Title
Electric Power Sensing for Demand Response

Authors
Leland, Eli S.
Minor, Peter
Paprotny, Igor
et al.

Publication Date
2009

Electric Power Sensing for Demand Response

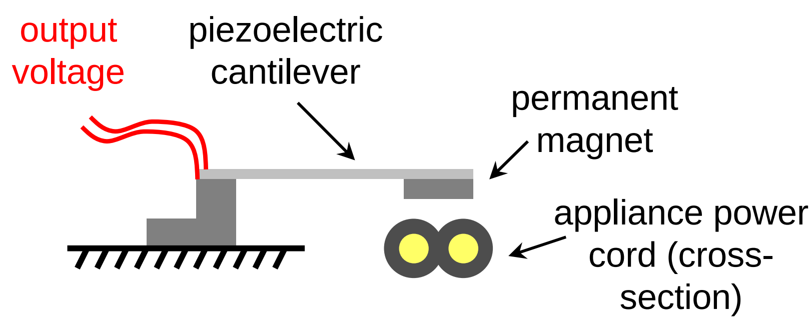
September 15, 2009

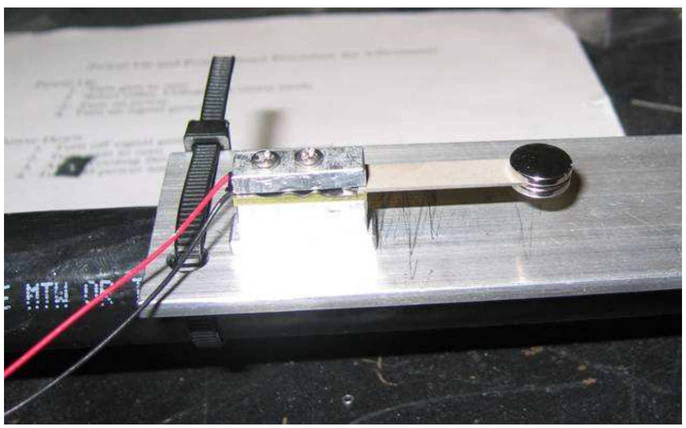
Eli S. Leland, Christopher T. Sherman, Peter Minor,
Dr. Igor Paprotny, Prof. Paul K. Wright, Prof. Richard M. White

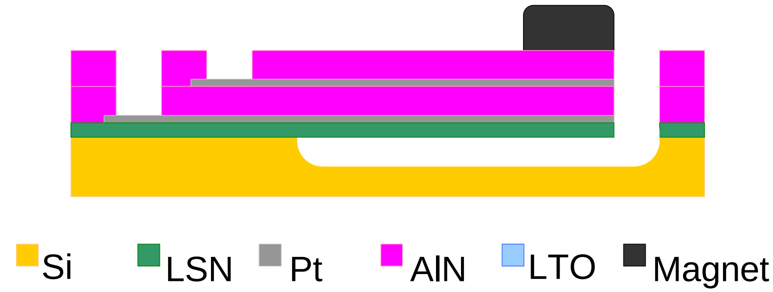
PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

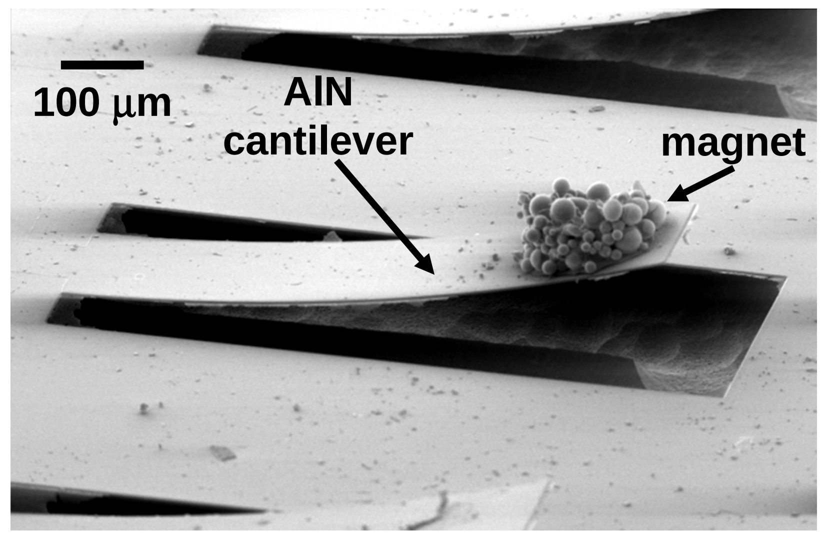
STATE OF CALIFORNIA
ENERGY COMMISSION

Mesoscale to microscale...





