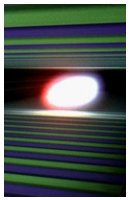


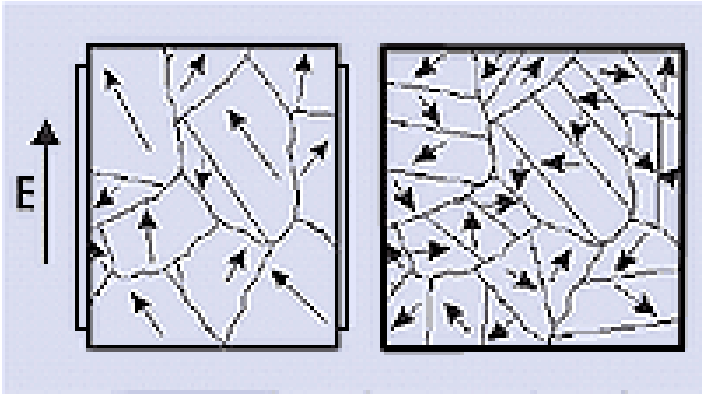
PZT damage tresholds, recent results

Mariusz Grecki

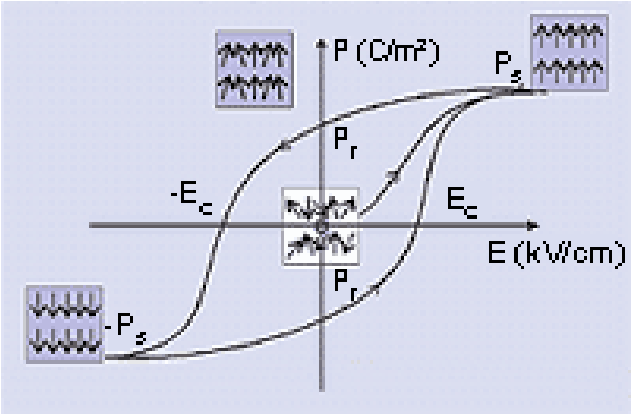
Agenda

- Piezo operation principle / piezo effect
- Piezo operation at FLASH/XFEL
  - Piezo driver development
  - Control principles
  - Results acieved
- November 2011 Piezo event and consequences
- Damage mechanisms at piezos
- Optimization of the piezo lifetime
- Conclusion

