Energy Scavenging with Shoe-mounted Piezoelectrics[1]

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Source: Shenck, N.S.; Paradiso, J.A., "Energy scavenging with shoe-mounted piezoelectrics," *Micro, IEEE* , vol.21, no.3, pp. 30-42, May/Jun 2001

Outline

- Overview
  - Problem Statement
  - Existing Solutions
  - Proposed Solution
  - Overview of Concept

- Performance
  - Power and Efficiency Characteristics

- Detailed Exploration of Design Issues

Problem Statement

- Wearable electronic devices, which are increasing in number and decreasing in size, must have a power source.

- Existing solutions:
    - Battery cells: A nuisance to replace.
    - Centralized, wearable power pack: Unwieldy and impractical as number of devices increases.

Proposed Solution

• Tap into wasted energy from common human activities:

1) Wire directly from source to device.

2) Trickle charge a battery for later use.

- Only partly solves the problem of battery replacement.

• Starner estimates 67 watts available from heel strike of average person walking at a brisk pace.

• <u>Objective</u>: Install flexible piezoelectric materials in heel and insole of shoe to harvest energy from walking while minimizing effects on shoe feel and comfort.

Overview of Concept

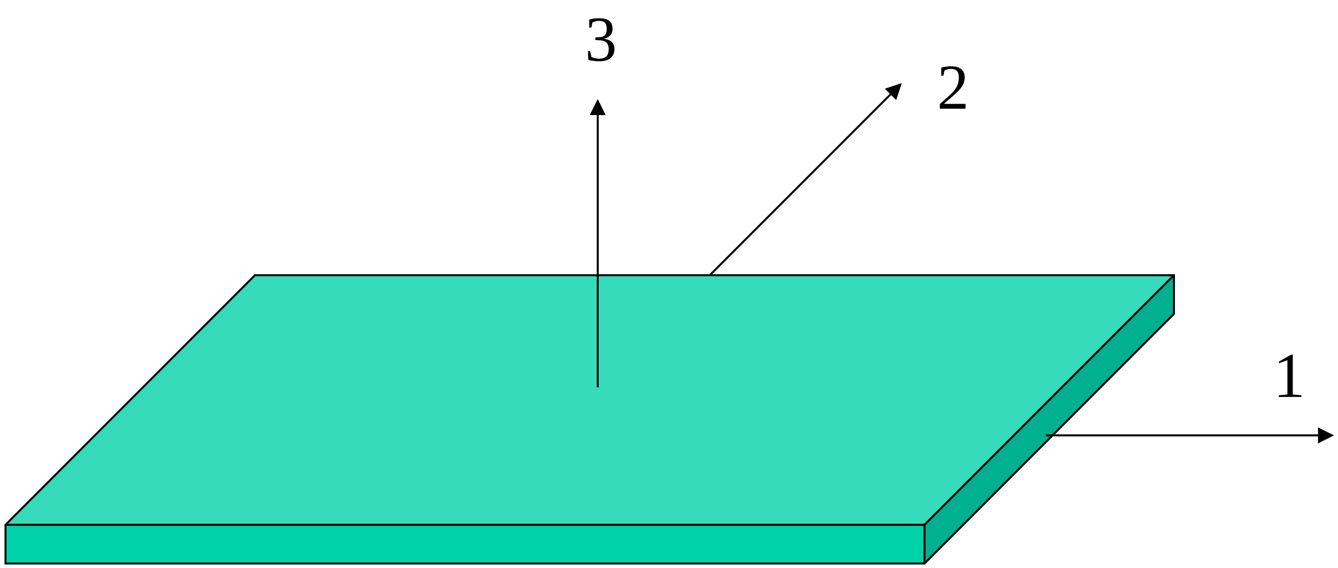
Piezoelectric Effect

- One type of piezoelectric is a crystalline material made up of unit cells (defining its physical properties) that lack a center of symmetry, while charges are oriented symmetrically, making the material electrically neutral
- Mechanical stress disrupts the symmetry of the charges, producing a voltage across the faces

Overview of Concept

Piezoelectric Effect

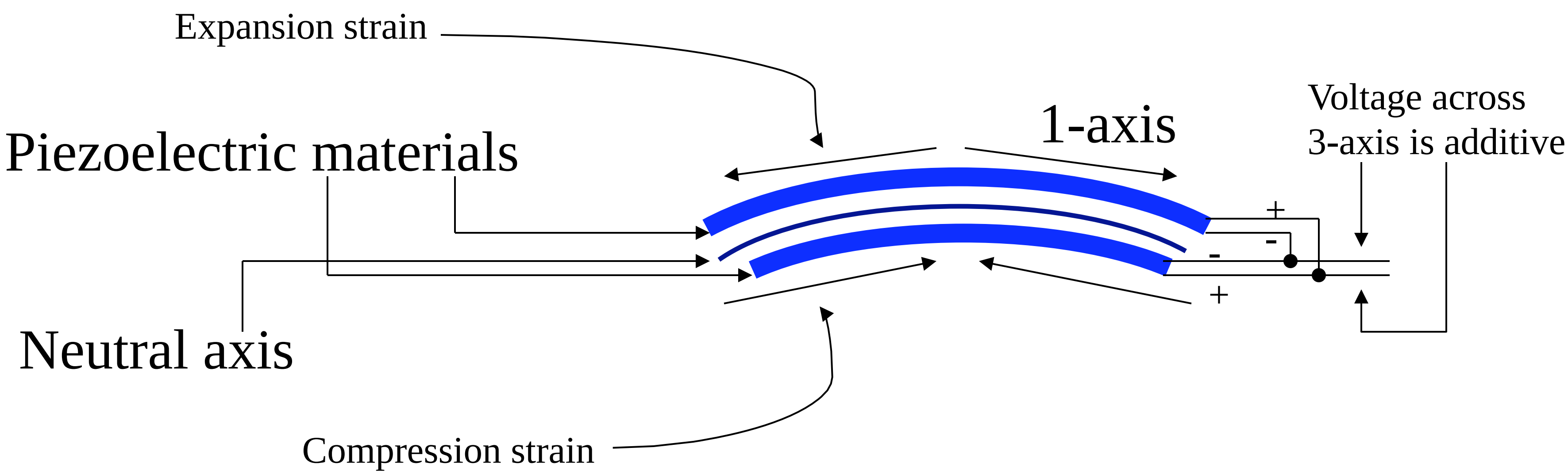
- Voltage across material is described in format of *"xy-mode"*
- *x* axis is the axis along which voltage is produced, and *y* axis is the axis being stressed



