Research Update

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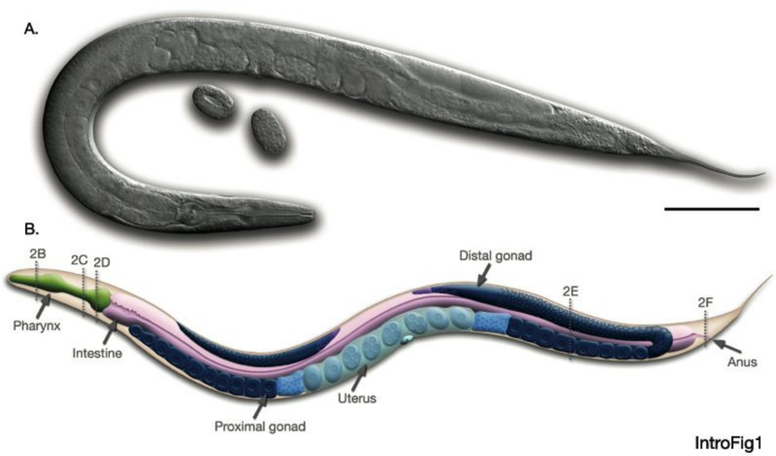
Worm Club
10/1/2009

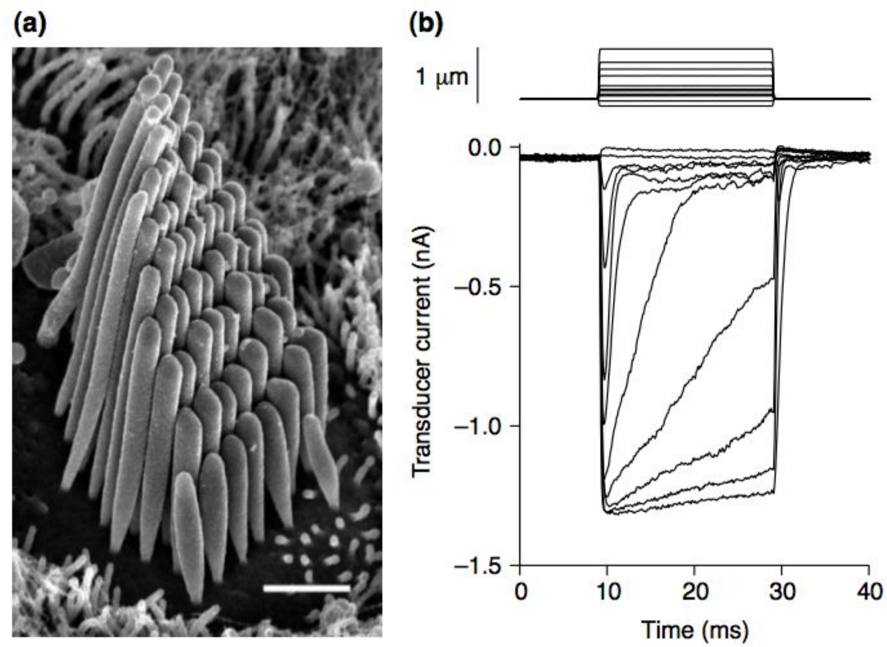
Today

- Feedback modeling
- Circuit design
- Printed circuit boards
- PR+PE Characterization

Motivation



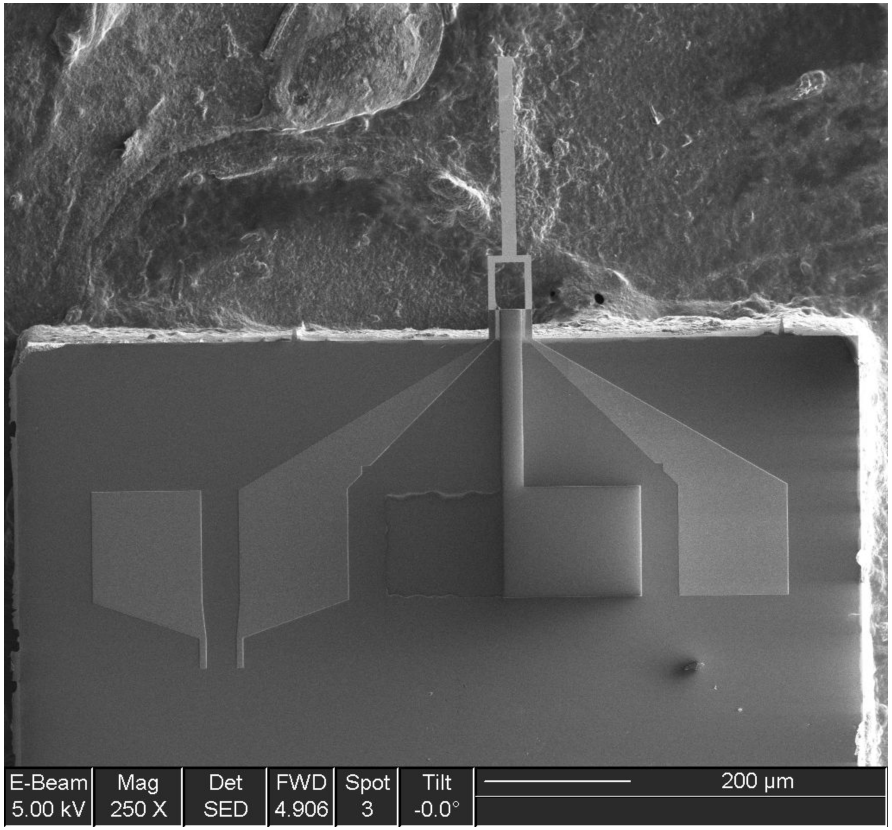
Worm TRNs

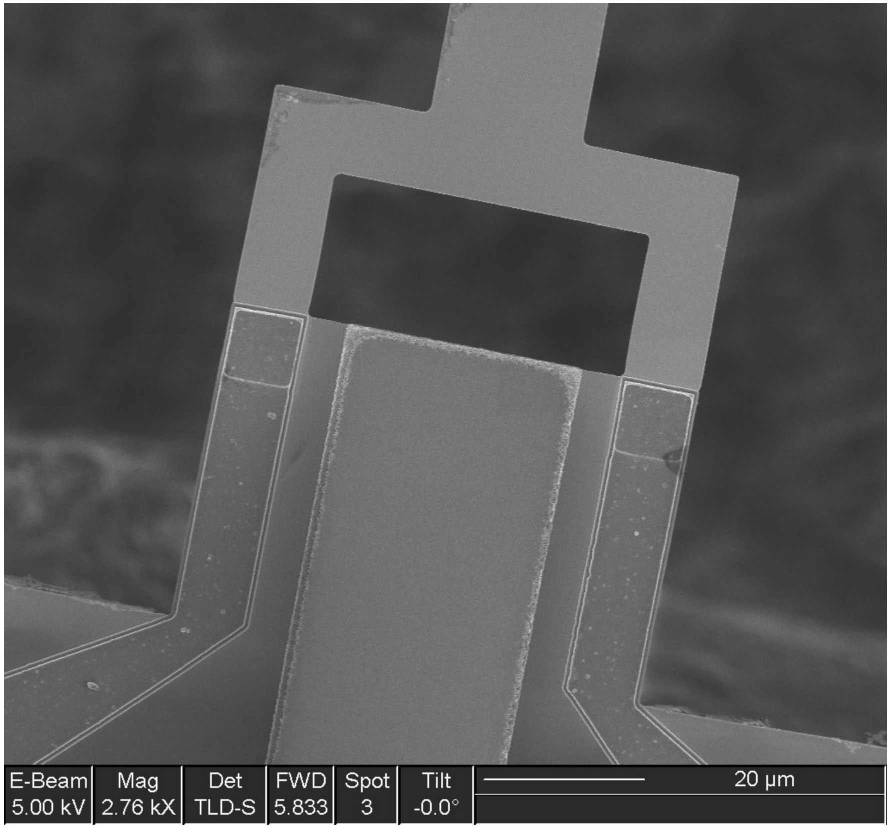


Turtle hair cell

Images from Worm Atlas and Clues to the cochlear amplifier from the turtle ear, Fettiplace, Ricci and Hackney, 2001

