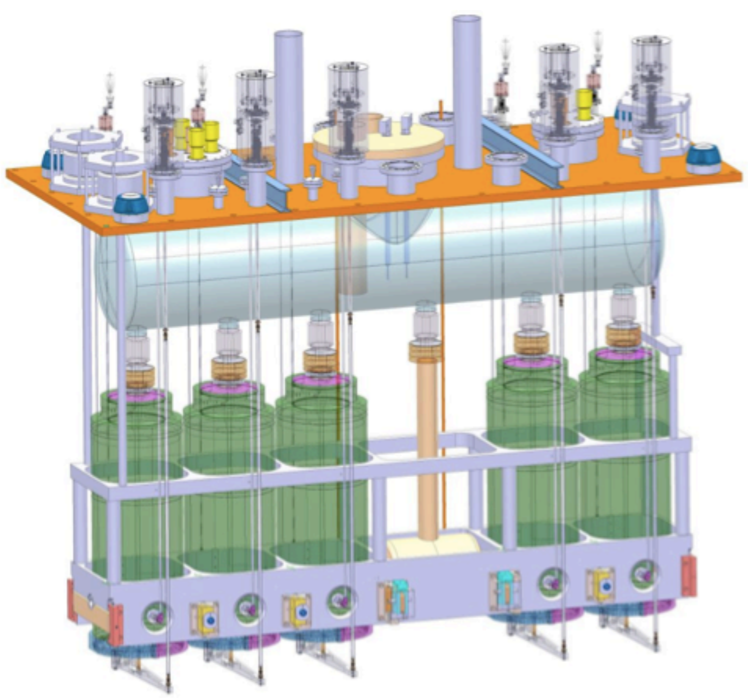
RF system for the HIE-ISOLDE

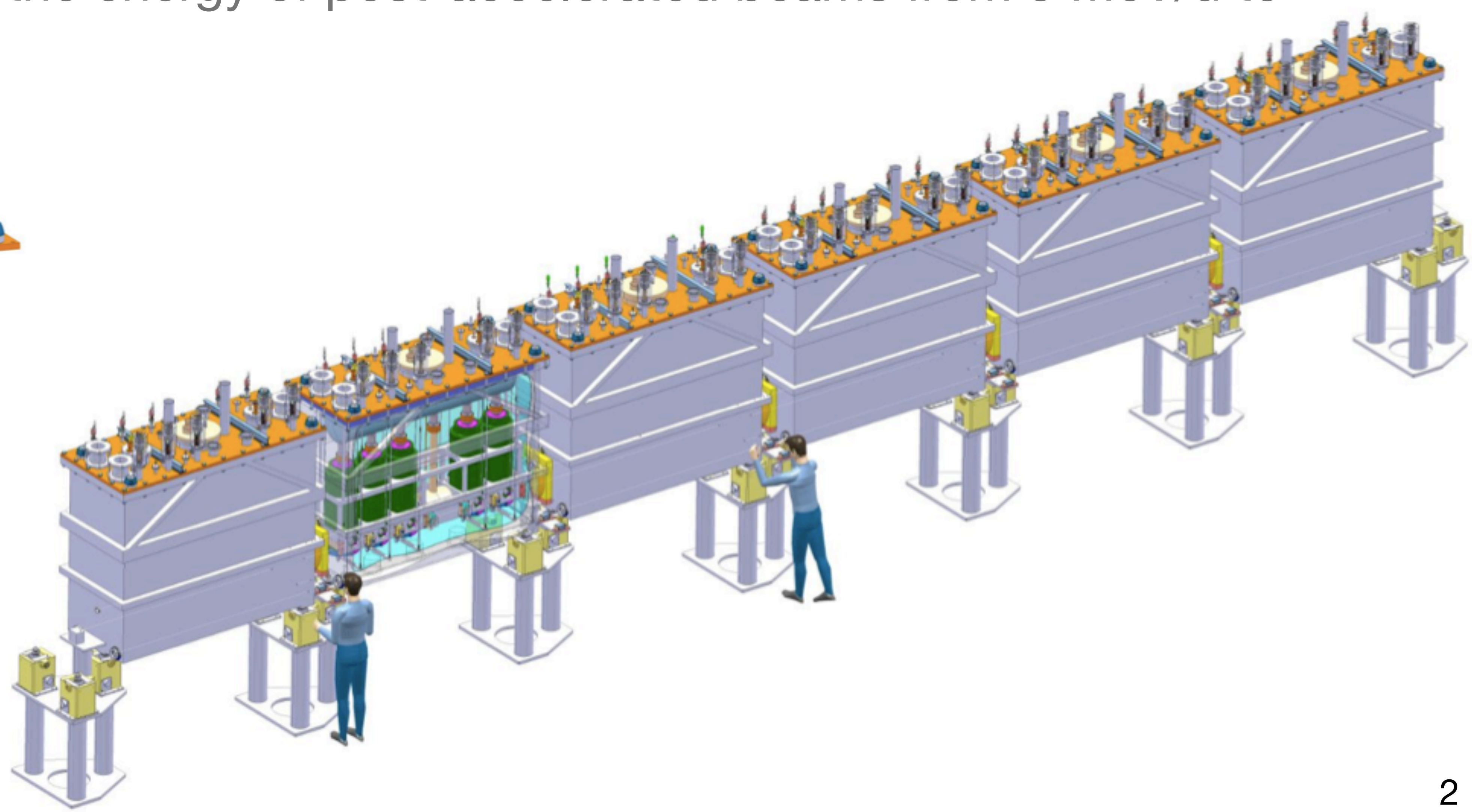
Daniel Valuch, Michal Elias

with valuable help of
L. Arnaudon, A. Boucherie, Z. Brezovic, F. Dubouchet, D. Glenat, G. Hagmann, W. Hofle, M. Jaussi, Y. Kadi, T. Levens, T. Mastoridis, I. Mondino, A. Rey, W. Venturini, P. Zhang

HIE-Isolde project 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
- The linac will raise the energy of post-accelerated beams from 3 MeV/u to over 10 MeV/u.





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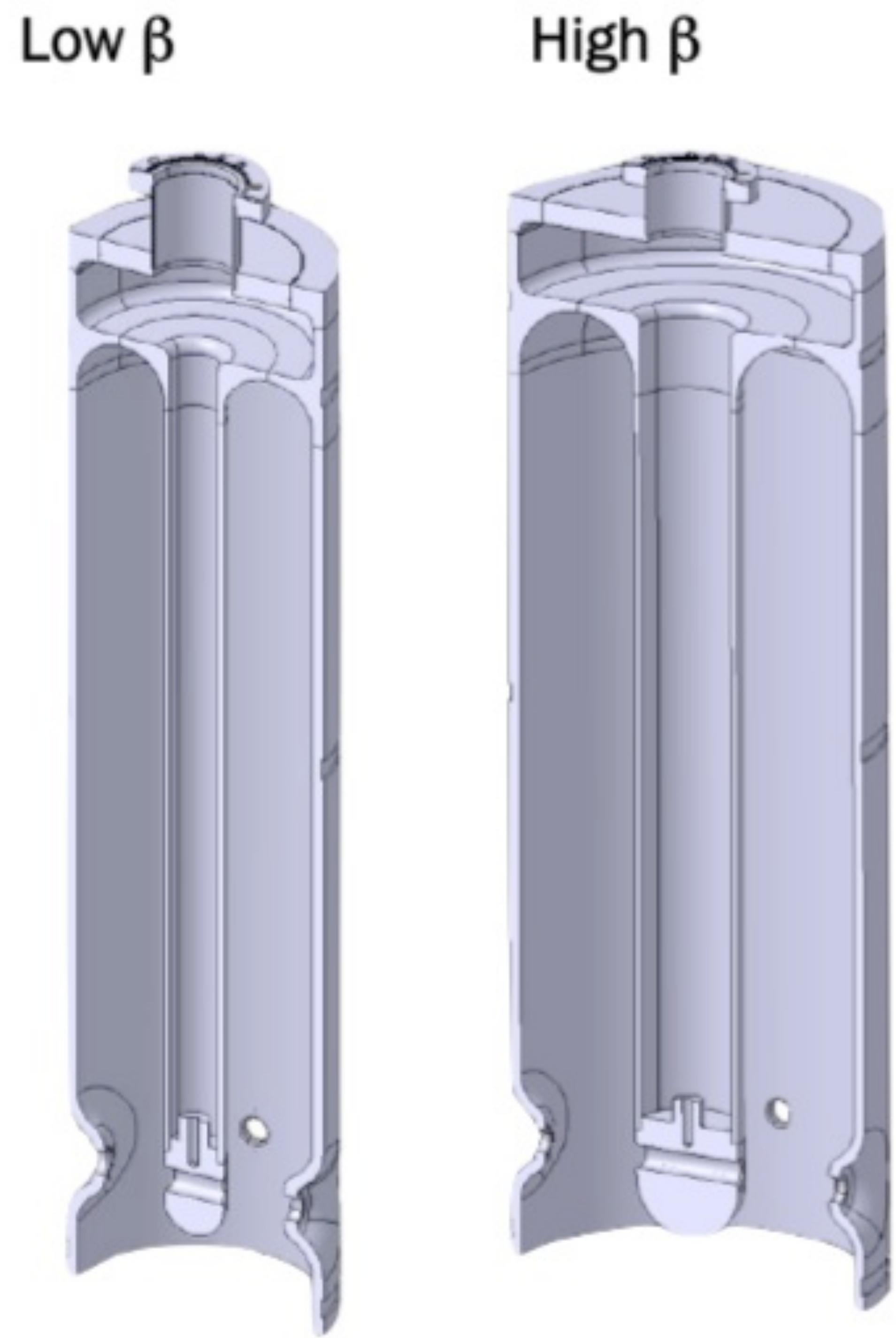
HIE-Isolde RF system

- Nb on copper sputtered, quarter wave resonators
- RF dissipation 10 W at nominal 6 MV/m accelerating gradient
- Very narrowband operation (0.1...15 Hz BW)
- Common beam and insulation vacuum

