Universidad del País Vasco / Euskal Herriko Unibertsitatea
ZIENTZIA ETA TEKNOLOGIA FAKULTATEA
FACULTAD DE CIENCIA Y TECNOLOGÍA
SCIENCE AND TECHNOLOGY FACULTY
LEIOA
GAUDEE Research group
Experimental Automatic Control

HZB Helmholtz Zentrum Berlin

Superconducting radio-frequency virtual cavity for Hardware-In-the-Loop testing

J. Jugo[1]
P. Echevarria[2], E. Aldekoa[1], J. A. Neumann[2], A. Ushakov[2], J. Knobloch[2], I. Badillo[1]
(1) University of the Basque Country (UPV/EHU) , (2) Helmholtz Zenrtrum Berlin

24-26 October 2018

[Second Topical Workshop on Microphonics, LLRF Workshop Series]

MRCW18

Outline

MRCW18

- Introduction
  - Collaboration between HZB and UPV/EHU
- FPGA based simulator for SRF cavities
- Hardware-In-the-Loop testing: microphonics
- Conclusions and future work

MRCW18

Collaboration between HZB and UPV/EHU

in the field of LLRF control since December 2016

- Helmholtz Zentrum Berlin, internationally recognized research center, operating two large scientific facilities, BER II and BESSY II
- University of the Basque Country (UPV/EHU) Laboratory of accelerator technology (IZPIlab)

Experience in modeling and control of electromechanical systems

Collaboration topics:

- SRF Cavity simulator, initially developed in HZB
- Microphonics compensation algorithms studies
- RF phase drifts compensation techniques
- Experimental vibration mode determination
- Mechanical transfer function fitting

Erasmus+ stays in HZB:
Graduate and Post Graduate students from the UPV/EHU

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First Collaboration Result:

Superconducting radio-frequency virtual cavity for control algorithms debugging
P. Echevarria, E. Aldekoa, J. Jugo, A. Neumann, A. Ushakov, J. Knobloch,
Review of Scientific Instruments, Volume 89, Issue 8 ,(2018)

- Experimental vibration mode determination
- Mechanical transfer function fitting

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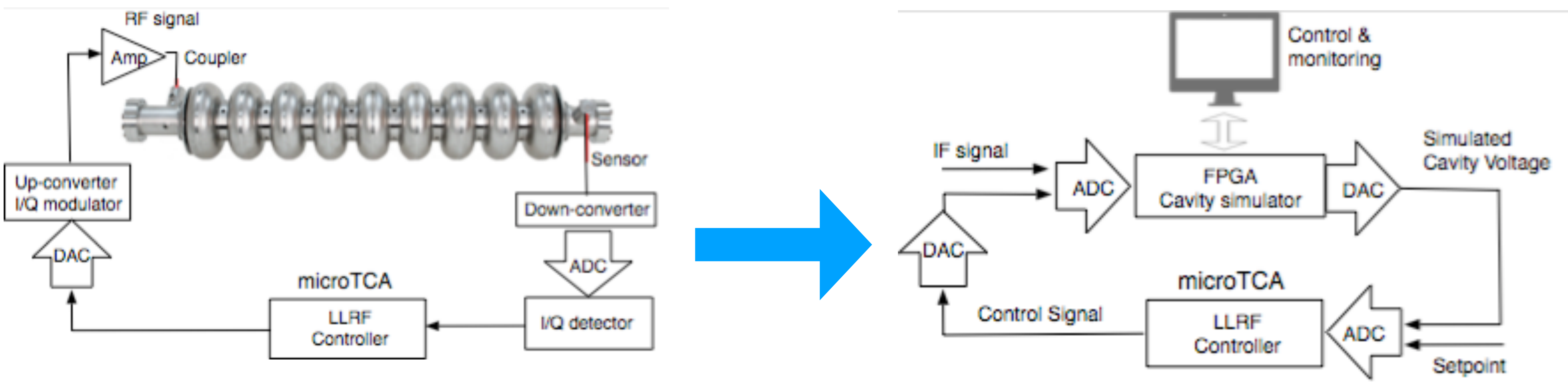
Simulator for SRF cavities



Main purpose: Hardware-in-the loop prototyping

- Test of different LLRF control techniques
- Microphonics compensation algorithms studies

Example in this session :

Control system design for SRF cavity based on Kalman Filter observer

Andrey Ushakov

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- Introduction
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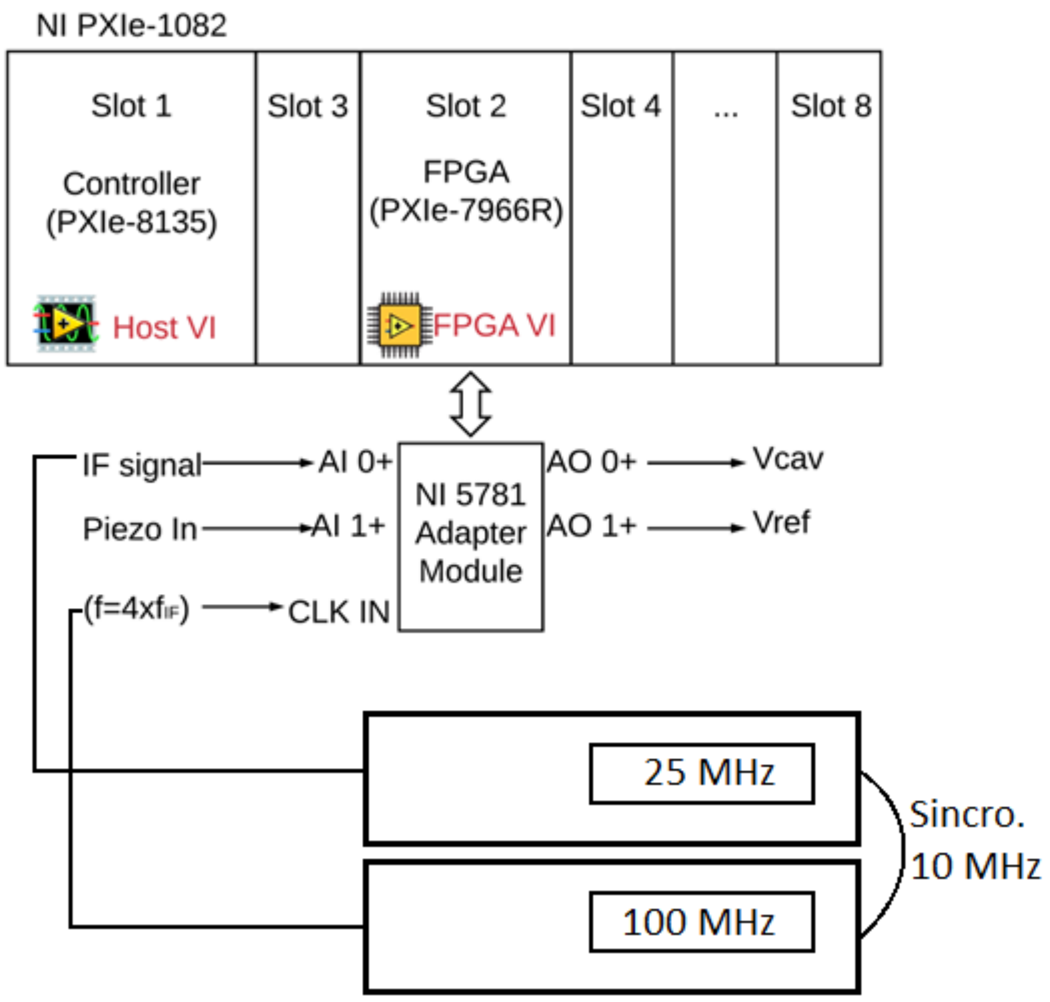
- **FPGA based simulator for SRF cavities**
- Hardware-In-the-Loop testing: microphonics
- Conclusions and future work

