MicroTCA.4 based Single Cavity Regulation

including Piezo Controls

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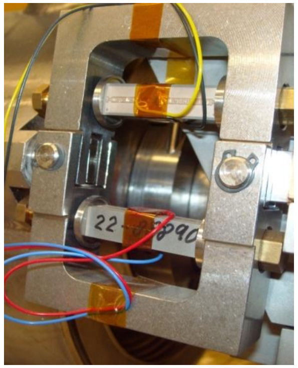
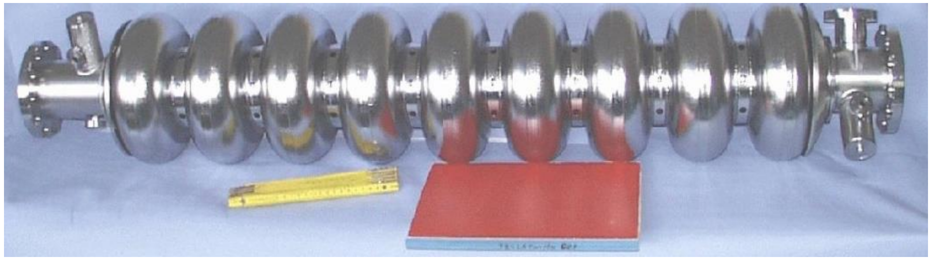
Busan, Korea, 08-13.05.2016
on behalf of MSK Group, DESY, Warsaw University of Technology and Helmholtz Zentrum Berlin





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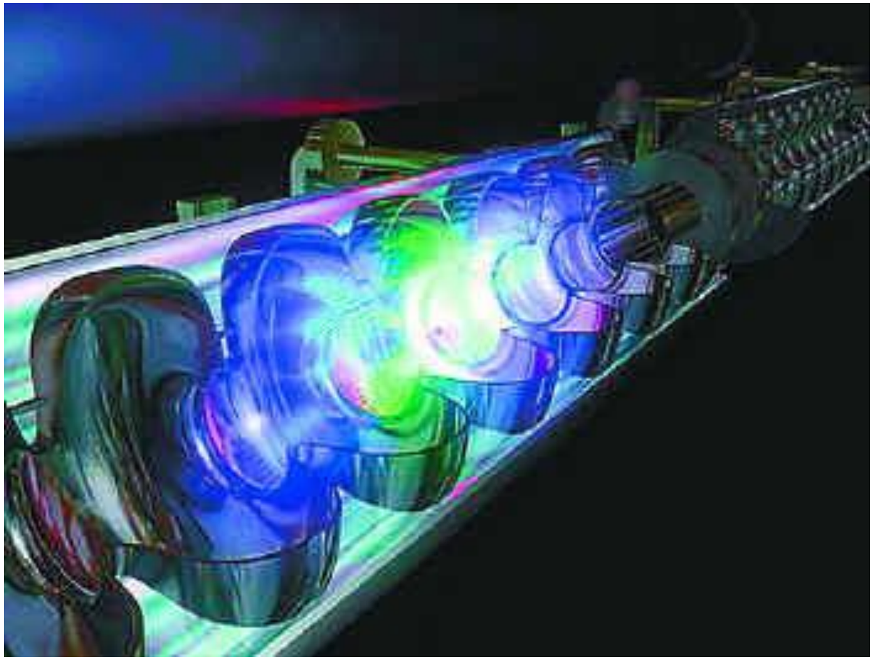
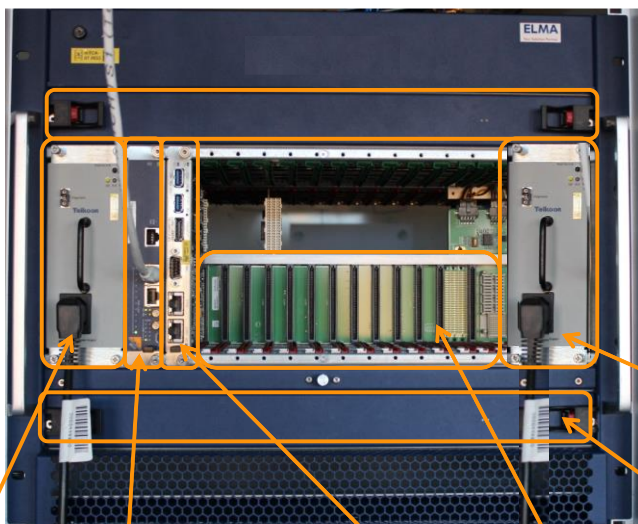
Outline

- MTCA.4 Standard
- DESY developments
- RF Cavity
- Firmware
- Software
- Why not CW?
- CW experiment
- Future plans



MTCA.4 Standard

- **Modular + modern architecture**
  - Reusability + PCIe + Ethernet
- **High availability**
  - Redundant power, MCH and CU
  - Well defined remote management
  - Hot plug support
- **High digital and analog performance**
  - Very low analog distortions (diff.lines)
  - 4 lanes PCIe (Gen3): 1 GByte/s/lane



- Chassis and cooling units
- Backplane
- Power Supplies
- MTCA Carrier Hub
- CPU
- System stability, reliability

Redundant Power Supply

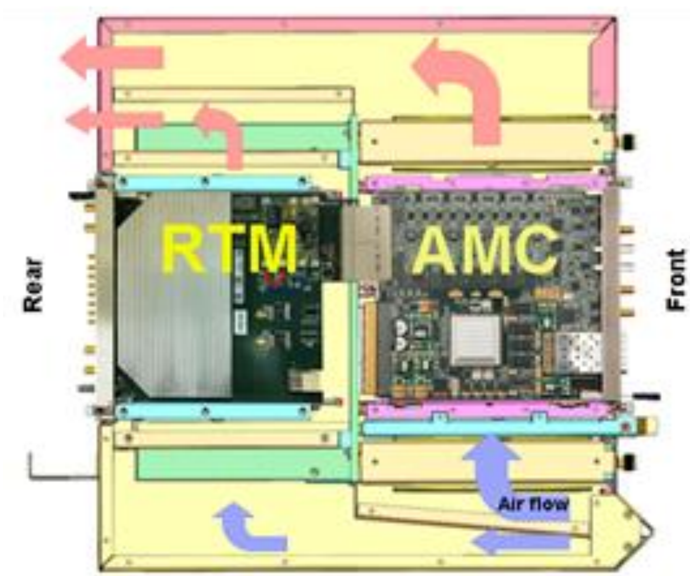
Cooling Unit

Primary Power Supply

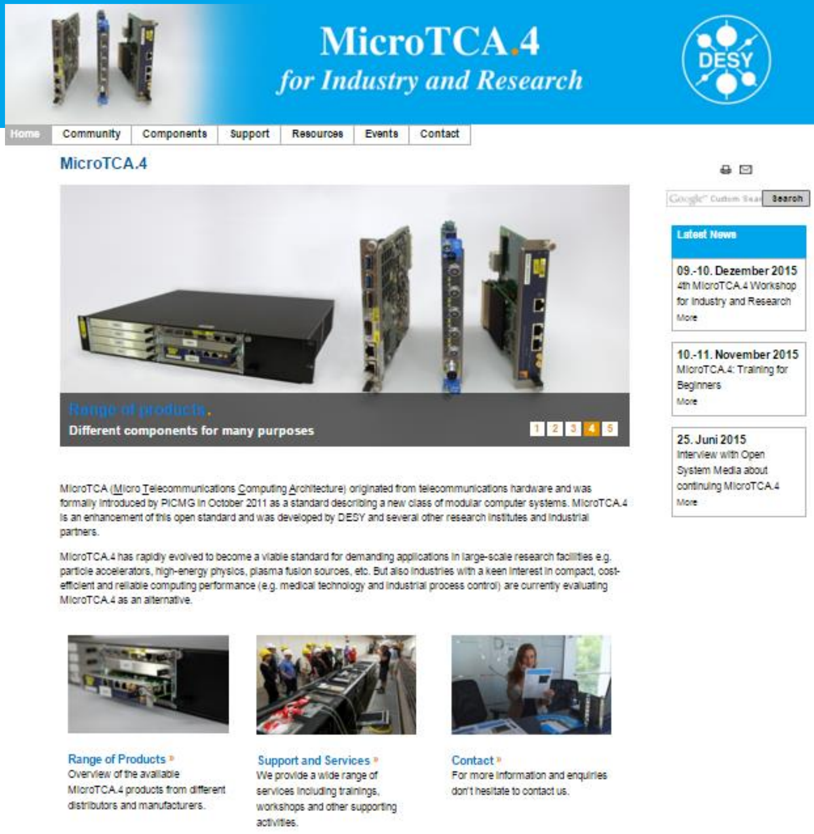
CPU

MTCA Carrier Hub (MCH)

Backplane



DESY-MSK Developments



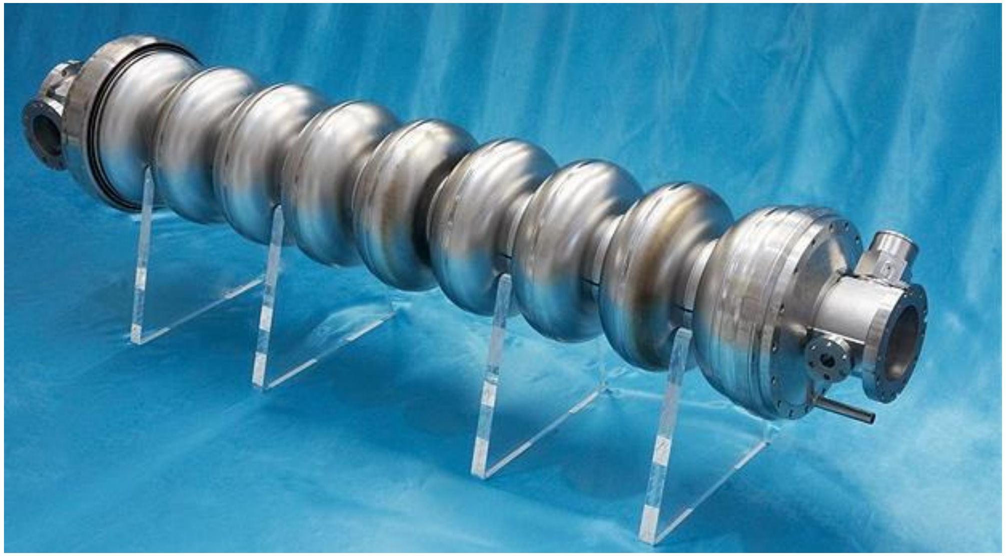
- FMC carriers:
  - DAMC-FMC20
  - DAMC-FMC25
- FMC modules:
  - DFMC-MD22
  - DFMC-SFP4
  - DFMC-AD16
  - DFMC-UNIO
- Backplanes:
  - RF Backplane
- AMC
  - DAMC-TCK7
  - DAMC-DS800
- RTM
  - DRTM-DWC10
  - DRTM-DWC8VM1
  - DRTM-DS8VM1
  - DRTM-VM
  - DRTM-uLOG
  - DRTM-AD84
  - DRTM-PZT4

15 boards developed (industry licensed or direct sale), several more under development

RF Cavity

> **RF cavity parameters (i.e. XFEL):**

- Resonance frequency
  f_0 = 1.3 GHz
- Loaded quality factor range
  $Q_L \approx$ 3e6 ÷ 1.5e7
- Bandwidth range
  B.W ≈ 433 ÷ 87 Hz
- Accelerating gradient range
  $E_{acc} \approx$ 3 ÷ 42 MV/m (DESY record!)
- Fine tuning with piezos (**$C_L \approx$ 4 μF@2K**)
- Coarse tuning with motorized stage
  Sanyo Denki



