The challenge of operating a super-conducting cavity at 5 Hz bandwidth

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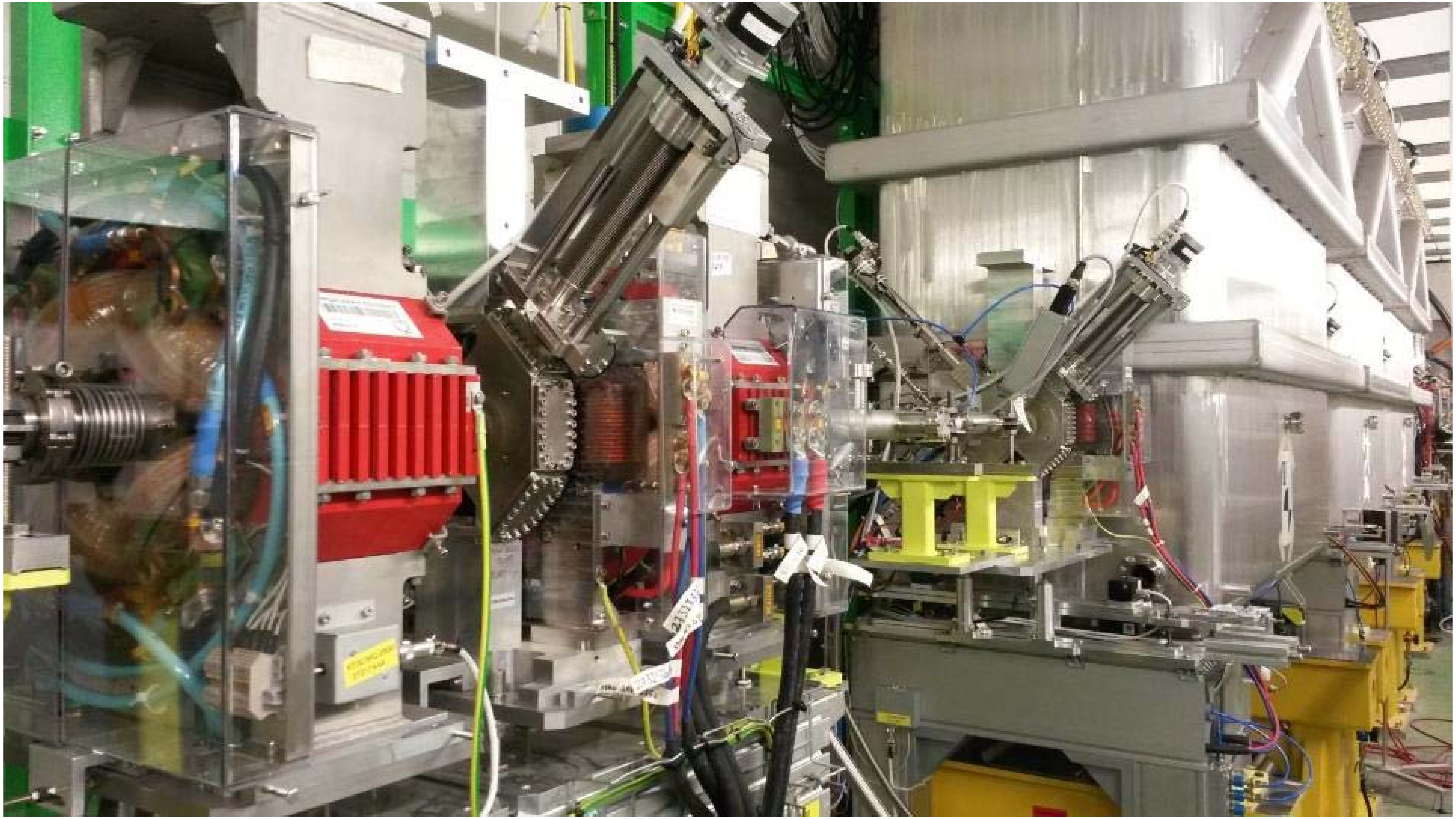
HIE-Isolde at CERN

- HIE-Isolde is a major upgrade of the radioactive beams facility at CERN
- 40 MV superconducting linac based on 32 independently phased superconducting quarter-wave resonators
- 20 SC cavities installed early 2018

HIE-Isolde at CERN



HIE-Isolde at CERN

- RF system runs at 101.28 MHz, direct RF sampling and RF generation, direct digital quadrature demodulation
- Cartesian P-I feedback controller, with dynamically calculated set-points, self excited loop, generator driven mode, closed loop operating modes
- Cavities are operated in CW at 5 Hz bandwidth (Q_{ext} ~$2x10^7$, P_{fwd} ~70 W)
- 700 W solid state power amplifiers
- Aim to keep the forward power below 100 W

QWR resonance control challenge

- The cavity tuning plate is very thin – large LFD
  - 75 Hz from zero to max field → 25x operating bandwidth (BW)

- Operational experience:
  - Typical microphonics ~0.5-1 BW_{peak}, perturbation frequencies 50++ Hz
  - Typical “slow” detuning due to “fast” lHe pressure variation up to 10 BW within 30 seconds

