Powering Sigfox Nodes with Harvested Energy

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Outline

- Our activities in low power wireless
- Introduction and motivation
- Short introduction to Sigfox
- System and results
- Questions

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Areas of Core Competences

- Wireless Communication, Self-sufficiency, IoT, Security of Embedded Systems
  - 3 groups deal with related activities
- FPGA-based systems
- Time synchronization
- high availability Networks
- Safe and dependable Systems

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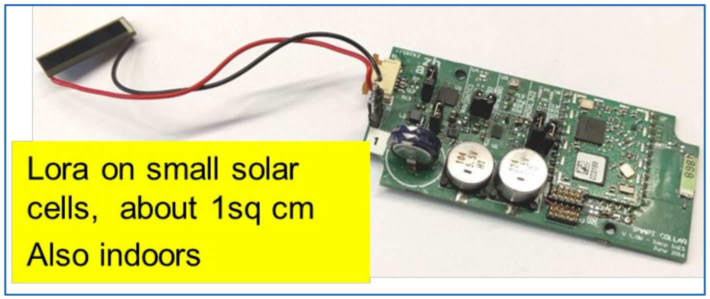
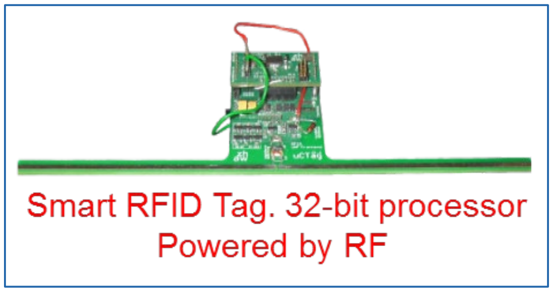
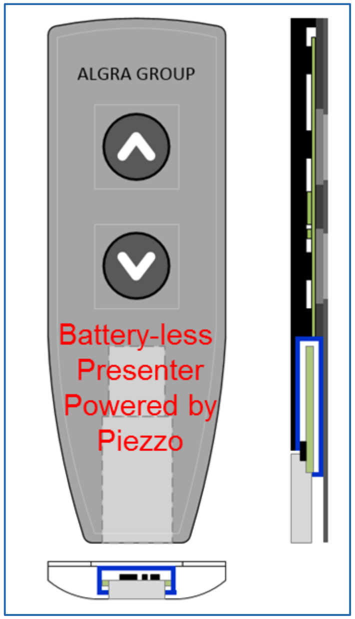
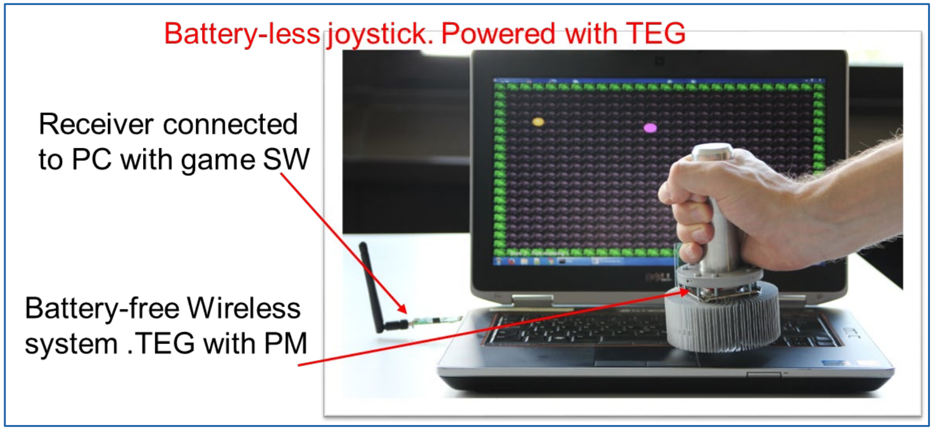
Working with different energy sources, different wireless systems, different microcontrollers

