Using New Memory technologies to Reduce the Energy Requirements of LPWAN Nodes (status of the work)

Authors:

M. Meli, S. Kunz (ZHAW, Switzerland)

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Presented by: Marcel Meli, Stefan Kunz, ZHAW,

Correspondence to: mema@zhaw.ch

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Agenda

- **Motivation**
- **Reducing energy losses and issues**
- **Implementation**
- **Evaluation of a ReRAM MCU**
- **Conclusion**
- **Support acknowledgements**
  - Part of the work related to research projects at ZHAW-InES
  - Part of the work related to Amanda H2020 project

Motivation

- **Lost energy**
  - Many nodes are event driven. Spend time in LP modes when not active
    - Smaller currents than in active modes (a few µA against several mA)
  - How much energy is lost in typical LP mode if in LP mode 50% of time?
    - RTC + memory retention (wake on RTC, measure, process, transmit, sleep)
    - 2µA @ 3V → 6*24*3600*0.5 → ~260mJ
    - 4µA @ 3V → ~520mJ
  - Battery life using CR2032 (250mAh)
    - For an average of 5µA → ~5.7 years
    - For an average of 7µA → ~ 4 years
  - A few µA can seriously affect lifetime

EFR32BG24 Wireless SoC Family Data Sheet
Electrical Specifications

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
Current consumption in EM2 mode, VSCALE0	I_{EM2_VS}	256 kB RAM and full Radio RAM retention, RTC running from LFXO[1]	—	4.2	—	µA
		256 kB RAM and full Radio RAM retention, RTC running from LFRCO[1]	—	4.2	—	µA
		16 kB RAM and full Radio RAM retention, RTC running from LFXO[1]	—	1.8	—	µA
		16 kB RAM and full Radio RAM retention, RTC running from LFRCO[1]	—	1.9	—	µA
		16 kB RAM and full Radio RAM retention, RTC running from LFRCO in precision mode[1]	—	2.8	—	µA
Current consumption in EM3 mode, VSCALE0	I_{EM3_VS}	256 kB RAM and full Radio RAM retention, RTC running from ULFRCO[1]	—	3.9	—	µA
		16 kB RAM and full Radio RAM retention, RTC running from ULFRCO[1]	—	1.5	—	µA

Motivation

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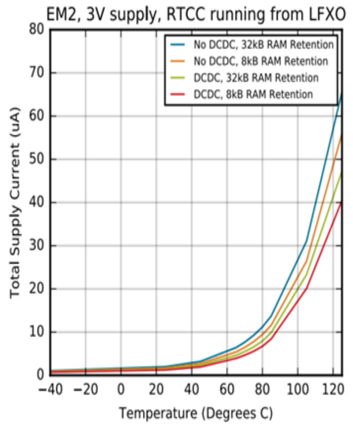
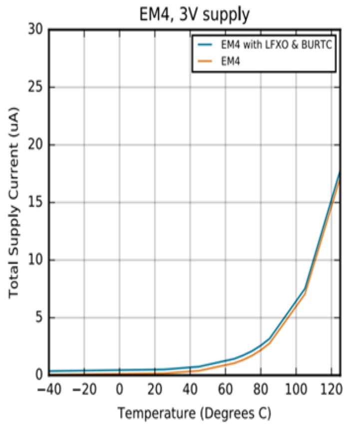
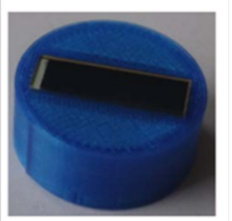
- **Lost energy**
  - Current exponentially depends on temperature
    - Energy losses higher when temp. increases
  - If harvested energy used (say small solar cell)
    - In LP, more current is like an extra load
      - ▶ Shifts minimal light intensity for EH
      - ▶ Harvesting process stops earlier
      - ▶ Storage emptied earlier or must be larger
- **How can one reduce/stop those losses?**



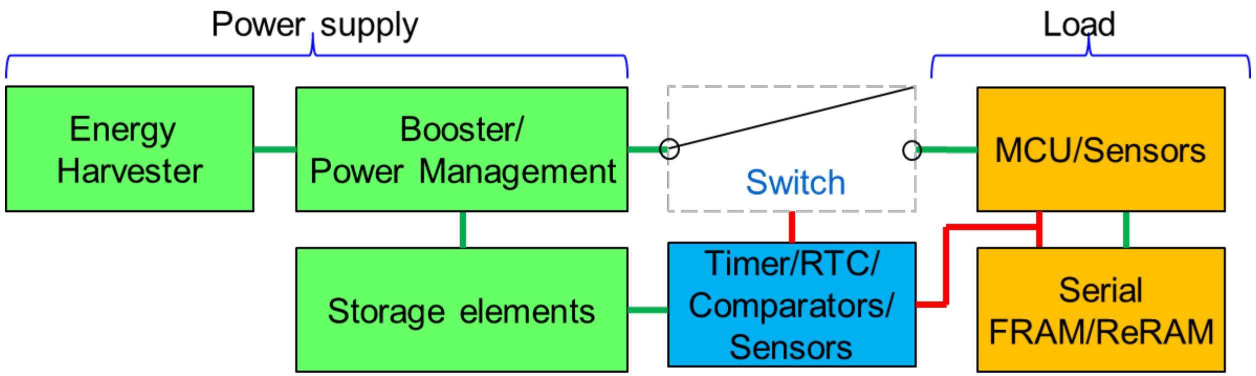


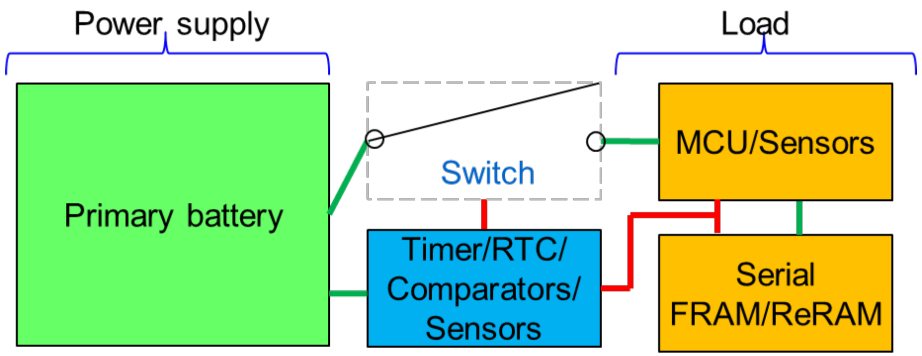


Small SC with BLE
Source ZHAW-InES

Reducing energy losses

- **Method**
  - Save status of embedded system in NV memory (retention energy = 0)
  - Switch off all the loads (current = 0; No temp. dependency)
  - Use external RTC/timer with small current to schedule events
    - Some low-power RTC/timers require <100nA (depending on accuracy)
  - Energy cost: Reboot, save/restore status, RTC/timer.
    - Gains exceed losses if ES often in PD and frequency of change to PD mode is low





