Piezo lifetime - limiting LLRF slew rate and other PZT Amplifier Requirements

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SRF PZT History
(my limited view)

- Piezo actuators are robust and they are used in many demanding applications -
  - Use with SRF has a checkered past
    - leads to very wary operations
- Failure have been attributed to -
  - misalignment, bad mechanical design, over or under preload, over voltage, over power (heating), high frequency content in drive, slot cracks
- Strategy going forward –
  - Design, model, test in spiral design cycles
  - Comprehensive designs and efforts are now in progress and need to be integrated with LLRF teams at test stands for long test periods
  - Be as gentle as possible avoiding fast load changes (slew rate limit)
  - Operate tuners in linear regions if possible (bandwidth limit)

Piezo Guidelines from Vendor

- Do not apply voltage exceeding maximum rating voltage, or do not do rapid charging and discharging. These might lead to degradation of the reliability or mechanical fracture.
- Use the actuator so as not to cause bending, twisting or tension. Furthermore, align the center axis of displacement of the actuator with the center axis of the mechanical load.
- Do not drive the actuator so that the rising speed is more than three times as much as the resonance period in order to prevent the device from damaging by ringing.
- Store the resin-coated type(AE series)preferably in a dry atmosphere(desirably below 40% RH)at ordinary temperatures(- 5 to + 40℃). Avoid condensation on the product surface.
- Store actuators where there is no vibration.