- See talk of Walter Venturini



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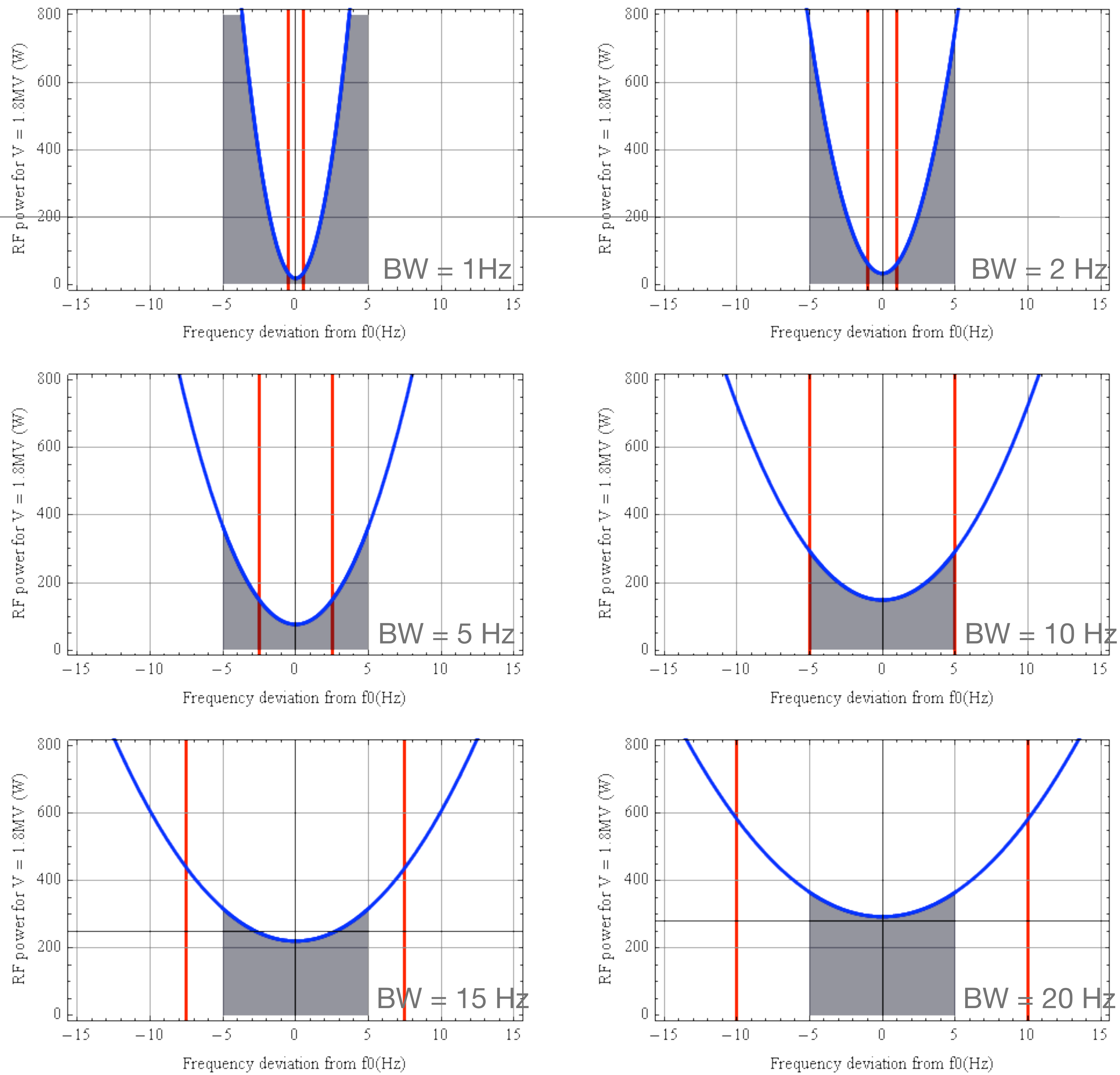
HIE-Isolde RF system

- Cavity field stability requested by the beam dynamics
    - 0.2% amplitude, 0.2° phase (RMS)
- Different cavity configurations for each species and energy
    - some cavities always on, others used to build up the requested voltage
- Aim at a very low complexity for controls *“OFF -> cavity start -> RF ON”*
- Fully automatic cavity phasing for different ion species

HIE-Isolde cavity power requirement to obtain nominal gradient 6 MV/m.

- Anticipated 10 Hz_{pk-pk} microphonics

- Optimal working point for minimum mean power



Red - desired operating bandwidth

Gray - simulated microphonics

Blue - power required for 6 MV/m

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RF cavity power requirement

- RF power requirement to obtain acc. gradient 6 MV/m (gap voltage 1.8 MV) for different operating bandwidths

Desired operating bandwidth (Hz)	Q_{loaded}	Forward power P_g (W) at resonance	Reflected power P_r (W) at resonance	Dissipated power in the cavity (W) at resonance	Forward power P_g (W) 1BW from resonance	Forward power P_g (W) 2BW from resonance
1	1.012×10^8	19.22	10.36	8.86	33.67	77.00
2	5.060×10^7	33.49	24.63	8.86	62.39	149.1
5	2.024×10^7	76.74	67.87	8.86	148.9	365.7
10	1.012×10^7	148.9	140.1	8.86	293.4	726.8
15	6.747×10^6	221.2	212.3	8.86	438.0	1088
20	5.060×10^6	293.4	284.5	8.86	582.3	1449
30	3.373×10^6	437.9	429.0	8.86	871.3	2172

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RF power system

- Required RF power per cavity is well within solid state amplifier range
- Standard broadcasting equipment could be used (water cooled)
- External circulator and RF load assembly
- Whole RF power system fits into 7 racks

Prototype 100 MHz, 750 W solid state amplifier for SM18 test stand

Low Level RF system

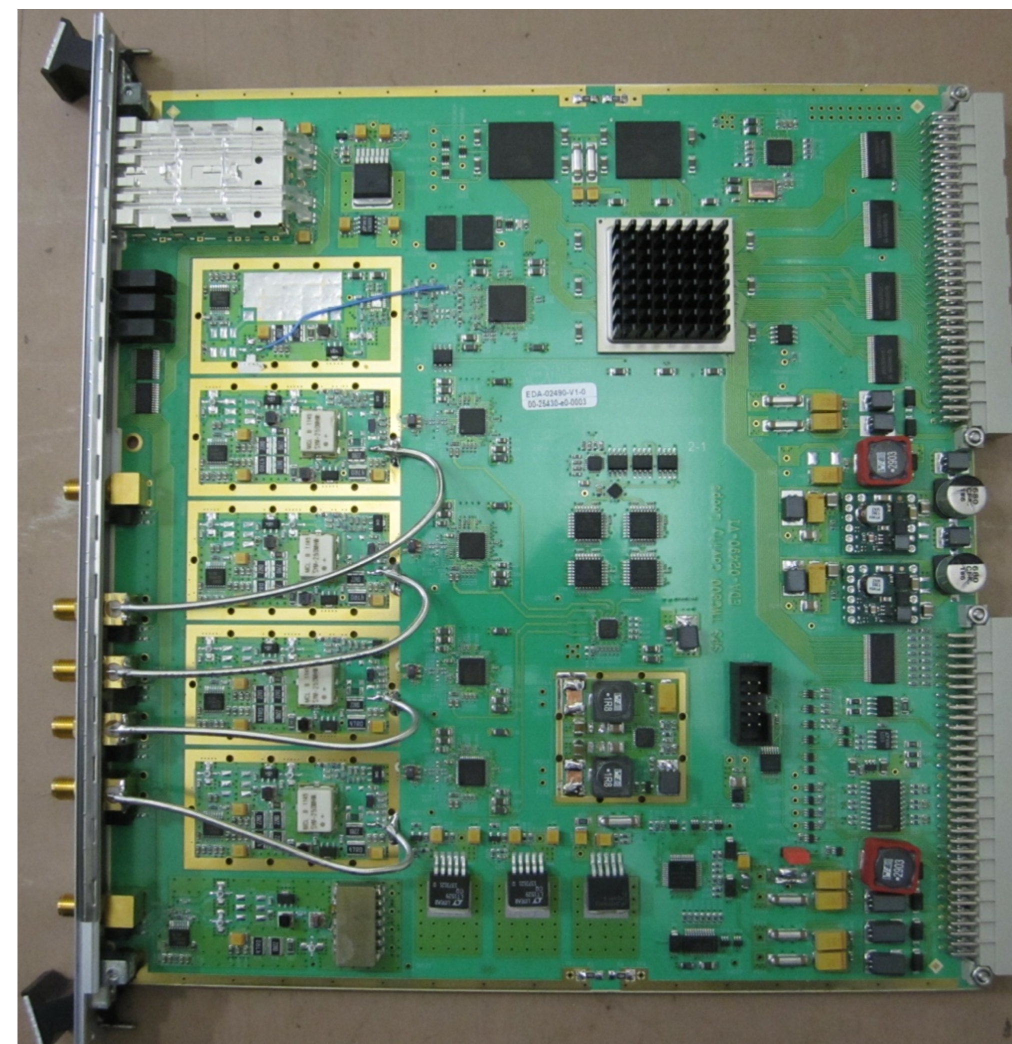
- Operating frequency of 101.28 MHz is comfortable for
  - direct RF sampling by ADC
  - direct RF generation by DAC
  - clever sampling frequency choice allows for direct digital IQ demodulation
- The complexity is shifted from the RF hardware to the FPGA code

- LHC based design - FPGA, observation memories, custom backplane
- Whole LLRF for 32 cavities with all house keeping fits into 7 VME crates