- Implementation details

  - LabVIEW based using PXI and FlexRIO technology
  - Reconfigurability
  - Rapid prototyping
  - Compatible with the technology used in la UPV/EHU lab

Image: From National Instruments



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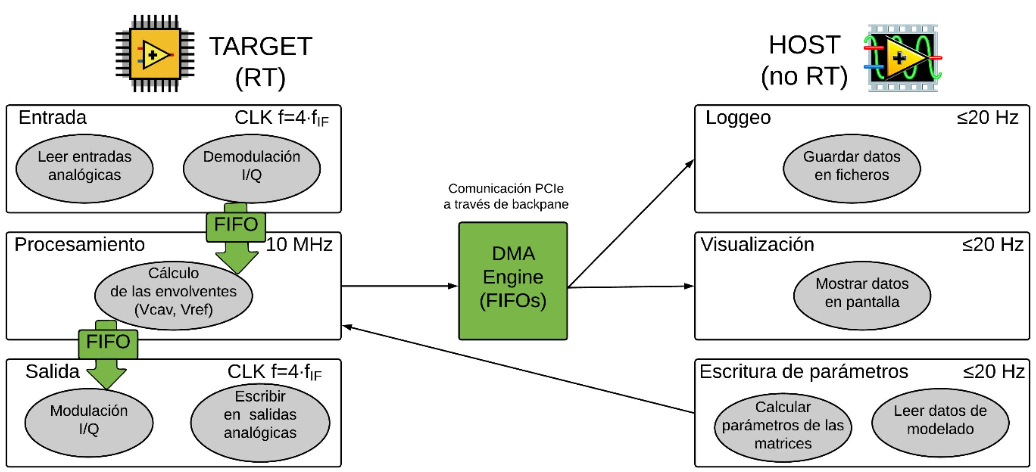

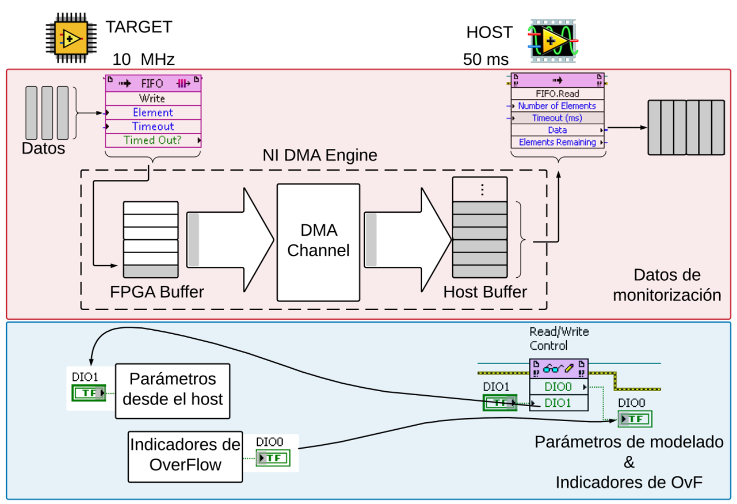

Sampling clock (ADC) , 100MHz

Computation clock (FPGA) , 10MHz

Communication between host (LabVIEW APP) and FPGA -> DMA based FIFO

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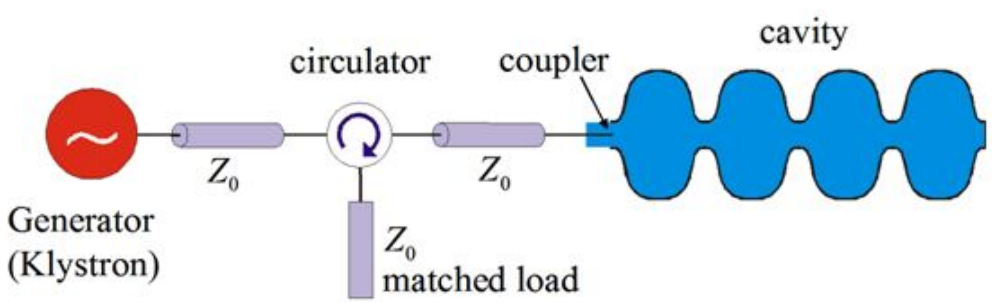
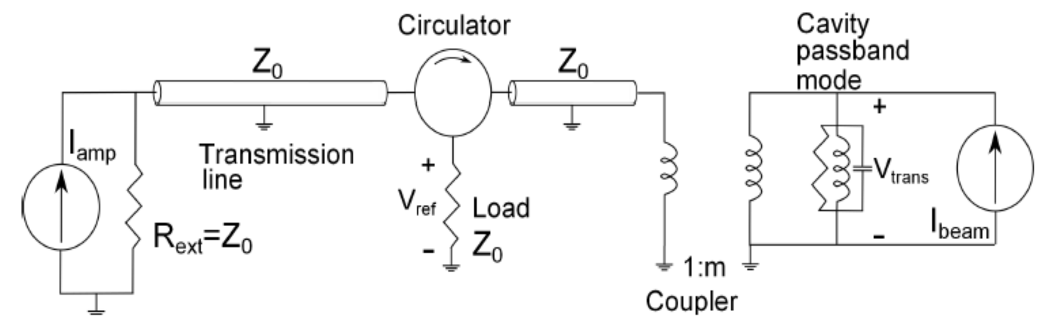
- Implementation details: cavity model





Electric part model

$$\frac{d}{dt}\boldsymbol{V_{cav}} = \begin{pmatrix} -\omega_{1/2} & -\Delta\omega \\ \Delta\omega & -\omega_{1/2} \end{pmatrix} \boldsymbol{V_{cav}} + \begin{pmatrix} R_L\omega_{1/2} & 0 \\ 0 & R_L\omega_{1/2} \end{pmatrix} \boldsymbol{I_{in}}$$

