Piezo heating experience

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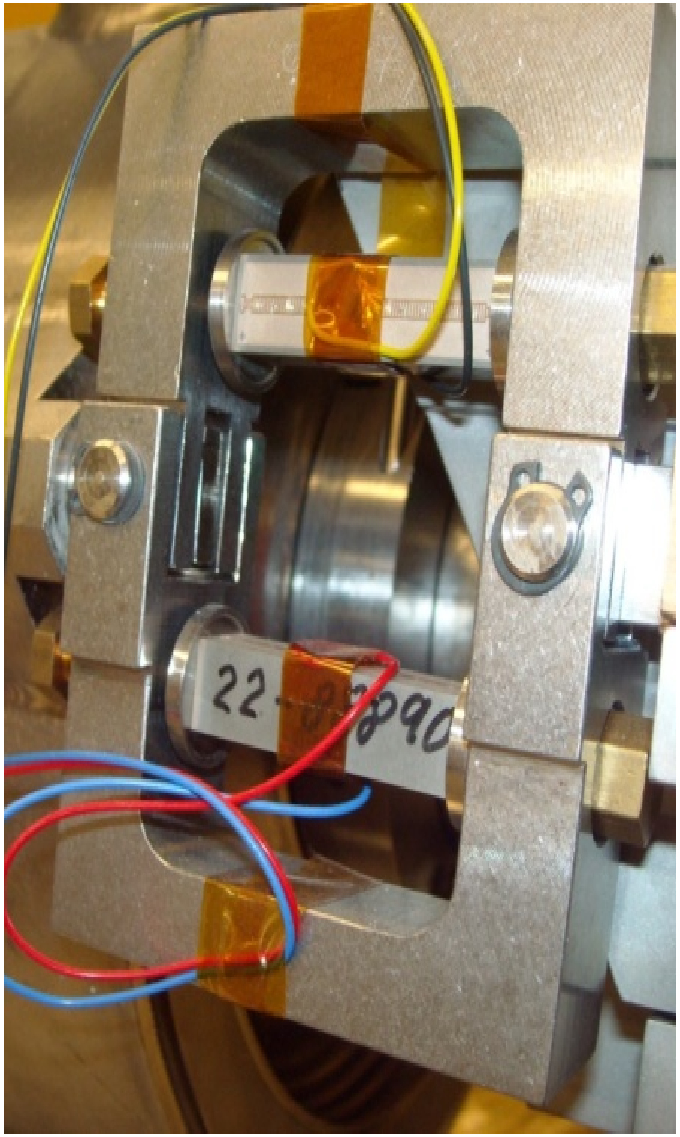
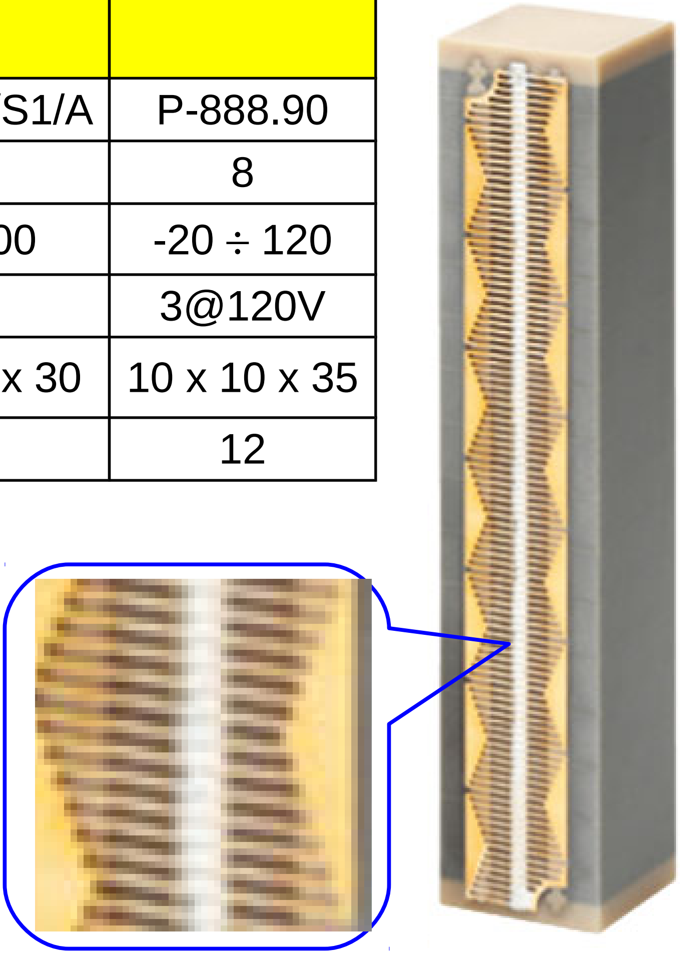
Piezo's and piezo tuners



Manufacturer ratings	Noliac	PI Ceramics
Model	SCMAS/S1/A	P-888.90
Cells	8	8
Voltage range [V]	0 ÷ 200	-20 ÷ 120
Blocking Force [kN]	6	3@120V
Size [mm^3]	10 x 10 x 30	10 x 10 x 35
Capacitance [uF]	6	12