Reducing energy losses

- **Issues**
  - Save status of embedded system in NV memory
    - How often can one save/restore? Endurance of NV memory is important
  - Restart embedded system, save/restore status cost energy
    - Need low-power NV memory
    - Need to minimize these operations
  - Example: Schedule for every 5 mins
    - >100k cycles per year and > 1 million cycles after 10 years
    - Scheduling control depends on application. Sensors could also be used.
  - Which type of memory could allow this?
    - Non volatile; low power at read/write; high endurance; low cost

Reducing energy losses

- **Memory technologies**
  - Flash: Most popular. Lowest cost. Found in most MCUs
    - Endurance is lowest: Tens of thousands of cycles; Retention 10 years
    - Slowest to program. Need more energy to program (high voltage circuit integrated)
  - FRAM:
    - Stand alone serial; Integrated in MCUs (MSP430); Retention > 10 years
    - Endurance of > 10^{14} cycles; read is destructive (must be followed by write)

Ferroelectric random access memory (FRAM)
- Up to 64KB of nonvolatile memory
- Ultra-low-power writes
- Fast write at 125 ns per word (64KB in 4 ms)
- Unified memory = program + data + storage in one single space
- 10^{15} write cycle endurance
- Radiation resistant and nonmagnetic

Ref: https://www.ti.com/lit/ds/symlink/msp430fr5043.pdf

Reducing energy losses

- **Memory technologies**
  - MRAM; very good endurance and retention; fast and low power.
    - Stand alone or embedded
    - High end MCUs (Apollo4, Gap9)
  - ReRAM: Low power; Retention > 10 years
    - Endurance better than Flash but not as good as FRAM/MRAM
    - Many issues in production have led to slow down of commercialisation
    - Renewed interest

EVERSPIN TECHNOLOGIES MR25H256

FEATURES

- No write delays
- Unlimited write endurance
- Data retention greater than 20 years
- Automatic data protection on power loss
- Block write protection
- Fast, simple SPI interface with up to 40 MHz clock rate
- 2.7 to 3.6 Volt power supply range
- Low current sleep mode

https://www.everspin.com/getdatasheet/MR25H256

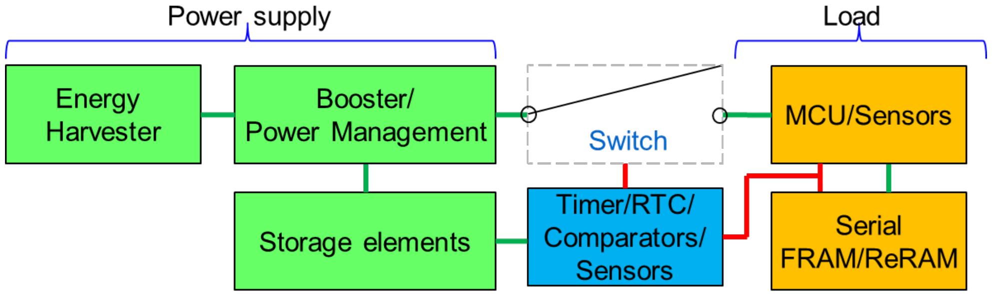
FEATURES

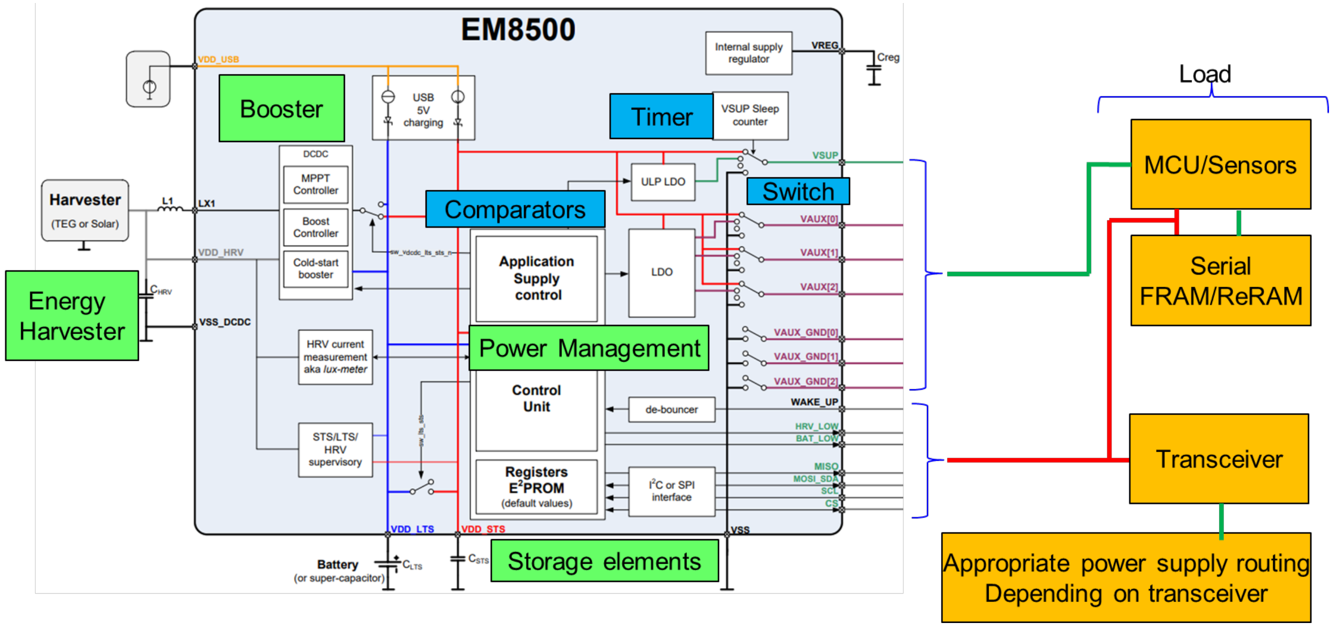
• Bit configuration	: 8 Mbits (1,048,576 words × 8 bits)
• Serial Peripheral Interface	: SPI (Serial Peripheral Interface) Correspondent to SPI mode 0 (0, 0) and mode 3 (1, 1)
• Write buffer size	: 256 bytes
• Operating frequency	: 10 MHz (Max)
• Data endurance	: 1×10^6 times / 4bytes* *4 bytes are selected by A1 to A0.
• Data retention	: 10 years (+85 °C)
• Operating power supply voltage	: 1.6 V to 3.6 V
• Operating power supply current	: Write current 1.5 mA (Typ) Read current 0.15 mA (Typ@5 MHz) Standby current 60 µA (Typ) Sleep current 6 µA (Typ)