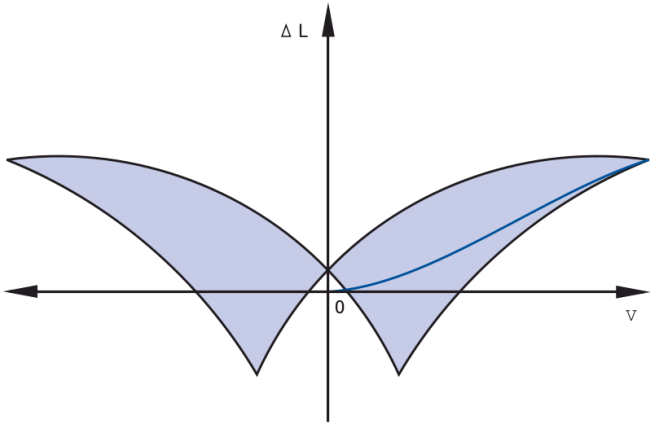
Piezo effect



Ferroelectric domains

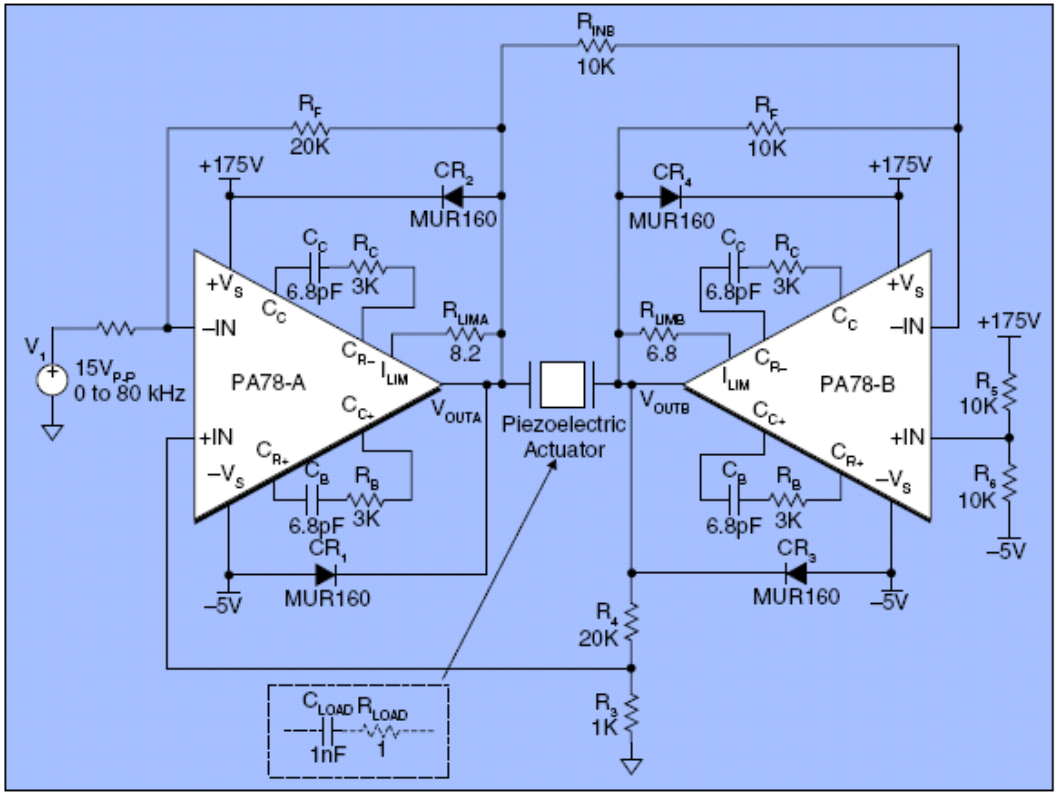


Polarization hysteresis



Elongation curve

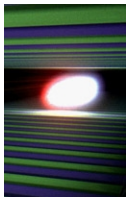
Old Piezo Driver

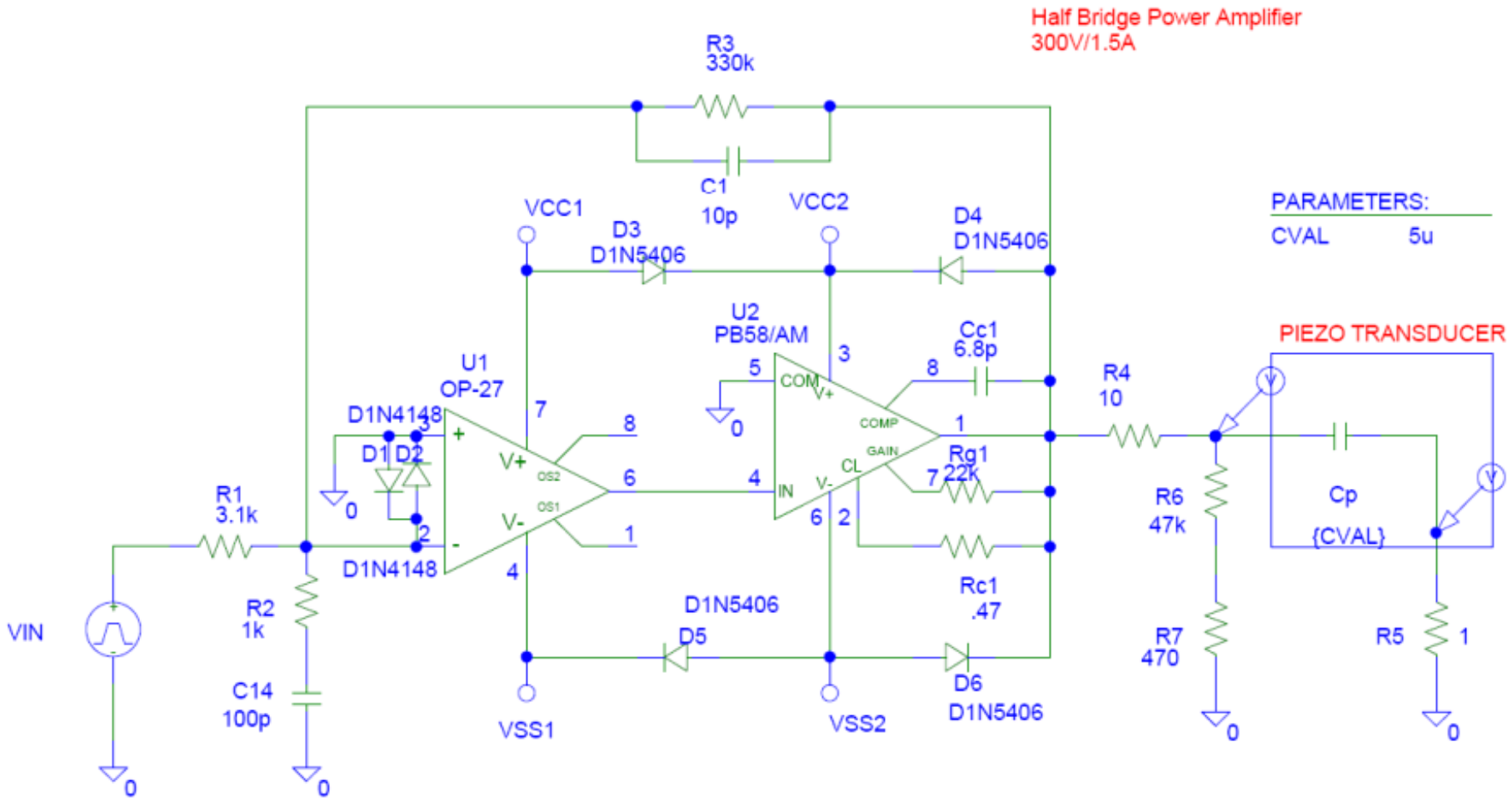


- designed by Nikolay Ignatian
- “Old” piezo driver used in FLASH
  - based on PA58, full bridge
  - 2 separate amplifiers on single euro PCB
  - low gain (40V/V) not allowing to use SIMCON to drive the piezo amplifier