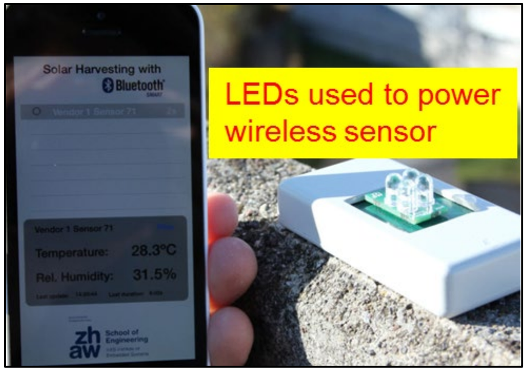


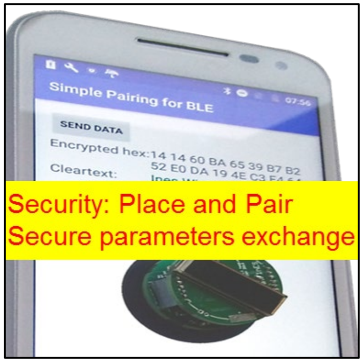




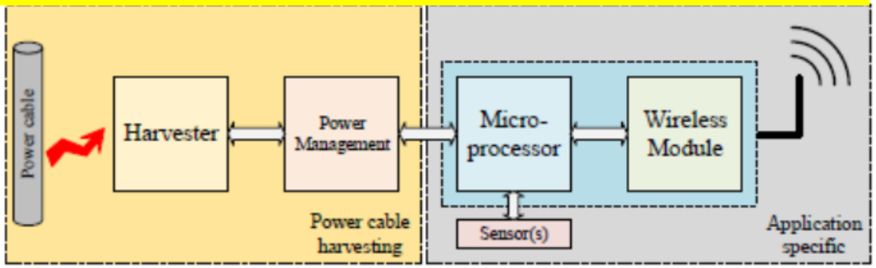


Working with different energy sources, different wireless systems, different microcontrollers

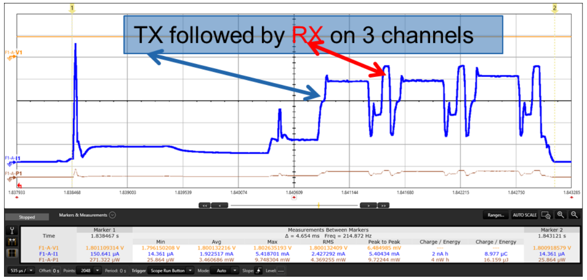




Harvest energy from electrical cables (Clip2Go)



Comparison of BT Smart devices (New: 2018 version)



ADV event (active part)
- Time: 4.6ms
- Energy: 16.16 µJ

Total ADV event cycle (100ms)
- Time: 100ms
- Energy: 16.34 µJ

Measurements also made for 1000ms

Introduction and Motivation

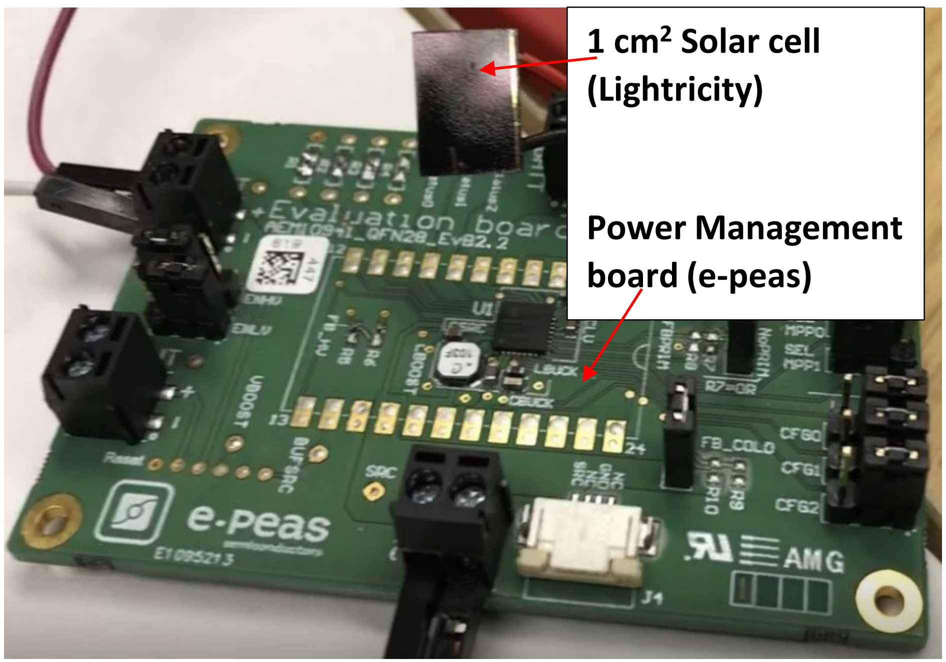
- Billions of nodes expected for the Internet of Things
  - Many nodes are (or will be) difficult to access
  - Wireless communications needed in several cases
    - LPWAN systems such as Sigfox, Nb-IoT, LoRa, Mioty, … etc
- Energy Autonomy is important for many IoT nodes
  - Batteries are mostly used today (sometimes mains)
    - But they "run out of energy" and need to be exchanged
    - Maintenance costs to access nodes and exchange batteries
  - Energy Harvesting as alternative, bust still costly
    - More energy for LPWAN (wrt. WPAN) → extra costs
    - Size/reliability can also be issues (depending on the harvester type)