Overview of Concept

Piezoelectric Effect

- This work uses two types of piezoelectrics operating in 31-mode



Overview of Concept

Piezoelectric Effect

- Important point is that voltage across material exhibits output characteristics similar to that of a capacitor due to intrinsic capacitance of material (stress is still present, but electric field goes away – do charges regain symmetry?)
- This becomes important in design of regulator when utilizing the energy

Overview of Concept

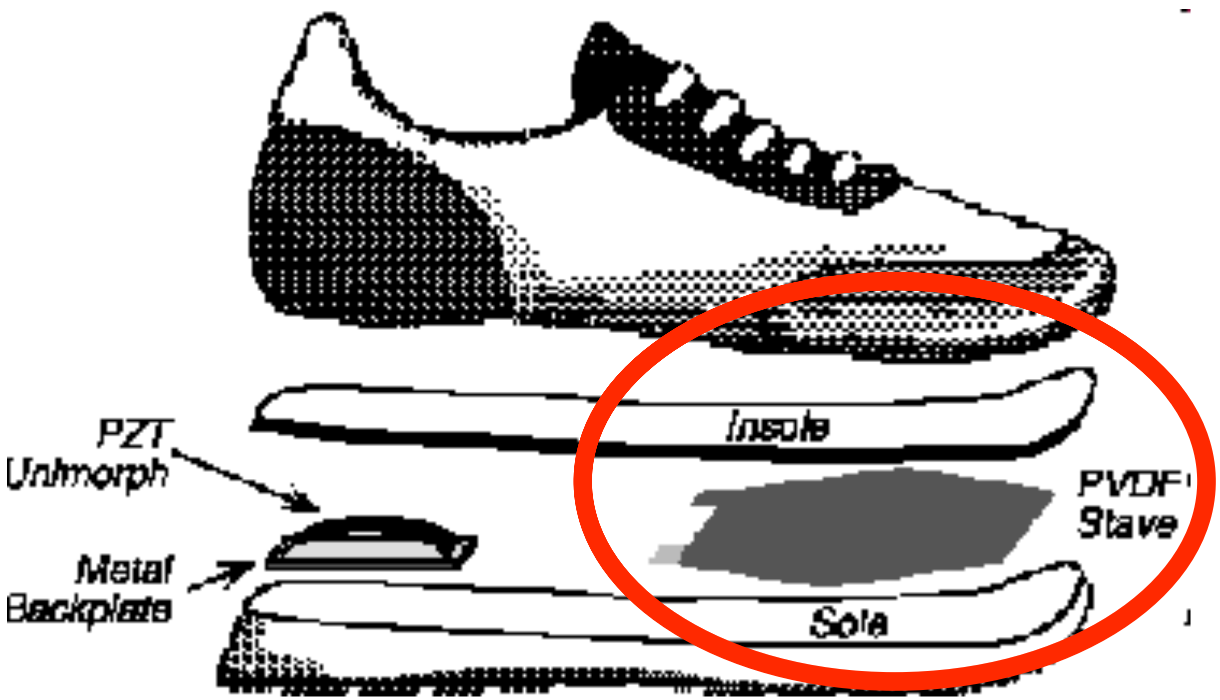
Scavenging Methods

- First method: harness energy dissipated in the bending of the ball of the foot

Overview of Concept

Scavenging Methods

• Use a flexible, multilaminar polylvinylidene fluoride (PVDF) bimorph stave mounted in insole