European XFEL

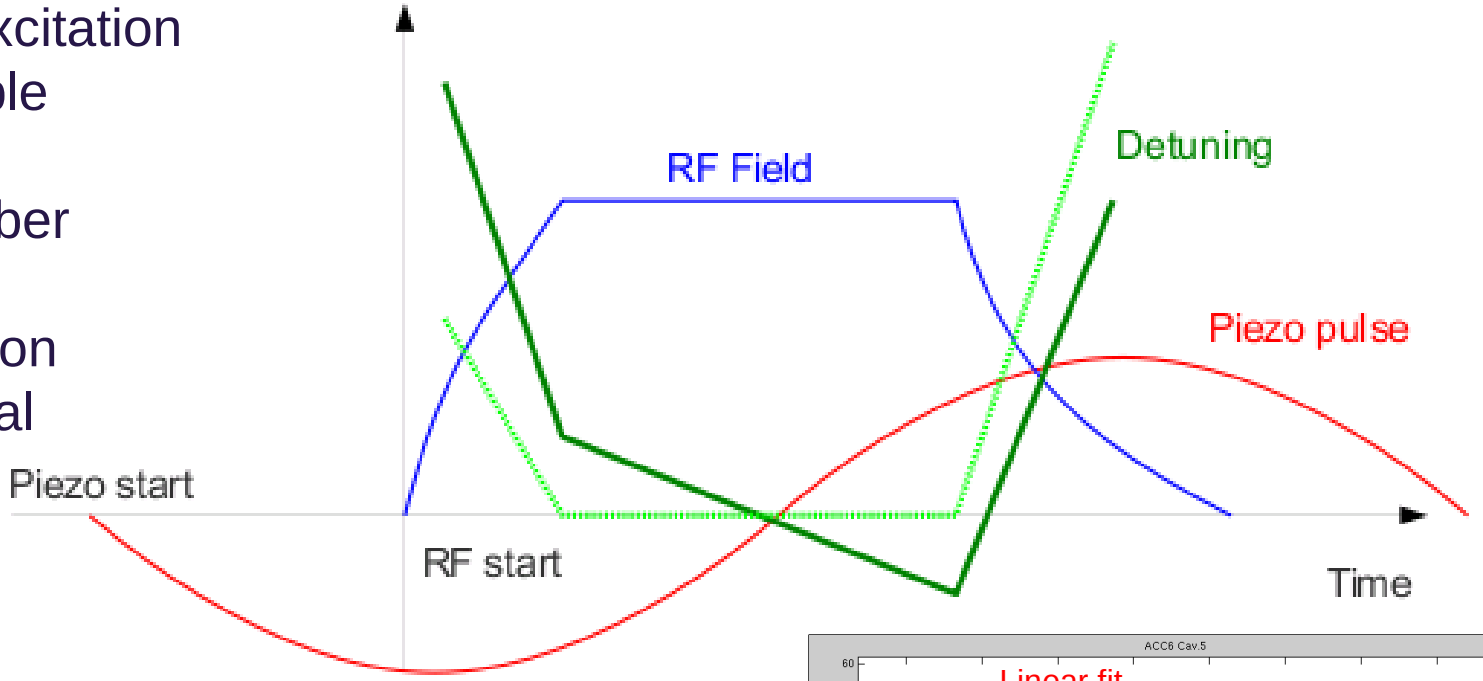
Piezo driver - schematic diagram





Piezo control for LFD compensation

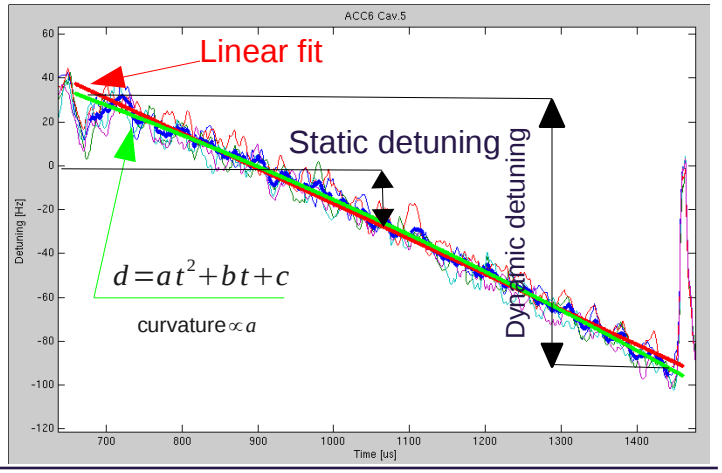
Sinusoidal excitation
with adjustable
– Frequency
– Pulse number
– Amplitude
– Time position
– DC pedestal