Typical drive parameters

Hysteresis creates nonlinear response

Capacitance and displacement drop with low temperature

Fig-10 Voltage vs. Displacement

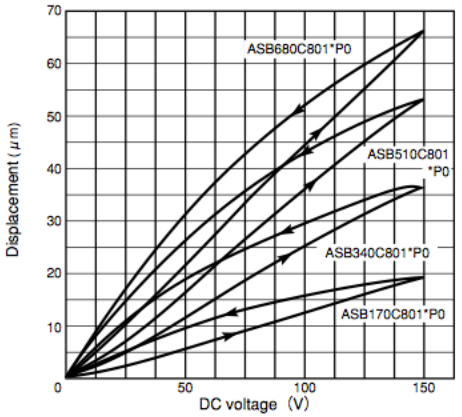


Fig-11 Compression load vs. Displacement

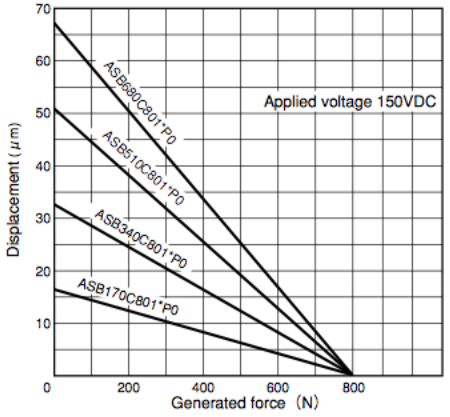


Fig-12 Drive frequency vs. Displacement

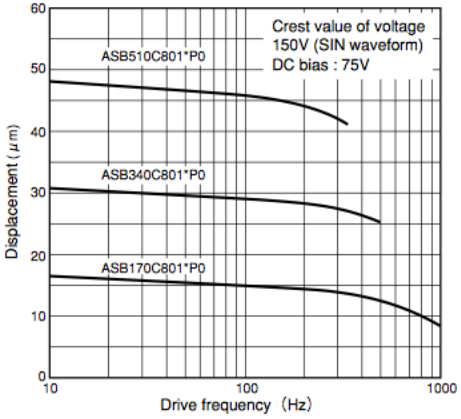


Fig-13 Temperature vs. Displacement

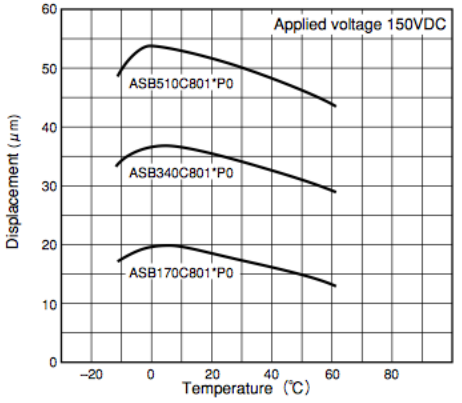


Fig-14 DC bias vs. Capacitance

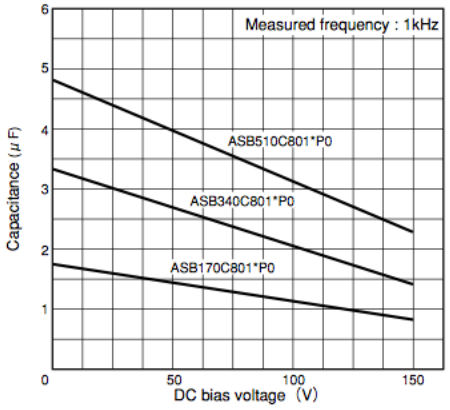
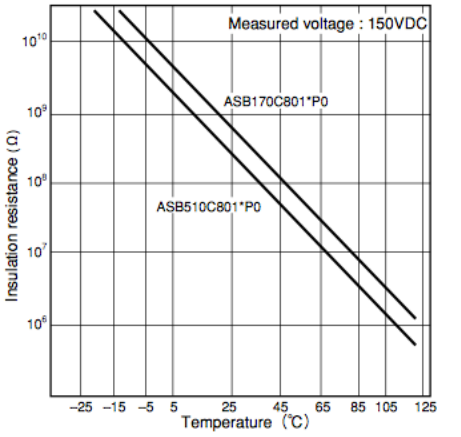


Fig-15 Temperature vs. Insulation resistance



Heat generation

Heating caused by dielectric losses and will raise local capacitance raising local current

Fig-8 Heat generation vs. Drive frequency-1

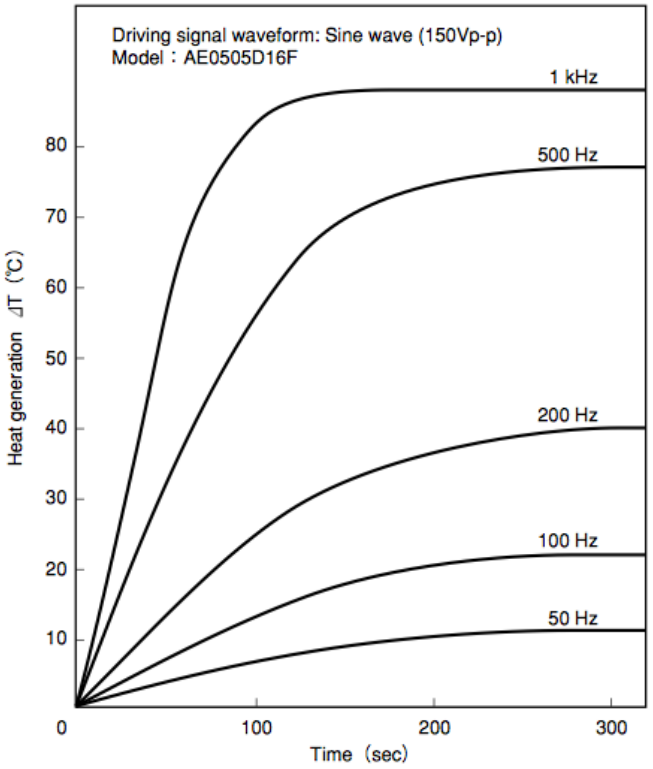
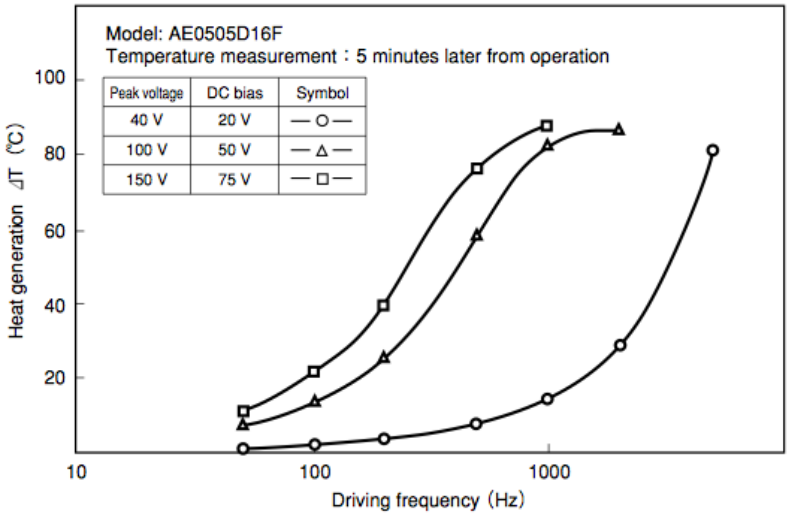