- Operating this cavity at high field is not always easy…

Transmitted power method

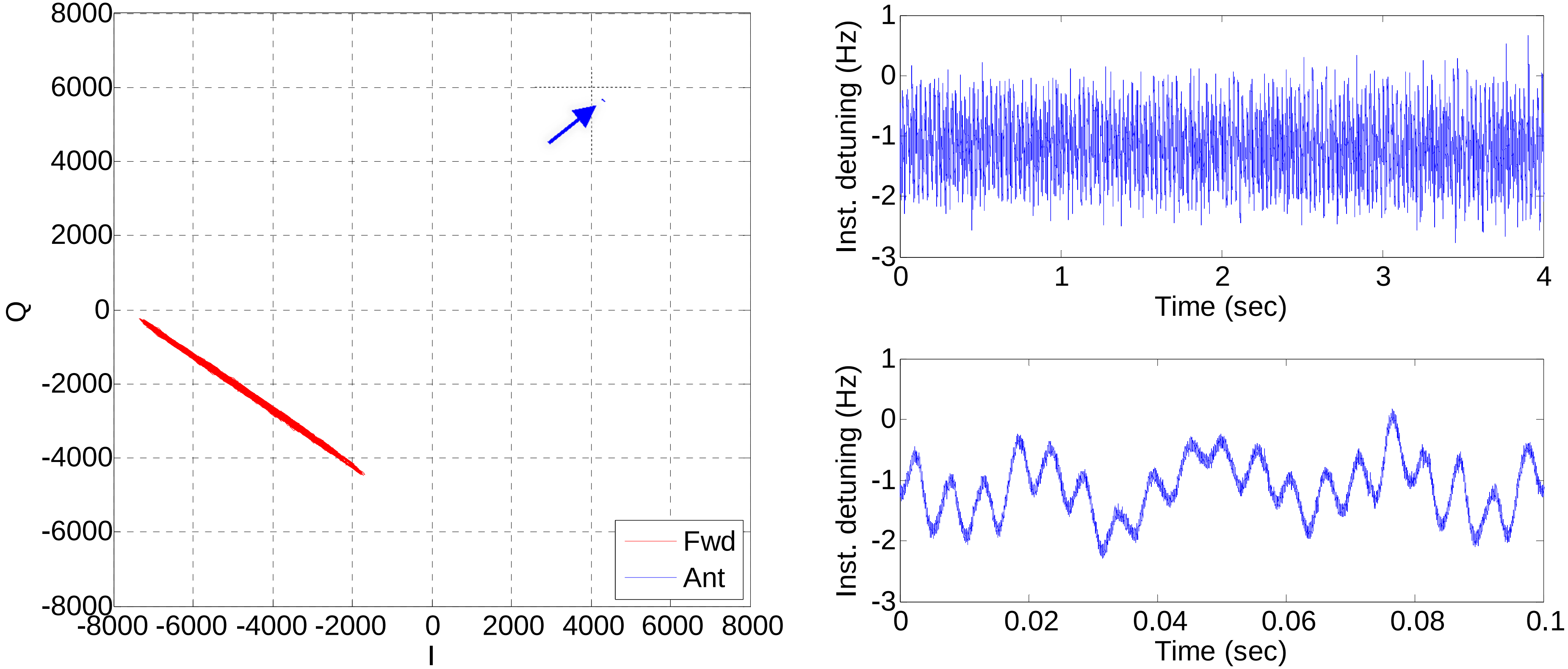
- The instantaneous cavity tune state can be calculated from the forward and antenna signals

$$\Delta f = \frac{1}{2} BW \frac{|V_{fwd}|}{|V_{ant}|} \sin(\varphi_{ant} - \varphi_{fwd})$$

f_{RF}=101.28 MHz, Q_0=6.6x10^8, BW=5 Hz

In reality…

- The instantaneous cavity tune state can be calculated from the forward and antenna signals

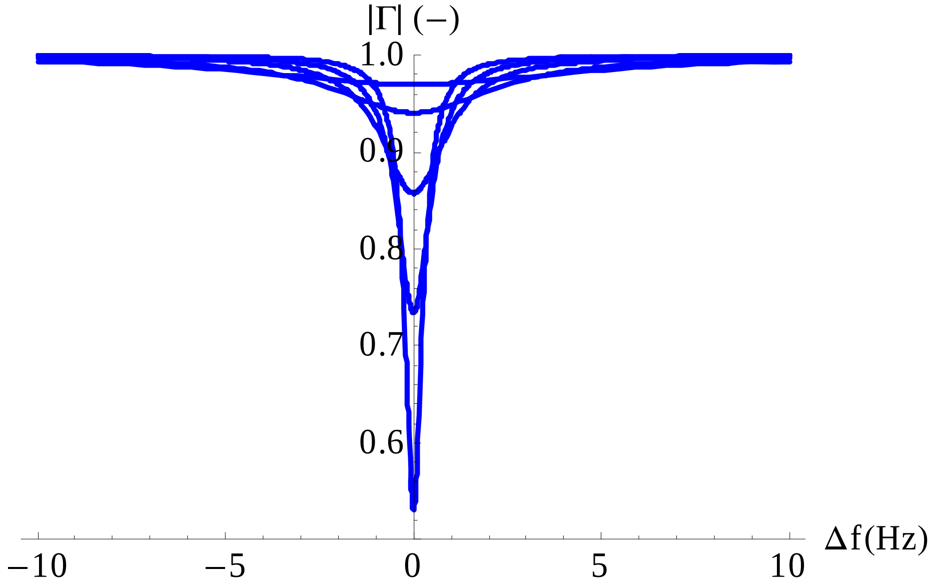


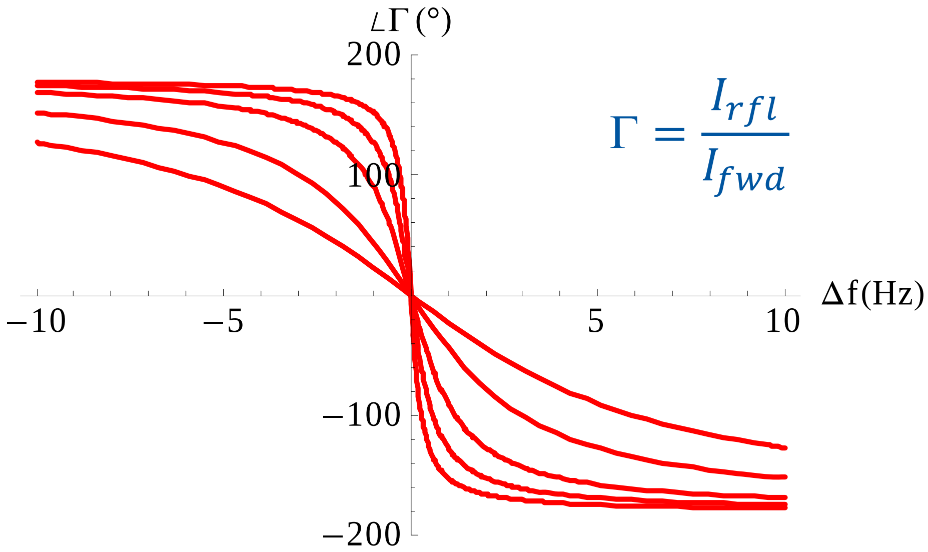
Reflection coefficient method

- The instantaneous cavity tune state can be calculated from the measured reflection coefficient

$$I_{fwd} = \frac{V_{acc}}{2\,R/Q}\left(\frac{1}{Q_{ext}} + \frac{1}{Q_0}\right) - i\,\frac{V_{acc}\Delta\omega}{\omega\,R/Q}$$

$$I_{rfl} = \frac{V_{acc}}{2\,R/Q}\left(\frac{1}{Q_{ext}} - \frac{1}{Q_0}\right) + i\,\frac{V_{acc}\Delta\omega}{\omega\,R/Q}$$

