A Ferroelectric Fast Reactive Tuner for Superconducting Cavities

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SRF, July 2019

Paper WETEB7

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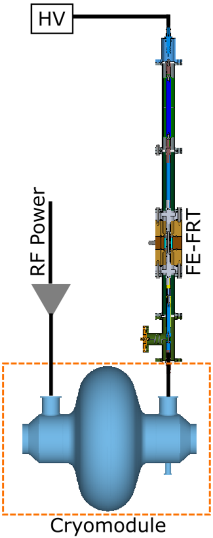
- Nb_3Sn/New Materials.

Thank you for Listening.

Any Questions?

Back Up Slides

How does it work?



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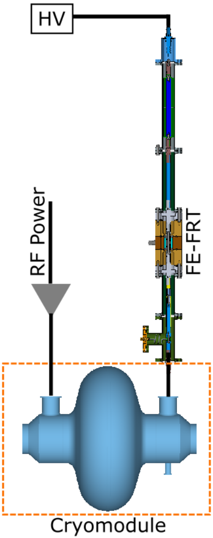

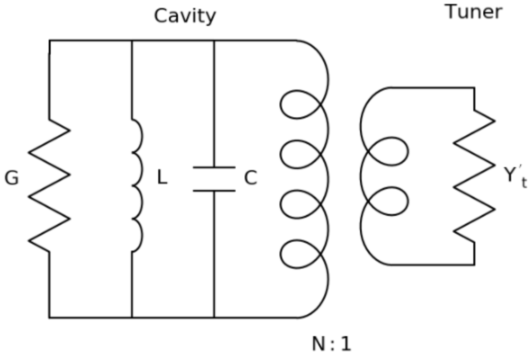

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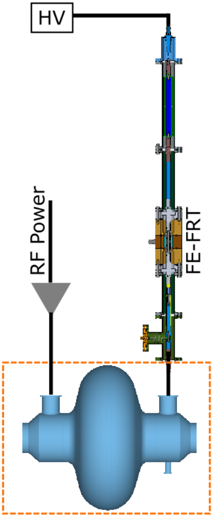

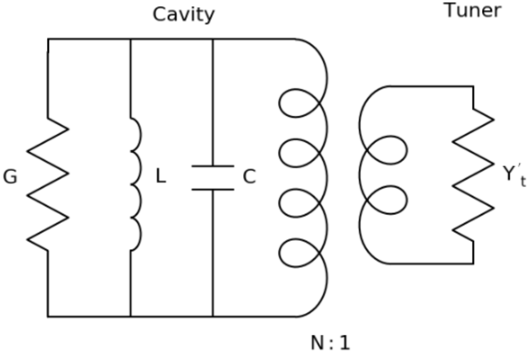

$$\Delta\omega_{12} = \frac{-\omega_0 \Delta B'_{t12} \, {}^{R}\!/_{Q}}{4N^2}$$

$$\Delta \mathrm{BW}_n = \frac{G'_{tn}}{N^2 C_c}$$

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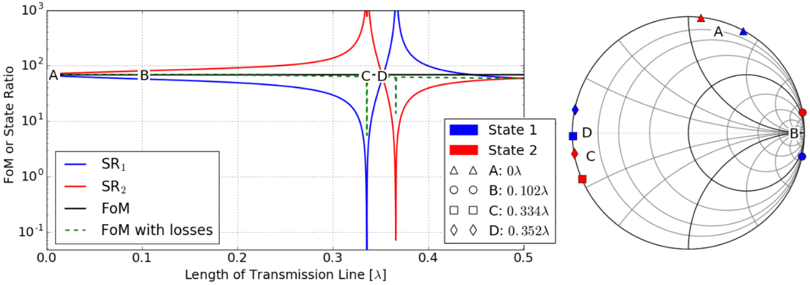

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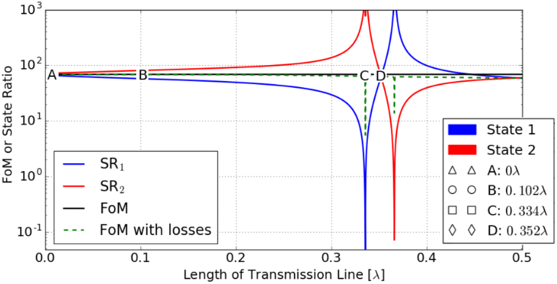

