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W. Xu

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Electron-Ion Collider

Brookhaven National Laboratory

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Evaluation of baseline 5-cell cavity for EIC RCS, HSR and SHC ERL

Wencan Xu, Jiquan Guo, R. Rimmer, A. Zaltsman, K. Smith, E. Daly

Abstract

This note is to record survey results of SRF requirements for EIC RCS, HSR and SHC ERL, and evaluate applicability of the baseline cavity for these systems.

I. Summary of survey results

The survey of SRF requirement was carried out by querying system experts (Vahid and Mike for RCS and HSR, Erdong for ERL), and the following table summarizes the requirements of each system that impact the cavity design. This table sets the evaluation criteria of applicability of a cavity design for each system.

Table I. Requirement of the 5-cell SRF cavity in each system

Parameters	RCS	HSR	ERL
Nominal frequency (MHz)	591.14924	591.1492	591.1492
Tuning range	+/- 1.5 frev	+/- 1.5 frev	Not a concern.
Cavity voltage [MV]	20	20	20
Number of cavities	3	1	10
Max. RF power [kW]	65	75	75
Longitudinal impedance threshold	159 KOhm (< 1GHz) and 160 kOhm-GHz (> 1GHz) (cir def.)	150 Kohm(cir def.) @600 MHz, store.	Need a spec but not a concern.
Transversal impedance threshold	12 Mohm/m	2.5 Mohm/m	1 Mohm/m (cir Def.)
Same passband mode	159 KOhm (< 1GHz)	< 300 KOhm, Ramping.	Need a spec but not a concern.
Space	Not a concern	Not a concern	Not a concern but cost saving.

Note: 1. the RCS longitudinal impedance threshold is based on merging at 400 MeV; 2. ERL transversal impedance threshold is based on conservative estimation.

II. Baseline cavity

The baseline cavity in EIC CDR was a scaled version of 650 MHz 5-cell cavity, which was optimized for high current ERL (6 pass 50 mA ERL). Detailed RF design, engineering design and preliminary test results of 650 MHz 5-cell cavity can be found in published references. Figure 1 shows the cavity model. Figures 2 and 3 show the transversal and longitudinal impedance. Table II listed the same passband modes in the 5-cell cavity, which have highest longitudinal impedance. Figure 4 shows the mechanical model of the 650 MHz cavity, and its mechanical properties are shown in Table III.

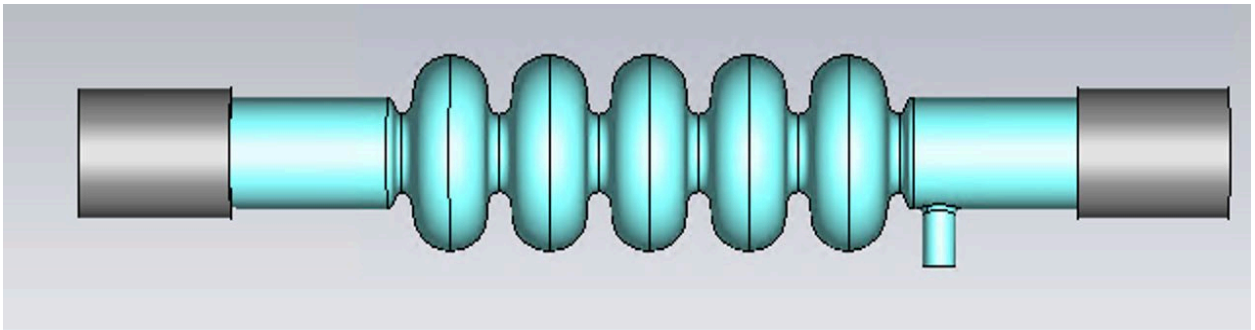

Figure 1. Scaled 591 MHz 5-cell Cavity.