> **Goals:**

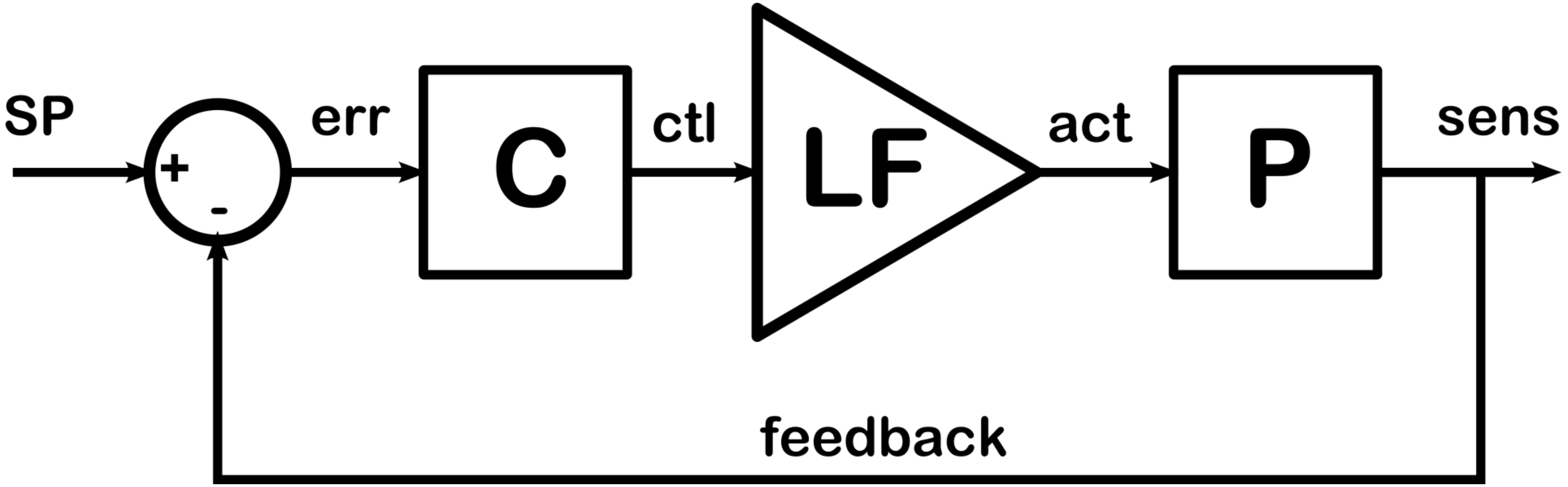
- Sense 1.3 GHz RF signals and drive 1.3 GHz high voltage RF source
- Stabilize RF field
  (**dA/A > 0.01%, dP ~ 0.01 degrees**)

> **Problems:**

- Lorentz force detuning (**Δf < 1 kHz), SP mode**
- Microphonics (**μ < 10 Hz), CW mode**

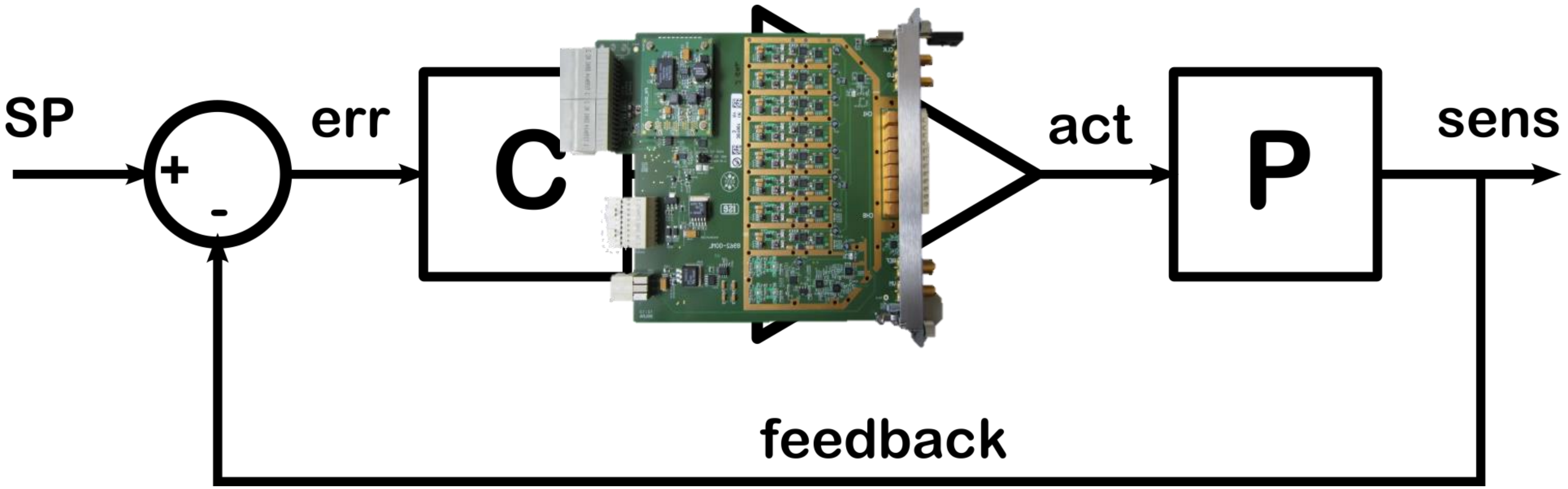
RF Cavity Controller Design

- Control Theory Point of View



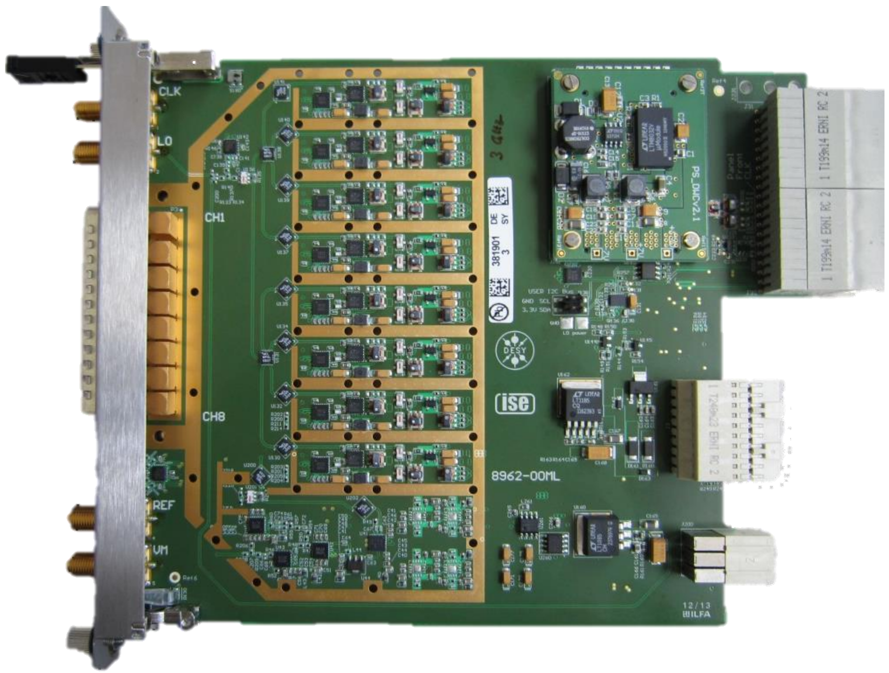
RF Cavity Controller

> RTM sensor and actuator



MTCA.4 Electronics: RTM
8 Channel Down-Converter 1 channel Vector-Modulator

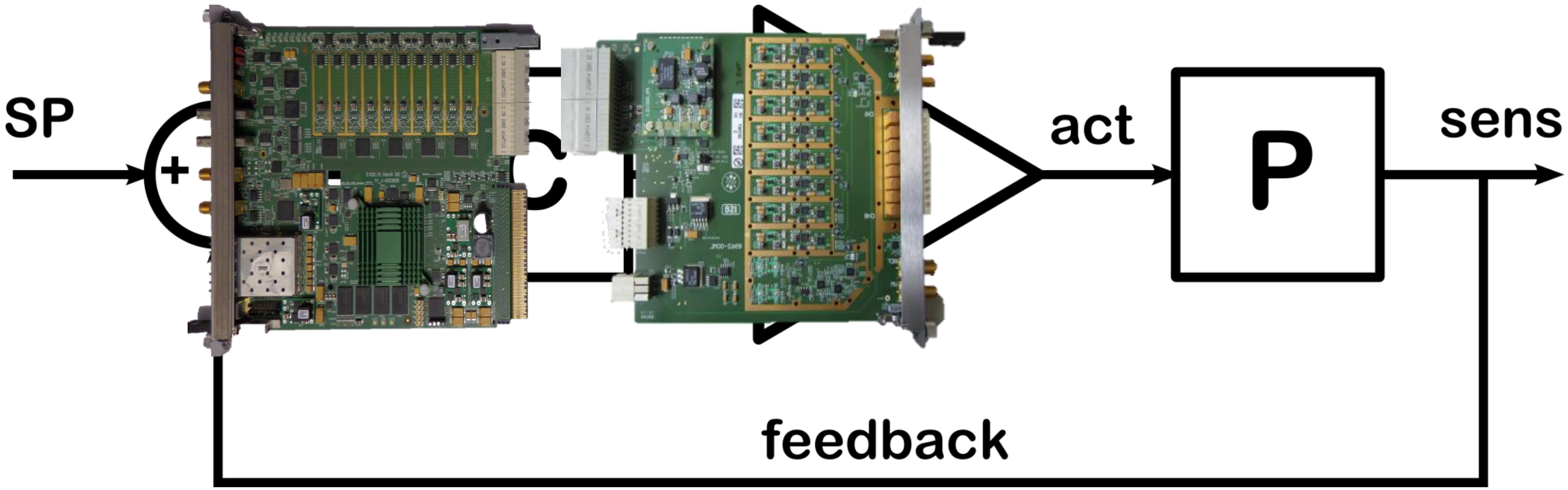
- Double width MTCA.4, Mid-Size Rear-Transition Module (RTM), Class A1.0, A1.1, A1.2 compatible
- Features:
  - 8 down-conversion input channels (AC) with programmable attn.
  - LO input for analog down-conversion 1.3 GHz
  - 2 analog general purpose inputs (DC)
  - 1 up-conversion output channel (AC) with programmable attn.
  - REF input for analog up-conversion 1.3 GHz
  - ADC clock input (AC) up to 125 MHz
  - Interlock signal support