Low Level RF system

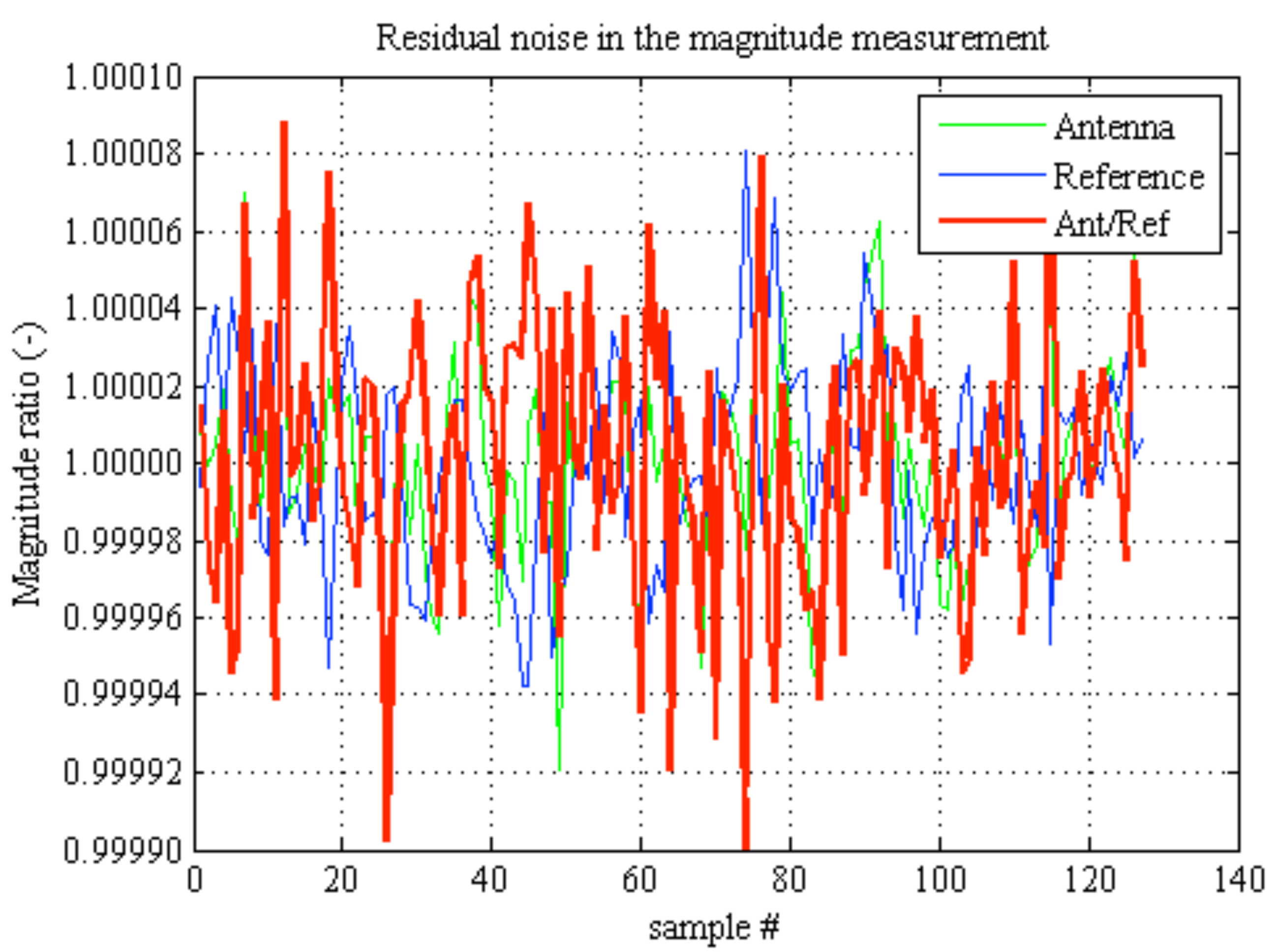
Warm LLRF test stand

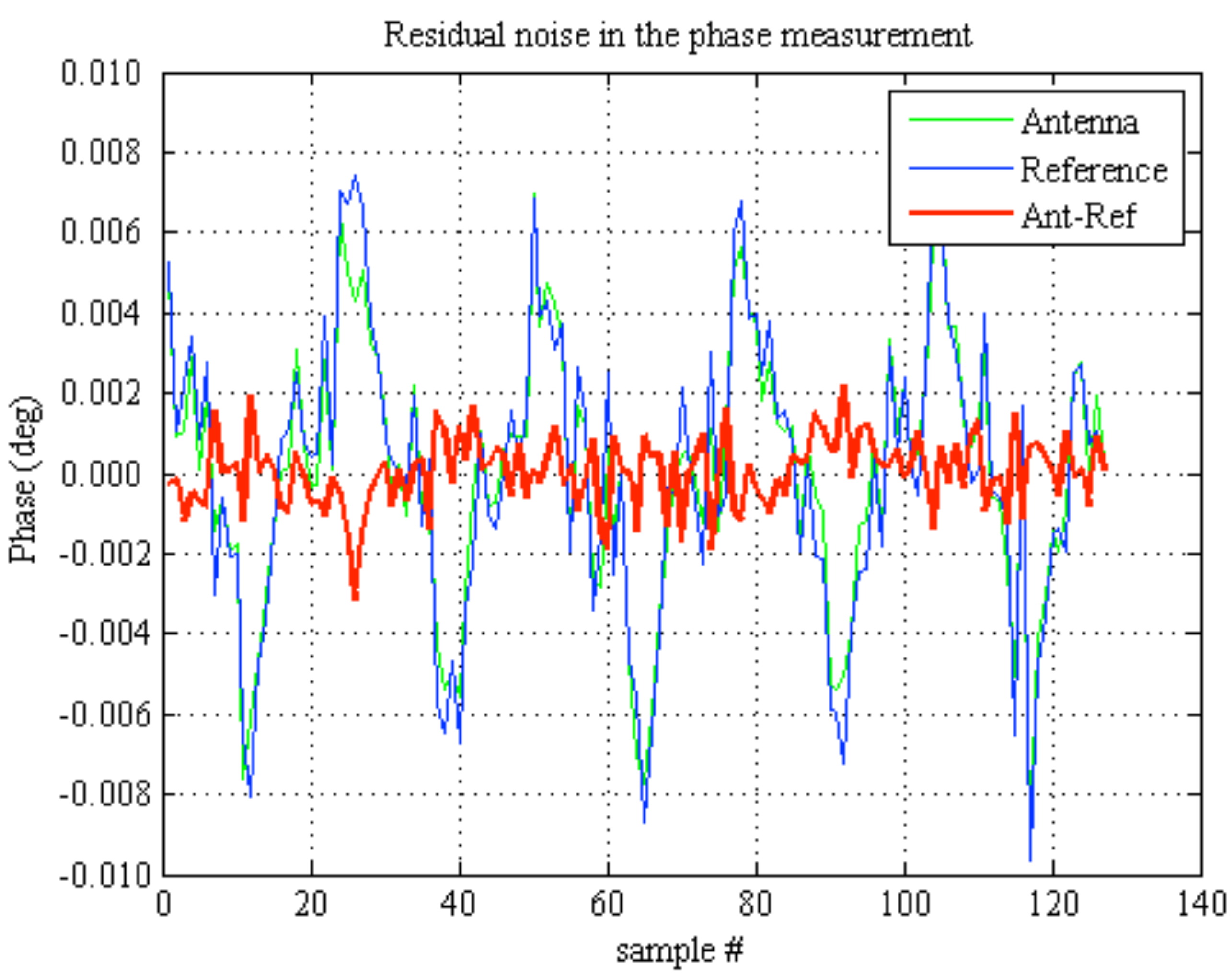
HIE Isolde LLRF controller, version 0



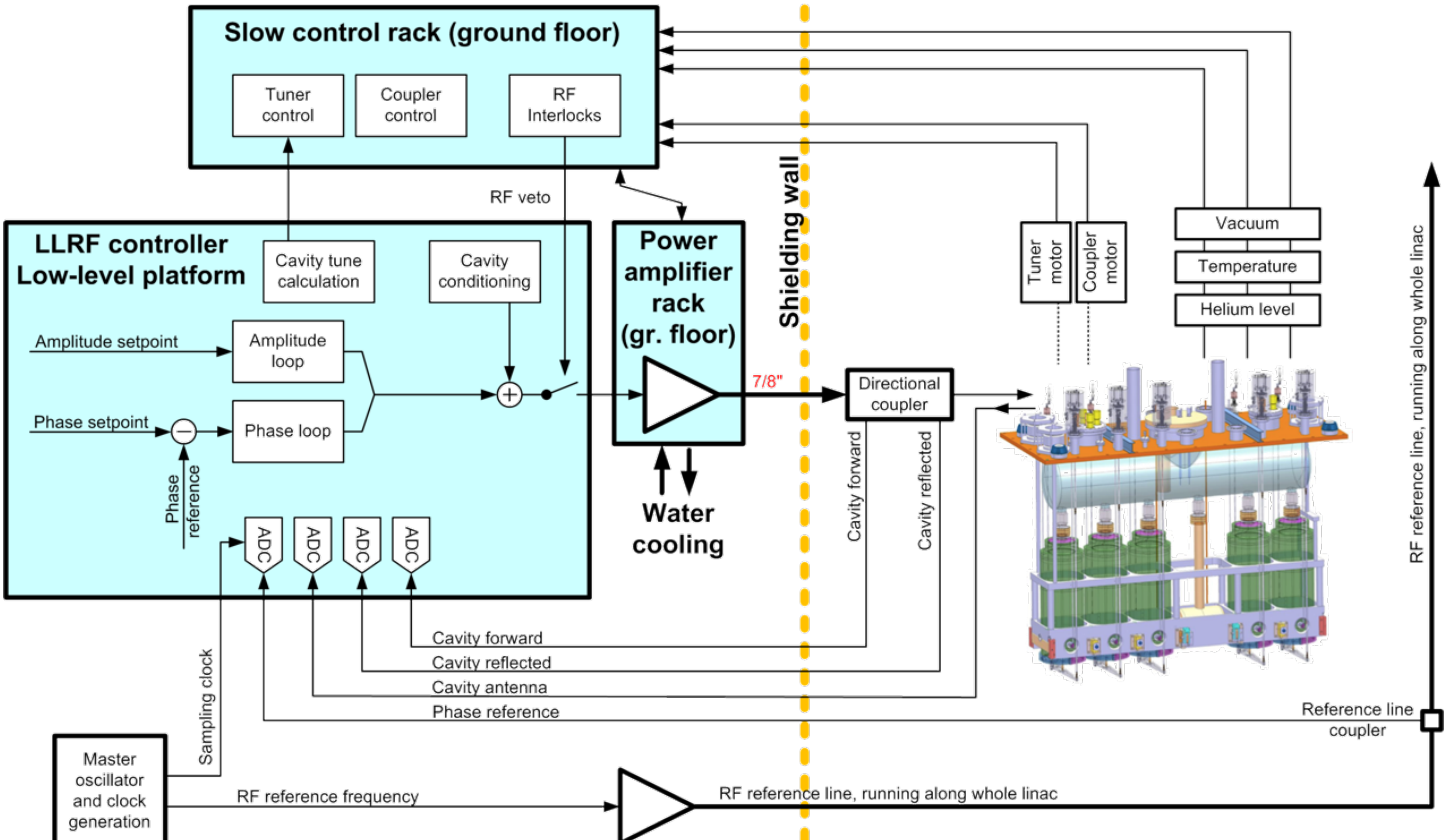
Low Level RF system

- Measured performance - noise floor at 10^{-4} magnitude, 0.002° phase (pk-pk)