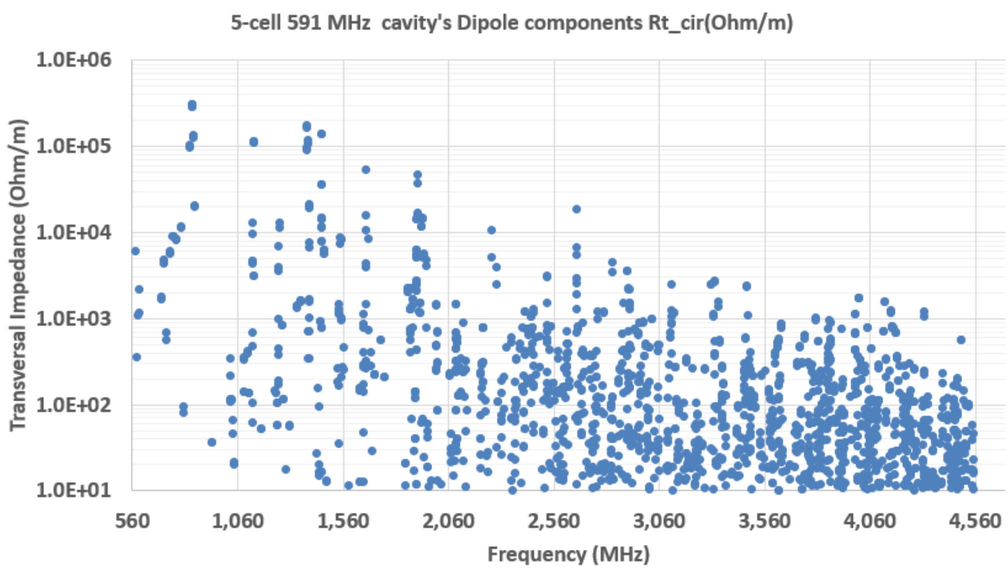

Figure 2. Transversal impedance

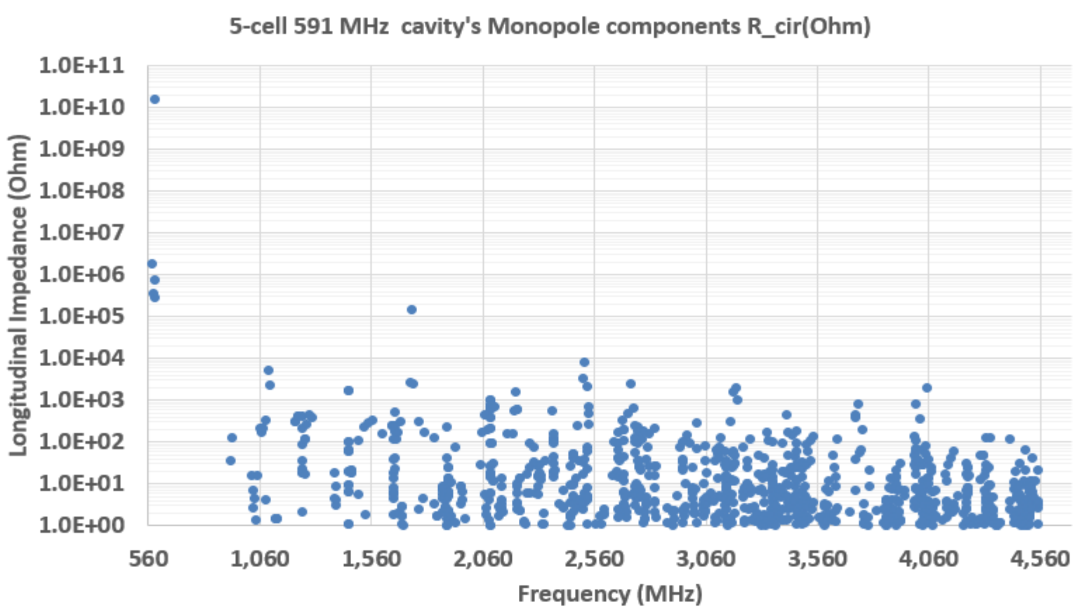

Figure 3. Longitudinal impedance

Table II. scaled 5-cell cavity same passband mode.