DRTM-DWC8VM1
licensed by Struck Innovative Systems

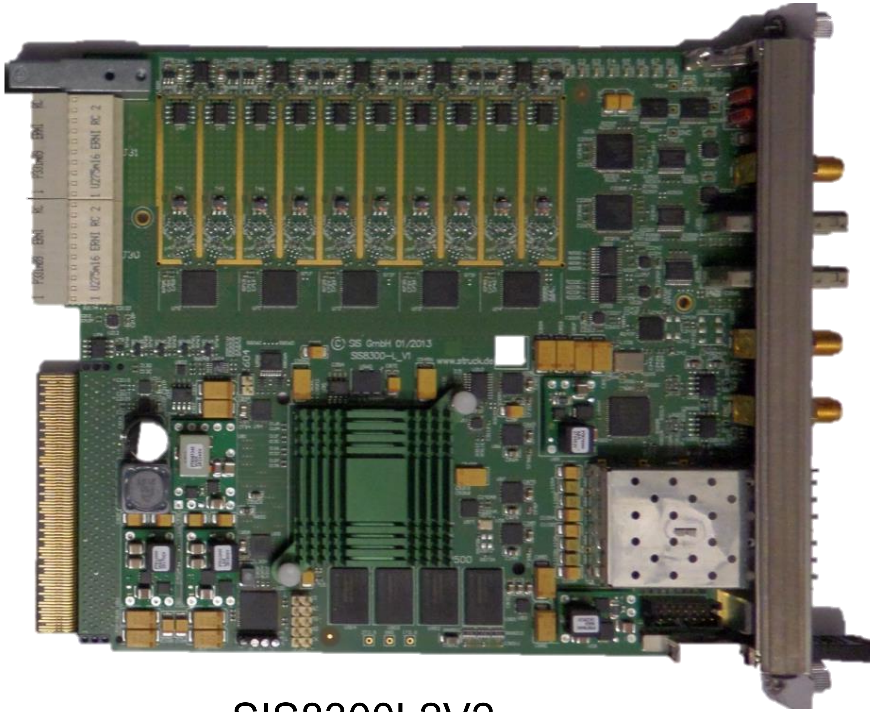
RF Cavity Controller

> AMC data processor



MTCA.4 Electronics: AMC Fast Digitizer

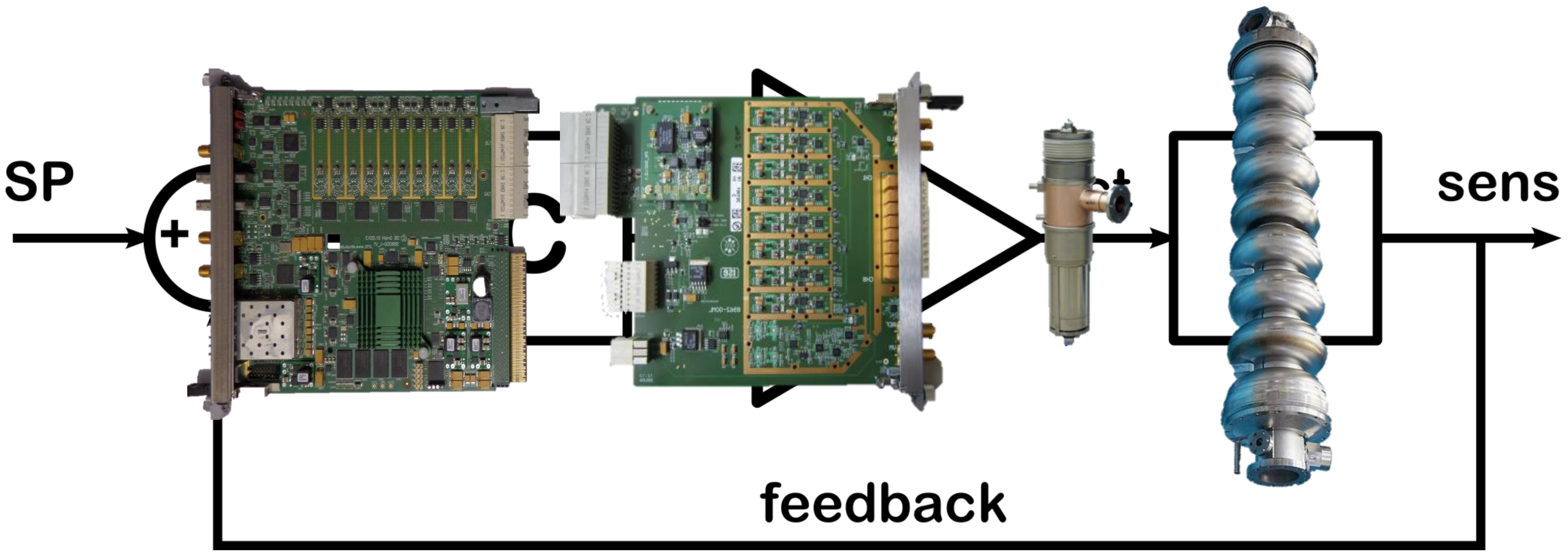
- Double width MTCA.4, Mid-Size Advanced Mezzanine Card (AMC), Class A1.0, A1.1 compatible
- Features:
  - 10x Analog Inputs: ADC 125 MSPS
  - 2x Analog Outputs: DAC 125 MSPS
  - RTM linked to Virtex 6 FPGA
  - RTM hotplug support
  - PCIe 4x => Virtex 6 FPGA
  - 6 MGTs (4xLLL + 2x SFP) => up to 10 Gbps AMC backplane connection on ports 12-15
  - Interlock signal support



SIS8300L2V2
Struck Innovative Systems
with DESY collaboration

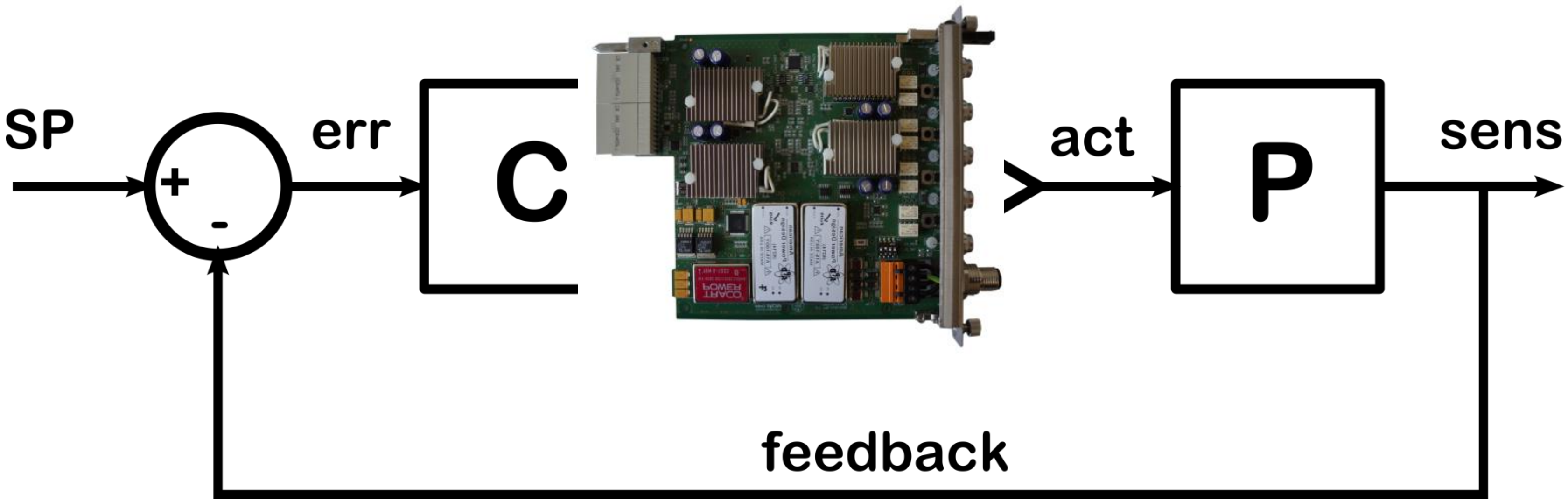
RF Cavity Controller

- RF cavity with IOT



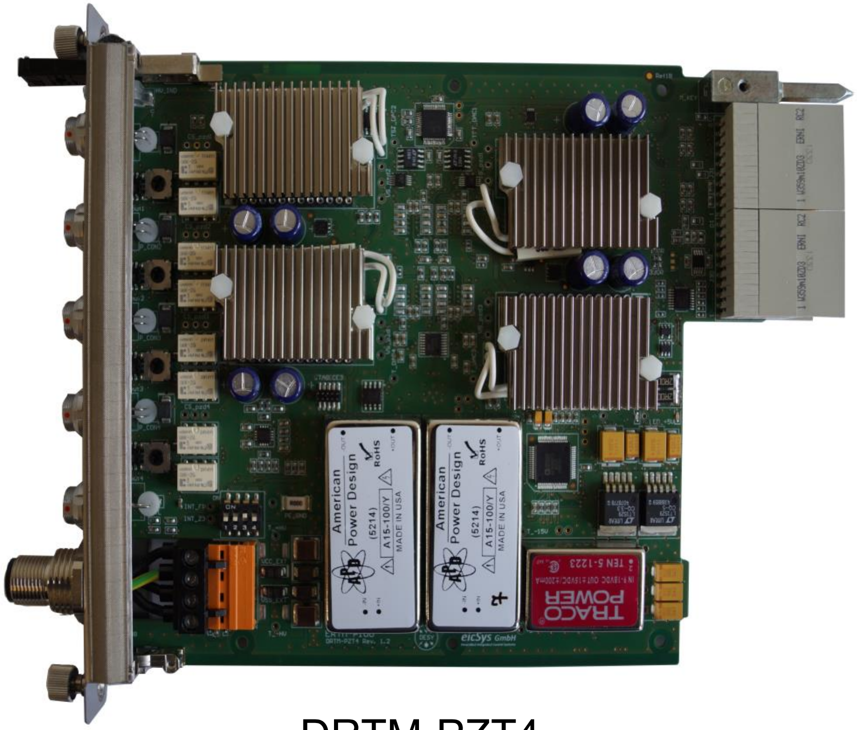
RF Cavity Detuning Controller

- RTM sensor and actuator



MTCA.4 Electronics: RTM
4 Channel Piezo Driver

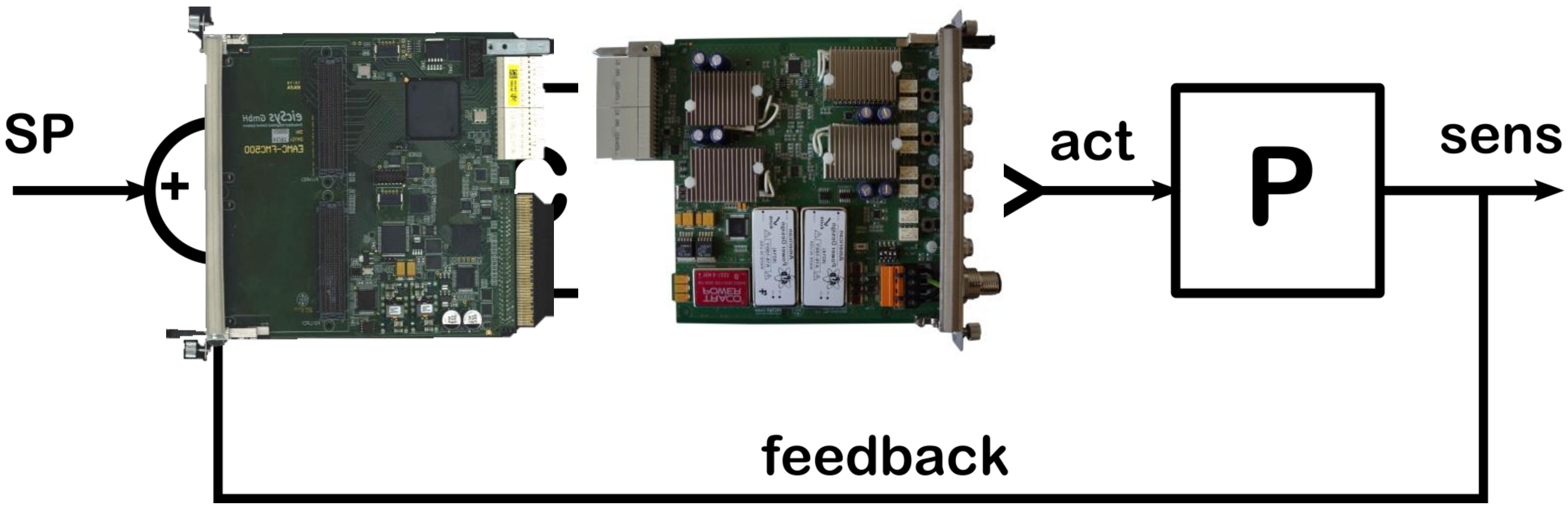
- Double width MTCA.4, Mid-Size Rear-Transition Module (RTM), Class D1.0, D1.1, D1.2 compatible
- Features:
  - Supports 4-channel Piezo Drivers and Piezo Sensors
  - Remotely switchable actuator and sensor functionality
  - Remotely switchable driving input source (ext./int.)
  - 4x DAC 18-bit up to 0.5 MSPS
  - 16x ADC 18-bit up to 100 kSPS
  - Unipolar: 0..+100 V and bipolar: ±100 V piezo power supplies (ext./int.)
  - Interlock signal support