Overview of Concept

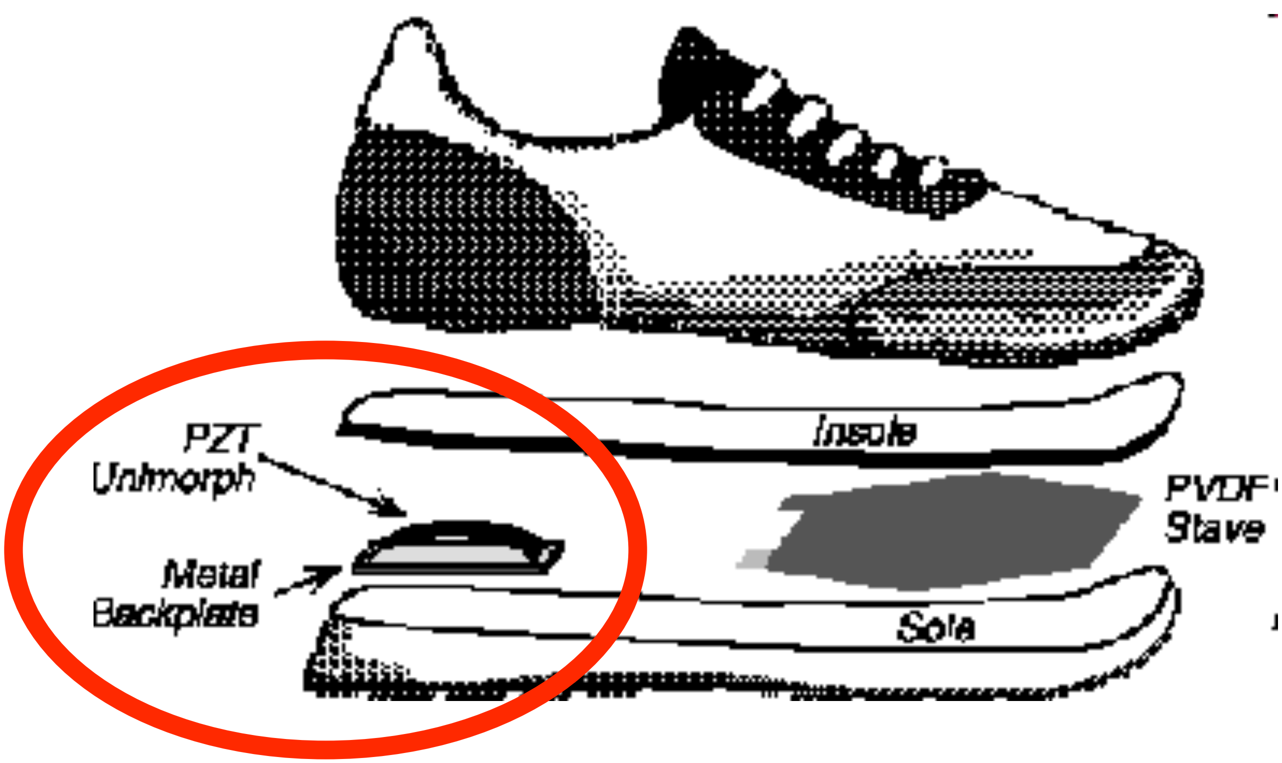
Scavenging Methods

- Second method: harness energy dissipated in heel strike

Overview of Concept

Scavenging Methods

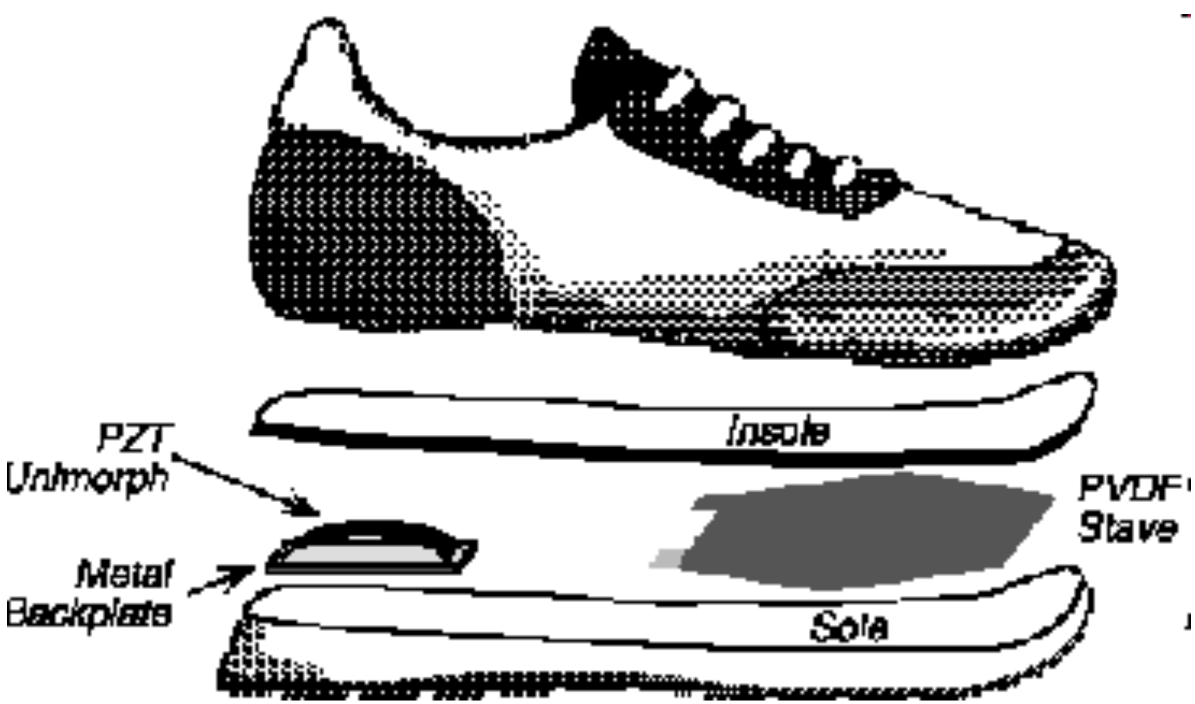
• Done by flattening out two curved metal strips made of piezoelectric lead zirconate titanate (PZT) formed into an ellipse called a dimorph



Overview of Concept

Scavenging Methods

• Piezoelectrics are reportedly "unnoticeable" during regular shoe usage conditions



Performance

Voltage and Power Output Characteristics

Insole Stave:
Test load: 250-ohms
Average power: 1.3 mW
Electromechanical efficiency: 0.5%

Dimorph:
Test load: 500-ohms
Average power: 8.4 mW
Electromechanical efficiency: 20%