Introduction and Motivation

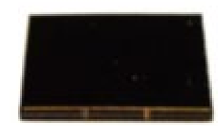
- There have been several works looking into the use of EH for LoRa/LoRaWAN
  - E.g. See some of our publications
  - Not much work with Sigfox, Nb-IoT, Mioty technologies
    - Important LPWAN technologies with interesting characteristics
- Here we look at the use of small solar cells for Sigfox
  - First steps in exploring size/cost optimization for Sigfox
  - We present results of this first phase

Introduction and Motivation

- We use a small but efficient solar cell
  - Harvests 22.7uW @200 lux



Performance (indication only)	Module
	200 lux white LED spectrum
Size	11.65 x 8.85 x 0.65 mm³
Active area	98 mm²
Number of cell(s)	1
Open circuit voltage	1.15 V
Short circuit current	22.7 µA
Operating voltage	1.0 V
Operating current	21.7 µA
Operating power	**21.7 µW**
Power density (active area)	22.1 µW.cm⁻²



Short introducion to Sigfox

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- In Sub-GHz ISM band (868MHz in Europe)
  - Ultra narrow bands Several Kms range; 100Hz band in Tx
  - Uplink: 100bps; Max 140 messages per day
    - 1 frame with 12 bytes payload → >2.08 seconds
  - DL: 600bps: Max 4 messages per day

Uplink frame format. 14-29 bytes	Preamble 19 bits	Synch + Header 29 bits	Device ID 32 bits	Payload 0-96 bits	Message Auth. Code 16-40 bits	FCS 16 bits

Downlink frame format. 21-29 bytes	Preamble 91 bits	Synch + Header 13 bits	ECC 32 bits	Payload 0-64 bits	Message Auth. Code 16 bits	FCS 16 bits