DRTM-PZT4
direct sale by DESY

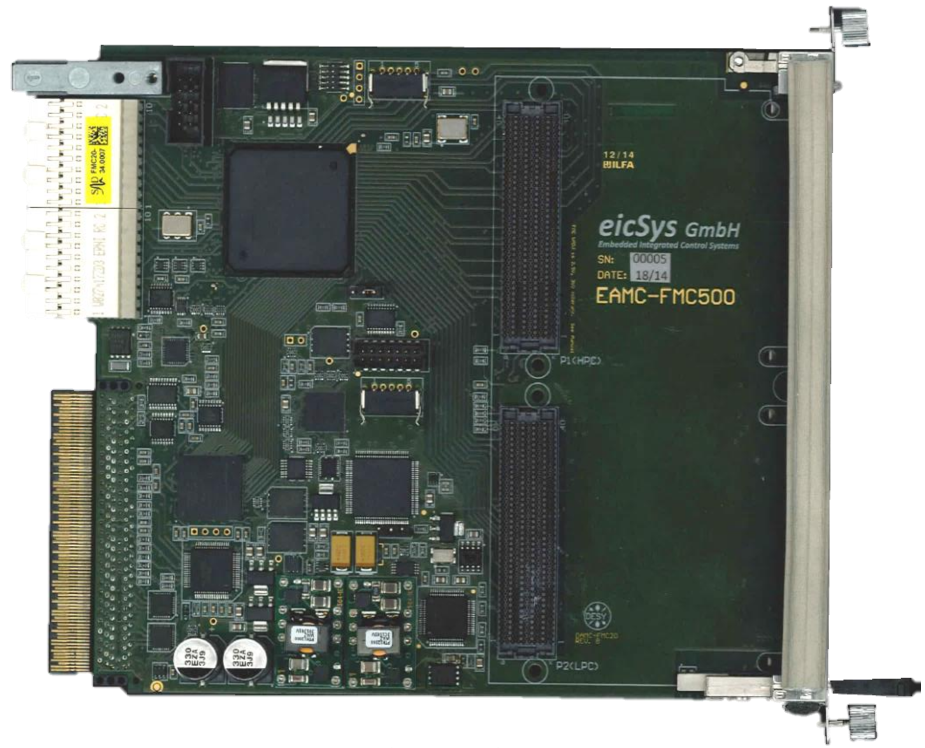
RF Detuning Controller

- AMC data processor



MTCA.4 Electronics: AMC
Dual FMC Carrier Board

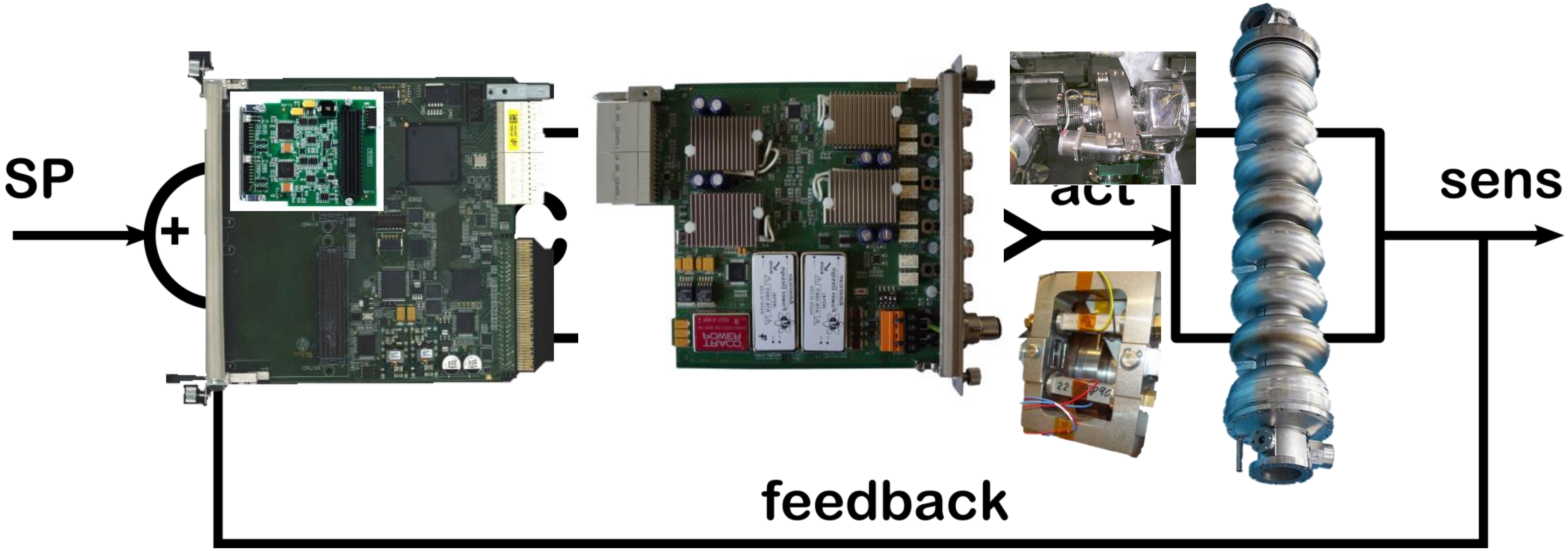
- Double width MTCA.4, Mid-Size Advanced Mezzanine Card (AMC), Class D1.0 compatible
- Features:
  - 1x HPC and 1x LPC FMC linked to Spartan 6 150 FPGA
  - RTM linked to Spartan 6 150 FPGA
  - RTM hotplug support
  - PCIe 1x => Spartan 6 45 FPGA
  - 1x MGT => up to 3 Gbps
    AMC backplane connection on ports 12-15
  - Interlock signal support



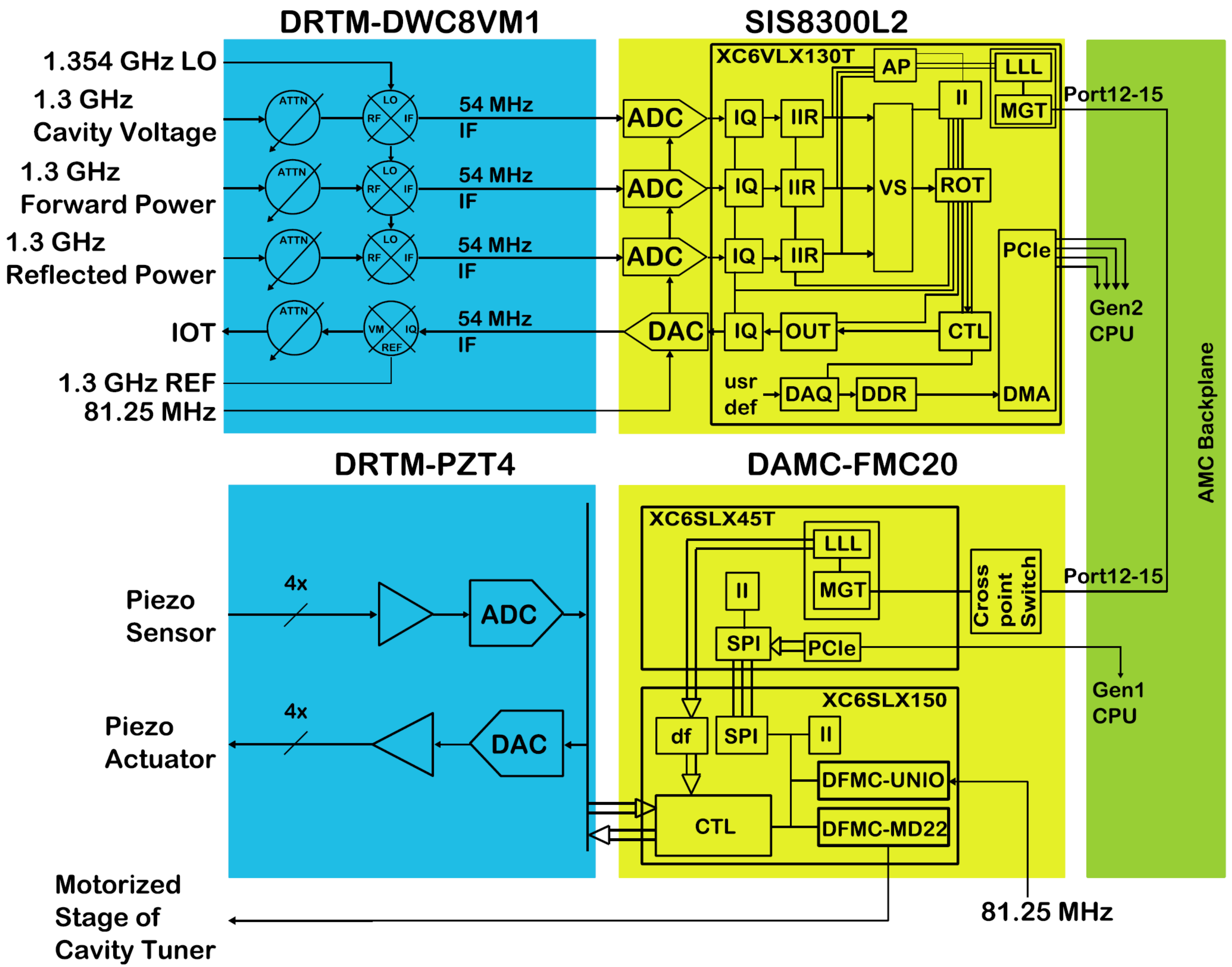
DAMC-FMC20
licensed by Eicsys

RF Detuning Controller

- Cavity Tuner with Piezos



RF Cavity and Detuning Controller (Firmware)



RF Cavity and Detuning Controller (Software)

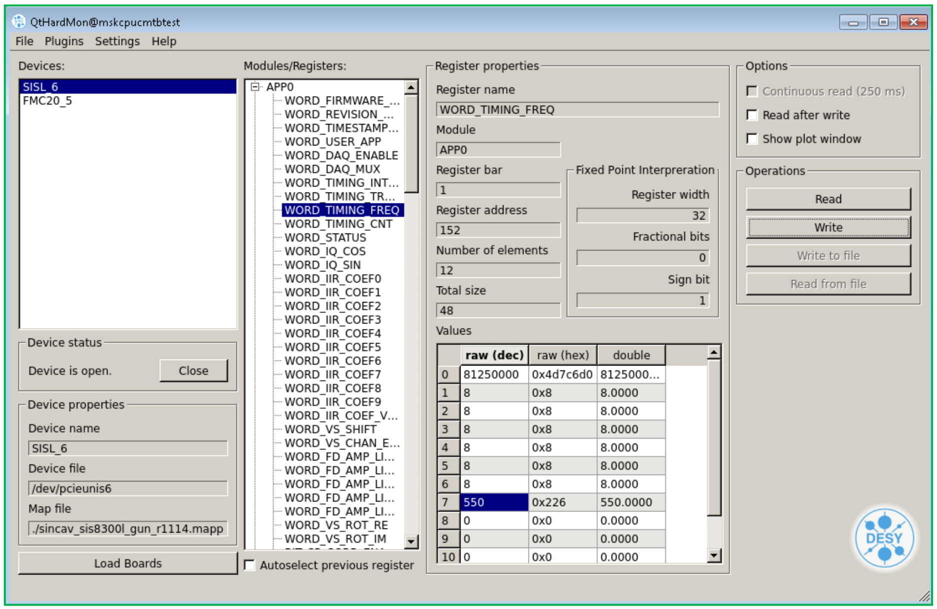
rf_c=mtca4u('SISL_6')
pzt_c = mtca4u('FMC20_5')

rf_ctl_init(rf_c)

rf_ctl_ff(rf_c,val)

rf_ctl_sp(rf_c,val)

rf_ctl_fb(rc_c,val)



piezo_ctl_init(pzt_c)

piezo_ctl_ff(pzt_c,val)

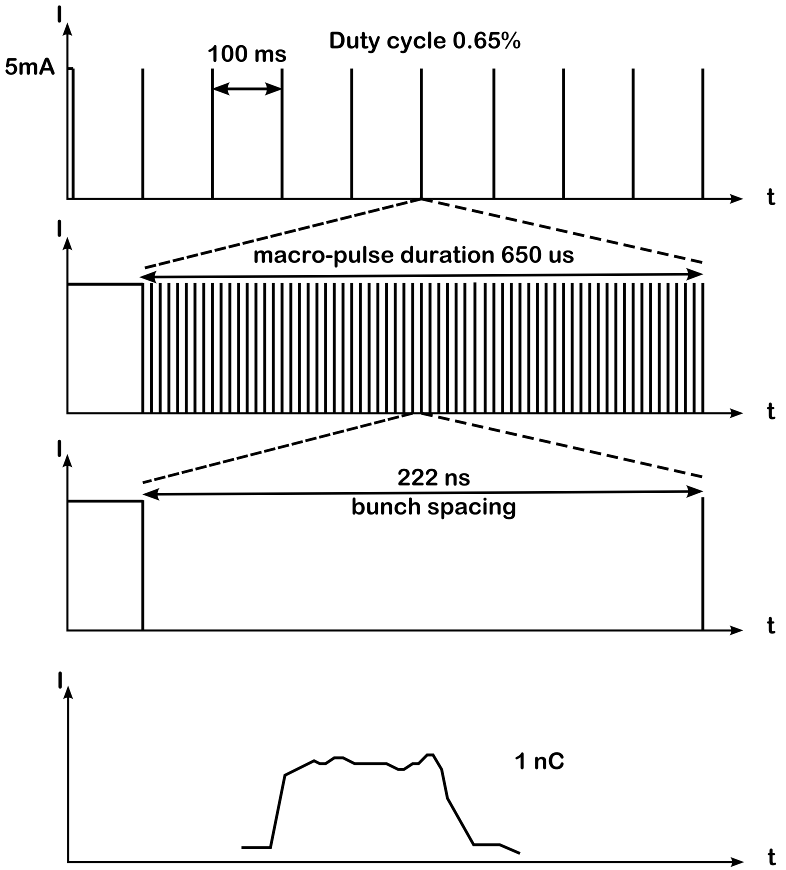
piezo_ctl_sp(pzt_c,val)

piezo_ctl_fb(pzt_c,val)