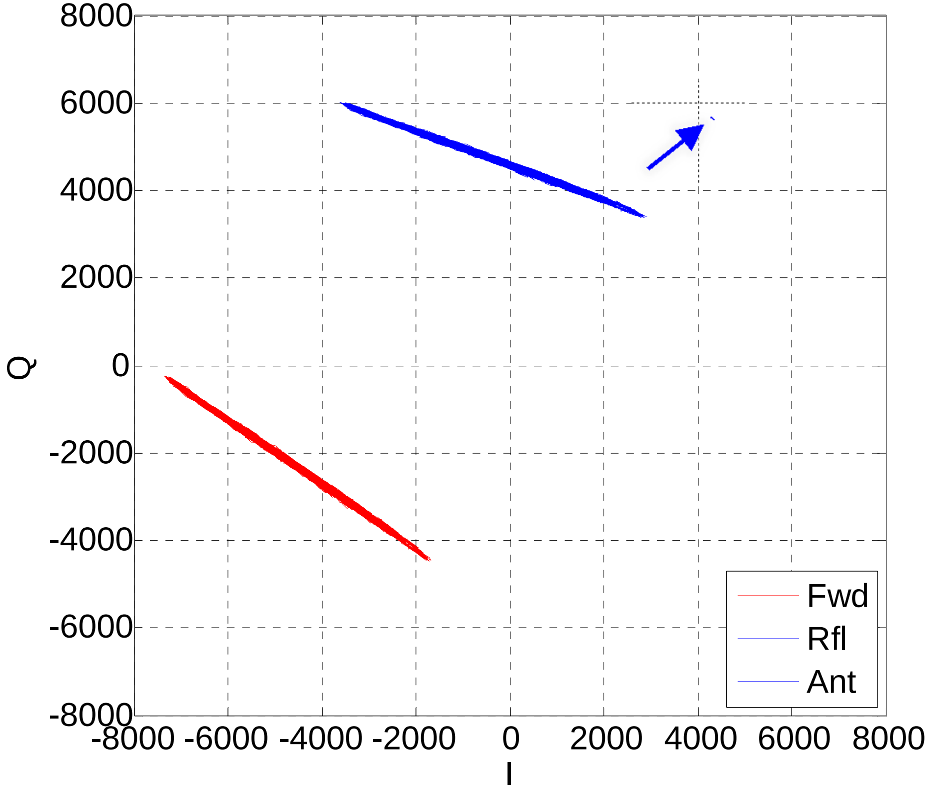




f_{RF}=101.28 MHz, Q_0=6.6x10^8, BW=0.5,1,2,5,10 Hz

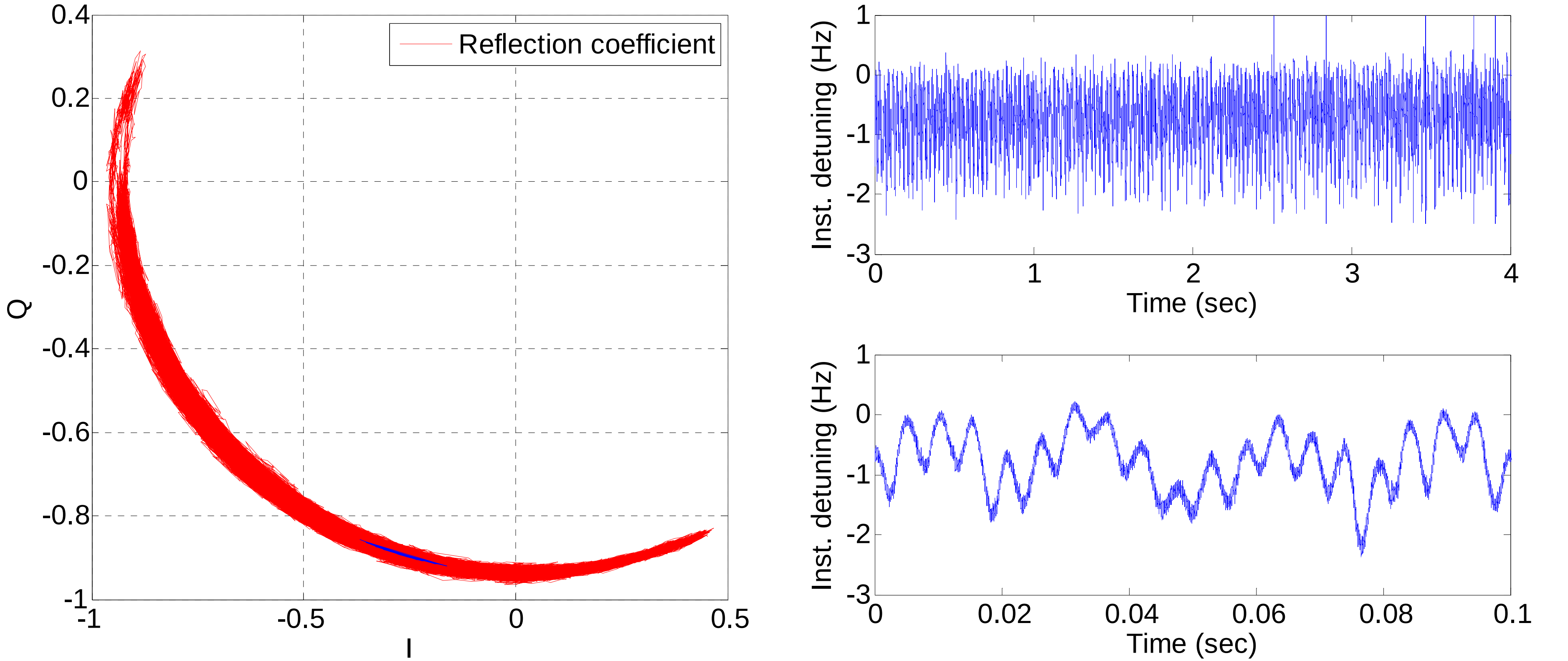
In reality…

- The instantaneous cavity tune state can be calculated from the measured reflection coefficient