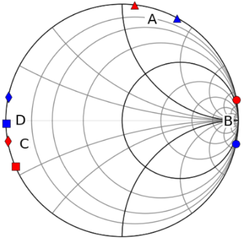

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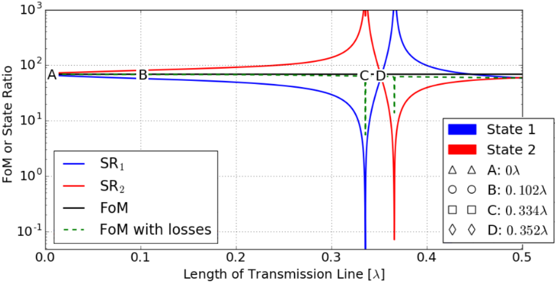

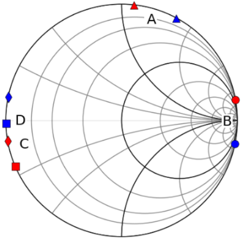

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$$\boxed{\textbf{FoM} = \frac{\text{Tuning Range}}{\text{Geometric Average of increase in BW}}}$$

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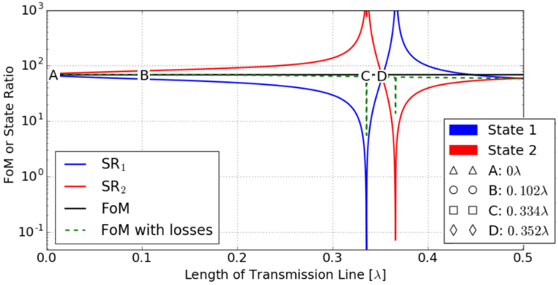

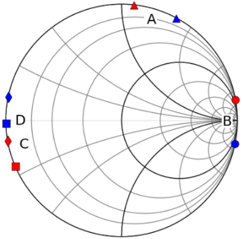

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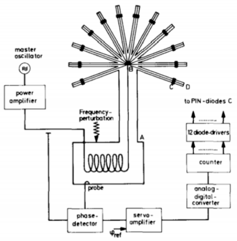
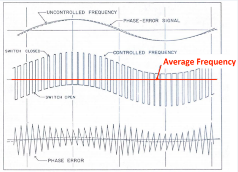
$$\boxed{\mathbf{FoM} = \frac{\boldsymbol{\Delta}\omega_{12}}{\sqrt{\boldsymbol{\Delta}\mathrm{BW}_1\boldsymbol{\Delta}\mathrm{BW}_2}} \approx \frac{2|\sin\frac{\Delta\theta_{12}}{2}|}{\sqrt{(1-|\Gamma_1|^2)(1-|\Gamma_2|^2)}}}$$

Other Reactive Tuners

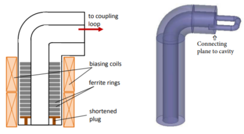
Pin Diode Tuners





O. Despe, K. Johnson and T. Khoe, *IEEE Trans. Nucl. Sci.*, vol. 20 (3), p. 71, Jun. 1973.
D. Schulze *et al.*, in *Proc. 1972 Proton Linear Accelerator Conference*, Los Alamos, NM, USA, October 1972, G01, pp. 156–162.

Ferrite Tuners



C. Vollinger and F. Caspers, "Ferrite-tuner Development for 80 MHz Single-Cell RF-Cavity Using Orthogonally Biased Garnets", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015.

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- So why hasn't this been done before?

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- Suitable material only recently developed.[2]

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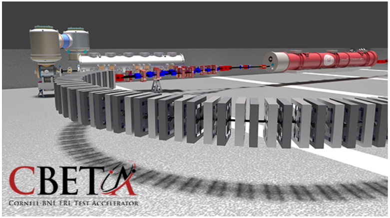
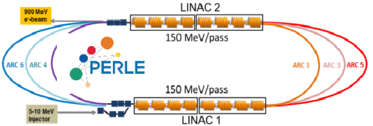
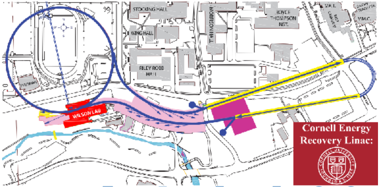
- Low beam loading machines