Short introducion to Sigfox

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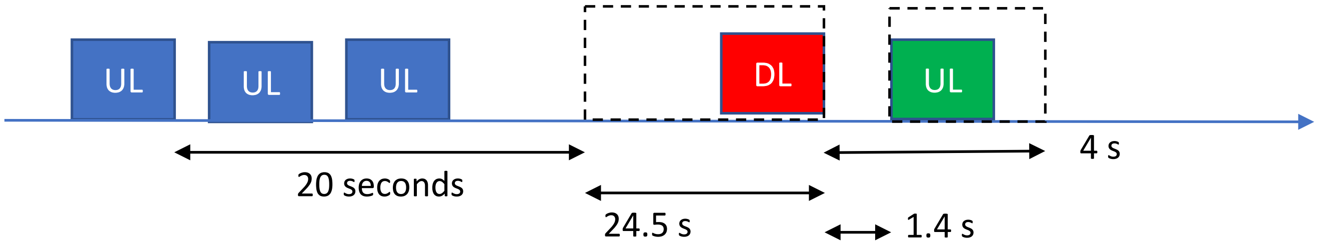
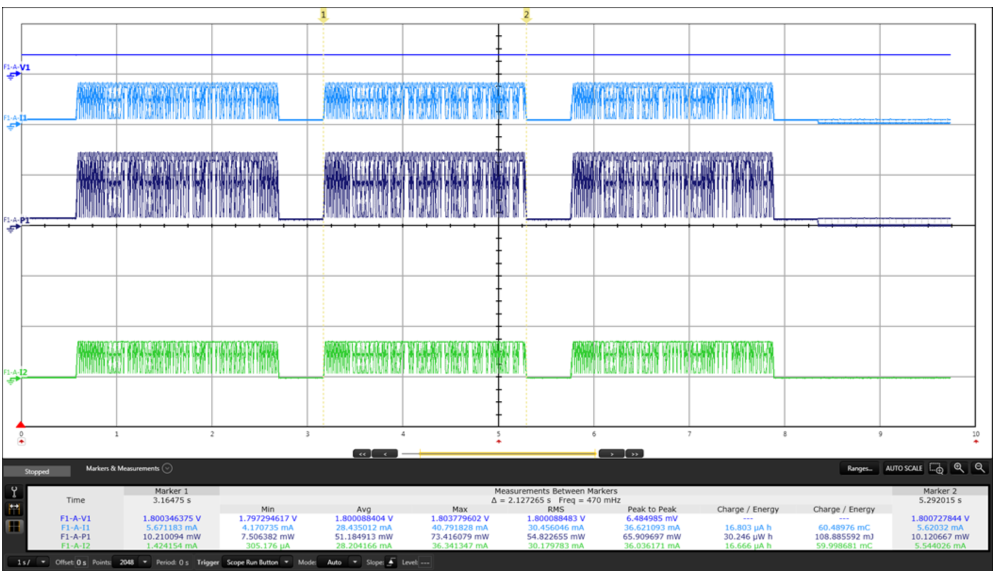
- In Sub-GHz ISM band (868MHz in Europe)
  - Normally, a message is sent 3 times
    - Increases reception probability, but (much) more energy needed
  - Strongly asymmetric (max 4 DL per day) (Tx without ACK)



Unidirectional exchange. Only the node sends data to the Base Station (BS)
Uplink: same UL frame sent up to 3 times on different random frequencies channels
Bidirectional exchange. BS also sends information (ACK/Command) to the node
Downlink: UL message, then switch to Rx mode to get DL frame from the gateway
The node acknowledges reception of the DL by sending another UL (OOB)

An idea of energy requirements of Sigfox

- Measurements with 12 bytes pload,
  - Using S2 radio (ST Micro)
  - Done with a STABLE VDD. No LDO (LDO → more energy)
  - Measurements taken from WC2019 (Meli @ Lorentz)