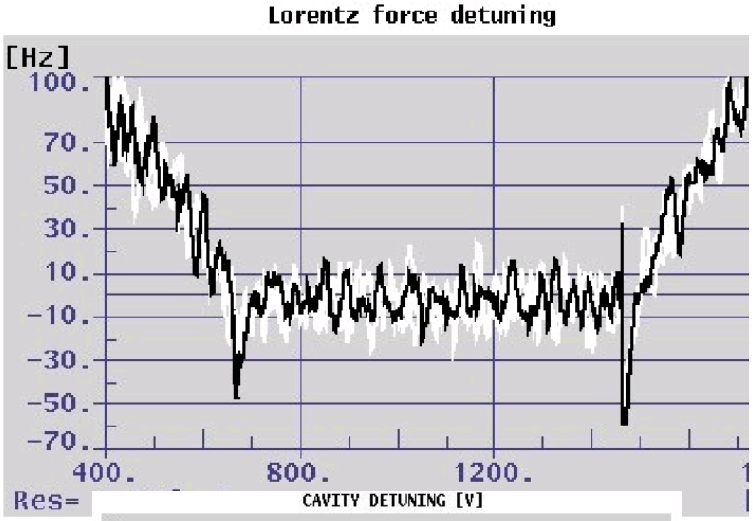
Amplitude → dynamic detuning

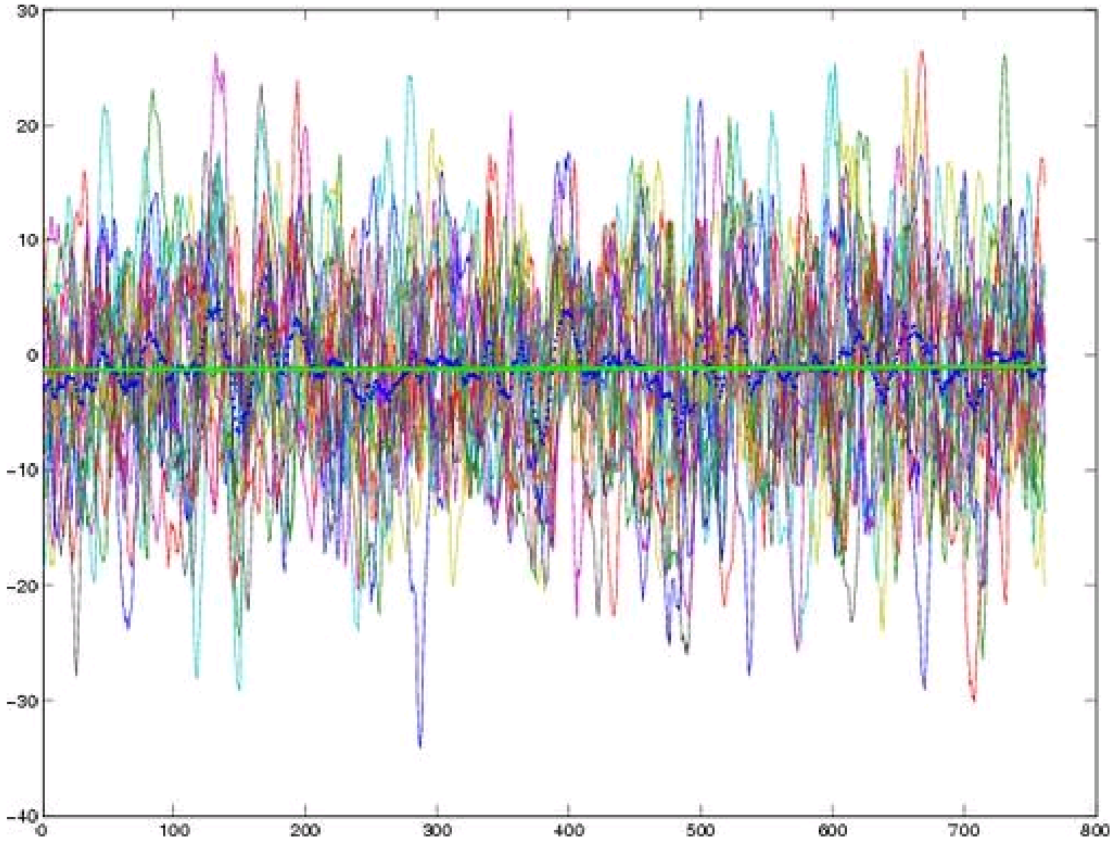
DC pedestal → static detuning

Time position → curvature



Tuning of cav. 1 at ACC6

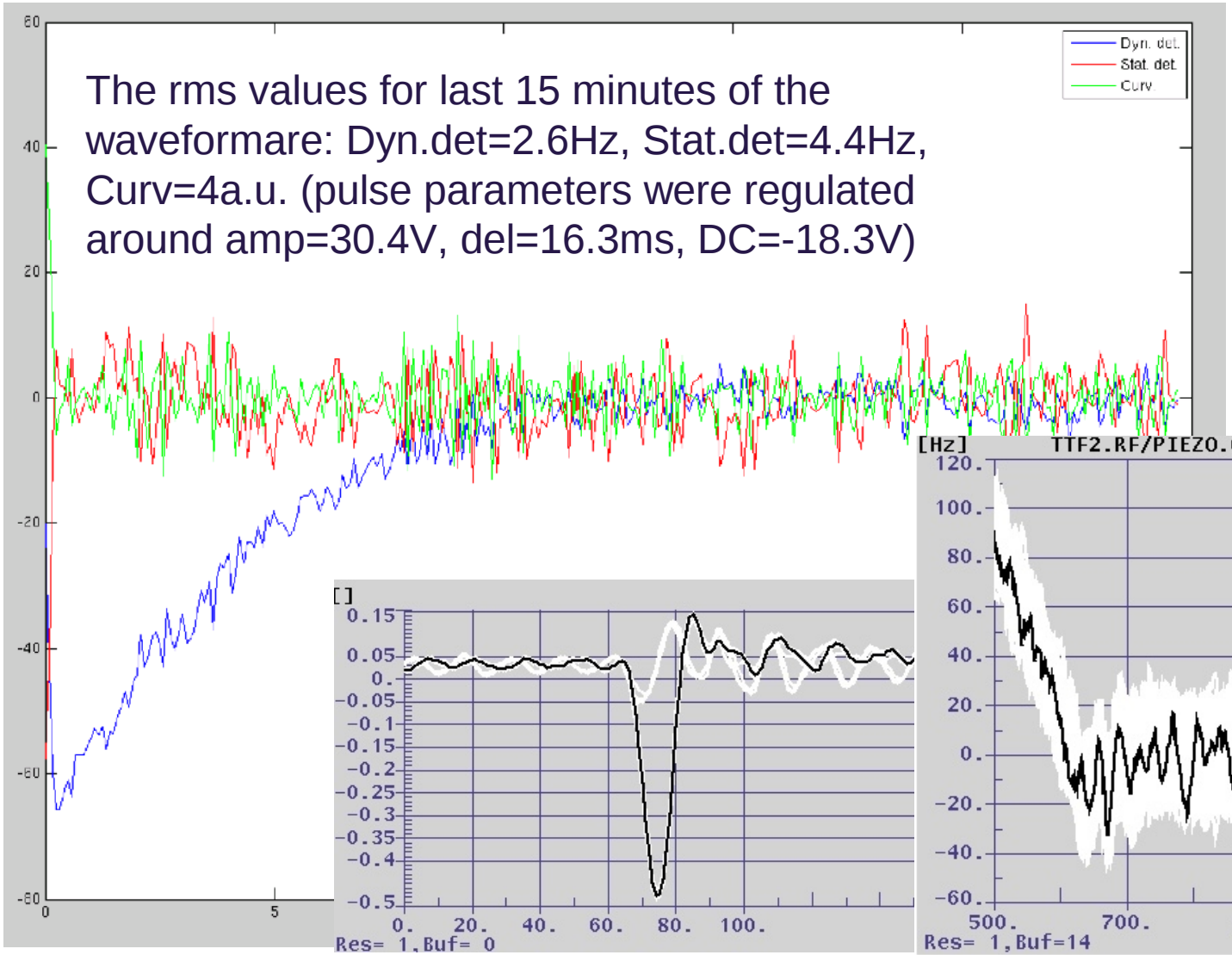


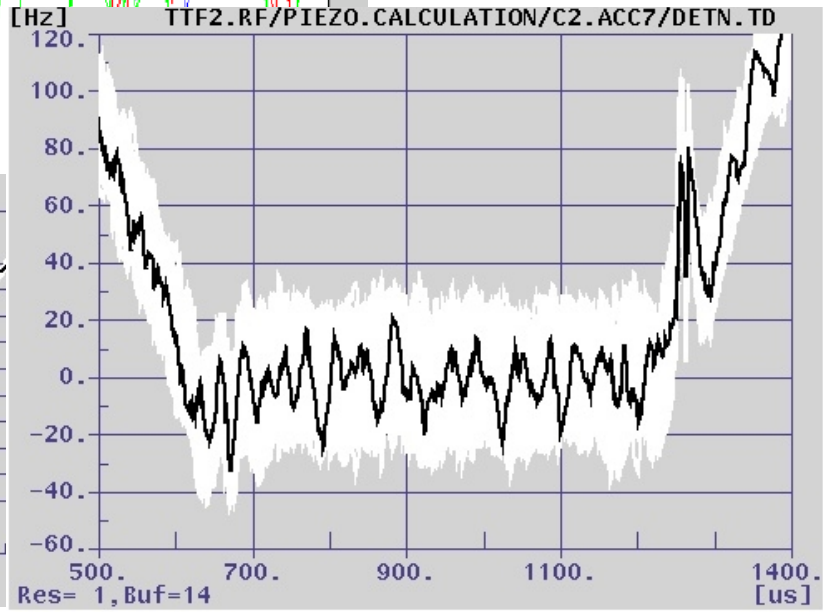


c1@acc6: measured over 20 pulses. The achieved parameters: dynamic detuning 0.3190Hz static detuning: -1.1760Hz, curvature: 0.1774 a.u. (linear and quadratic approximation covers in the picture). Settings for the piezo: bipolar mode, 200Hz, 1 pulse, 19.12ms after A2, amp=-23.06V, DC off=-36.62V

Automatic tuning of cav. 2 ACC7

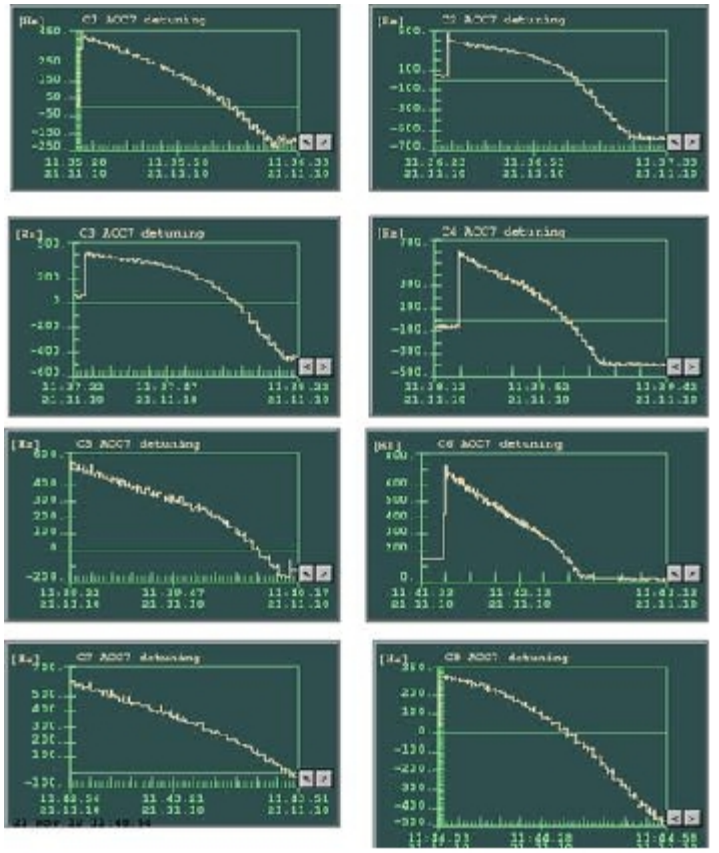
The rms values for last 15 minutes of the waveformare: Dyn.det=2.6Hz, Stat.det=4.4Hz, Curv=4a.u. (pulse parameters were regulated around amp=30.4V, del=16.3ms, DC=-18.3V)





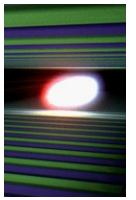
November 2010 Piezo Event

- Piezo failure at FLASH during tests on 21.11.2010
  - The purpose of the piezo tests was to scan the static detuning versus DC offset voltage applied to the piezo. The range of the voltage applied to the piezo was from maximum negative (-70 V) voltage up to maximum positive (+70 V) voltage with single step of 5 V
  - The scan procedure has been repeated by execution of the Matlab script several times for different settings of loaded Q without any noticed problems
  - At the end of the shift (14.33 p.m.) the cavities in ACC7 have been moved back to the initial loaded Q values and the last piezo DC offset voltage scan was applied for the module ACC7
  - During it we have observed no response of the cavity 1 to the piezo voltage change