Mechanic part model

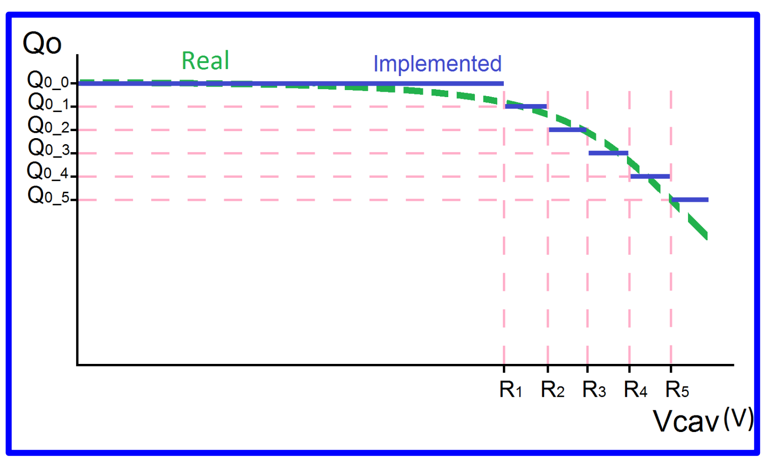
Lorenz force detuning + microphonics effects

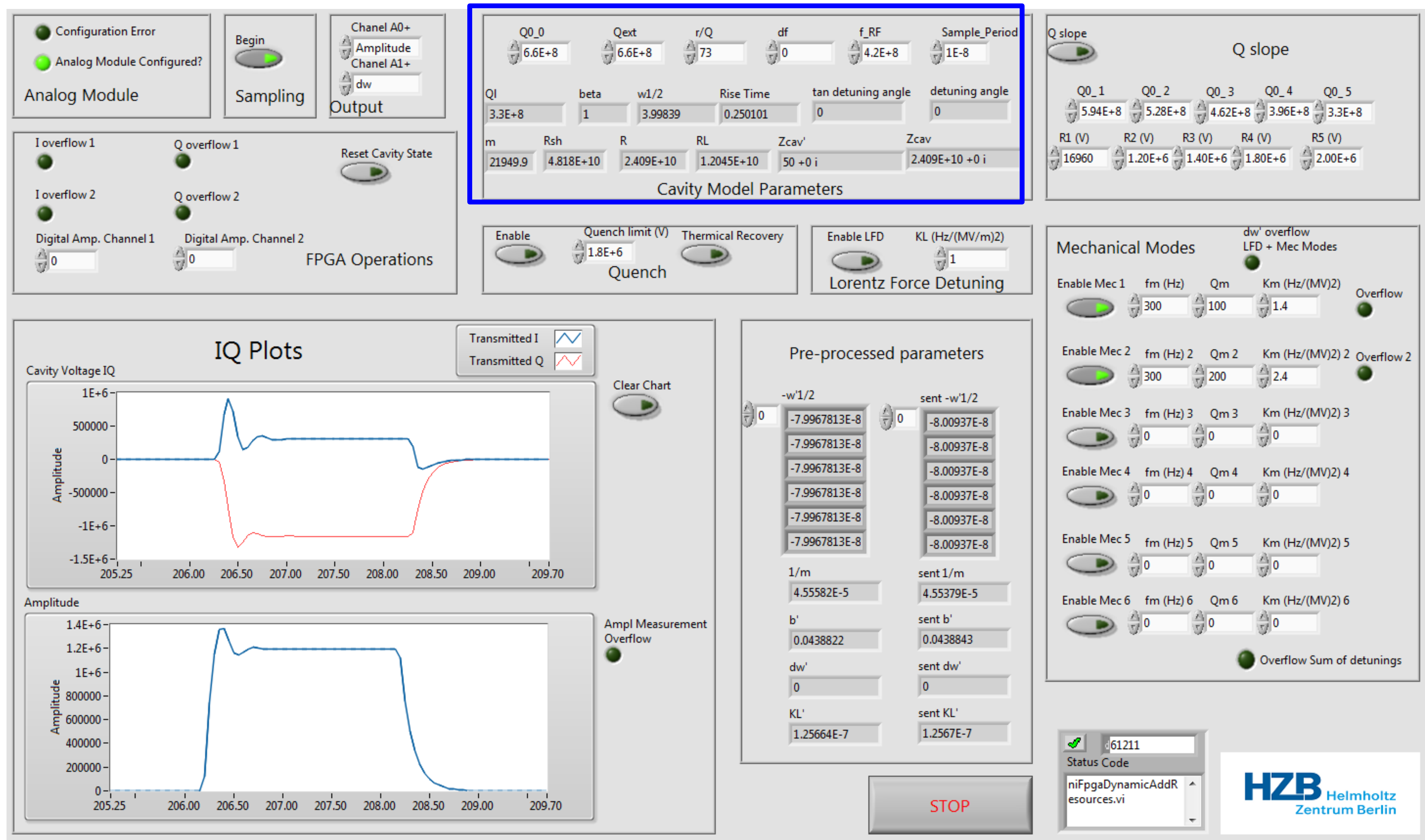
$$\frac{d}{dt}\begin{pmatrix} \Delta\omega_m(t) \\ \Delta\dot{\omega}_m(t) \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -\omega_m^2 & -\frac{\omega_m}{Q_m} \end{pmatrix} \cdot \begin{pmatrix} \Delta\omega_m(t) \\ \Delta\dot{\omega}_m(t) \end{pmatrix} + \begin{pmatrix} 0 \\ -K_m\omega_m^2 \end{pmatrix} \left(E_{cav}^2 + U_{pert}\right)$$

- Implementation details: GUI

Host VI

- Electric model parameters
- Mechanical model parameters
- Non linear effects
  - Q slope
  - Quench