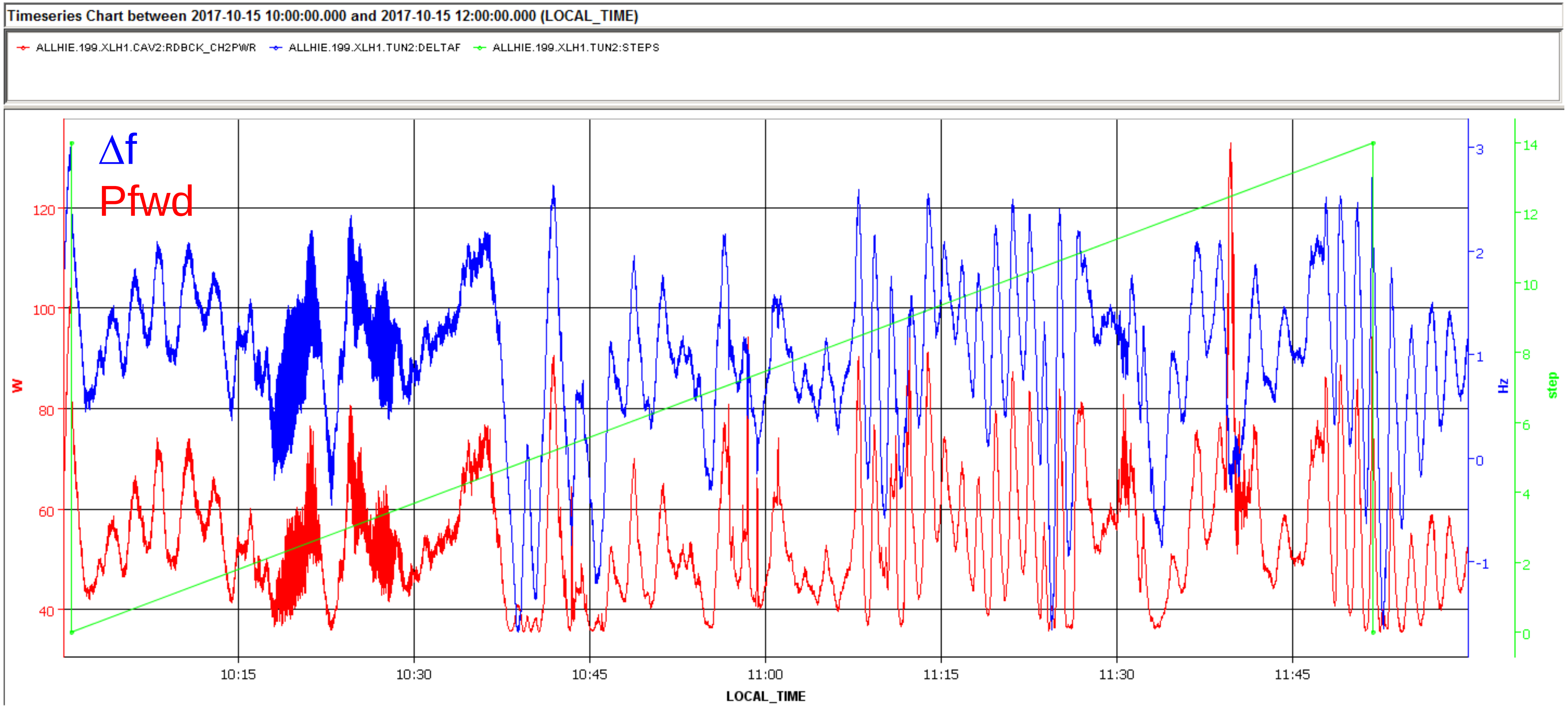
In reality…

- The instantaneous cavity tune state can be calculated from the measured reflection coefficient