ReRAM reference: https://www.fujitsu.com/jp/group/fsm/en/documents/products/reram/lineup/MB85AS8MT-DS501-00060-2v1-E.pdf

Implementation

- The EM8500/EM8502 integrates several of the needed blocks
  - Booster that allows the use of solar cells
  - The switch and the timer are internal
    - ► The switch can be controlled by the internal low power timer





Implementation

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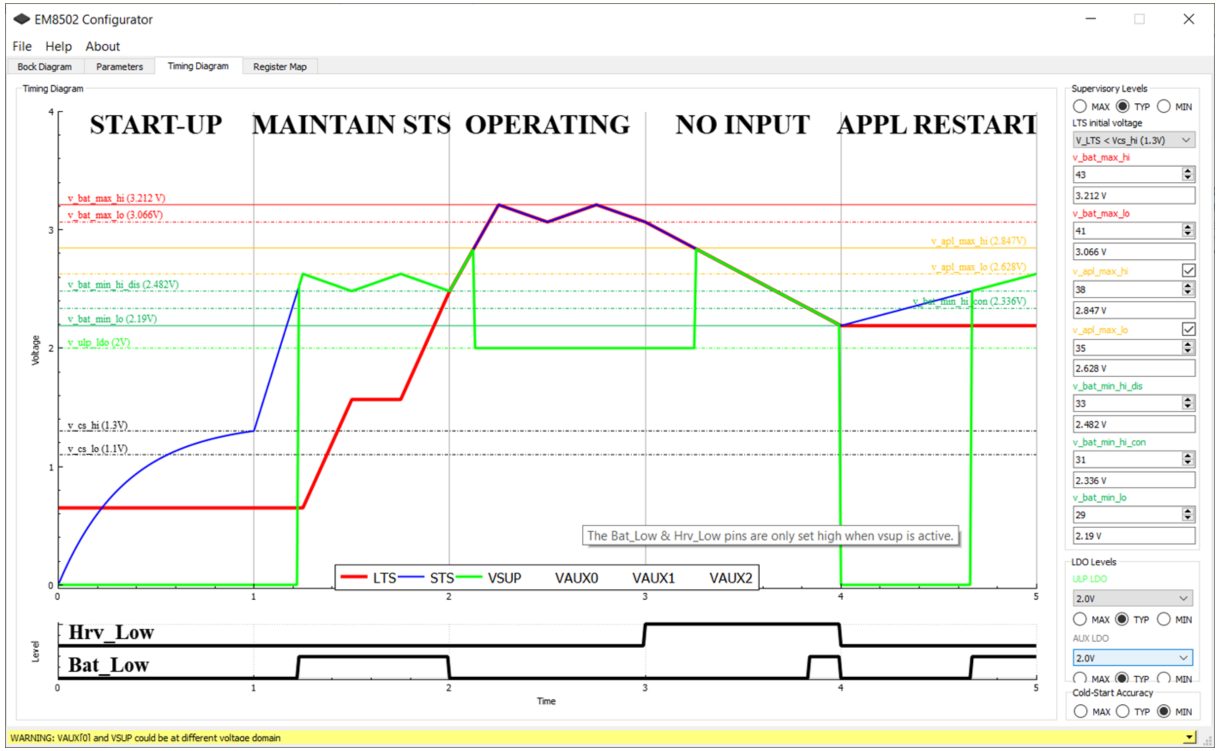
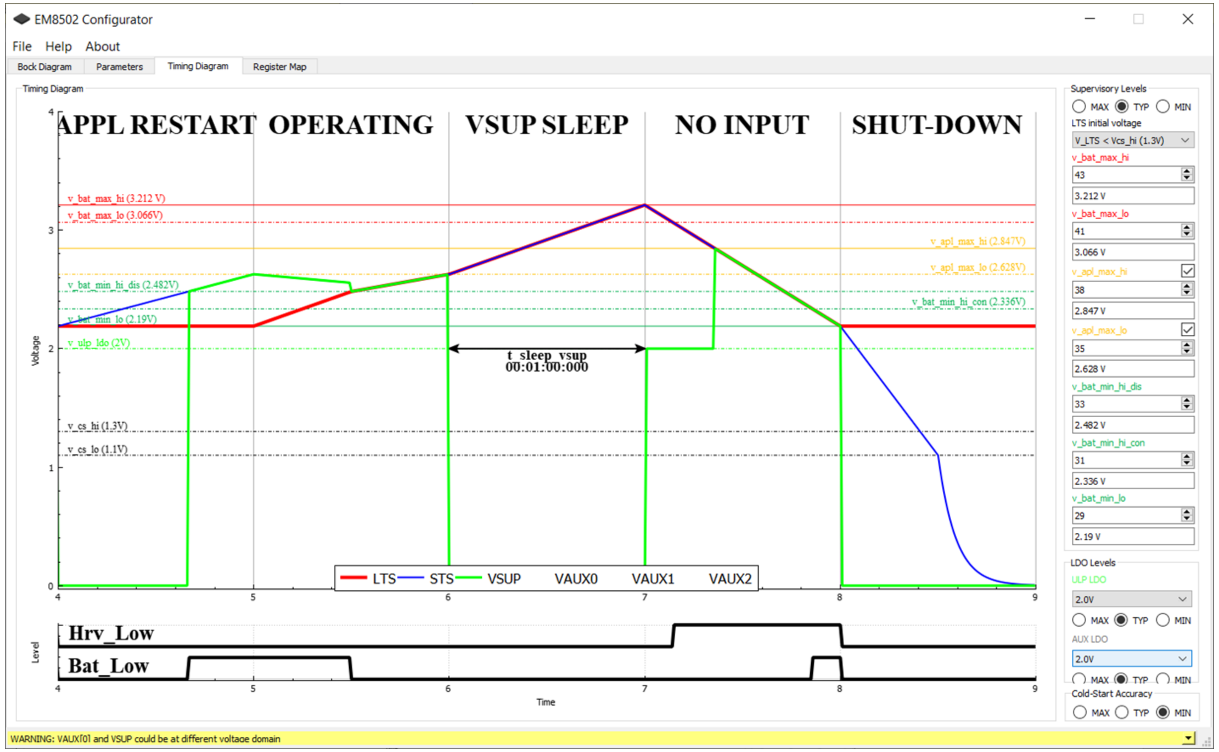
The ZHAW configurator can be used to set the parameters such as comparator thresholds, LDO values, timer value (to control the switch)