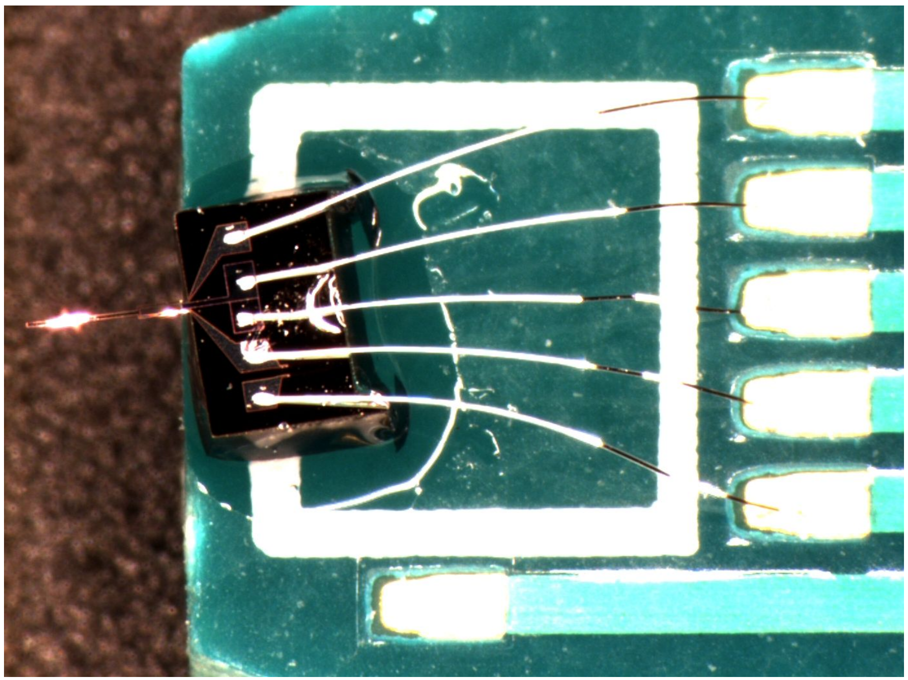
The Device

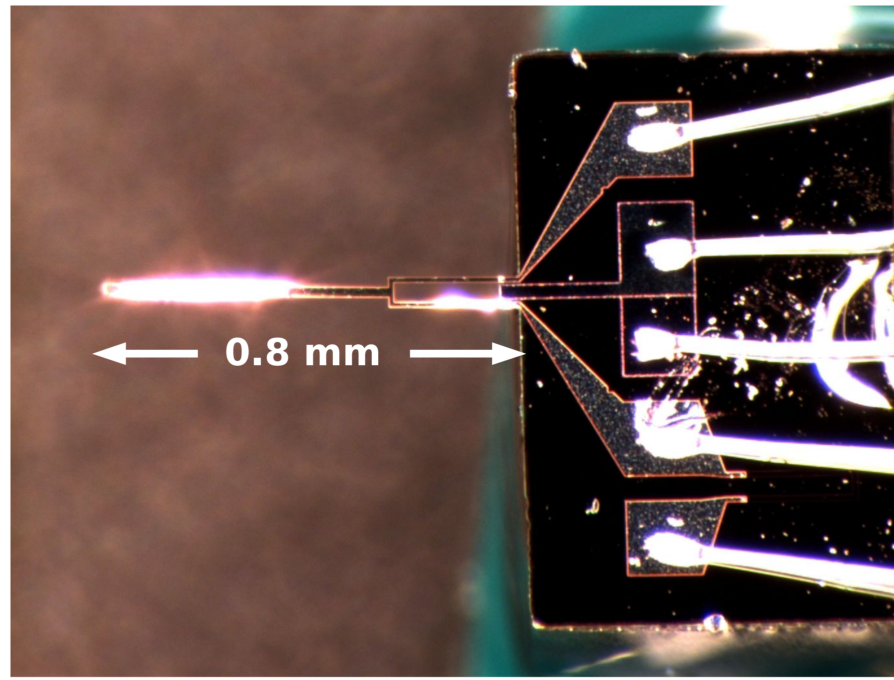




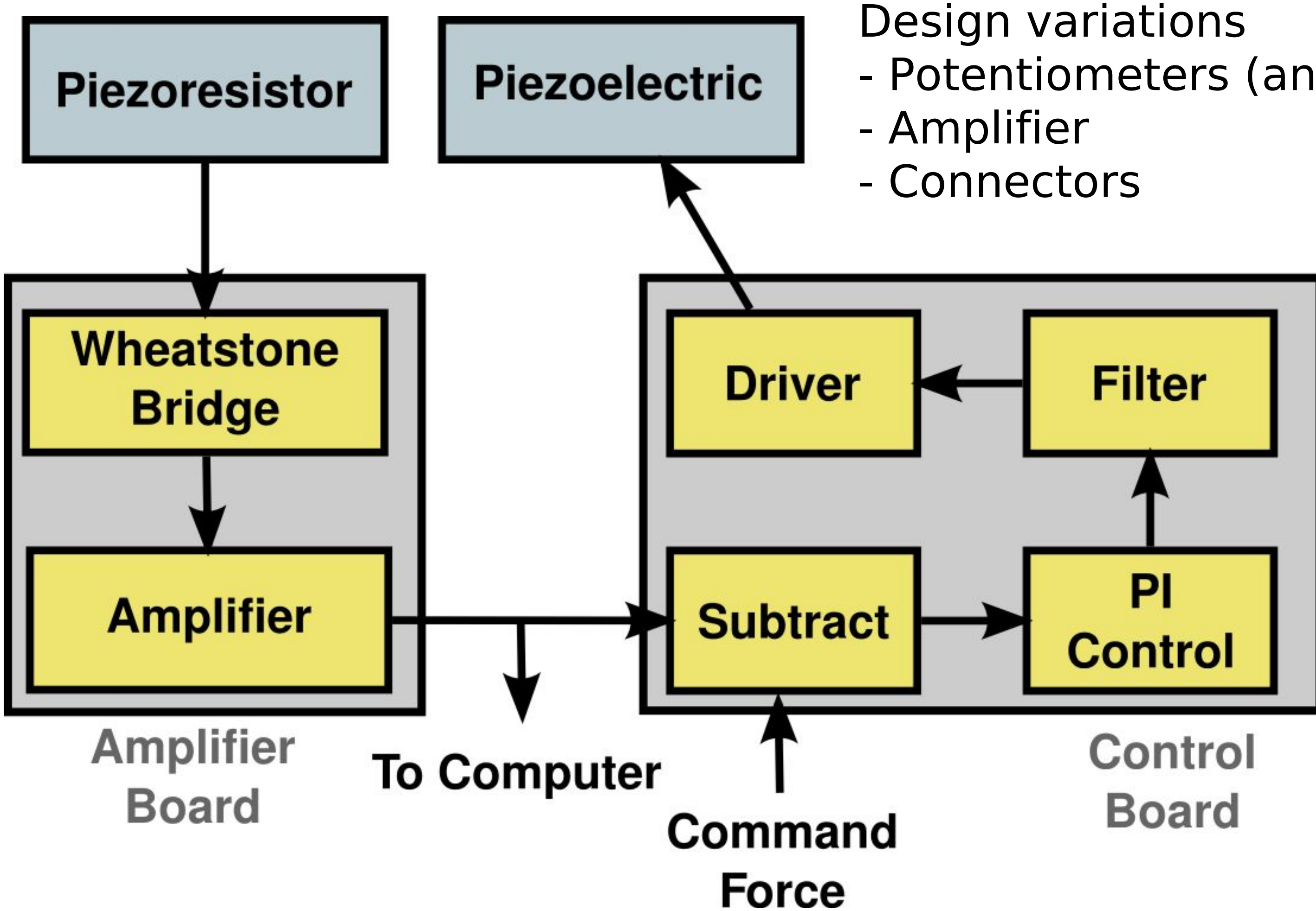
Piezoresistive force detection
Piezoelectric actuation