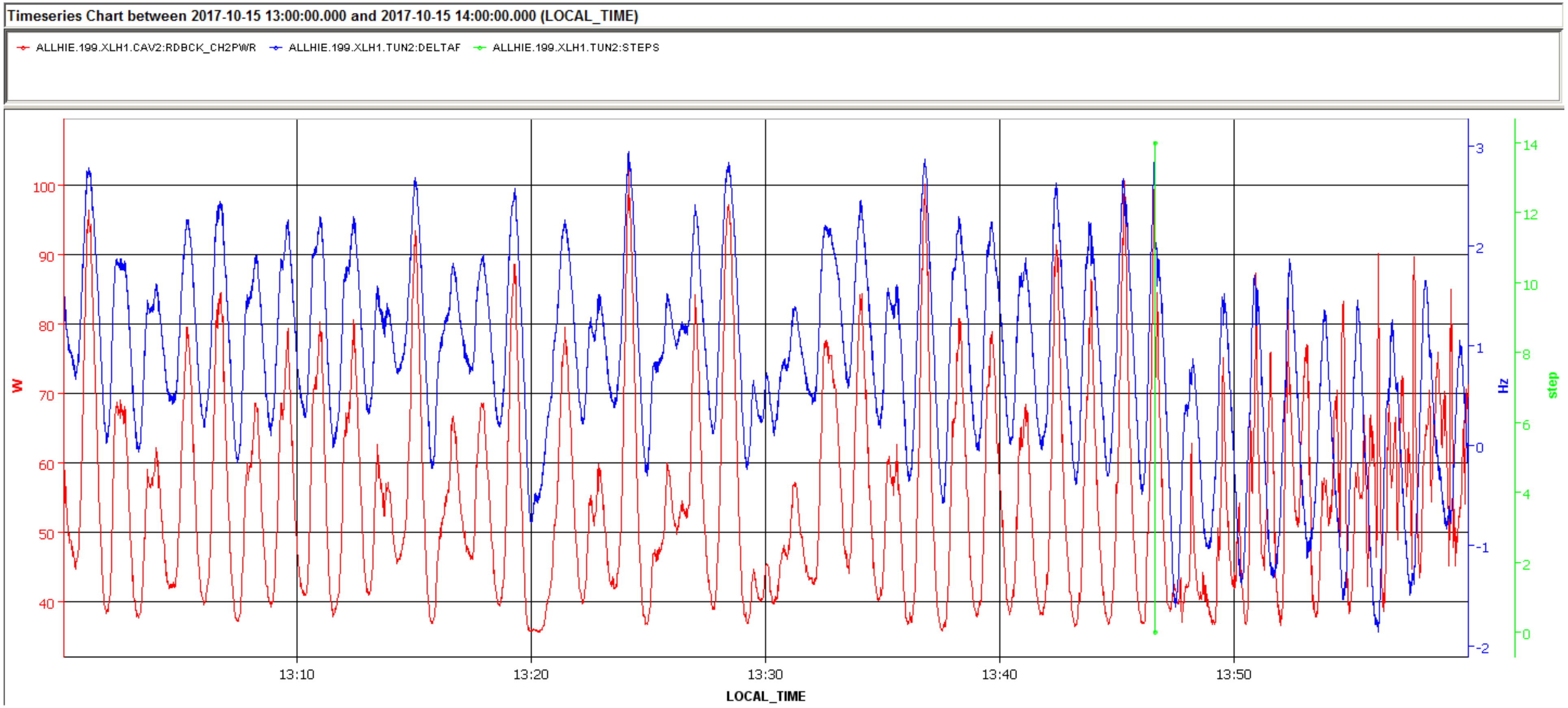
In reality…

- No tuner movement in 2 hours, cavity freq. within +/-2.5Hz



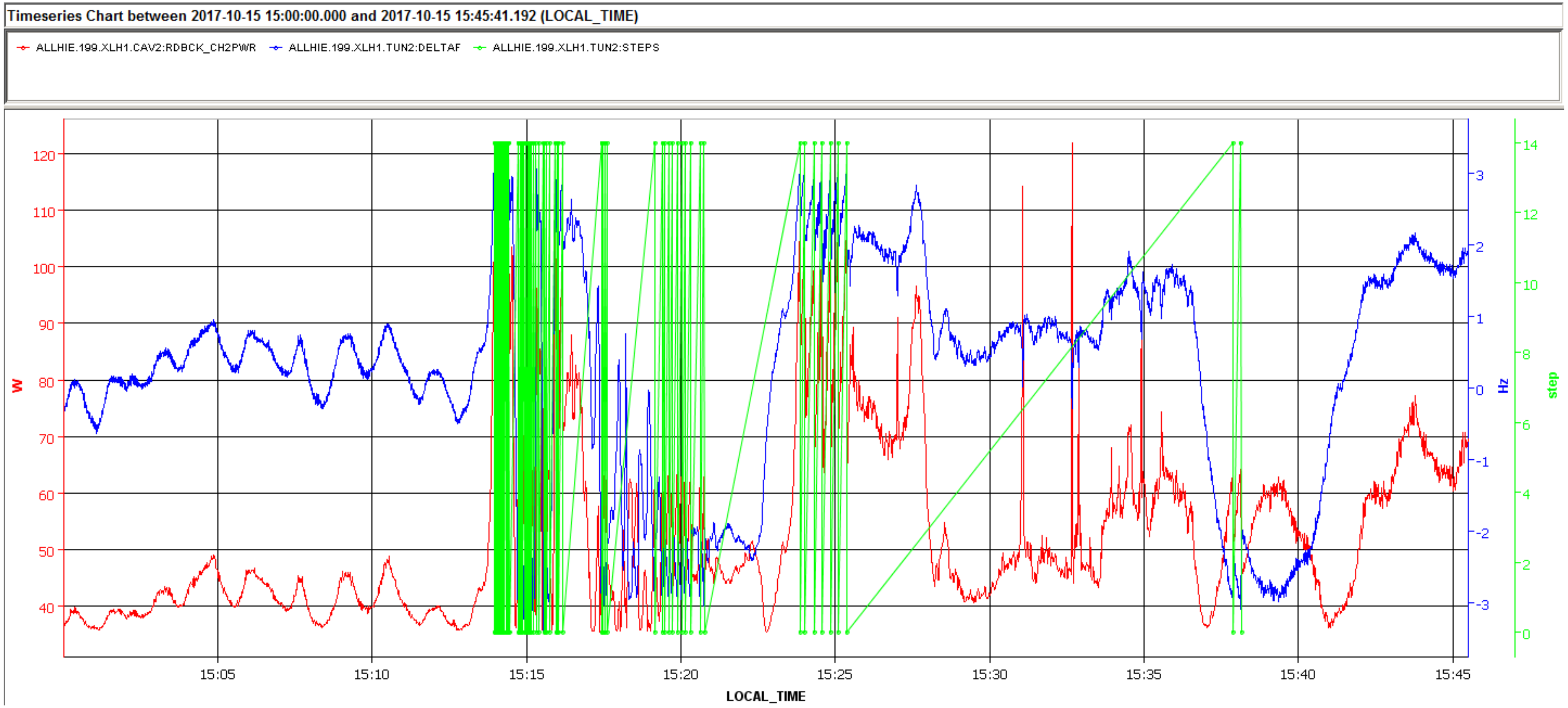
In reality…

- Slow lHe pressure variation with a minute cycle



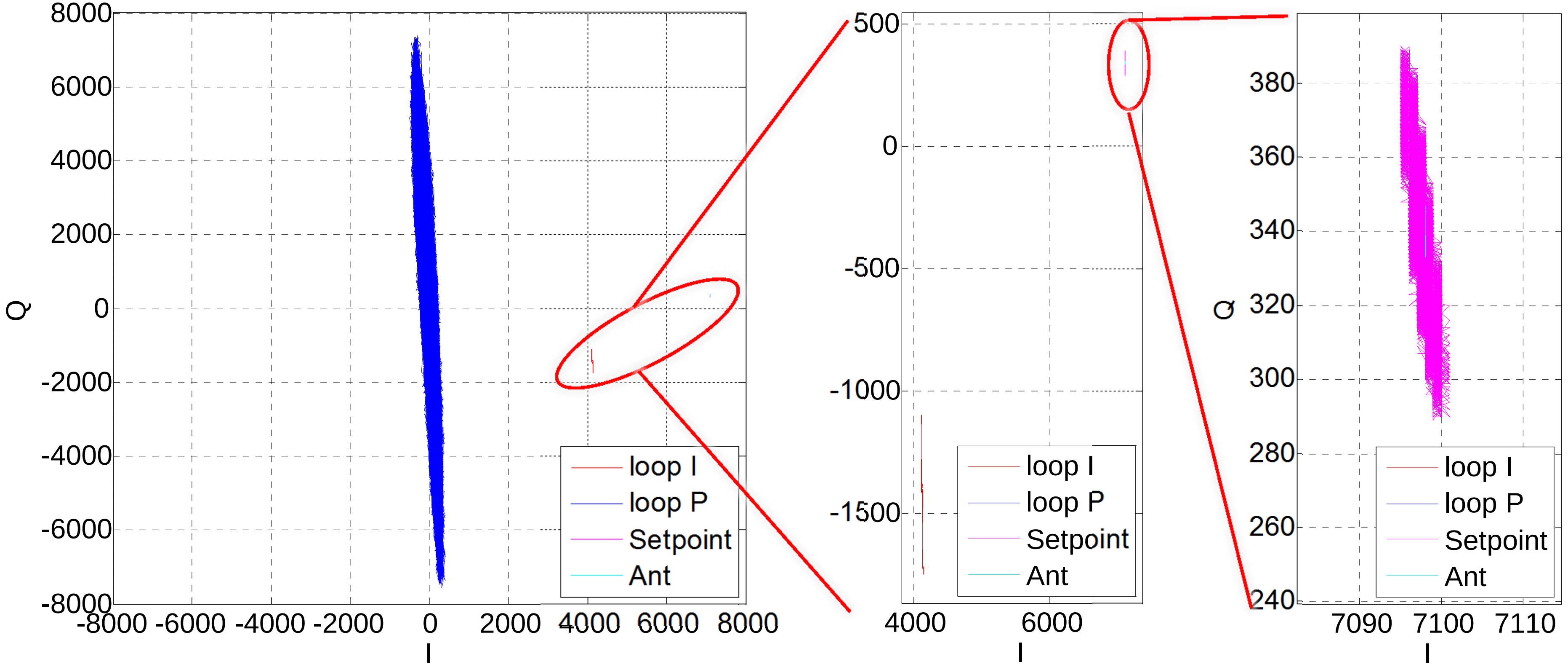
In reality…

- Then the perturbation comes…



A way out?