Implementation

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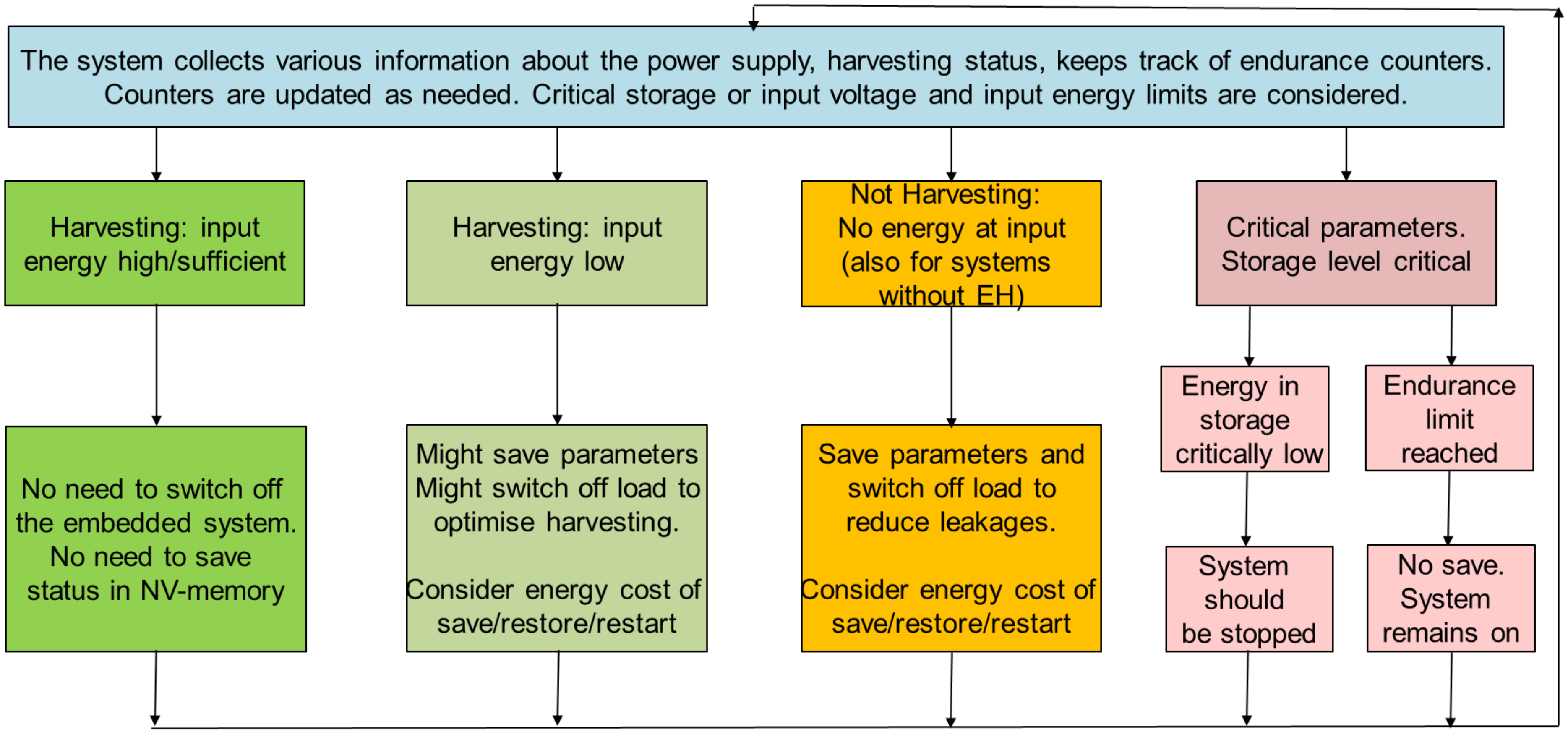
Take memory and power supply parameters into account. Save in NV memory only when needed

Example of chart that could help optimise the use of the method



Evaluation of a ReRAM MCU

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- **Why?**
  - ReRAM is seen as a potentially low-cost technology
  - There is renewed interest in that technology
  - We intend to use it for IoT nodes. Not much has been done in that direction
- **The device**
  - 8-bit MCU from Panasonic. Launched in 2013
  - Operating voltage and frequency 1.1V to 3.6V ; 40KHz – 10 MHz
  - Program memory: ReRAM with 1000 endurance of cycles
  - Data memory: ReRAM with 100’000 endurance cycles
  - ReRAM min read voltage 1.1V; Min write voltage 1.3V

