Demo Abstract: On-Demand Communication with the Batteryless MiroCard

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ABSTRACT

Over the last decade, energy harvesting has seen significant growth as different markets incorporate green and sustainable electrical energy production. Even though costs have fallen, few products in the Internet-of-Things marketplace have embraced solutions based on energy harvesting. This is partly due to a mismatch in both the power density and timeliness of energy production and consumption. Until recently, harvesting-based systems required a battery or supercapacitor to be functional. After years of research, advances in energy management techniques have enabled the design of fully batteryless sensing devices. This demo introduces the batteryless MiroCard, a novel smart-card powered by light. Its fast wake-up times and energy-efficient operation allow the MiroCard to emit BLE beacons even in low ambient light conditions.

CCS CONCEPTS

• **Hardware → Renewable energy**; **Sensor applications and deployments**; • **Computer systems organization → Sensor networks**.

KEYWORDS

Batteryless systems, Energy harvesting, Low power communication

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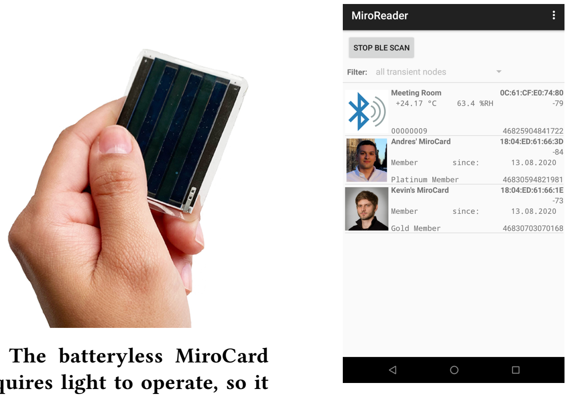
1 INTRODUCTION

Batteryless systems with passive elements such as Radio Frequency Identification (RFID) cards have been in wide circulation for decades, but they perform only simple computation, have little memory and require specialized readers to energize and communicate with them. More recently, researchers have studied batteryless systems with active components to harvest more abundant primary (naturally occurring) energy to perform complex sensing, processing and broadcasting. Batteryless systems with active elements such as photovoltaic cells [1], thermoelectric generators [2] or kinetic energy harvesters [3] can have high power densities. This demonstration presents the MiroCard, a batteryless smart-card powered by light. Since MiroCards covered by any light-blocking material cannot be remotely energized, their activation is exclusively on-demand: when a user *chooses* to expose them to light. The MiroCard is less than 2 mm thick, and has a surface area of only 45 mm × 60 mm, shown in Figure 1a. The top side is covered by an organic solar panel with an active area of 35 mm × 53 mm, and all electronics are placed on the bottom. Thanks to its optimized hardware and software, the MiroCard is able to harvest enough energy to communicate wirelessly, even in low indoor lighting conditions down to 170 lx. While its component costs are low, several Swiss Francs at high volume, it is indeed more expensive than passive Automatic identification and data capture (AIDC) technologies such as RFID. However, the active batteryless technology behind the MiroCard offers key advantages in addition to higher power densities. The MiroCard's Cortex M3 provides high processing capabilities for advanced applications with secure communication protocols, and also features enough memory for Internet application protocols such as the Constrained Application Protocol (CoAP).



Meeting Room 0C:61:CF:E0:74:80
+24.17 °C 63.4 %RH -79
00000009 46825904841722

Andres' MiroCard 18:04:ED:61:66:3D
-84
Member since: 13.08.2020
Platinum Member 46830594821981

Kevin's MiroCard 18:04:ED:61:66:1E
-73
Member since: 13.08.2020
Gold Member 46830703070168

(a) The batteryless MiroCard requires light to operate, so it is immune to RF skimming.

(b) The companion app gathers and visualizes MiroCard data.

Figure 1: Light-powered MiroCards provide sensor and identification data to any BLE compatible device.

2 MIROCARD OVERVIEW

The MiroCard project is an evolution of the Transient BLE Sensor Node project [4]. The hardware design is based on the energy management unit (EMU) first introduced in [5], which proposed current and voltage decoupling between a transducer and the application circuit through *energy bursts*. In doing so, simultaneous optimization of energy harvesting, through maximum power point tracking (MPPT), and application energy, through dynamic voltage and frequency scaling (DVFS), becomes possible.

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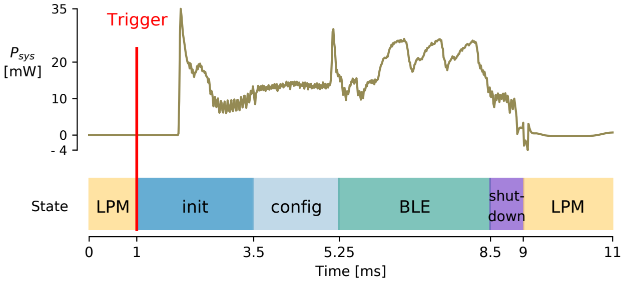

Figure 2: In Low Power Mode (LPM), the MiroCard's average system current is only 2.47 µA. When triggered, a single activation broadcasts 3 BLE packets and lasts less than 8 ms.