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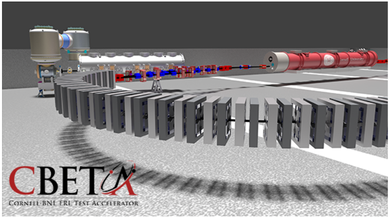

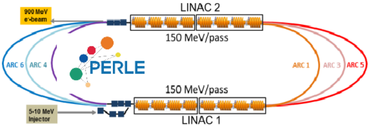

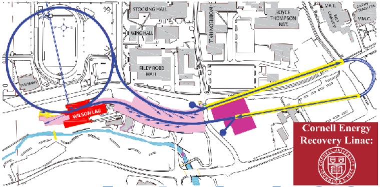

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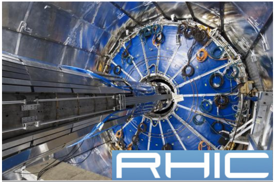

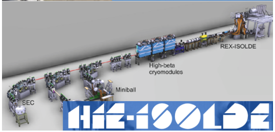

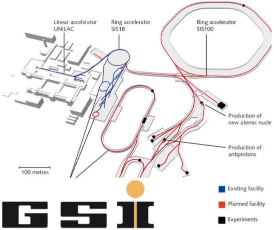

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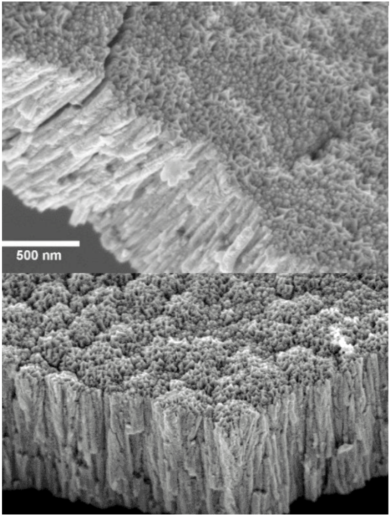

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- Where easy maintainability is a key concern

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U_c	$141\,\mathrm{J}$
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PERLE Case Study

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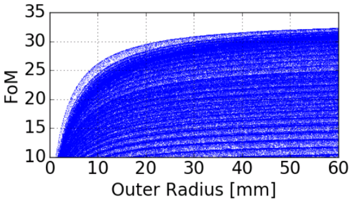
Monte Carlo method applied to FE-FRT Transmission Line Model for $801.58\,\mathrm{MHz}$.



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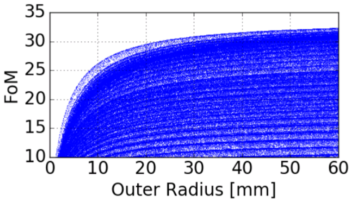

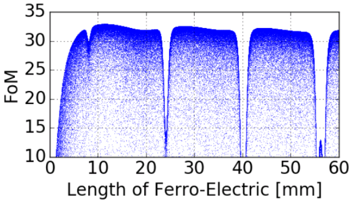

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$$P_{RF} = \frac{V_c^2}{4 R/_Q Q_L} \frac{\beta + 1}{\beta} \left[1 + \left(2 Q_L \frac{\Delta\omega_\mu}{\omega_0} \right)^2 \right]$$

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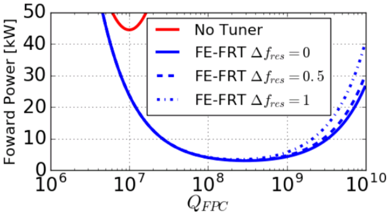

P_f vs Q_{FPC} for PERLE. Without tuner and with tuner.

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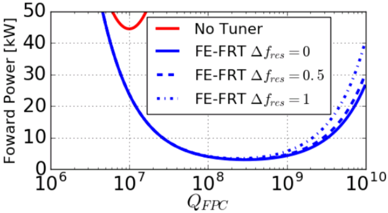

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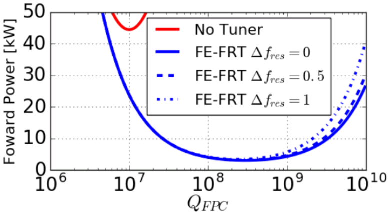

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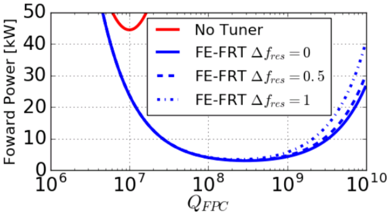

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- We can do even better at lower frequencies!