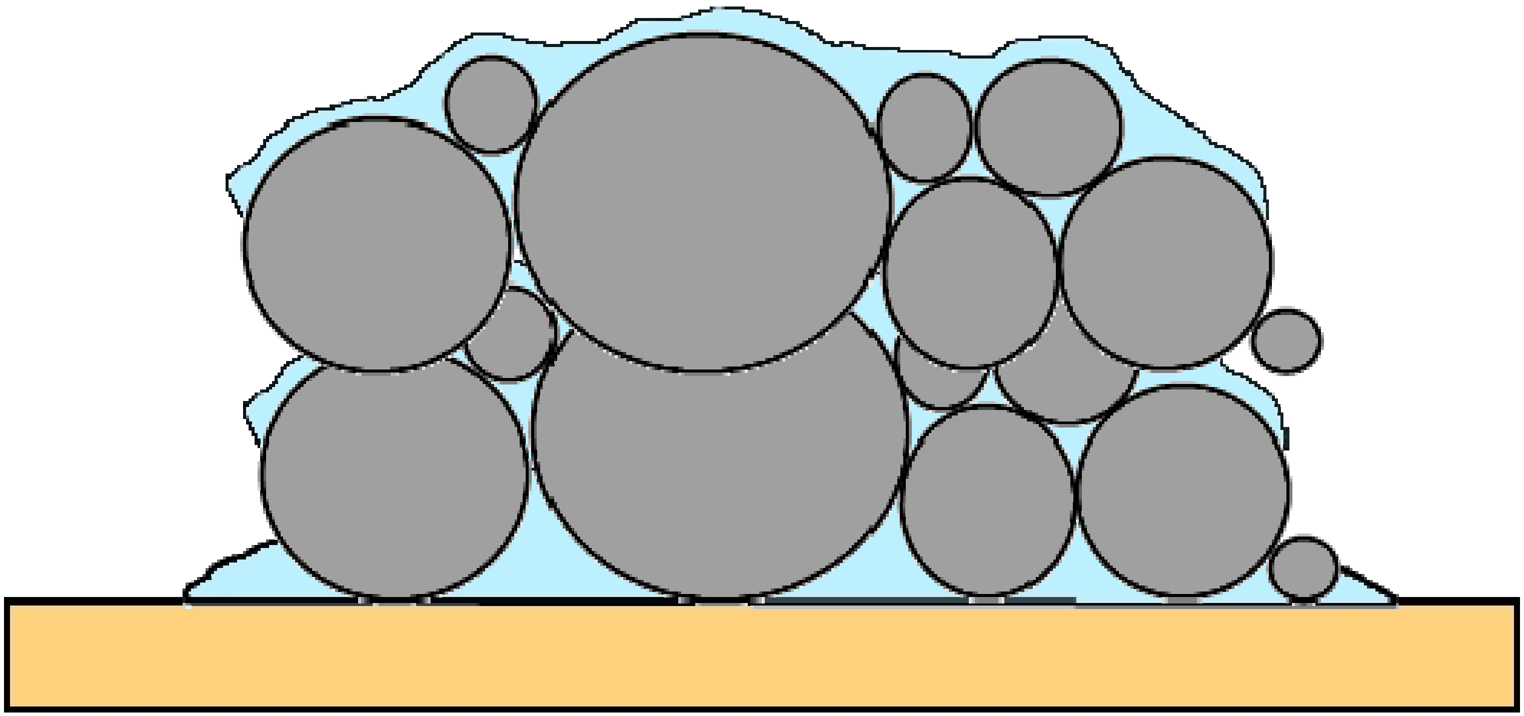




MEMS magnet development for current sensing

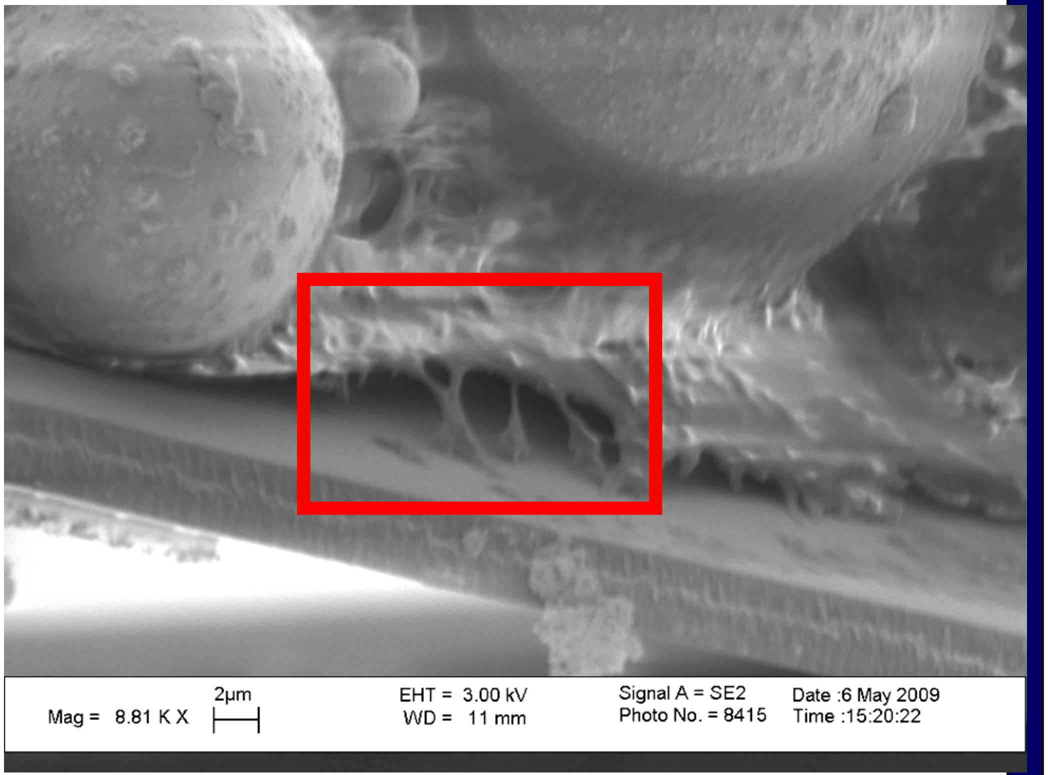
Dispersed-powder method for magnet fabrication

Process can be repeated to improve aspect ratio



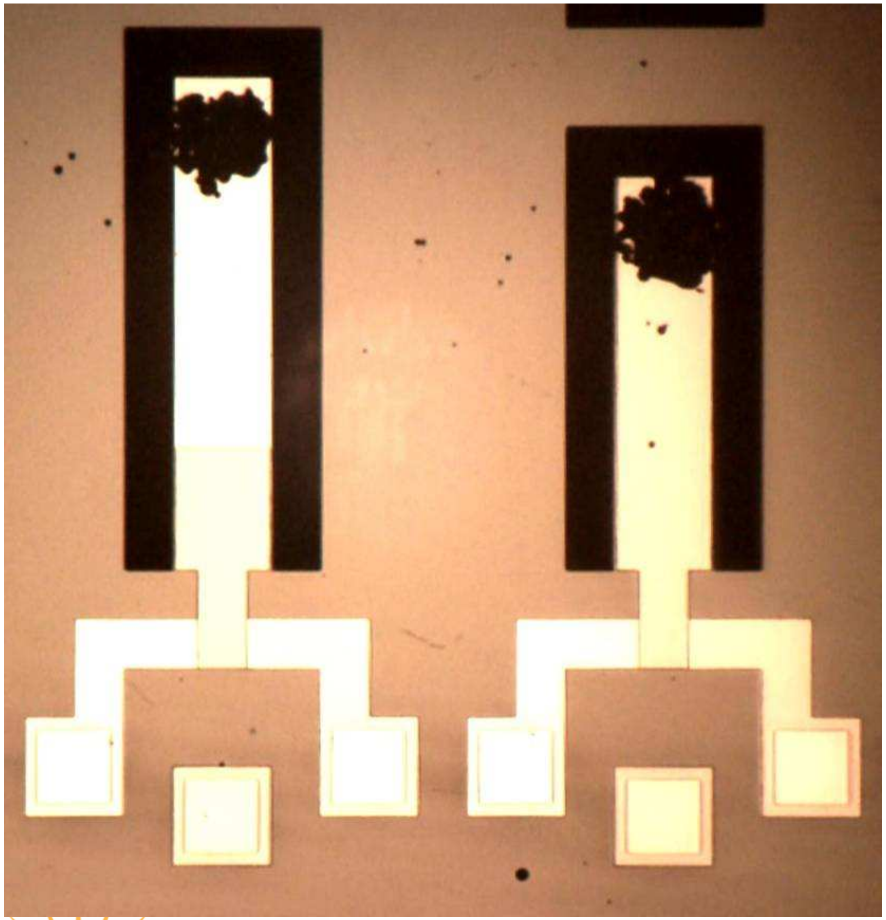
Problems with PVDF

- PVDF initially chosen due to printer compatibility
- But evaporation of NMP solvent causes volume change
  - Possible delamination from substrate during curing

