# MEMS Power Sensors

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UCB Mechanical Engineering
DRETD TAC Meeting
February 21, 2007

# MEMS Power Sensors

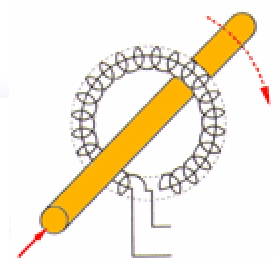
- Self-powered
- Proximity-based
- Microfabricated

# MEMS Power Sensors

- Self-powered
  - improves sensor node battery life
  - potentially a source of power for sensor node
- Proximity-based
  - don’t require electrical connection to or wraparound of conductor
  - don’t require precise alignment to conductor
- Microfabricated
  - small and cheap
  - embeddable in devices or cables
- Electric power is product of current and voltage
  - my research focuses on current sensors at present, but development of voltage sensors will begin soon
  - Professor Dick White has a conceptual design for a micro-scale voltage sensor

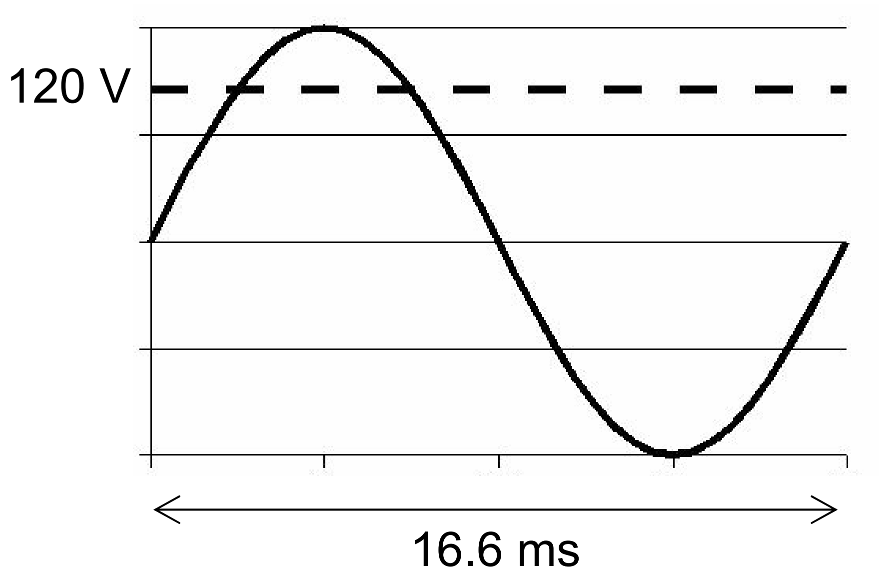
# Existing Technology

- Kill-A-Watt
  - shunt resistor-based
  - in-line
- Current Transformer
  - self-powered
  - requires wraparound – impractical for many applications
- Hall Sensor
  - proximity-based
  - requires 10s of mW of power
- Rogowski Coil
  - voltage scales with square of linear dimension so small scales = small voltages
  - difficult to microfabricate a coil of many turns
- No MEMS current sensor on the market

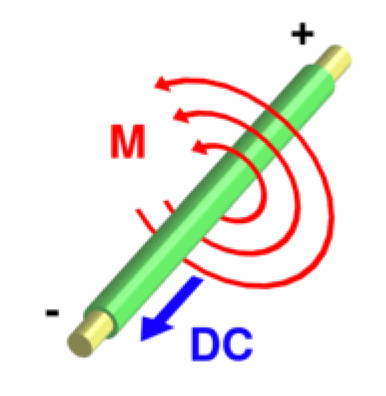


# Wires and Magnetic Fields

- Electric power is 60 Hz AC in the americas, 50 Hz in europe
- Voltage and current are sinusoidal – rated value is rms
- Magnetic field surrounding a current-carrying wire is circumferential (right-hand rule) and alternating