Freq (MHz)	R/Q(Ohm) (Cir def.)	Impedance (Ohm)	Comment
576	4.35E-03	1.83e06	Pi/5
580	3.38E-03	3.68e05	2pi/5
585	1.39E-02	7.39e05	3pi/5
589	7.58E-03	2.76e05	4pi/5
591	2.52E+02	1.63e10	Pi

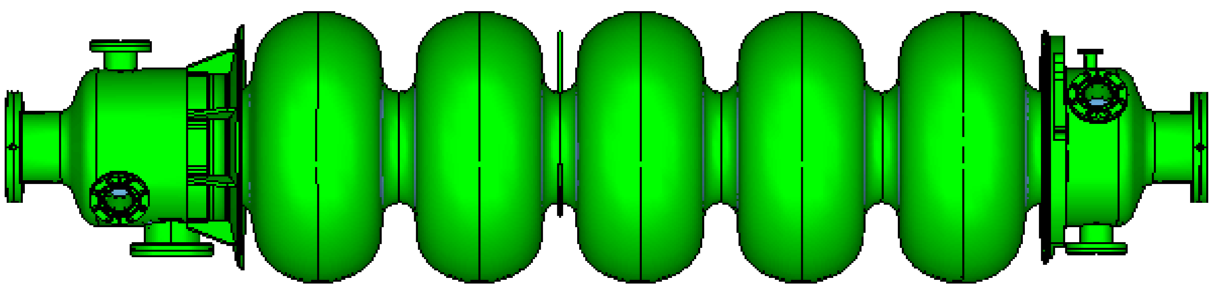

Figure 4. Mechanical model of the 650 MHz cavity.

Table III. 5-cell cavity mechanical properties.

Cavity mechanical properties*	Results
Wall thickness	4.4 mm
Tuning range	+/- 174 kHz
Tuning range	+/- 2mm
Tuning load	533 lb/mm
First mode freq.	107 Hz
Lorentz detuning factor (591MHz)	0.77 Hz/(MV)^2

*Note: Except for Lorentz detuning factor, the rest of the mechanical data was for 650 MHz, which is believed to have similar results for the scaled 591 MHz cavity.

III. Applicable for RCS

1. Mechanical properties satisfy RCS requirements.
2. Transversal impedance of the baseline cavity satisfies RCS requirement.
3. Longitudinal impedance conditionally satisfies RCS requirements, with the either of two following conditions met.
    1) Merging electron bunches at 1 GeV instead of 400 MeV (see Figure 5.)
    2) An active beam damper is built.