HIE-Isolde RF system architecture



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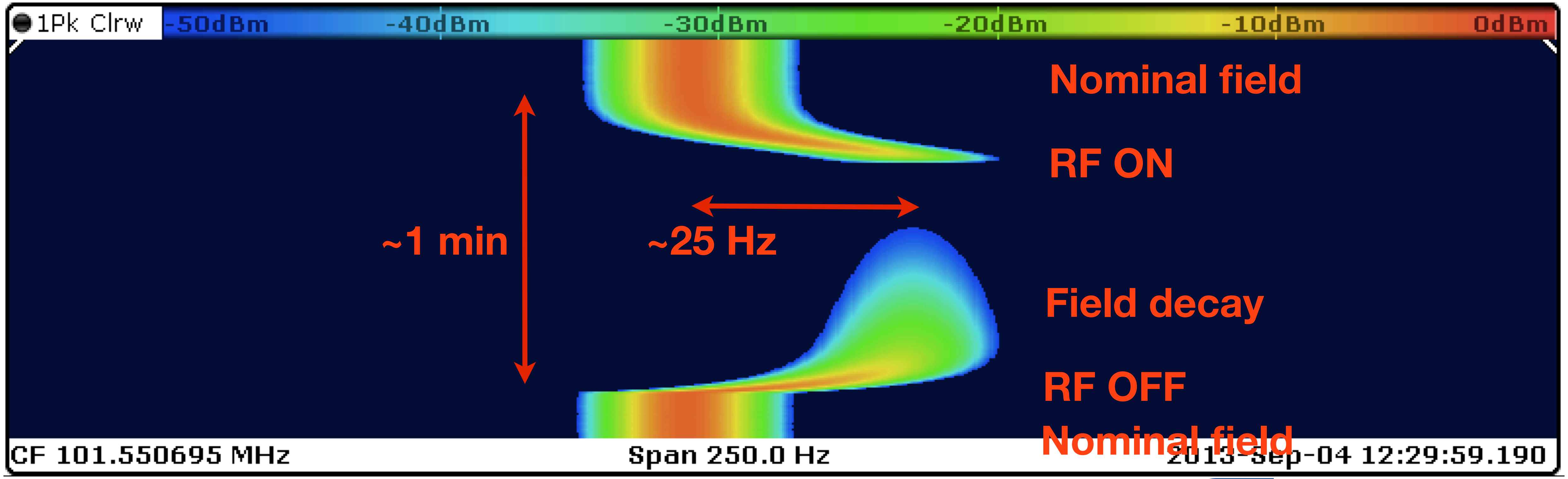
Operational challenges to the RF system

- Very narrow bandwidth operation
  - Cavity intrinsic BW <0.1 Hz
  - Operating BW 1..10Hz
- Large span, very fine resolution mechanical tuner (see talk of Pei Zhang):
  - Full range ~30 kHz (fabrication tolerances, loading by fundamental coupler)
  - but... step size ~0.3 Hz (He pressure drift, keep cavity on tune due to LFD...)

- Initial worry: ***microphonics*** will be the crucial factor for the cavity operation
- Instead, the ***Lorentz force detuning*** (LFD) of the tuning plate turned out to be the killer

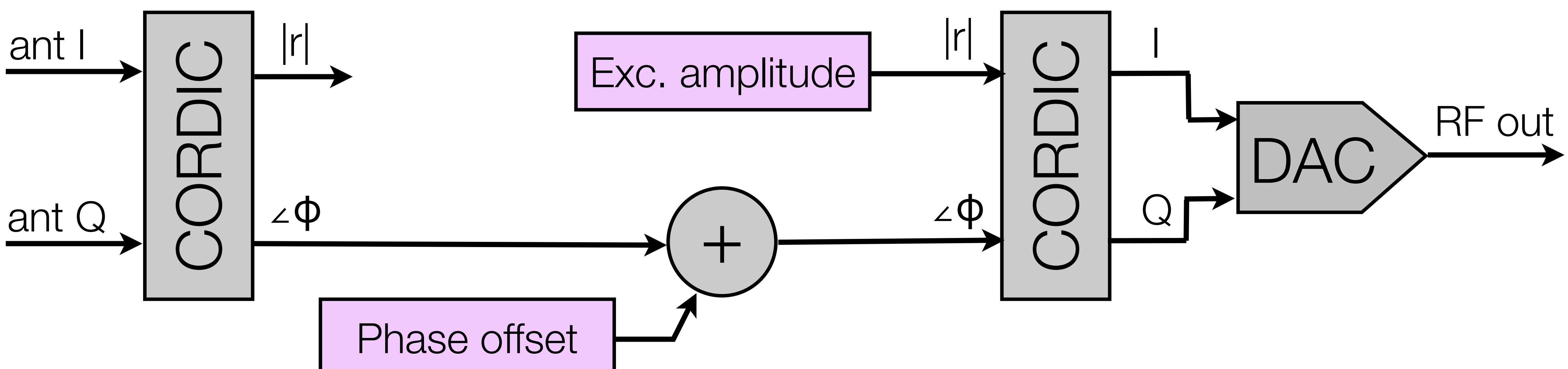
Cavity start-up

- In two words: ***VERY TRICKY***
  - 0.1Hz bandwidth resonator could sit anywhere within the 30kHz range
  - Once some field is in, the LFD will push the resonant frequency off by tens of bandwidths
  - Self Excited Loop (SEL) helps to start the cavity



Self excited loop (SEL)

- Very useful concept for narrowband cavities and/or cavities with large LFD
  - start up the cavity
  - conditioning (when warm and cold)
- Precise control of the injected forward power, loop brings up the field within the cavity time constant
- Very simple to implement in digital domain



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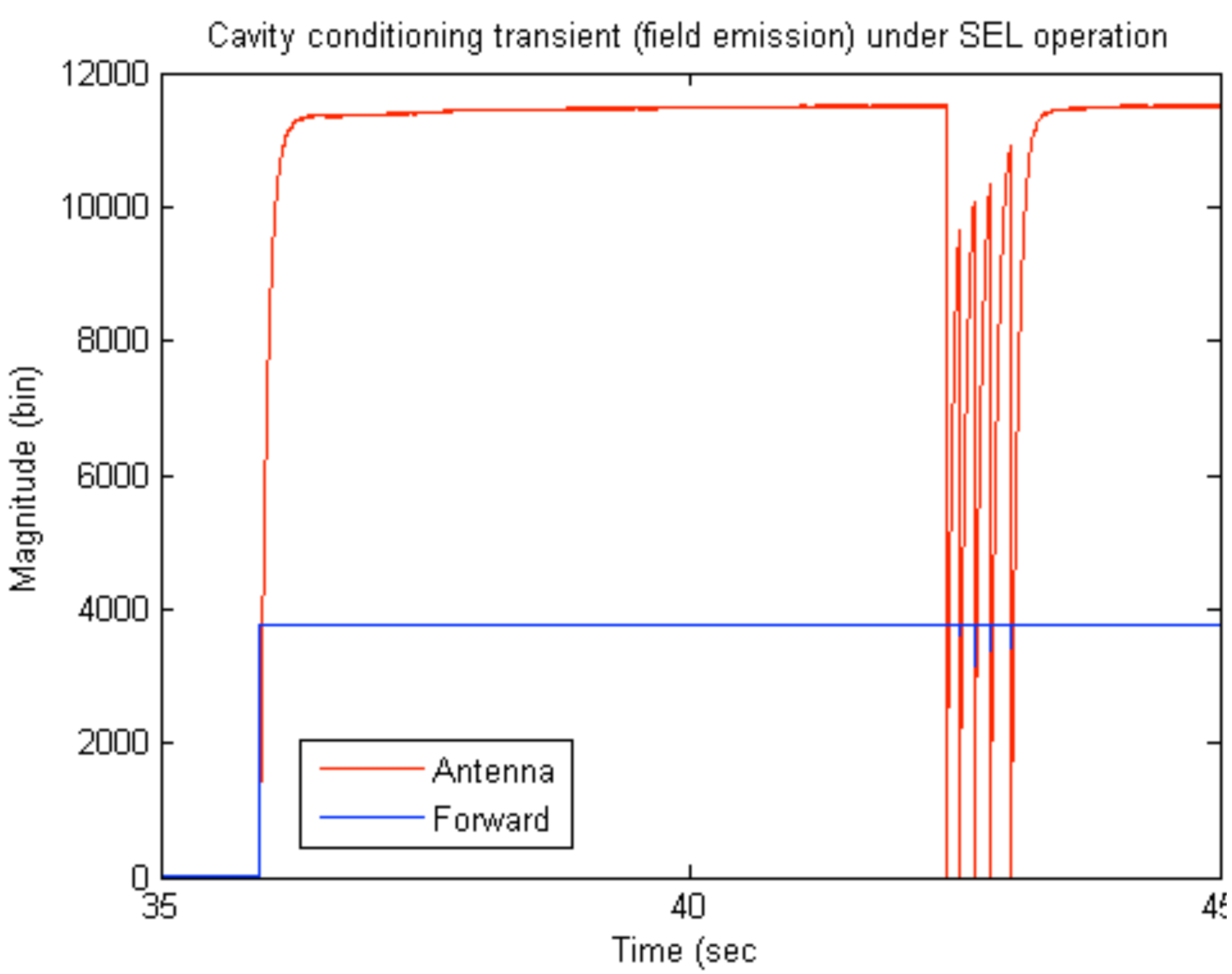
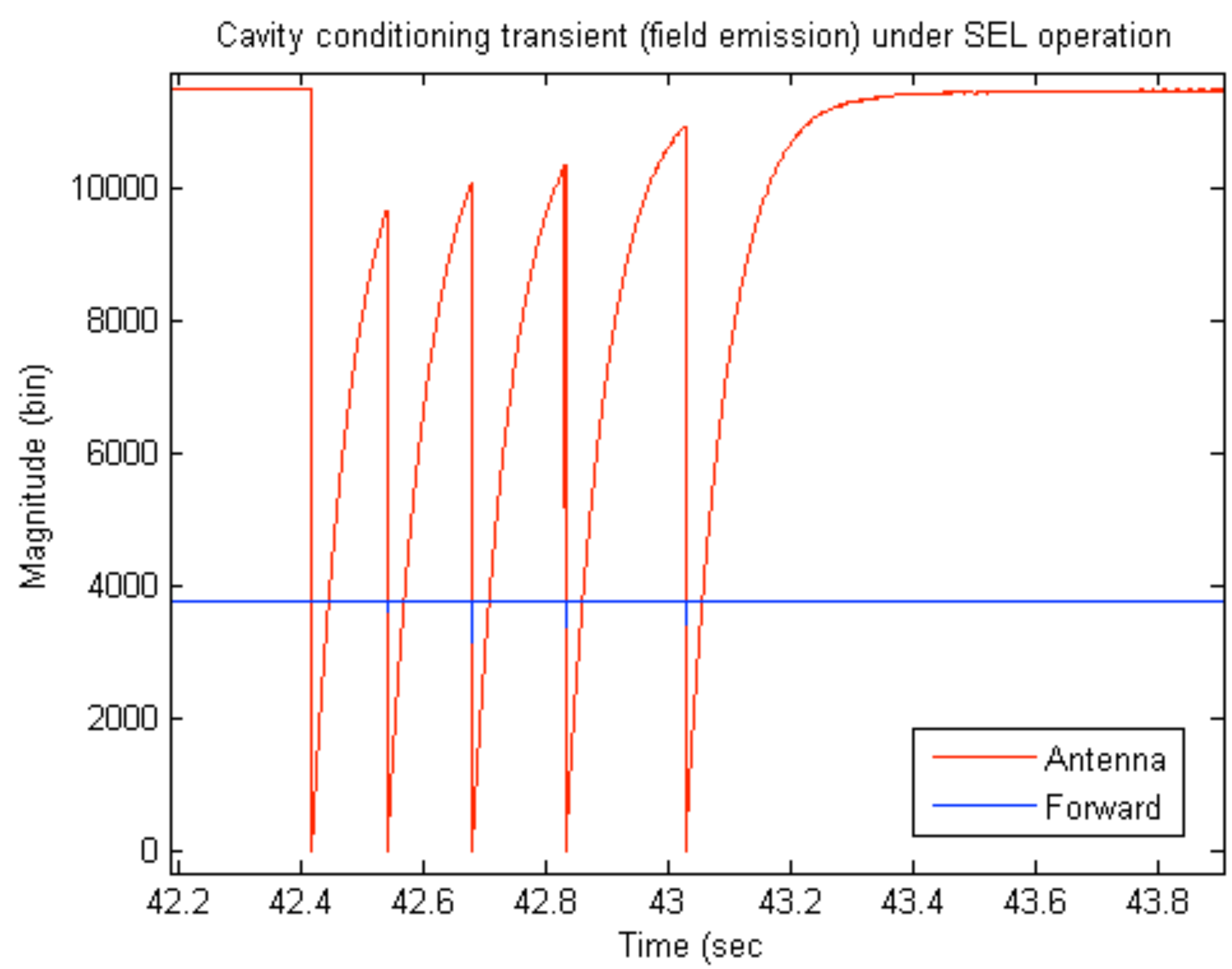
Cavity conditioning with SEL