The Device



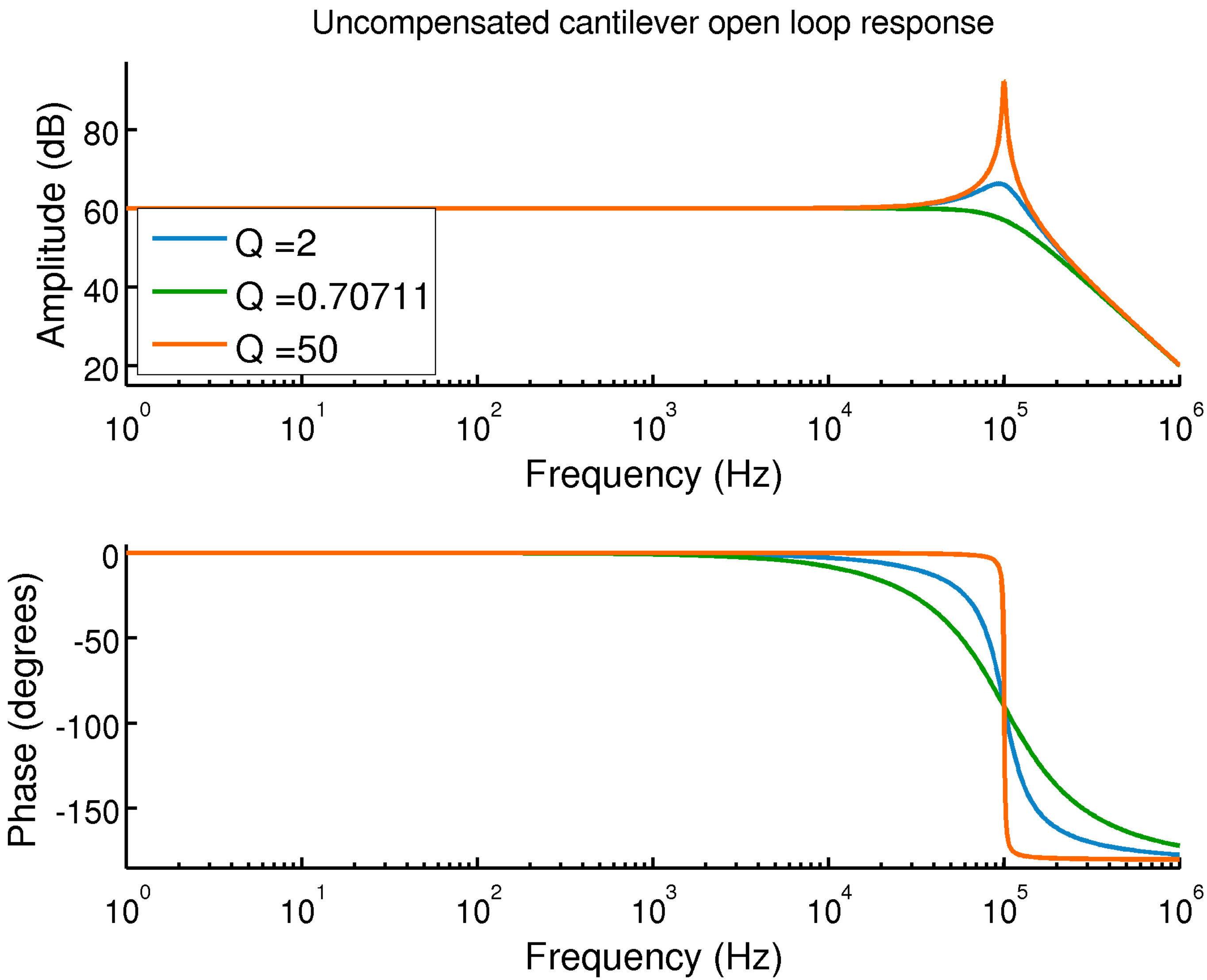


Circuit/Control Overview

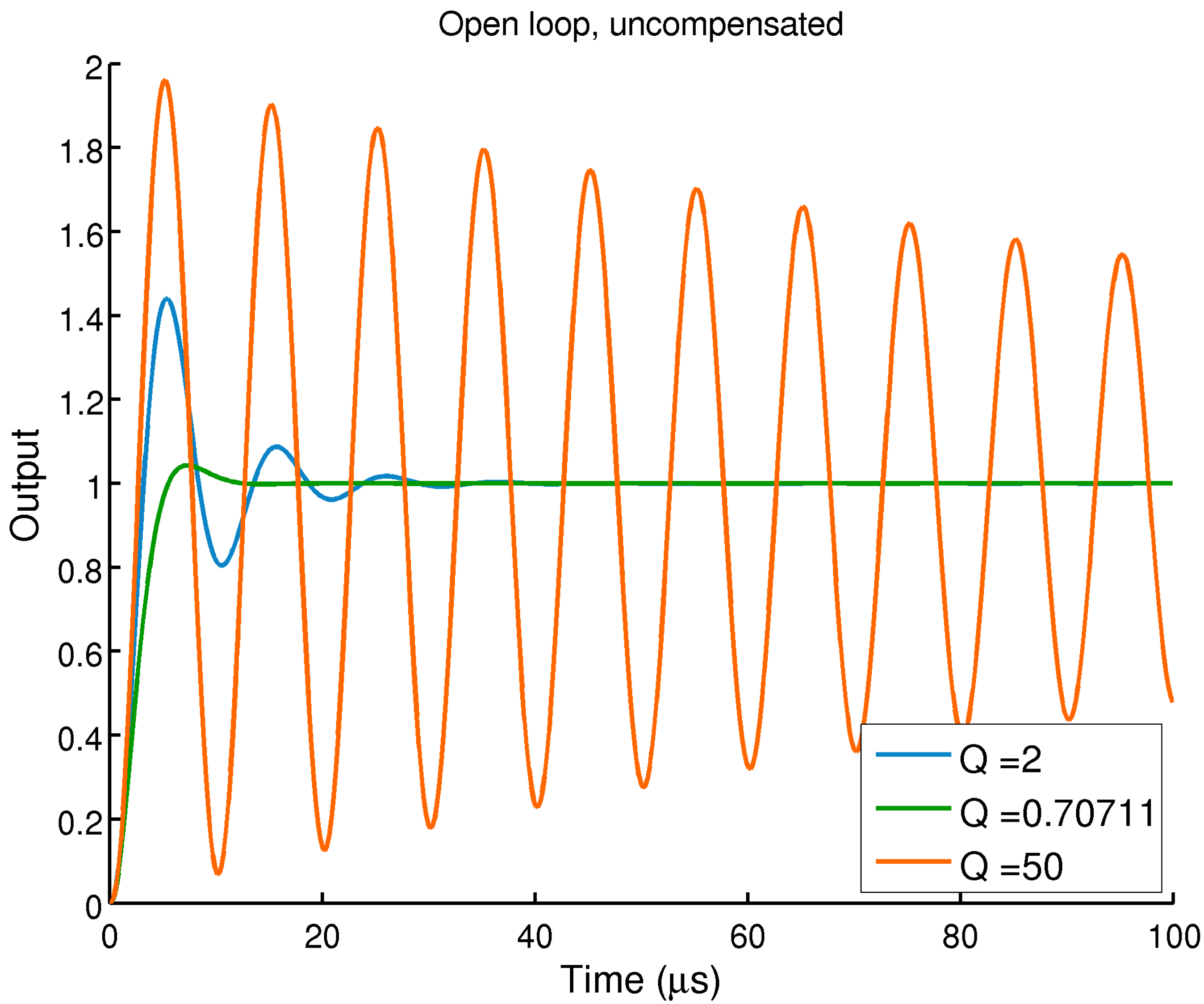


Design variations
- Potentiometers (analog, digital)
- Amplifier
- Connectors

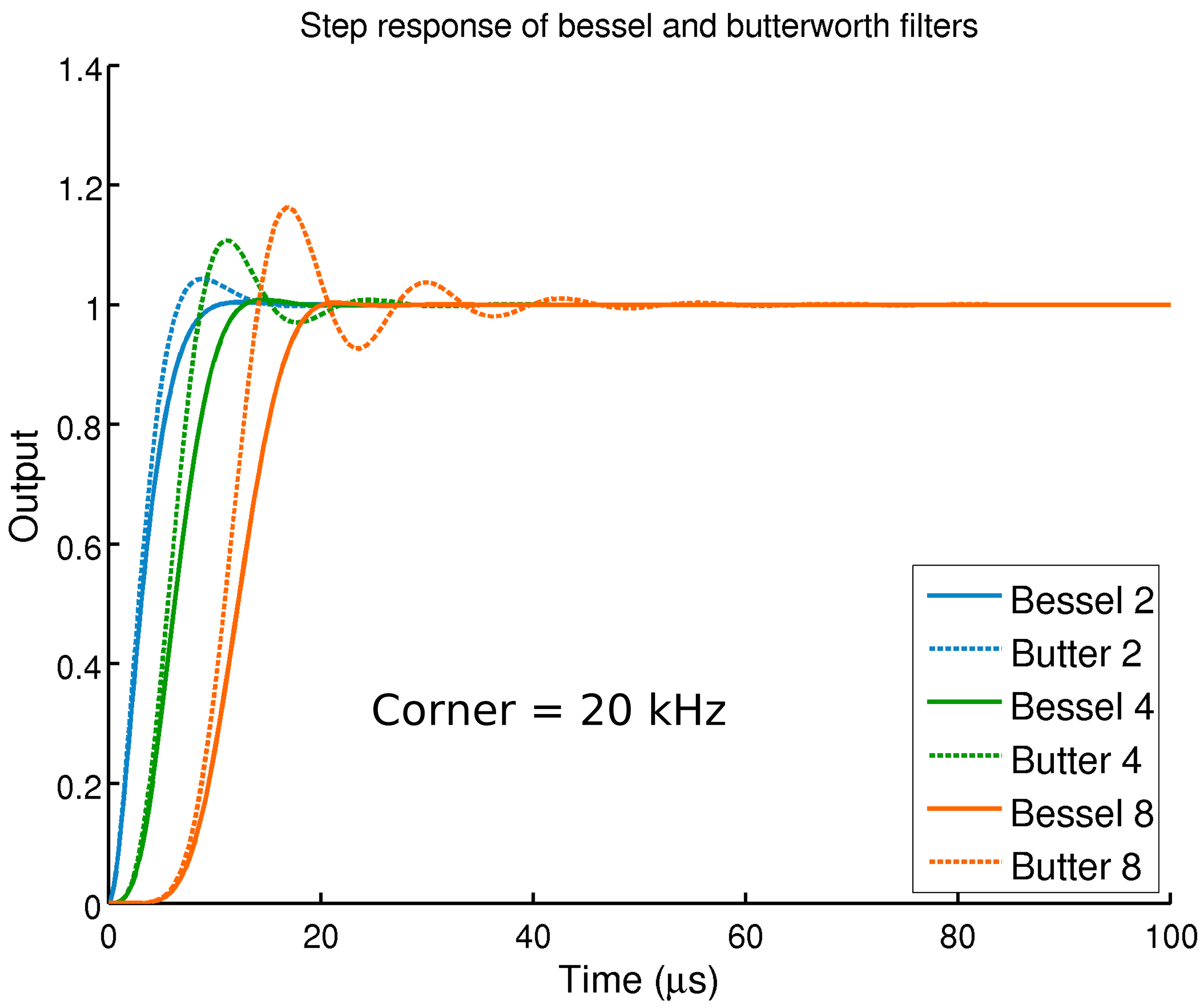
Feedback Modeling



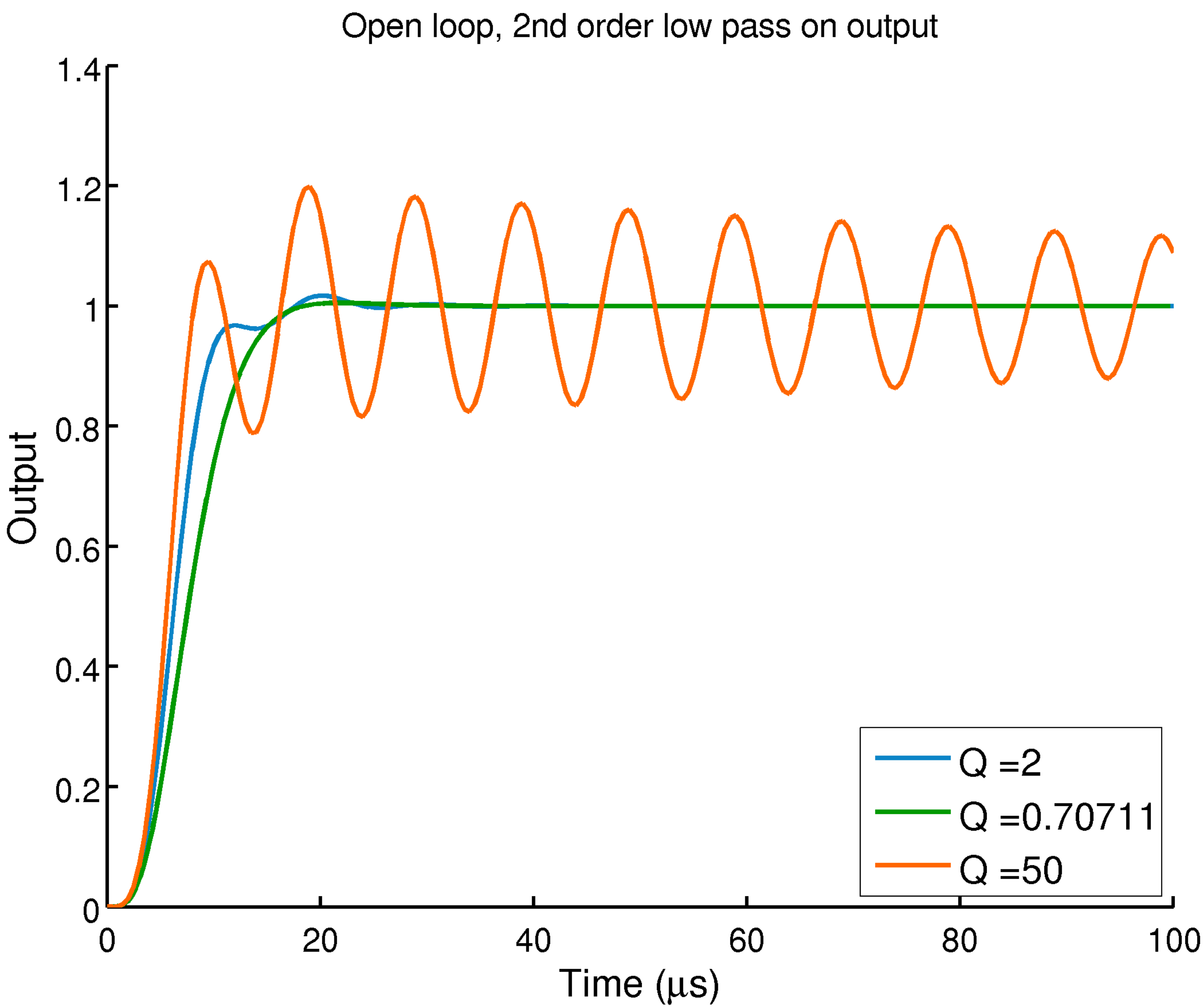
Feedback Modeling