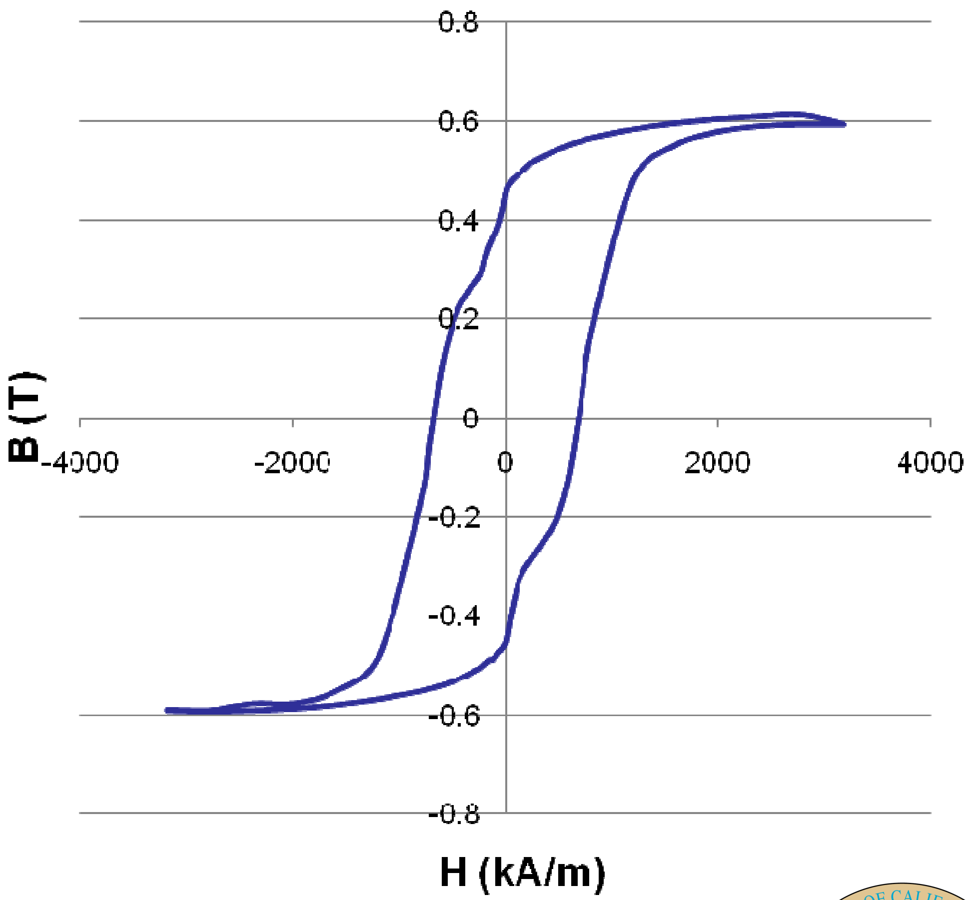


Results with epoxy

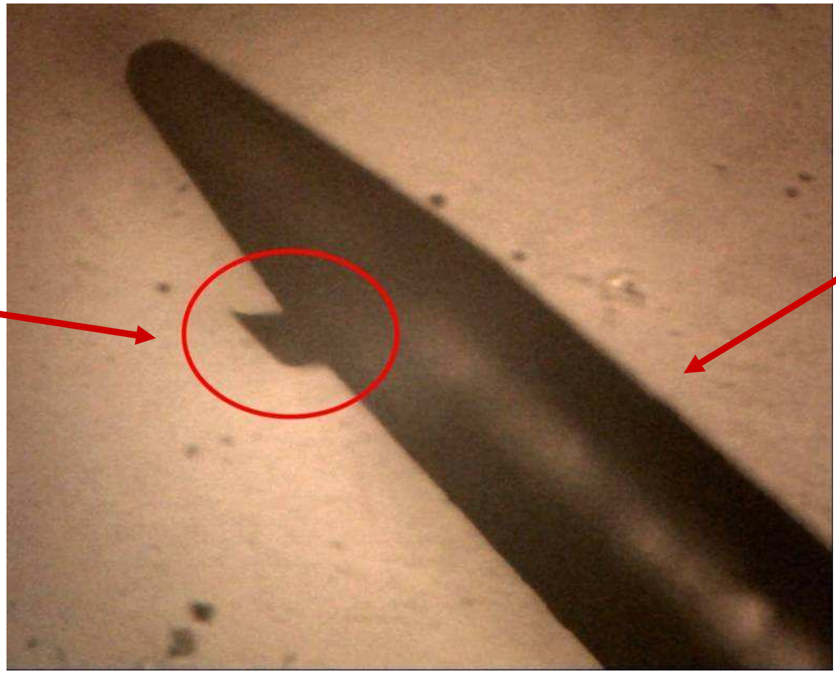
Magnets on Cantilevers



Magnetic Performance



Real-world magnet test

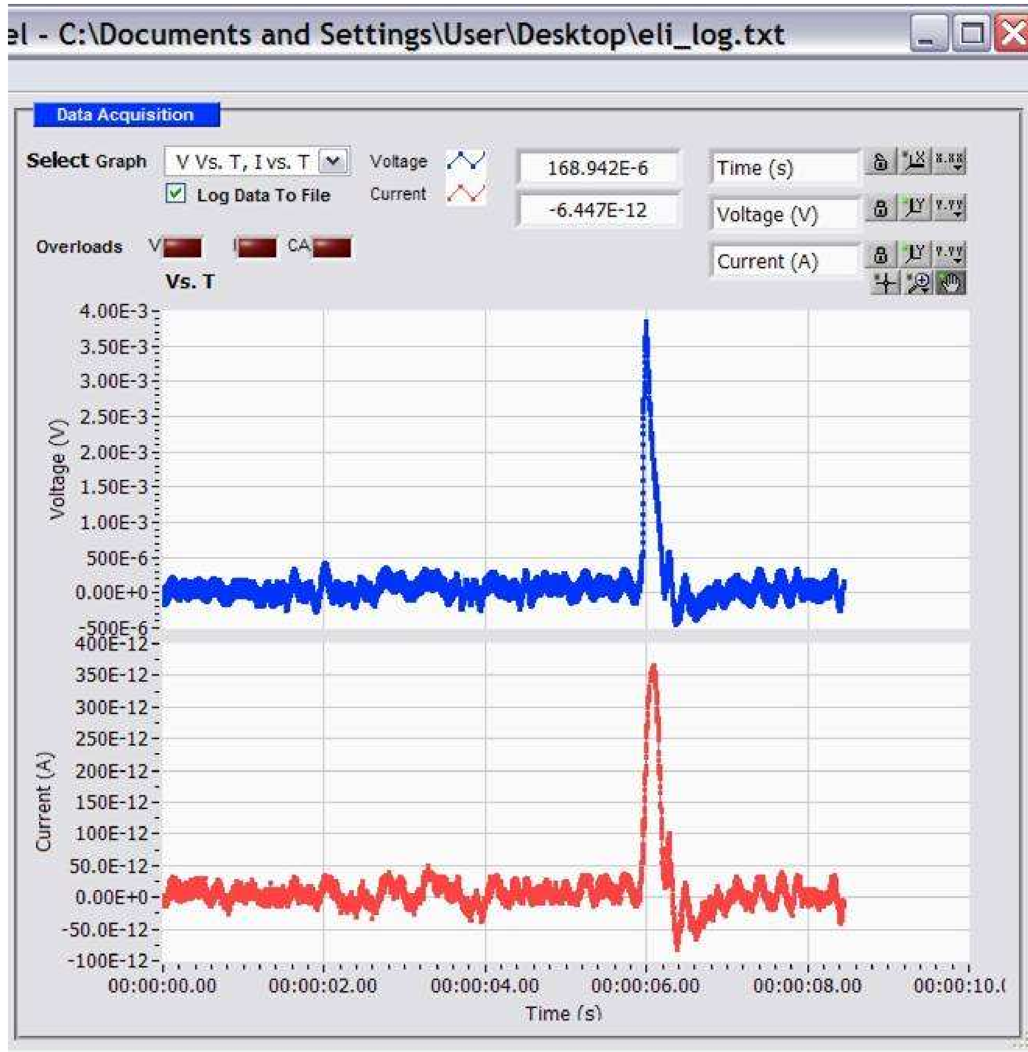


- Although magnetic testing indicated remanent magnetization, we wanted to make sure that translated into actual devices
- It sticks to a safety pin!

MEMS integrated device testing

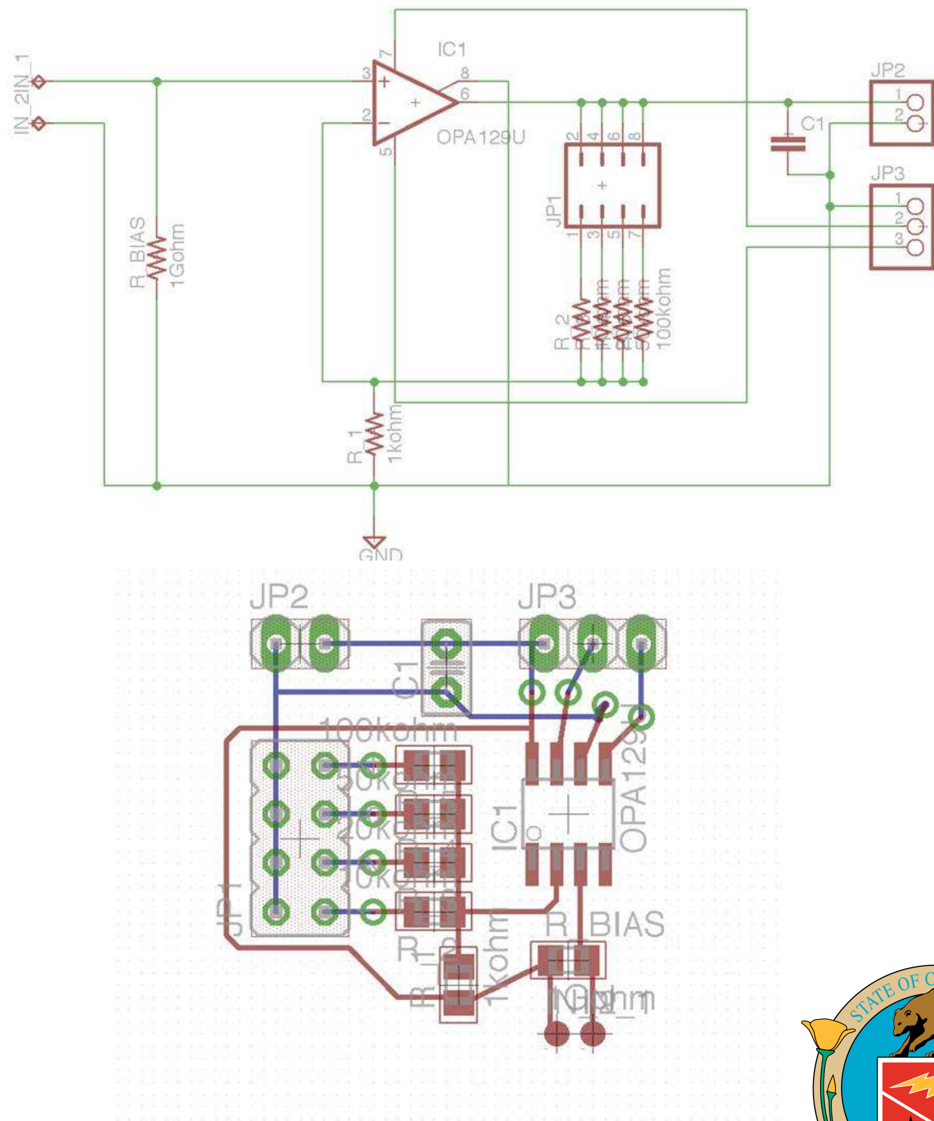
"Hello, world"

- Mounted sample on probe station, probed two electrodes, "plucked" an AlN cantilever with a third probe tip
- Recorded ~4 mV signal using Gamry Reference 600 galvanostat/potentiostat
- In this experiment, a 10 MOhm resistor was placed in parallel with the MEMS cantilever (doesn't work otherwise)