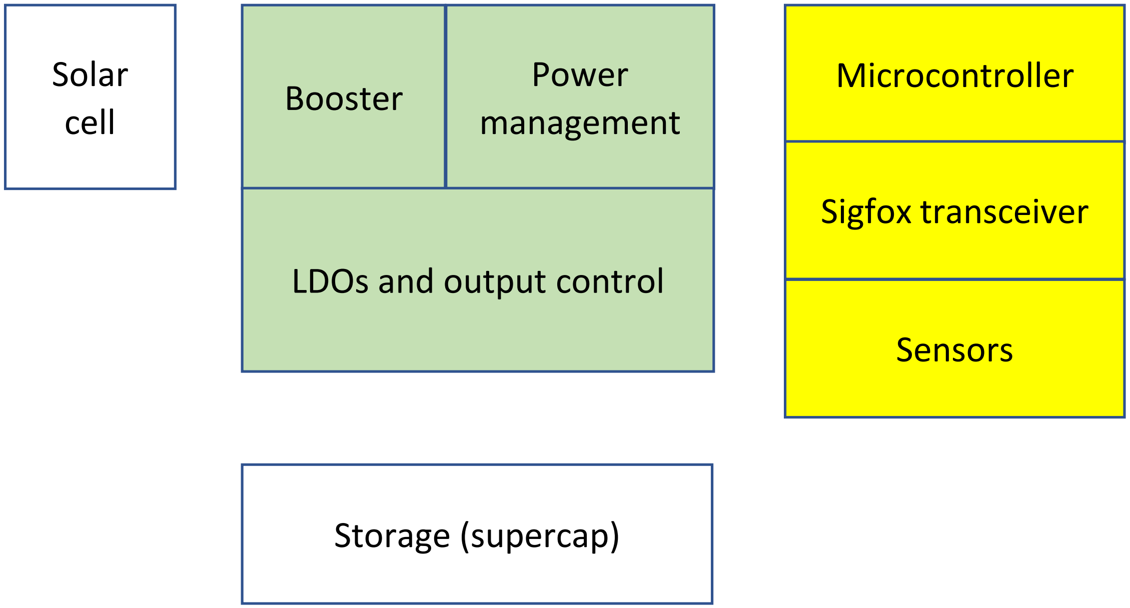


Measurements for a single Tx in 1 channel. Multiply by 3 for the 3x Tx, since Sigfox transmits 3 times the same frame

3TX+ wait + RX + OOB → 834mJ (see ref.)

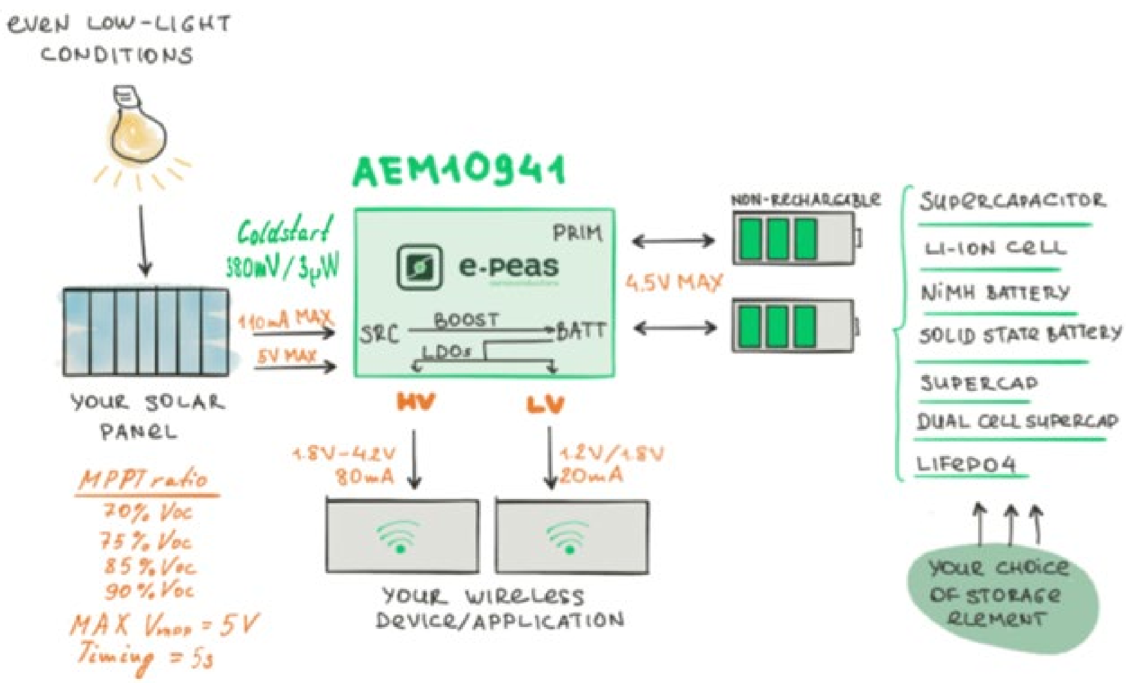
P_{TX}	V_{Supply}	I_{TX} (avg.)	I_{TX} (peak)	Energy
14 dBm	3.3 V	16.2 mA	20.7 mA	114 mJ
14 dBm	1.8 V	28.2 mA	36.3 mA	108 mJ
0 dBm	3.3 V	5.7 mA	13.9 mA	39.8 mJ
0 dBm	1.8 V	8.9 mA	17.2 mA	33.93 mJ