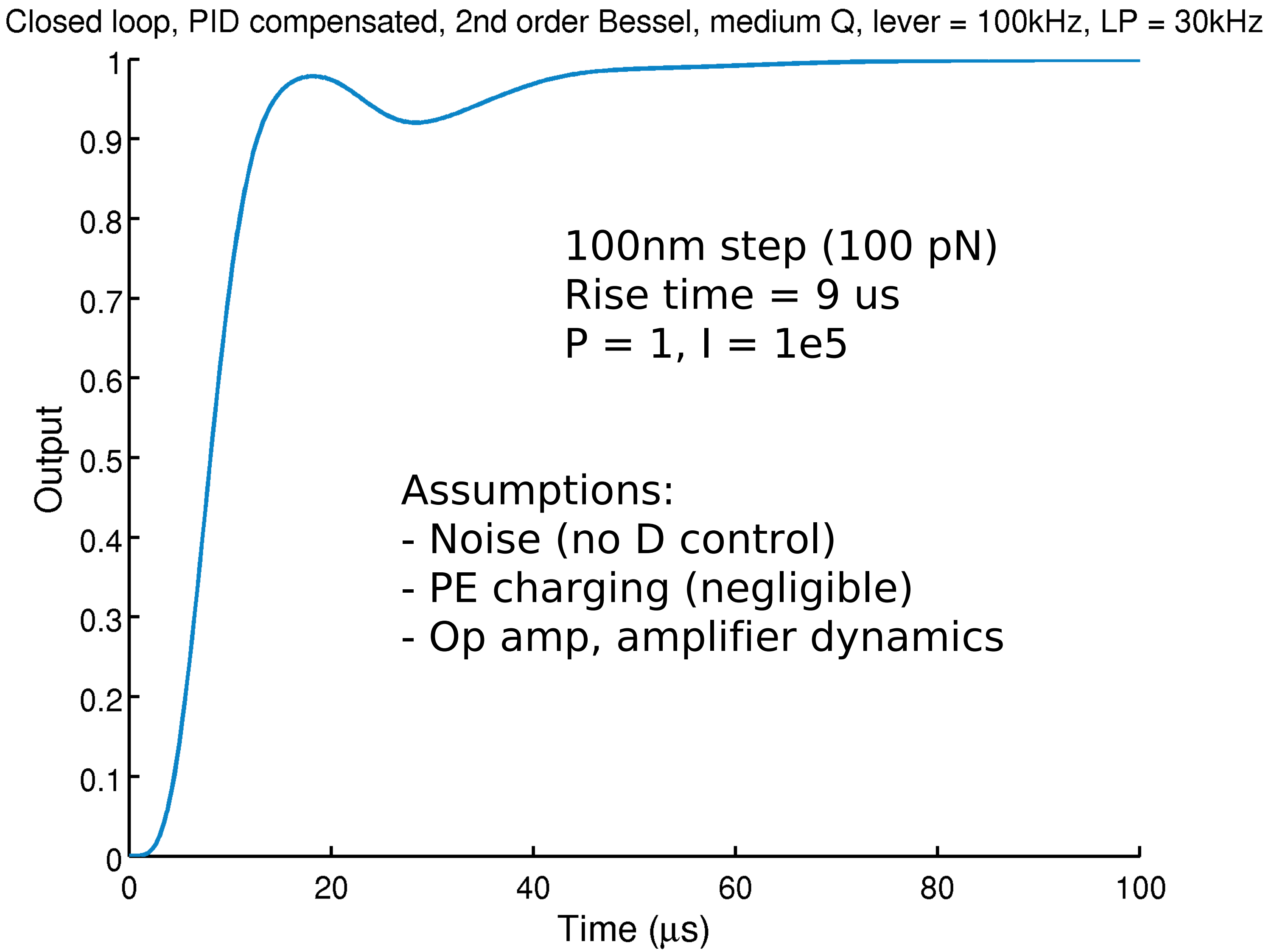
Feedback Modeling



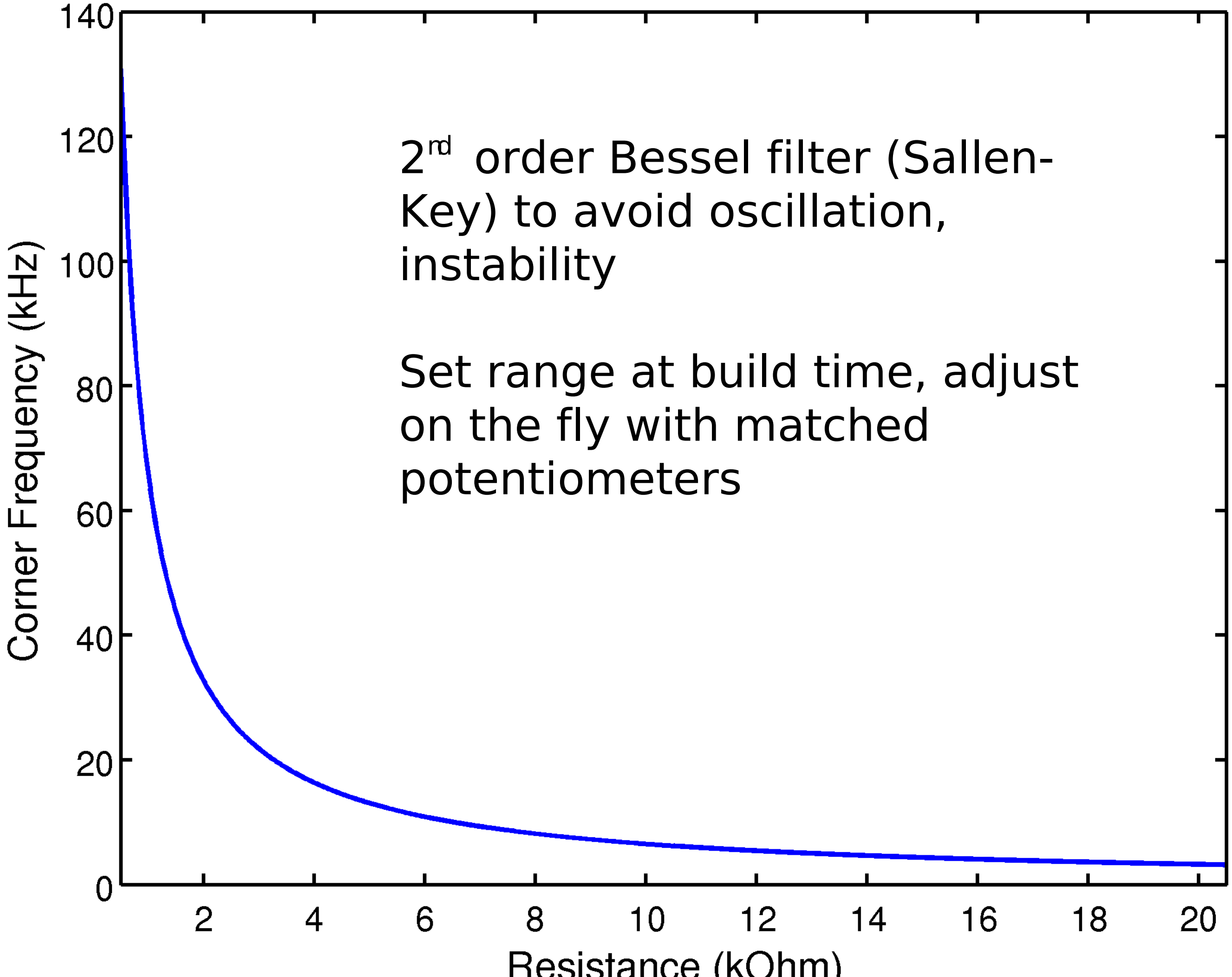
Feedback Modeling



Feedback Modeling



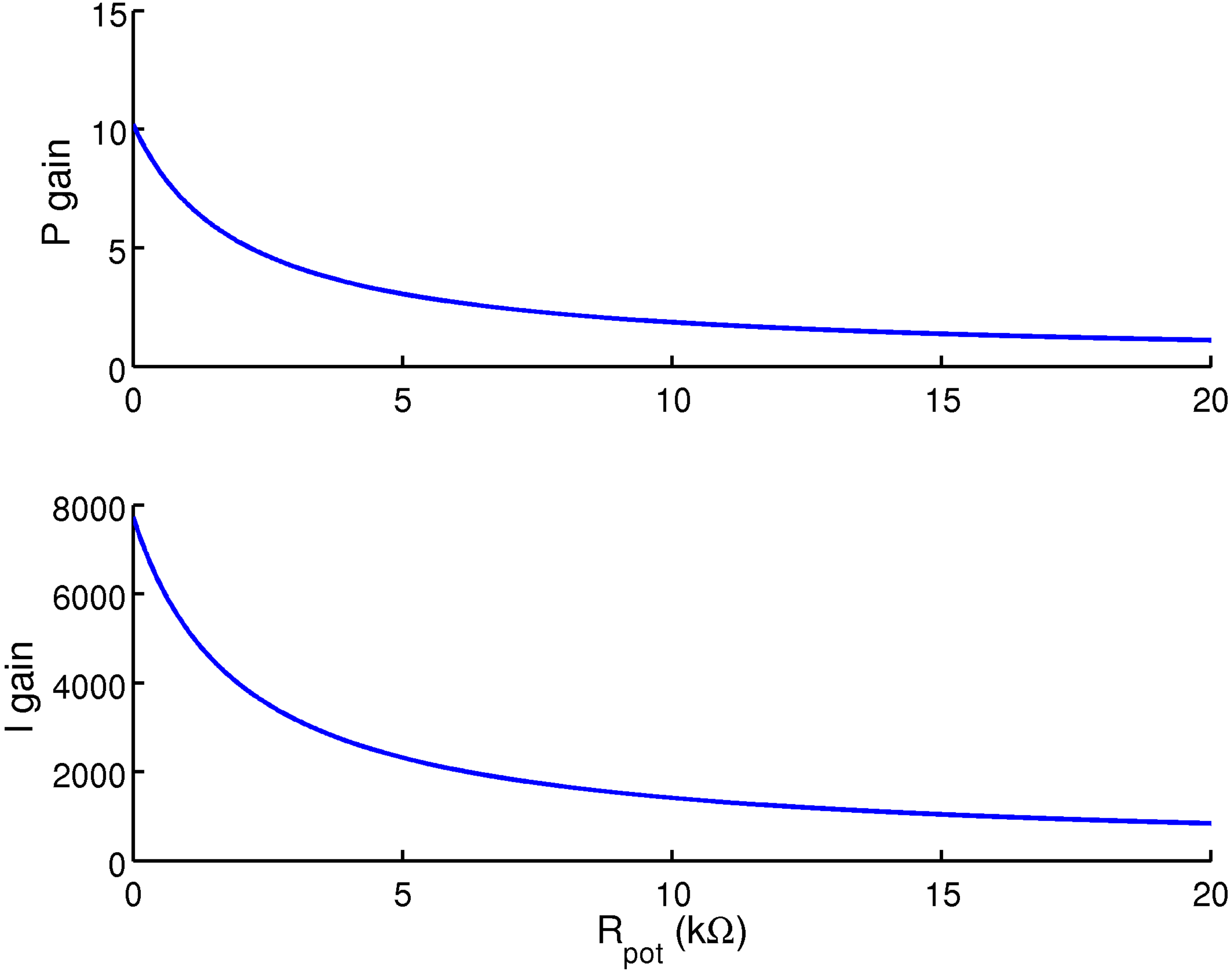
Circuit Design



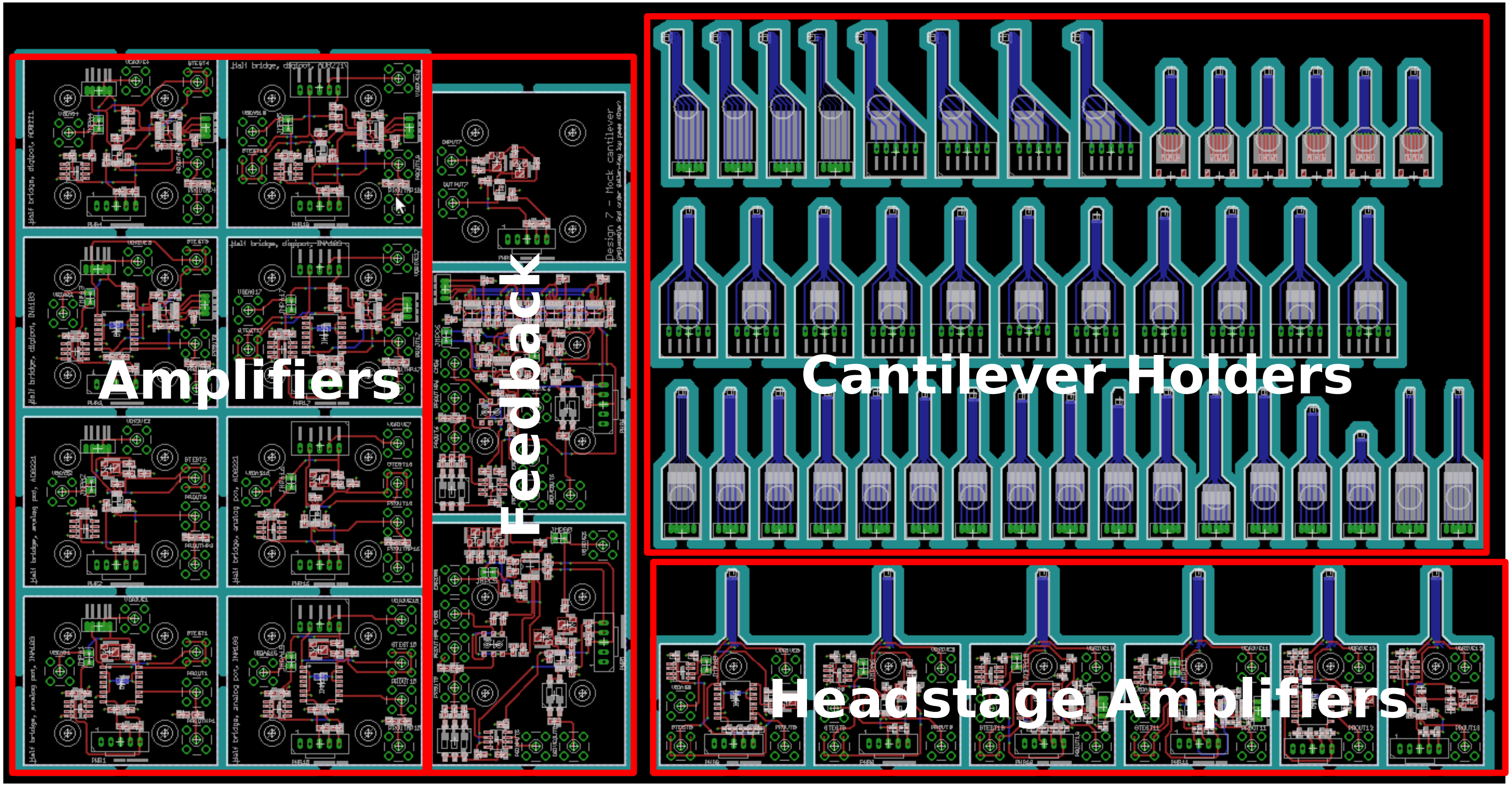
2[nd] order Bessel filter (Sallen-Key) to avoid oscillation, instability