Development of an op-amp circuit

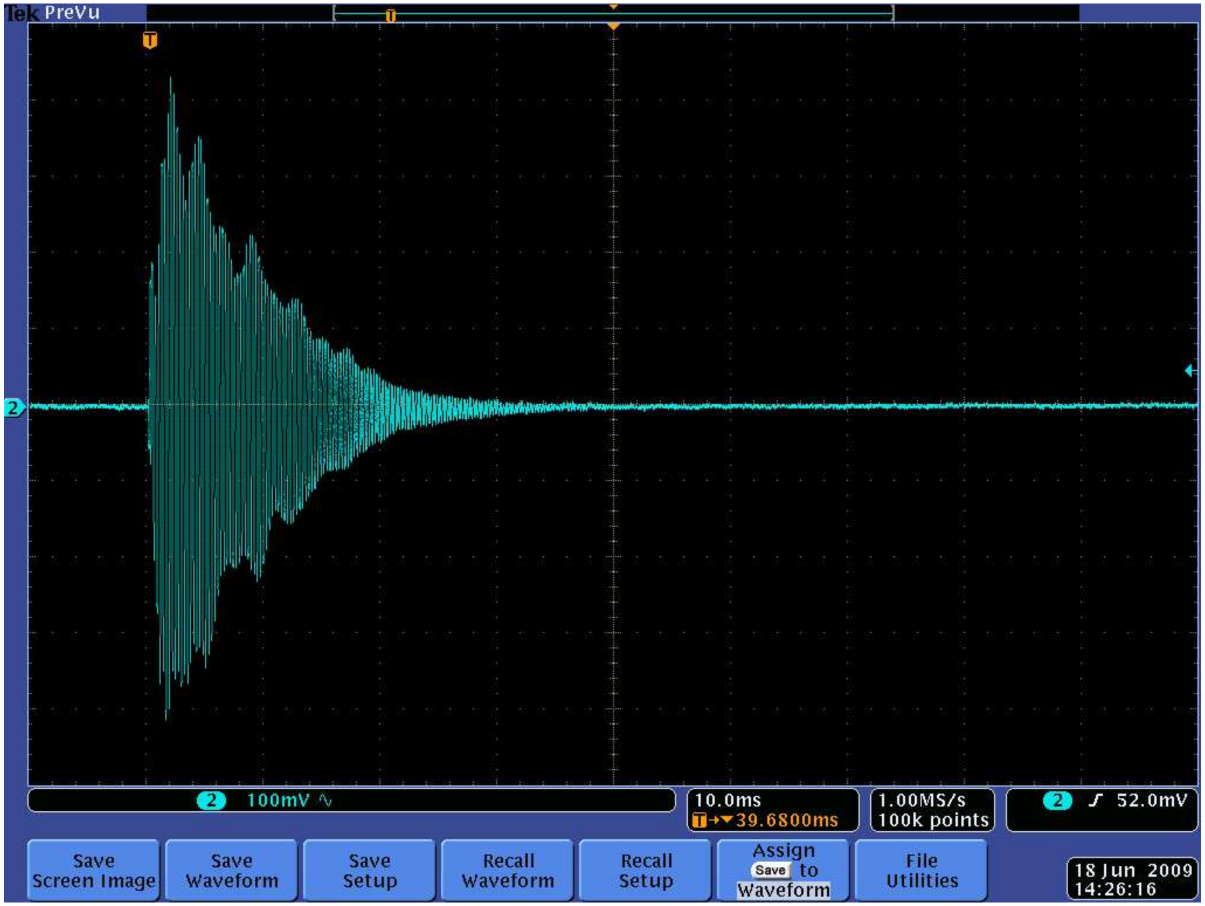
- Designed a straightforward non-inverting op-amp circuit using a TI/Burr-Brown OPA129 and jumper-selectable gain
- This time a 1 GOhm bias resistor prevents the input from floating
- Modeled piezoelectric device as an AC current source in series with a similar-value capacitor (in Spice) and did the same in actual breadboard circuit testing



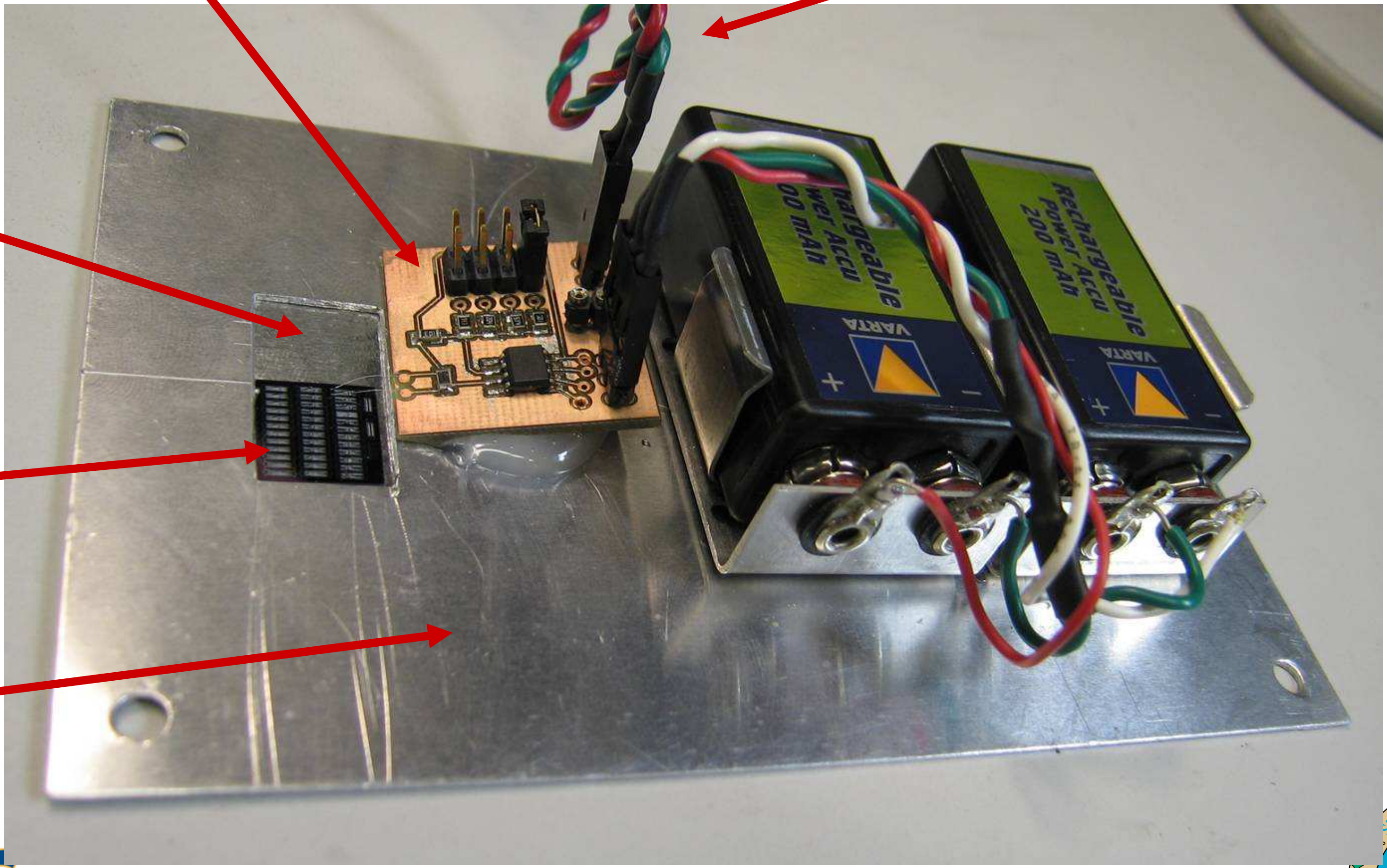
PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

AlN cantilevers are sensitive

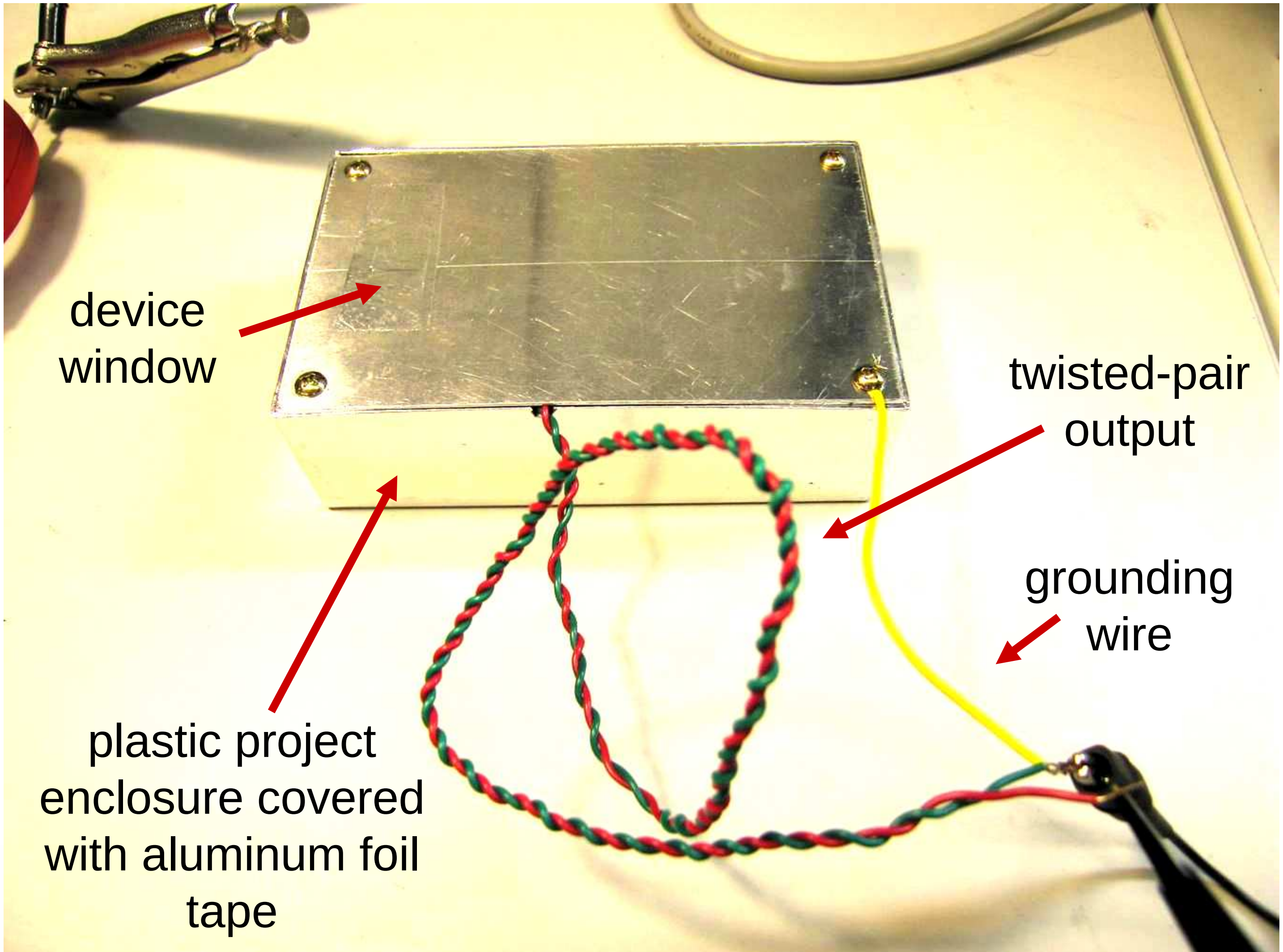
- Assembled in shielded enclosure with 100x op-amp
- Actuated by lightly tapping enclosure exterior with the end of a wire
- ~800 mV pk-pk
- Resonance frequency ~3.7 kHz (no magnet) on a 1000 x 150 um cantilever
- No noticeable noise when waving a zip-cord carrying 13 A nearby