Block Diagram of system



- Small solar cell of $1cm^2$ from Lightricity
- PM AEM10941 from e-peas
- Supercapacitor to hold enough energy. 100mF
- Transceiver is S2 from ST Micro
- Microcontroller compatible M0 from ST Micro
- Optional sensors (none used here)

The PM (AEM10941 from e-peas)



Reference: https://e-peas.com/products/energy-harvesting/photovoltaic/aem10941/

Energy can be stored in different types of storage elements

Configuration of different parameters using pins and resistances

Different voltages for powering the load

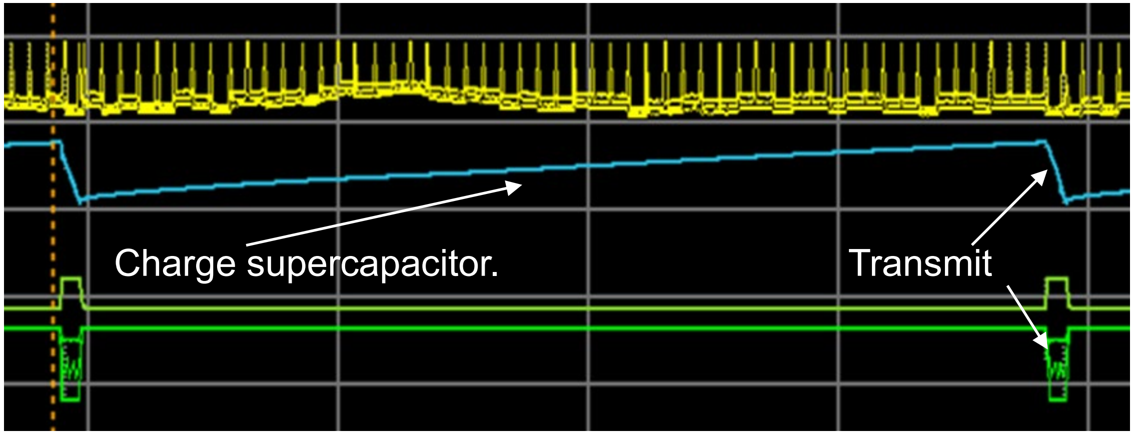
Output with LDOs:
- 80 mA is suitable for Sigfox
- 20 mA for other loads

MPPT helps improve efficiency
- MPPT ratio selectable

Cold start needs at least 380 mv and 3uW → single solar cell can be used
Once started, runs down to 50 mV

Accumulate and use strategy

- Harvested energy charges supercapacitor
  - Supercapacitor voltage higher than 4.4 volts (968 mJ)
    - Load is powered. Microcontroller initialises radio. Tx starts
  - Lower than 3.6 volts (648 mJ): System powered off
  - Energy available for activity is about 320 mJ
    - Loses in supercap (leakages several uA) and other components