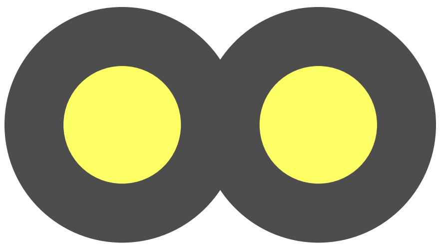


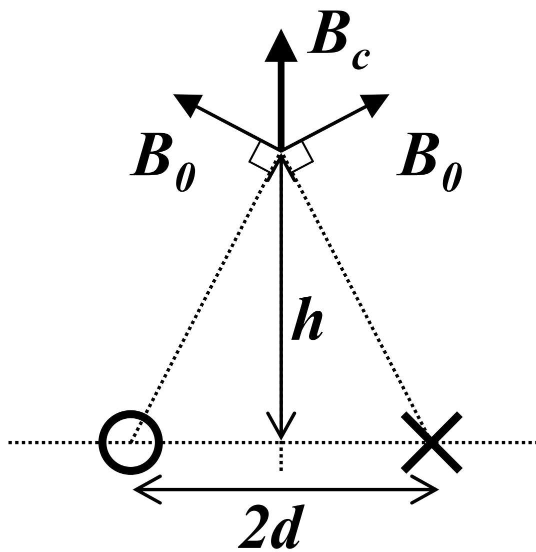

$$P = VI$$




$$B = \frac{\mu_0 i}{2\pi r}$$

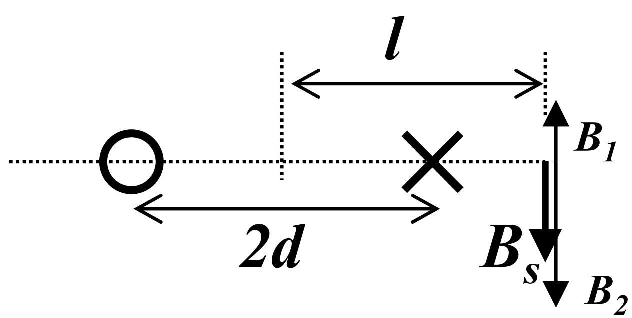
# Appliance Cord Magnetic Fields






$$B_c = \frac{\mu_0 i}{\pi}\left(\frac{d}{h^2 + d^2}\right)$$

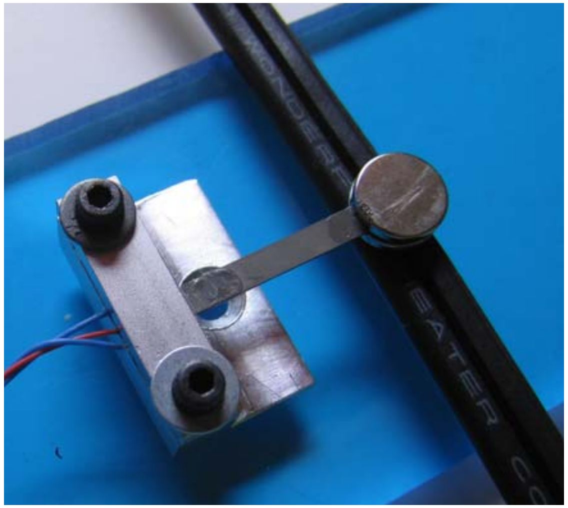
- Above the center of the cord is a good place for a sensor
- Wraparound sensors won't work on a 2-wire appliance cord