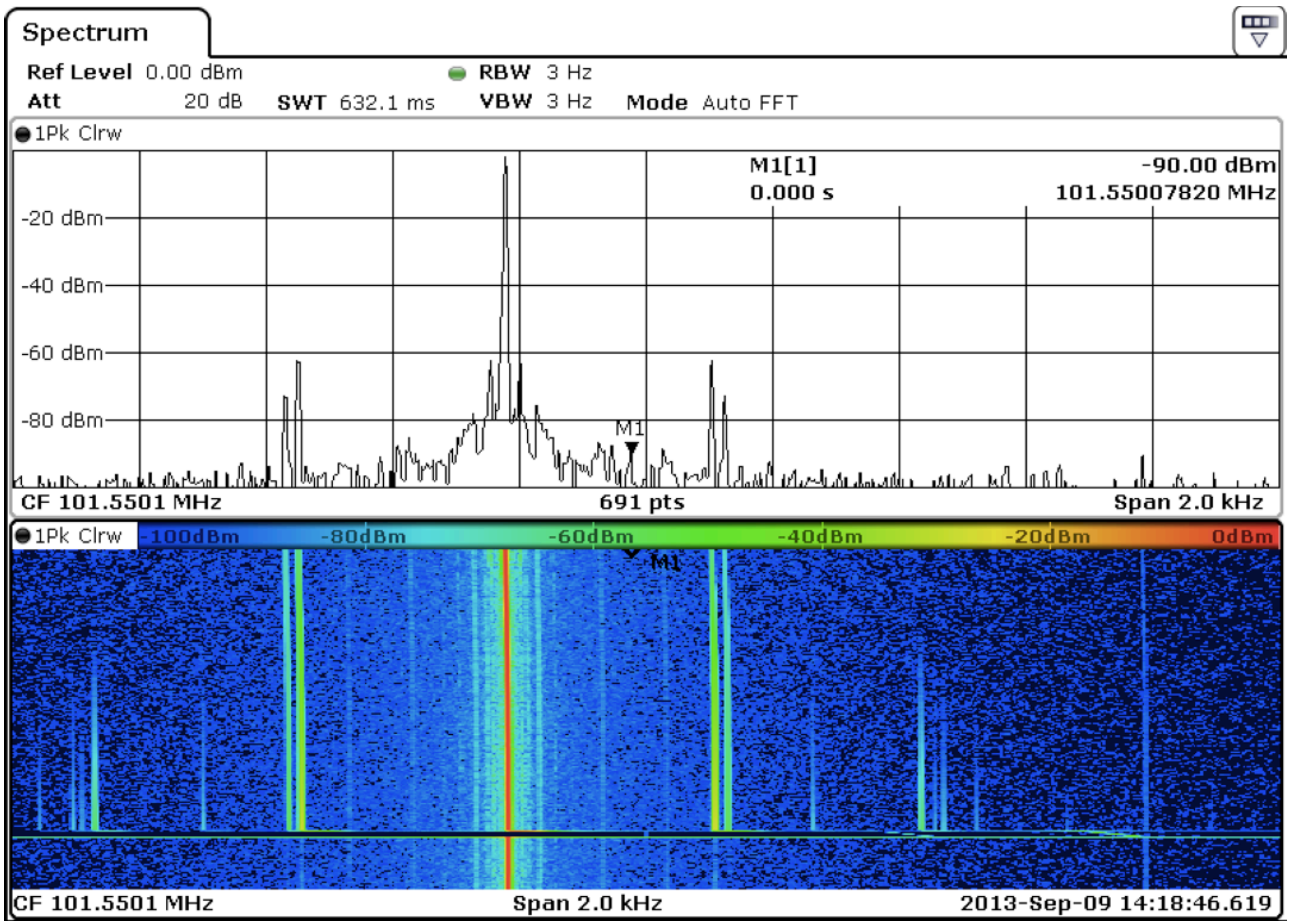
- Due to high LFD, cavity conditioning in “a traditional way” is difficult and ***very*** time consuming
- SEL allows to inject an desired amount of power under any conditions. Instant recovery from trips





