Demo: A Flexible Extension Board for IoT Devices to Enable their Batteryless Operation

Florian Mühlbacher, Markus Schuss, Hannah Brunner, and Carlo Alberto Boano
Institute of Technical Informatics, Graz University of Technology, Austria
E-mail:{florian.muehlbacher, markus.schuss, hannah.brunner, cboano}@tugraz.at

Abstract

Research on batteryless systems has recently bloomed, allowing the creation of IoT applications where devices operate exclusively from energy harvested from the environment. However, despite recent advances, batteryless systems still suffer from a *rigid hardware design*, with a given target device coupled with a built-in harvester and predefined components, which limits flexibility. We fill this gap and introduce BPMx: an extension board to build batteryless systems offering an unprecedented level of flexibility in the choice of target device and harvester. Moreover, BPMx integrates a fully-configurable power manager with user-defined voltage thresholds, supply voltage, and the ability to fully disconnect subsystems such as a built-in real-time clock and non-volatile memory. BPMx is affordable (≈ 40 EUR), open-source, compatible with the popular Arduino Rev3 pin layout, and needs as little as 30 µA to operate. In this demo, we showcase how BPMx enables the batteryless operation of an `nRF52840-DK` implementing a periodic sensing application.

CCS Concepts

• **Hardware** → *PCB design and layout*; *Renewable energy*; • **Computer systems organization** → *Embedded hardware.*

Keywords

BPMx, Battery-free system, Energy harvesting, Hardware, Low-power design, Power management, Non-volatile memory, RTC.

1 Motivation

The Internet of Things (IoT) is revolutionizing our society by enabling greener buildings and cities, or by enhancing agricultural and industrial processes. Unfortunately, IoT devices mainly use batteries as their primary power source, which is not ideal. In fact, batteries are bulky, heavy, not sustainable, and – even if rechargeable – wear out after some time, which leads to increased maintenance effort and costs [4].

Recent studies have focused on powering IoT devices only from ambient energy extracted from their surroundings (such as solar, thermal, or kinetic energy) via so-called *energy harvesters* [2]. These harvesters typically capture small amounts of energy from the environment and store it in a (super-) capacitor until there is enough power to operate the device.

Efficiently utilizing a (super-) capacitor's charge-recharge cycle to achieve the longest possible continuous runtime and the system's ability to respond to events in a timely manner requires proper hardware support, i.e., a set of configurable components such as power management and voltage monitoring, a reliable notion of time, and non-volatile memory (NVM).

The gap to fill. We argue that the community still needs to provide an affordable and flexible extension board for IoT DevKits and SoCs, enabling the creation of batteryless systems. Such extension board would sit in between a *harvester* scavenging energy and a *target device* fulfilling a given task; and would further provide the following key components.

- *Power manager.* This module maximizes the target's runtime and avoids undefined low-voltage states by enabling or disabling the target device at specific levels of charge.
- *Voltage monitor.* Accurate response to power dropouts is essential for a batteryless system. A voltage monitor takes care of this by enabling measurements of the capacitor's current level of charge and by including an interrupt pin that triggers alerts at configurable voltage thresholds.
- *Timekeeping.* To completely turn off the target device and not lose timing information (which is essential to maintain network synchronization or to schedule long-term events), a timekeeping module is required. The latter can be based, for example, on a real-time clock (RTC).
- *Non-volatile memory.* To ensure forward progress despite frequent power outages, batteryless systems implement state retention mechanisms such as checkpointing, where the application state is copied to NVM before a power failure and can be restored once enough energy is available.
- *Flexible conversion circuits.* Each component has its own optimal operating voltage (minimizing the leakage or maximizing performance). As such, it is crucial to supply individual components with different voltages. This necessitates to translate the electrical signals between devices.

Whilst some batteryless systems do provide these components, they are restricted by design to specific applications (i.e., they have a single-purpose use [1, 2]) or are tied to a specific target device (with the `Riotee` board by Nessie Circuits [3] being an example of this). `Riotee` offers an all-in-one solution with various shields to simplify custom application development. However, when it comes to adaptability, existing setups cannot easily be converted to batteryless operation without significant hardware modifications due to fixed CPU, memory size, and voltage thresholds. Hence, we aim to design a board providing greater modularity and flexibility, while allowing seamless integration into existing systems (i.e., a more versatile solution for a wider range of IoT applications).

Contributions. We fill this gap by introducing BPMx, an extension board to build batteryless systems offering an unprecedented level of flexibility in the choice of target device and harvester, as well as providing all aforementioned features (fully adaptable to the specifications of the target device with a user-specified operating voltage from 1.8 V to 3.3 V). Possible target devices include the popular `nRF52840-DK` and `STM32L152` Nucleo among a myriad of other compatible boards sharing the official `Arduino Rev3` pin layout.