Energy Harvesting Techniques for Internet of Things

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Why Charge It When You Can Harvest It?

Absrtact

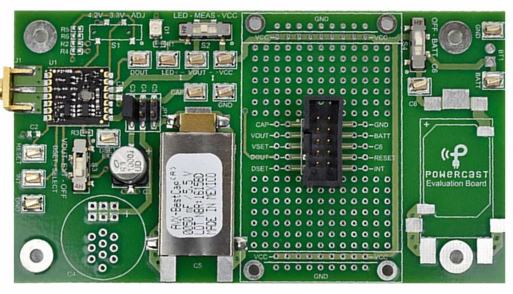
Traditional **IoT devices** rely on power sources, which are limited, making them inefficient for long-term deployment. **Energy harvesting** offers a sustainable solution for powering **IoT devices** by converting ambient energy sources such as **solar, thermal, and vibrational energy** into **electricity**. This reduces dependence on conventi–onal 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.

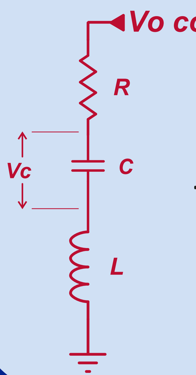
Methodology

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]**



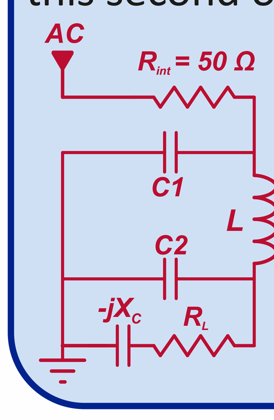
$$L_{ant}\frac{dI_{RF}(t)}{dt}+R_{ant}I_{RF}(t)=V_{RF}(t) \qquad (1)$$

The Final steady response equation:

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

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]**



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

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

$$I_m(t)=Ae^{(j\omega_0 t)}+Be^{(-j\omega_0 t)}+I_0\sin(\omega t) \qquad (4)$$

3. The Multi-Stage Rectifier

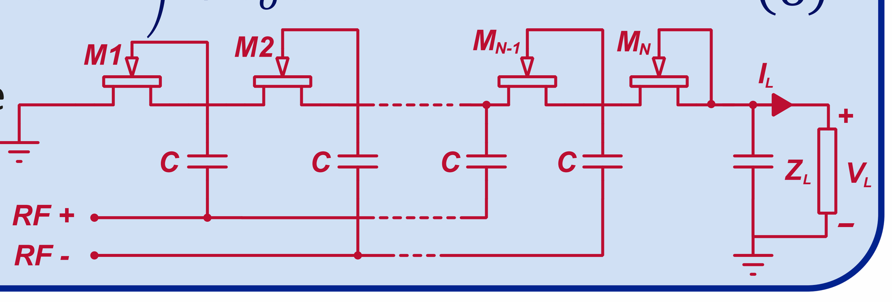
After impedance matching, the rectifier converts the **RF** AC signal into DC power, enabling energy harvesting; this behavior is modeled by the first-order **ODE [15]**

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

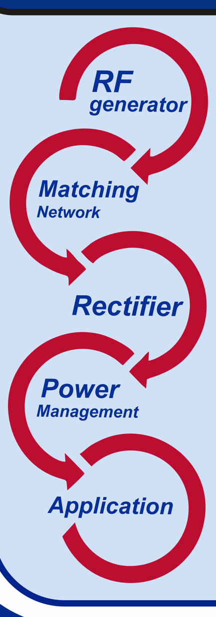
With the voltage response given by:

$$V_r(t)=I_0R_d\left(1-e^{\frac{-t}{C_rR_d}}\right)+V_o\,e^{\frac{-t}{C_rR_d}} \qquad (6)$$

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

$$P_L(t)=\frac{V_c^{\,2}(t)}{R} \qquad (7)$$

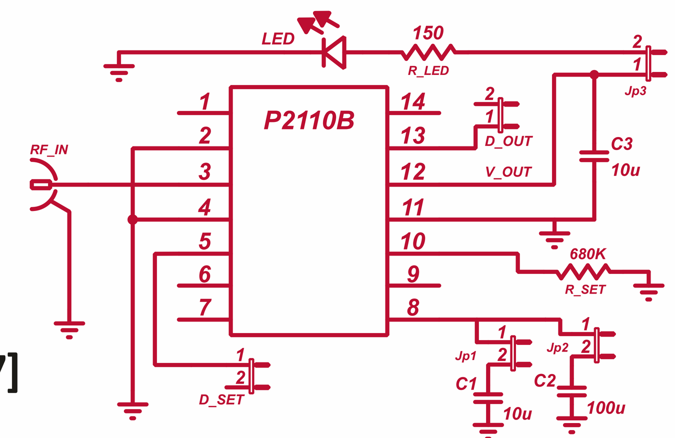
while the transient response of power from a storage capacitor is modeled as