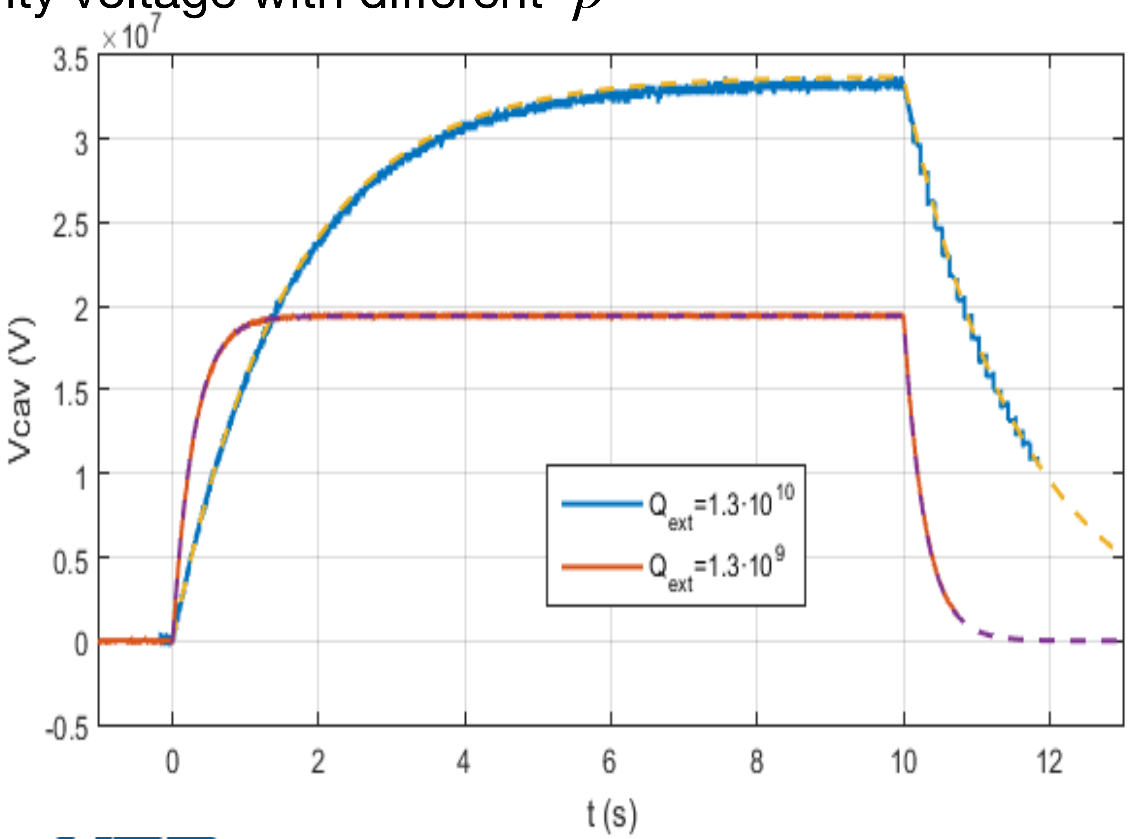




Extensive simulation tests

- Individual functionalities ✓
  - Electric model
  - Mechanic model
  - Microphonics
  - Lorenz Force Detuning
- Full model ✓

Test of TESLA (9 cells) cavity voltage with different β



Extensive simulation tests

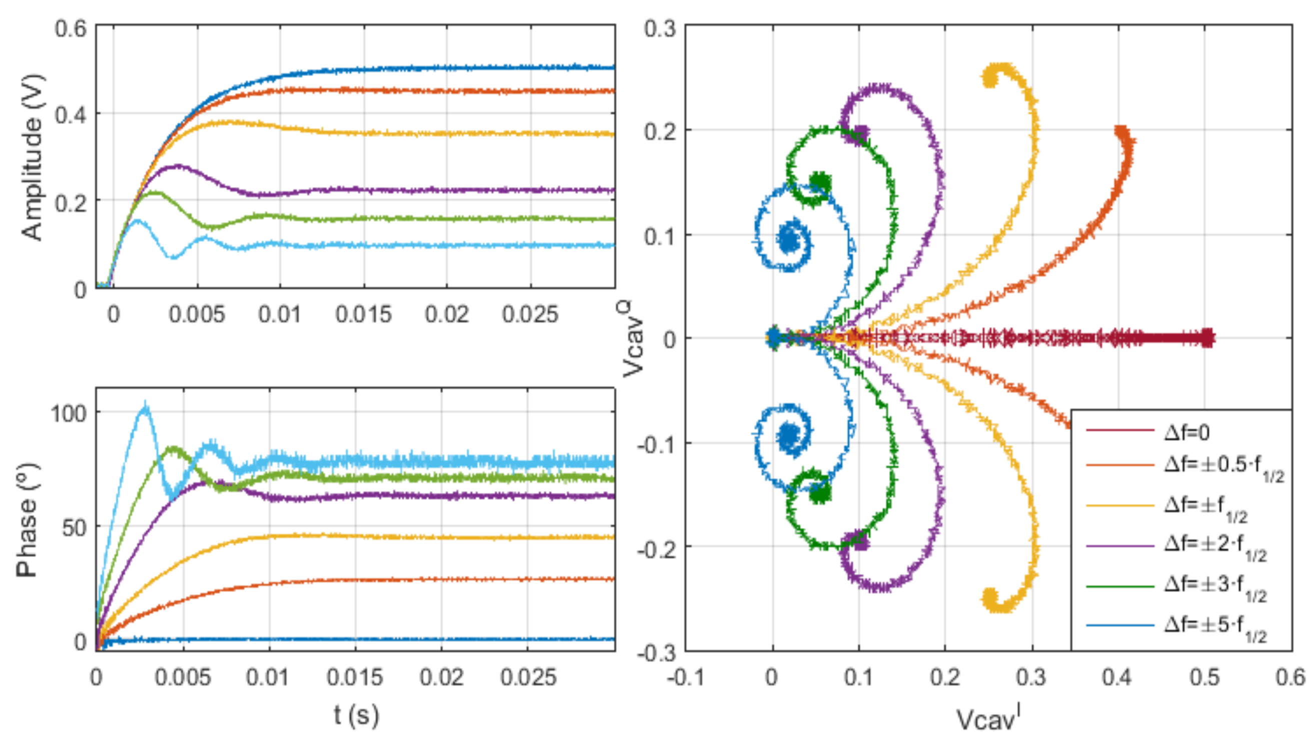
➢Individual functionalities ✓

- Electric model
- Mechanic model
- Microphonics
- Lorenz Force Detuning

➢ Full model ✓

Test of TESLA (9 cells) cavity:
Amplitude and phase with different detuning

$$A = \begin{pmatrix} -\omega_{1/2} & \Delta\omega \\ \Delta\omega & -\omega_{1/2} \end{pmatrix}$$