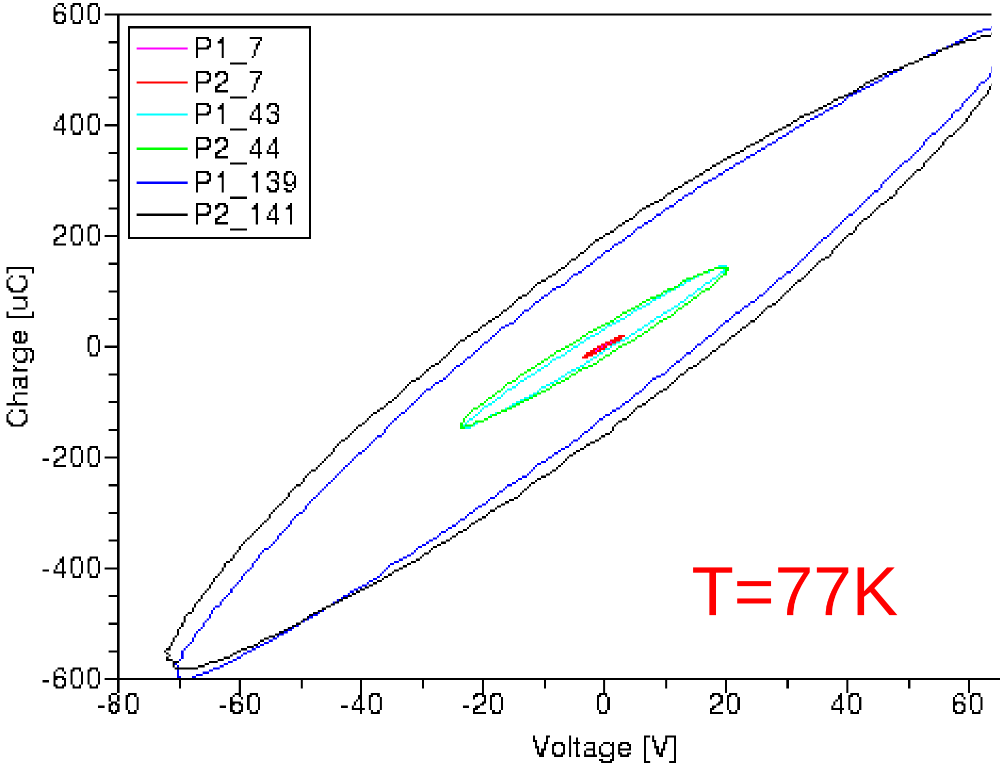
Manufacturer: **NOLIAC**
Dimensions: **10x10x30mm**

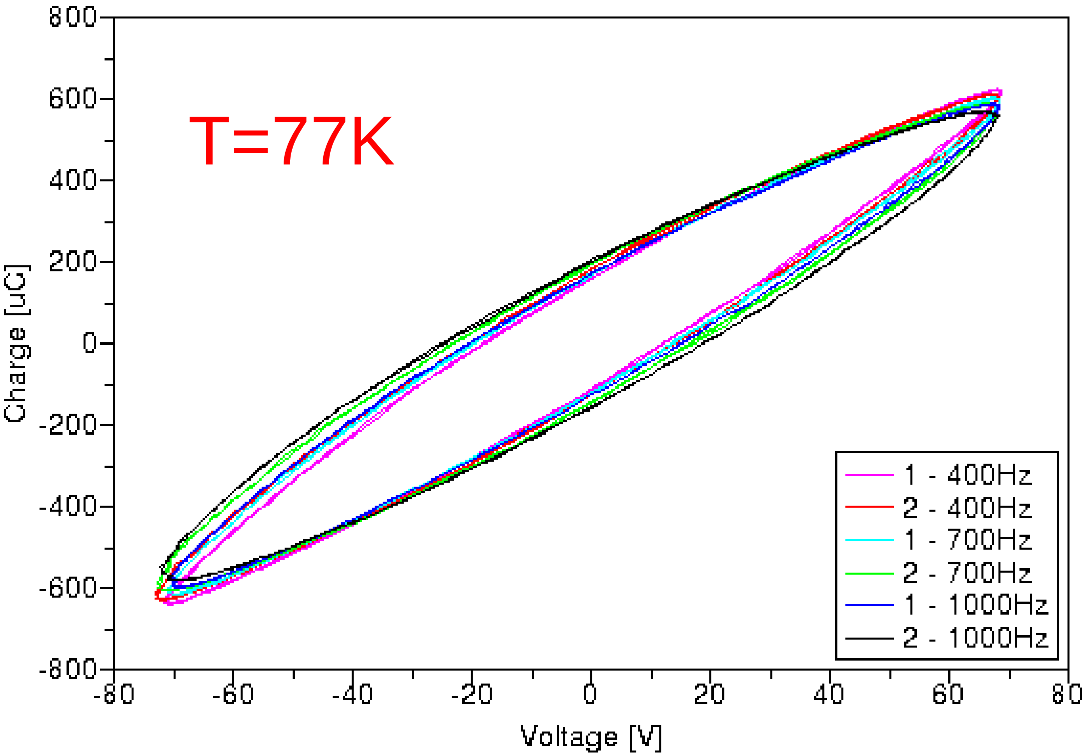


Manufacturer: **PI**
Dimensions: **10x10x36mm**

Energy dissipation at piezo

$$E=\int ui\,dt=\int u\,dq$$



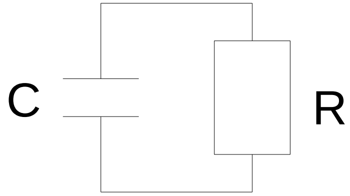


$E \sim V^2$

E=~30mJ/cycle at ±70V

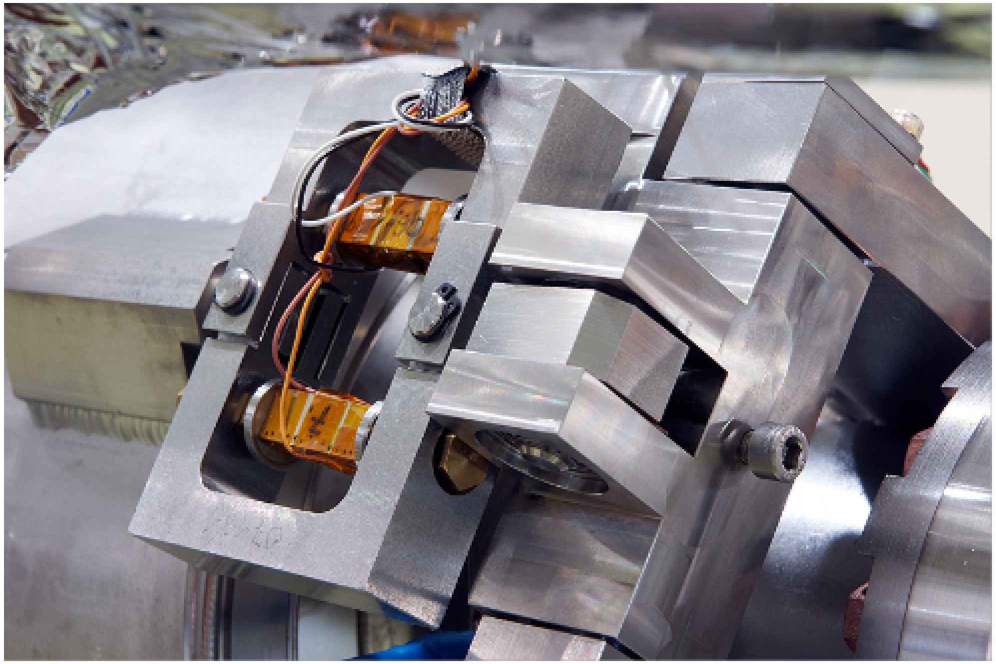
(that gives ~0.3W at 10Hz single pulse)

