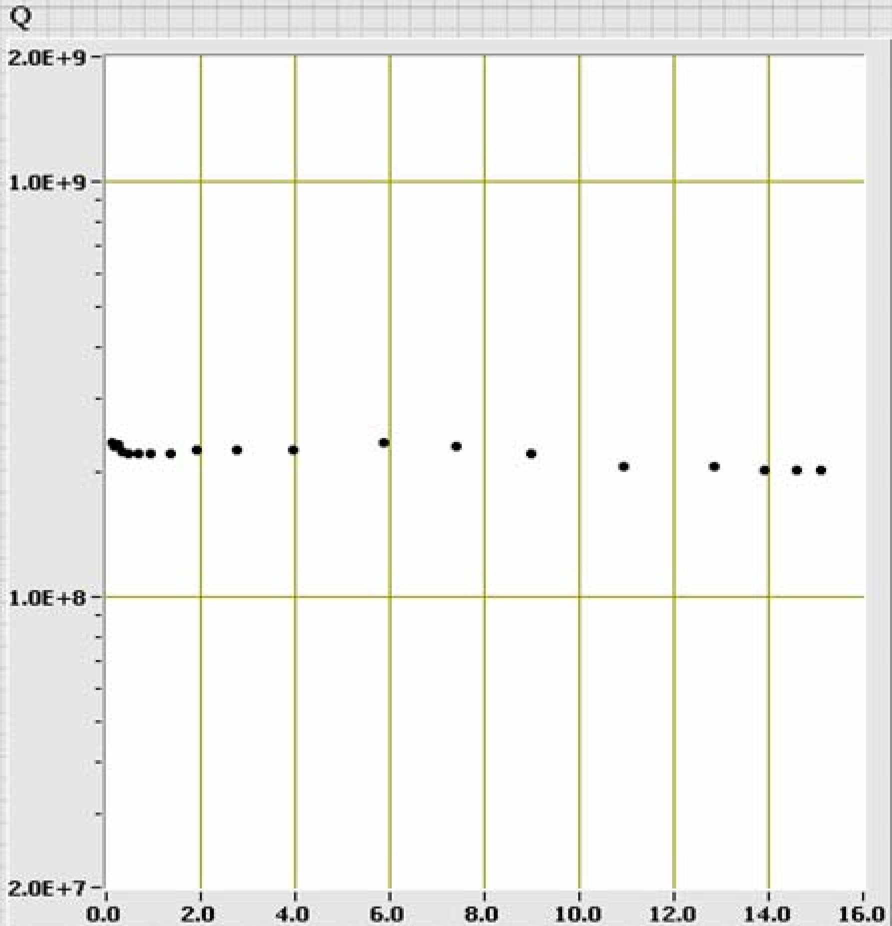
Measured frequency deviation on one cavity in cryomodule at 4.5K



