

# Energy Harvesting Techniques for Internet of Things

Submitted for MTHG103E project  
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## Why Charge It When You Can Harvest It?

### Absract

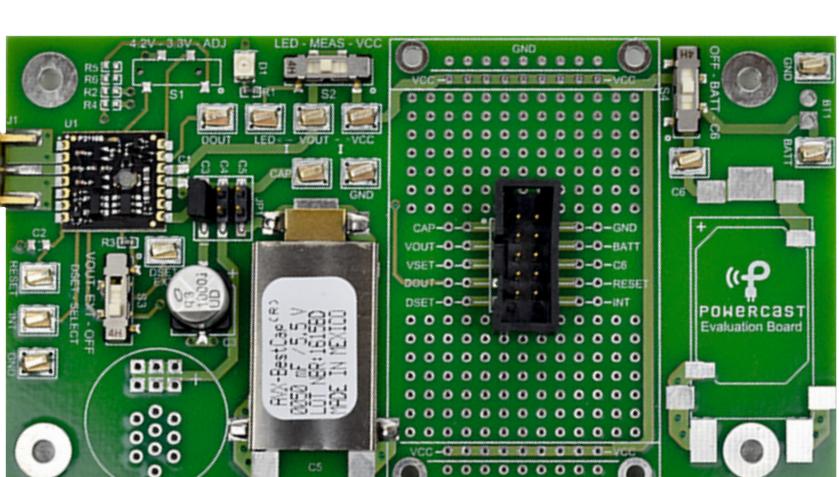
Traditional IoT devices rely on power sources, which are limited, making them inefficient for long-term deployment. Energy harvesting offers a sustainable solution for powering IoT devices by converting ambient energy sources such as solar, thermal, and vibrational energy into electricity. This reduces dependence on conventional power storage and enables long term, self-sustaining operation. This study explores various energy harvesting scenarios and optimizes energy usage through duty cycling strategies.

### Problem Definition

The paper explores energy harvesting (EH) as a sustainable alternative to batteries for powering IoT devices. While EH uses ambient sources like sunlight and vibrations, it faces challenges such as low efficiency, scalability, and integration issues. These limit its reliability in real-world applications. The paper also points out the safety and environmental drawbacks of batteries and emphasizes the importance of improved energy management.

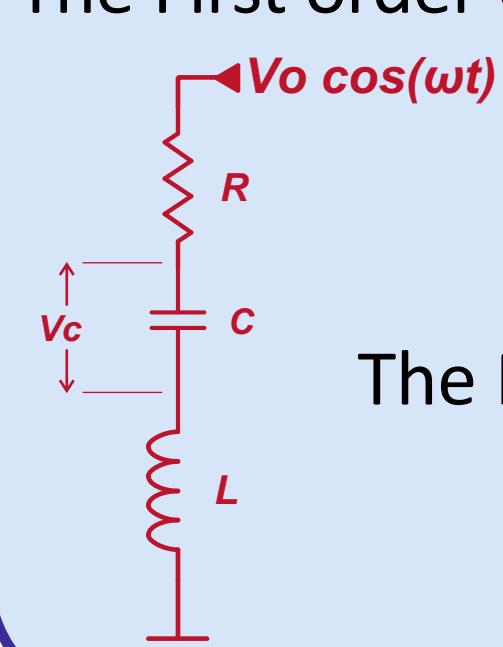
### Methodology

Power cast **P2110B** is an integrated circuit (IC) used in receiving very low Radio frequencies and harvest those frequencies to convert them into a good moderate DC output. The parts of the **P2110B** are the following:



#### 1. The Transmission Antenna

The antenna, modeled as an RLC circuit, responds to incident RF waves with a time-varying current governed by impedance and phase shift from electromagnetic coupling. The First order ODE model of the transmission antenna circuit: [13]



