A Ferroelectric Fast Reactive Tuner for Superconducting Cavities

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¹CERN, ²Brookhaven National Laboratory, ³Euclid Techlabs LLC, ⁴Lancaster University, ⁵Fermi National Accelerator Laboratory, ⁶Ceramics Ltd.

SRF, July 2019
FE-FRT: A new type of tuner.

- New class of tuner.
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- Heavy Ion.
- Nb$_3$Sn/New Materials.
Thank you for Listening.

Any Questions?
A Ferroelectric Fast Reactive Tuner

N. Shipman

Reactive Tuners

Ferroelectric Material

Applications

Prototype Tuner

Experimental Results

Conclusion
How does it work?

\[ \Delta \omega_{12} = -\omega_0 \Delta B' t_{12} R/4 N^2 \]

\[ \Delta BW_n = G't_n N^2 C c \]
How does it work?

\[
\Delta \omega = -\omega_0 \Delta B_t \frac{R}{Q^4 N^2}
\]

\[
\Delta B_W = G't' n N^2 C_c
\]
How does it work?

\[ \Delta \omega_{12} = -\omega_0 \Delta B'_{t12} \frac{R}{Q} \frac{1}{4N^2} \]

\[ \Delta BW_n = \frac{G'_{tn}}{N^2 C_c} \]
How does it work?

State Ratio\(_n\) = \(\frac{\Delta \omega_{12}}{\Delta \text{BW}_{n}}\)

State Ratio\(_n\) = \(\frac{\Delta B_t}{2G_{tn}}\)

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FoM = \(\text{Tuning Range}\)

Geometric Average of increase in BW
How does it work?

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FoM = \(\frac{\Delta \omega_{12}}{\sqrt{\Delta BW_1 \Delta BW_2}} \approx \frac{2|\sin \frac{\Delta \theta_{12}}{2}|}{\sqrt{(1 - |\Gamma_1|^2)(1 - |\Gamma_2|^2)}}\)
Other Reactive Tuners

Pin Diode Tuners

D. Schulze et al., in *Proc. 1972 Proton Linear Accelerator Conference*, Los Alamos, NM, USA, October 1972, G01, pp. 156–162.

Ferrite Tuners

Why use a ferroelectric?

- No moving parts
- Outside cryostat
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- Continuous tuning range
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- So why hasn’t this been done before?

---

Newly Developed Ferroelectric

- Suitable material only recently developed.\(^2\)

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- BaTiO\(_3\) - SrTiO\(_3\) solid solution (BST)

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**Table**: Material Properties at \(\approx 800\) MHz

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Where is an FE-FRT likely to be most useful?

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- Whenever you need really fast tuning
- Where easy maintainability is a key concern
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Monte Carlo method applied to FE-FRT Transmission Line Model for 801.58 MHz.
PERLE Case Study

\[ P_{RF} = \frac{V_c^2}{4R/Q/Q_L} \frac{\beta + 1}{\beta} \left[ 1 + \left( 2Q_L \frac{\Delta \omega}{\omega_0} \right)^2 \right] \]
PERLE Case Study

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\[ P_f vs Q_{FPC} \] for PERLE. Without tuner and with tuner.
PERLE Case Study

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\( P_f \) vs \( Q_{FPC} \) for PERLE. **Without tuner and with tuner.**
PERLE Case Study

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PERLE Case Study

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PERLE Case Study

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- \(\tan \delta \propto f\)
- Dielectric losses \(\propto f^2\)
Prototype Tuner, 3D model and transmission line model.
Experimental Setup
Experimental Setup

FE-FRT mounted on cryostat.

Cryostat insert.
FE-FRT mounted on cryostat.

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Cryostat insert.
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Demonstration of Frequency Tuning

Signal analyser measurement.

Experimental Setup.
Demonstration of Frequency Tuning

Signal analyser measurement.

Frequency calculated from I and Q measurements.

Experimental Setup.

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Timescale of Frequency Shift

Fall time and $\text{std}(f)$ vs. regression window length.
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Timescale of Frequency Shift

- Cavity response to tuner $< 50 \mu s$

Fall time and $\text{std}(f)$ vs. regression window length.
Cavity response to tuner < 50 µs

Cavity time constant
\[ \tau_L = \frac{Q_L}{\omega_0} \approx 46 \text{ ms} \]

Fall time and \( \text{std}(f) \) vs. regression window length.
Timescale of Frequency Shift

Cavity response to tuner $< 50 \mu s$

Cavity time constant $\tau_L = \frac{Q_L}{\omega_0} \approx 46 \text{ ms}$

Cavity responds faster to FE-FRT than $\tau_L$.

Fall time and $\text{std}(f)$ vs. regression window length.
Tested an FE-FRT with SC RF Cavity: World First!
Conclusion

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- Outside cryomodule, no moving parts \(\rightarrow\) easy maintenance and high reliability
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Thank you for listening.

Any Questions?