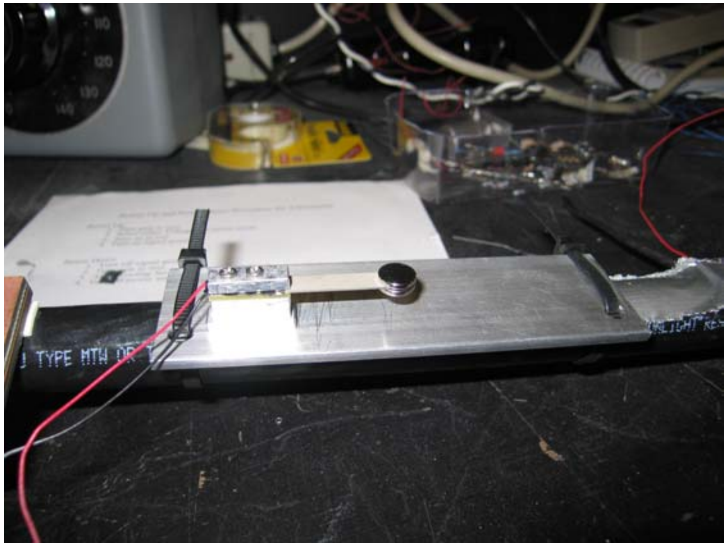


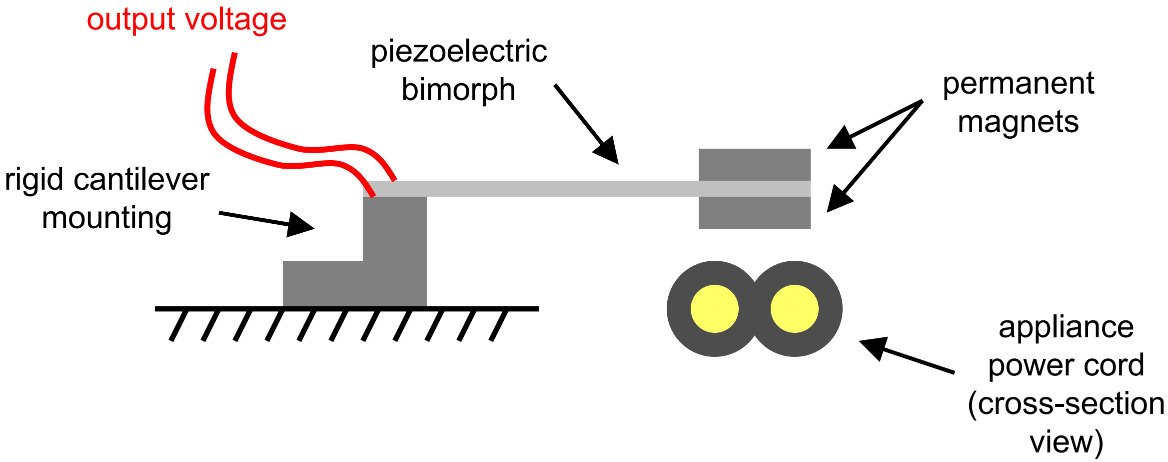

$$B_s = -\frac{\mu_0 i}{\pi}\left(\frac{d}{l^2 - d^2}\right)$$

# Meso-Scale Prototypes

- Piezoelectric bimorphs of varying sizes
- NdFeB high-strength permanent magnets
- Resonance frequency tuned by adjusting magnet position