[a b] = read_dma_daq({rf_c;pzt_c},no_chan, no_samp, addr)

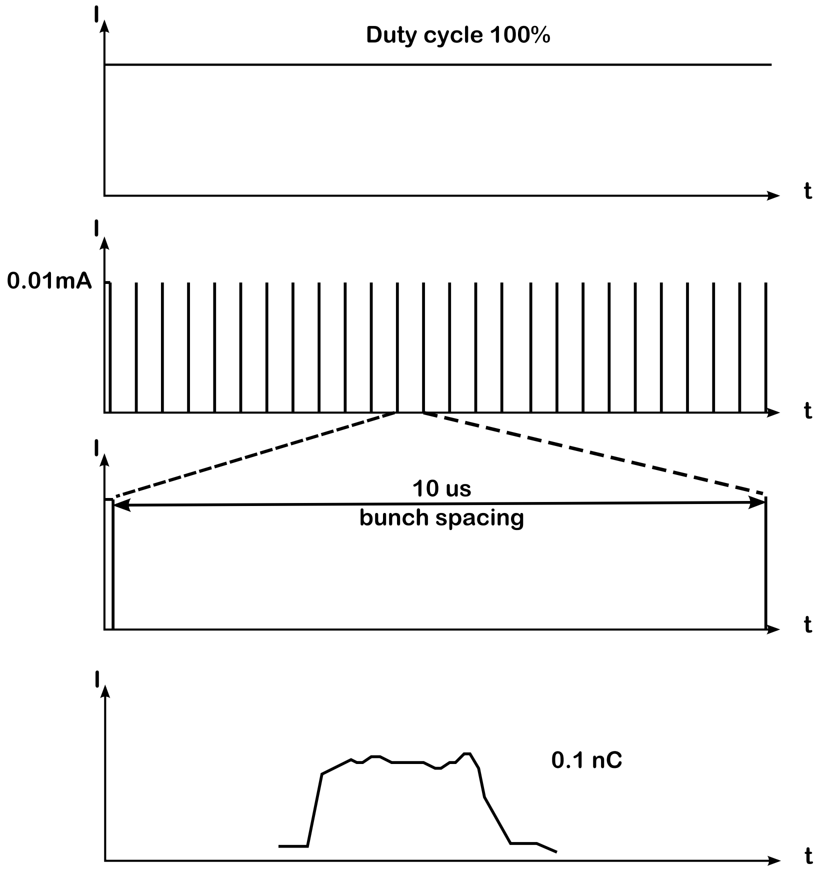
Why not CW?

- Short Pulse mode (default)



27000 bunches/s

CW mode (possible upgrade)

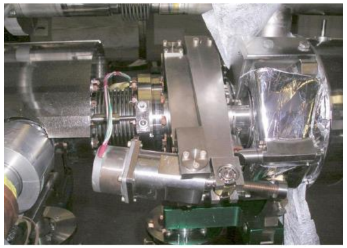


100000 bunches/s

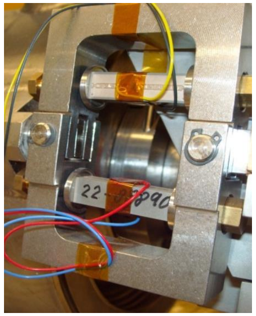
Cryo Module Test Bench Facility and CW experiment

Environment:

- 1.3 GHz 9-cell SRF cavities
- Q_L~1.5 e7 @ 2K
- B.W. ~ 87 Hz
- CW operation up to several MV
- High voltage power source: 120 kW IOT tube



- Cavity mechanical tuner (Saclay II model)
  - Sanyo motorized stage for cavity coarse tuning
  - Physik Instrument piezo elements (~4 μF) for cavity fine tuning



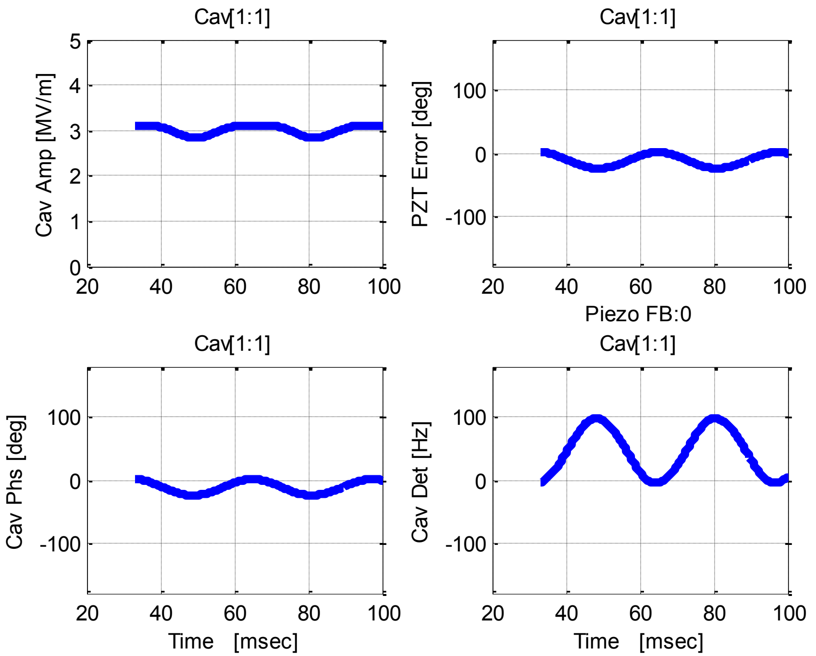
Goal:

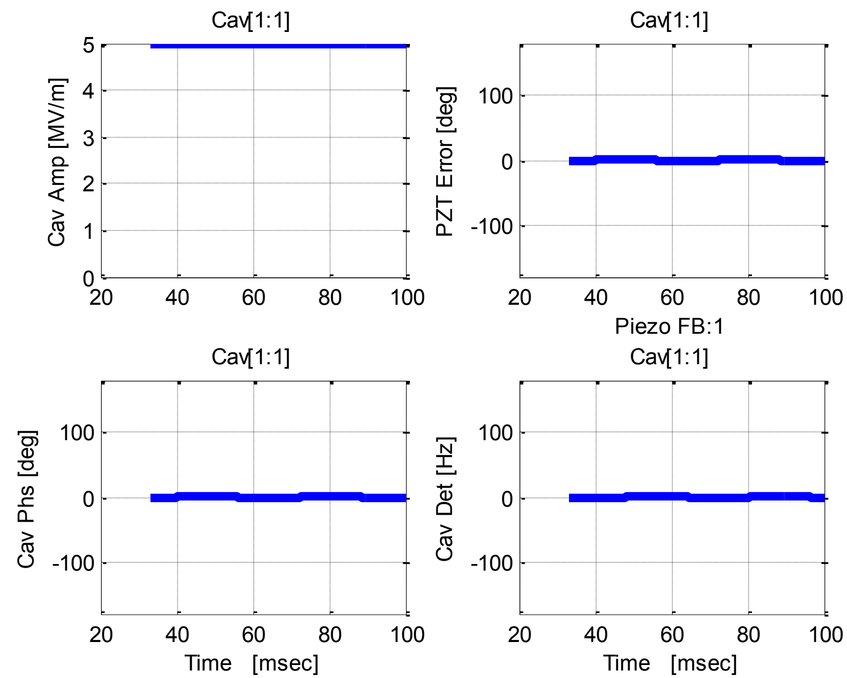
- Stabilize RF field amplitude and phase
- Minimize microphonics effect

RF Cavity and Detuning Controller (Simulation)

```
for ii=1:Ncav
    if NOISE && dw_m(ii).ena
        det(ii) = det(ii)+ 2*pi*dw_m(ii).ampl*sin(2*pi*dw_m(ii).freq*n*DT);
    end
end
```

> RF/Piezo Feedbacks off

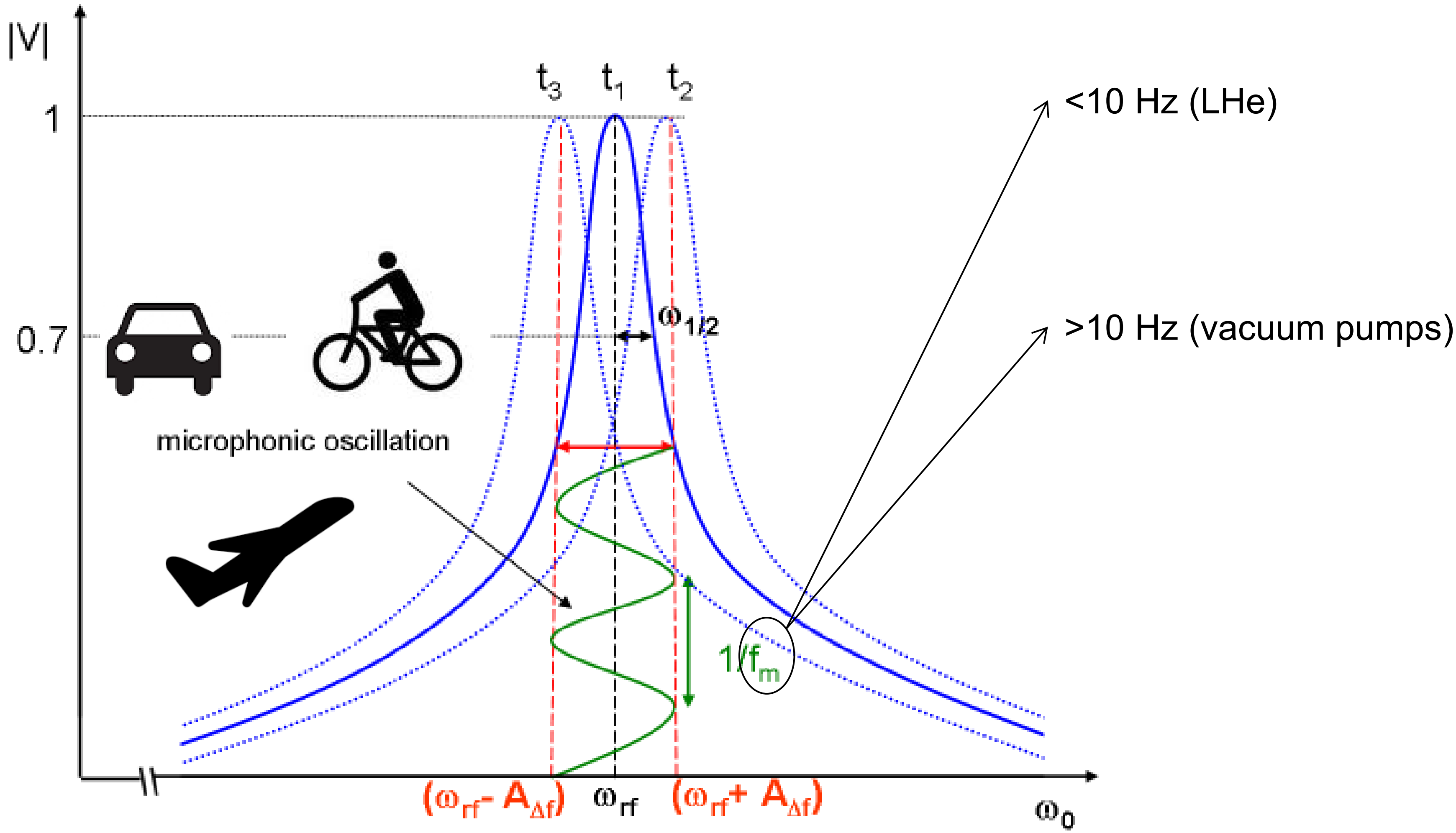





```
for ii=1:Ncav
    Vcav(n,ii)=(Vcav(n-1,ii)+DT*w0*rho*Ifwd*exp(1i*phig))...
      /(1+DT*(w12+1i*det(ii)));
  end
```