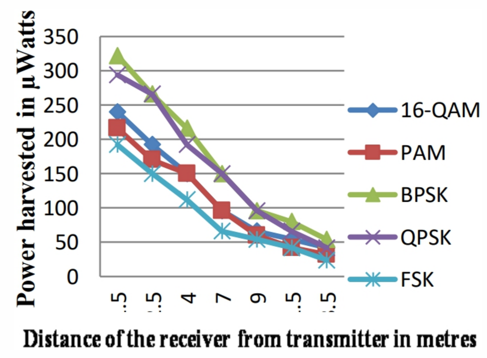
$$P_L(t)=I_r^2R_L\left(1-2e^{\frac{-t}{R_LC_s}}+e^{\frac{-2t}{R_LC_s}}\right) \qquad (8)$$

Simulations & Results

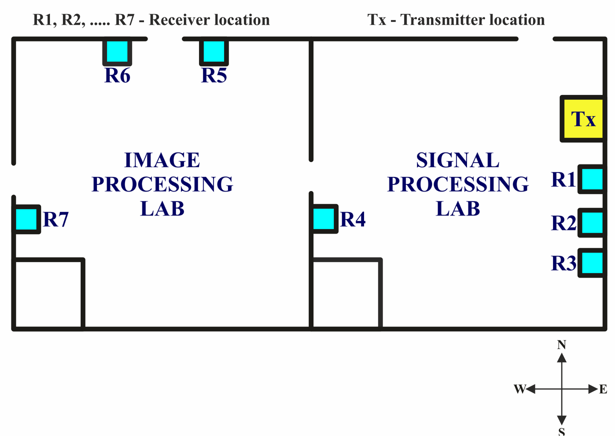
Efficiency Analysis of RF-to-DC Conversion in Energy Harvesting Systems Using Different Modulation Schemes

- 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

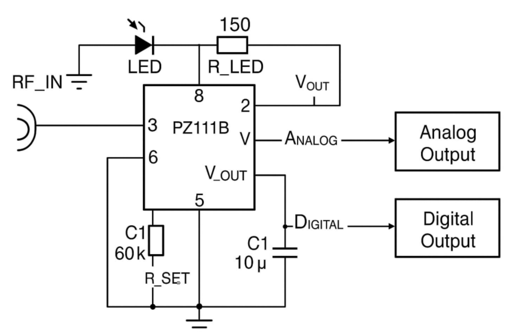


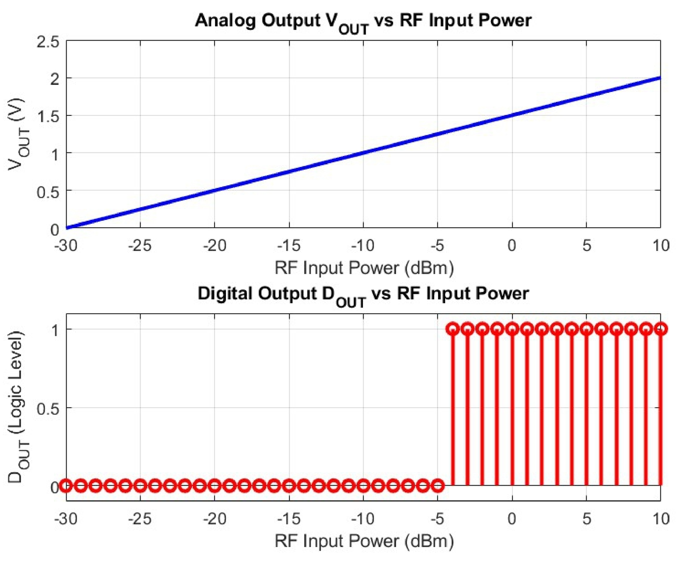
Map showing the locations where the transmit and receive antenna are placed

Location Number	Distance of Location from the transmitter (m)	Angle of the location from the transmitter (degree)	Measured voltage (mV)	Harvested power(µW) R= 150 Ω
R1	1.5	0	220	322
R2	2.5	0	200	266
R3	4	0	180	216
R4	7	55	150	150
R5	9	100	120	96
R6	11.5	110	110	80
R7	13.5	60	90	54