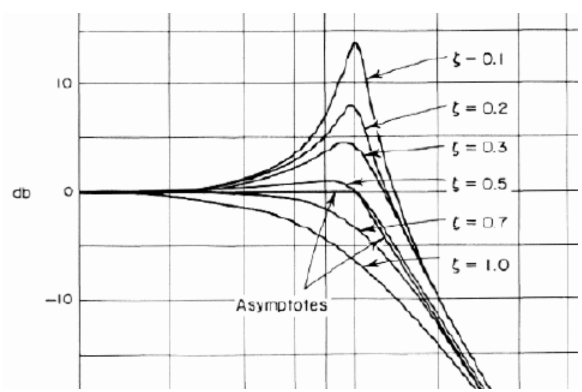


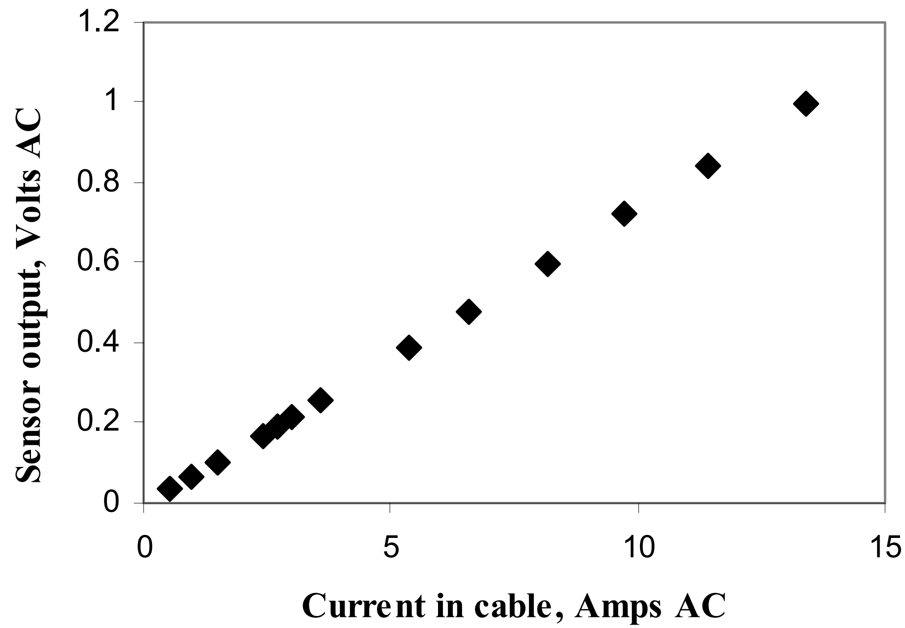




# Linear Sensor Behavior

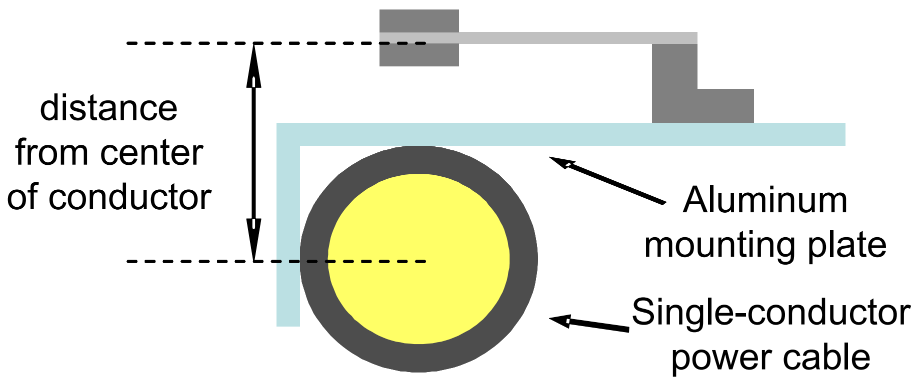
- Sensor response is highly linear ($R^2 > 0.99$)
- Resonance frequency tuned significantly higher than 60 Hz for optimal sensor performance