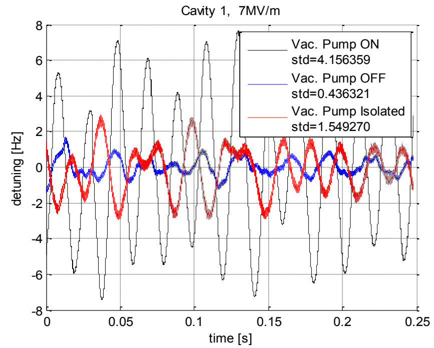
> RF/Piezo Feedbacks on

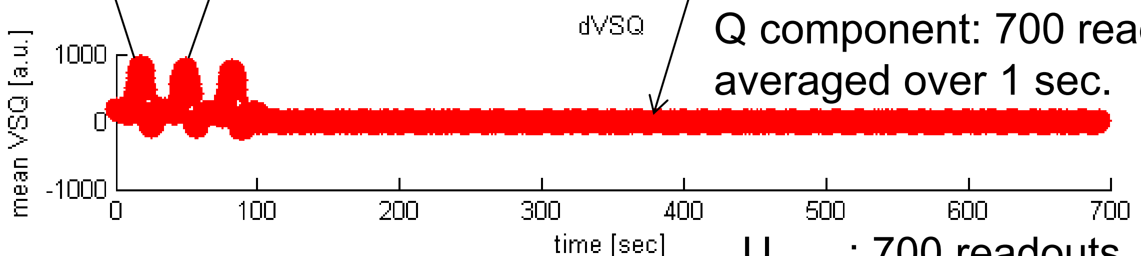
Microphonics Sources



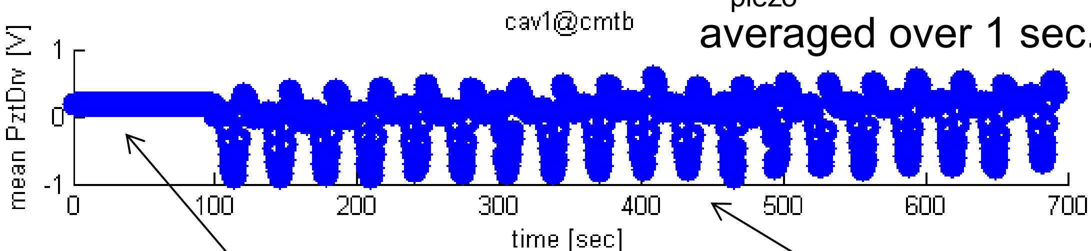
Slow Microphonics Compensation (<10 Hz)

F_m~0.03Hz





Q component: 700 readouts averaged over 1 sec.



U_{piezo} : 700 readouts averaged over 1 sec.

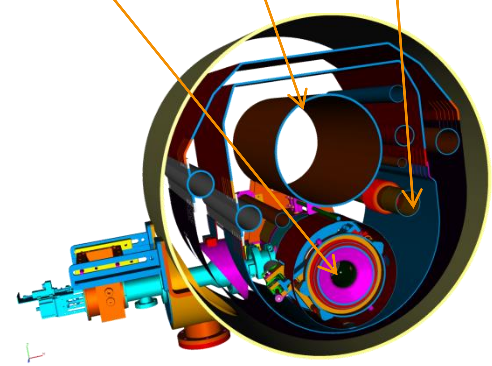
Piezo compensation off

Piezo compensation on (PI controller)

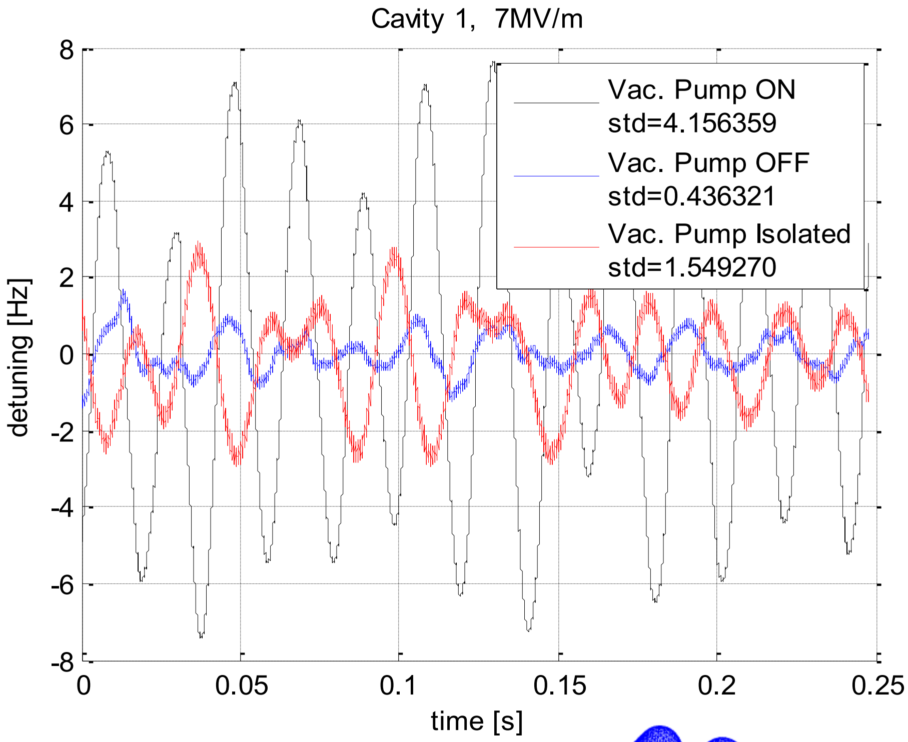
RF cavity

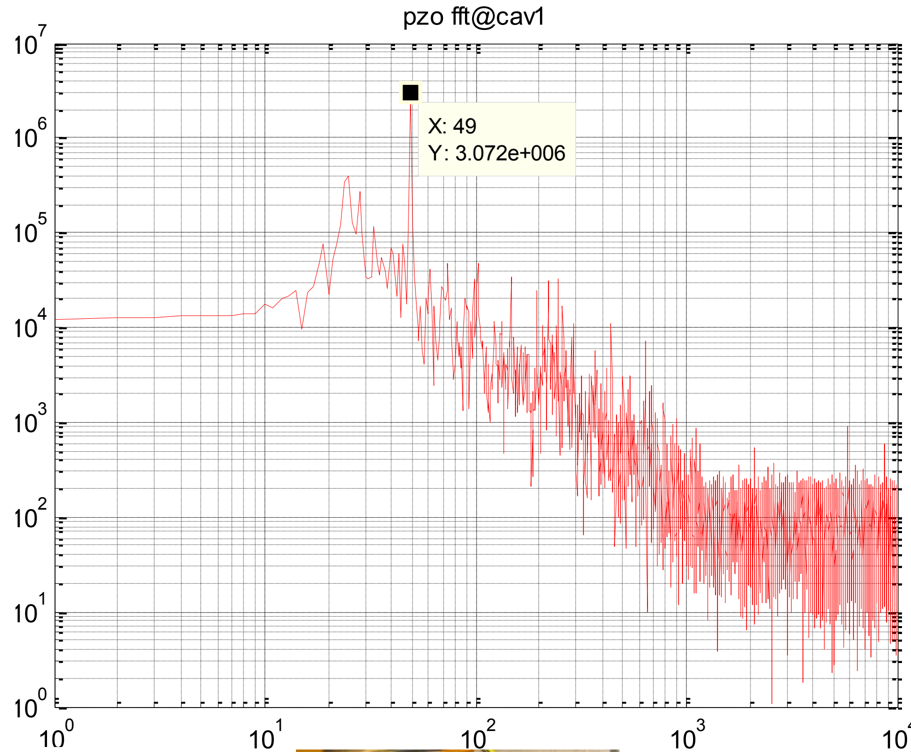
He gas return pipe

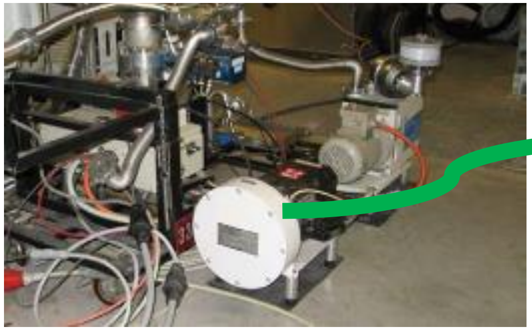
2 phase LHe pipe

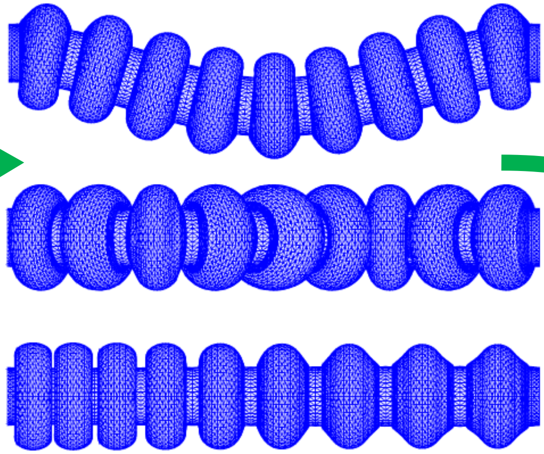


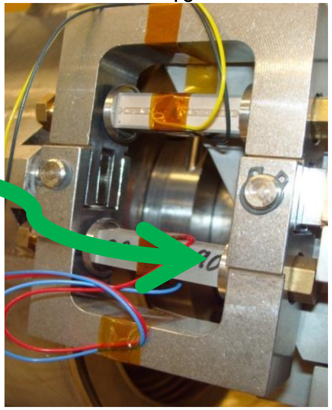
Fast Microphonics Source (>10 Hz)





