Battery Life matters!

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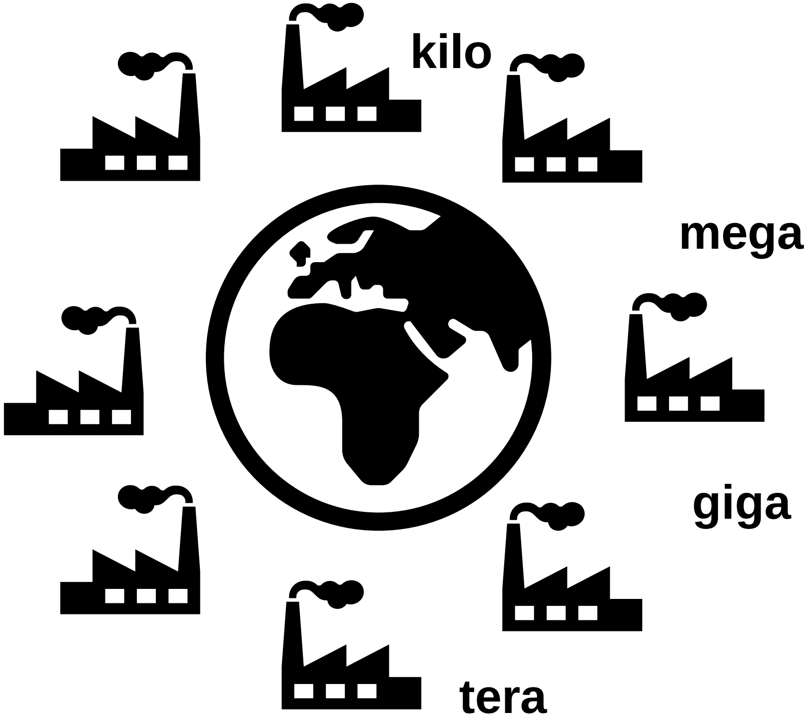
Welcome to the milli-micro world!



Agenda

- Welcome to the milli-micro world!
- How long lasts a coin cell?
- The basics: power, capacity, energy, charge
- Energy consumption - system components
- Energy consumption – ideal vs. reality
- Ways to reduce energy consumption
- EnergyLab: A simple battery model lab setup
- Classroom experiments:
  1. Characterize the energy leakage of EnergyLab
  2. Experiments to reduce energy consumption
  3. How long does a TI-Nspire CXII battery last?
- Summary – key learnings

How long lasts a coin cell?

?

- The only correct answer: It depends!

How long lasts a coin cell?

- Excerpt from Varta CR2032 datasheet:
  - Typical capacity: 230mAh, at a continuous load of 5600 Ohms
  - Time to reach end voltage (2.0V) @ 5.6kOhms load: 460h
  - Typical energy: 645mWh
- Let's do some Math:
  - I_{start} = U/R => 3V/5600 Ohms = 535.6 µA
  - I_{end} = U/R => 2V/5600 Ohms = 357.1 µA
  - 460h/24h = 19.2 days
- Let's put things in perspective:
  - One Google search consumes about 300mWh

How long lasts a coin cell?

- Now, how can it be that your bicycle computer runs on a single coin cell for more than one year?

- Let’s do some Math (again):
  - 1 year (365 days,24 hours) = 8760 hours
  - I_{avg} = 230mAh/8760h = 0.0262mA = 26.2µA

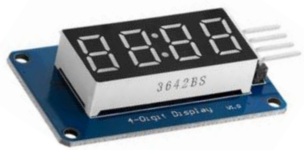
The basics: power, energy, charge, capacity

- Let's recap some electrical Physics:
  - Power [mW]: $P = U * I$
  - Energy [mWh]: $E = P * t = U * I * t$ or: $e_{(pulse)} = \int p(t)dt$
  - Charge [Coulomb], [As]: $Q = C * U$, where C = Capacitance in [F]
  - Battery Capacity [mAh]: "Battery capacity" is a measure of the charge stored by the battery, and is determined by the mass of active material contained in the battery.