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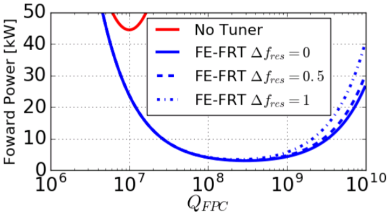

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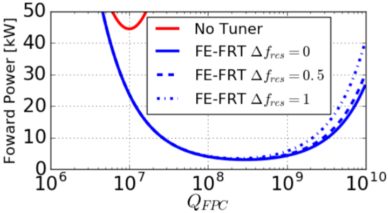
Table: FE-FRT properties for PERLE

Parameter	Value
FoM	30
Δf_t	80
Q_{FPC}	3×10^8
P_{RF}	$3\,\mathrm{kW}$
P_t	$2.4\,\mathrm{kW}$
Max. $\mathcal{P}_t$	$71\,\mathrm{kVar}$

- $\approx$ 15 fold reduction in RF power
- We can do even better at lower frequencies!
- $\alpha_d = 9.11 \times 10^{-8} f \sqrt{\epsilon_r} \tan\delta$

PERLE Case Study

$$P_{RF} = \frac{V_c^2}{4 R/_{Q} Q_L} \frac{\beta + 1}{\beta} \left[1 + \left(2 Q_L \frac{\Delta\omega_\mu}{\omega_0} \right)^2 \right]$$



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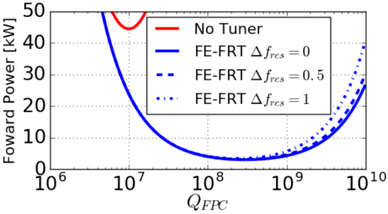

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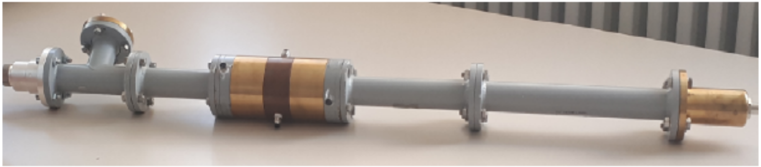
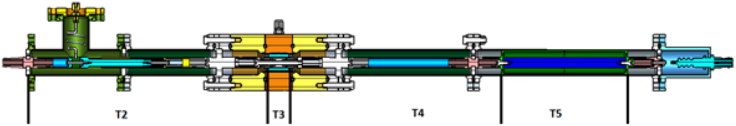
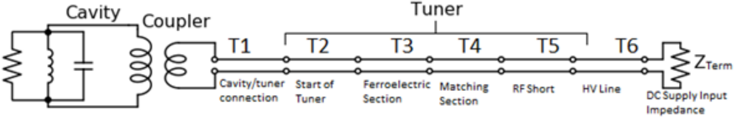
Prototype Tuner

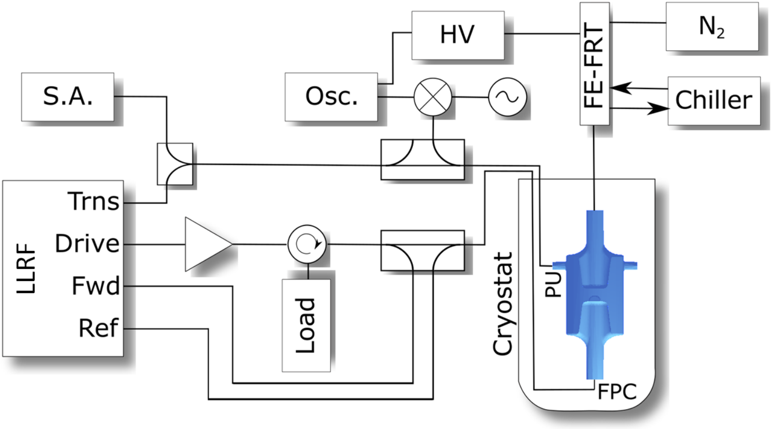






Prototype Tuner, 3D model and transmission line model.