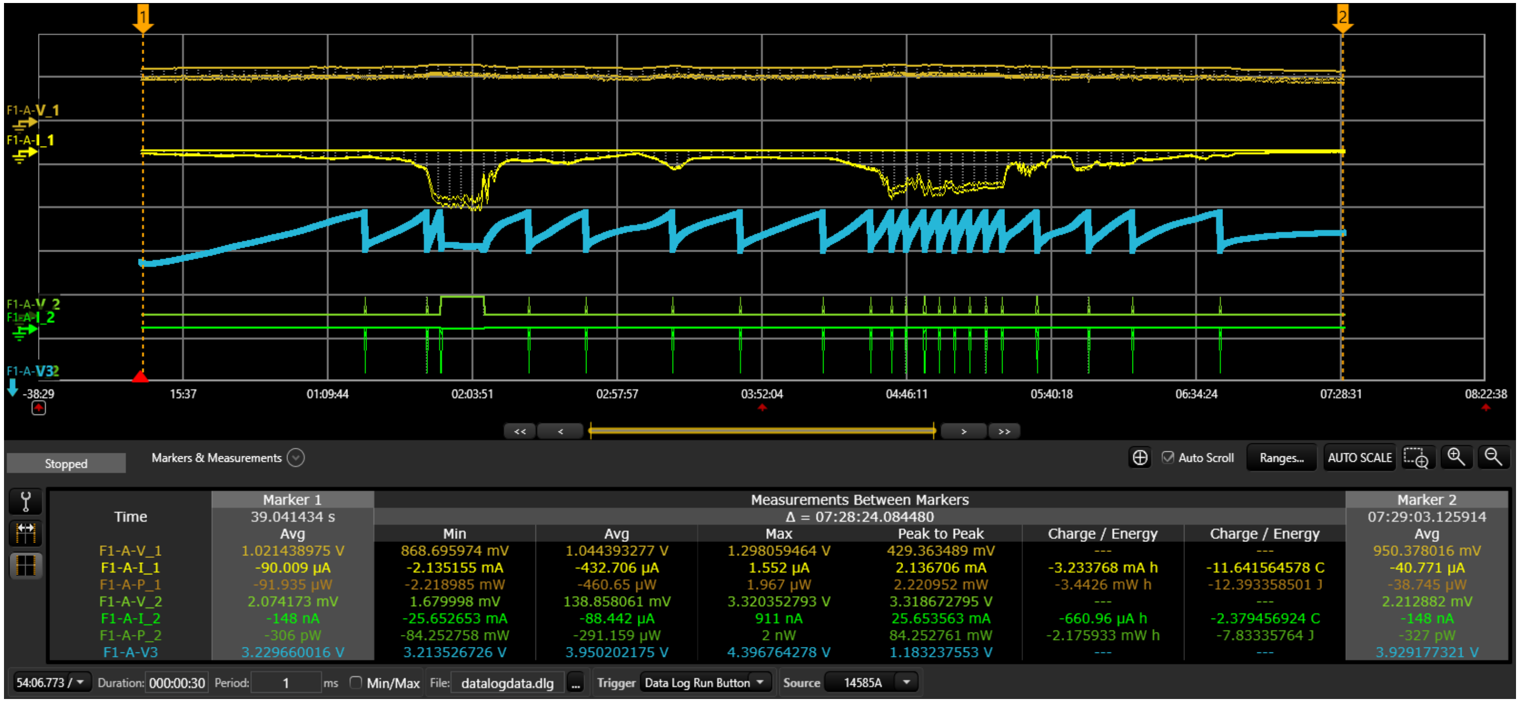


Figure 2. More than 7 hours recording of input energy (I1,V1) and used energy (I2,V2). V3 is the supercapacitor voltage. Towards the end of the day, the energy delivered by the solar cell is not enough to reach the 4.4 volts threshold needed to start a transmission.

Results (more results in paper)