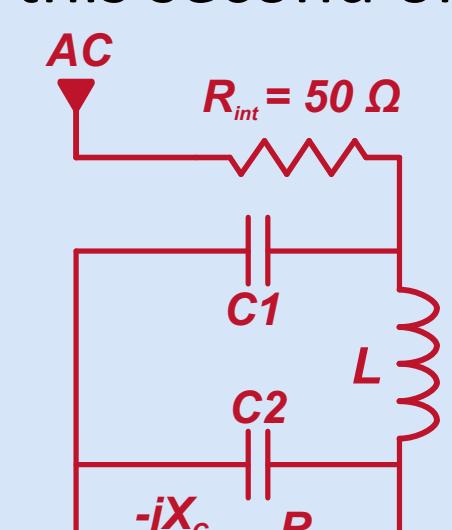
$$L_{ant} \frac{dI_{RF}(t)}{dt} + R_{ant} I_{RF}(t) = V_{RF}(t) \quad (1)$$

The Final steady response equation:

$$I_{RF}(t) = \frac{V_0}{Z_{ant}} \cos(\omega t - \phi) \quad (2)$$

#### 2. The Matching Network

Modeled as an RLC circuit, transforms the antenna's output impedance to match the load, maximizing power transfer efficiency. The matching network circuit can be described with this second order ODE model: [14]



$$L_m \frac{dI_m(t)}{dt} + \frac{1}{C_m} \int I_m(t) dt = V_{RF}(t) \quad (3)$$

With its complete time-domain solution given by the superposition of natural and forced response:

$$I_m(t) = A e^{(j\omega_0 t)} + B e^{(-j\omega_0 t)} + I_0 \sin(\omega t) \quad (4)$$

#### 3. The Multi-Stage Rectifier

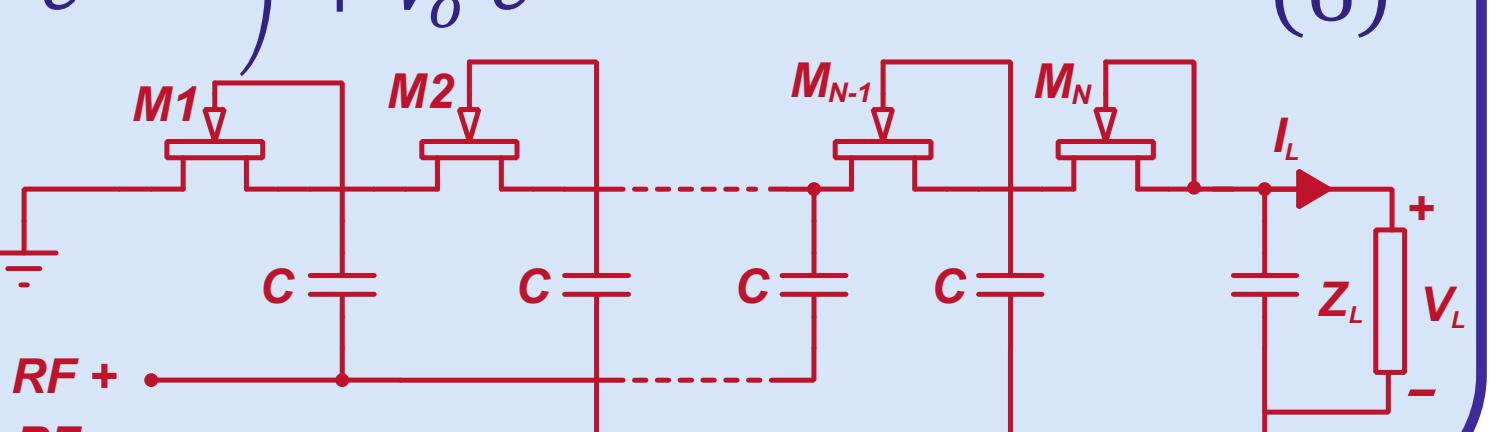
After impedance matching, the rectifier converts the RF AC signal into DC power, enabling energy harvesting; this behavior is modeled by the first-order ODE [15]

$$C_r \frac{dV_r(t)}{dt} + \frac{V_r(t)}{R_d} = I_m(t) \quad (5)$$

With the voltage response given by:

$$V_r(t) = I_0 R_d \left( 1 - e^{-\frac{t}{C_r R_d}} \right) + V_0 e^{-\frac{t}{C_r R_d}} \quad (6)$$

showing capacitor charging and steady-state behavior.