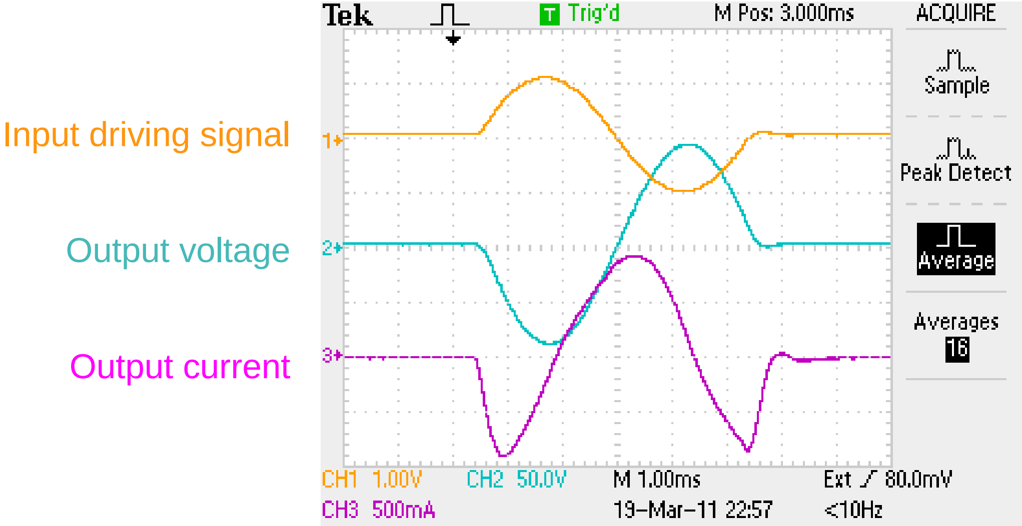
$$C=\frac{dQ}{dV}$$

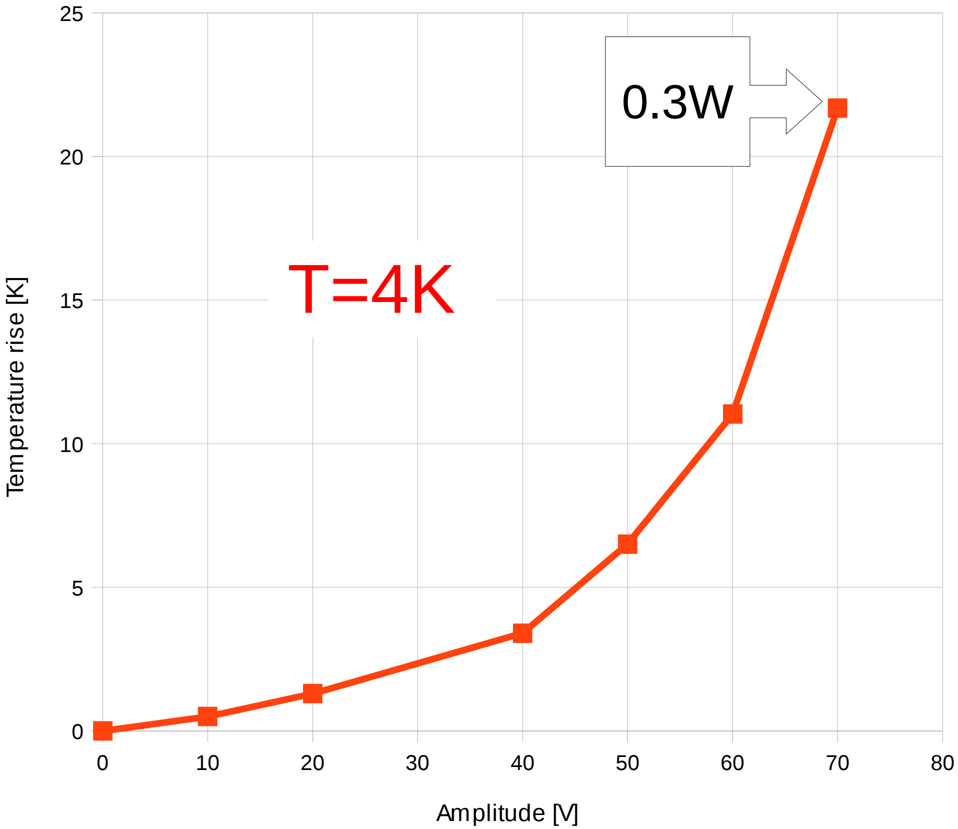


$$Y_p=\frac{1}{R_1}f+j\,2\pi f\,C \qquad Z_p=\frac{Z_1}{f}$$

Experiments at Chechia (1)