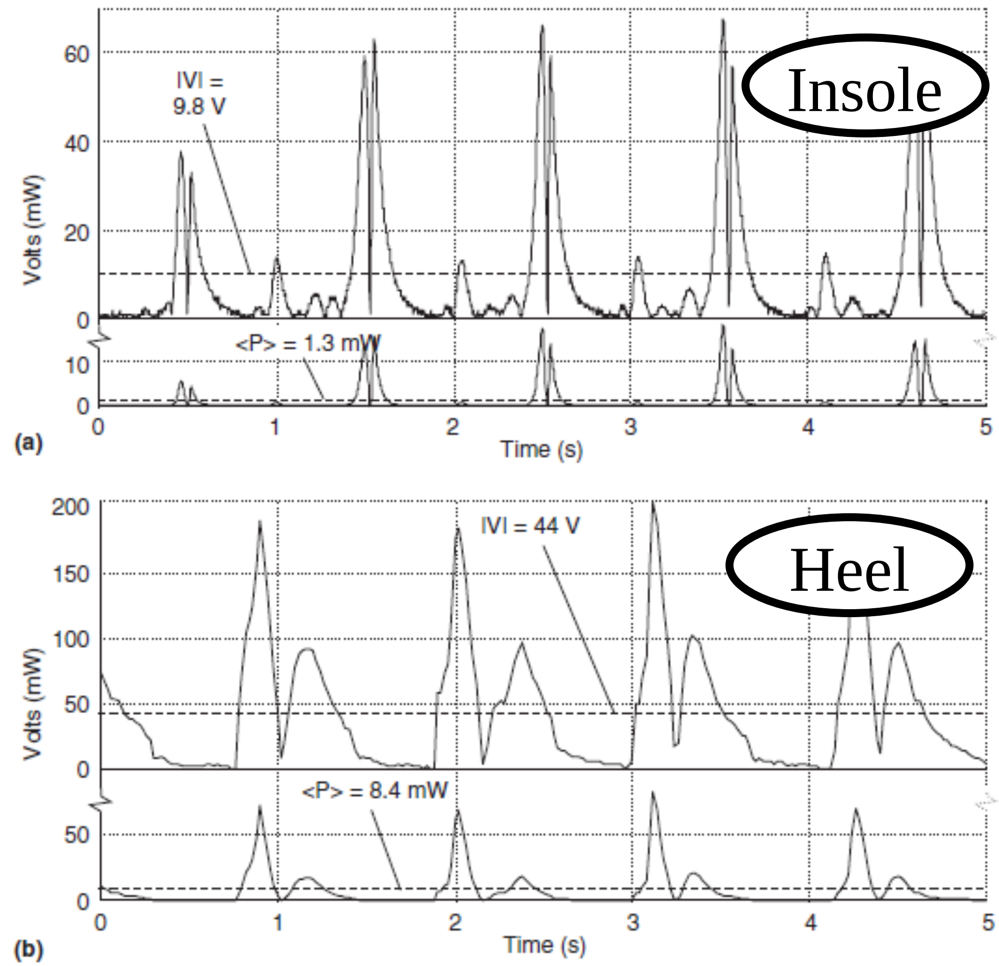


Figure 4. Power and rectified voltage waveforms from brisk-walking tests of optimally loaded PVDF stave (a) and PZT dimorph (b).

Performance

Voltage and Power Output Characteristics

Output exhibits bipolar characteristics:

Initial impact

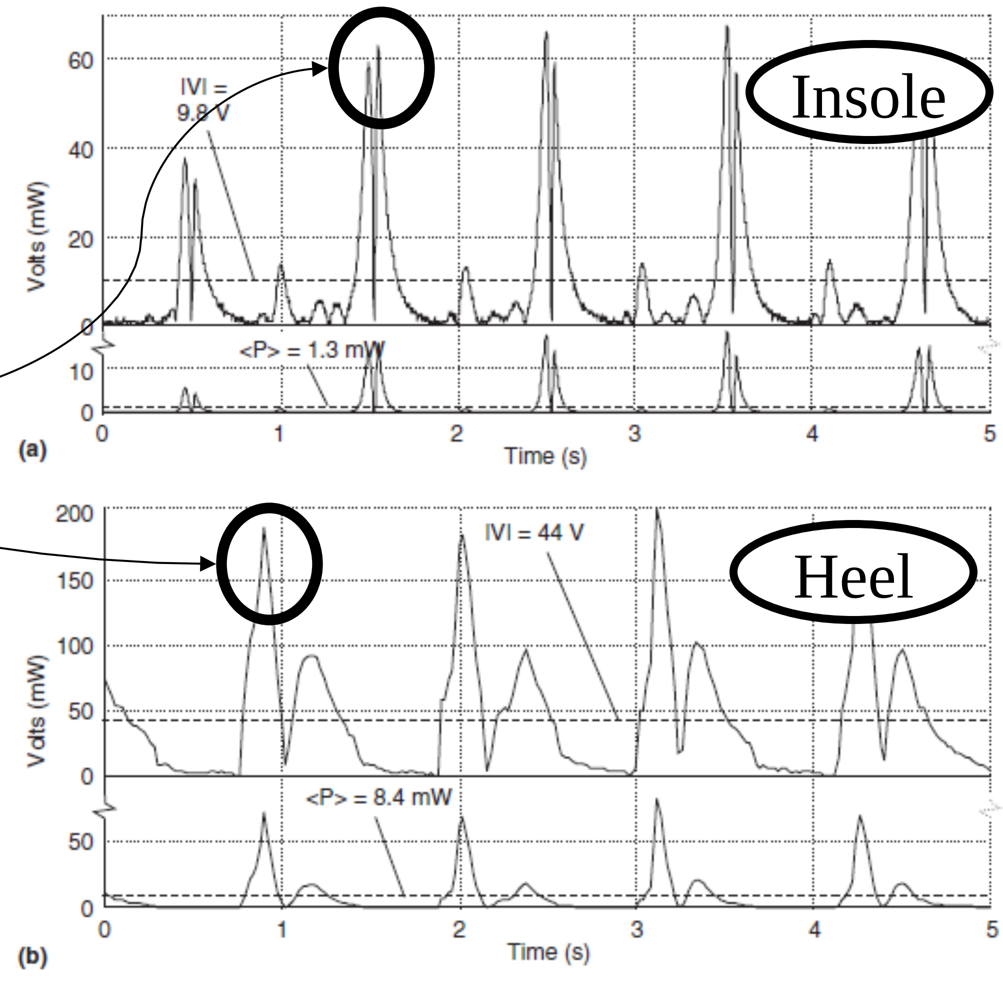


Figure 4. Power and rectified voltage waveforms from brisk-walking tests of optimally loaded PVDF stave (a) and PZT dimorph (b).

Performance

Voltage and Power Output Characteristics

Output exhibits bipolar characteristics:

Weight Shift

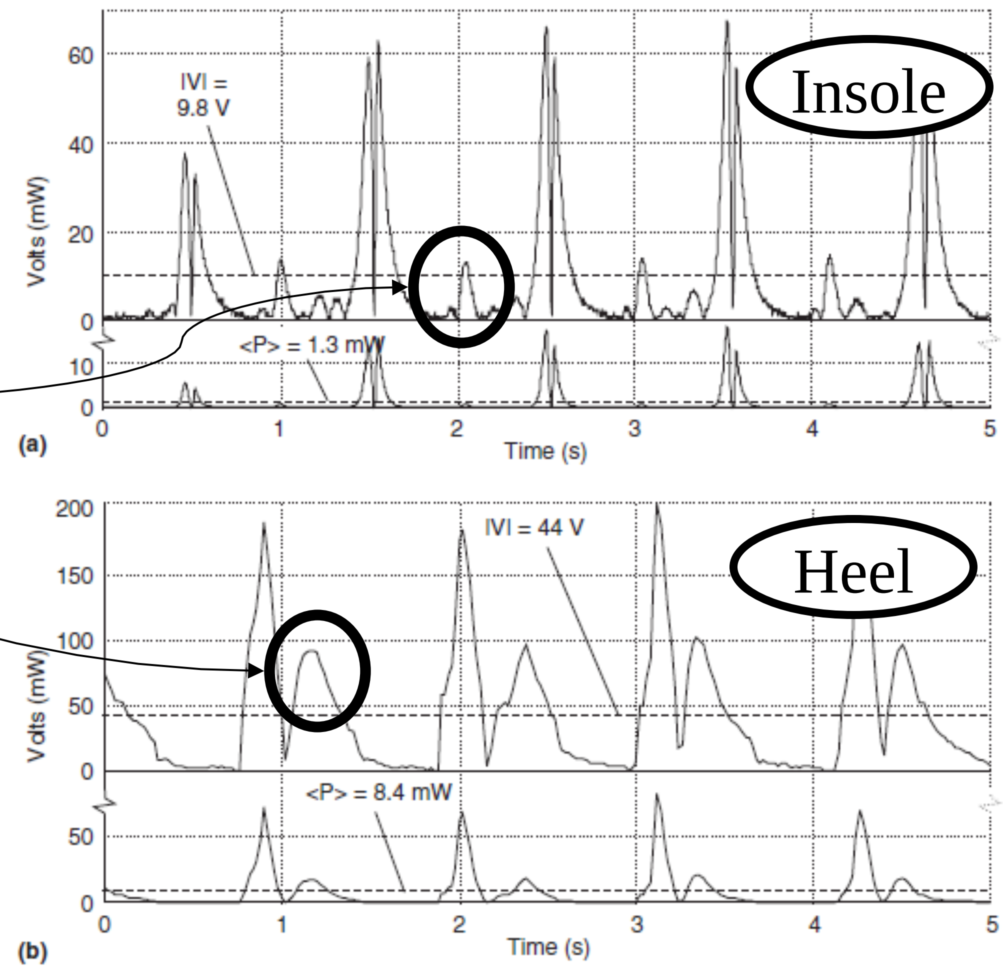


Figure 4. Power and rectified voltage waveforms from brisk-walking tests of optimally loaded PVDF stave (a) and PZT dimorph (b).

Performance

Voltage and Power Output Characteristics

Voltage regulation is required to make use of this energy source for the application considered here.