Results from Eukeni Aldekoa's Master Degree

Extensive simulation tests

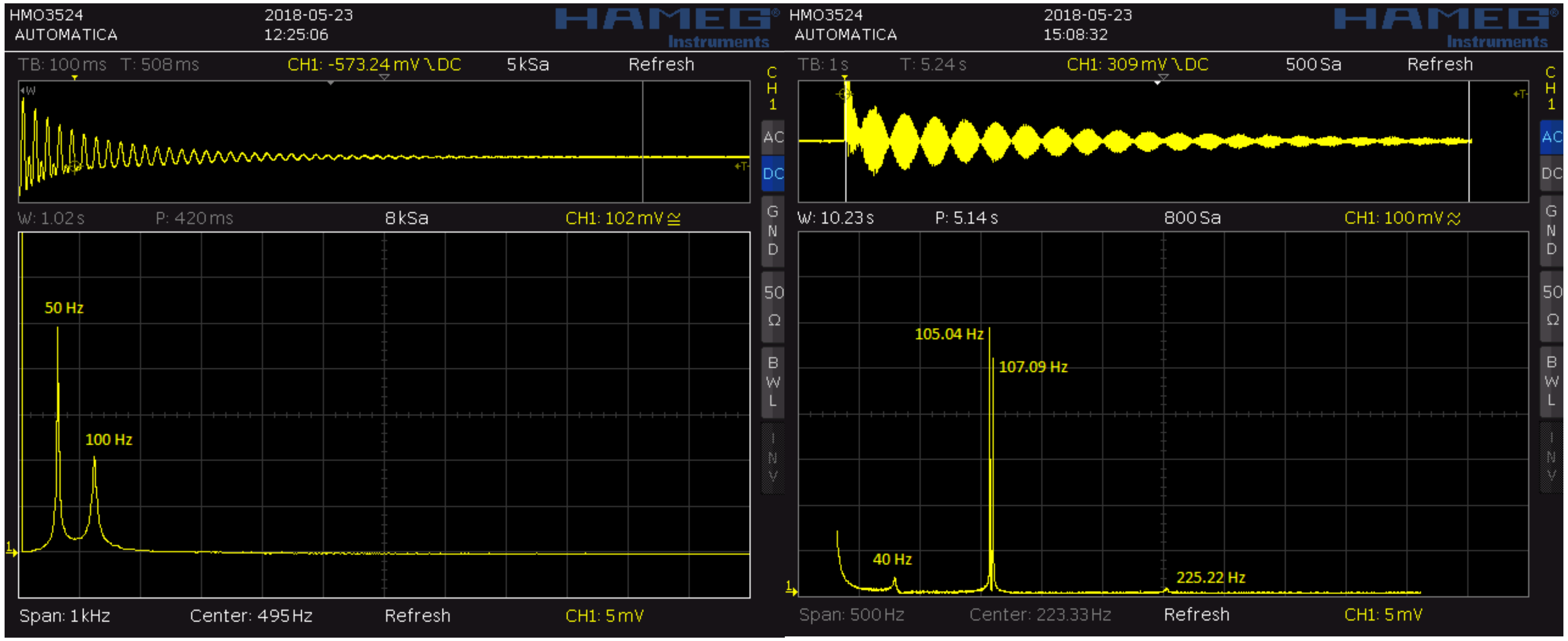
➢ Individual functionalities ✓

- Electric model
- Mechanic model
- Microphonics
- Lorenz Force Detuning

➢ Full model ✓

Test of TESLA (9 cells) cavity:

Detuning effect observed in the oscilloscope



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- **Hardware-In-the-Loop testing: microphonics**
- Conclusions and future work

- **HIL testing of control techniques, possibilities**

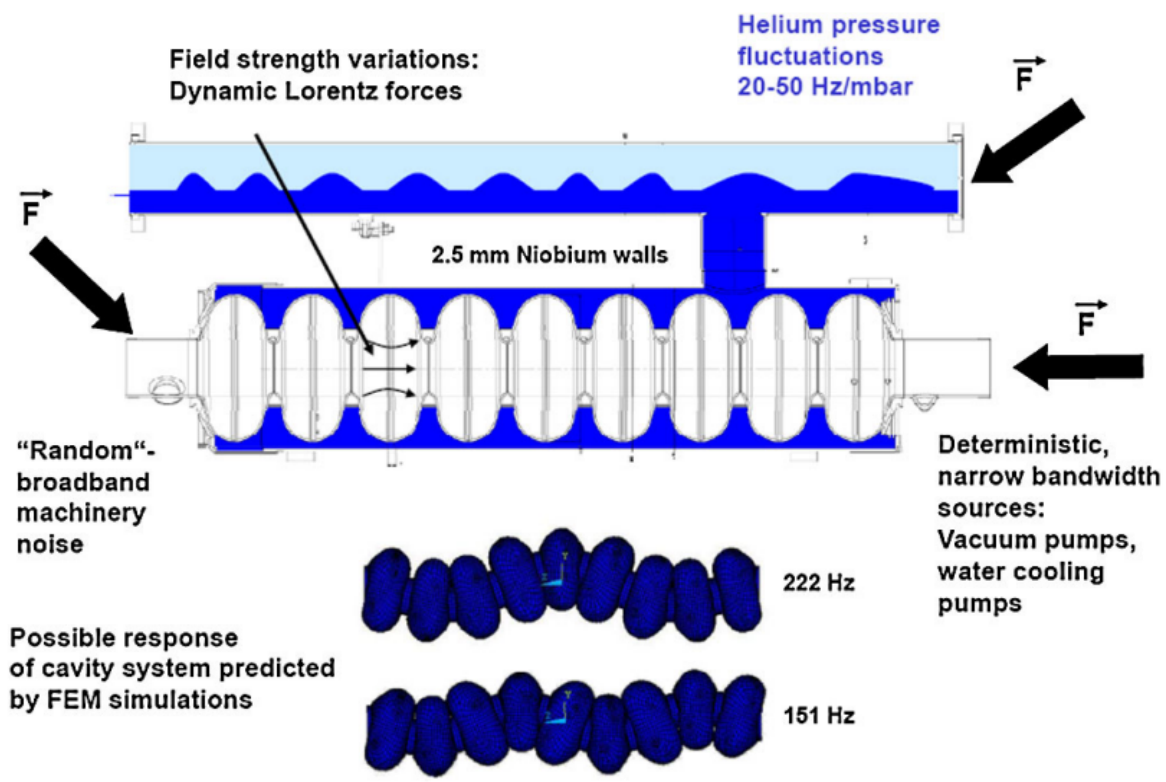
  - Amplitude and phase
  - Resonance frequency
    - Feedforward → LFD