Once the magnets are in place, put it all together



Enclosure


device window
twisted-pair output
grounding wire
plastic project enclosure covered with aluminum foil tape

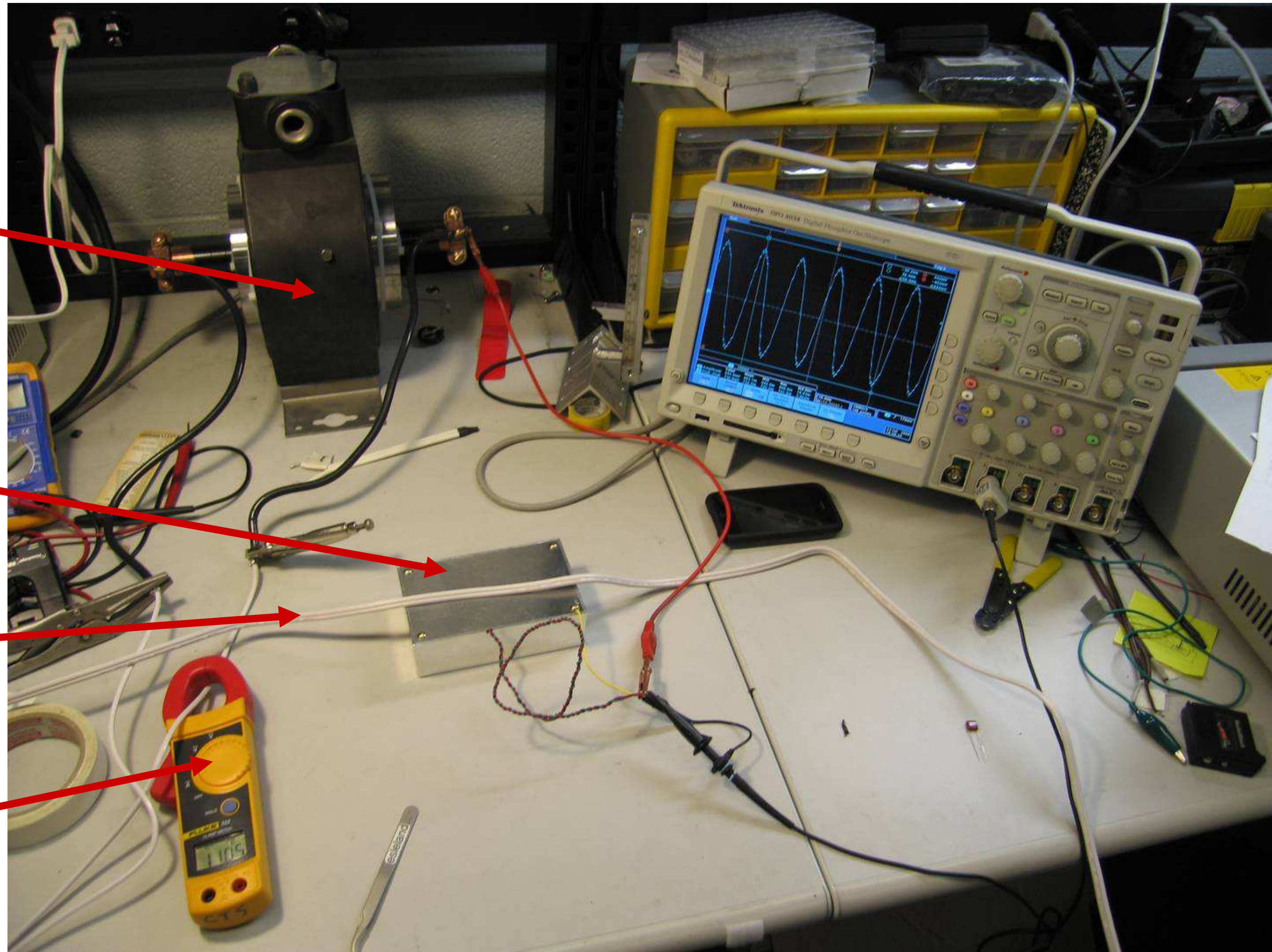
Put it all together and test

current transformer signal generator

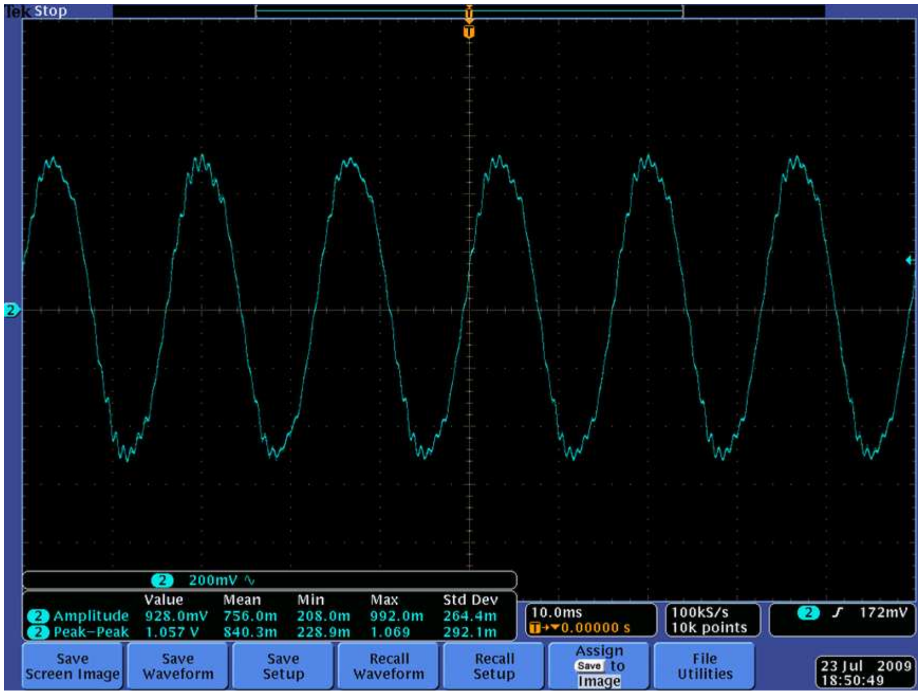
sensor enclosure

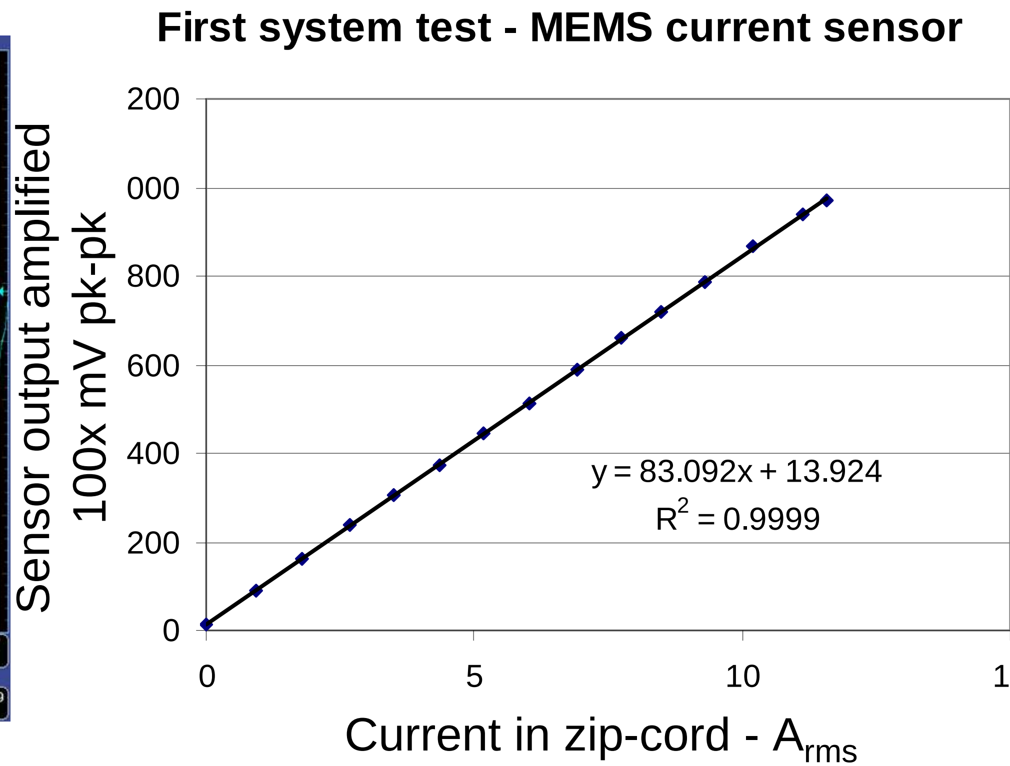
zip-cord

clamp meter for calibration



And...it works