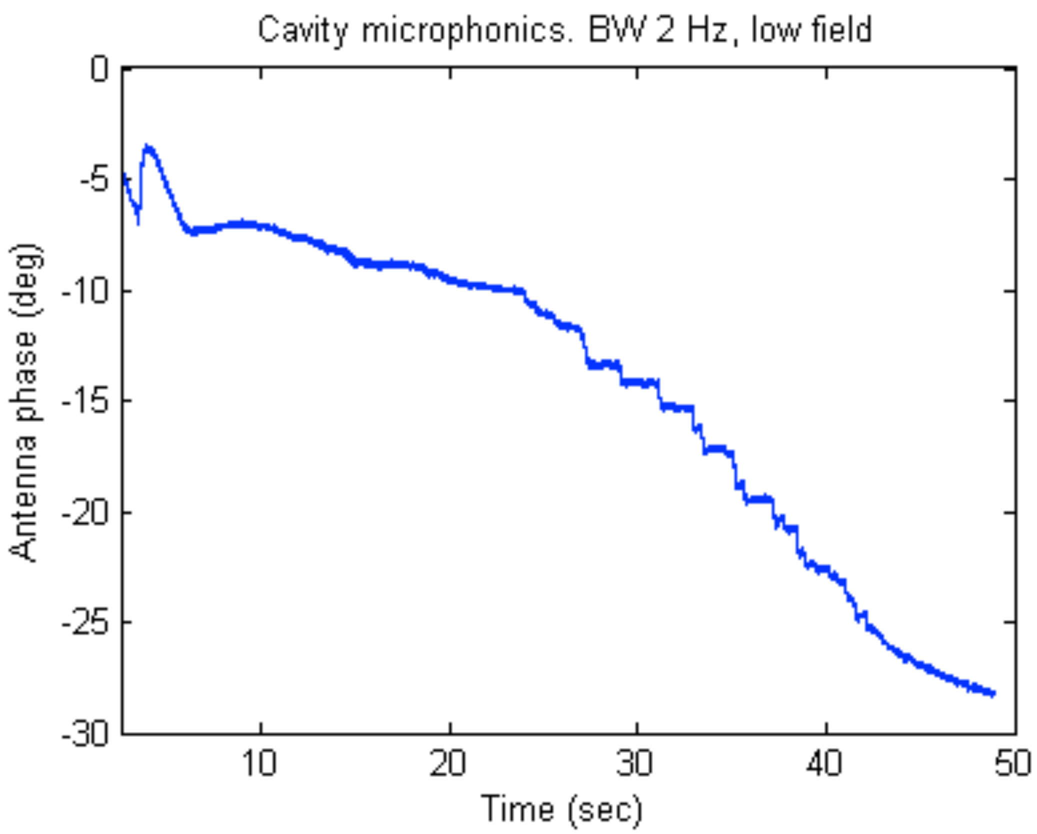
Cavity conditioning with SEL

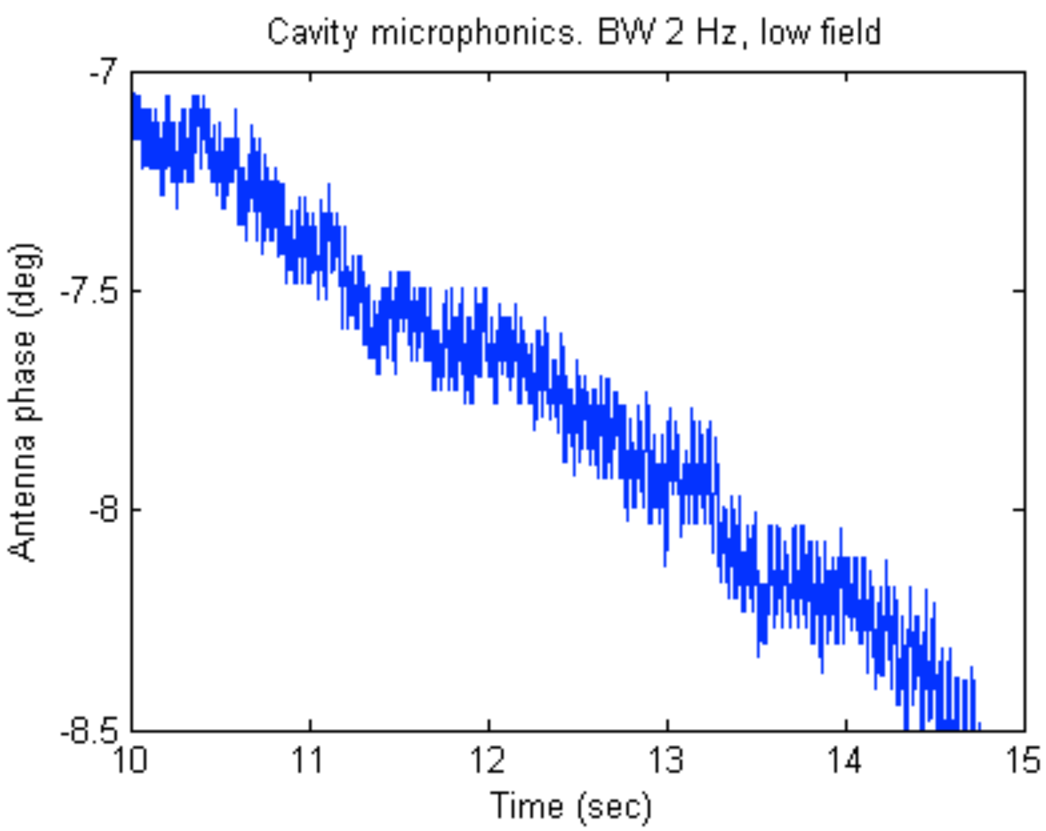
- Automatic conditioning algorithm on the way (X-ray emission monitoring)



Cavity microphonics measurements

- Results show much lower microphonics than anticipated
- Different behaviour at lower and nominal field, not completely understood yet





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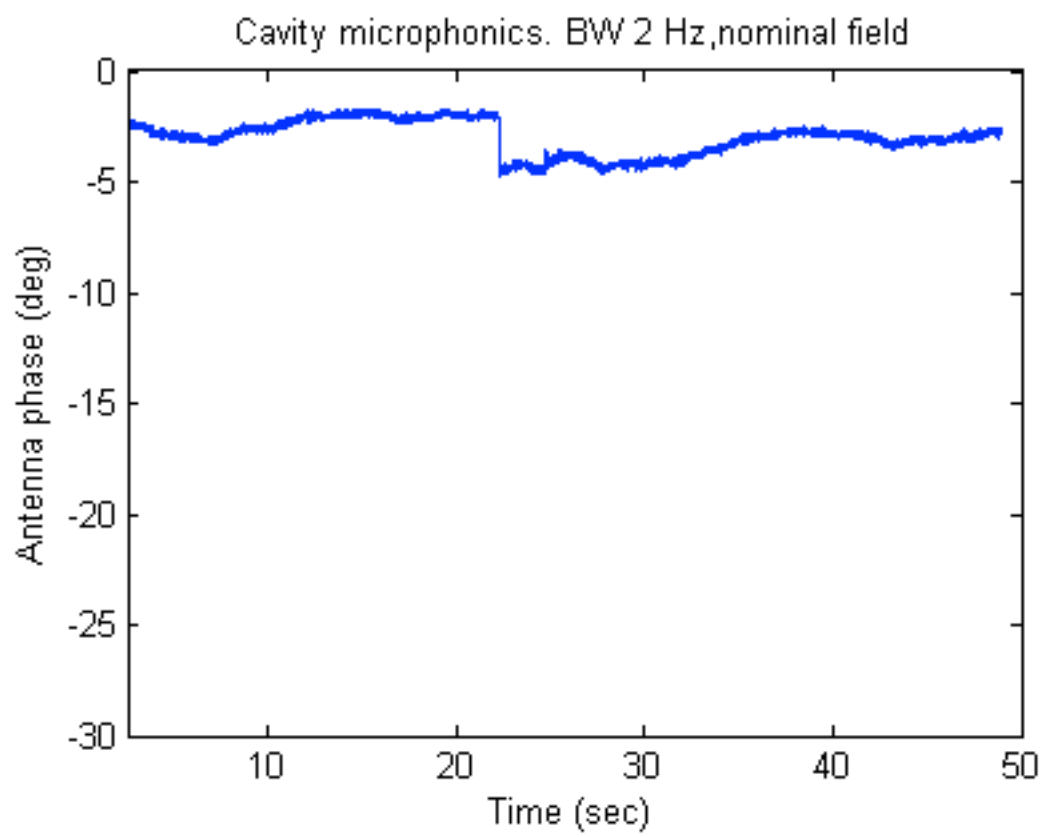

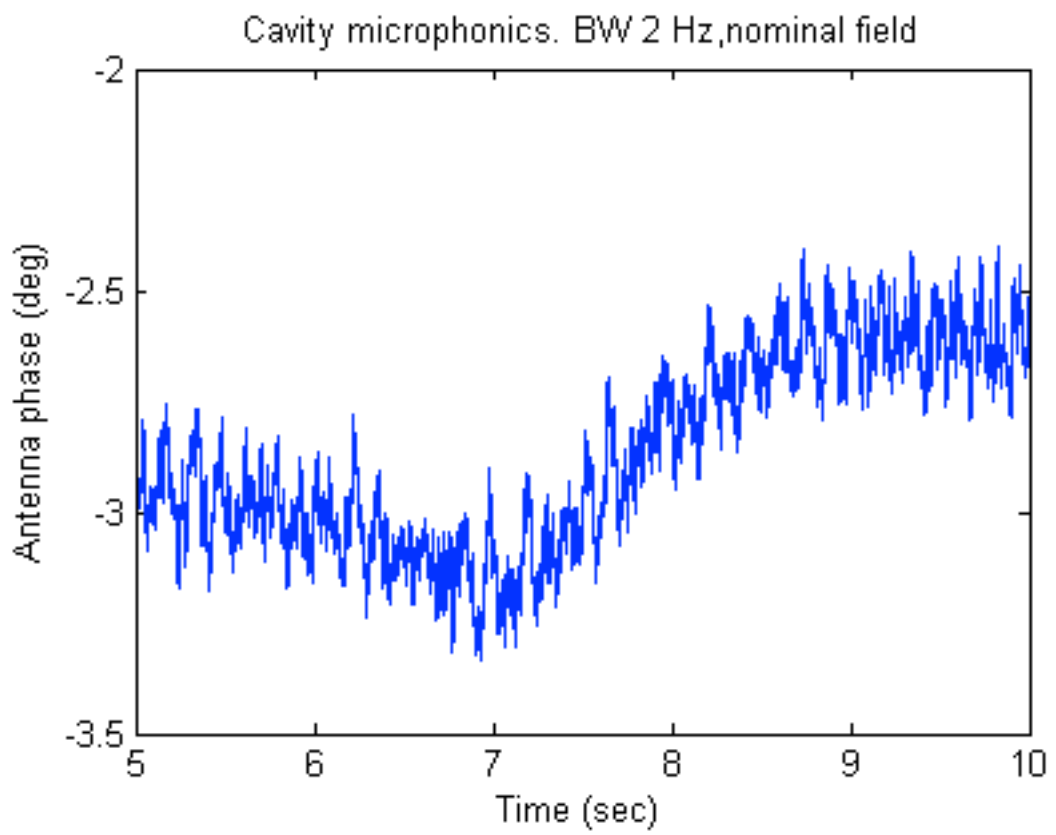

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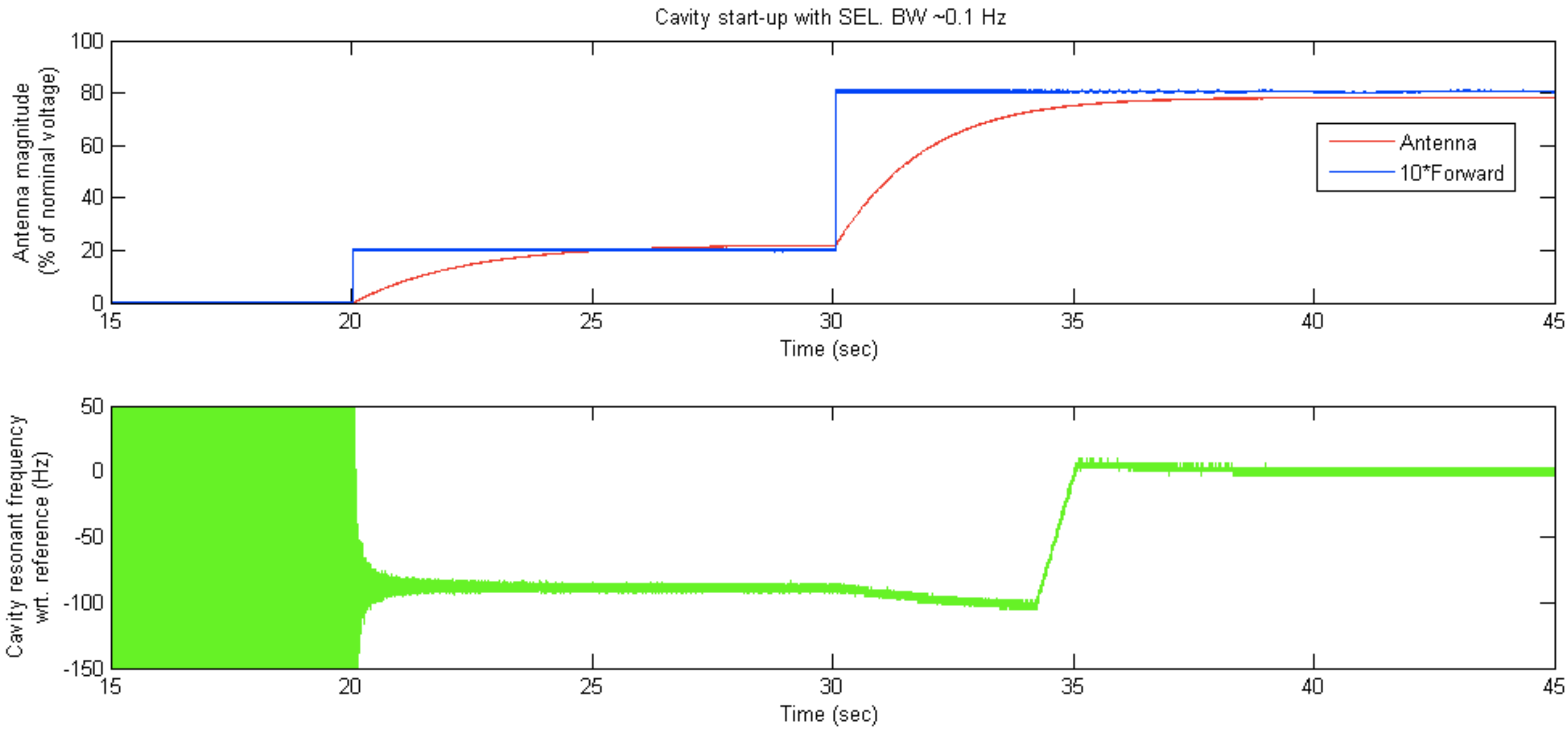
Automatic cavity start-up sequence