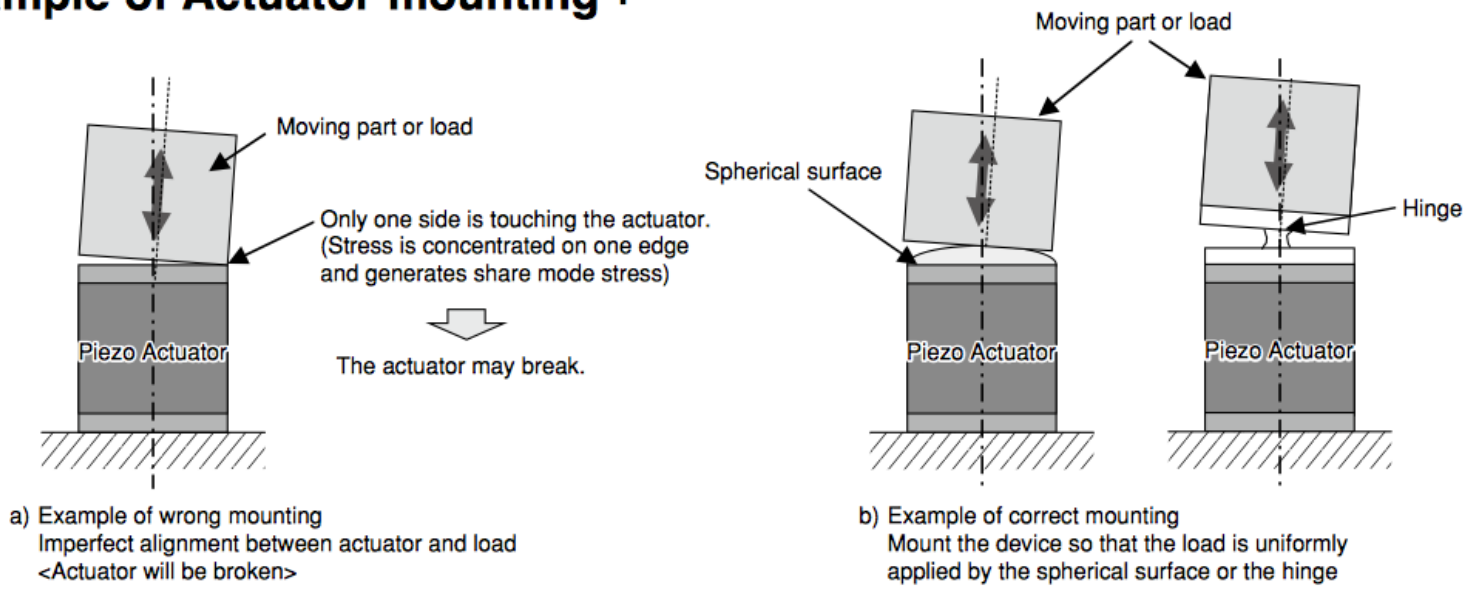
Fig-9 Heat generation vs. Drive frequency-2