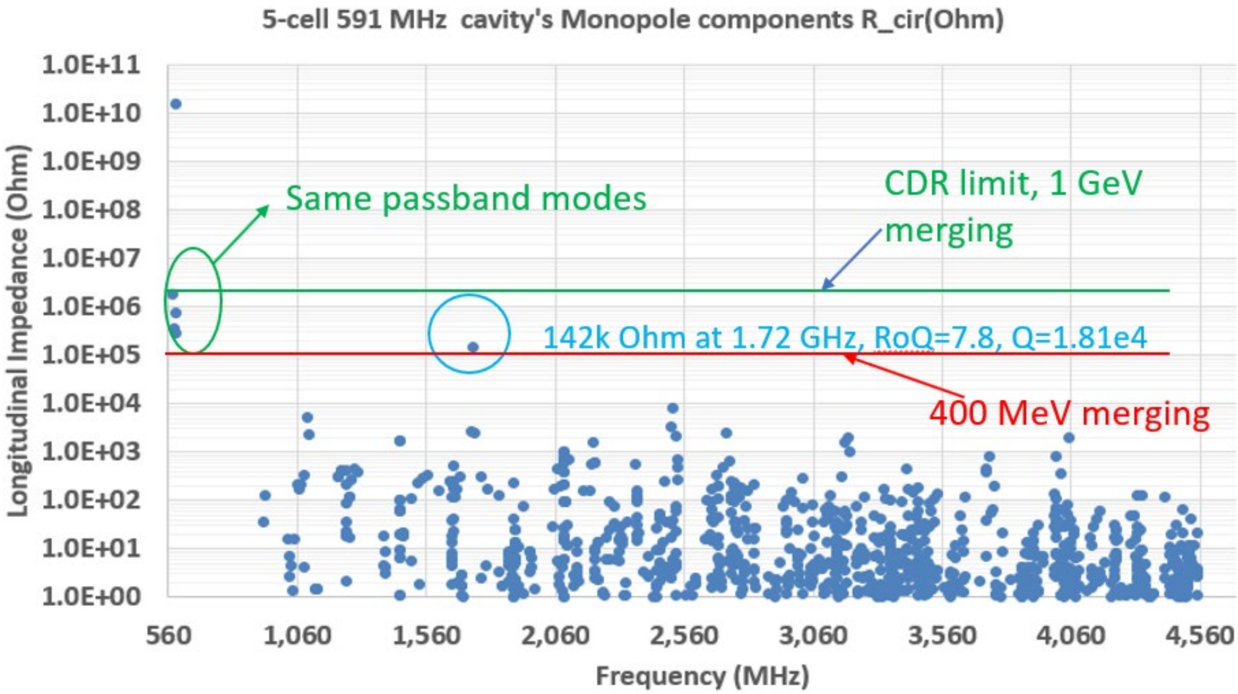

Figure 5. Merging energy in RCS affects impedance thresholds dramatically.

IV. Applicable for HSR

1. Mechanical properties satisfy HSR requirements.
2. Transversal impedance of the baseline cavity satisfies HSR requirement.
3. **3.** Longitudinal impedance doesn't satisfy HSR requirements, see Figure 6. As energy ramping sweeps frequency as large as 3 MHz, the fundamental passband modes will overlap with integer revolution frequency, and thus cause beam instability. Several fallback plan options were considered.
    1) Application of fundamental passband damper. However, it is impossible to damp all 5 modes with one damper due to drastic varies of each mode's field profile.
    2) Ferroelectric tuner for fast frequency jump. This is extremely challenging as well because preliminary results show that it requires up to 800 kHz of tuning for the cavity).
    3) RF Feedback to reduce impedance. This is impractical for a 5-cell because of complexity of RF systems (5 RF systems feeding on one cavity through 5 RF coupling ports.) However, feedback will work when the cavity's number of cell is

reduced from 5 cells down to 2 cells. More detail is described in the fallback plan section.