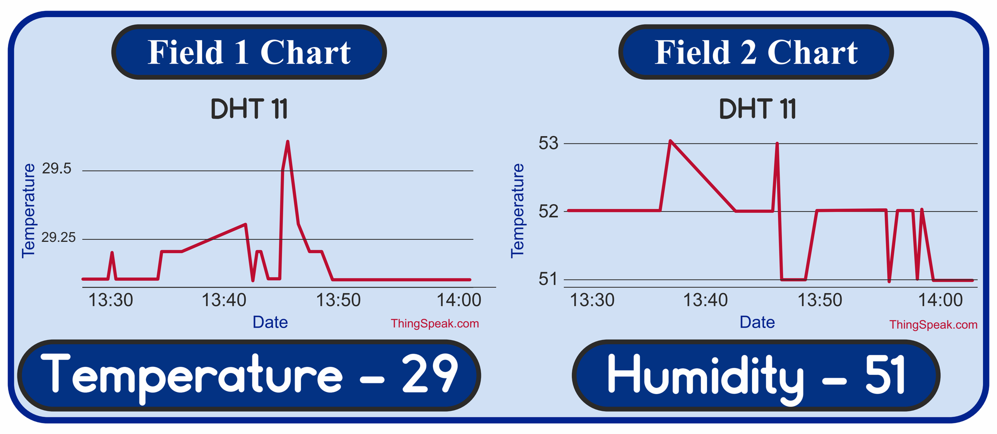
Power harvested for **BPSK** signal

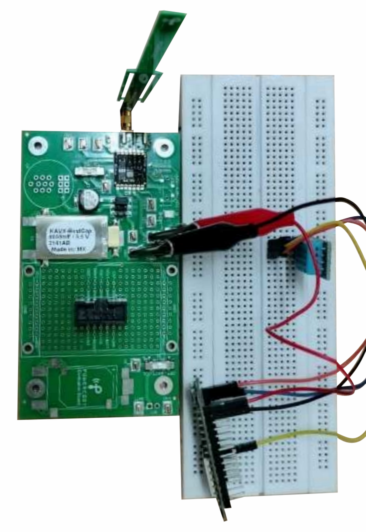
Our contribution as **MATLAB** Simulation and our results





More Energy Harvesting Techniques

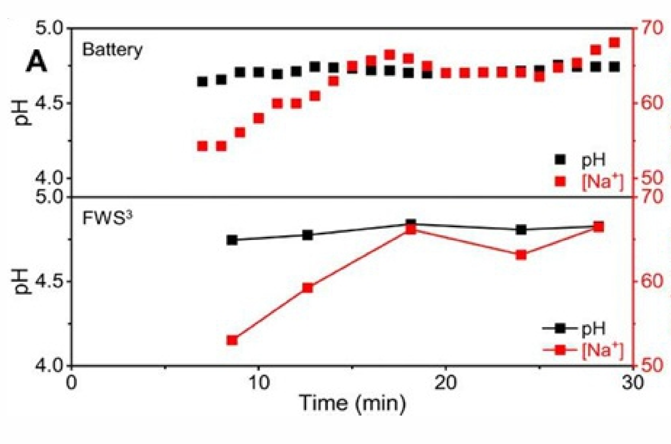


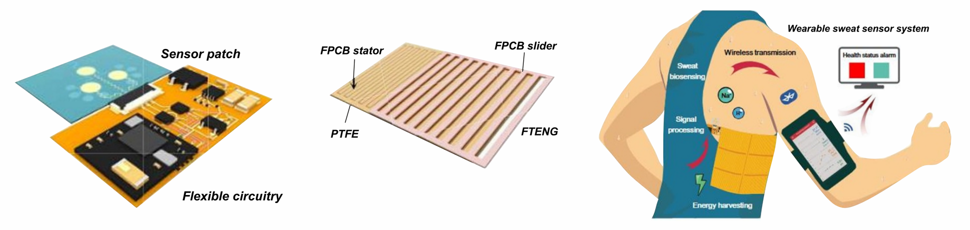


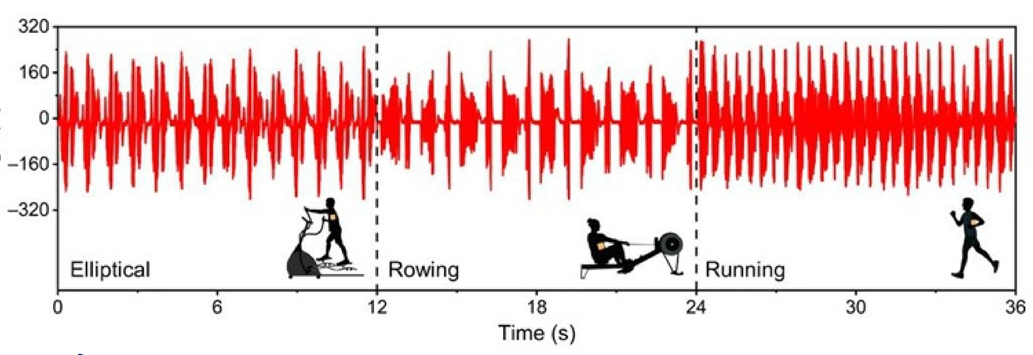
P2110B-EVB evaluation board served as the power source for a **NodeMCU microcontroller** instead of a conventional battery.

Temperature and humidity of **DHT11** sensorand **NodeMCU** in **ThingSpeak.** Sensors in this setup are powered only by RF energy, harvesred 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**

B The system's power generation during exercise.

Conclusion & Future work

The study used **LabVIEW** and **USRP** to transmit various modulated signals, measuring the harvested energy with a wercast **P2110B-based** circuit. Results showed that harvested power decreases with distance, and BPSK provided the highest energy harvesting efficiency.RF and triboelectric energy vesting 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.

Team Members

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References

Code