Energy consumption - system components

MCU

I_{active}: 80.00μA/MHz
$I_{standby}$: 0.63μA(RTC)



LED

I_{active}: 27.0mA
$I_{standby}$: 0.5mA

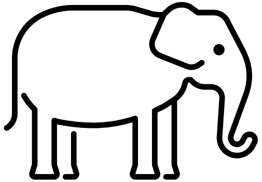
Radio

I_{active}: 130.0mA (Bluetooth)
$I_{standby}$: 0.001mA

LCD

I_{active}: 1.9μA
$I_{standby}$: 0.5μA

$I_{average/year}$: 26.2μA

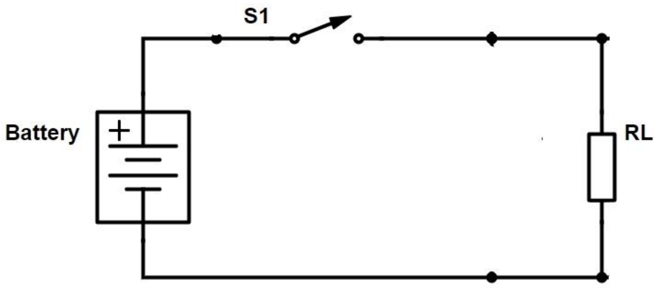


$\Sigma\ I_{standby}$: ??? μA

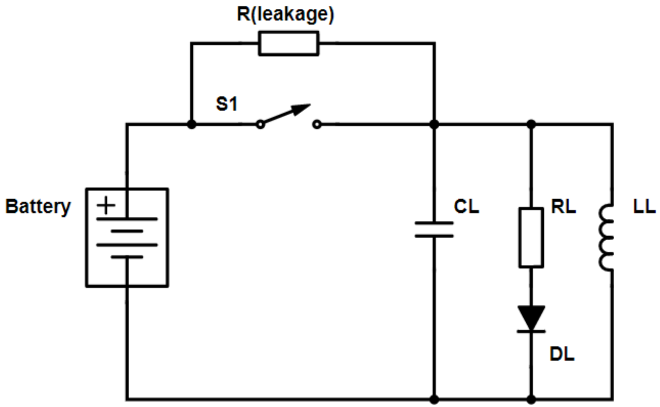
e-paper

I_{active}: 8mA
$I_{standby}$: 0nA

Energy consumption – ideal vs. reality

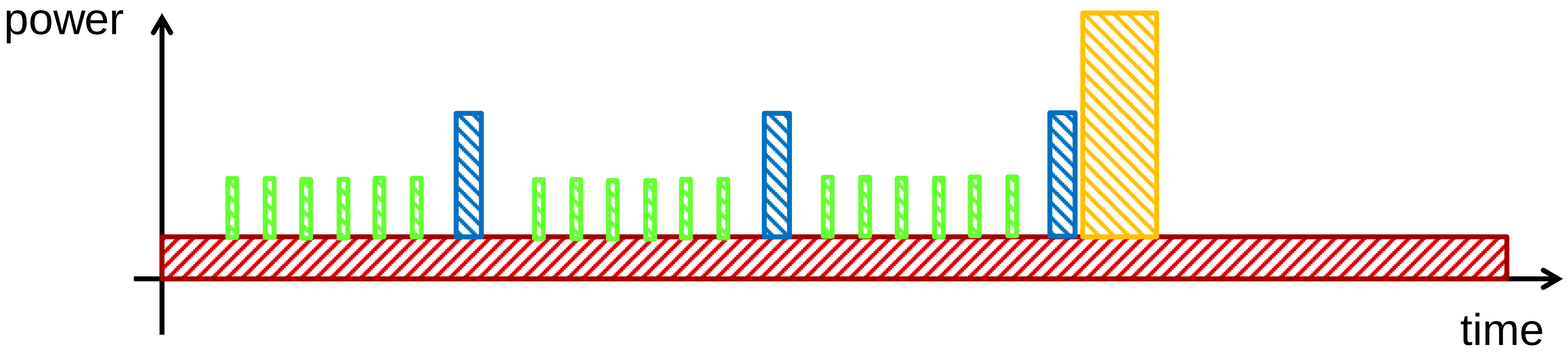


Ideal:
- No leakage
- Linear load characteristic



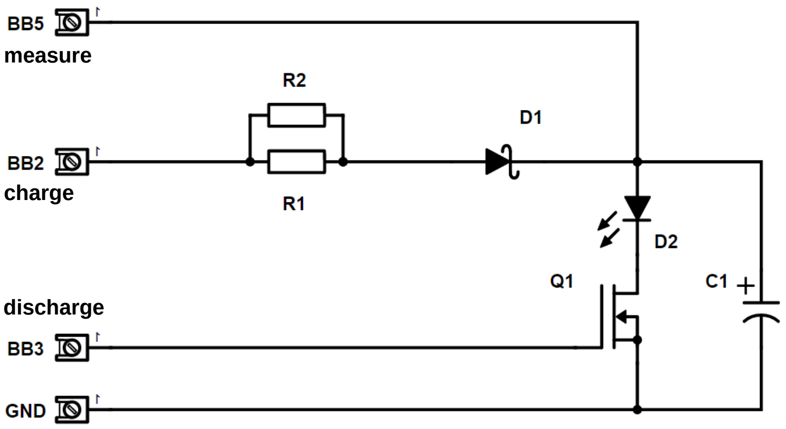