- Is there a more “quiet” signal representing the cavity tune state?



A way out?

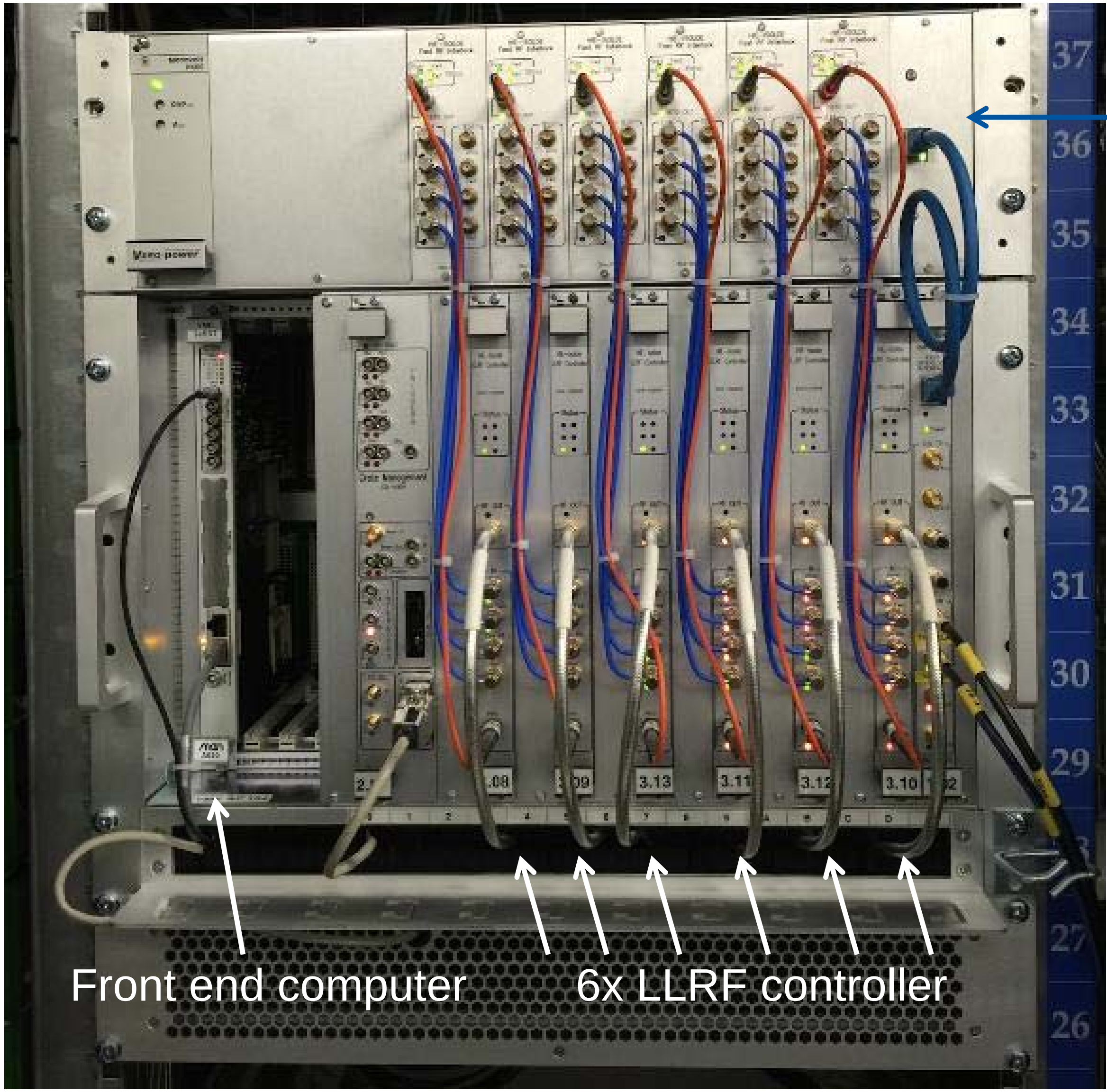
- The integral loop contribution can be used to **estimate** the cavity resonant frequency instead of **measuring** it using the very dynamic Fwd/Rfl signals

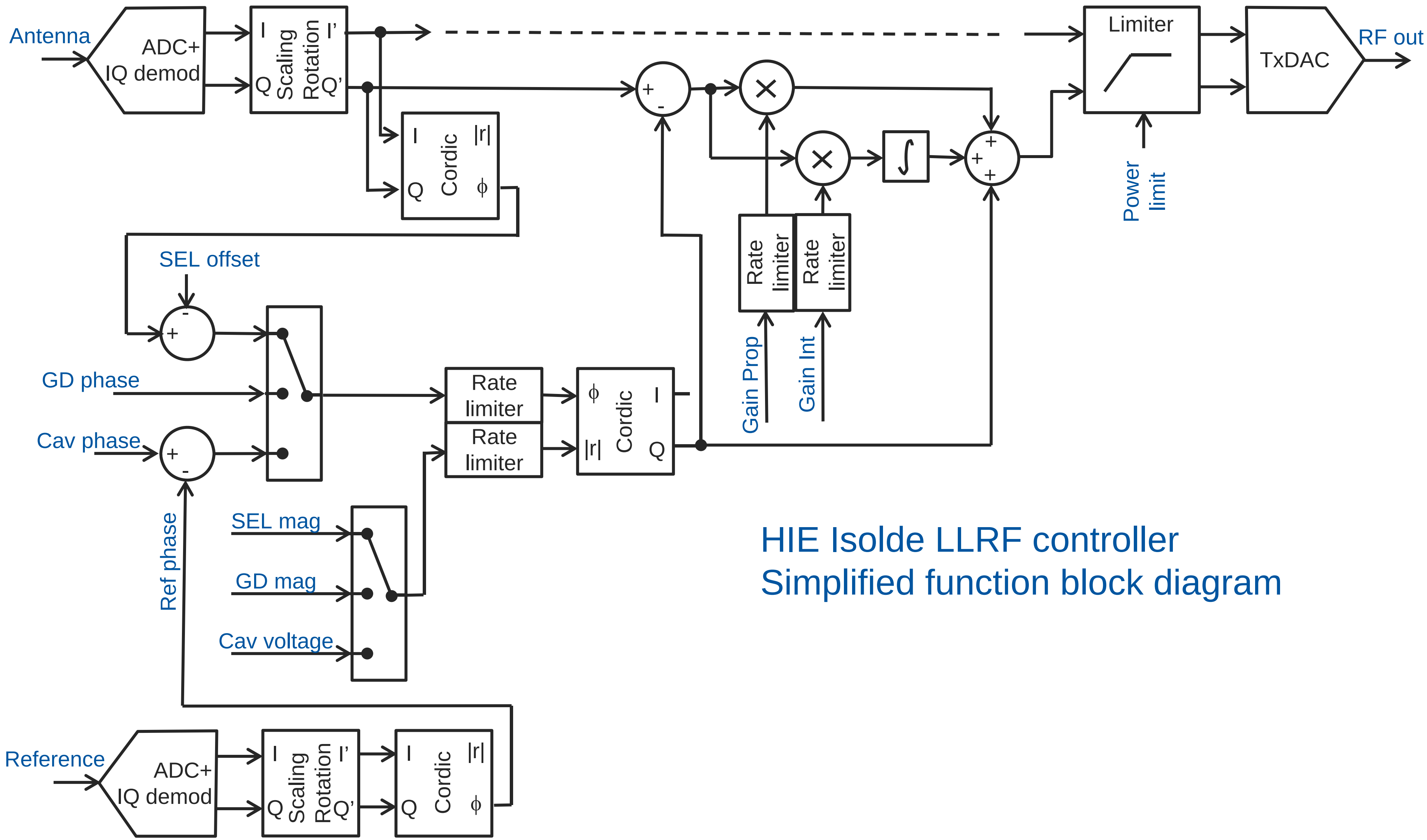
- Phase information seems to be sufficient for reliable tuning
- No need for minimum finding regulator → no tuner movement