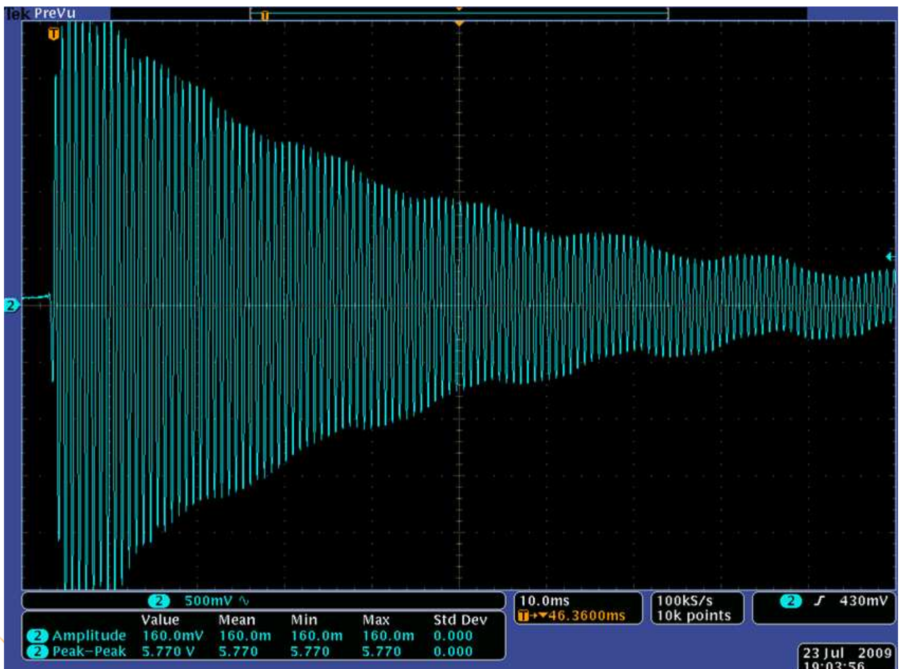




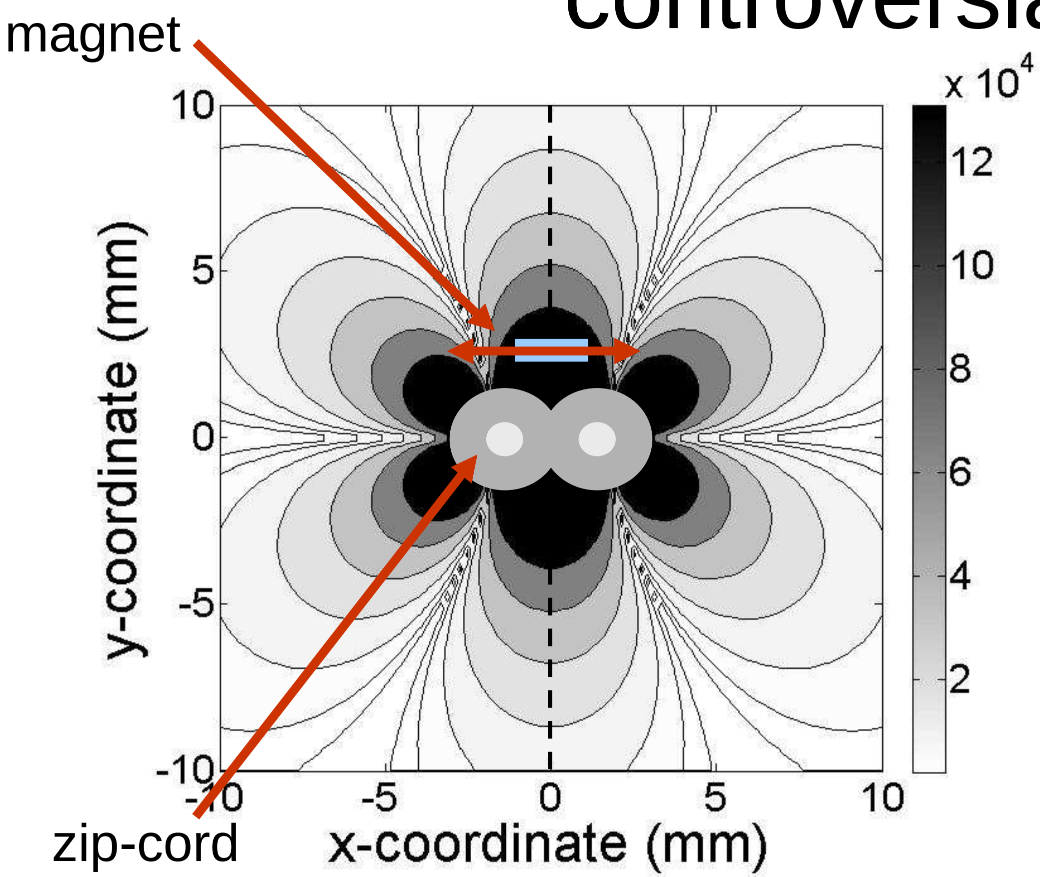
- Sensor response is highly linear measuring currents up to 11 A in a two-wire "zip-cord"
- Higher-order harmonics are also captured up to the device's resonance frequency (~1.2 kHz), research on transient response continues

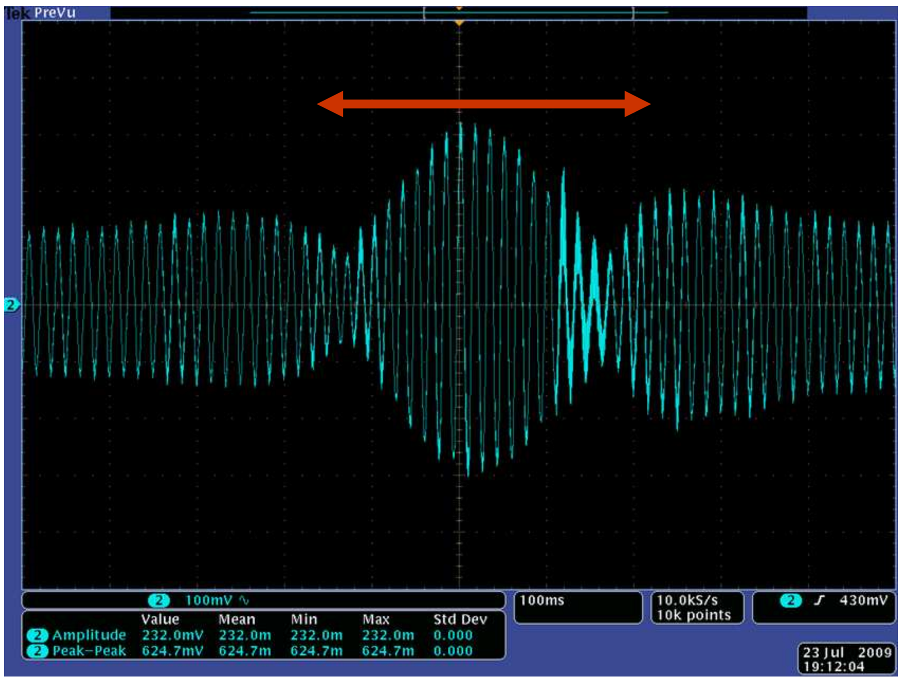
Device characterization

- With the magnet in place resonance frequency of a 1000 x 200 um cantilever is 1.22 kHz