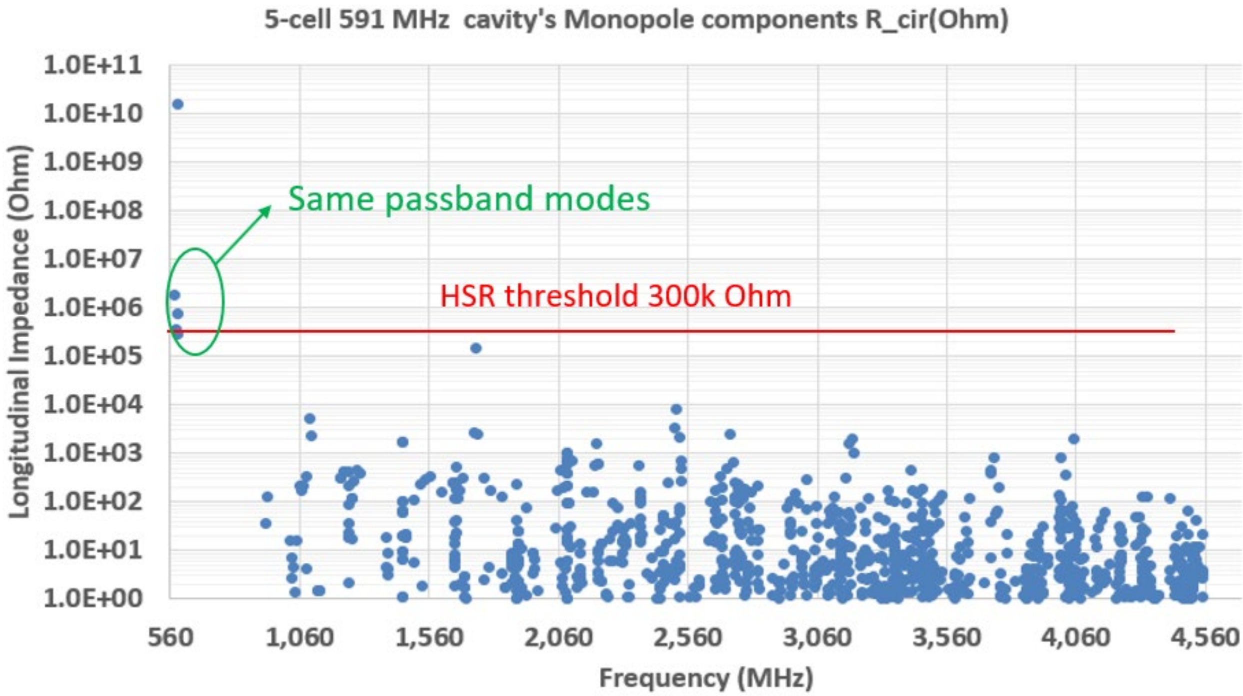

Figure 6. Longitudinal impedance threshold for HSR

V. Applicable for ERL

1. Mechanical properties satisfy ERL requirements.
2. Transversal impedance of the baseline cavity satisfies ERL requirement.
3. Longitudinal impedance satisfies ERL requirements.

Figure 7 shows the BBU simulation results done by Nickolas Taylor from Xelera. This simulation is a very conservative simulation with aligning all HOM with the same dipole angle and frequency spread of 1e-3. The results (in Figure 7) show that the minimum BBU threshold current will be 600 mA, which is 6 times higher than the requirement of 100 mA.