Set range at build time, adjust on the fly with matched potentiometers

Circuit Design

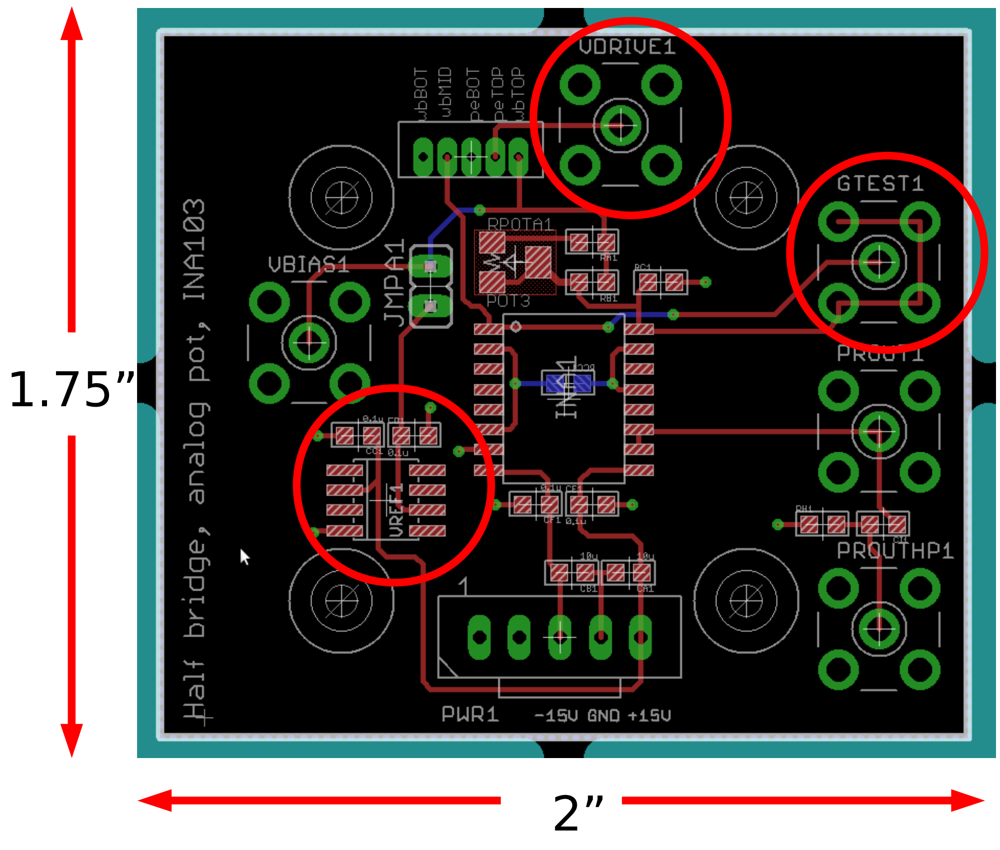


PCB Layout

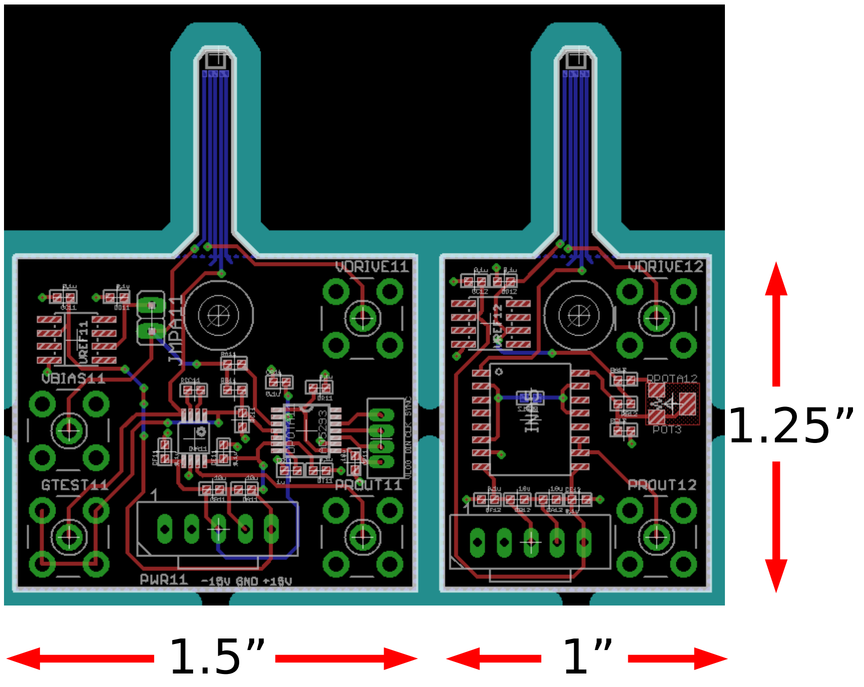


Ordered, received, mostly assembled and tested

Circuits - Amplifiers



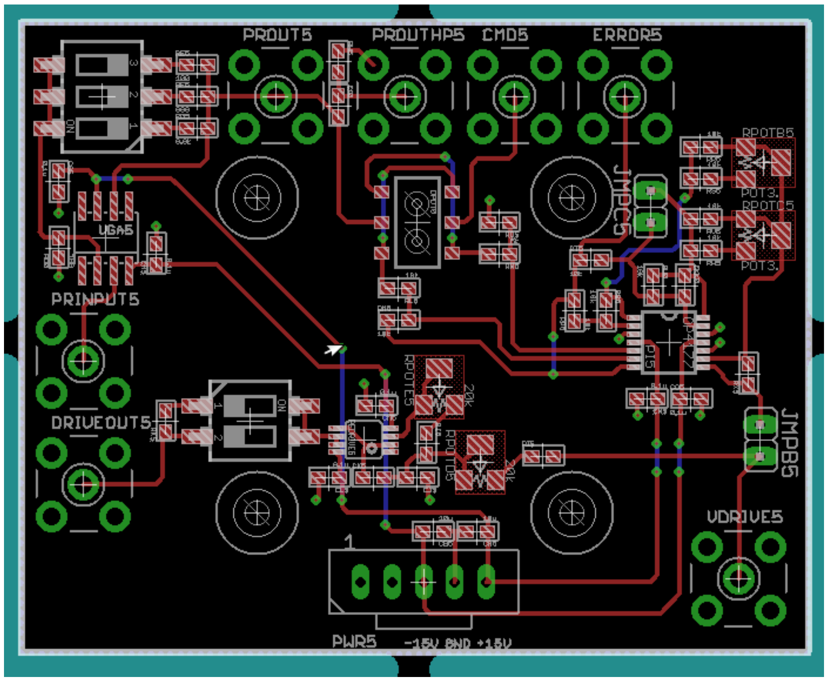
Skinnier tips this time



Circuits - Feedback

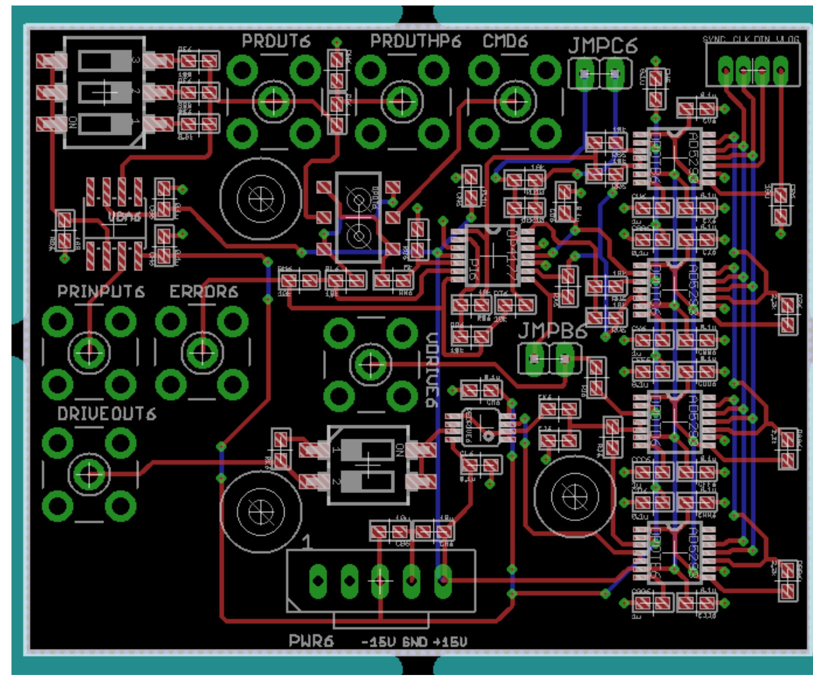
Analog Potentiometers

2”



2.5”