Losses in the ceramic become a cryo load and can create a failure mode

Drive issues

Example of Actuator mounting :



a) Example of wrong mounting
Imperfect alignment between actuator and load
<Actuator will be broken>

b) Example of correct mounting
Mount the device so that the load is uniformly
applied by the spherical surface or the hinge

Driving Method:

- Connect the red lead wire to the positive (+) terminal of the power supply. Also prevent reverse voltage application.
- Basically the voltage controls the aimed displacement and generated force. In driving, however, it is also necessary to take ringing due to the resonance or hysteresis of the element itself into consideration. In pulse driving, it is further necessary to pay sufficient attention to heat generation due to dielectric loss, charge/discharge current due to the capacitive component and the power output impedance as well. Please refer to the separately printed

Drive calculation examples

PiezoDrive **Power Bandwidth Calculator**

Input Parameters			
Load Capacitance (effective)	C	1	uF
Output Voltage Peak to Peak	Vpp	100	V

Amplifier Specifications	PDu100B*	PDm200**	PDL200	PDX150b	PDX200b
Peak Current (Amps)	0.1	0.3	0.6	2	1.5
Average Current (Amps)	0.015	0.038	0.1	0.7	0.5
Slew Rate (V/us)	1	20	4	4.5	4.5
Max Voltage (Peak to Peak)	200	400.00	210	180	230

Results	PDu100B*	PDm200**	PDL200	PDX150b	PDX200b
Maximum Frequency (Hz)					
Sinewave	48	380	1000	6369	4777
Triangle	75	380	1000	10000	7500
Square	38	190	500	5000	3750
Maximum No Load Freq. (Hz)					
Sinewave	3185	63694	12739	14331	14331
Triangle	5000	100000	20000	22500	22500
Square	2500	50000	10000	11250	11250

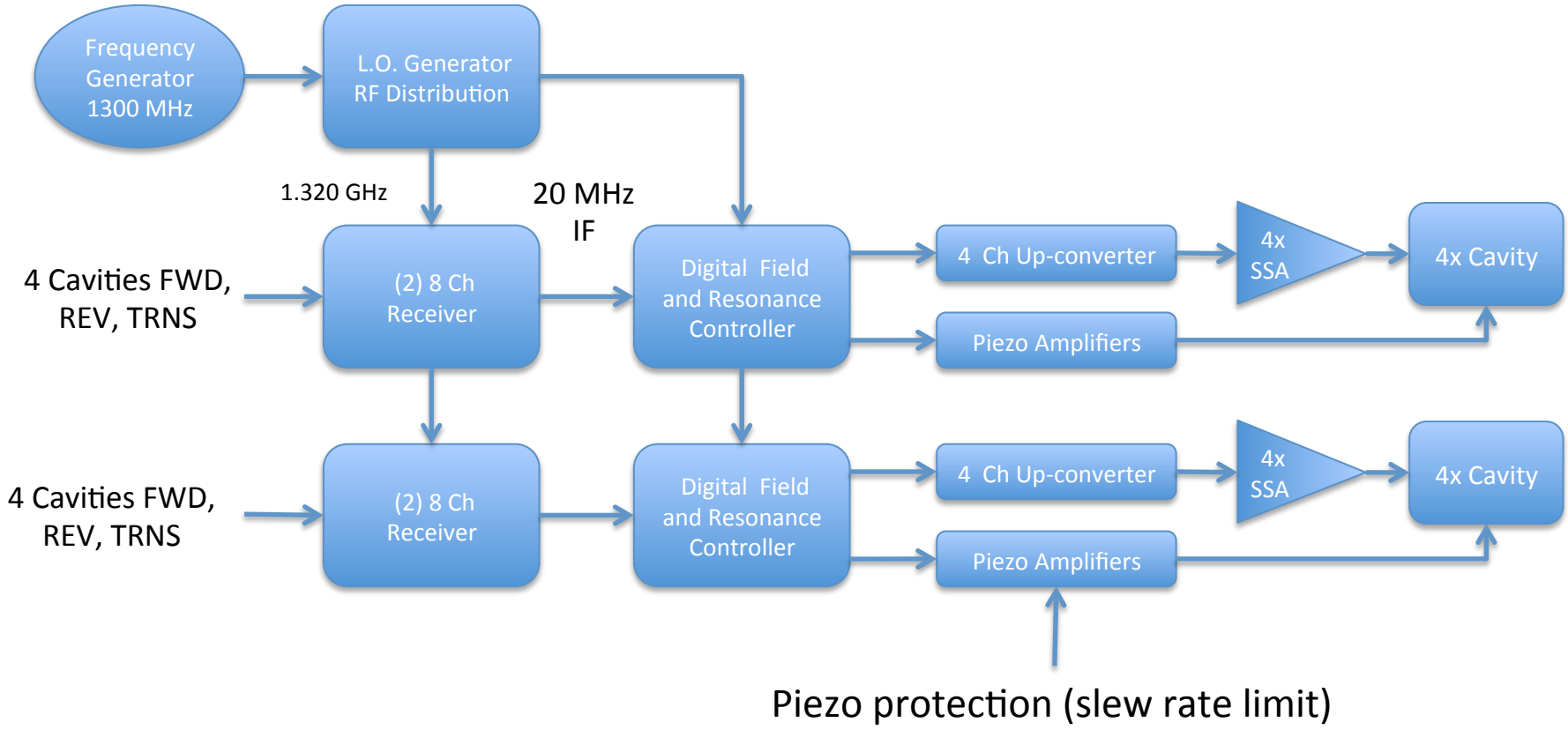
http://www.piezodrive.com/introduction.html