Energy Characterization. For this demonstration, a BLE beaconing application is chosen. With each activation, the MiroCard emits three BLE packets at the lowest transmission power, −21 dBm, to broadcast a user's presence. Following EMU [5] design rules, it is first necessary to determine energy requirements set by the application's atomicity. The MiroCard's power consumption was recorded using a RocketLogger measurement device [6] and a DC source. The power trace of a single activation can be seen in Figure 2, with annotations indicating the system state. The average energy consumption of the base BLE application is 175.31 µJ, including converter inefficiencies. Adding temperature and humidity increases the application energy by around 30 µJ [6]. Two 47 µF ceramic capacitors are enough to guarantee energy bursts of these sizes when $V_{cap} \in [2.8\,\text{V}, 4.37\,\text{V}]$, even if it is less than the chip spec of 150 µF.

3 DEMONSTRATION

Set-up. For this demonstration, a RocketLogger is connected close to ground to measure the current and voltage generated by the organic solar cell, as well as the MiroCard's GPIOs, capacitor voltage V_{cap} and supply voltage V_{cc}. To measure the worst-case startup time, all capacitors are manually shorted to ensure initial empty condition before light exposure.

MiroCard Performance. When a fully-off MiroCard is first exposed to light, it enters a startup phase as it charges its internal capacitors. In this phase, the AEM10941 harvester chip optimizes the charge transfer to its small storage capacitor and quickly stabilizes the regulated V_{cc} voltage, as shown in Figure 3. Afterwards, the MiroCard enters energy-driven execution where it stays in LPM, consuming only 2.47 µA, as it waits for an EMU trigger. The EMU triggers the application once the maximum capacitor voltage of 4.37 V is reached, and three identification beacons are transmitted.

Table 1: MiroCard performance in indoor-light conditions.

Luminosity	Startup Time	Average Input Power	Average Comm. Rate
2 600 lx	2.88 s	978 µW	16.25 pkt/s
1 000 lx	7.17 s	372 µW	6.17 pkt/s
500 lx	13.62 s	181 µW	2.92 pkt/s
250 lx	33.49 s	85 µW	1.9 pkt/s
170 lx	60.04 s	60 µW	0.75 pkt/s

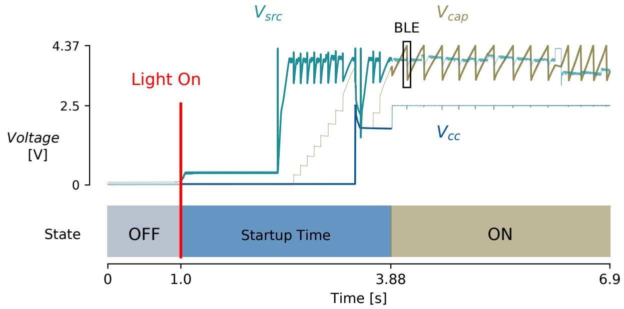

Figure 3: Power-on trace of a MiroCard, indoors with natural and artificial light (2 600 lx). It starts up within 2.9 s and transmits BLE beacons at an average rate of 16.25 pkt/s. BLE transmission is triggered when $V_{cap} = 4.37\,\text{V}$ (black box).

In this demonstration, the raw BLE packet size is 42 bytes, containing 25 bytes of advertisement data. The MiroCard can integrate current and historical sensor data (e.g. temperature and humidity) at the cost of a slightly larger energy consumption, as presented in [4]. An Android device is placed in the vicinity to demonstrate the simplicity of data gathering, as shown in Figure 1b. As the environment provides more light, the MiroCard's execution rate increases automatically, thanks to the EMU's energy proportionality. In dynamic environments, MPPT plays an important role in optimizing the energy input, especially if the MiroCard is only exposed to light for short periods of time. Sample measurements using a solar testbed [7] at different luminosity levels are summarized in Table 1.

Summary. The MiroCard is one example of how active batteryless sensing systems can optimize the form factor and component costs and also simplify housing, storage and shipping of new products. These systems can offer higher performance and significantly more memory than comparable RFID technologies, although at a higher price point. Their physical inability to energize in the absence of primary energy (e.g. light) is a powerful security- and privacy-enhancing feature. Requiring little primary energy to function, these on-demand systems can provide a new class of advanced services to cyber-physical systems including user authentication, localization, financial and internet transactions, among others.

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REFERENCES

[1] Alexei Colin, Emily Ruppel, and Brandon Lucia. A reconfigurable energy storage architecture for energy-harvesting devices. In *Proc. ASPLOS Conf.* ACM, 2018.

[2] Y. K. Ramadass et al. A batteryless thermoelectric energy-harvesting interface circuit with 35mv startup voltage. *IEEE J Solid-State Circuits*, 2010.

[3] Josiah Hester and Jacob Sorber. Flicker: Rapid prototyping for the batteryless internet-of-things. In *Proc. SenSys Conf.* ACM, 2017.

[4] Lukas Sigrist et al. Harvesting-aware optimal communication scheme for infrastructure-less sensing. *ACM Transactions on Internet of Things*, 2020.

[5] Andres Gomez et al. Dynamic Energy Burst Scaling for Transiently Powered Systems. In *Proc. DATE Conf.*, pages 349–354. IEEE, 2016.

[6] Lukas Sigrist et al. Measurement and Validation of Energy Harvesting IoT Devices. In *Proc. DATE Conf.* IEEE, 2017.

[7] Lukas Sigrist et al. Environment and application testbed for low-power energy harvesting system design. *IEEE Trans. Ind. Electron.*, in press.