C1@ACC7	Piezo 1	Piezo 2
Capacitance [μF]	0.01	4.27
Resistance [Ω]	4.57	>10e6

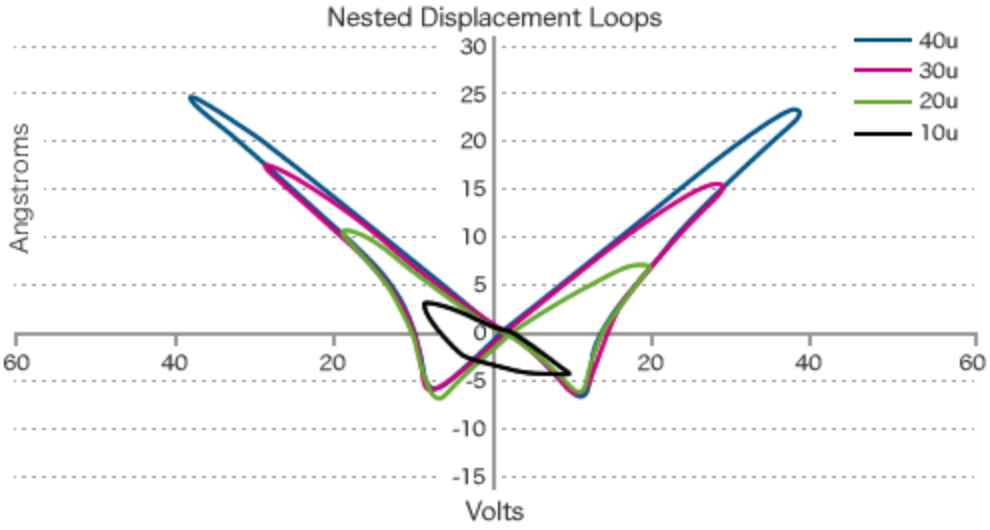
Actions performed

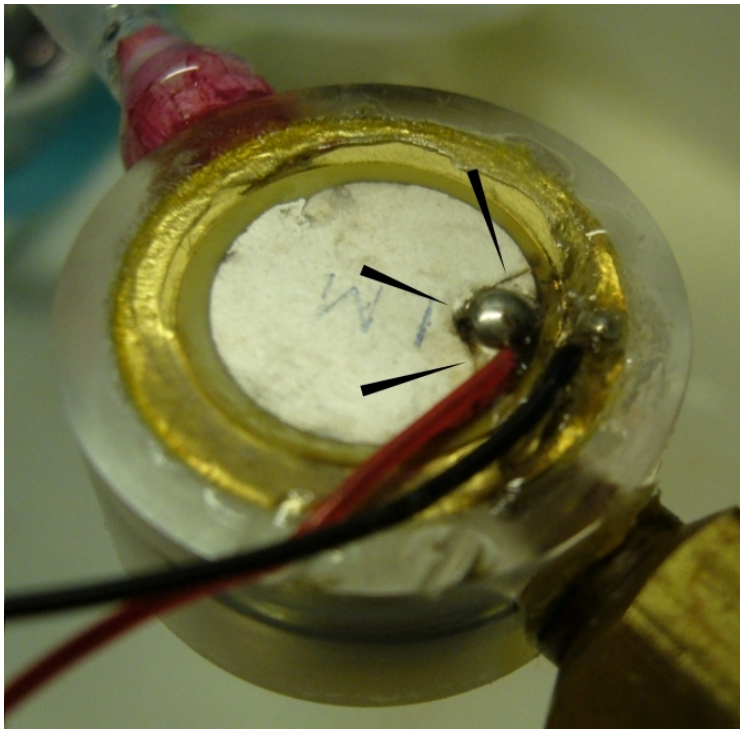


- Piezo operation at FLASH has been stopped
- After analysis of tests conditions the suspicions focused on piezo reloading process from +70V to -70V between scans (in single step)
- Simulation of the tests conditions has been performed
- Measurements in lab has been performed using capacitor instead of real piezo
- Common conclusion from simulation and measurements
  - the piezo current limited by the piezo driver to ~1.5A
  - no voltage spikes observed
  - the slew rate of the current during the reloading few tens higher than in normal operating conditions (sinusoidal excitation of the piezo)
- The procedures preventing fast reloading of the piezo implemented in software (DOOCS server)
- The destructive tests in horizontal cryostat performed.
  - ~3 weeks of tests in February 2011, 2 piezos installed in the cavity. Mostly focused on piezo no.1, for piezo no.2 the same tests but for short time.
  - Goal: to learn on piezo damage mechanizm.
  - Bipolar mode 0¸±70V, 10/200Hz, single pulse.
  - Simulation of scan tests (failure reason?).
  - Bipolar mode 0¸±120V, 10Hz, rectangular waveform.
  - DC ±300V for few minutes.
  - Piezos survived all tests

Piezo breaking mechanizms

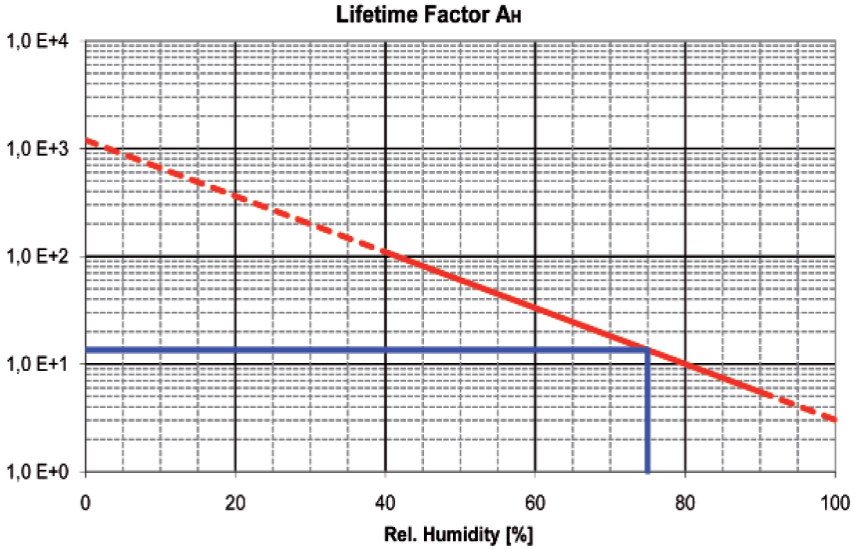
- Voltage breakout
- Overcurrent (including to high slewrate)
- Overheating
- Repolarization
- Mechanical damage

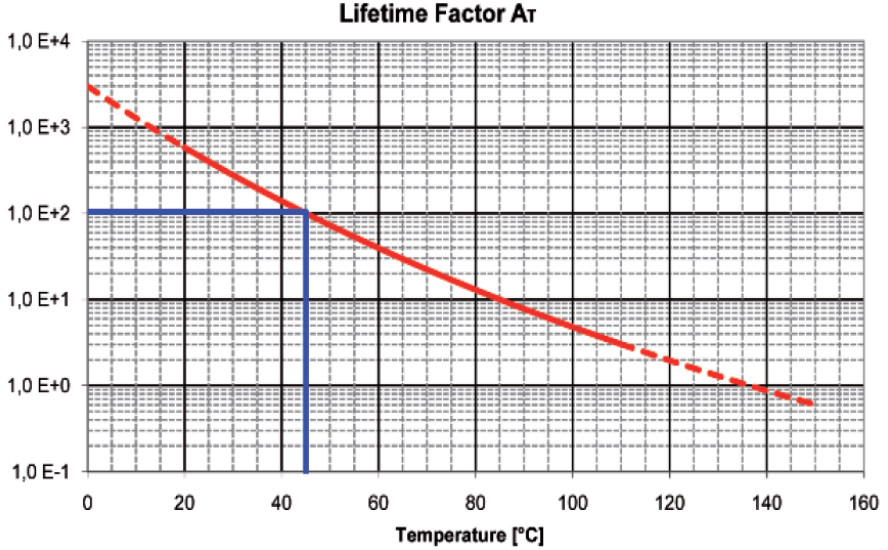




Repolarization cannot be a source of piezo shortcut...