Real:
- Leakage
- Non-linear load characteristic

Ways to reduce energy consumption



- $E_{total} = \int p_{leakage}(t)dt + \int p_{measure}(t)dt + \int p_{compute}(t)dt + \int p_{radio}(t)dt$
- Minimize the number and the size of the squares!
- 4 key elements to reduce energy consumption:
  Hardware, software, system architecture and: The user!

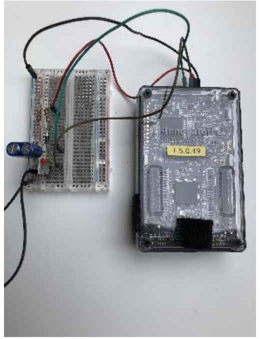
EnergyLab - a simple battery model lab setup

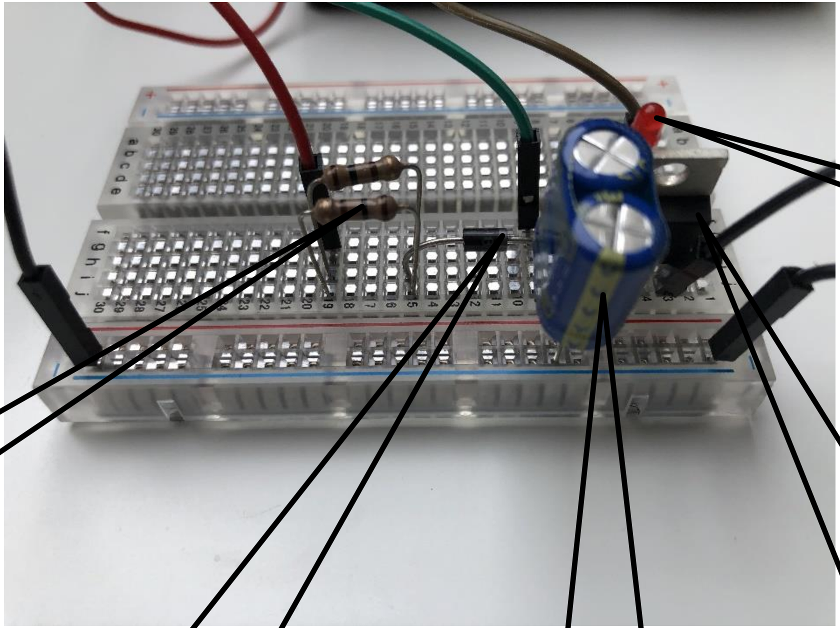


Operation	BB2	BB3	BB5
	Digital output	Digital output	Analog input
Charge	H	L	Measure charge
Discharge	L	H	Measure discharge
Leakage	L	L	Measure leakage