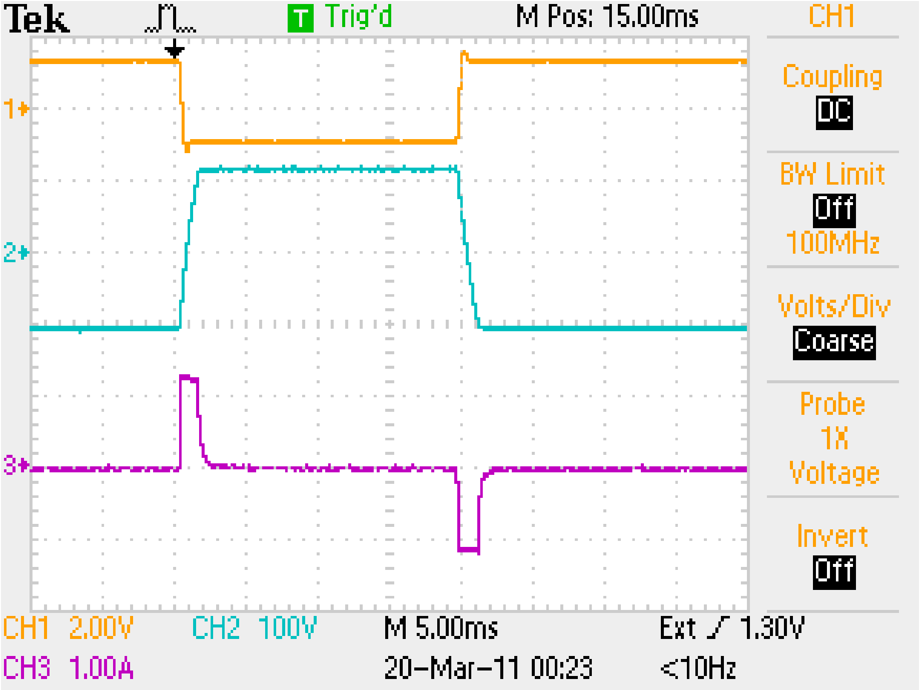


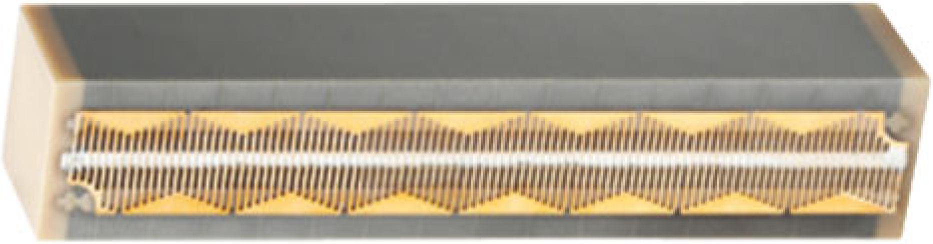


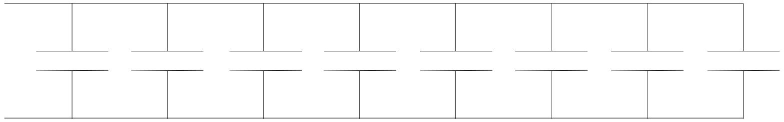


Temperature rise in function of pulse amplitude, single pulse 200Hz, 10Hz repetition rate
It does not depend on piezo bias.

Experiments at Chechia (2)







Rectangular pulse ±100V, 20ms, 10Hz repetition rate

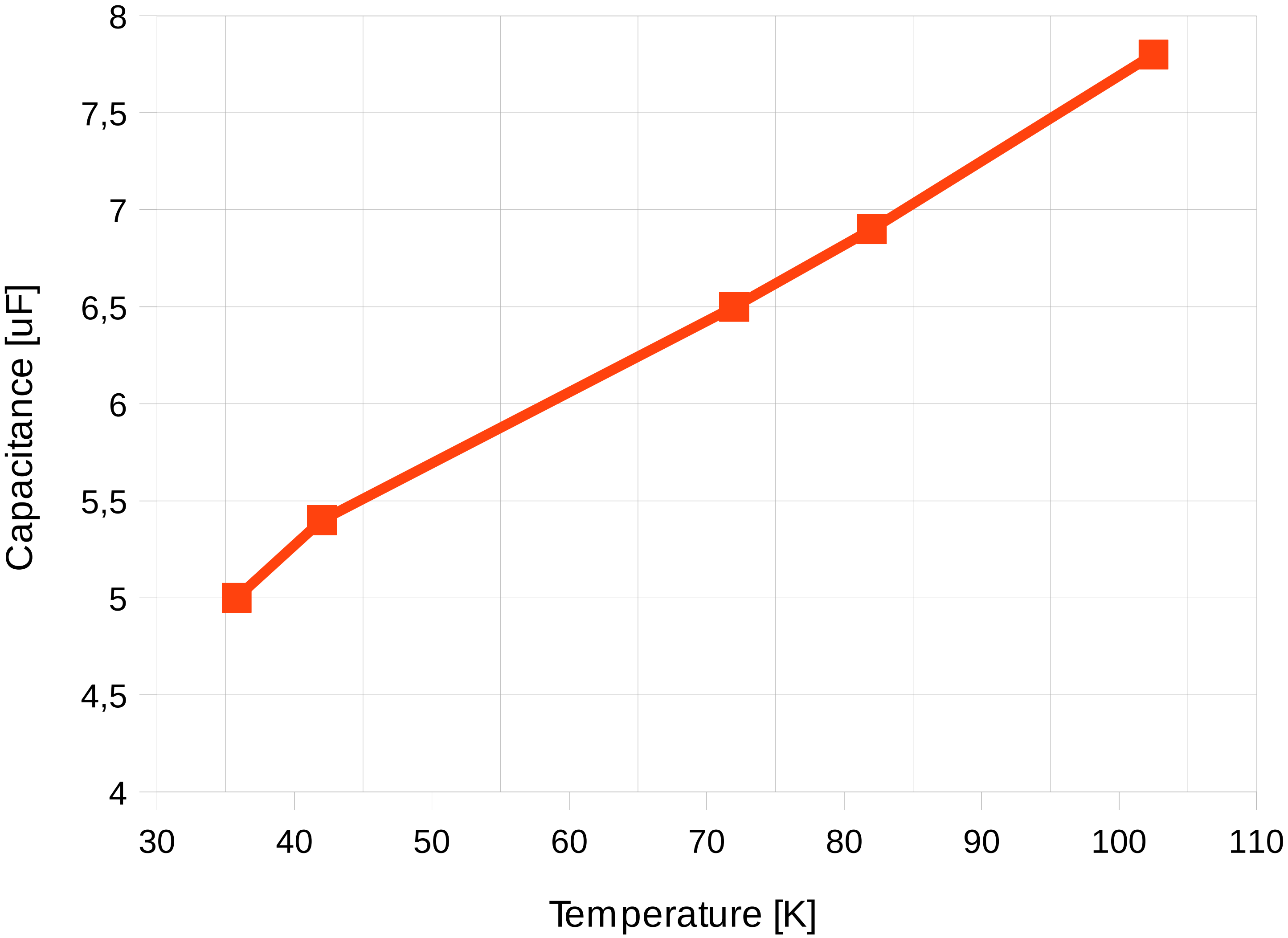
Temperature rise for this conditions was over 90K!