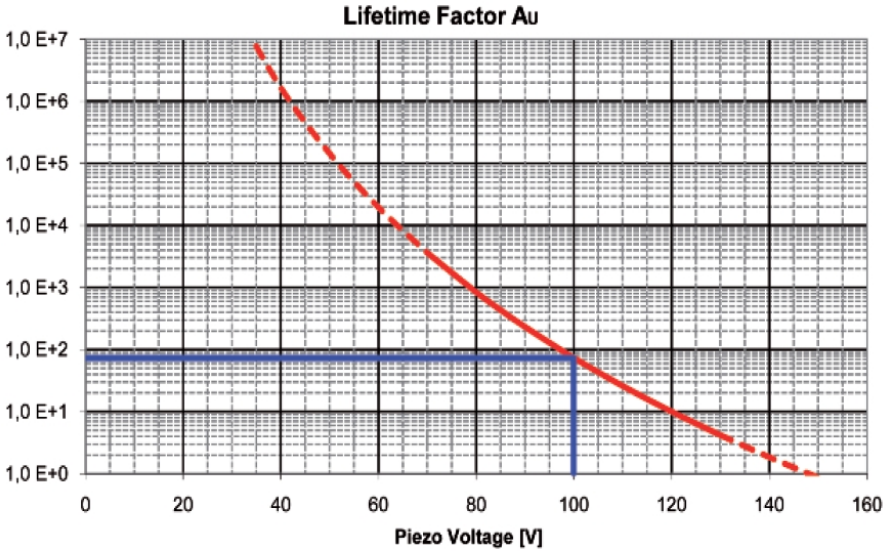
Piezo lifetime optimization



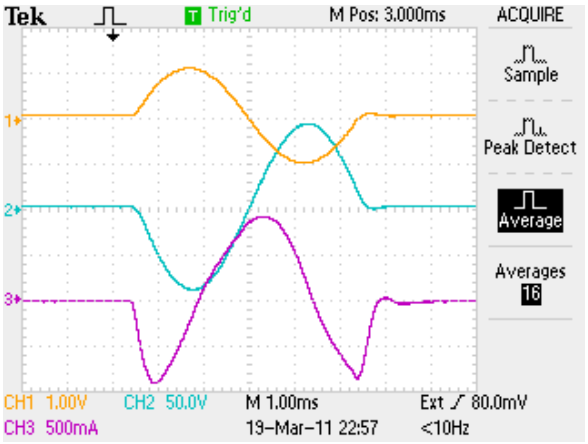


$$MTTF[h] = A_U * A_T * A_F$$

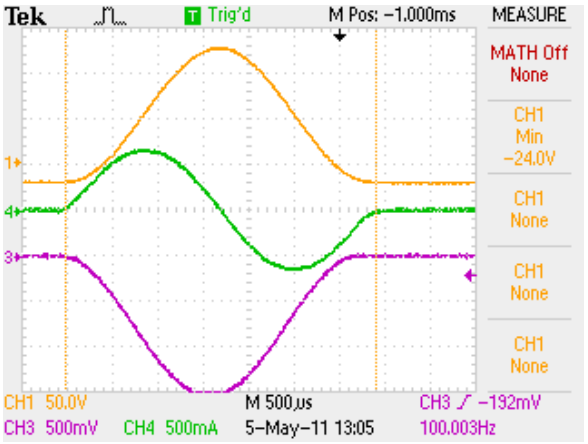
… The lifetime to be expected at 80V DC is ~10 times higher than that to be expected at 100V DC. ...



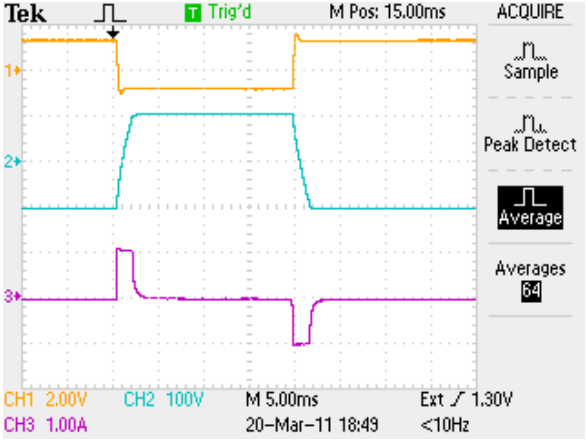
Measured performance at Chechia

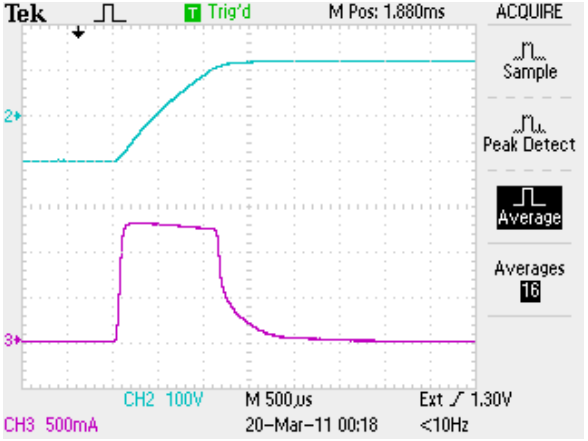


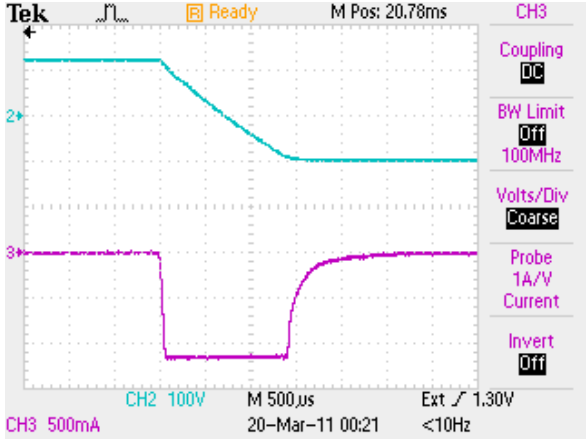
Bipolar drive



Unipolar drive



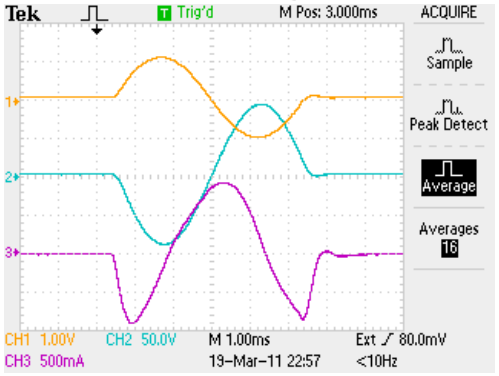




Switching up and down (±100V)