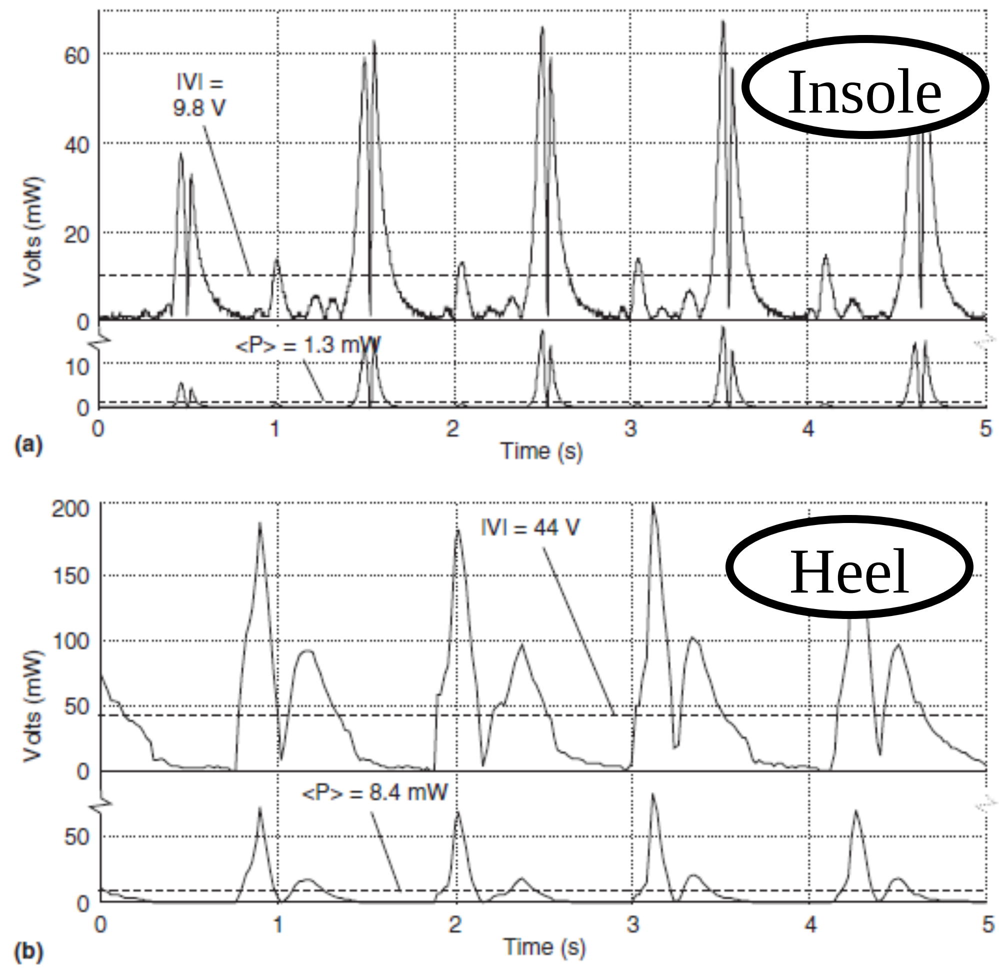


Figure 4. Power and rectified voltage waveforms from brisk-walking tests of optimally loaded PVDF stave (a) and PZT dimorph (b).

Application

• Voltage from piezoelectrics is used to power RFID tag system mounted on shoes.

• No additional power source is required.

Application

• System outputs a non-directional transmission of a 12-bit identification code which is useful in smart environments for adapting surroundings to the user or information routing

Application

• Remainder of paper focuses voltage regulation in the circuitry that transfers energy from piezoelectric to the RFID tag system

Energy Usage

Linear Regulation: Design

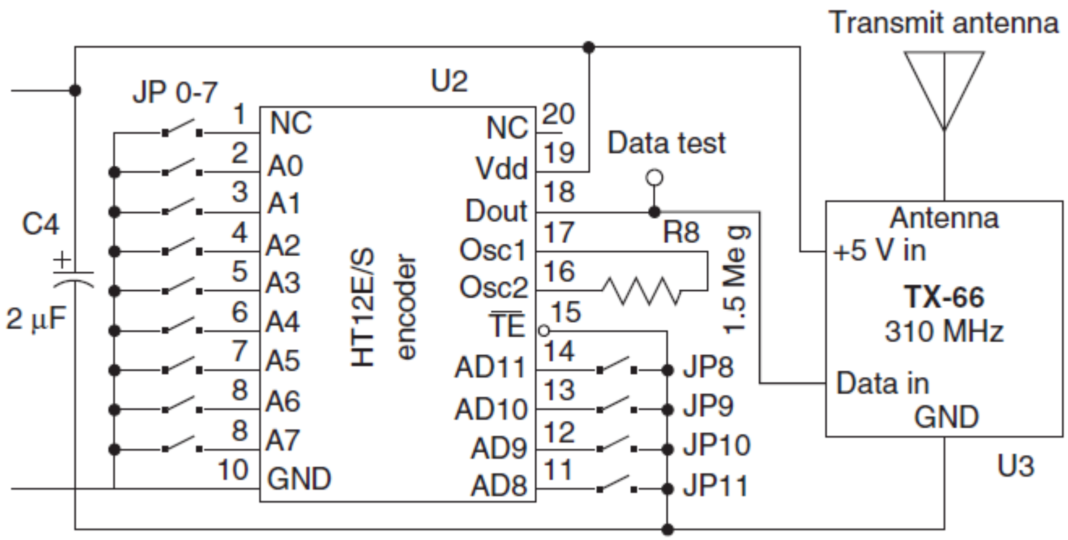


Figure 6. Schematic of power-conditioning electronics and encoder circuitry for the shoe-powered RF tag system.