Evaluation of a ReRAM MCU

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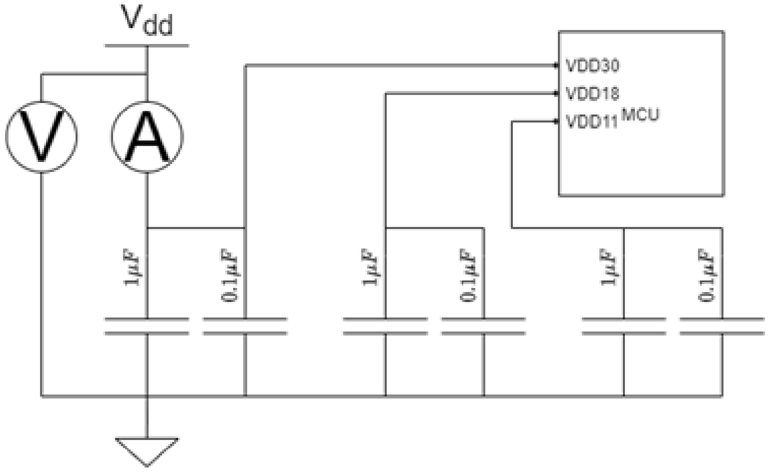
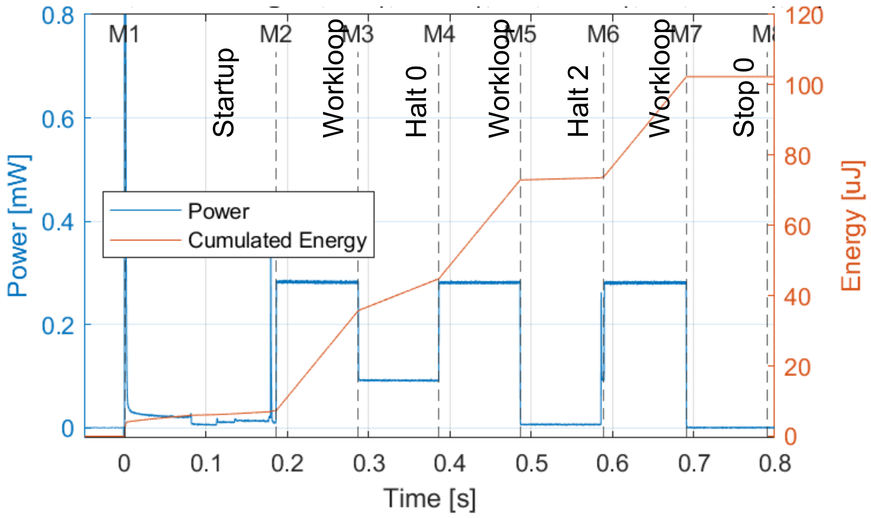
Measurement setup:



Measurement with 1MHz Clock speed @ 1.3V:

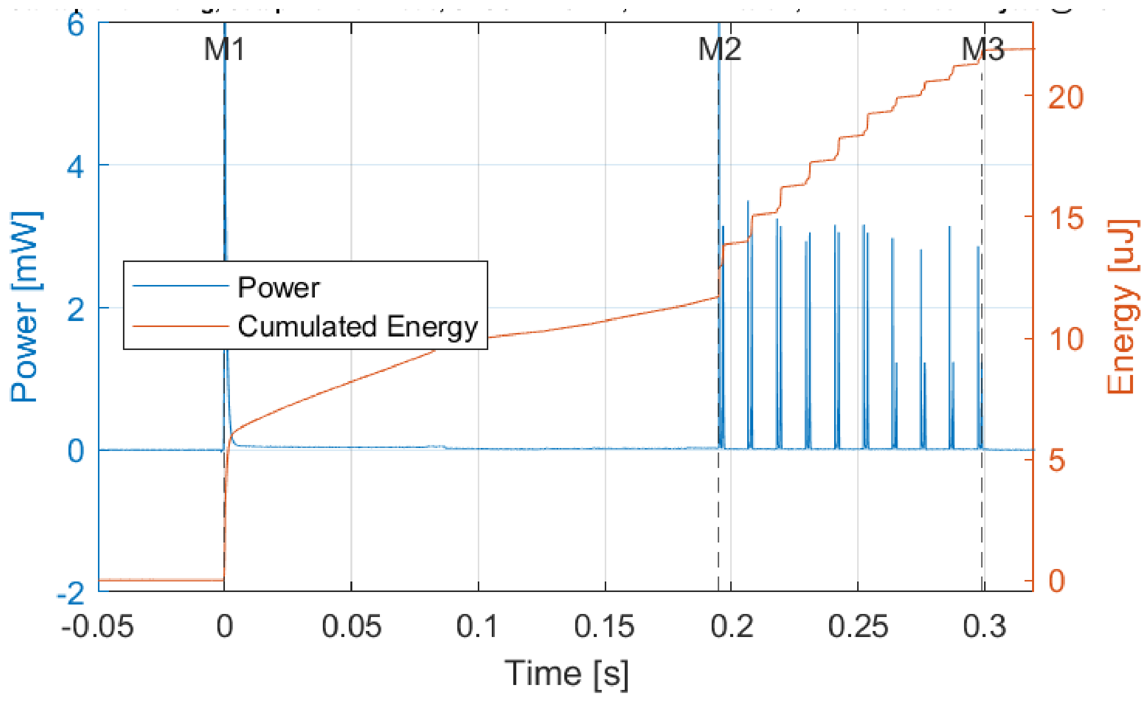


Measurements of energy consumption give values that mostly fit with the manufacturer’s specifications:

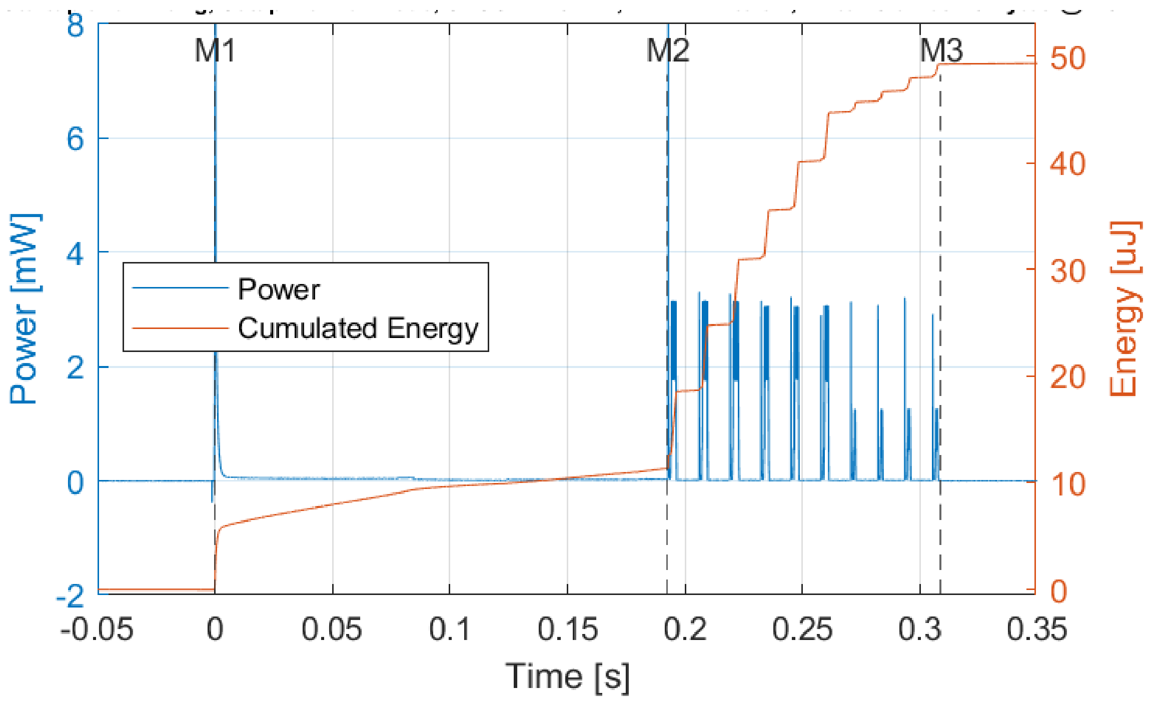
Setup	Startup	Startup		Workloop / Halt0/ Halt2 / Stop0
Clock speed	**Voltage supply**	**Duration**	**Energy consumption**	**meanpower**
10 MHz	1.8 V	184.00 ms	11.70 uJ	3632.0 uW / 540.17 uW / 24.36 uW / 0.33 uW
1 MHz	1.8 V	192.00 ms	11.56 uJ	408.21 uW / 142.88 uW / 18.35 uW / 2.39 uW (?)
1 MHz	1.3 V	186.00 ms	6.74 uJ	280.61 uW / 93.27 uW / 8.00 uW / 0.51 uW
Setup	**Startup**	**Startup**		**Workloop / Halt1 / Halt3 / Stop1**
Clock speed	**Voltage supply**	**Duration**	**Energy consumption**	**meanpower**
40 KHz	1.8 V	179.00 ms	10.55 uJ	24.43 uW / 11.42 uW / 9.63 uW / 0.48 uW
40 KHz	1.3 V	167.00 ms	5.60 uJ	16.84 uW / 7.93 uW / 6.99 uW / 0.15 uW
40 KHz	1.1 V	170.00 ms	4.13 uJ	13.82 uW / 6.39 uW / 5.64 uW / 0.10 uW

Evaluation of a ReRAM MCU

- Startup MCU in Slow Mode (SYSCLK: 40Khz)
- write 10 times **2 Bytes** to ReRAM (1 MHz write clk)
  - 6 times change of bits
  - 4 times no change of bits



- Startup MCU in Slow Mode (SYSCLK: 40Khz)
- write 10 times **20 Bytes** to ReRAM(1 MHz write clk)
  - 6 times change of bits
  - 4 times no change of bits

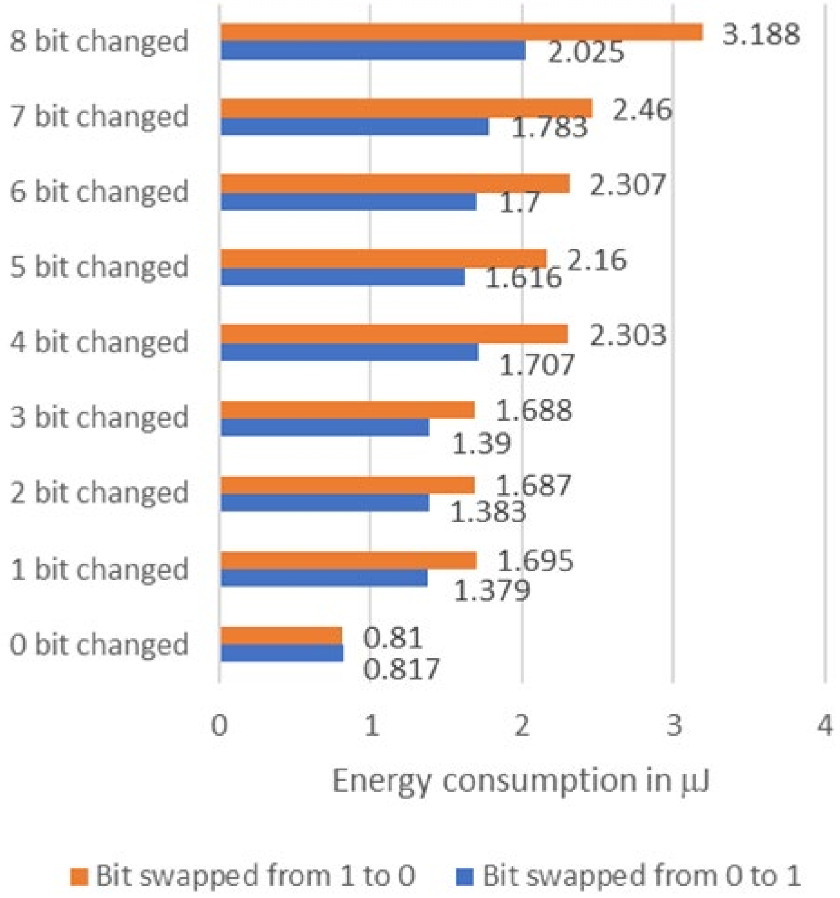


Evaluation of a ReRAM MCU

Comparison of power consumption depending on memory-cell content (Setup: Normal mode, SYSCLK: 10 MHz, 10 MHz write clk, write 18 times 1 Byte)

The writing process does not always require the same amount of energy.