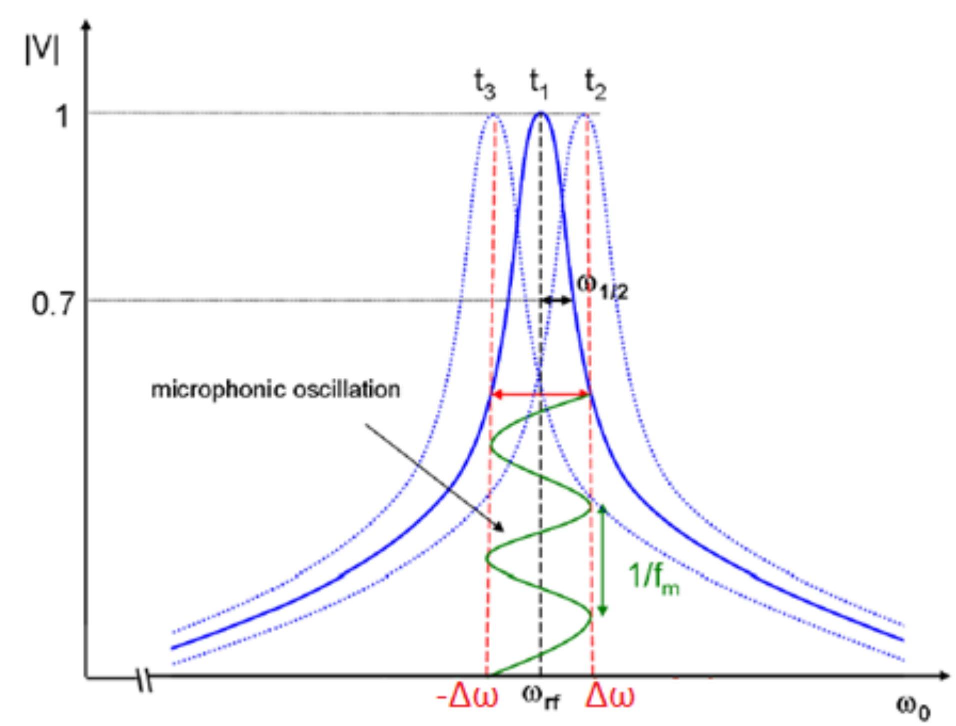
and microphonics?

- Test of different disturbances:
  - impulse, step, sinusoidal signals, white noise

Motivation

Analysis and active compensation of microphonics in continuous wave narrow-bandwidth superconducting cavities
A. Neumann, W. Anders, O. Kugeler, and J. Knobloch
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, 13



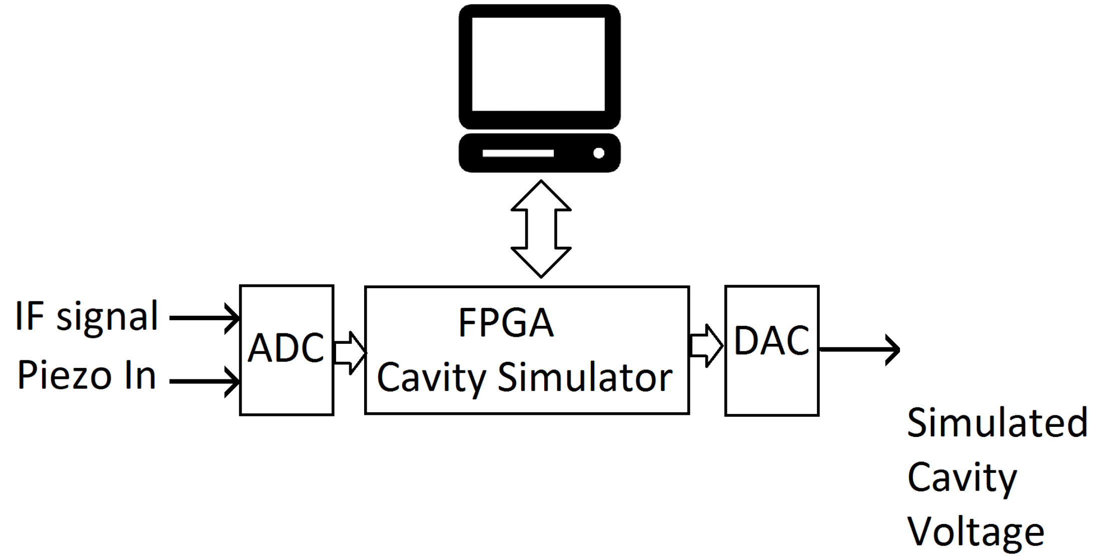


- New functionalities: Piezoelectric actuator model

Piezoelectric actuator model (discrete version)

$$\Delta\omega^{DC}(k) = \frac{M_0 T_s}{T_s + \tau} V_{piezo}(k) + \frac{\tau}{T_s + \tau} \Delta\omega^{DC}(k-1)$$

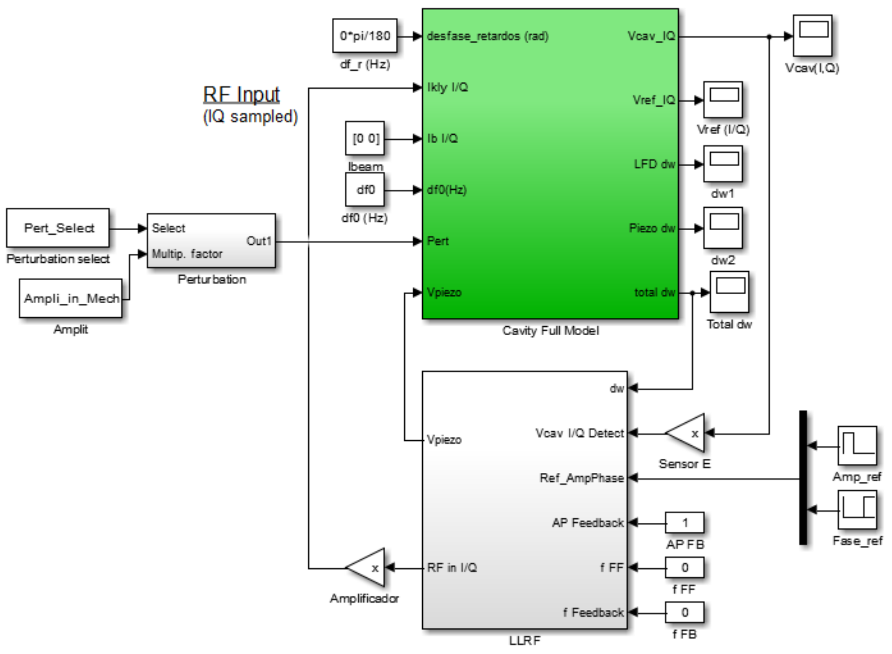
New possibility: HIL testing of control techniques against microphonics effect