#### 4. Load Power Consumption

In the final stage, energy is stored in a capacitor, and the voltage level is monitored to determine if sufficient energy has been harvested to power the load or if further accumulation is required. The power delivered to the load is given by

$$P_L(t) = \frac{V^2(t)}{R} \quad (7)$$

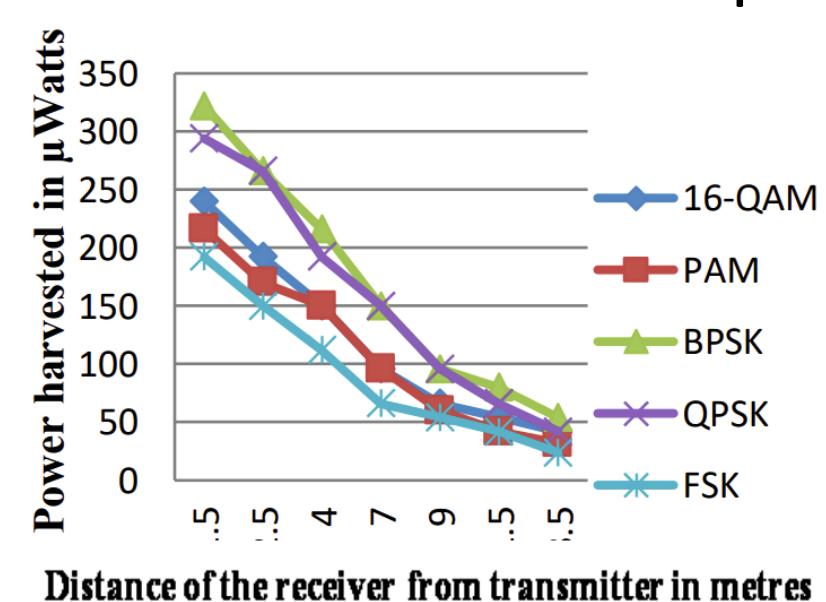
while the transient response of power from a storage capacitor is modeled as

$$P_L(t) = I_r^2 R_L \left( 1 - 2e^{-\frac{t}{R_L C_s}} + e^{-\frac{2t}{R_L C_s}} \right) \quad (8)$$