One could expect power heat dissipation and temperature rise twice more than at ±70V (~50K) but rectangular pulse makes a difference...

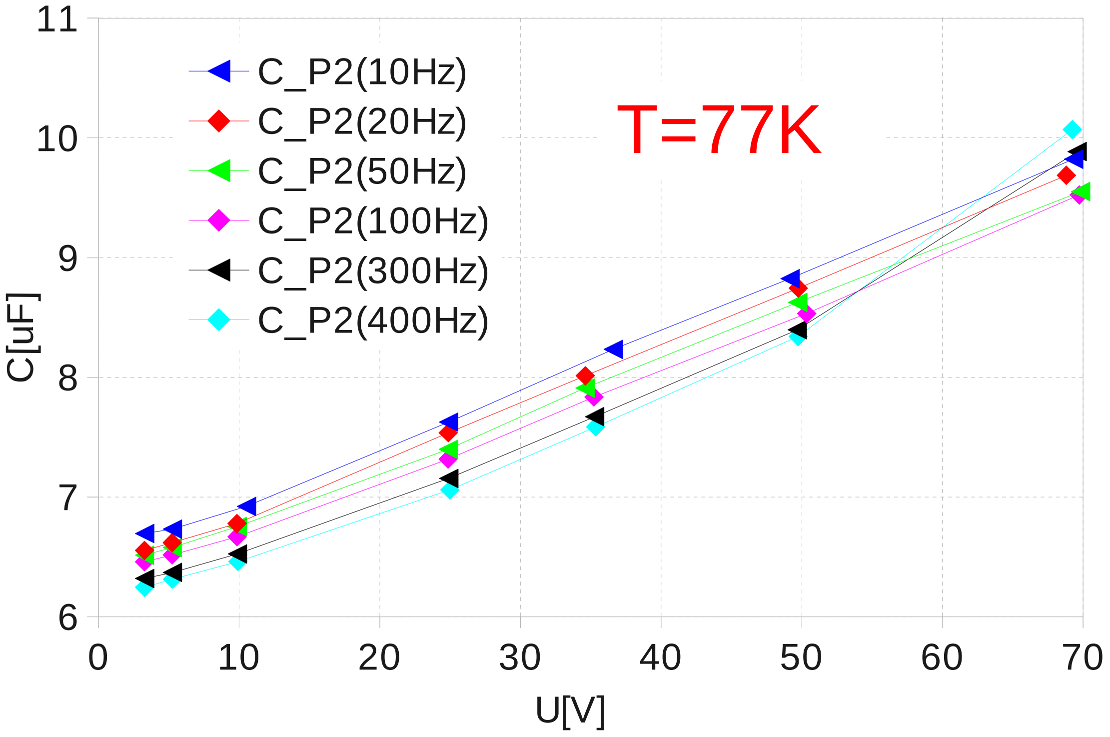
In case of nonuniform current distribution at piezo structure the positive thermal feedback may happen!

I↑T↑Z↓(C↑,↑R↓) I↑↑..

Piezo temperature measurement
(indirectly through piezo capacitance)



