# Resonance Control as a part of LLRF system

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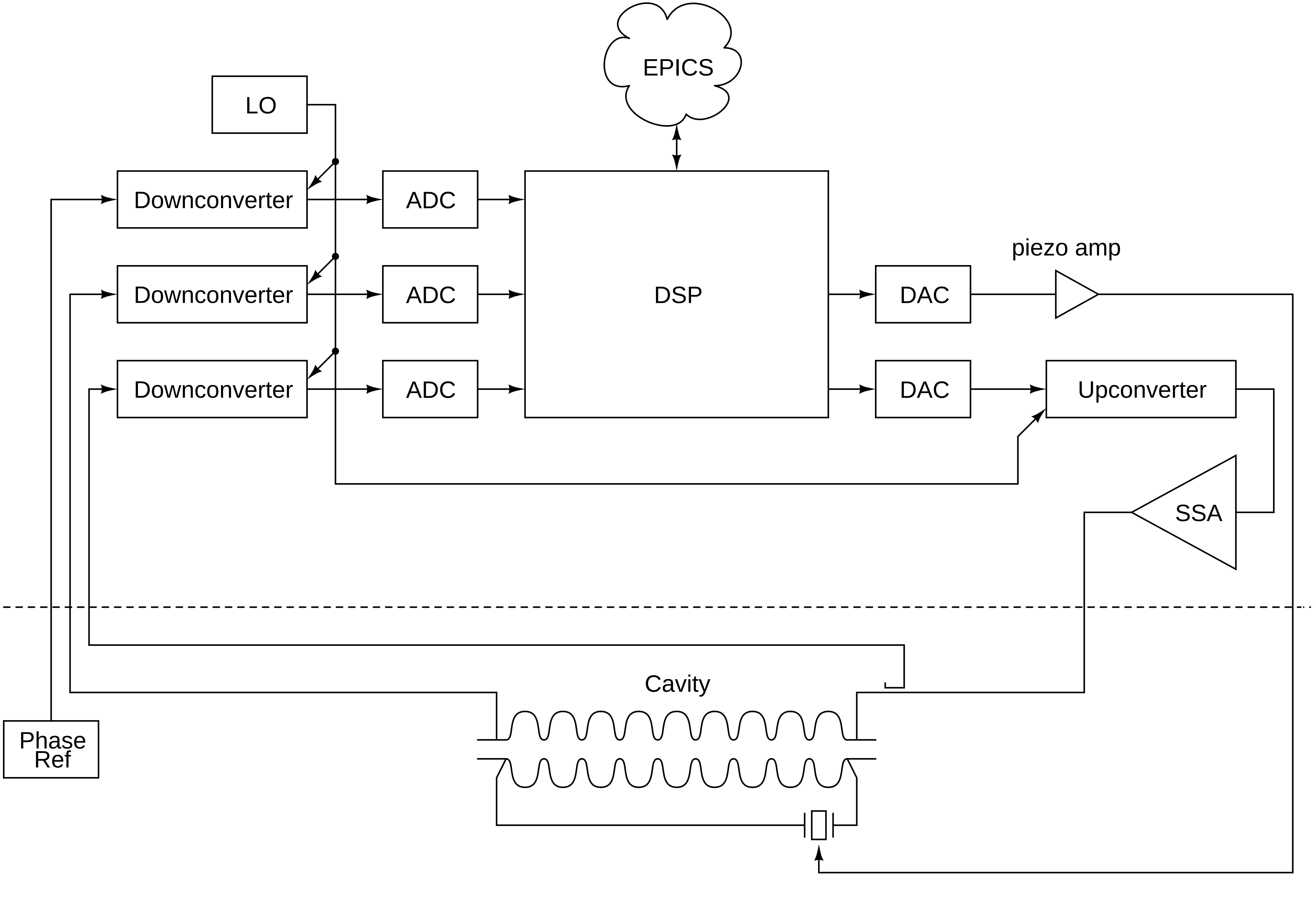


EPICS
LO
Downconverter
ADC
Downconverter
ADC
DSP
Downconverter
ADC
DAC
piezo amp
DAC
Upconverter
SSA
Cavity
Phase
Ref