Energy Usage

Linear Regulation: Design

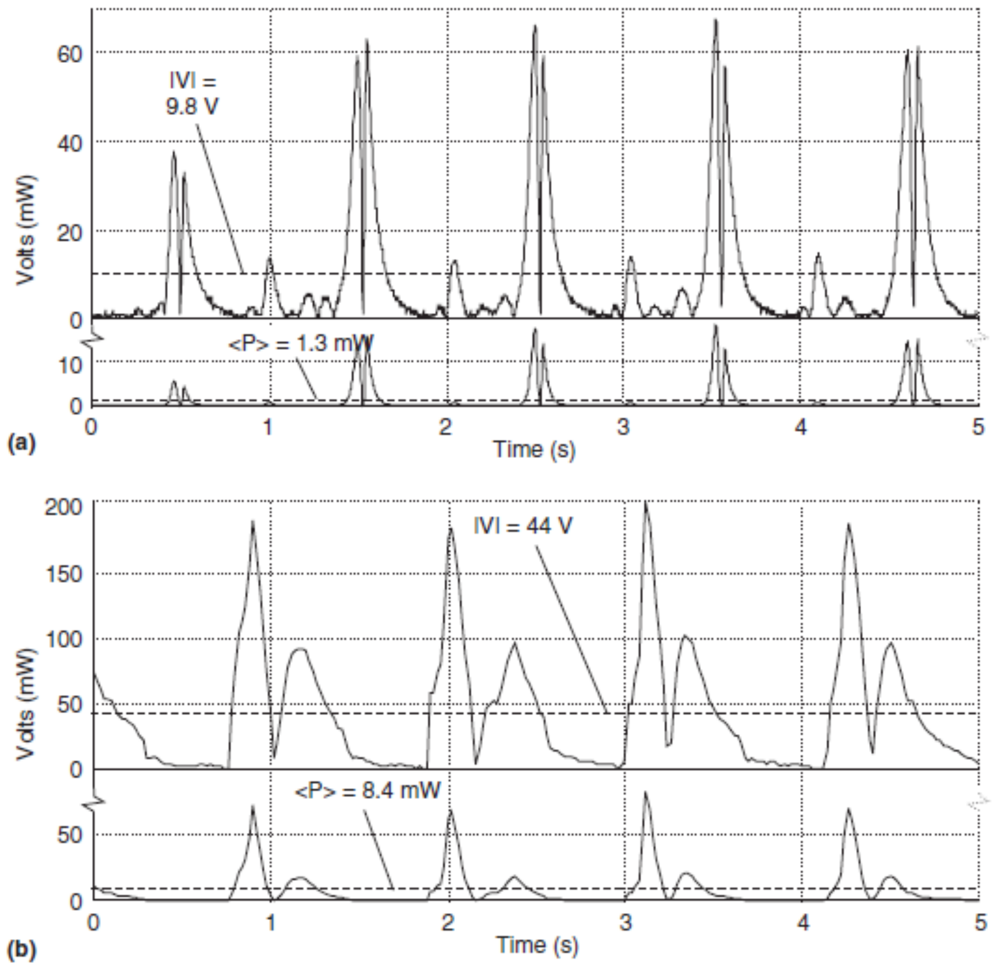


Figure 4. Power and rectified voltage waveforms from brisk-walking tests of optimally loaded PVDF stave (a) and PZT dimorph (b).

Energy Usage

Linear Regulation: Design

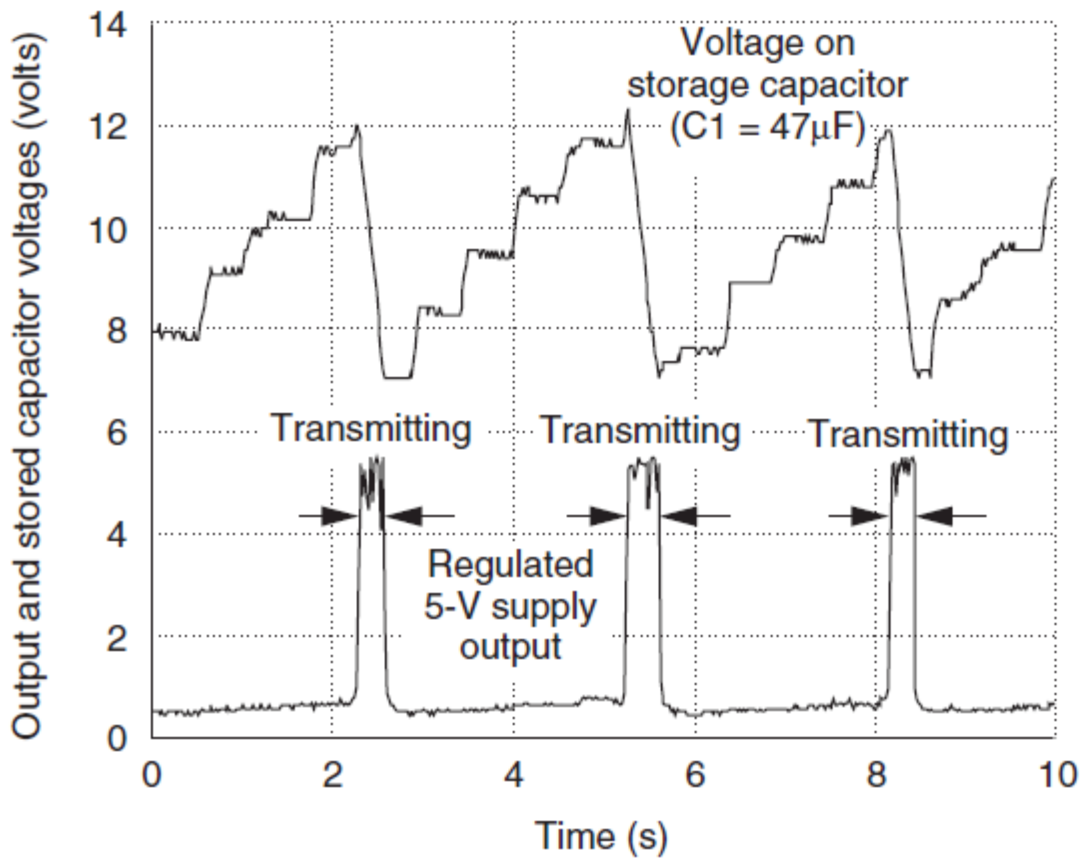
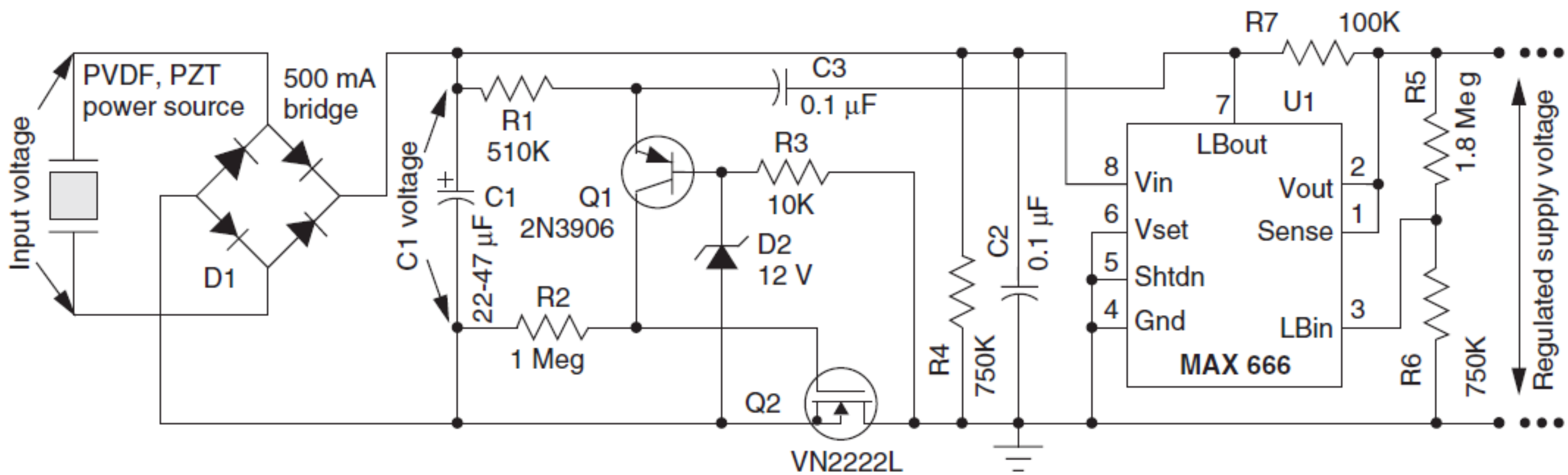