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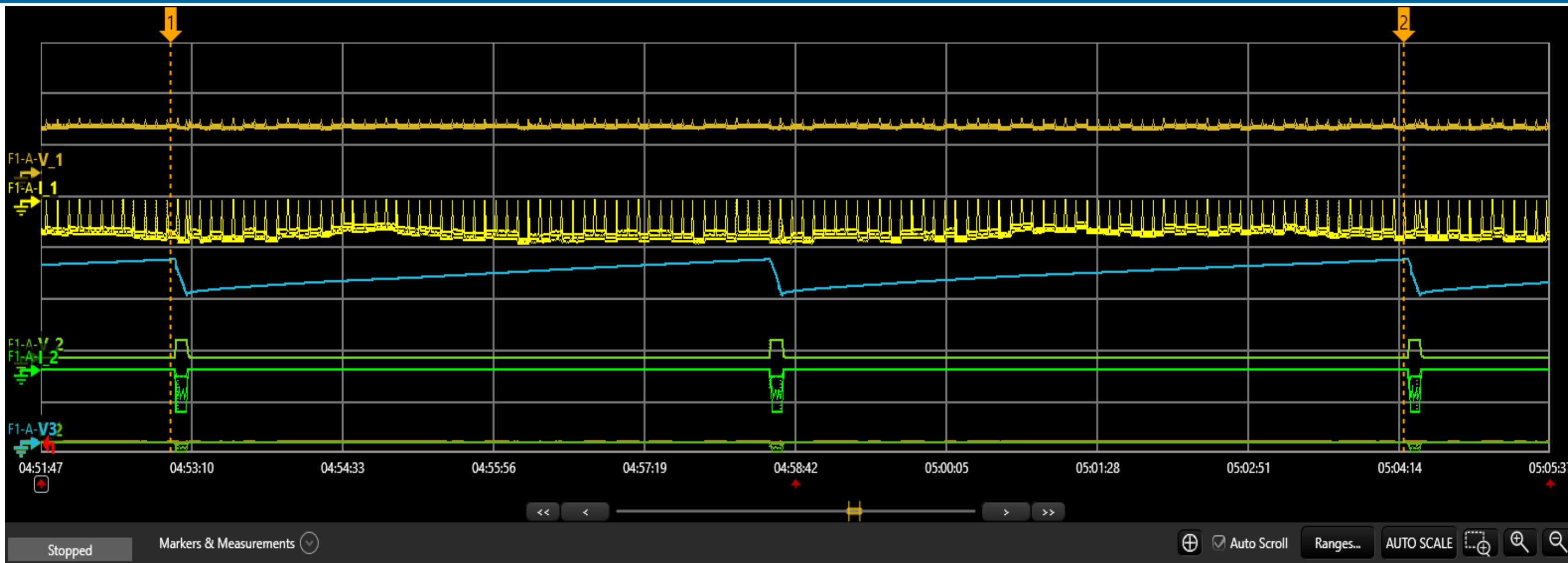

Time	Marker 1	Measurements Between Markers						Marker 2
	04:52:58.677043	Δ = 11:17.697946						05:04:16.374989
	Avg	Min	Avg	Max	Peak to Peak	Charge / Energy	Charge / Energy	Avg
F1-A-V_1	1.129271313 V	1.030147791 V	1.094453536 V	1.284807801 V	254.66001 mV	---	---	1.068368985 V
F1-A-I_1	-1.213203 mA	-1.627842 mA	-1.246251 mA	1.266 µA	1.629108 mA	-234.606 µA h	-844.581876 mC	-1.389663 mA
F1-A-P_1	-1.368938 mW	-1.690326 mW	-1.358182 mW	1.611 µW	1.691937 mW	-255.677 µW h	-920.437403 mJ	-1.484449 mW
F1-A-V_2	2.339941 mV	1.807547 mV	70.122351 mV	3.310786486 V	3.308978939 V	---	---	2.320441 mV
F1-A-I_2	-150 nA	-25.597649 mA	-277.324 µA	911 nA	25.59856 mA	-52.206 µA h	-187.942092 mC	-150 nA
F1-A-P_2	-351 pW	-84.070262 mW	-912.933 µW	2 nW	84.070264 mW	-171.859 µW h	-618.69249 mJ	-347 pW
F1-A-V3	4.387646734 V	3.523159027 V	4.040273527 V	4.393165112 V	870.006084 mV	---	---	4.387919074 V

01:22.989 / Duration: 000:00:30 Period: 1 ms Min/Max File: datalogdata.dlg Trigger Data Log Run Button Source 14585A

Figure 3: Zoom on 2 harvest/transmit cycles when illuminance high

Harvest time for one cycle is 320 s. For the next cycle, it is 343 sec. The variations are related to how much energy is being harvested (depends on illuminance)

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Acknowledgements

- The work presented here is the result of an internal project of the ZHAW Institute of Embedded System.
  - We acknowledge the support of Innosuisse for certain aspects of the work (grant 31354.1 IP-ICT).
  - The work is also partly associated to the Amanda Project sponsored by the Horizon2020 program under the grant agreement ID: 825464.
    - Specifically, the solar cell used is from the firm Lightricity.
    - The power management used is a product of the firm e-peas. Both firms and ZHAW are part of the Amanda Consortium.
  - Thanks to the firm Heliot for providing a user account for our works related to Sigfox.

Questions

Questions, suggestions, corrections:

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