PiezoDrive **Current And Power Calculator**

Input Parameters			
Capacitance (effective)	C	1	uF
Voltage Peak to Peak	Vpp	100	V
Frequency	f	500	Hz

Results			
Sine Wave			
Peak Current	Ipk+	0.157	A
Average Current	Iav+	0.050	A
RMS Current	Irms	0.111	A
Required Slew-rate	SR	0.16	V/us
RMS Voltage	Vrms	35.4	Vrms
Power Supplied to Load	Pload	3.9	W
Piezo Heat Dissipation	Pdiss	0.39	W
Triangle			
Peak Current	Ipk+	0.100	A
Average Current	Iav+	0.050	A
RMS Current	Irms	0.100	A
RMS Voltage	Vrms	28.9	Vrms
Power Supplied to Load	Pload	2.89	W
Piezo Heat Dissipation	Pdiss	0.29	W
Square Wave			
Average Current	Iav+	0.050	A
RMS Current	Irms	0.100	A
RMS Voltage	Vrms	50.0	Vrms
Power Supplied to Load	Pload	5.0	W
Piezo Heat Dissipation	Pdiss	0.50	W

8 Cavity CMTS LLRF RF and IF Signal Flow



PZT Amplifier Requirements for LCLS-II

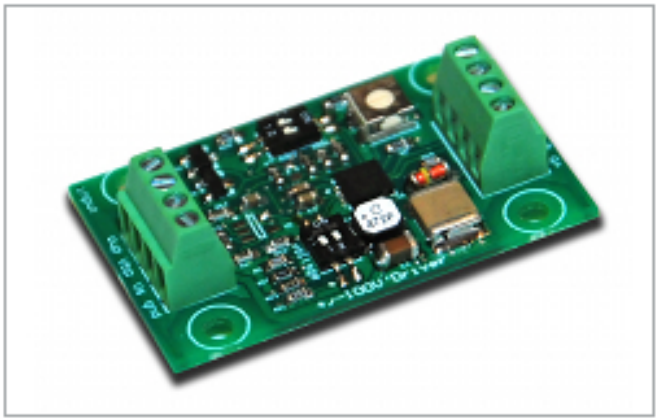
- Bipolar differential output drive + - 100V
  - limit max voltage to ground, reduced ground bounce interactions
  - 150V for polarization?
- Drive large capacitance (1 to 5 μF TBD)
- Voltage controlled current source
  - reduces hysteresis in control
- Integrated power limit
  - reduce chance of thermal runaway
- Small signal programmable bandwidth limit (100Hz to 10 kHz)
  - reduce the chance of hitting mechanical resonance
- Slew rate limit(see next slide)
- Readback voltage and current waveforms -> capacitance
- A load cell on the PZT would provide much more information