Figure 7. Stored voltage (top) and regulated power output (bottom) waveforms for shoe-powered RFID transmitter while walking.

Energy Usage

Linear Regulation: Design



Energy Usage

Linear Regulation: Design

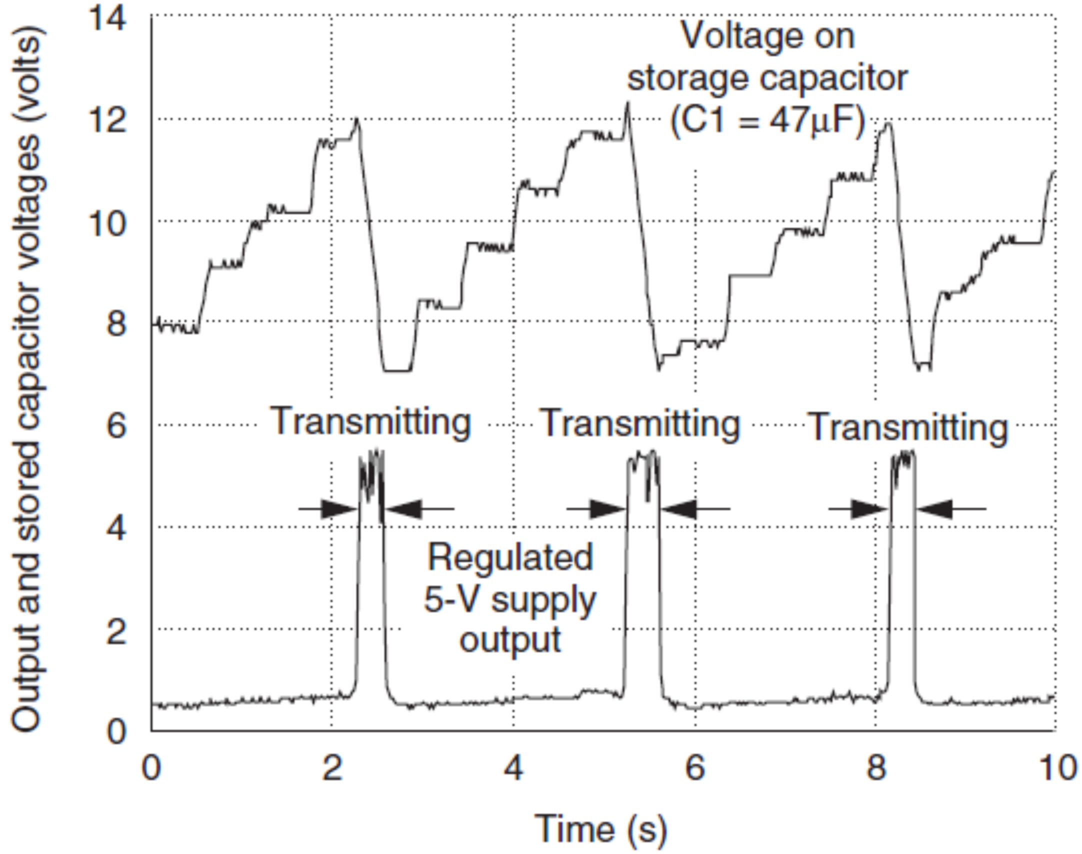


Figure 7. Stored voltage (top) and regulated power output (bottom) waveforms for shoe-powered RFID transmitter while walking.

- While simple, the linear regulator suffers from inefficiency (due to losses across BJTs), which is a major shortcoming for this application