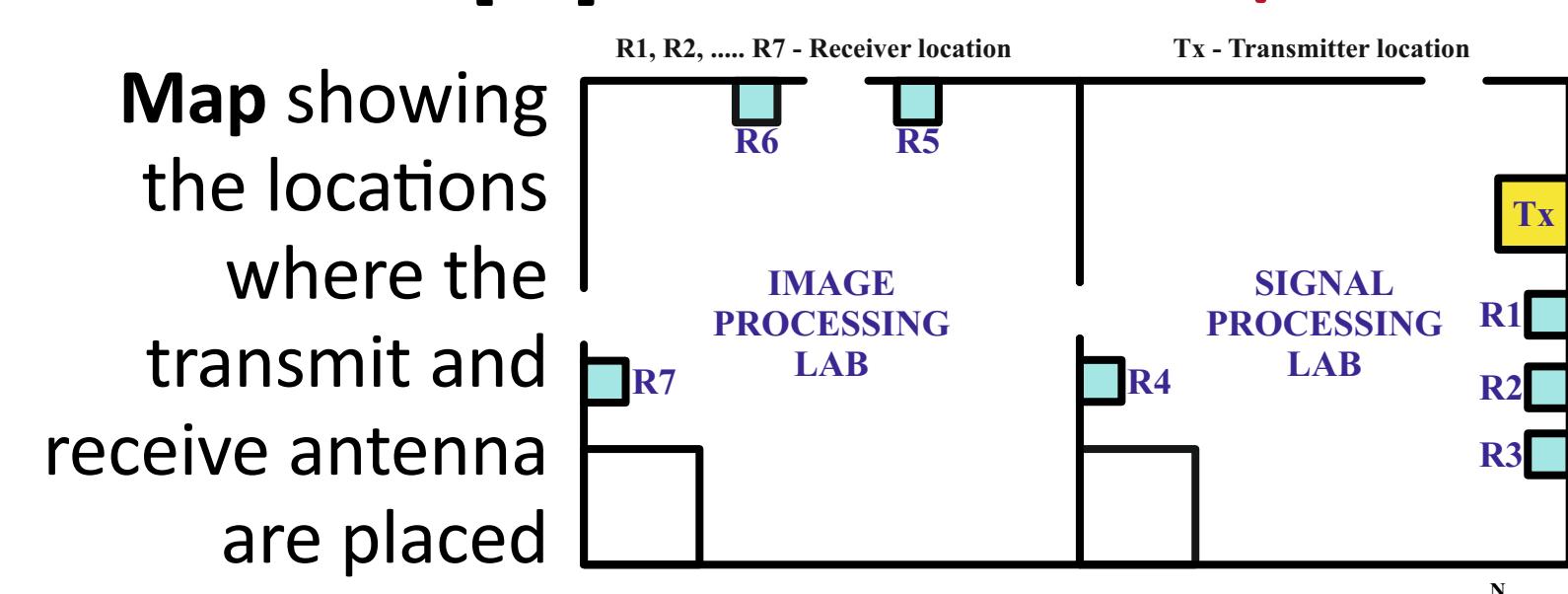
### Simulations & Results

#### Efficiency Analysis of RF-to-DC Conversion in Energy Harvesting Systems Using Different Modulation Schemes

- Converts incident RF energy to DC power.
- Stores harvested energy in an external capacitor.
- Implements threshold-based voltage regulation:
  - Activates output when capacitor voltage reaches upper threshold.
  - Deactivates output when voltage falls below lower threshold.
- Provides stable DC output voltage for connected loads. [17]



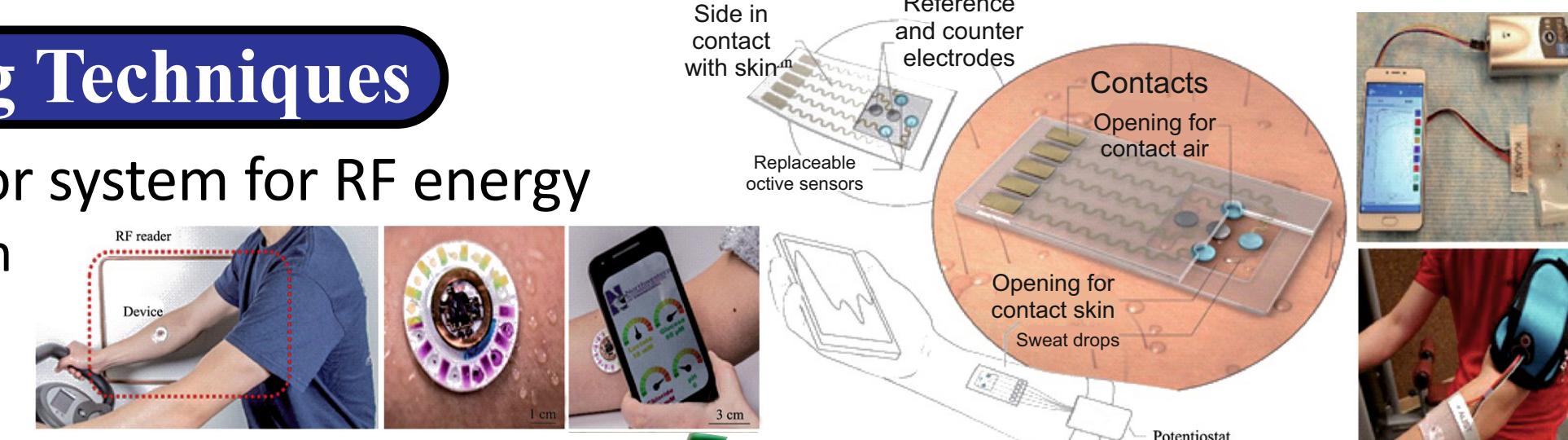
Different modulation scheme harvested energy