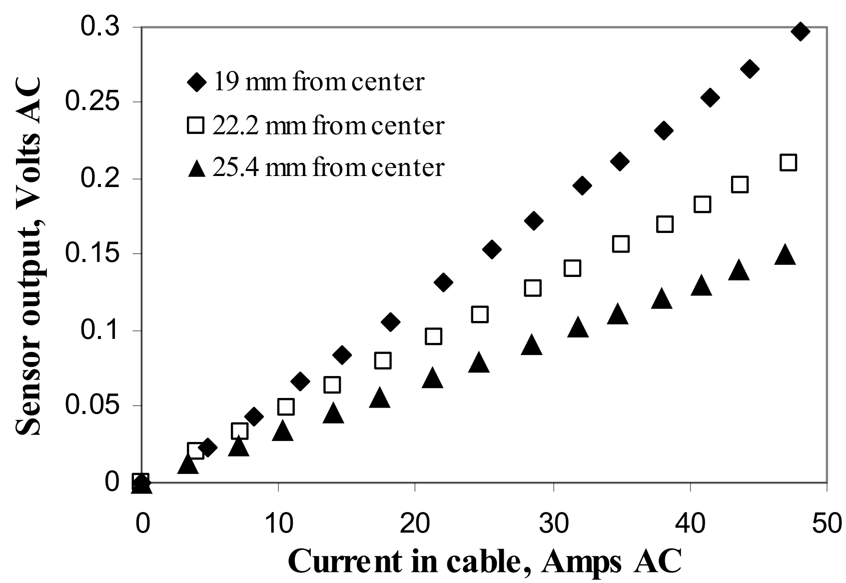



# Sensor Response Varies Predictably with Distance

Sensor mounted on a single-conductor power cable



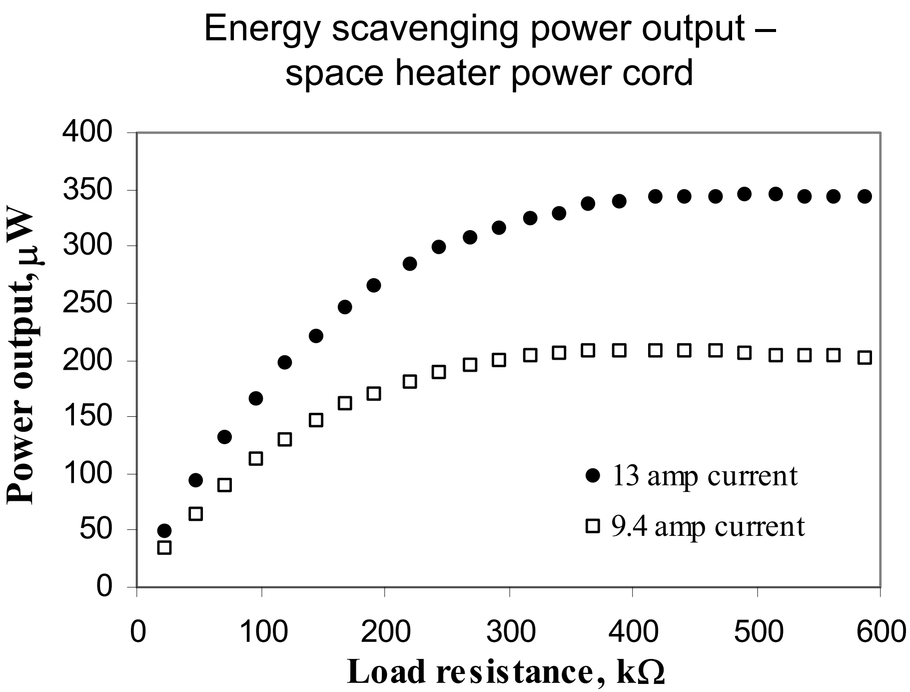

Current sensor response – varying distance from power cable




Signal varies with inverse of distance, allows current measurement without precise alignment

# Energy Scavenging Potential

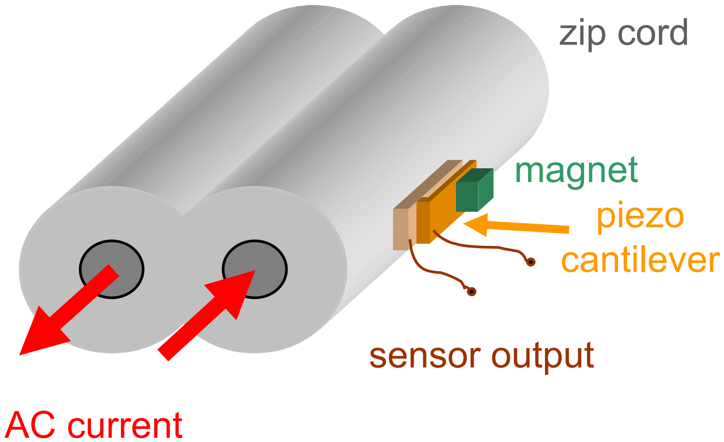
- Device scavenged 350 microwatts from a standard 1500W space heater appliance cord, sufficient to power a commercially-available wireless sensor node at a 1% duty cycle
- Tuned to 60 Hz resonance frequency for maximum coupling and power output



# Getting Smaller

- Develop analytical and finite element models to evaluate scaling effects and optimize microscale design
- Identify appropriate piezoelectric materials including AlN and PZT (sputtered, PLD, direct-write)
- Investigate magnetic MEMS materials and deposition techniques
- Goal is small, cheap, integratable, embeddable sensors

Sputttered PZT film on 25μm steel shim



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