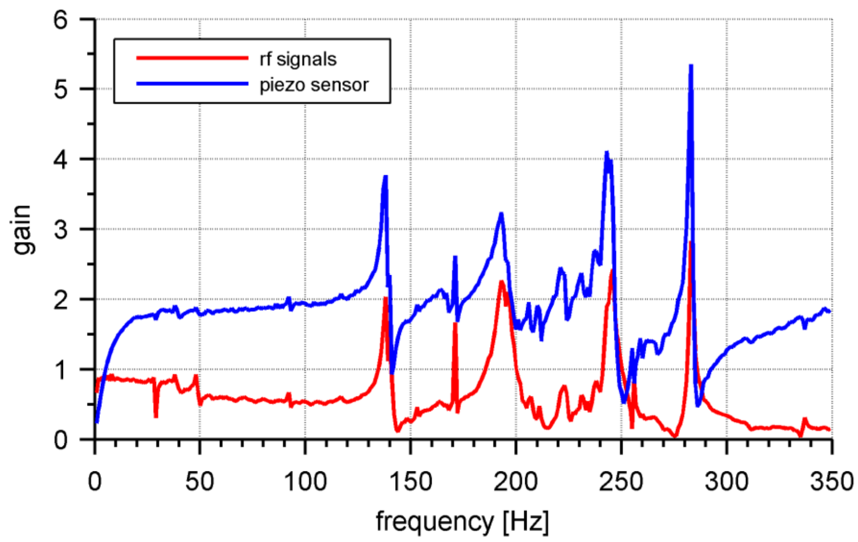


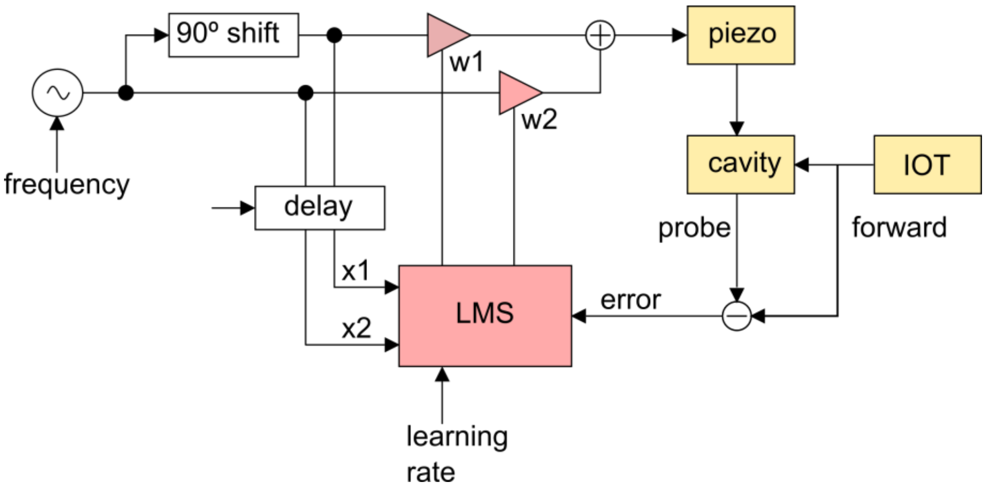




Microphonics compensation strategy

- Conventional PI control insufficient due to complicated piezo->detuning transfer function (<10Hz)
- Narrowband Active Noise Control algorithm for the dominating disturbances
  - Adaptive feed forward
  - LMS update: w(i+1)=w(i)+learning_rate*error*x(i)
  - FPGA implementation based on the CORDIC algorithm
  - Optionally multiple frequencies compensation
  - Accurate transfer function is not required