#### Power harvested for BPSK signal

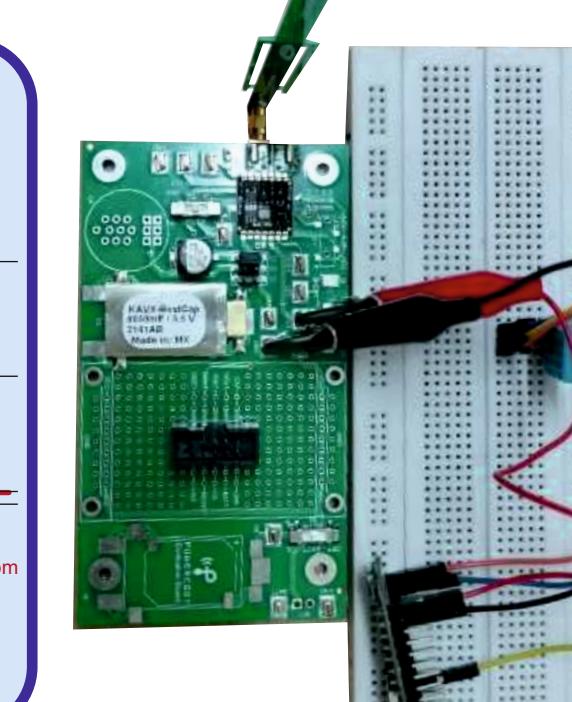
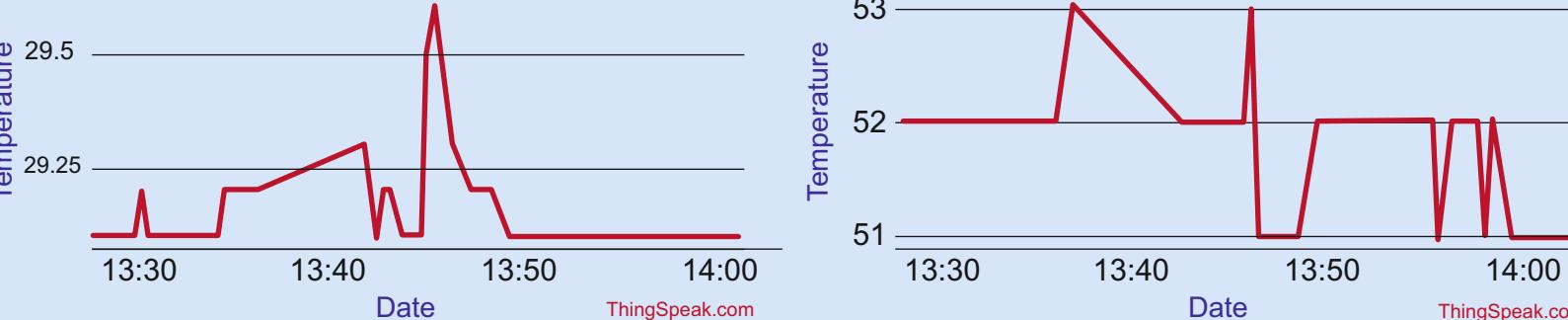
#### More Energy Harvesting Techniques

Wireless battery-free sweat sensor system for RF energy harvest with a smartphone Bluetooth for analysis and monitoring. [20]