Typical fast tuner window ~45 Hz

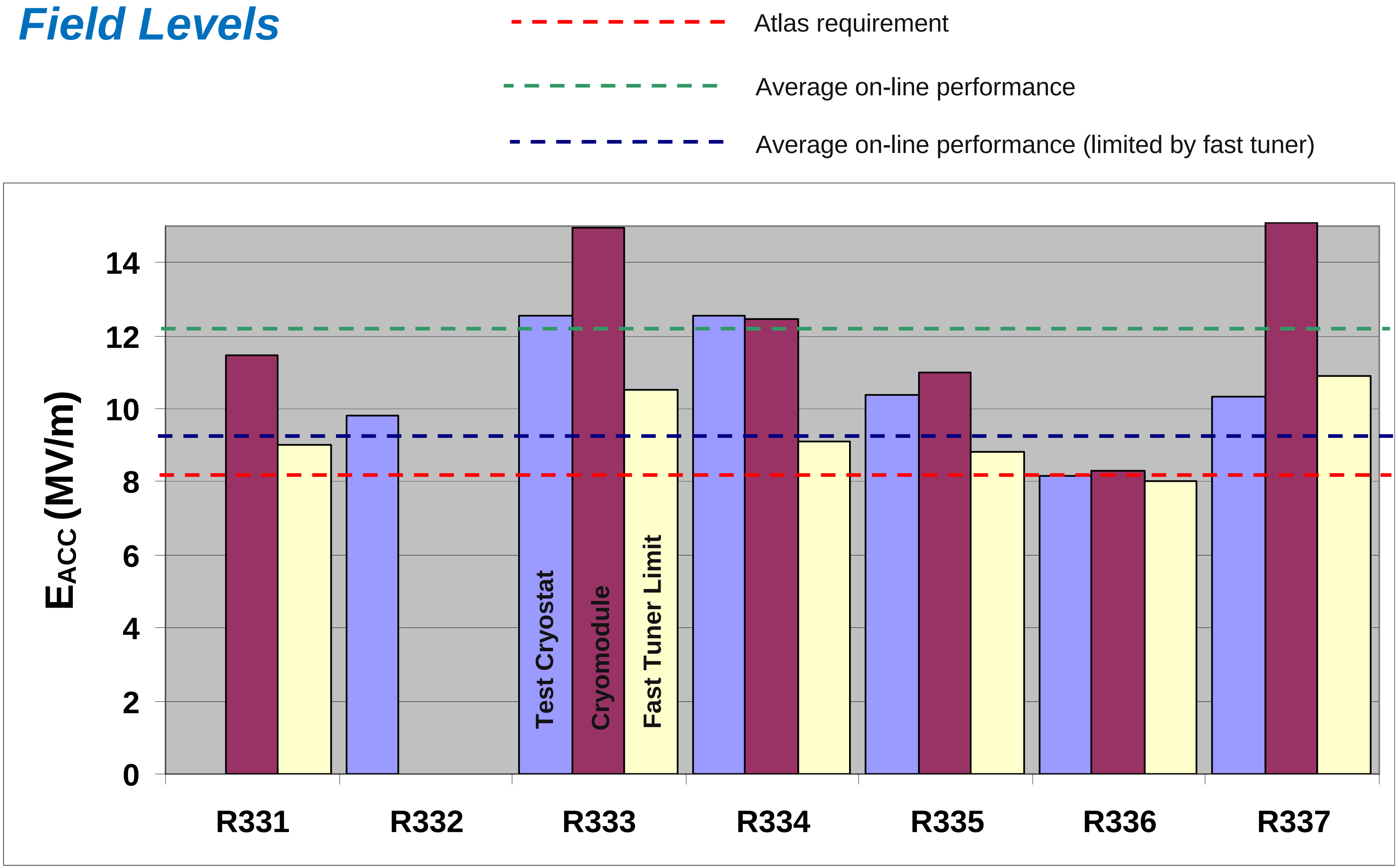
Q Curve (of course the best) for a Cavity in the Cryomodule

Vsig	Vin	Pin	Ea	Q
23.40	24.00	0.01	0.12	2.36E+8
26.60	27.00	0.01	0.17	2.30E+8
29.60	29.80	0.03	0.24	2.34E+8
32.60	32.90	0.06	0.34	2.24E+8
35.60	35.90	0.12	0.48	2.22E+8
38.60	38.90	0.24	0.67	2.22E+8
41.60	41.90	0.48	0.95	2.21E+8
44.60	44.90	0.96	1.35	2.21E+8
47.60	47.80	1.87	1.90	2.26E+8
50.80	51.00	3.90	2.75	2.26E+8
54.00	54.20	8.15	3.97	2.26E+8
57.40	57.40	17.02	5.87	2.36E+8
59.40	59.50	27.60	7.40	2.31E+8
61.10	61.40	42.76	8.99	2.21E+8
62.80	63.40	67.76	10.94	2.06E+8
64.20	64.80	93.54	12.85	2.06E+8
64.90	65.60	112.46	13.93	2.01E+8
65.30	66.00	123.31	14.59	2.01E+8
65.60	66.30	132.13	15.10	2.01E+8
0.00	0.00	0.00	0.01	-7.56E+6
0.00	0.00	0.00	0.00	6.79E+8
0.00	0.00	0.00	0.00	6.79E+8



Vin0	Vsig0	Stored Energy (J)	Frequency (Hz)	date	time
45.09	42.02	0.1700	109137855.00	5/15/2009	4:00 PM

Field Levels



Conclusions

- The development parameters used to calculate all of the effects of the different processes performed on the cavity were correct
  - The first cavity that was trimmed to size was trimmed over several iterations
  - The remaining cavities were trimmed in two steps
  - All cavity cold frequencies were exactly on target

- Both RF power couplers performed well
  - The capacitive coupler is clearly the design to use on the quarter wave cavity where the coupling port is in an electric field region
  - Although the inductive coupler is in an electric field region , the design works well enough to use on the quarter wave cavity

- The slow tuners all functioned as expected and the Master Oscillator frequency was in the middle of the slow tuner range

- We measured the microphonics on all of the cavities and the fast tuner and slow tuner ranges are more that adequate to phase lock the cavities

- The design goal field level was 8 MV/m; the average operating field on the tested cavities is 9.25 MV/m (limited by fast tuner performance)