- Method already tested in the machine, very promising results

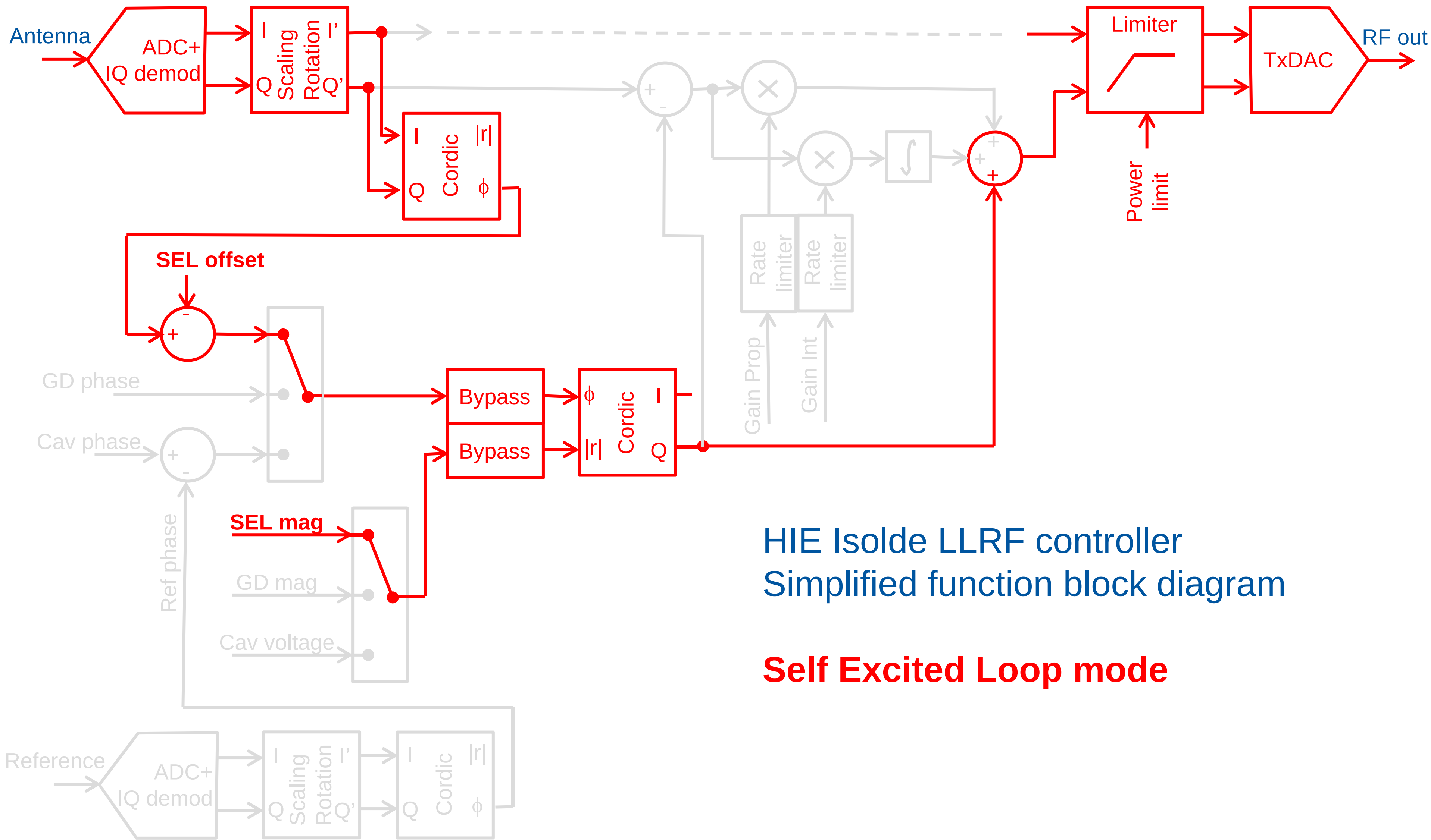
Thank you for your attention

LLRF system for a complete cryomodule housing 6 cavities





HIE Isolde LLRF controller
Simplified function block diagram



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Self Excited Loop mode