#### Temperature – 29

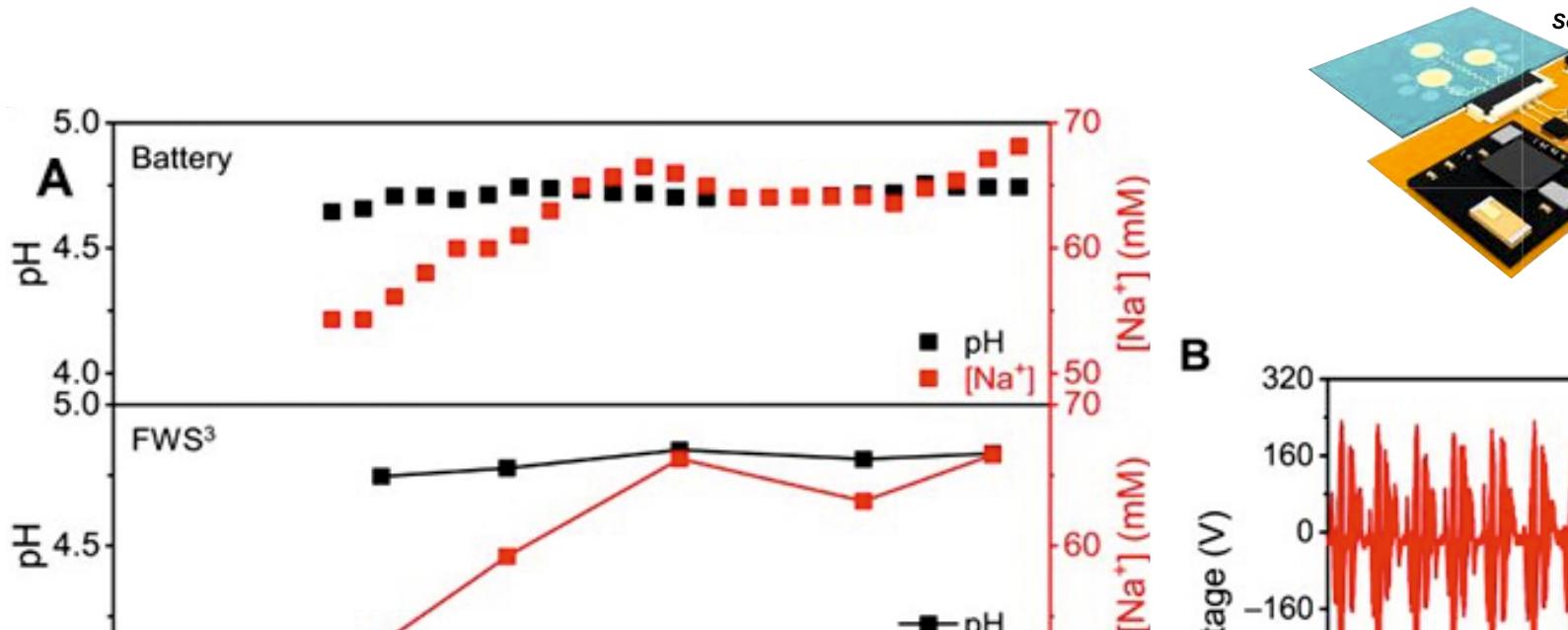
#### Humidity – 51



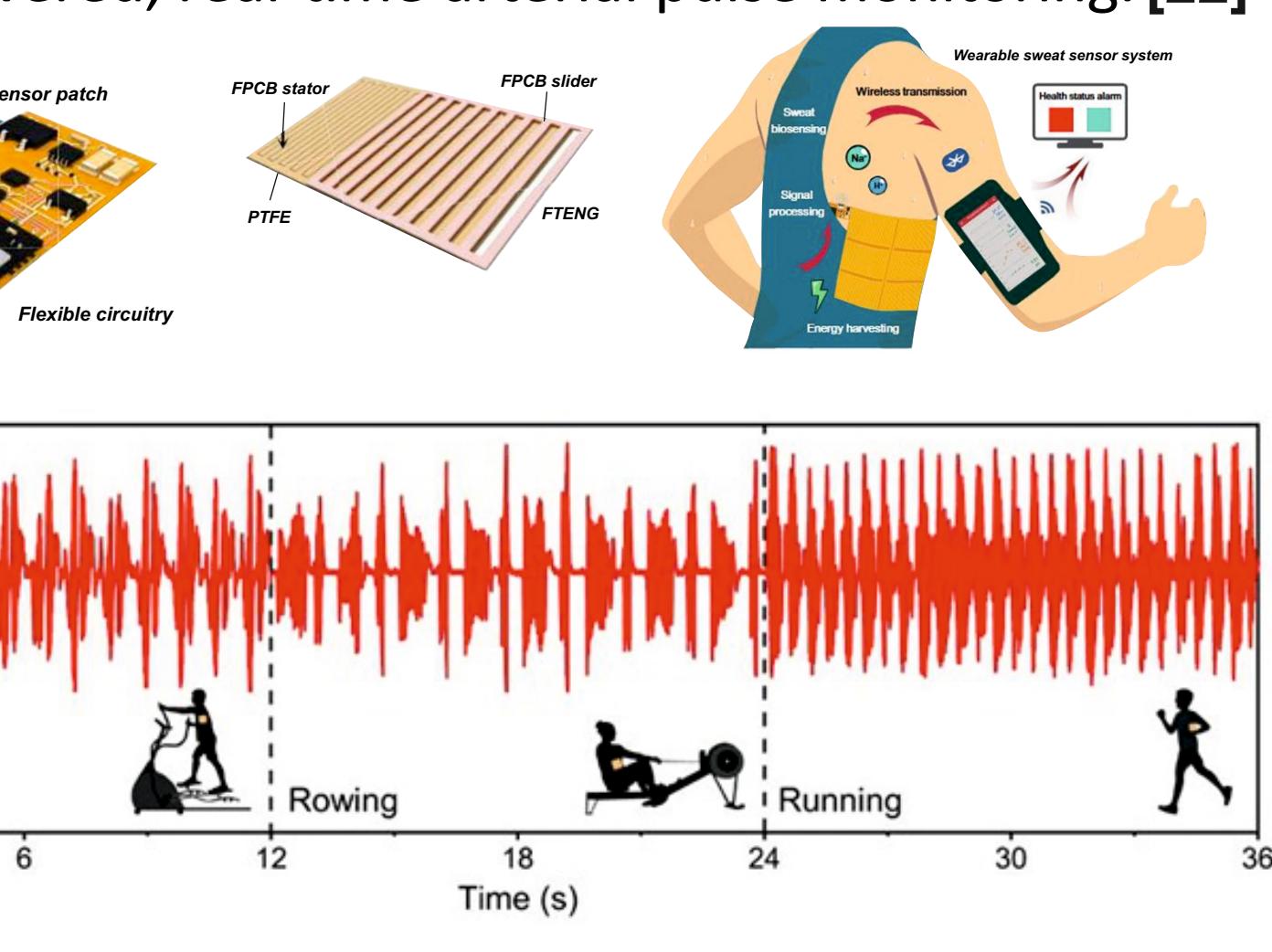
P2110B-EVB evaluation board served as the power source for a NodeMCU microcontroller instead of a conventional battery.

Temperature and humidity of DHT11 sensor and NodeMCU in ThingSpeak. Sensors in this setup are powered only by RF energy, harvested by the P2110B-EVB board. [18]

Ultra-thin epidermal piezoelectric sensor for self-powered, real-time arterial pulse monitoring. [22]



A Real-time sweat pH obtained from the wearable systems charged by a lithium battery and by an FTENG



## Conclusion & Future work

The study used LabVIEW and USRP to transmit various modulated signals, measuring the harvested energy with a

Powercast P2110B-based circuit. Results showed that harvested power decreases with distance, and BPSK provided the highest energy harvesting efficiency. RF and triboelectric energy harvesting enable self-powered, battery-free sensors for real-time monitoring. Future work will explore hybrid energy systems that combine more than one energy harvester to improve efficiency.