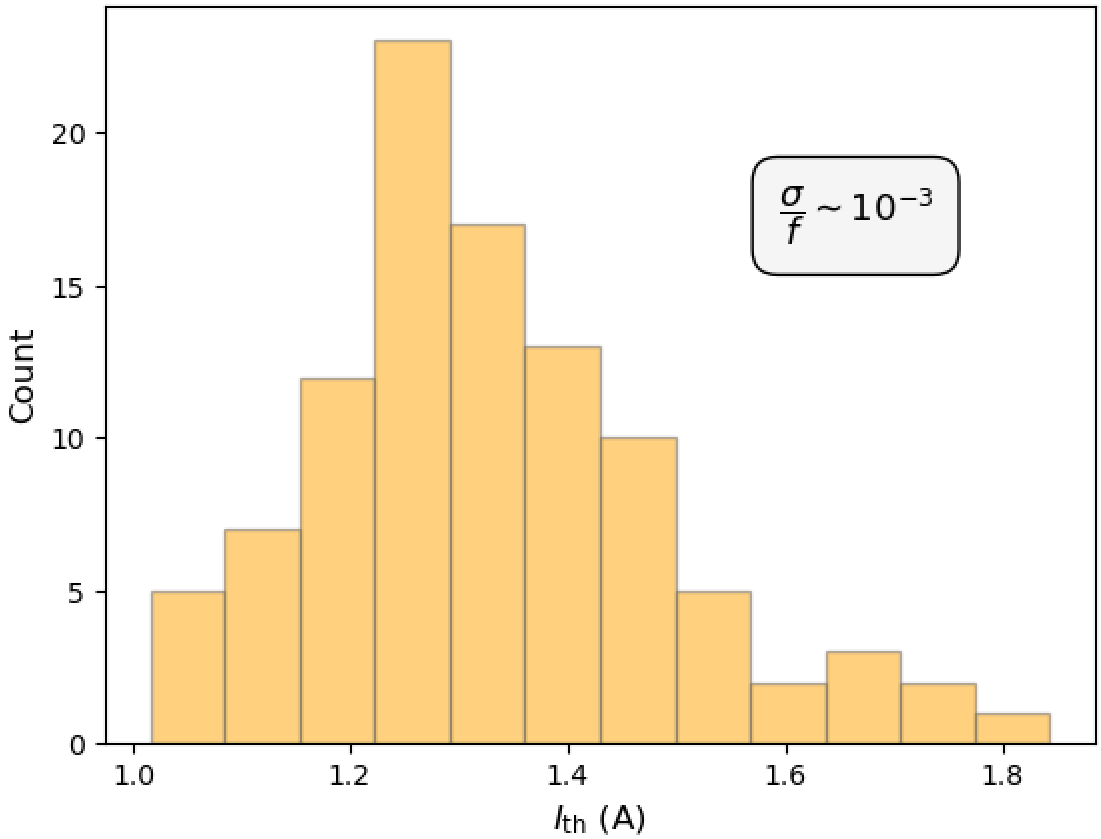

Figure 7. BBU Simulation results by Nicholas Taylor from Xelera.

VI. Fallback plan for HSR (and RCS if needed): RF Feedback on a 2-cell cavity.

A fallback plan for HSR SRF cavity is using three 2-cell cavities instead of one 5-cell cavity. Figure 8 shows a 2-cell cavity model using two end cells from the 5-cell cavity and its same passband modes are listed in Table IV. Here is a summary of findings.

1. Assuming open loop impedance of pi/2 mode is 10 MΩ, only 30 dB gain of feedback system will knock the impedance down to 300 kΩ. This is shown in Figure 9.
2. Figure 10 shows feedback on the fundamental mode, a 69 dB, 1 us delay of feedback system will bring the impedance from 1 GΩ to 360 kΩ, which is close to 300 kΩ. This can be done with direct feedback and comb filter.
3. Other benefits of using 2cell cavity for HSR include avoiding single point failure, avoiding complicate fundamental mode damper, et al.

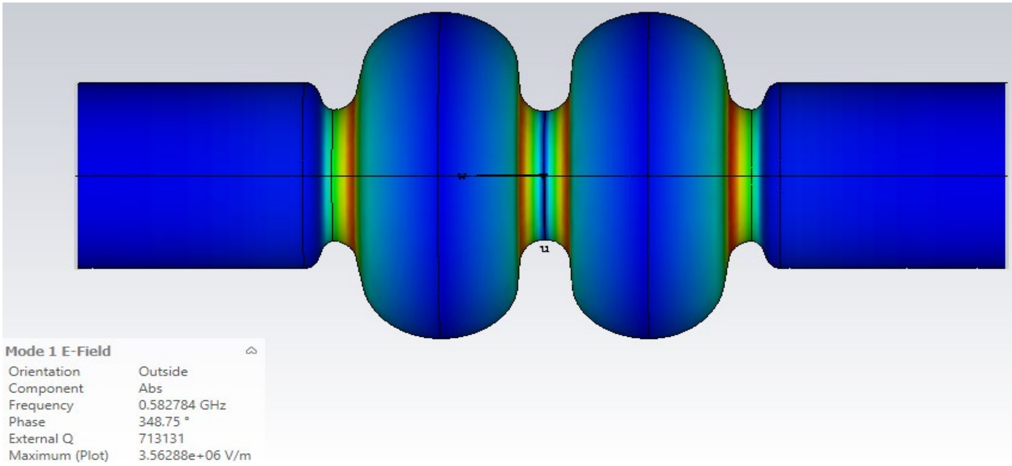

Figure 8. 2-cell cavity model

Table IV. 2-cell cavity's same passband mode.