HIE Isolde LLRF controller
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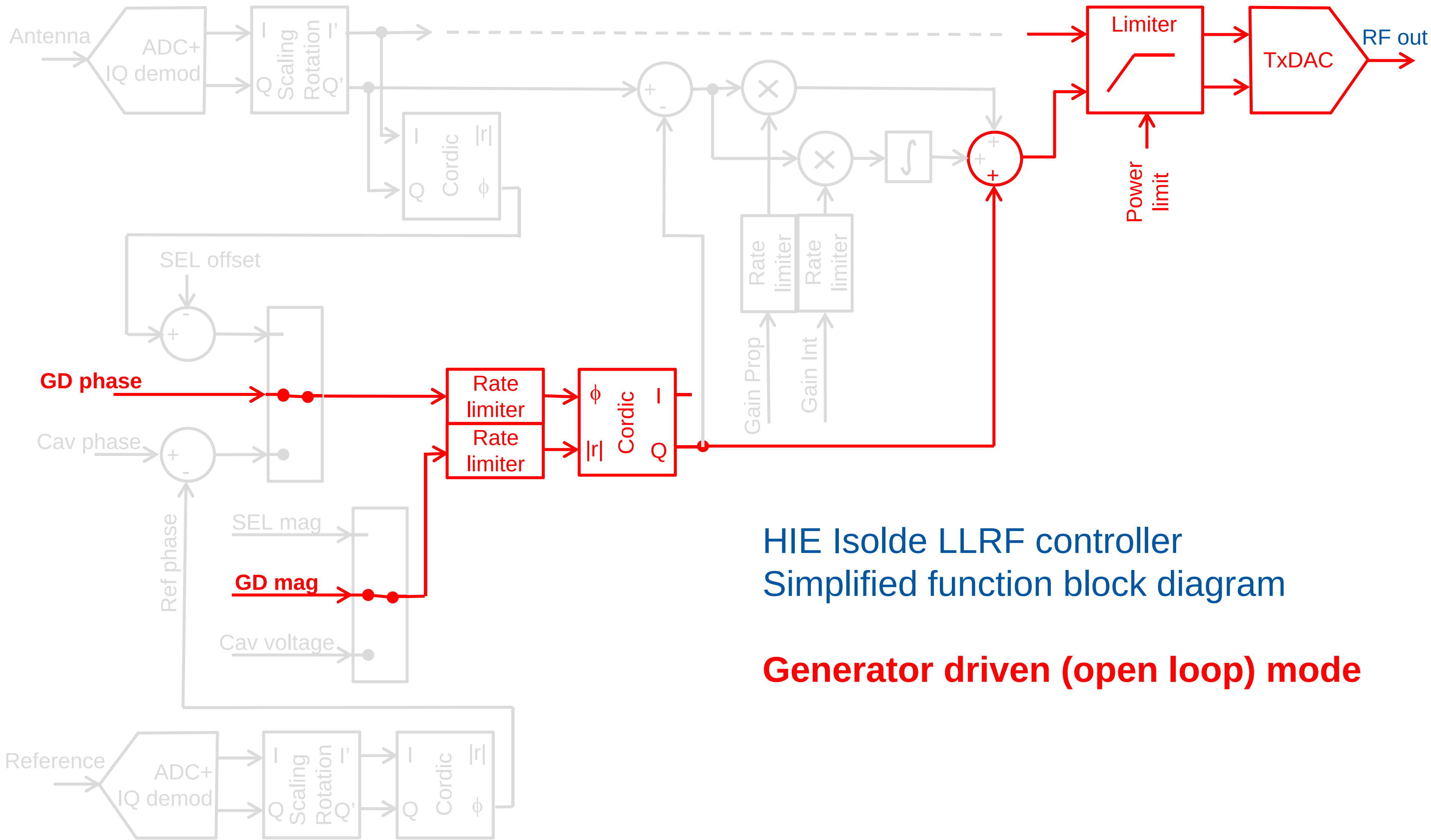
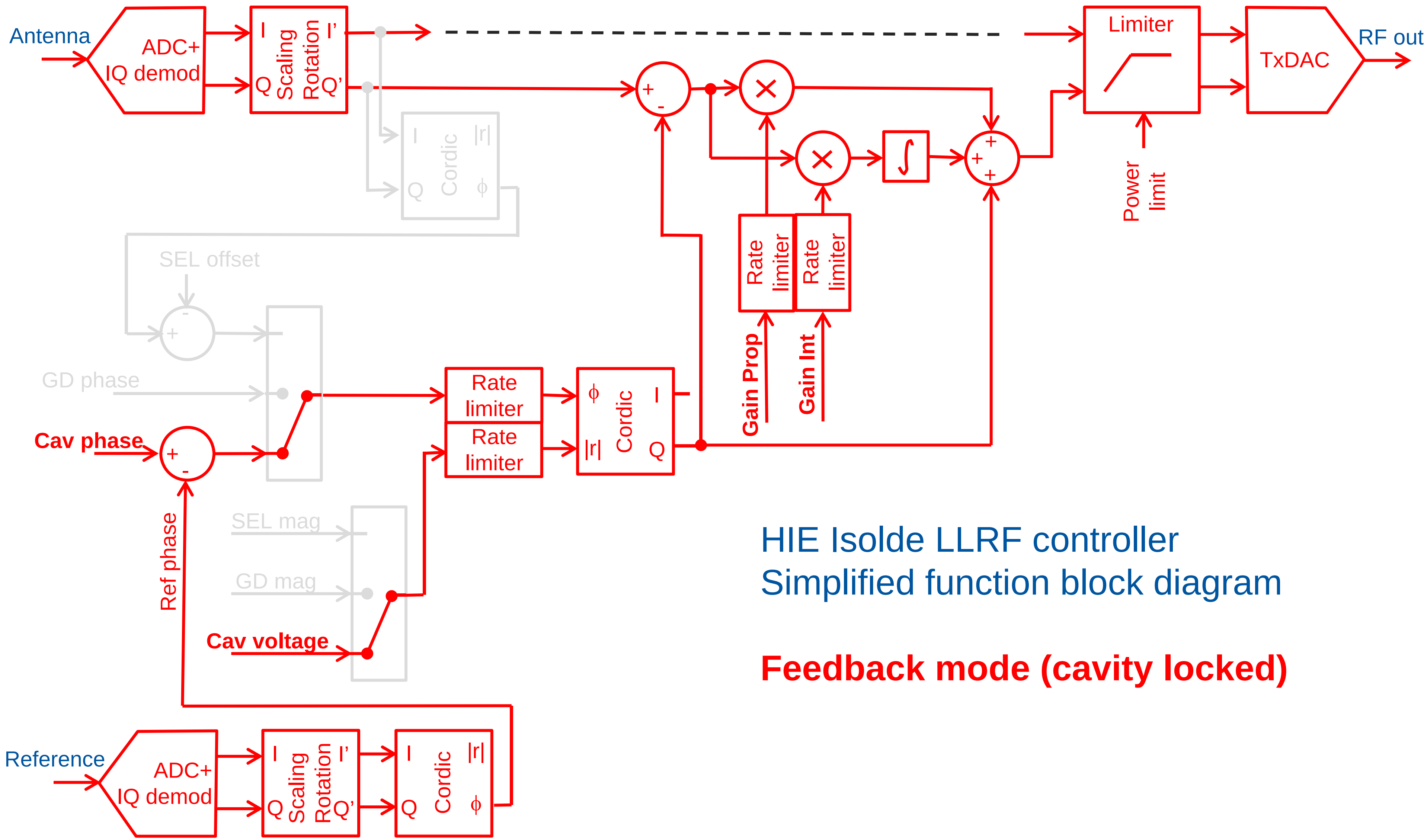
Generator driven (open loop) mode





HIE Isolde LLRF controller
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Feedback mode (cavity locked)