Experimental Setup



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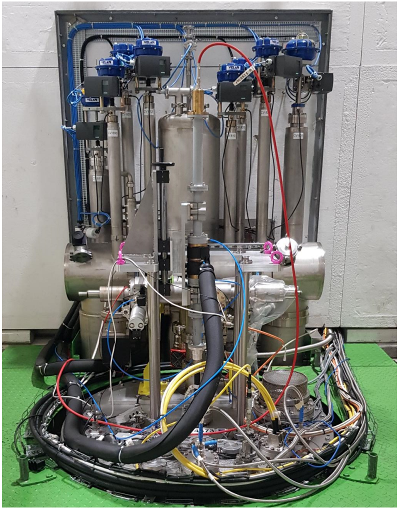

FE-FRT mounted on cryostat.

Cryostat insert.

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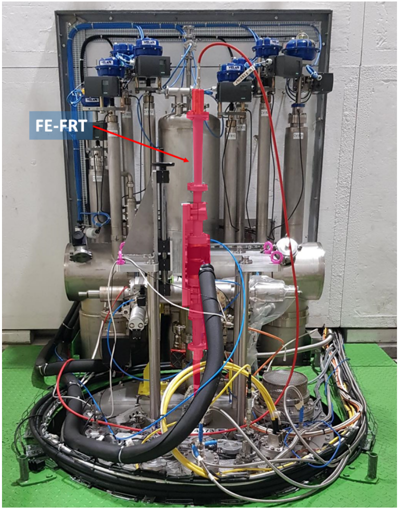

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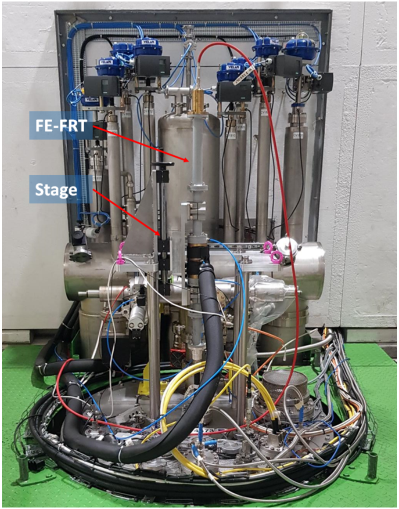

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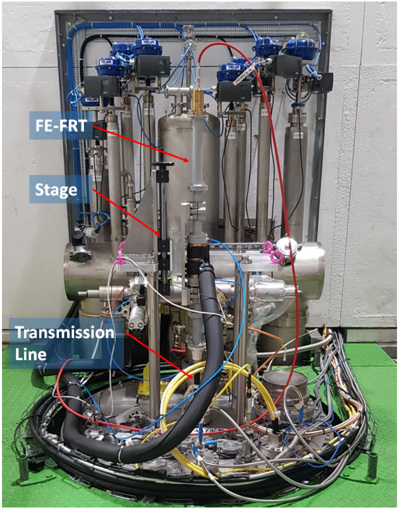

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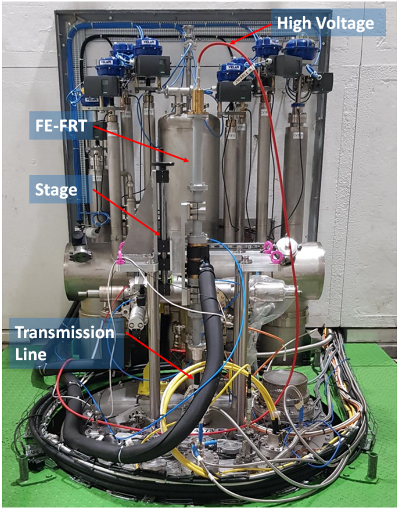

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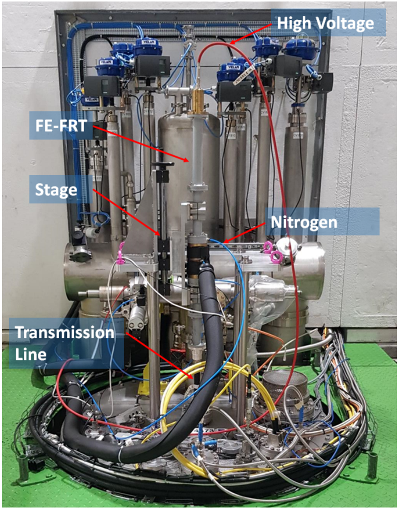