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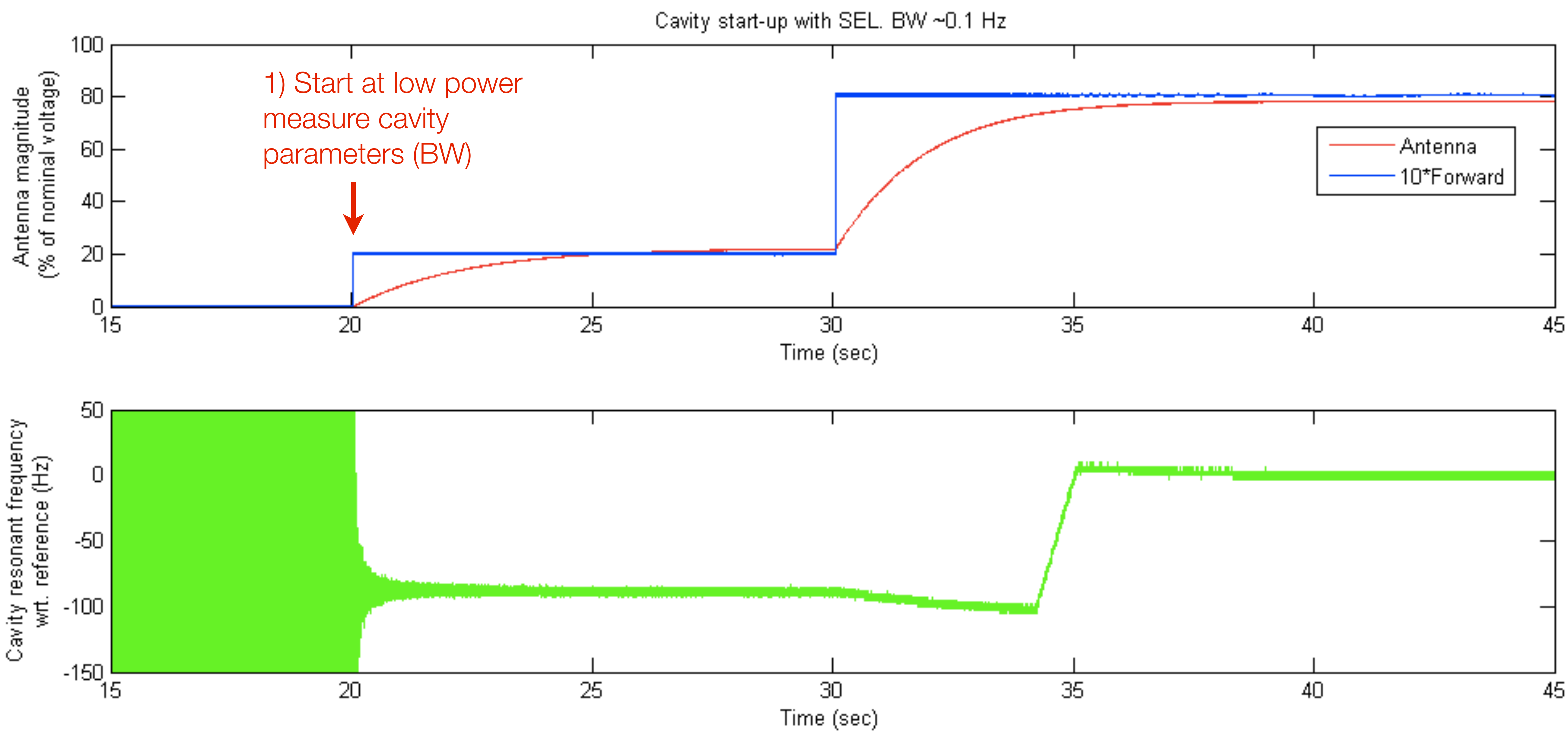

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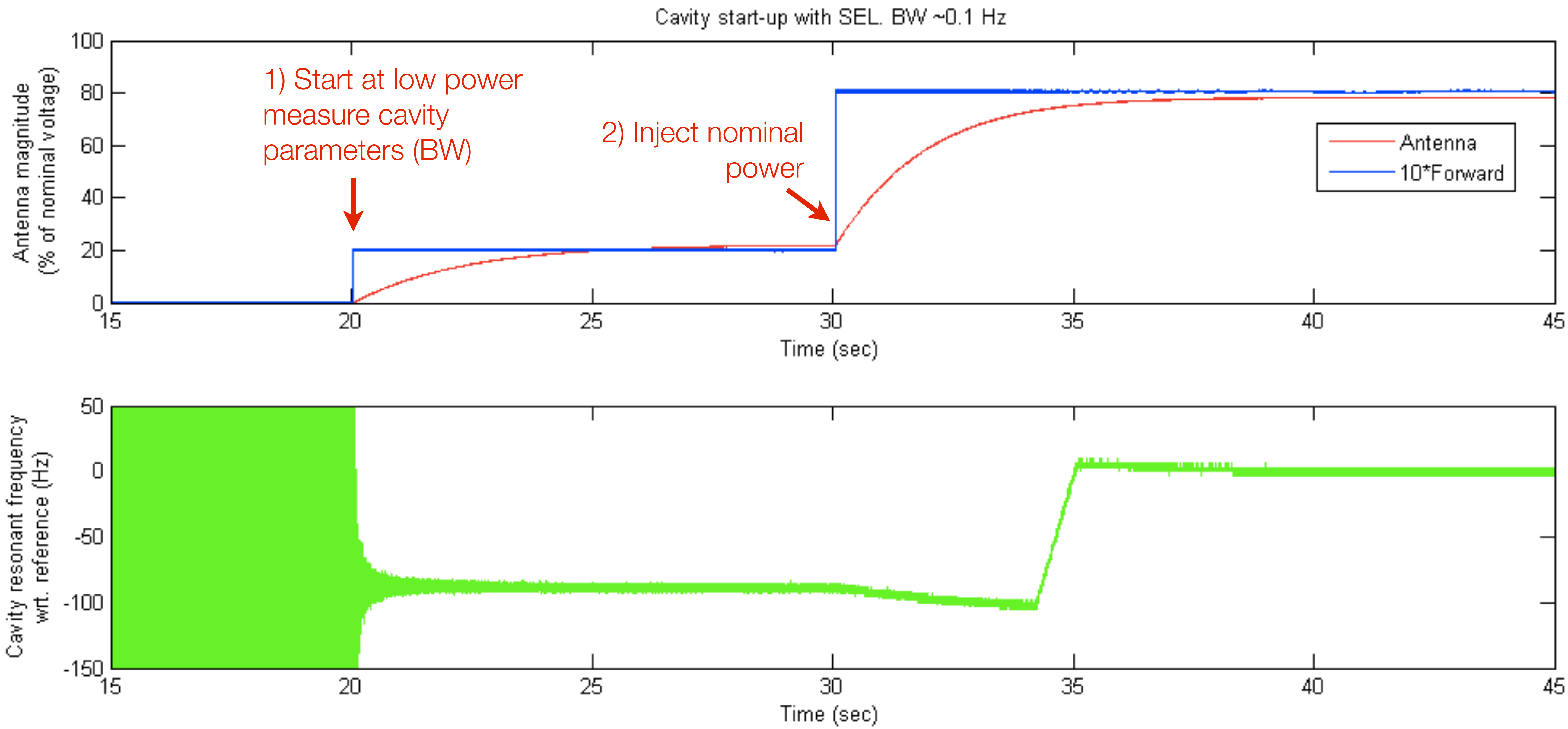

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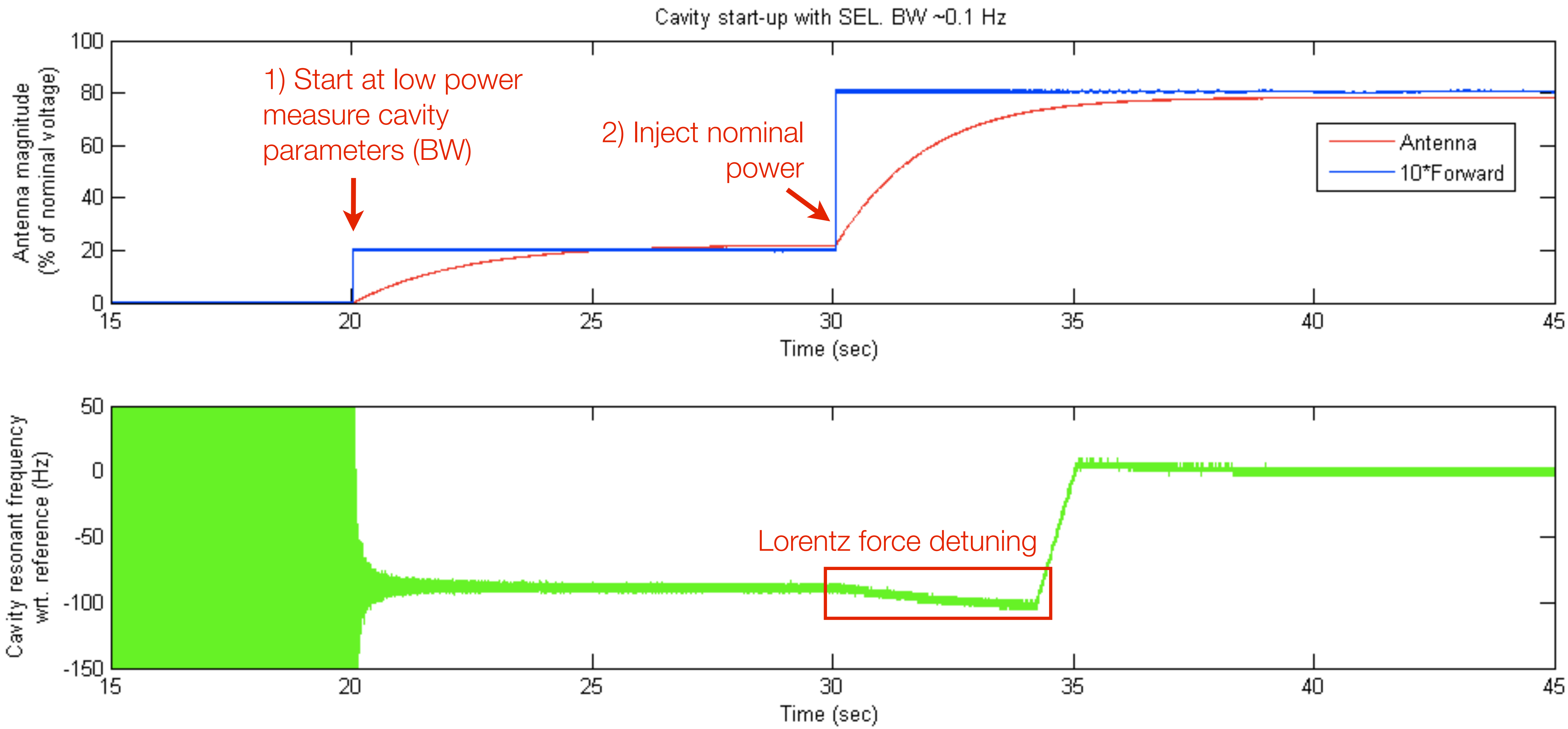

