Passive, Proximity-based Electric Current Sensors for Demand Response Enabled Homes

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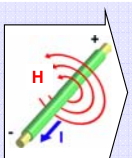
Vision

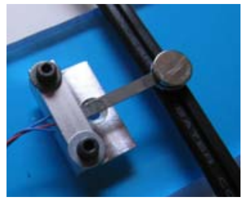
- Inexpensive MEMS electric power sensors integrated with low power wireless radios will monitor end-user loads in homes and businesses, equipping electricity customers to respond to Demand Response events and ultimately facilitating remote management of loads.
- Sensors will be passive, requiring no power source for operation and thus dramatically improving the sensor node's energy budget.
- Sensors will function accurately as proximity devices, requiring no contact to or wraparound of conductor, simplifying integration and retrofit.

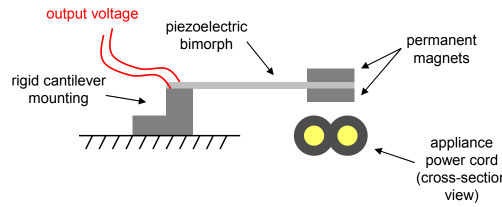
$$\vec{f} = \nabla(\vec{H}\cdot\vec{B})$$

$$H = \frac{i}{2\pi r}$$

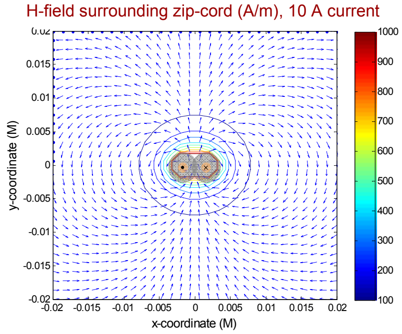


$$F_y = B_r \int \frac{d(H_y)}{dy}\, dV$$

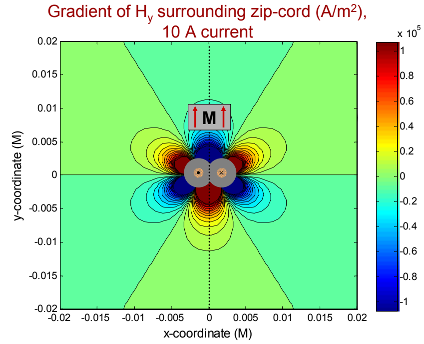




H-field surrounding zip-cord (A/m), 10 A current



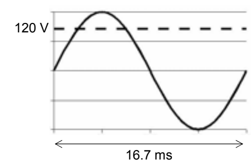
Gradient of H_y surrounding zip-cord (A/m²), 10 A current



Research Questions

- What is the relationship between current in the wire and voltage out of the sensor?
- How will this current sensor's output be affected as the device shrinks down to the microscale?
- What is the best way to fabricate the piezoelectric and hard magnetic components of a microscale current sensor?

Methods



- A novel design for a passive, proximity-based electric current sensor uses a permanent magnet mounted on the end of a piezoelectric cantilever. The magnet is subjected to a sinusoidal force due to the AC magnetic field surrounding the conductor, and the piezoelectric element transduces this force into a measurable voltage signal.
- Experimental results, analytical models, and numerical simulations drive decisions about process and materials selection for the fabrication of a microscale device.

	PZT		Aluminum Nitride	
	1 mm cantilever	500 µm cantilever	1 mm cantilever	500 µm cantilever
resonance frequency (Hz)	281	927	434	1425
sensitivity (mV/A)	**0.59**	**0.28**	**2.4**	**1.2**

$$V_{out} \approx F_{in}\left(\frac{d_{31}}{\varepsilon}\right)K$$

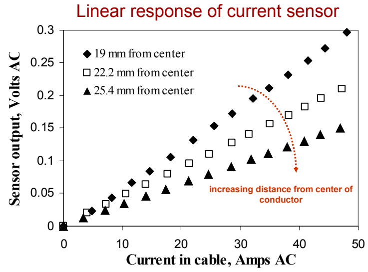
	PZT	AlN
d_{31} (pm/V)	-138	-3
ε_r	1800	9
d_{31}/ε_r	8.66 x 10^{-3}	37.7 x 10^{-3}

Numerical simulations suggest Aluminum Nitride as a promising piezo material for initial microscale prototypes

Findings

Sensor voltage output is linearly proportional to current in wire as predicted by theory and confirmed by experiment

Linear response of current sensor

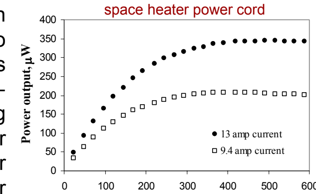


$$V_{out} = current \times f(B_r, d_{31}, \varepsilon, c_p, \rho, \zeta_m, \omega, geometry)$$

Variable	Comments
V_o	Amplitude of sensor voltage output (V)
current	Amplitude of current being measured (A)
B_r	Remanent flux density of permanent magnet (T)
d_{31}	Piezoelectric coefficient (m/V)
ε	dielectric permittivity of piezo material (F/m)
c_p	elastic modulus of piezo material (Pa)
ρ	Density of sensor materials (kg/m³)
ζ_m	Dimensionless damping constant
ω	Frequency of AC current (60 Hz = 377 rad/s)

This design could also be used as an energy-scavenging power source for sensor nodes

Energy scavenging power output – space heater power cord



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