Fewer the number of bit changes → less energy required for the write process. This can be used to define some variables in a way that the required energy is minimized.



Evaluation of a ReRAM MCU

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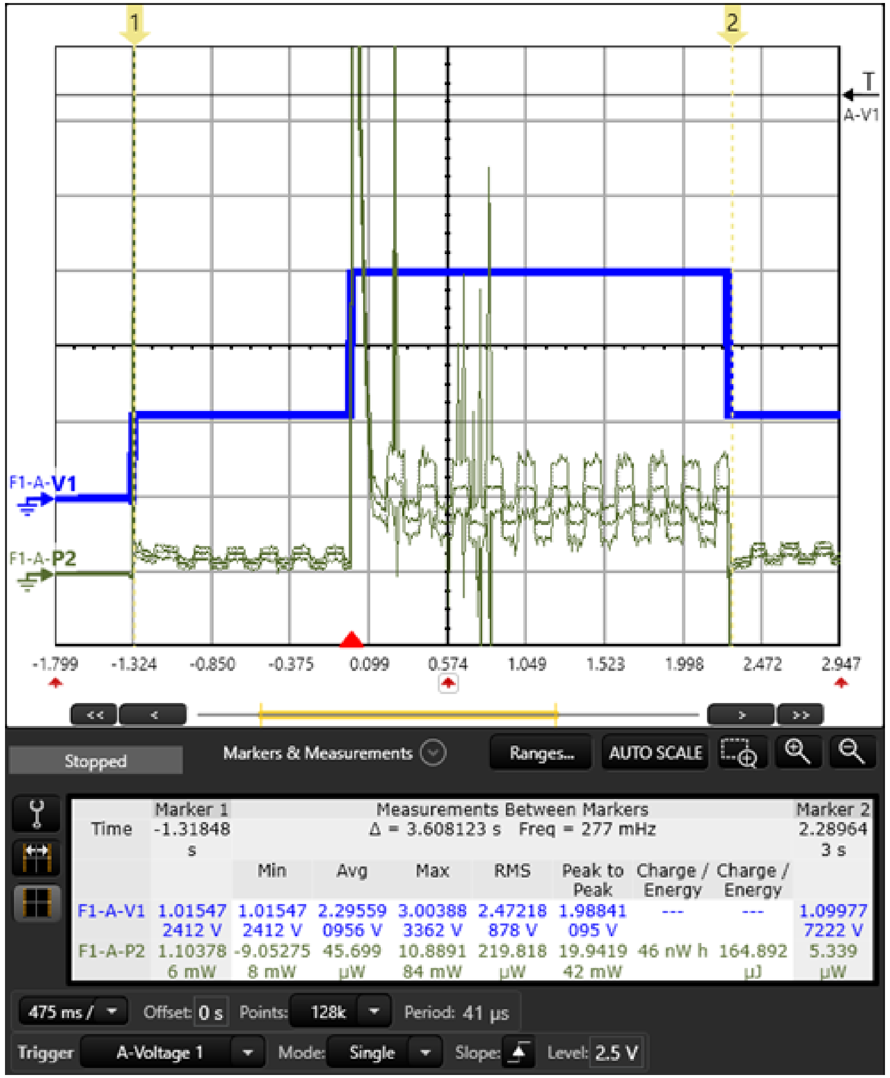
Monitoring of supply voltage

- Change of supply voltage → interrupt
- Useful when PSU not stable (e.g. use of EH)
- Measurement scenario. Starts with power off
  - PSU at 1.1V. Tasks run at 40KHz
  - PSU at 3V
    - ReRAM accessed in interrupt routine
    - MCU then returns to previous task.
  - PSU back to 1.1V
    - System continues tasks
- Power at 1.1V 4 times less that power at 3V



Conclusions

- **Current LP modes**
  - Allow important energy optimisation
  - However, there is potential for more savings in some cases
- **Careful use of NV memories such as FRAM/MRAM/ReRAM**
  - Low power read/write operation is advantageous
  - Take into account memory parameters
    - Endurance is a critical parameter
  - Take into account power supply characteristics
    - Energy harvesting systems introduce other requirements
  - Careful design enables substantial improvements
  - Keep and eye on ReRAM (if it really proves to be low-cost)

Question time

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Example of configuration setting of the PM