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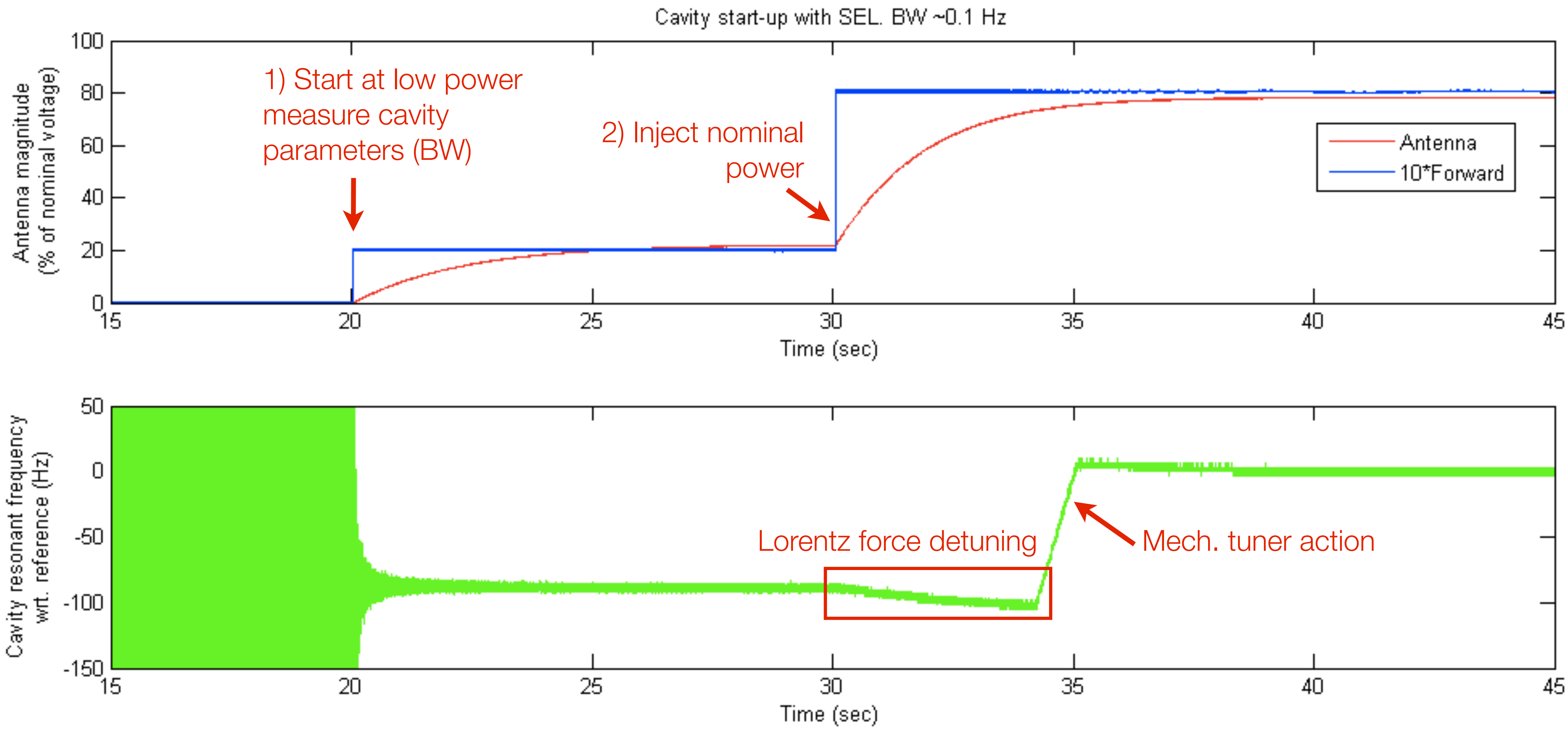

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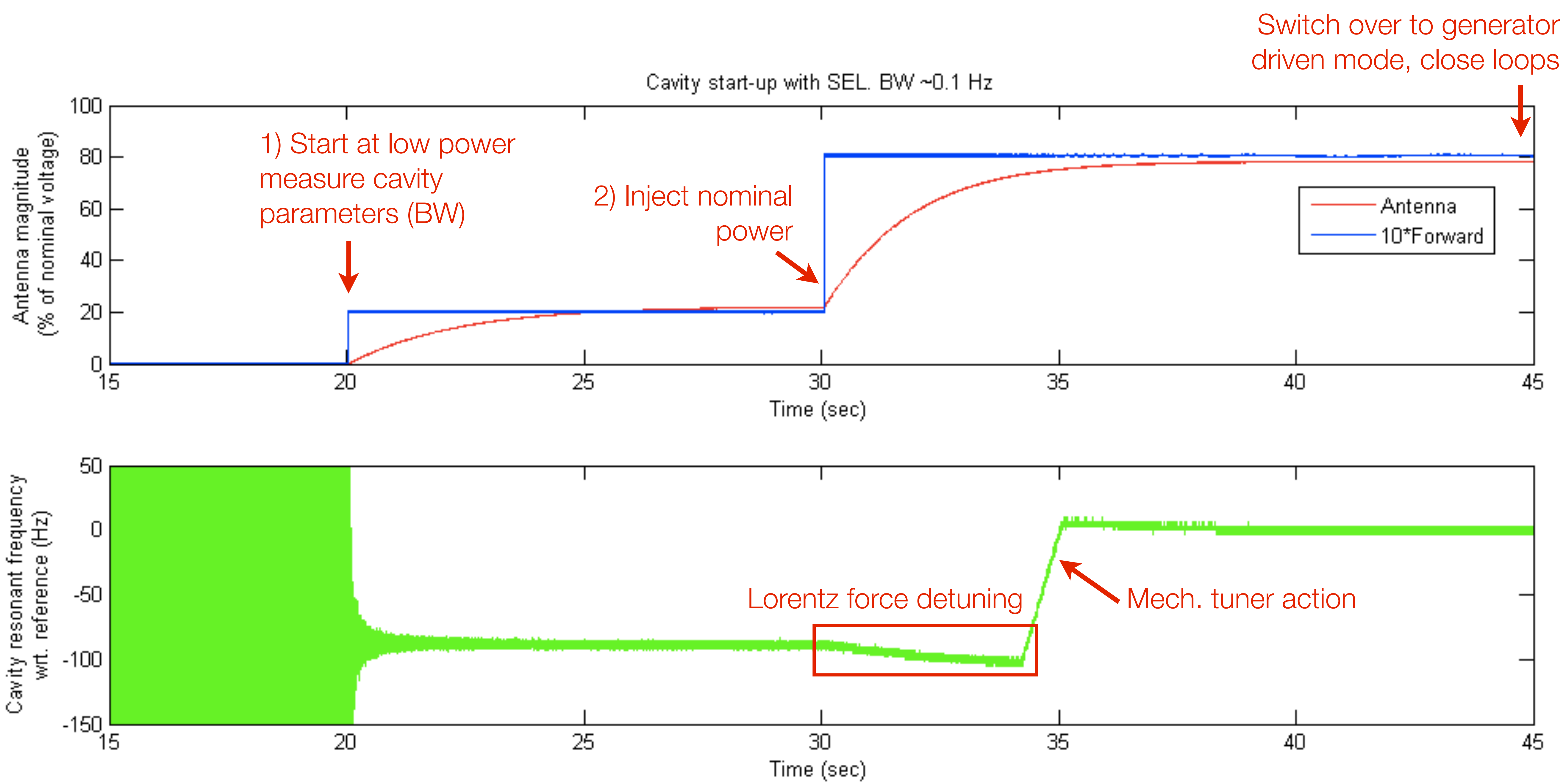

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Automatic linac phasing

- HIE Isolde may change the species and operating mode ***several times a day***
- With 32 cavities no room for manual setting up
- Robust RF design allowed for automatic linac phasing algorithm based on beam dynamics (M. Fraser)
  - Enter the species, desired energy, constraints on cavity voltage partitioning
  - The whole linac should set up automatically just by "pressing a button"
  - Tests on the current normal conducting structures successful

References:

M. Fraser et al.: Preliminary Beam Tests at REX for an Automatic Cavity Phasing Routine at HIE-ISOLDE
S. Haastrup et al.: An application for the automatic tuning of the RF cavities of the HIE-ISOLDE linac

On-going work and planning

- Implementation of the feedback controller
- "Physicist-proof" design to minimize the need of RF expert interventions
  - OFF -> cavity start -> RF ON -> Linac Ready

- Integration mostly finished (shielded racks, cooling/ventilation)
- Procurement of solid state amplifiers, racks, cabling ongoing
- Three prototypes of the LLRF controllers already arrived
- Software work ongoing (low level, high level, user interfaces)
- ***First RF in the machine expected in <12 months.***

Summary

- 32 Nb sputtered quarter wave resonators running at ~Hz bandwidth (@101.28 MHz)
- Solid state RF amplifiers (750 W)
- LLRF system fully digital (direct RF sampling/generation)
- Automatic linac setting up based on desired species and final energy
- Automatic cavity conditioning system with self excited loop
- Difficult cavity start up and handling procedure (SEL/tuning/feedback)

- Steady progress, first RF in the machine expected in <12 months

Thank you for your attention