Slew Rate Limiting
(part of a larger control strategy)

- Limiting the voltage slew rate or limiting the drive current in the drive amplifier provides one way to control a safe operation area for the system by limiting-
  - the mechanical velocity of the PZT
  - the maximum power dissipation
  - the maximum large signal frequency
  - the range of forces on the PZT
  - the possibility of chatter from unloading PZT
- Limits are implemented in PZT amplifier, not controller
- Limits are programmable and may be asymmetric
- Set just above the system needs – larger for pulsed machines (~500 mA), small for CW (~10s of mA)
  - iterate with needs for small signal bandwidth and control

Example COTS solution for LCLS-II

PDu100B - Miniature Piezo Driver



$AU95 + Shipping Buy Now

> View Specifications
> Power Bandwidth (+/-60V Range)
> Power Bandwidth (+/-100V Range)
> Enquiry
> Obtain a quote
> Standard Terms

The PDu100B is a complete miniaturized power supply and linear amplifier for driving piezoelectric actuators. The PDu100B provides variable gain and offset, switchable voltage ranges, and the choice between ground referenced or differential inputs and outputs. The PDu100B can drive two-wire piezoelectric actuators and benders up to +/-100V and three-wire piezoelectric benders and stack actuators up to +100V. Applications include piezoelectric valves, motors, pumps and low-power positioning and manipulation systems.

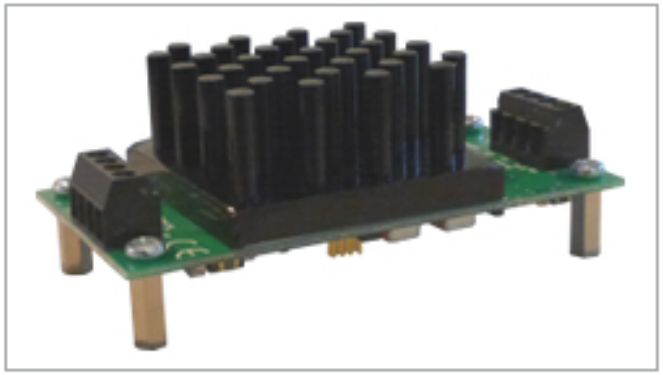
Key features include:

- Selectable output voltage range 100V, 90V, or 60V
- Bipolar or unipolar output
- Bias supply for three-wire bender actuators
- Peak output current: 100mA
- Supply voltage: 3V to 5.5V
- Dimensions: 25x40mm (1x1.5in)
- Mass: 5.5 grams (0.2oz)

http://www.piezodrive.com/products.html#pdq

Example COTS solution for ILC

PDm200 - Miniature High Voltage Amplifier



$AU250 + Shipping Buy Now

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> Standard Terms

The PDm200 is a complete high-performance power supply and linear amplifier module for driving piezoelectric actuators. The output voltage range can be switched between bipolar or unipolar modes with a range of 100V, 150V, or 200V. Up to +\-400 V can be achieved in the bridged configuration. In the unipolar mode, the negative output range is fixed at -30V for use with stack actuators. Applications include: electro-optics, ultrasound, vibration control, nanopositioning systems, and piezoelectric motors.

Key features include:

- Selectable voltage range from +100V to +/-400V
- Bipolar or unipolar output
- Bias supply for 200V bender actuators
- Signal Bandwidth: 200kHz
- Power Bandwidth: 63kHz (100Vp-p)
- Noise: <1mV (1uF load)
- Peak output current: 300mA
- Dimensions: 71x38mm (2.8x1.5in)

Thank you!