Freq (MHz)	R/Q(Ohm) (Cir def.)	Comment
582.7	0.012	Pi/2
591	96	Pi

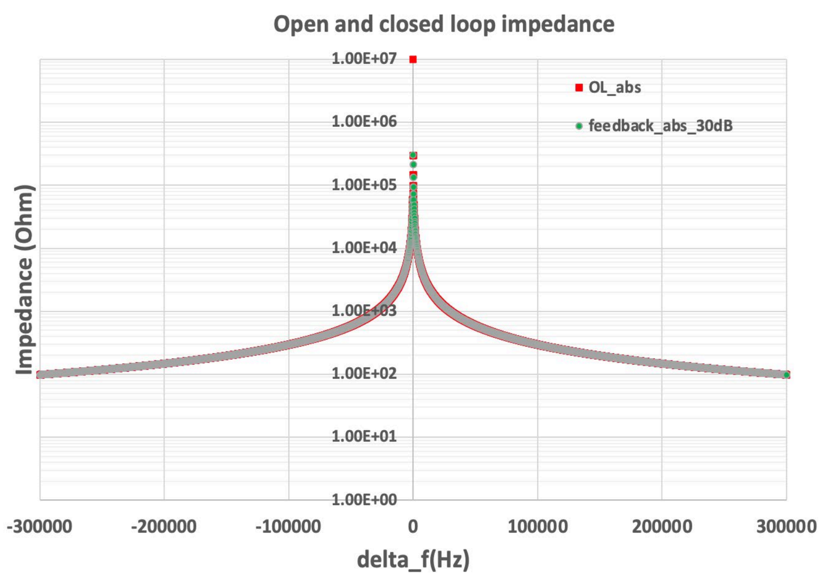

Figure 9. open and close loop of 2-cell cavity impedance.

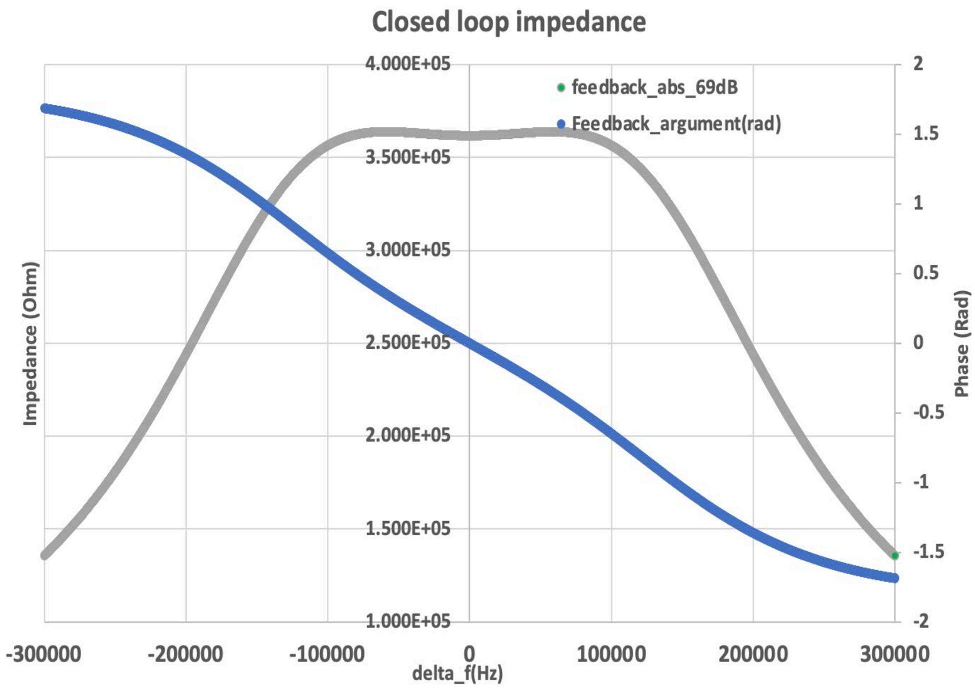

Figure 10. Open and close loop of 2-cell cavity's fundamental mode.

VII. Conclusion

The conclusion of applicability of baseline 5-cell cavity for RCS, HRS and ERL is listed in Table V.

Baseline 5-cell cavity	RCS	HSR	ERL
Transversal impedance	Yes	Yes	Yes
Longitudinal impedance	yes*	No for the same passband modes	Yes
Tuning range	Yes	Yes	Yes

* The condition is either of the following condition met: 1. Active beam damper; 2. Merge at 1 GeV

A fallback plan for HSR is using 2-cell cavity instead of 5-cell cavity. Then, a relatively simple solution (avoid fundamental damper) with application of RF feedback will satisfy HSR requirement. It is worth pointing out 1-cell cavity for HSR is applicable as well and we need to consider various aspects (cost, space, complexity, et al) for final decision.