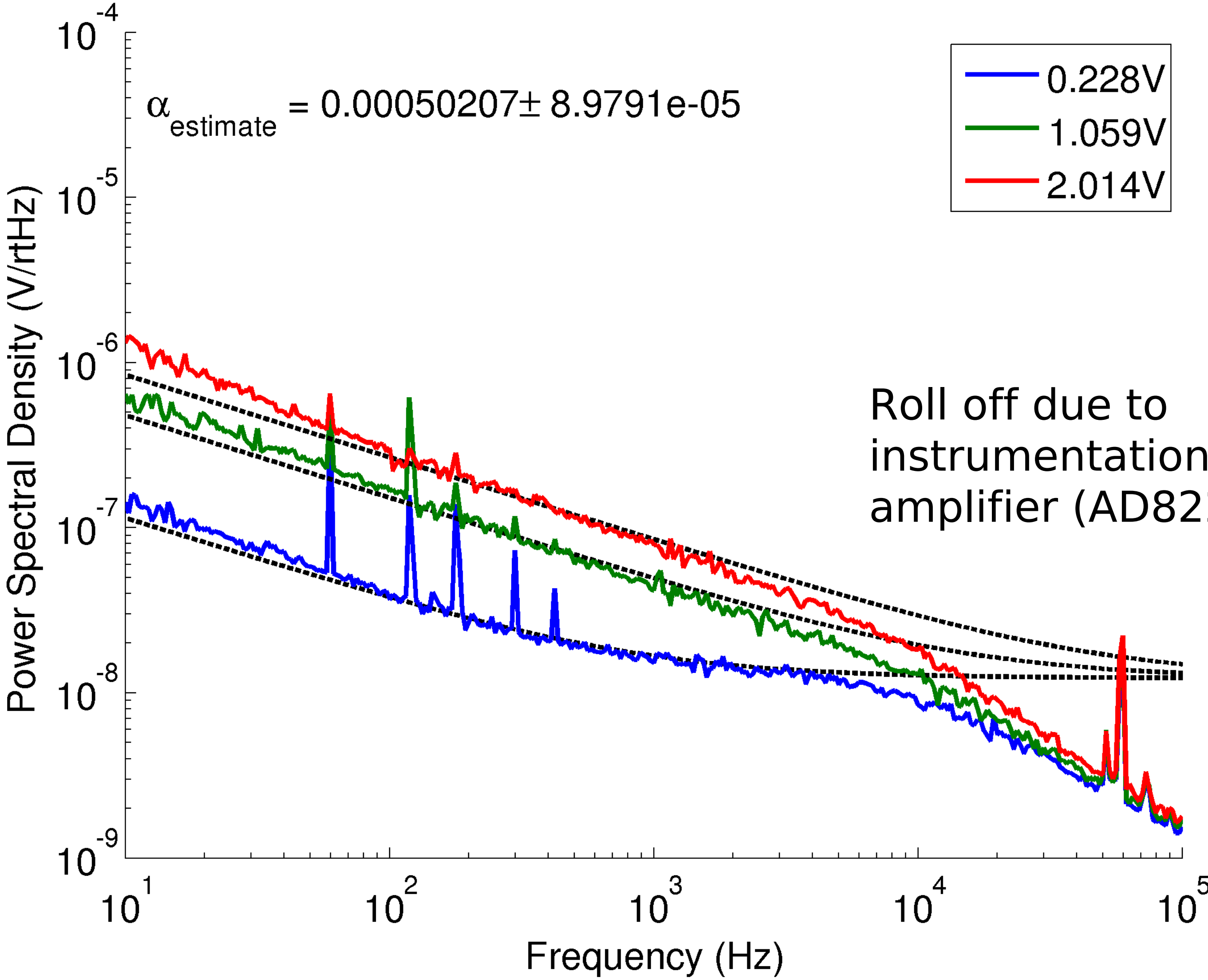
Digital Potentiometers



Device Characterization

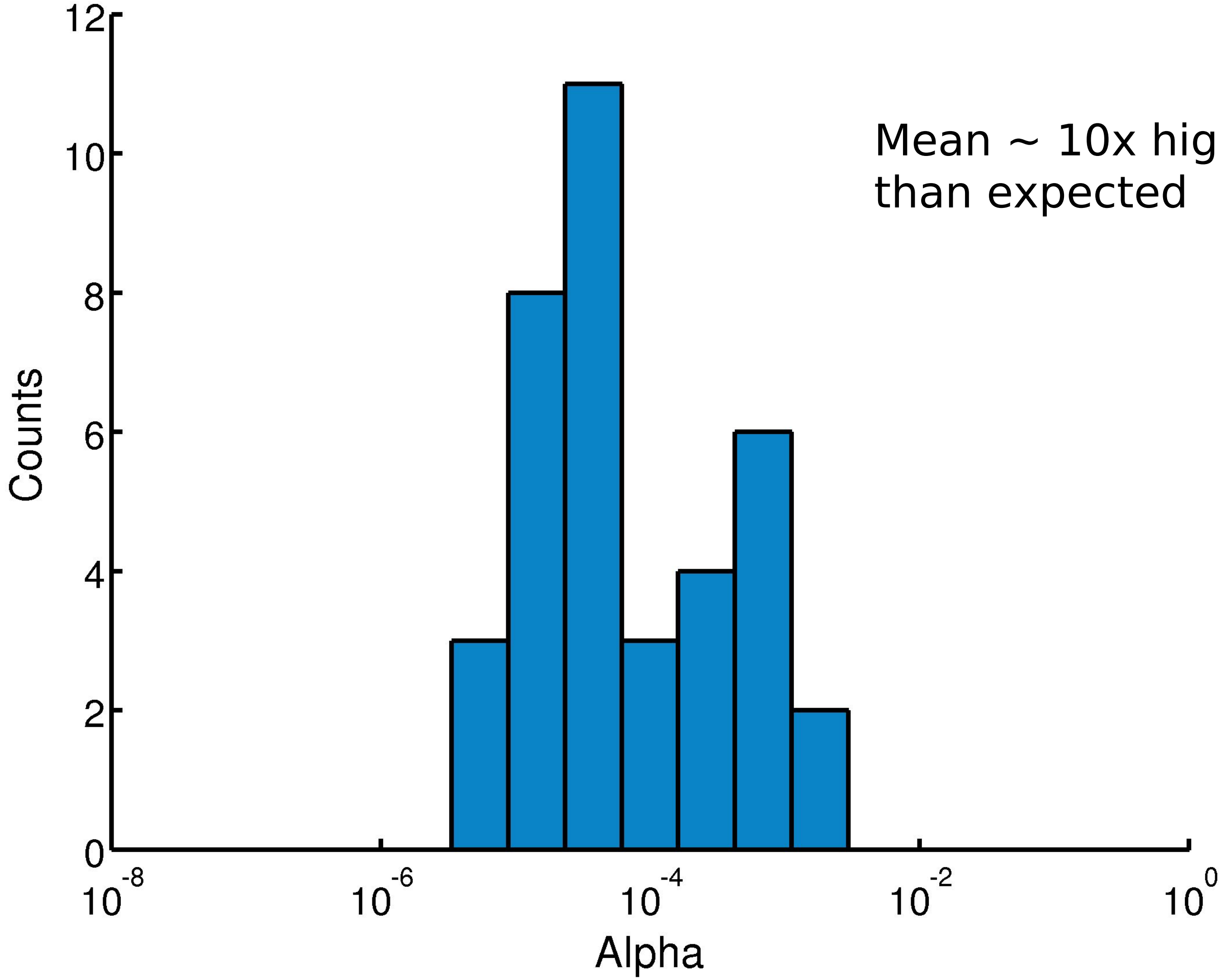
- **Noise spectrum**
- **Piezoresistor resistance**
- **Spring constant**
- **Electrical cross-talk**
- Force/displacement sensitivity
- Actuation distance

Noise spectra look good



Roll off due to instrumentation amplifier (AD8221)

1/f noise higher than expected

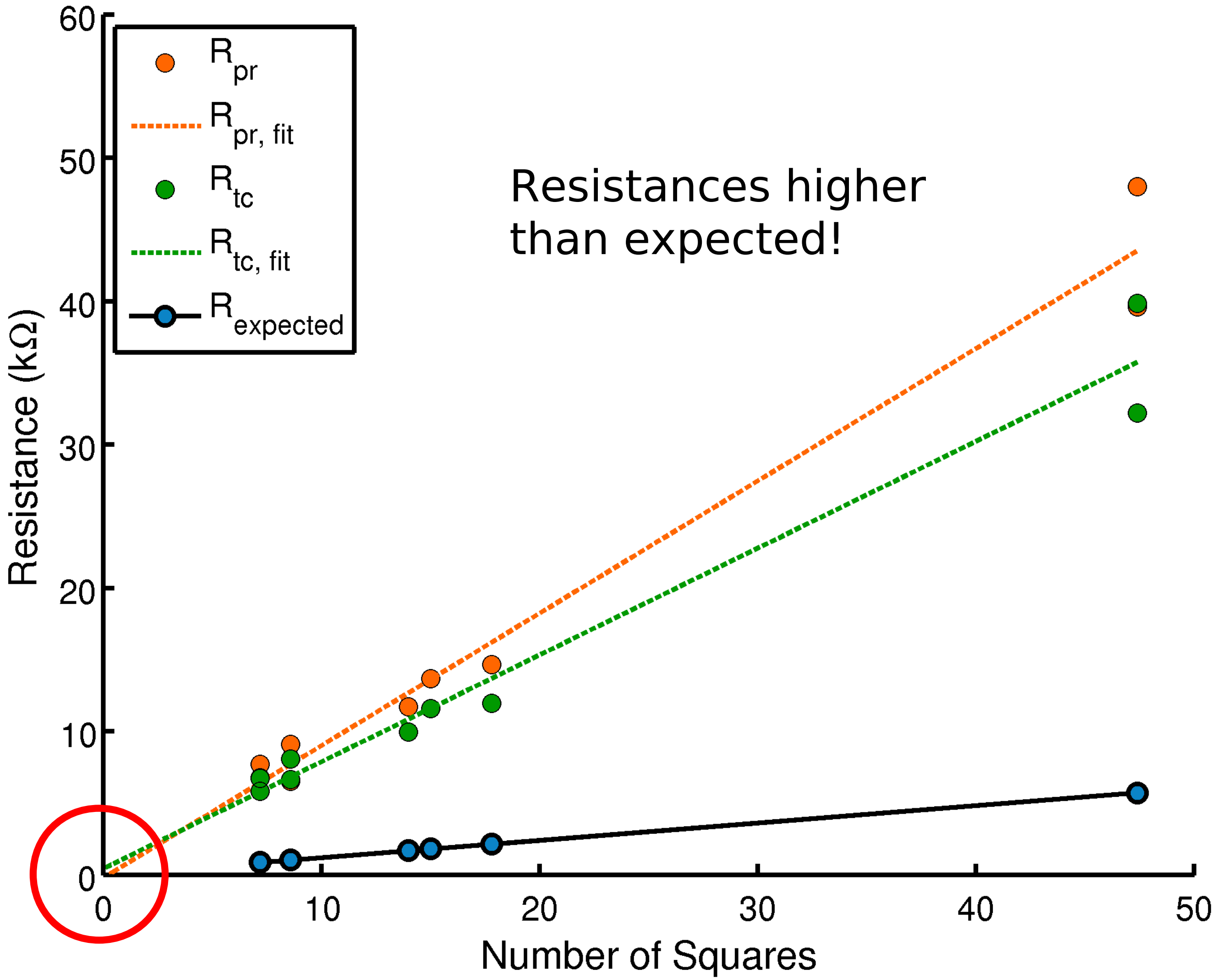


Mean ~ 10x higher than expected

Two unknowns, one equation

- Alpha is higher than expected or Nz is lower than expected. Which?
- Need an additional parameter for fitting.

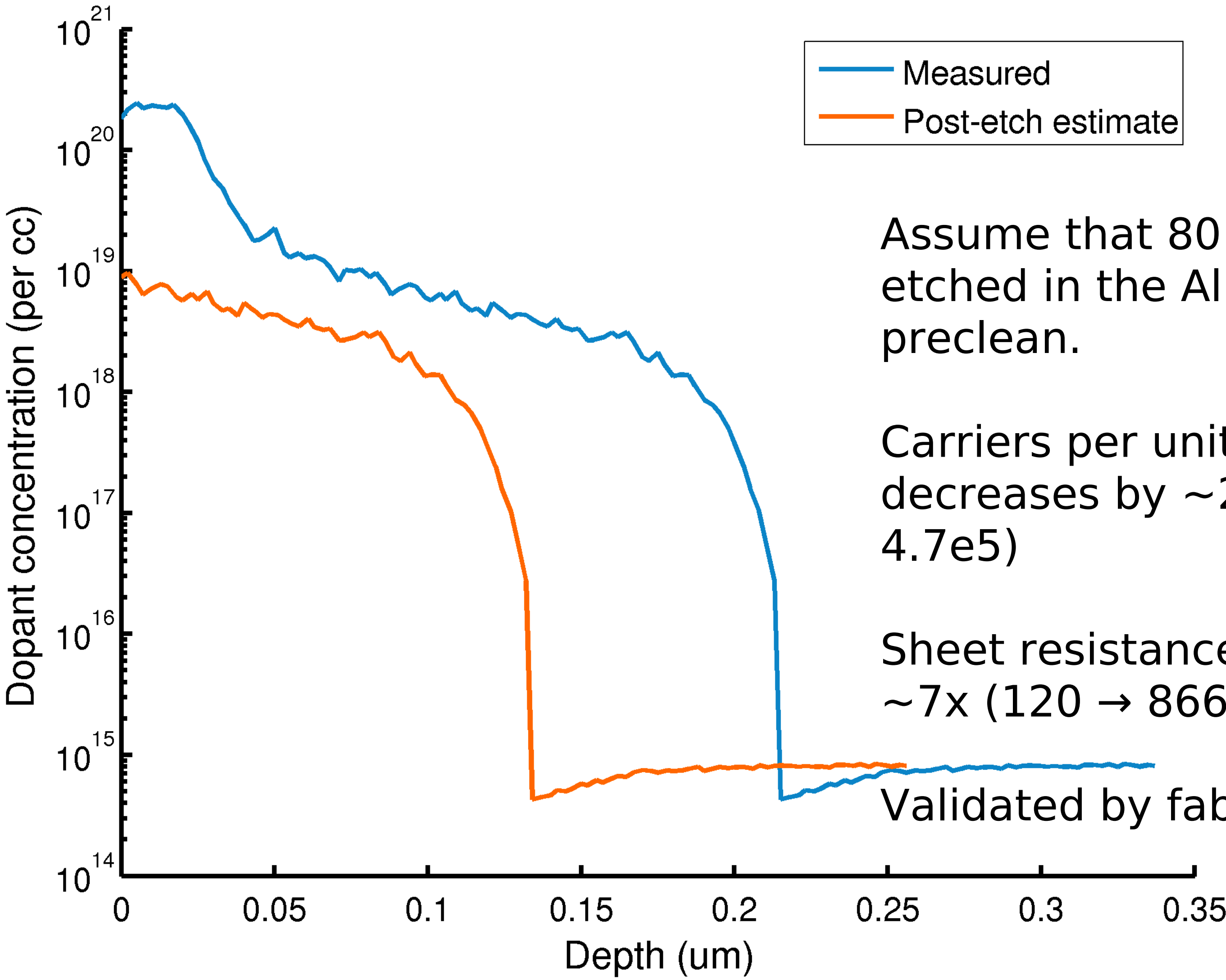
Piezoresistor resistance



Resistances higher than expected!

Contact vias are good!

Accidental etching



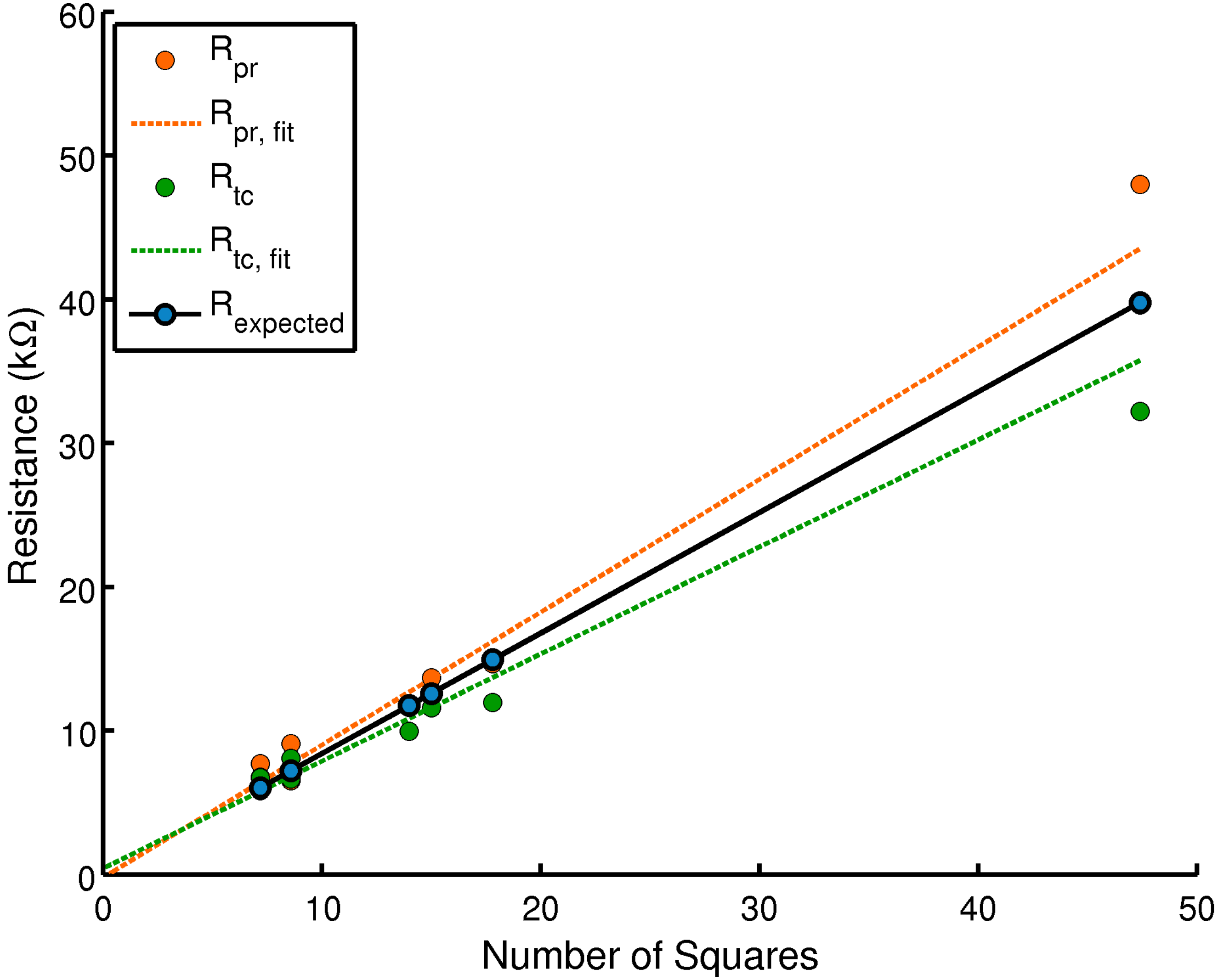
Assume that 80 nm of Si was etched in the AlN deposition preclean.