**Field control**

- In equilibrium can be analyzed as PI control, with latency

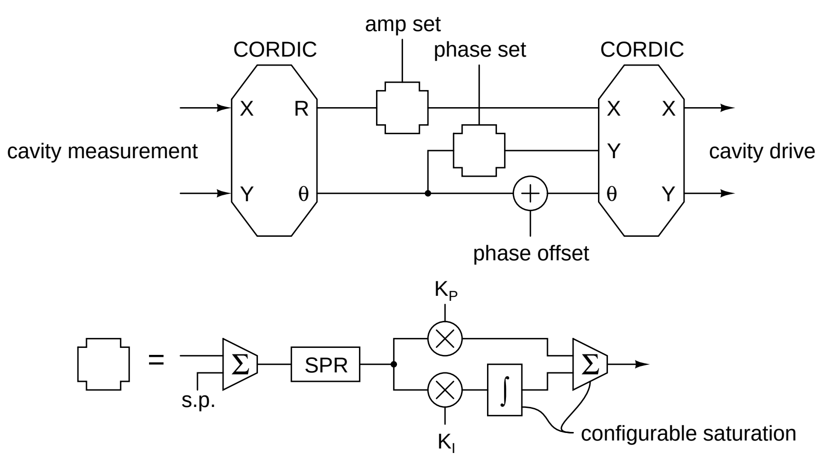
| | | |
|---|---|---|
| 50 | ns | input analog BPF |
| 170 | ns | ADC pipe (16 cycles at 94.3 MHz) |
| 64 | ns | Precision Rx DSP (12 cycles at 188.6 MHz) |
| 140 | ns | GTP and fiber latency |
| 106 | ns | Controller DSP (20 cycles at 188.6 MHz) |
| 530 | ns | bandpass filter in DSP (300 kHz) |
| 70 | ns | notch filter in DSP ($\sim$800 kHz for $8\pi/9$ mode) |
| 40 | ns | DAC (7 cycles at 188.6 MS/s) |
| 20 | ns | sideband selection filter |
| 170 | ns | Estimated SSA |
| 100 | ns | cables and waveguides |
| 80 | ns | contingency |
| 1540 | ns | total, can sustain 65 kHz closed loop bandwidth |

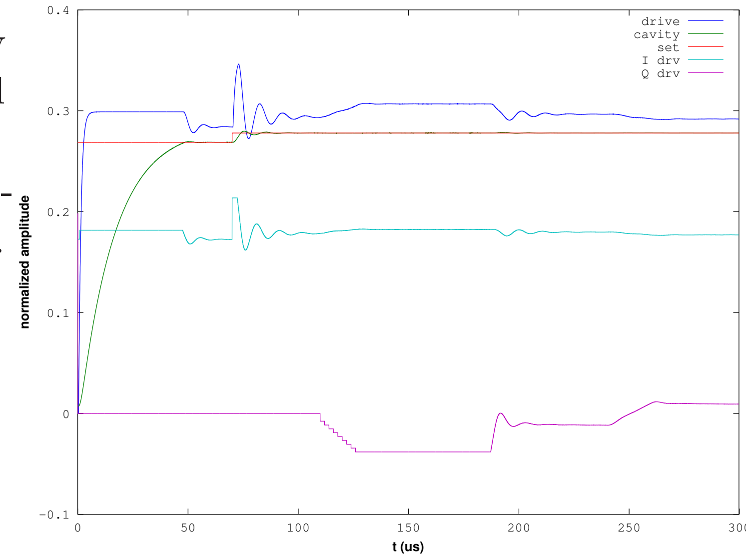
**Resonance control**

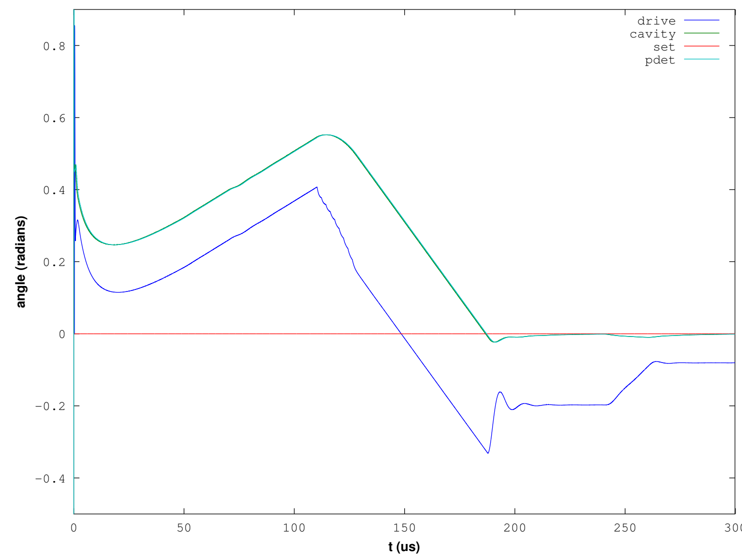
- Computations done in LLRF FPGA based on RF measurements
- Cable drift and cavity detuning look similar in a CW cavity; can disambiguate with:
  - Pound technique (only when beam off)
  - Decay analysis (fails if machine MTBF is too long)
  - Forward wave locus fit (fails if cavity is too quiet, but can dither with piezo)
- Results sent to Piezo and Stepper hardware for actuation