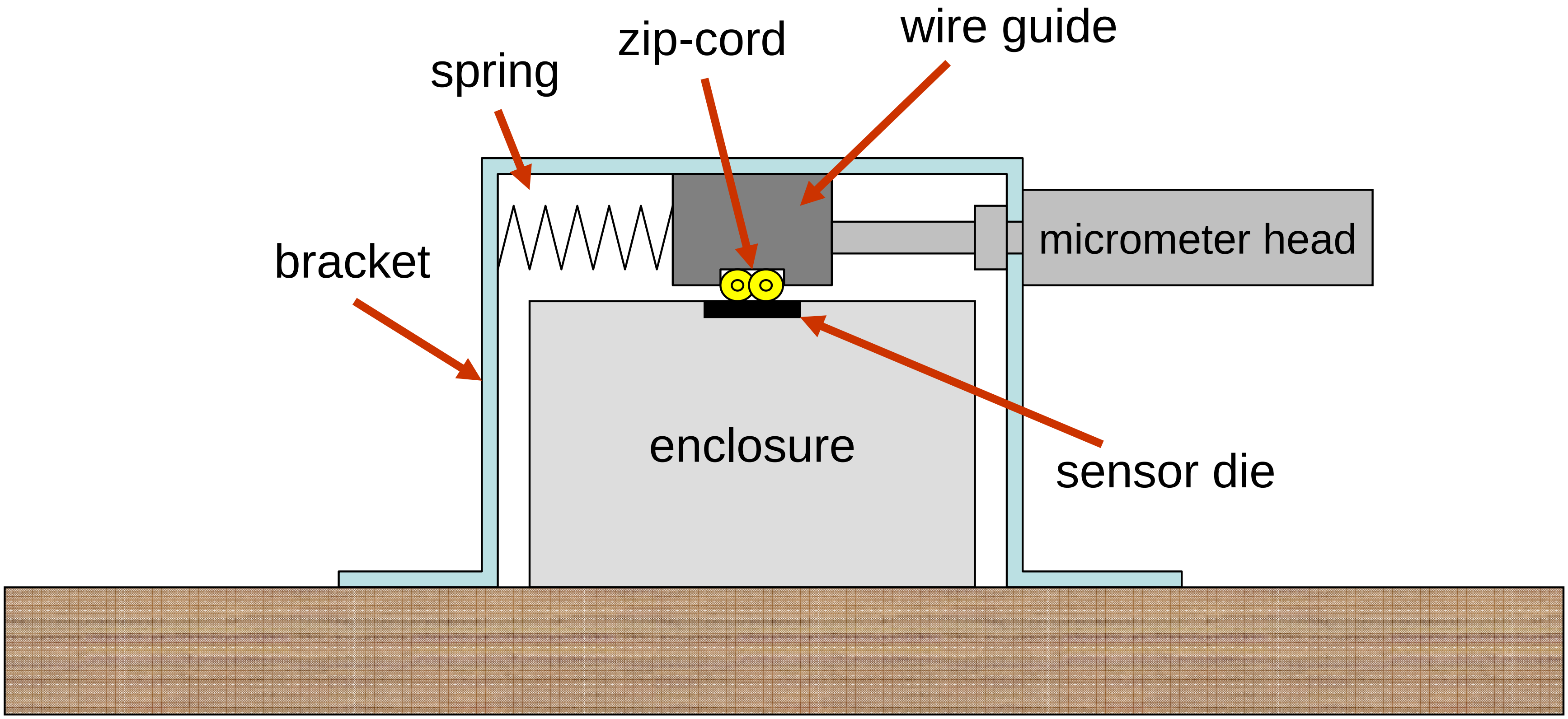
Confirmation of a (somewhat) controversial model





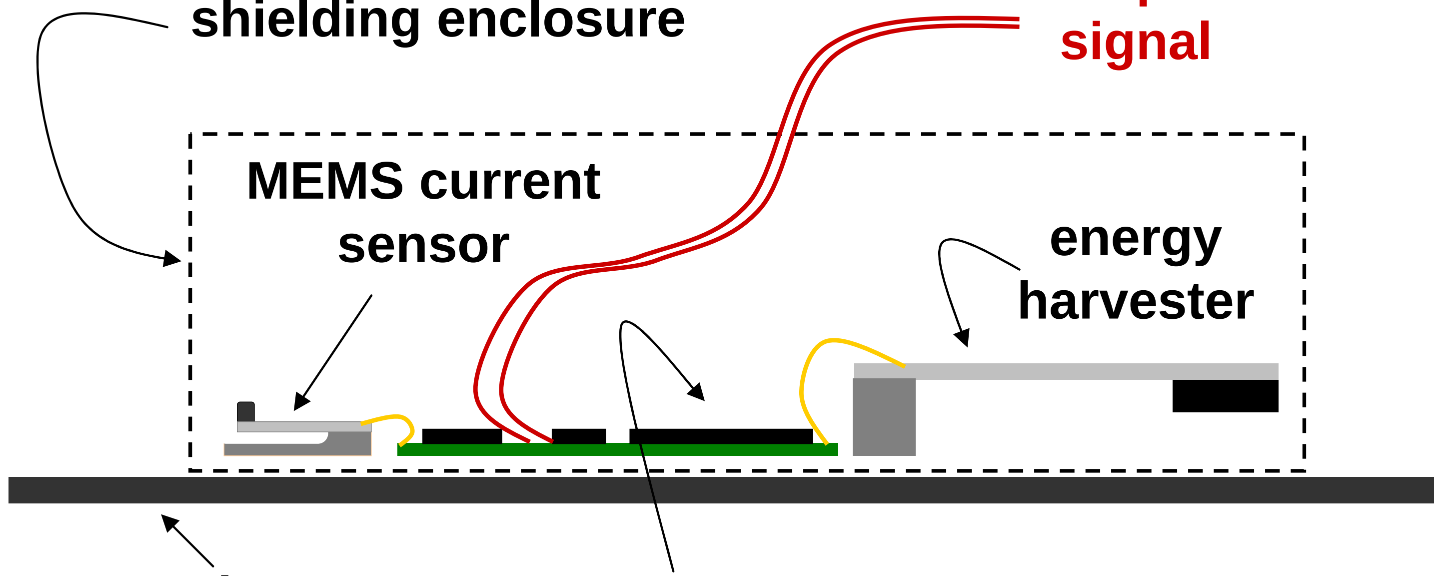
- By scanning the zip-cord over the sensor window, "force-field" plot is verified

Test apparatus schematic



- This apparatus will allow detailed testing and characterization of multiple sensor and wire configurations
- As sensor is not visible from outside enclosure, micrometer allows for optimal positioning of wire relative to sensor