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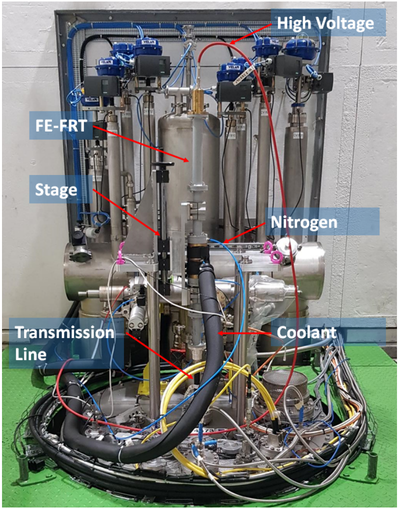

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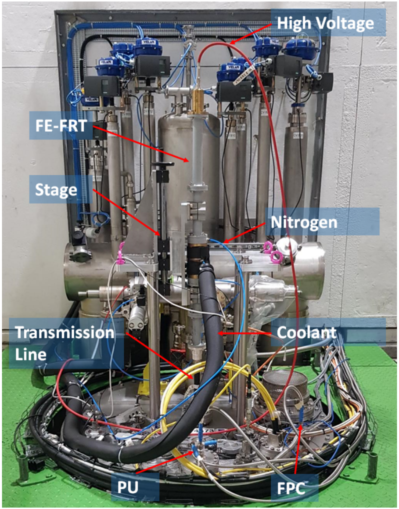

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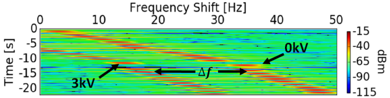
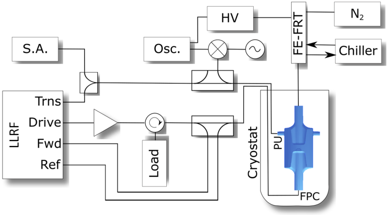
Demonstration of Frequency Tuning



Signal analyser measurement.



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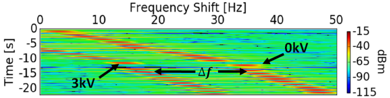

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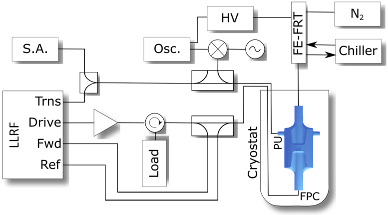

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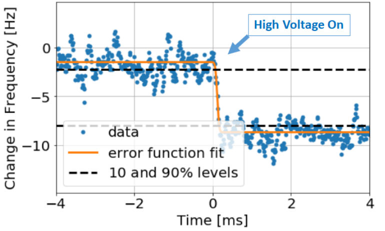
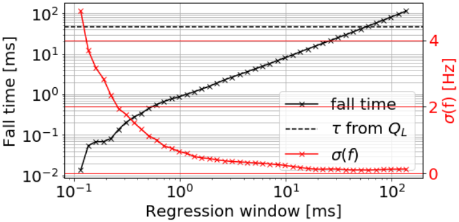


Frequency calculated from I and Q measurements.

Timescale of Frequency Shift



Fall time and $\mathrm{std}(f)$ vs. regression window length.

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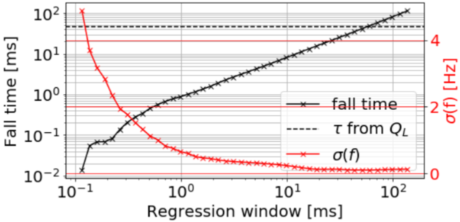

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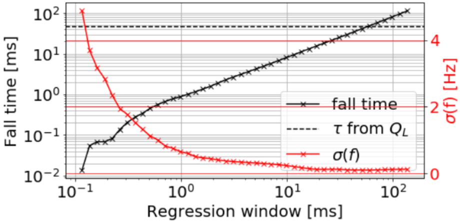

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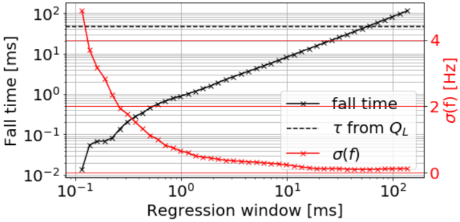

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- Cavity responds faster to FE-FRT than τ_L.

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Thank You

Thank you for listening.

Any Questions?

Paper WETEB7