Carriers per unit depth decreases by ~20x (7e6 → 4.7e5)

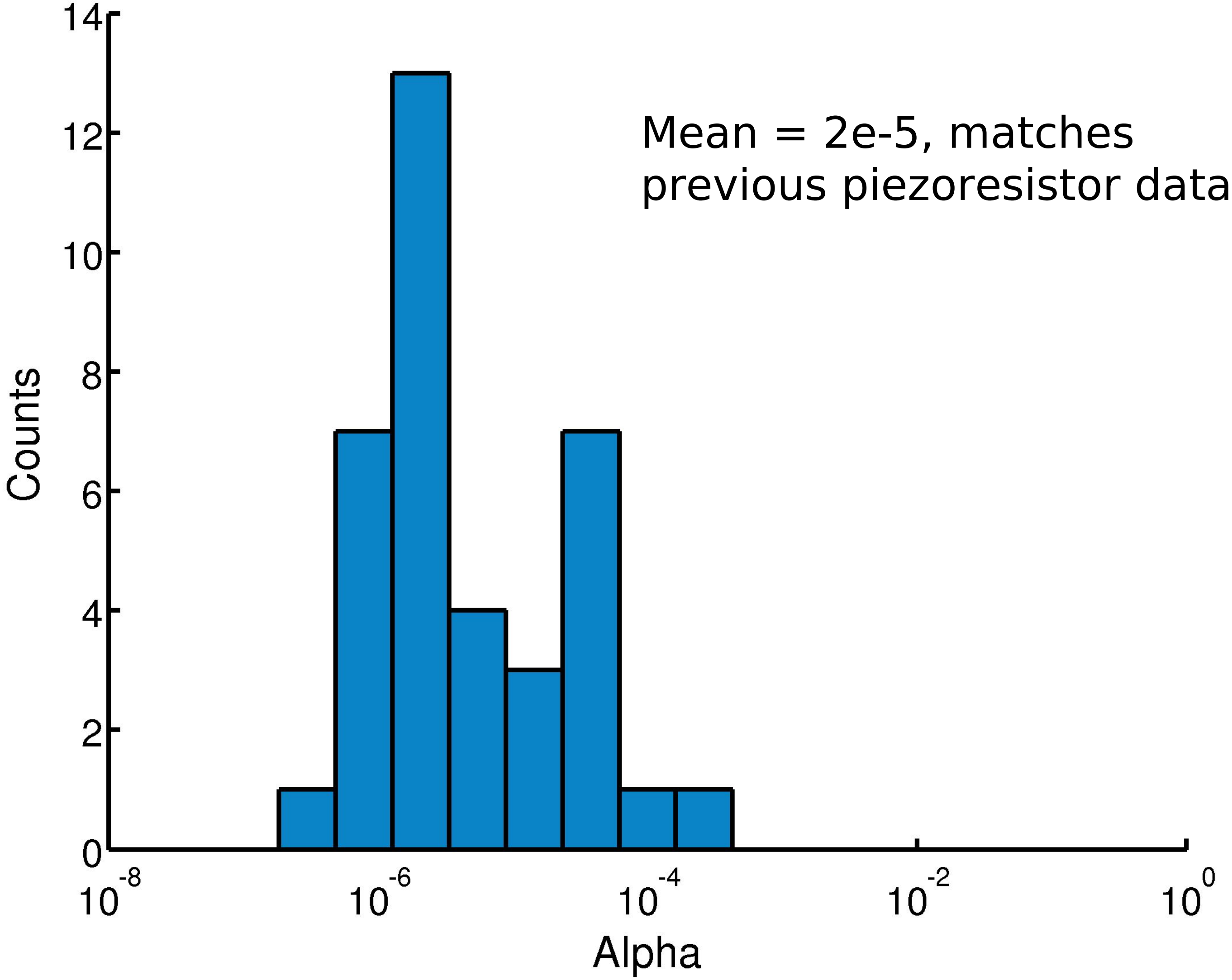
Sheet resistance increases by ~7x (120 → 866 ohms/sq)

Validated by fab measurements

Adjusted resistance model



Alpha adjustment



Mean = 2e-5, matches previous piezoresistor data

Overall impact?

- Noise is higher
  - Johnson noise ~2.5x higher
  - 1/f noise ~10x higher
- Sensitivity is higher
  - Beta* ~2x higher
  - Thickness ~50% less
- Net effect = 5x worse force resolution
  - Back of the envelope, will vary...

Spring Constant

- Can estimate spring constant from resonant frequency, cantilever geometry
  - Complicated geometry, made some assumptions for now, FEA later
- Measured thermomechanical noise spectrum using LDV

Spring Constant

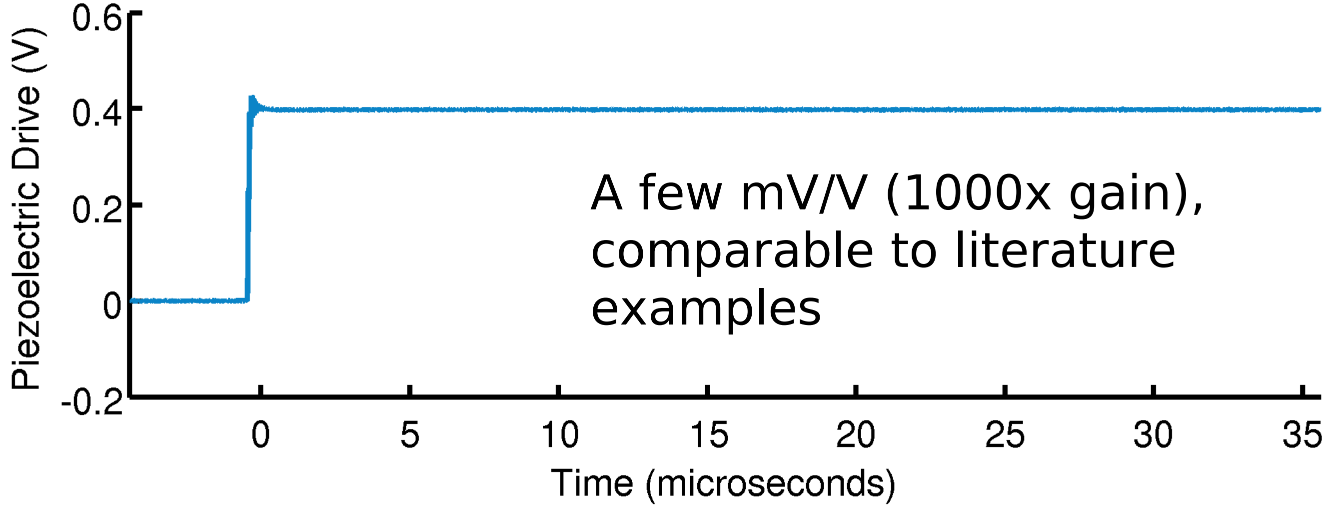
Design #	Theoretical Frequency (kHz)	Measured Frequency (kHz)	Estimated Stiffness (pN/nm)
1	0.5	0.5	2.0
2	2.1	1.8	0.02
3	10.7	13.2	0.1
4	84.8	128.9	3
5	0.9	1.2	100
6	4	8.25	0.09

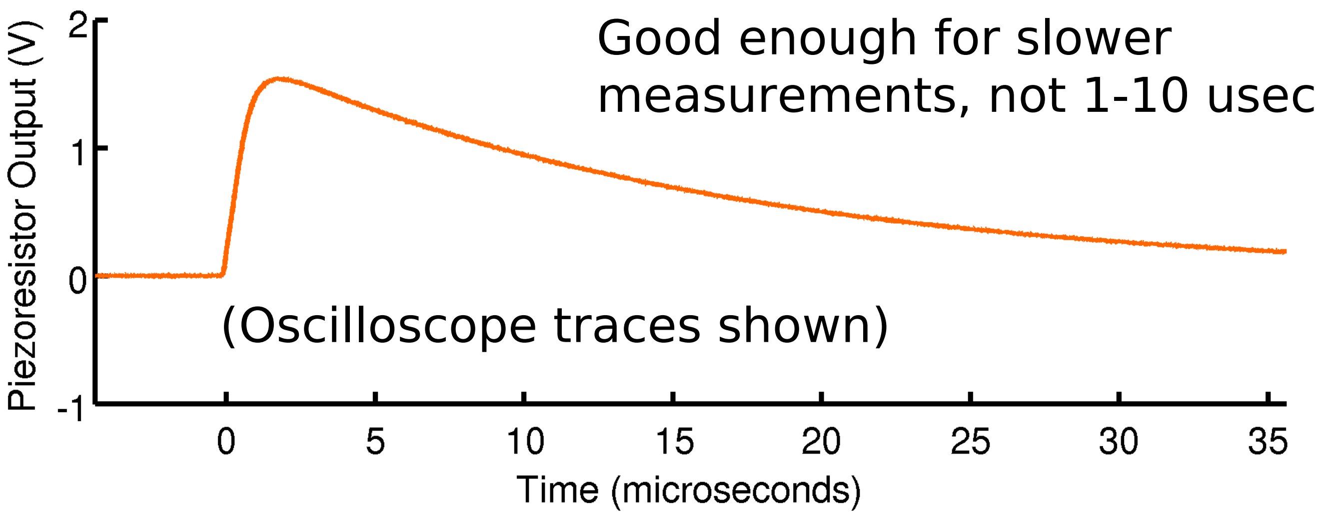
Ballpark estimates. N=1 for each, simplified model.