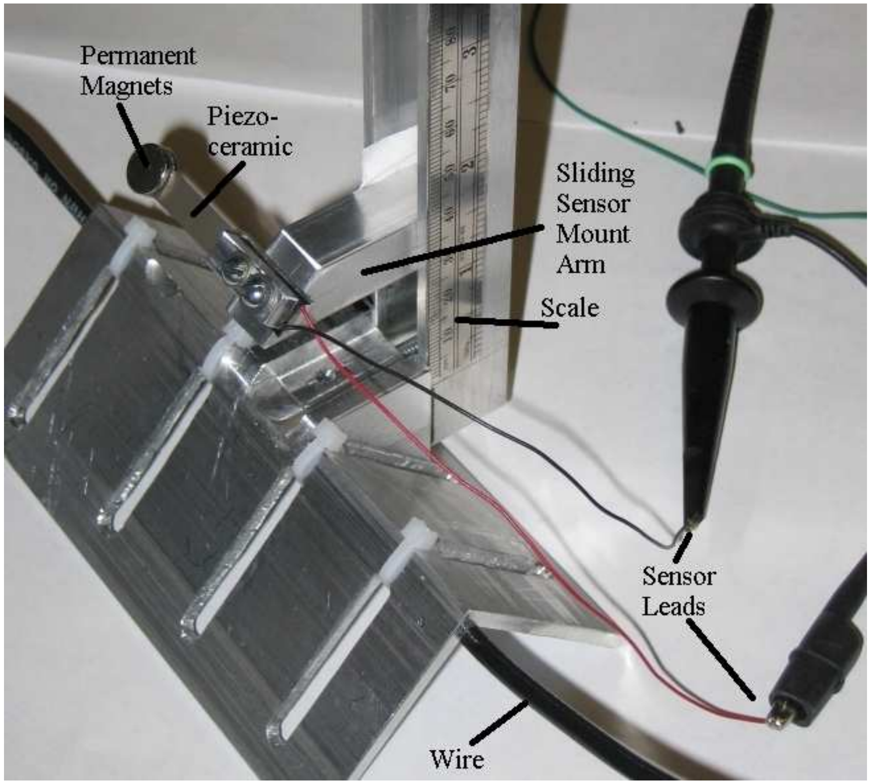
Self-powered sensor demo

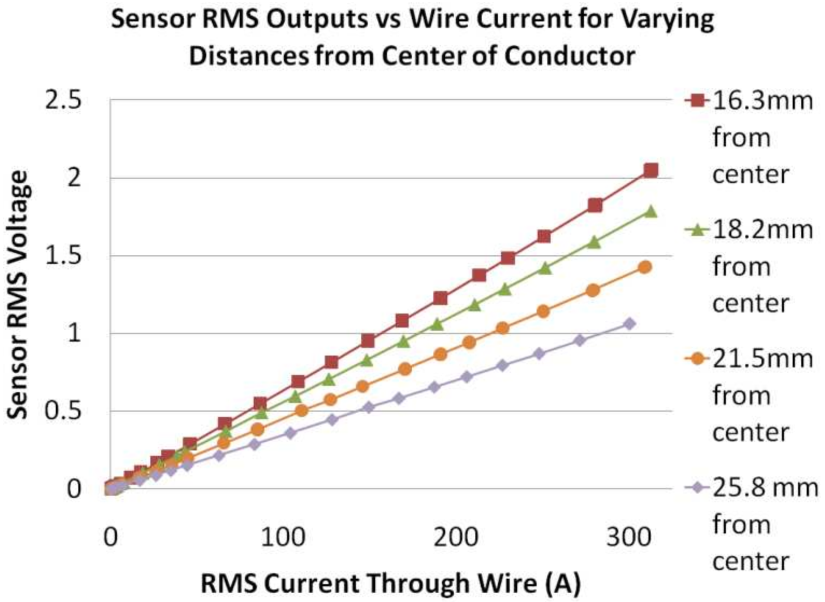


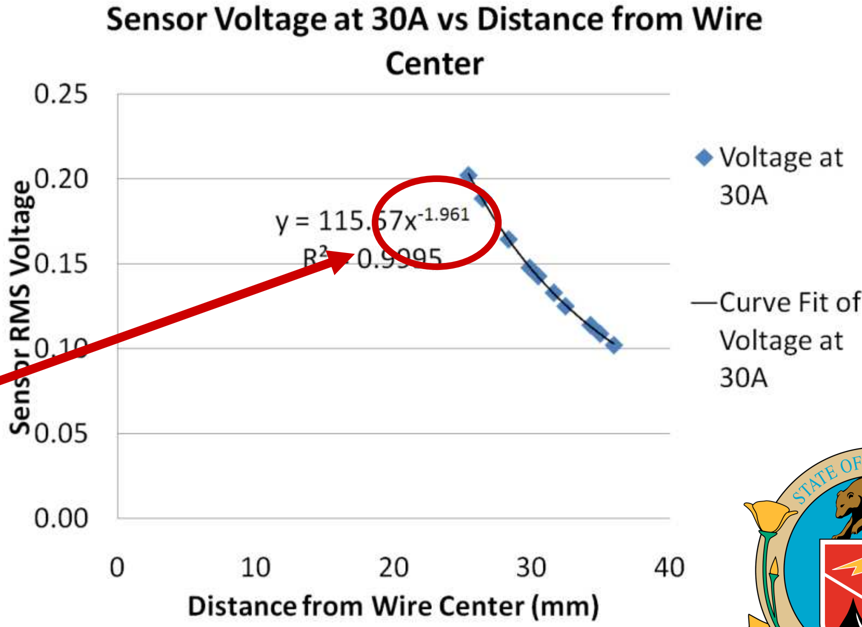
- Combine MEMS sensor with energy harvester and power conditioning and storage to demonstrate self-contained, self-powered sensor package
- All components have been fabricated, assembly and testing are underway

Other continuing sensors research

Analytical model confirmation at the meso-scale





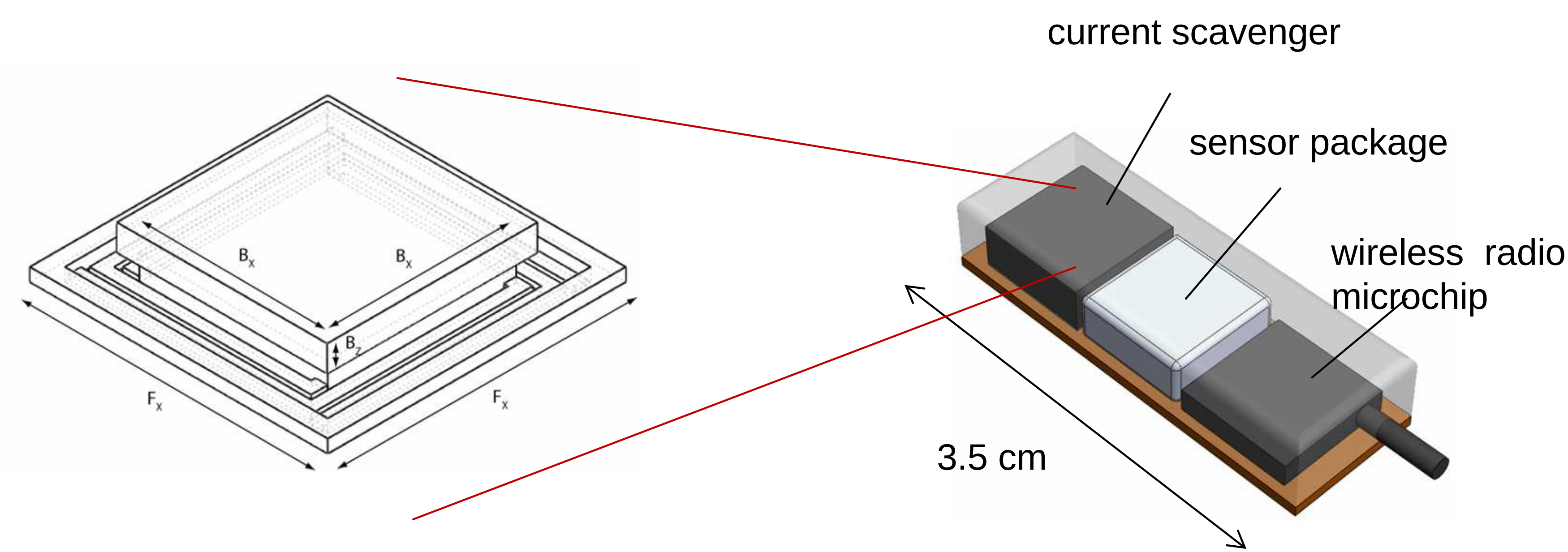


As sensor moves further from conductor, model predicts an inverse-square relationship, experimental result is $x^{-1.96}$

PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

STATE OF CALIFORNIA ENERGY COMMISSION

In development: Optimized die-sized current scavenger for wireless sensor nodes

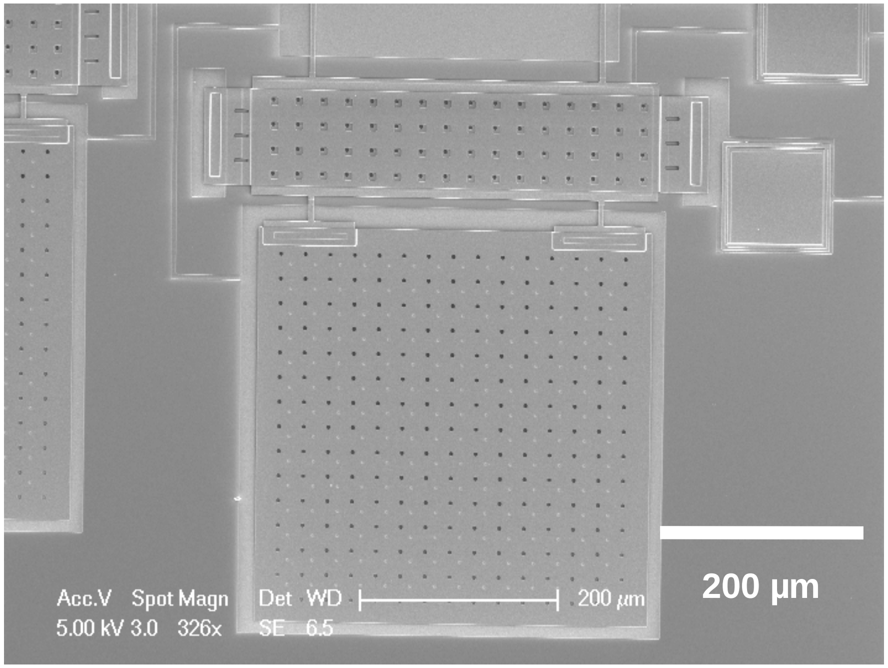


- In development: Optimizing a die sized (10x10x4 mm) current scavenger (to be presented at *PowerMEMS 2009, Washington D.C.)*

- Combining MEMS and macro-scale fabrication to optimize the efficiency of the scavenger given form-factor constraints

Voltage and power sensing

- Prof. White and Dr. Igor Paprotny have fabricated an integrated MEMS power sensor and are working on MEMS voltage sensors. Research continues on these devices



SEM of a fabricated MEMS passive proximity power sensor (testing ongoing)

Thanks!

Questions?