## SEL (Self Excited Loop) controller firmware

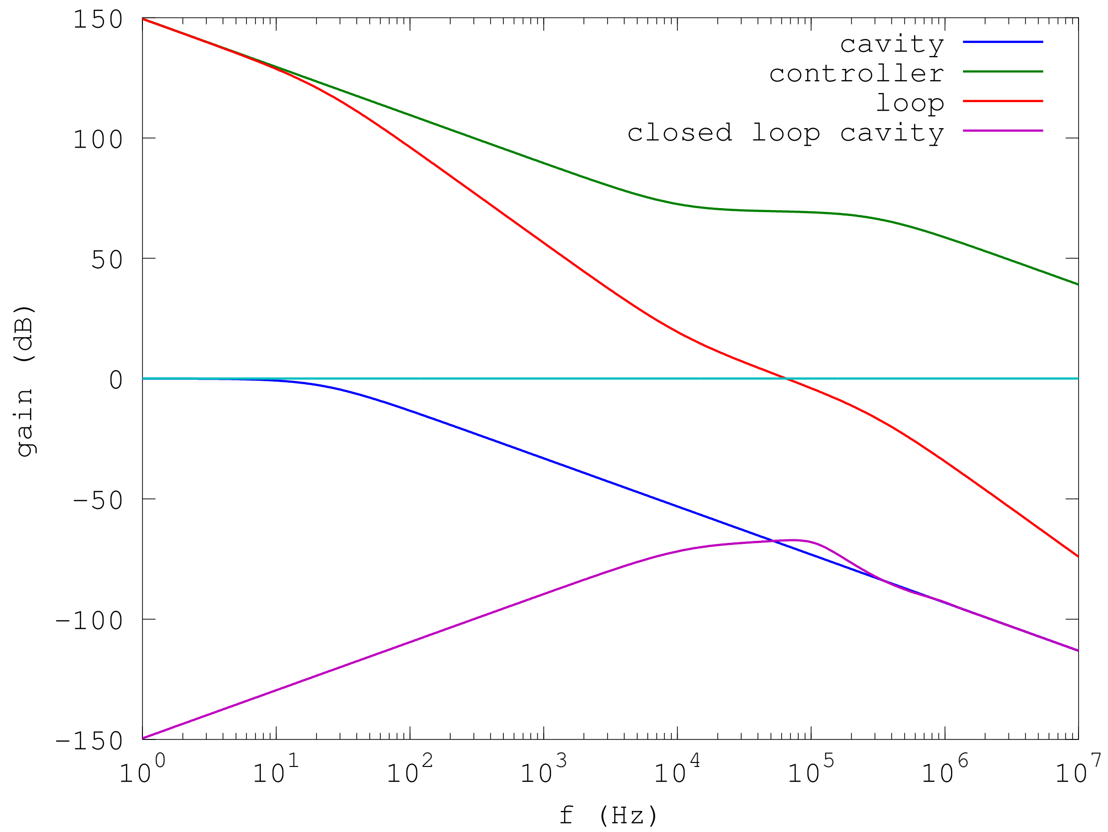
- With all features from Delayen 1978 implemented, linearized behavior around the operating point exactly matches a GDR (Generator-Driven Resonator) control loop.
- During large cavity frequency excursions from microphonics, the phase loop clips and its gain goes to zero. The system naturally reverts to cavity tracking mode **without disrupting the amplitude control loop** (crucially important in the context of significant Lorentz forces).
- Recovery to stable phase and beam-ready operation is also a natural response of the system design.
- This correctly covers the most important “exception condition” that DESY talks about at conferences.



**Small-signal frequency response**




Need to limit the bandwidth of the controller's P (proportional) term, to keep the magnified ADC noise from overwhelming the drive signal sent to the SSA.

Already has an "extra" controller pole at 10 kHz, more aggressive than the classical op-amp stability model, to drive loop gain higher in the crucial audio band.

**Electronic Frequency Stabilization of Microwave Oscillators,**
R. V. Pound, Rev. Sci. Instr. 1946

Injects moderate amounts of high-frequency modulation on forward wave, looks at the phase of the scattered signal on the reverse coupler. Unlike dithering techniques, it does not depend on the cavity field (stored energy) changing. The small amounts of field perturbation induced could be cancelled by pairing cavities.

Answer is perturbed by beam current loading, best to use when beam is off or at least really weak.

To my knowledge, not yet tested in the modern era on SRF cavities.