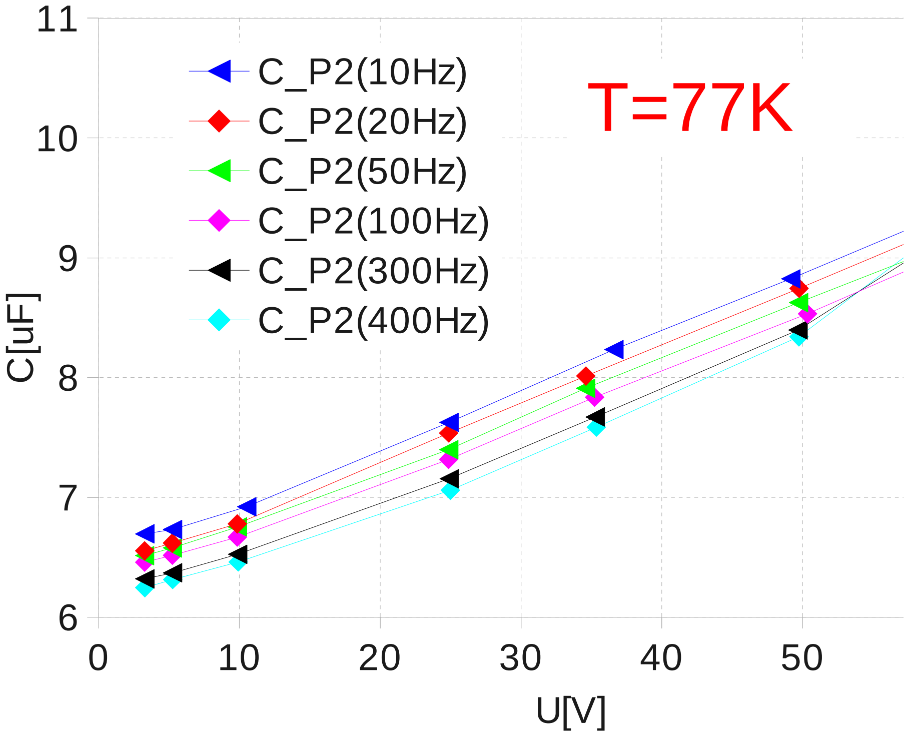
Piezo electrical parameters

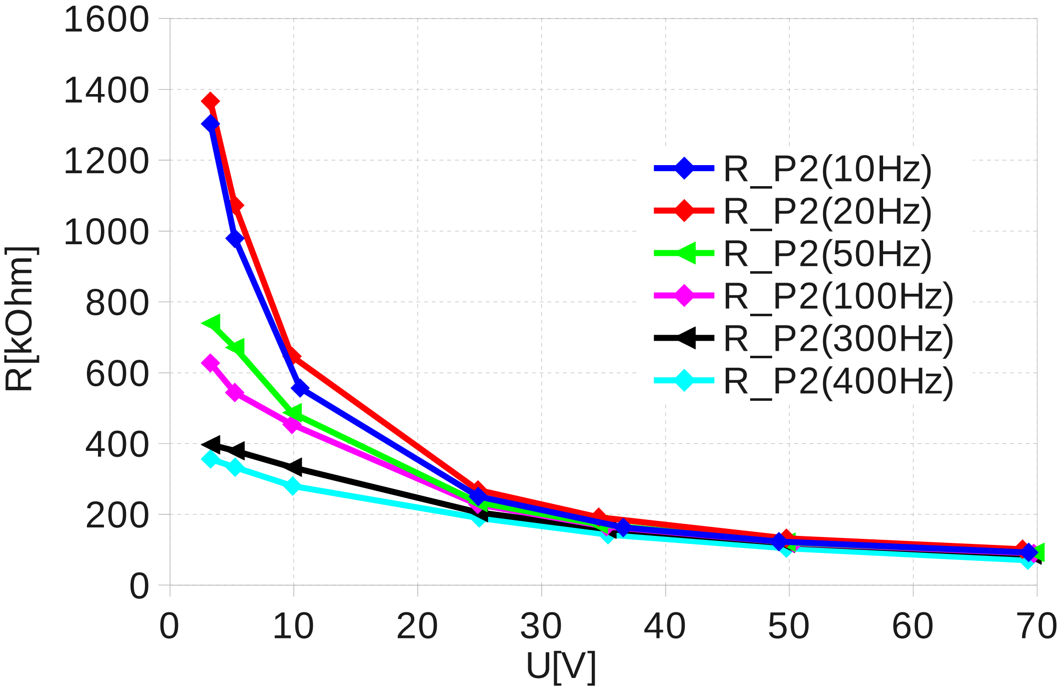


T=77K

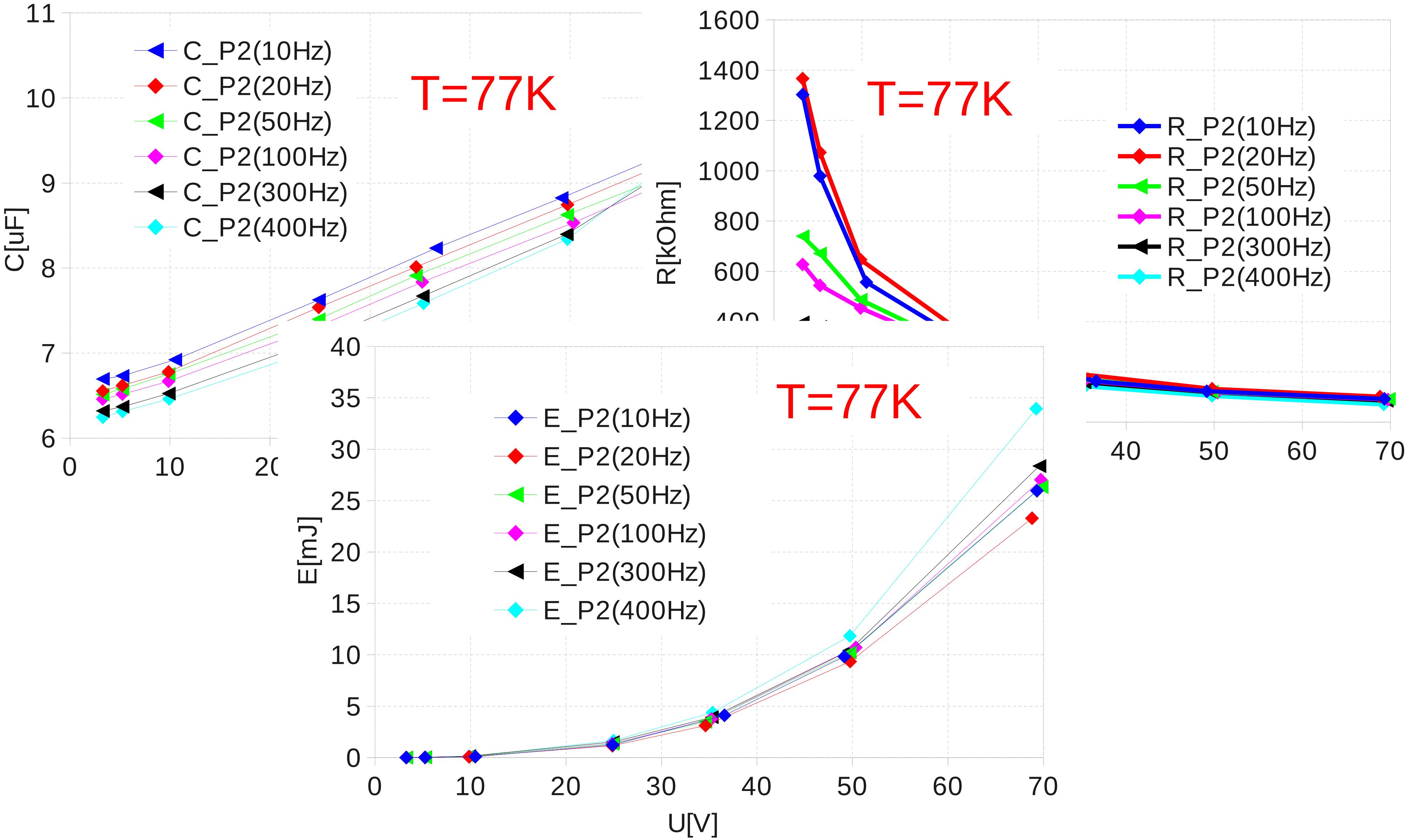
T=77K

Piezo electrical parameters

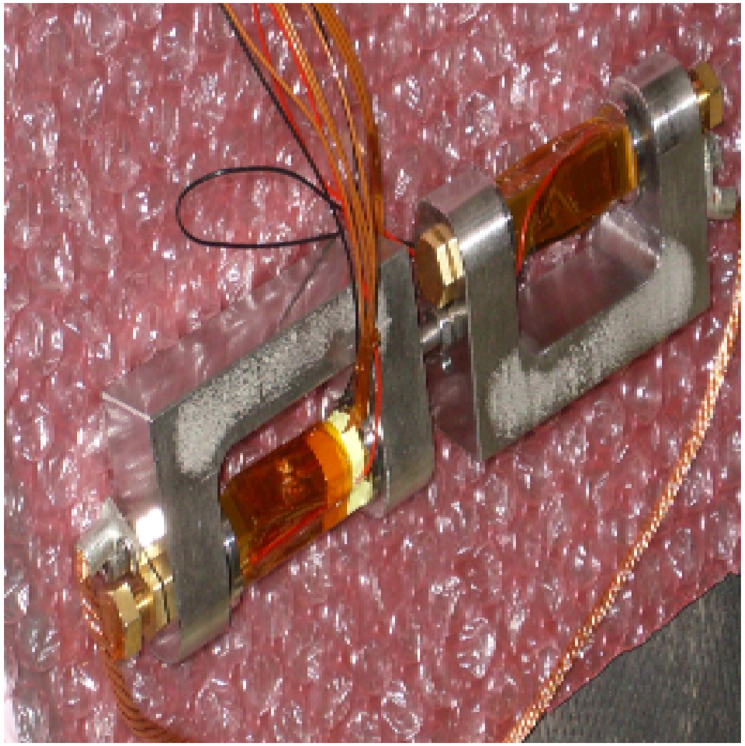


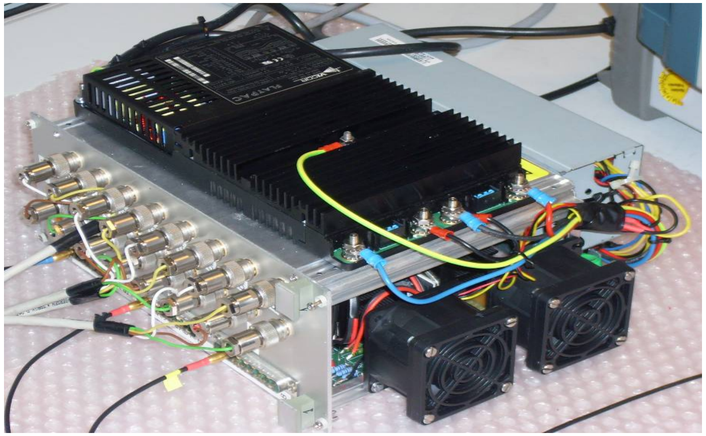


Piezo electrical parameters



Long term tests of piezo operation



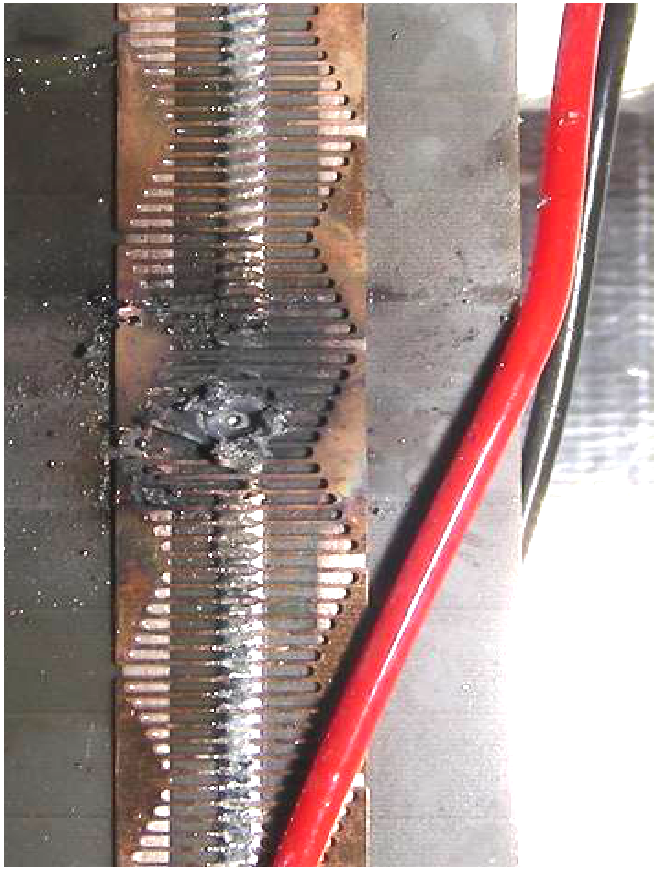


Summary of the test

Life-time test parameter	**Value**	**Unit**
Time duration	76	Days
Number of bipolar cycles	$3.3\ 10^9$	#
Excitation frequency	500	Hz
Piezo equilibrium temperature	79	K
Average AC voltage	138	V_{pp}
Average AC current	5.0	A_{pp}
LN2 loss rate (by balance)	0.25	kg/h
LN2 loss rate (by flow meter)	0.35	nl/min
Heat load (by balance)	14 +/- 1.7	W
Heat load (by flow meter)	14.5 +/- 2	W
Amount of LN2 used	515	l
Refills / transfers	8	
Piezo driver temperature	< 45	C

Destructive test

- After it has been proved piezo can withstand long term bipolar operation the destructive test has been performed (400Hz, rectangular waveform, ±70V).
- The operation of the piezo was not stable, after ~2 min. rapid temperature rise has occurred. Within the tiny time window allowed by the safety loop (about 2 seconds) the piezo temperature went up to 120 K before voltage shut down and the actuator failed.