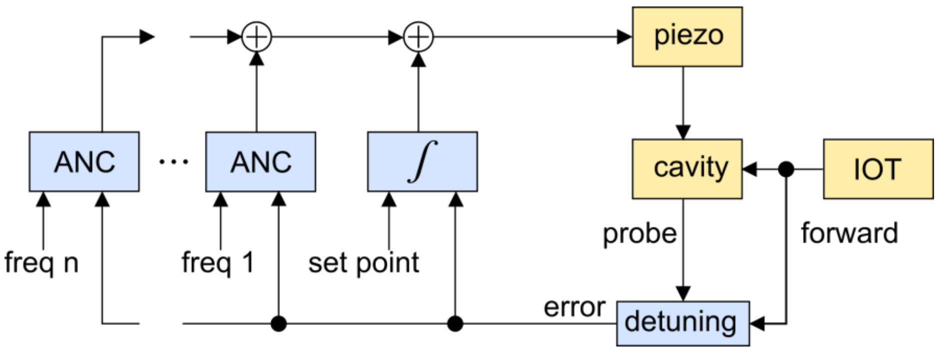


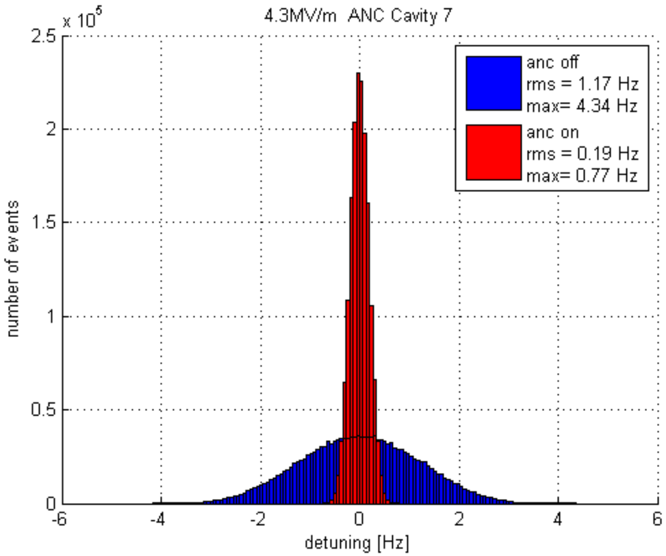


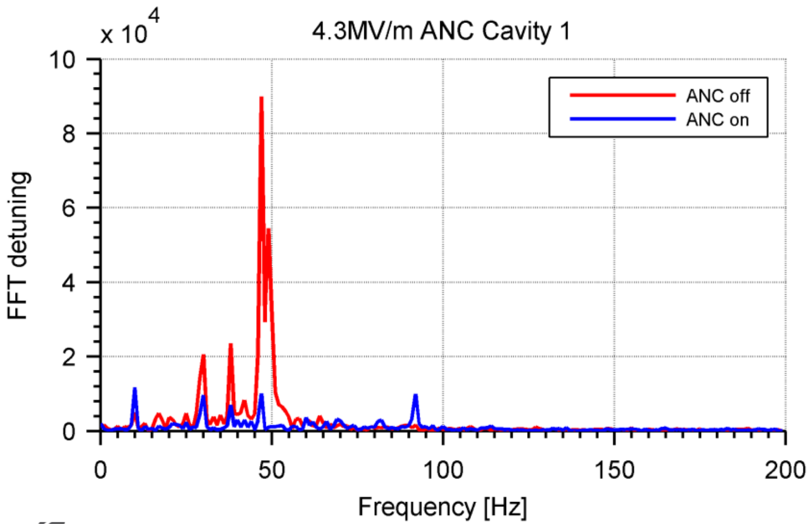
Courtesy by R. Rybaniec

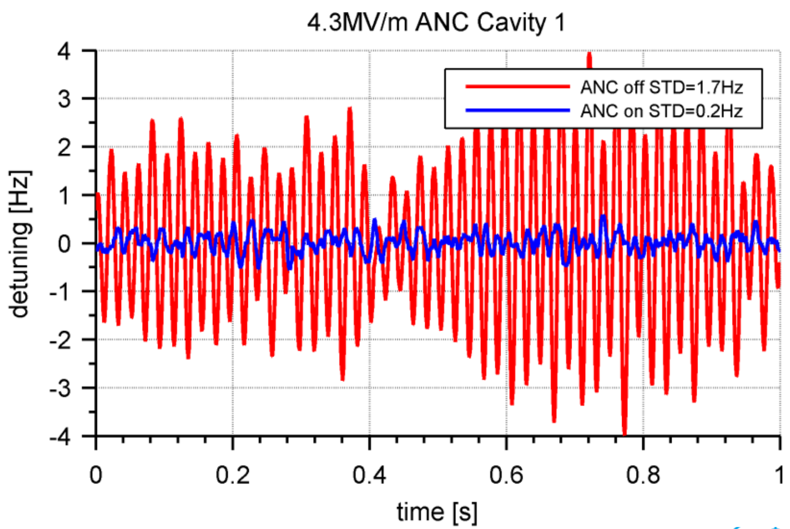
PI+ANC Combined Controller Results

- 30+49Hz ANC for dominating disturbances



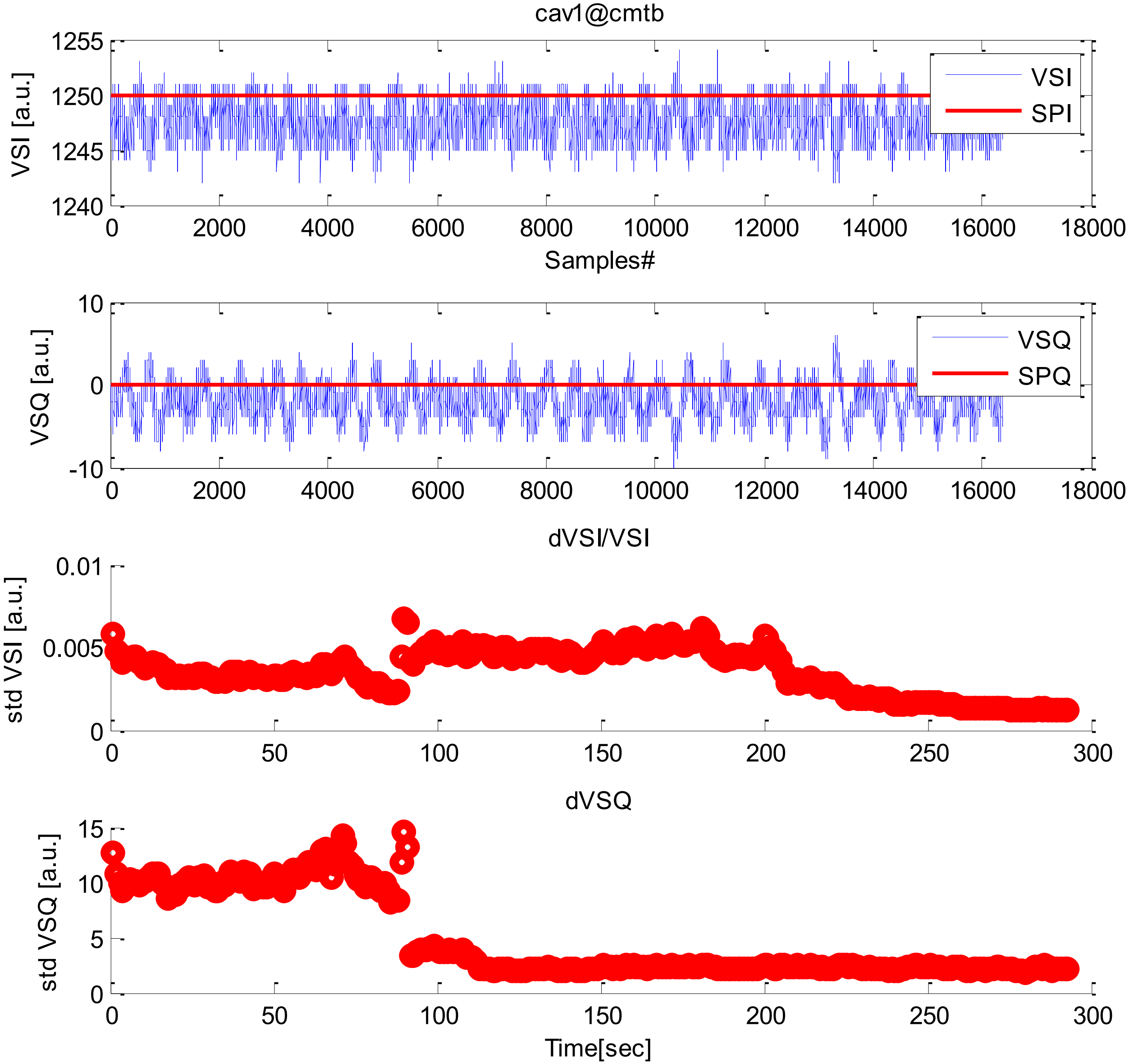




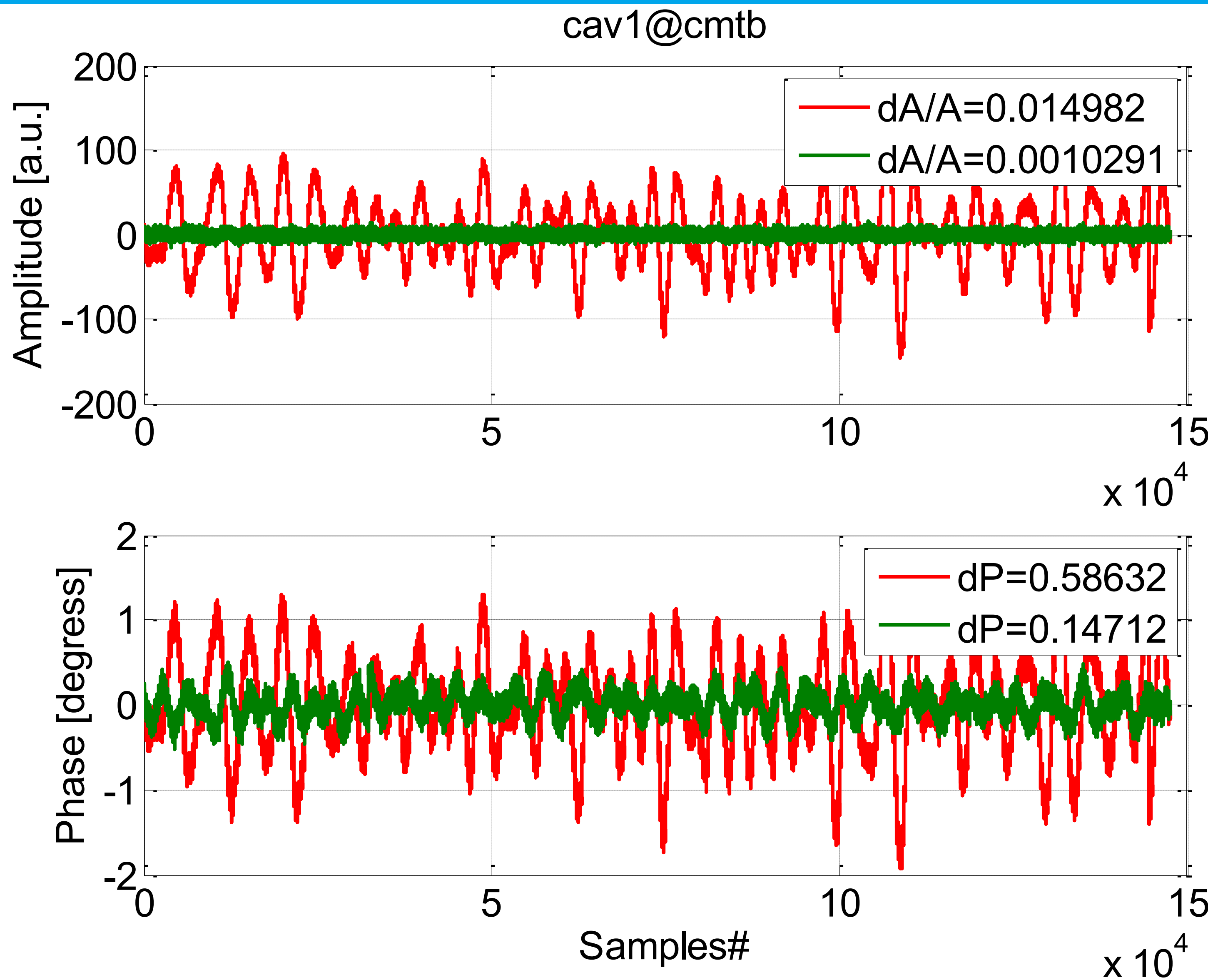


Courtesy by R. Rybaniec

RF and Piezo Feedbacks (long term measurements)



RF and Piezo Feedbacks (peak performance)



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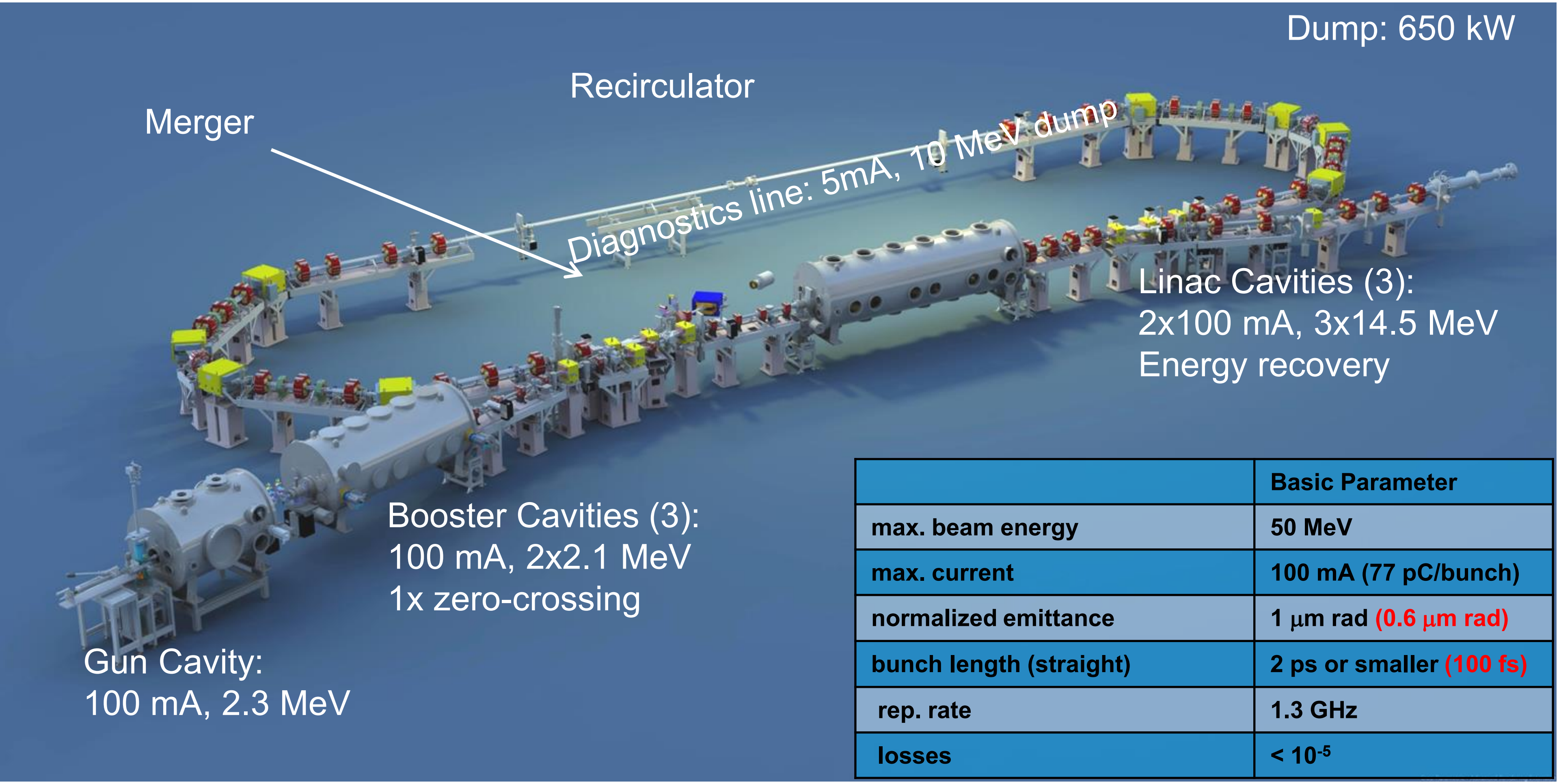
Possible Application (Parameters)

> Berlin Energy Recovery Linac Project **bERLinPro** at the Helmholtz Zentrum in Berlin:



	Basic Parameter
max. beam energy	50 MeV
max. current	100 mA (77 pC/bunch)
normalized emittance	1 µm rad (0.6 µm rad)
bunch length (straight)	2 ps or smaller (100 fs)
rep. rate	1.3 GHz
losses	$< 10^{-5}$

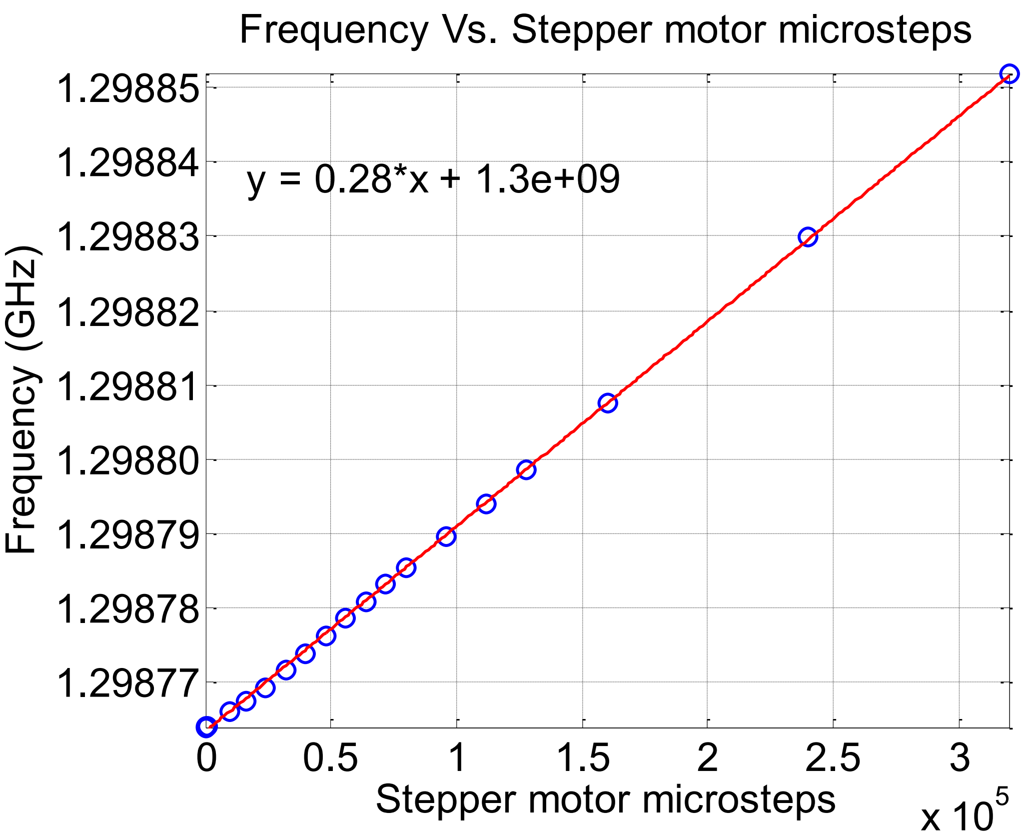
Courtesy by P. Echevarria

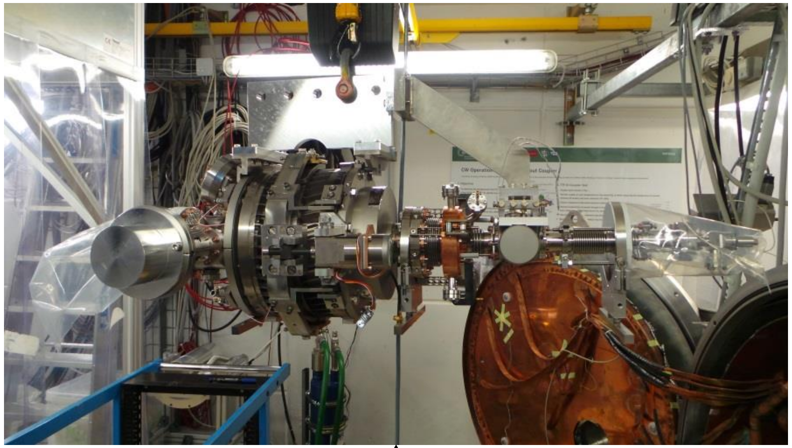
Possible Application (Goals)

- Berlin Energy Recovery Linac Project **bERLinPro** at the Helmholtz Zentrum in Berlin:
  - project goal is the generation of a high current (100 mA), low emittance (below 1 mm mrad) CW electron beam at 2 ps rms bunch duration
  - The LLRF control system will be implemented using the MTCA.4 technology and due to the fact each cavity of the accelerator will be fed by its own RF power source (klystrons for the gun and booster and SSA for the linac), the single cavity approach will be used.
  - The precise RF amplitude and phase control needed due to beam recovery process
  - The microphonics compensation needed due to narrow bandwidth of the cavities (especially at the linac module)
  - All of the cavities will be equipped with a blade tuner which will be driven by a stepper motor for slow coarse tuning and **four piezo actuators** for a fine fast compensation

Courtesy by P. Echevarria

Firsts Results with MTCA.4 Electronics





DFMC-MD22

More details by A. Ushakov at:
TUPOW035
“First LLRF Tests of BERLinPros Gun Cavity Prototype”

People Involved

> DESY

Valeri Ayvazyan

Christian Schmidt

Martin Killenberg

Konrad Przygoda

Radoslaw Rybaniec

Holger Schlarb

Jacek Sekutowicz

Robert Wedel

> HZB

Pablo Echevarria

Jens Knobloch

Oliver Kugeler

Axel Neumann

Andriy Ushakov

Thank You for Attention