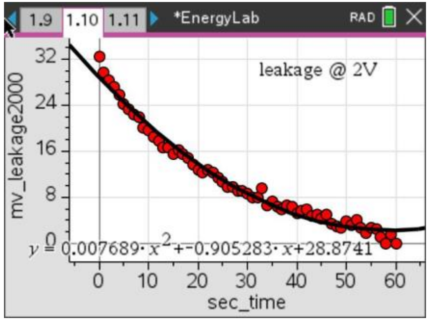
Symbol	Component	Purpose
R1,R2	Resistor, 100 Ohms	Ensure a gradual charge of the supercap, protect BB2 difital output
D1	Schottky Diode	Prevent a discharge into BB2, if BB2 digital output is low
D2	Red LED	Act as a load to discharge supercap, visualize the discharge process
C1	Supercap 0.5F	Act as a charge storage (a very small battery)
Q1	TTL MOSFET	Act as a switch to turn the load circuit on or off

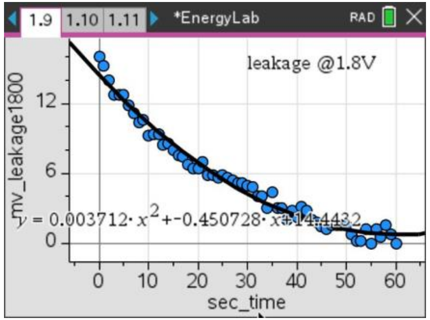
EnergyLab - a simple battery model lab setup