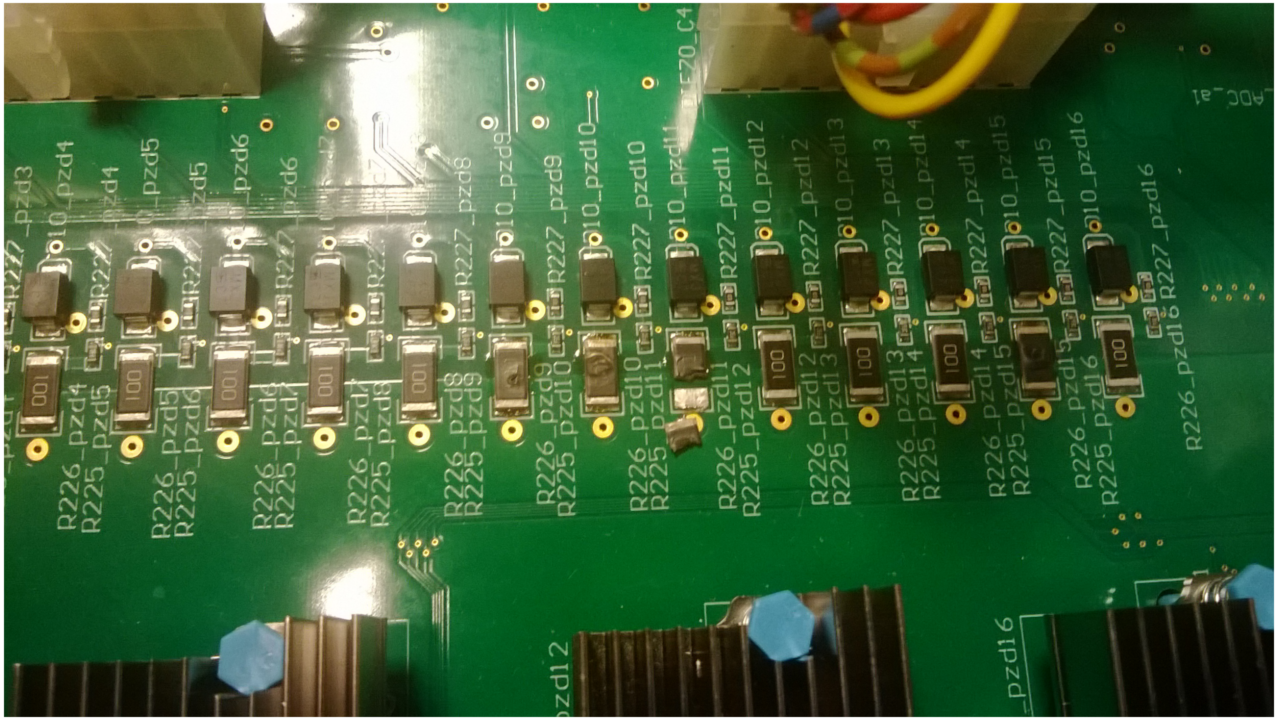
Piezo events at FLASH

- November 21 2010 (ACC7 cav.1 actuator died)
  - during scan of the static detuning versus DC offset voltage applied to the piezo. The range of the voltage applied to the piezo was from maximum negative (-70V) voltage up to maximum positive (+70V) voltage with single step of 5 V and then repeated with single fast transition from +70V to -70V
- Sometime in 2011 (ACC3 cav.1 actuator died)
  - Not clear what happened and when. Not working piezo was noticed but the piezo driver was blamed
- October 29 2013 (ACC7 cav.2 sensor and cav.3 actuator died)
  - During the firmware update at PZ16M and uTC at ACC67 on 29.10.2013 the erroneous behavior of PZ16 was observed

Understanding the October 29 2013 event (1)

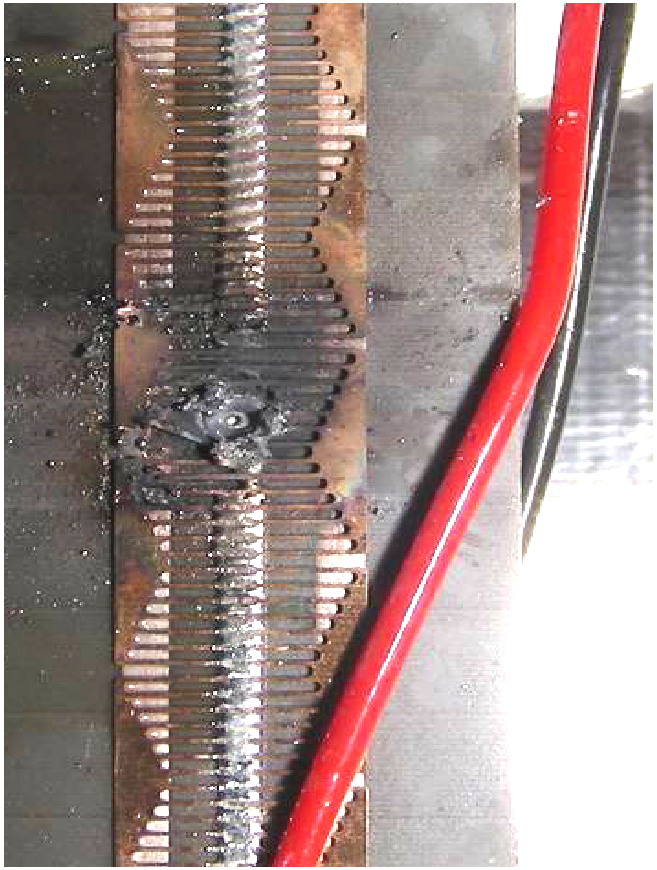
During the firmware update at PZ16M and uTC at ACC67 on 29.10.2013 the erroneous behavior of PZ16 was observed. The uTC generated random data bitstream that was driving the DAC and output switching relays. After some time (at least 30s, but it could be also few minutes – it was time needed to recognize something is wrong, removing the box upper cover, recognizing the relays clicking, etc.) the piezo control system was turned-off. Up to this time the relays clicks was heard and also a smell of burning components was felt.

During the event the DAC output was set to the random voltage levels with sampling frequency of 3.125kHz. Rough estimation of the average current for random data sent leads to ~0.92A for current limit 1.5A. The high value of the output current is confirmed by destroyed resistors at the output of the piezo driver and by the destroyed piezo driver in one channel. The dissipated power was 9.2W and 78W at the output resistors (10Ω) and power driver respectively.



Understanding the October 29 2013 event (2)

The expected heat dissipation at piezo can be estimated from Q vs. V characteristics (available for 77K only). For the full recharge cycle (+-70V) the dissipated heat is ~30mJ. Therefore one can estimate the average heat dissipation at piezo for 0.92A to ~18.4W. Since the relays were also randomly switching piezos the current and power dissipation were distributed between both piezos and therefore for single piezo the average current and heat power should be divided by 2. Anyway, ~9W dissipated at piezo for several tens of seconds with very limited heat transfer to the ambient (only through support) heats up the piezo (in particular the middle part) by several tens of degrees. As the destructive test has proven, warming up the piezo to 120K is dangerous. Applying reverse bias in such condition may lead to voltage breakout of the ceramics and to discharging of contiguous electrodes causing a significant metal sputtering and thus short-circuiting the piezo.



Thank you for your attention

and many thanks to people contributing in that work

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C. Albrecht, L.Lilje, DESY