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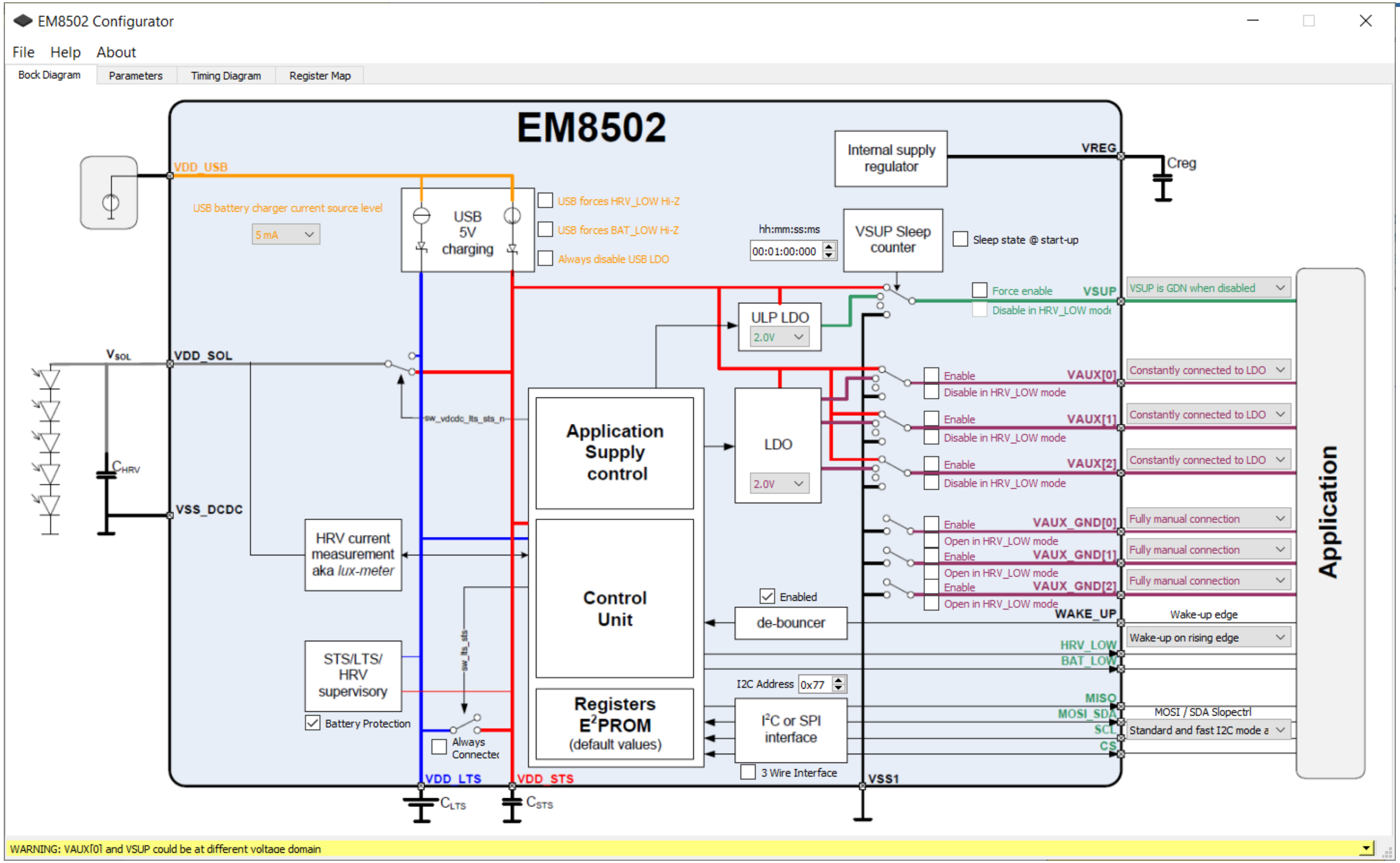

Example of configuration setting of the PM

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EM8502 Configurator

File Help About

Bock Diagram | Parameters | Timing Diagram | Register Map

	RegName in EEPROM area	Address	Related Register	Imp Value [hex]	Calc Value [hex]	Overwrite Value [hex]	Effective value [hex]	Physical representation
1	eeprom0	0x40	reg_t_hrv_period	0x05	0x05		0x05	8192 ms
2	eeprom1	0x41	reg_t_hrv_meas	0x03	0x03		0x03	128 ms
3	eeprom2	0x42	reg_t_sts_period	0x02	0x02		0x02	8 ms
4	eeprom3	0x43	reg_t_lts_period	0x05	0x05		0x05	1024 ms
5	eeprom4	0x44	reg_v_hrv_cfg	0x01	0x01		0x01	0.146 V (Typ) | Current Measurement ...
6	eeprom5	0x45	reg_hrv_check_lvl	0x01	0x01		0x01	2 µA
7	eeprom6	0x46	reg_lts_cfg	0x00	0x00		0x00	rechargable battery | battery protection:...
8	eeprom7	0x47	reg_v_bat_max_hi	0x29	0x2B		0x2B	3.212 V (Typ)
9	eeprom8	0x48	reg_v_bat_max_lo	0x28	0x29		0x29	3.066 V (Typ)
10	eeprom9	0x49	reg_v_bat_min_hi_dis	0x1E	0x21		0x21	2.482 V (Typ)
11	eeprom10	0x4A	reg_v_bat_min_hi_con	0x1E	0x1F		0x1F	2.336 V (Typ)
12	eeprom11	0x4B	reg_v_bat_min_lo	0x1D	0x1D		0x1D	2.19 V (Typ)
13	eeprom12	0x4C	reg_v_apl_max_hi	0x25	0x26		0x26	2.847 V (Typ)
14	eeprom13	0x4D	reg_v_apl_max_lo	0x21	0x23		0x23	2.628 V (Typ)
15	eeprom14	0x4E	reg_ldo_cfg	0x91	0xC4		0xC4	VAUX LDO: 2.0V | ULP LDO: 2.0V
16	eeprom15	0x4F	reg_pwr_cfg	0x00	0x00		0x00	
17	eeprom16	0x50	reg_vaux_cfg	0x00	0x15		0x15	
18	eeprom17	0x51	reg_vaux_gnd_cfg	0x00	0x00		0x00	
19	eeprom18	0x52	reg_mppt_ratio	0x06	0x06		0x06	80%
20	eeprom19	0x53	reg_ext_cfg	0x61	0x61		0x61	USB crt source: 5 mA | Wake-up on: ...
21	eeprom20	0x54	reg_t_sleep_vsup_lo	0xE8	0x60		0x60	Sleep delay
22	eeprom21	0x55	reg_t_sleep_vsup_mid	0x03	0xEA		0xEA	h:min:sec:ms
23	eeprom22	0x56	reg_t_sleep_vsup_hi	0x00	0x00		0x00	00:01:00:000
24	eeprom23	0x57	reg_t_hrv_low_cfg	0x07	0x07		0x07	t_hrv_low_period: 256 ms | ...
25	eeprom24	0x58	reg_spi_i2c_cfg	0x77	0x77		0x77	I2C Address: 0x77
26	eeprom25	0x59	reg_pwr_mgt	0x00	0x00		0x00	

WARNING: VAUX[0] and VSUP could be at different voltage domain

Example of configuration setting of the PM