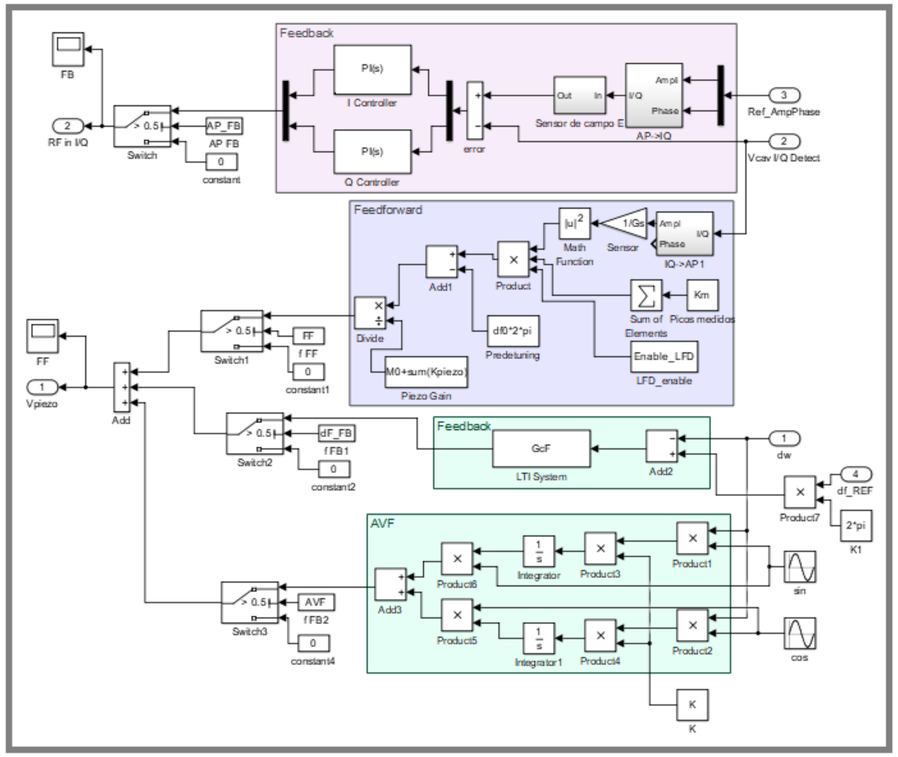


- Initial pure simulation test

Matlab/Simulink

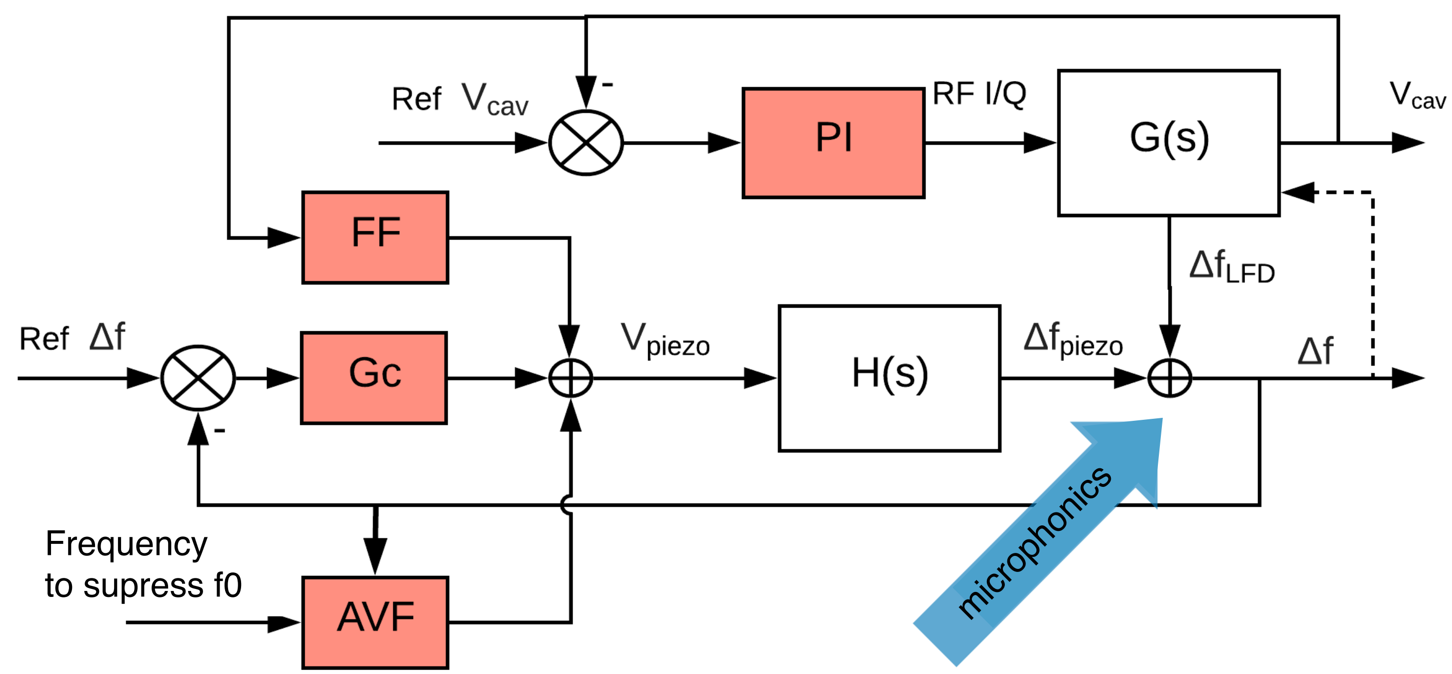
- Amplitude and Phase control
- Feedforward control for LFD
- Active vibration control





- Initial pure simulation test

Matlab/Simulink



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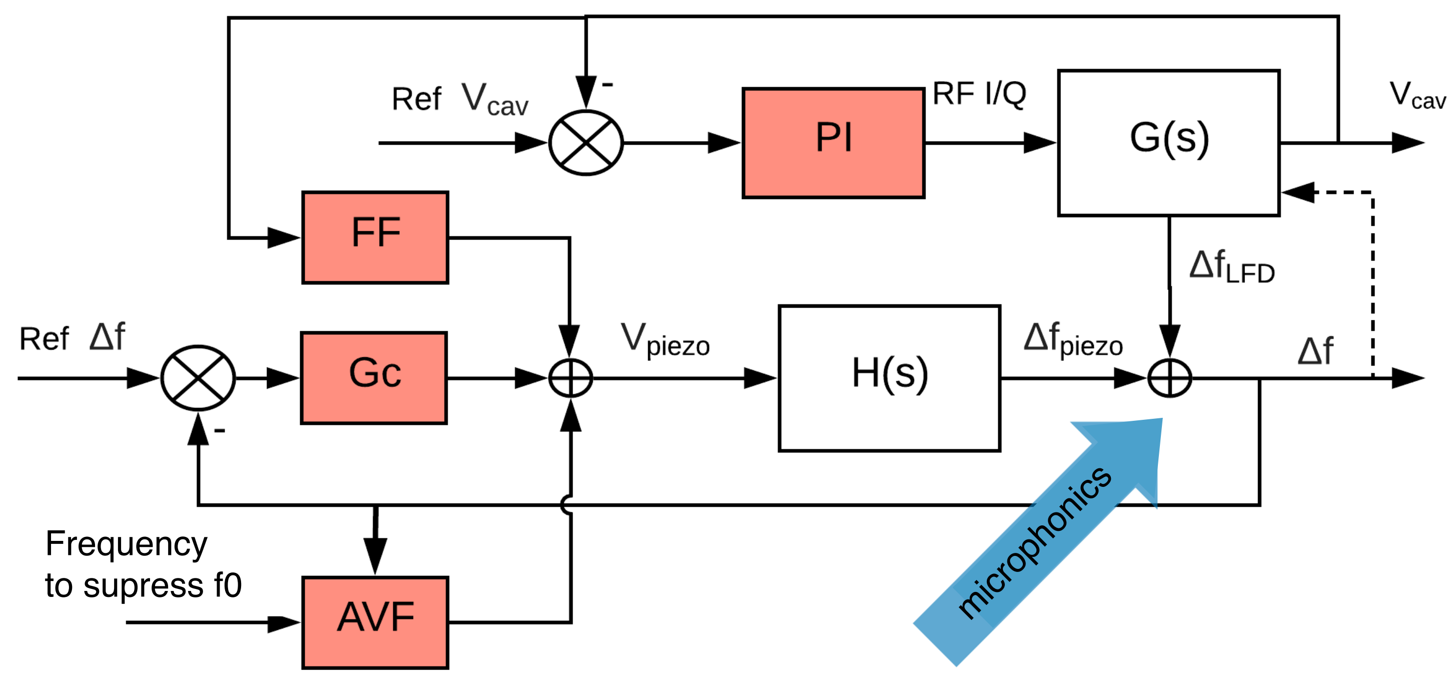