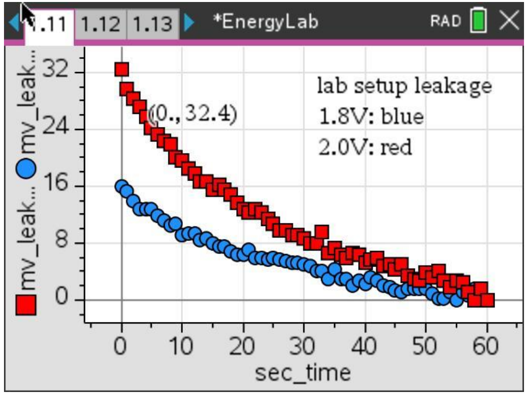




1. Characterize the energy leakage of the lab setup







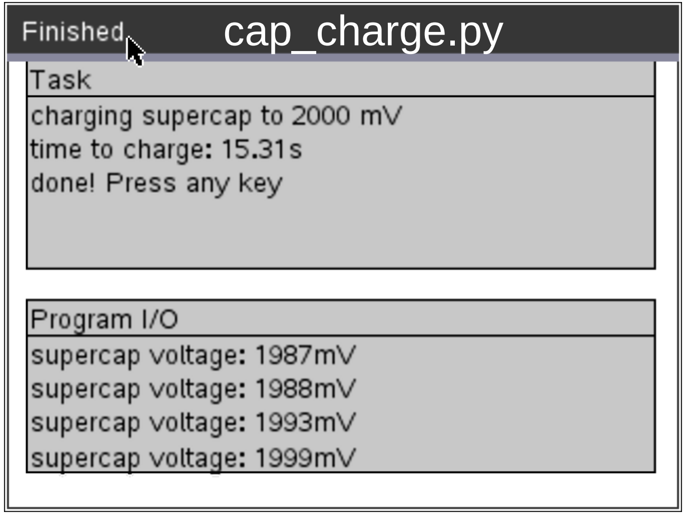
Python module: labsetupcheck.py

- Charges cap to desired voltage level
- Records leakage discharge for 60 sec

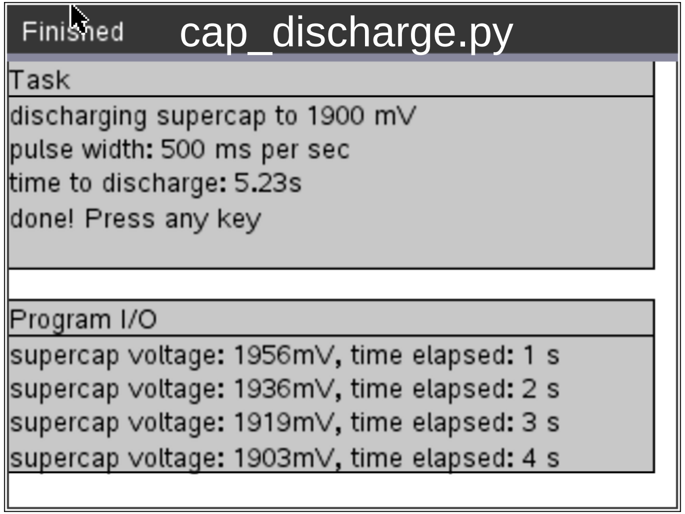
- Leakage is non-linear
- Leakage at U_{cap}=2V is about twice as much as at 1.8V

- $\Delta Q = C * \Delta U$ (Faraday's Formula)
- $Q_{leakage@1.8}$ = 0.5F * 16mV = 8mCoulomb
- $Q_{leakage@2.0}$ = 0.5F * 32mV = 16mCoulomb

2. Experiments to reduce energy consumption

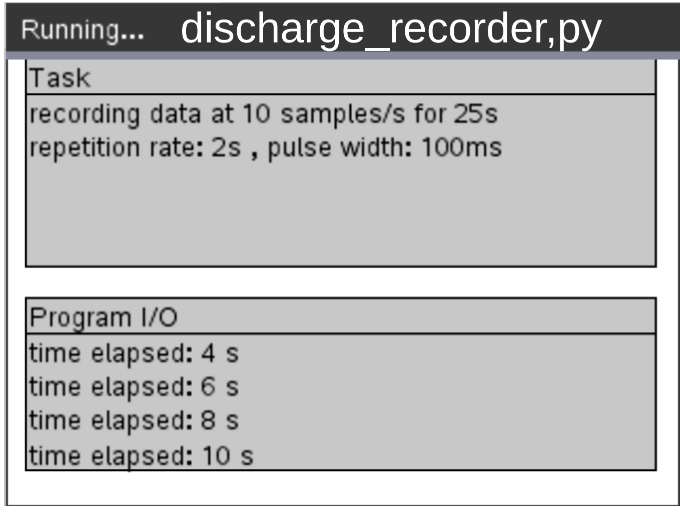


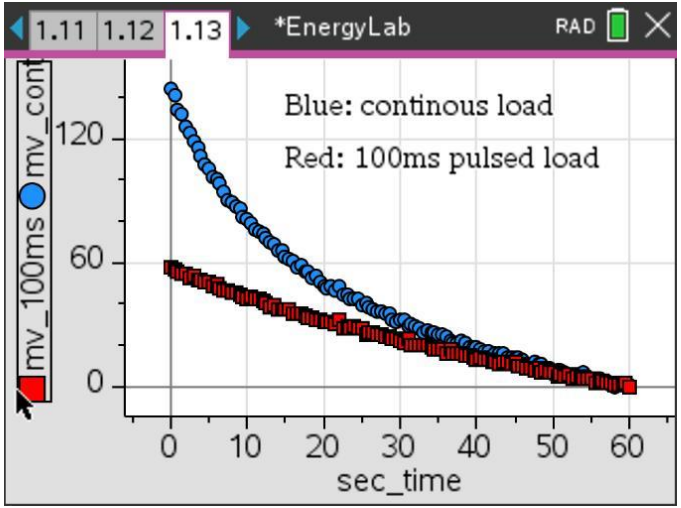
- Charges supercap to desired voltage
- Monitors progress & time to charge