Discussion with PI engineers

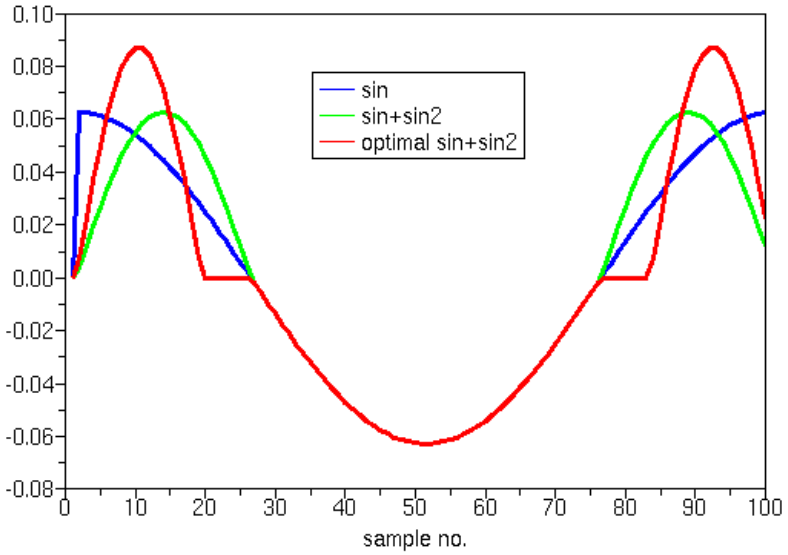
- Was piezo broken by overcurrent? Overvoltage? Bipolar operation?
  None seems to be the reason
- We need for LFD compensation the peak-to-peak voltage. For unipolar operation the maximum piezo voltage is ~2x higher than for bipolar mode.
  This can be a limiting factor →go bipolar for cryho temperatures
- We need DC voltage on piezo to tune cavities. Is it safe for piezos to drive them with several tens of Volts for the long time?
  This is not an issue but remember about voltage dependency.

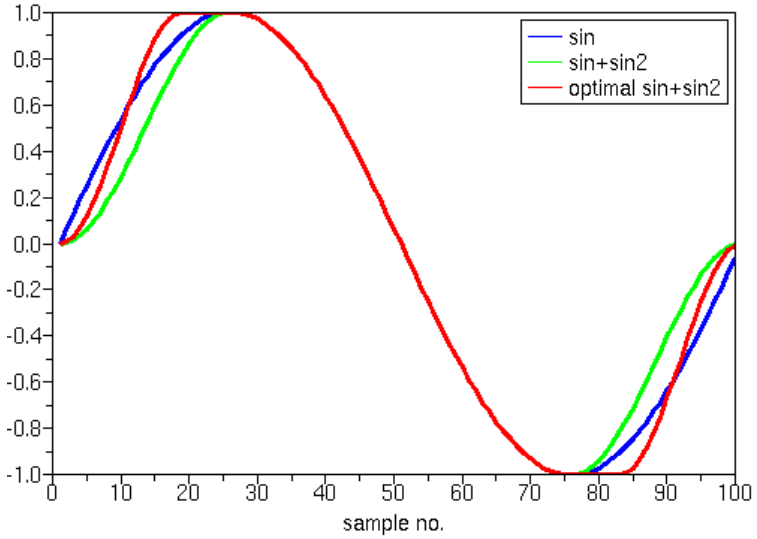


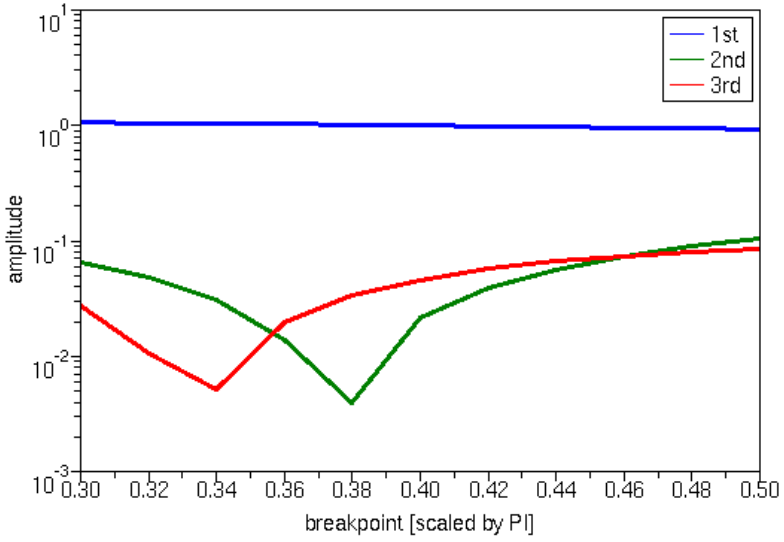
Comment: limit the current slewrate.

Limiting the current slewrate

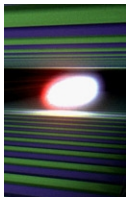
In order to reduce the current slewrate the beginning of the sinus curve (the first quarter) can be changed to its square optionally followed by constant (maximum) value







Conclusion



- Unipolar and bipolar mode of piezo operation provides comparable performance
- For cryho temperatures operation the bipolar mode of piezo operation promises longer piezo lifetime... but
  - We should have still possibility to run both mode of operation
  - The cryho OK signal is necessary to prevent driving hot piezos

Thanks for the attention