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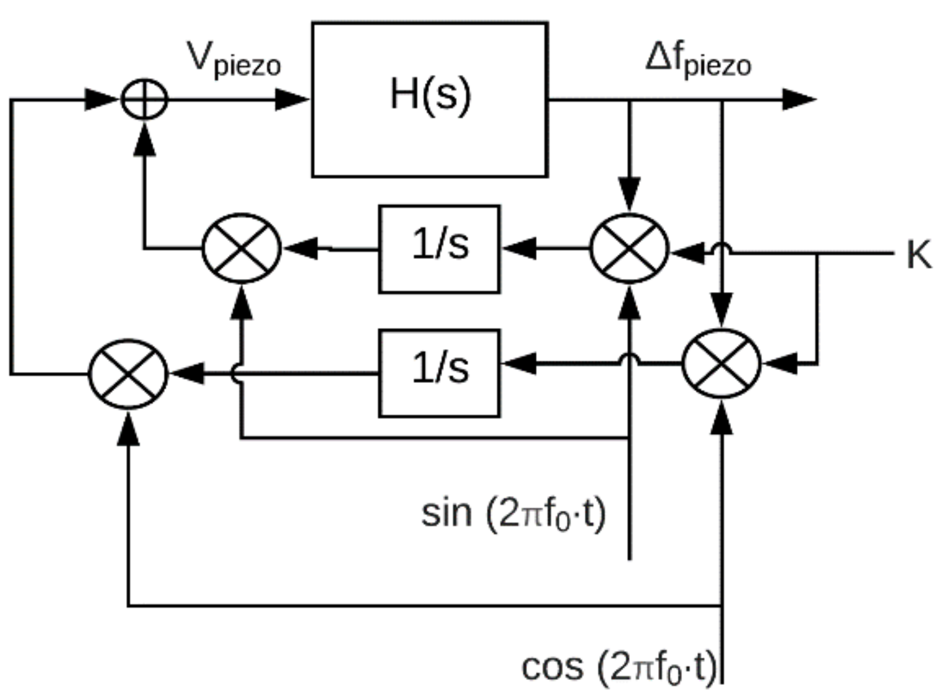

Active control using adaptative feedforward algorithm

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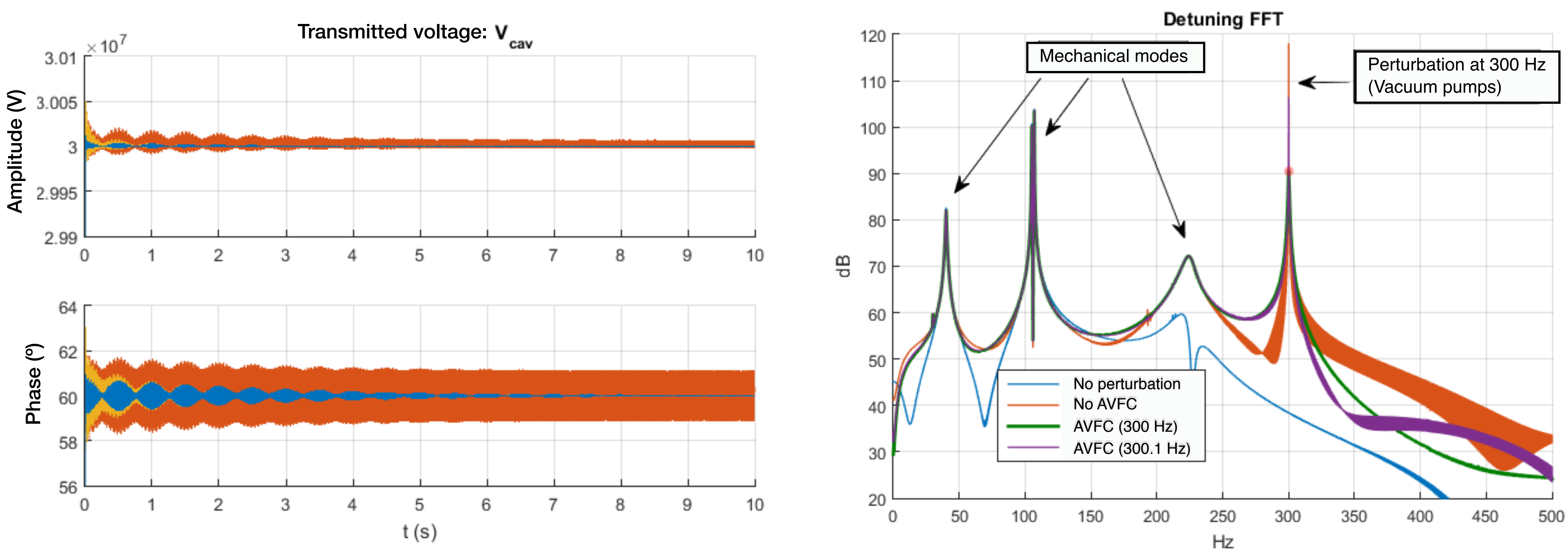
- Active control using adaptative feedforward algorithm



Results from Eukeni Aldekoa's Master Degree

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- **Conclusions and future work**

Conclusions and future work

- Reconfigurable simulator
  - FPGA: real time.
  - Realistic functionalities
    - Reflected wave, Quench, LFD, some disturbances
    - Piezoelectric actuator
- Applications
  - HIL Simulations
  - Teaching
  - Kalman filter debugging
- Microphonics: Future improvements
  - HIL test of active control techniques
  - New disturbances simulated and real
  - Non colocated control