- Applies load with desired pulse width at a 1s repetition rate
- Monitors progress and time to discharge to desired level

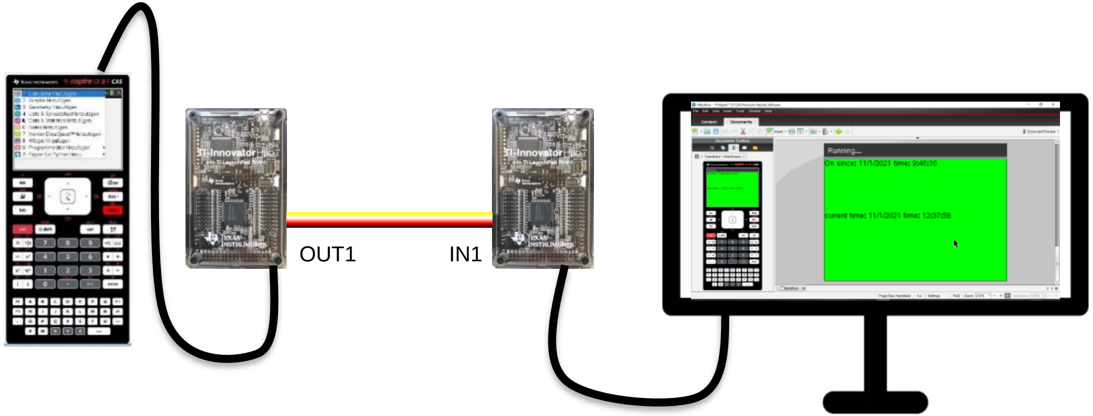
2. Experiments to reduce energy consumption





- Allows variable load pulse width and repetition rate
- Allows variable record time and samples/sec
- Please note: Don’t exceed # of records > 250

3. How long does a Nspire CXII battery last?



- marathon.py: A project to measure CXII battery life
  - runner.py: Code runs on the TI-Nspire CXII and is transmitting a 0.5Hz signal to OUT1 as long as the CXII battery lasts
  - coach.py: Code runs on a PC, detects loss of the 0.5Hz signal of the TI-Innovator Hub after the handheld battery died and records time stamp

… and here is the answer!

… it depends!

Setup	Result
Black text on a white background, max brightness	5 hrs 4 mins
Black text on a white background, min brightness	6 hrs 30 mins
White text on a black background, max brightness	4 hrs 58 mins
White text on a black background, min brightness	7 hrs 26 mins

Summary – key learnings

- Energy consumption, not power consumption, determines battery life
- Supercaps are a great substitute for batteries in a lab setup
- Faraday's formula: voltage of a battery/capacitor is proportional to the charge stored ($Q = C * U$)
- Energy leakage is the white elephant in the electrical system
- 4 factors affect battery life: hardware, software, sys architecture, user
- Battery life of a TI-Nspire CXII can be extended by cranking down the display brightness and using a black background color (works with your smartphone, too 😇)

Hope you enjoyed the presentation!

Helpful links

- Varta CR2032 coin cell datasheet, pictures on slides 4,8
  https://products.varta-microbattery.com/applications/mb_data/documents/data_sheets/DS6032.PDF

- Picture of Ciclo Bike Computer, slides 3,6,8: www.ciclosport.com

- Infographics showcase
  http://www.infographicsshowcase.com/how-much-energy-does-a-google-search-cost-infographic/

- Schottky diode 1N5817 datasheet
  https://eu.mouser.com/datasheet/2/389/cd00001625-1795544.pdf

- Supercap 0.5F datasheet
  https://www.vinatech.com/winko/data/product/WEC_5R4_505_QA_1025_data_sheet_%5B%C7%A5%C1%D8%5D_R2.pdf

- Visit T³ eu for a copy of EnergyLab, marathon, textbox, collect_hm Python code
  https://www.t3europe.eu/

- … or simply shoot me an email with questions, suggestions, feedback:
  hm-hilbig@web.de