Crosstalk overview

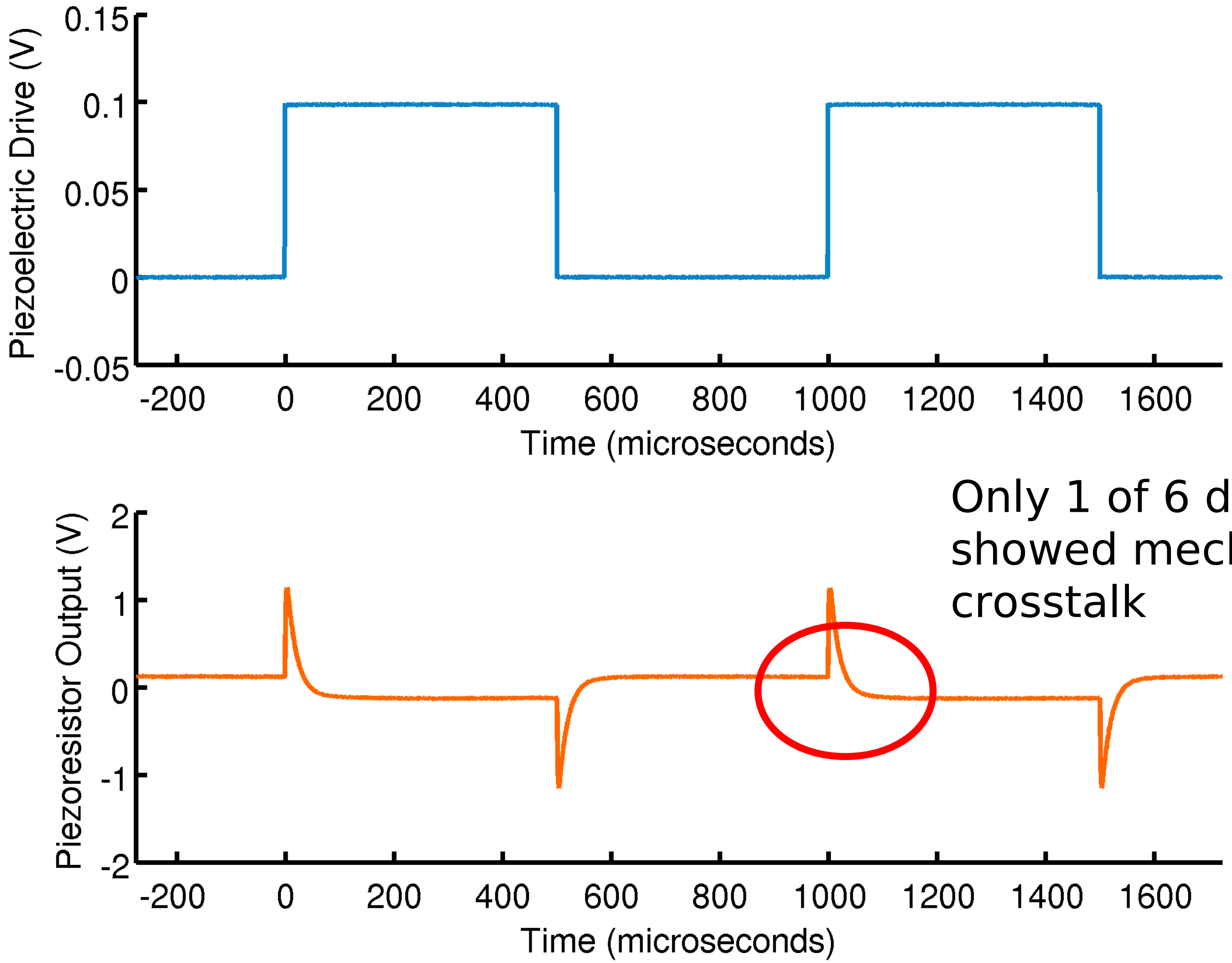
- Showed preliminary data last time, but not a realistic experimental setup
- This time: using actual PCB, cables, etc. that would be used for experiments
- Possible mechanisms
  - Capacitive: worse at higher frequencies, due to changing voltages in vicinity of each other
  - Mechanical: Piezoelectric bending changes piezoresistor resistance

There is capacitive crosstalk



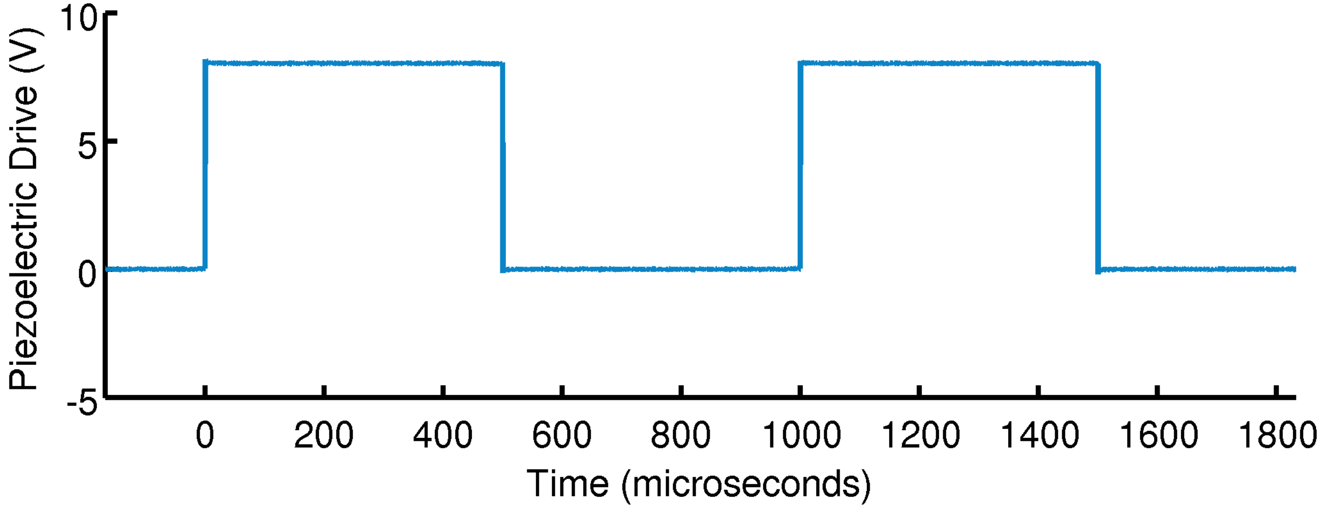


Some mechanical crosstalk

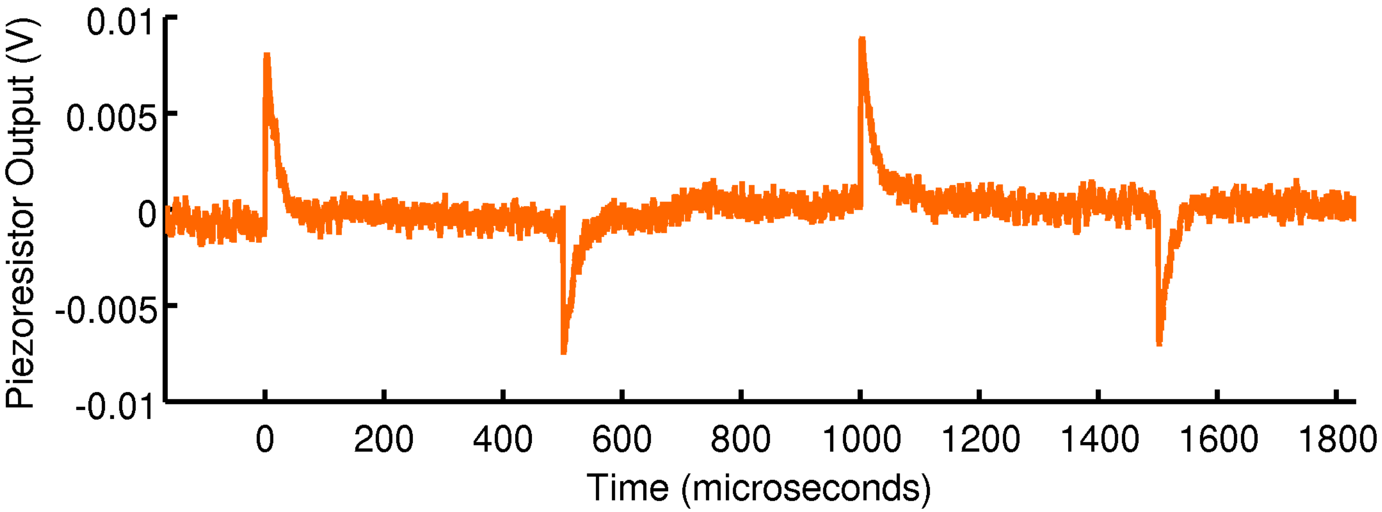


Only 1 of 6 designs showed mechanical crosstalk

Minimal crosstalk from PCB

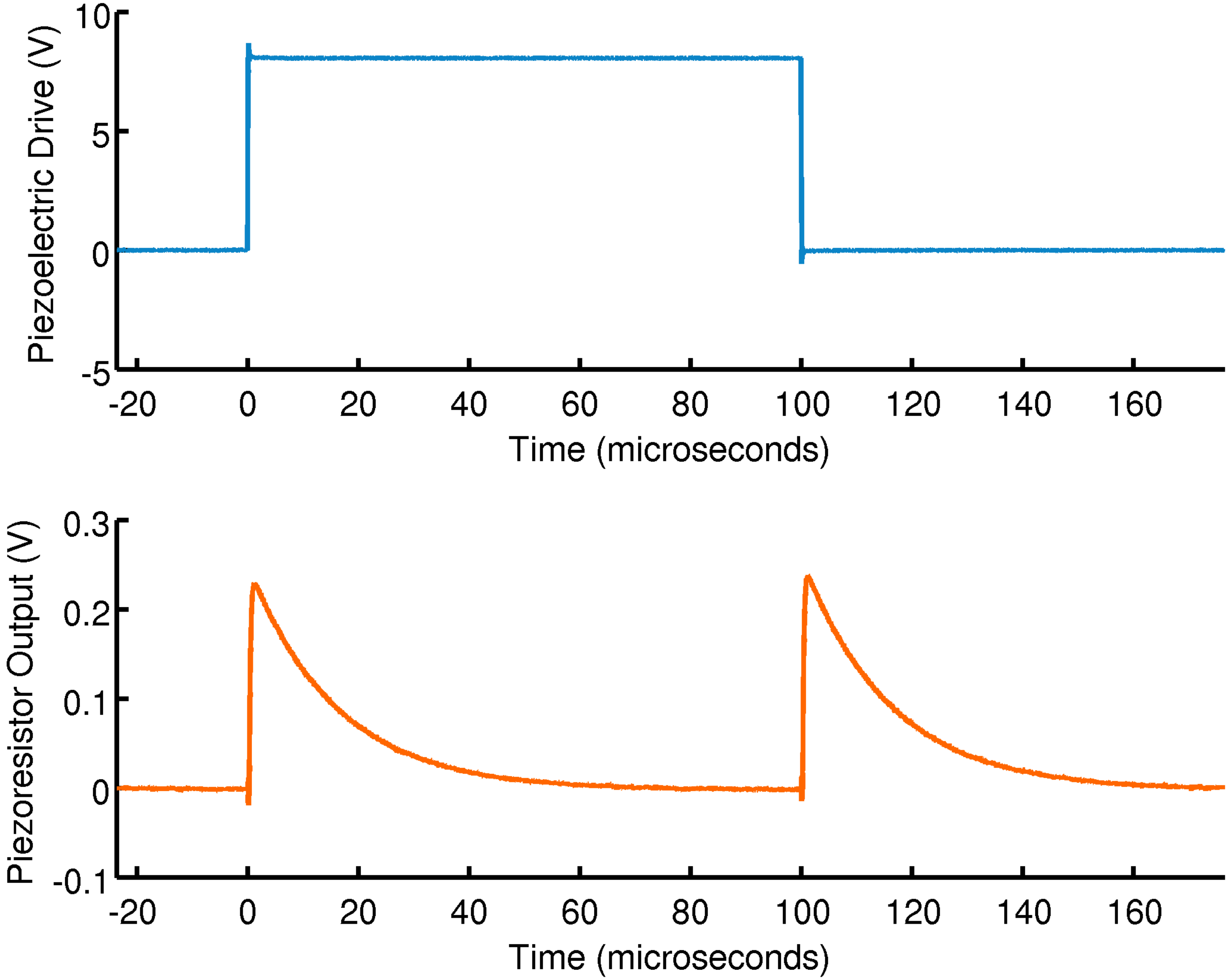


Connected discrete resistors and capacitors in place of the cantilever



Also no crosstalk from the cable (shielded)

Some crosstalk from cantilever PCB



Connected cantilever PCB, shorted the bondpads by wirebonding

Crosstalk – What next?

- Investigate with more devices, measurement conditions
- Model in terms of device design parameters
- Affects highest speed measurements, not bad enough to stop system development, slower demonstration measurements (msec)
- Solution: compensation on silicon die (next fab run) – piezoelectric next to temperature compensation PR

Conclusions

- Piezoresistors are noisier, higher resistance than expected, but minimal impact on performance.
- There is electrical crosstalk on the microsecond scale.
- Devices usable for system testing and some measurements.

What's next?

- Test feedback control (mock cantilever)
- Measure PR force sensitivity, tip deflection
- Demonstrate on microscope in MERL
- Choose an experiment based upon performance
- Fab run for improved devices