Hardware and energy consumption

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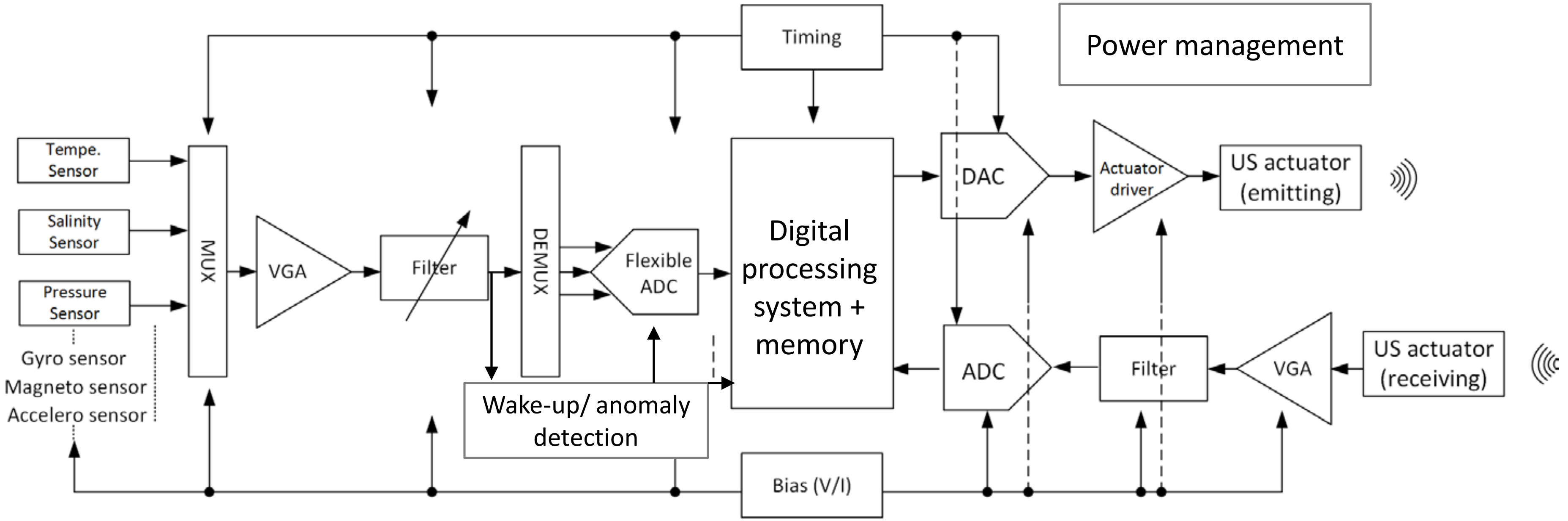
Phoenix hardware

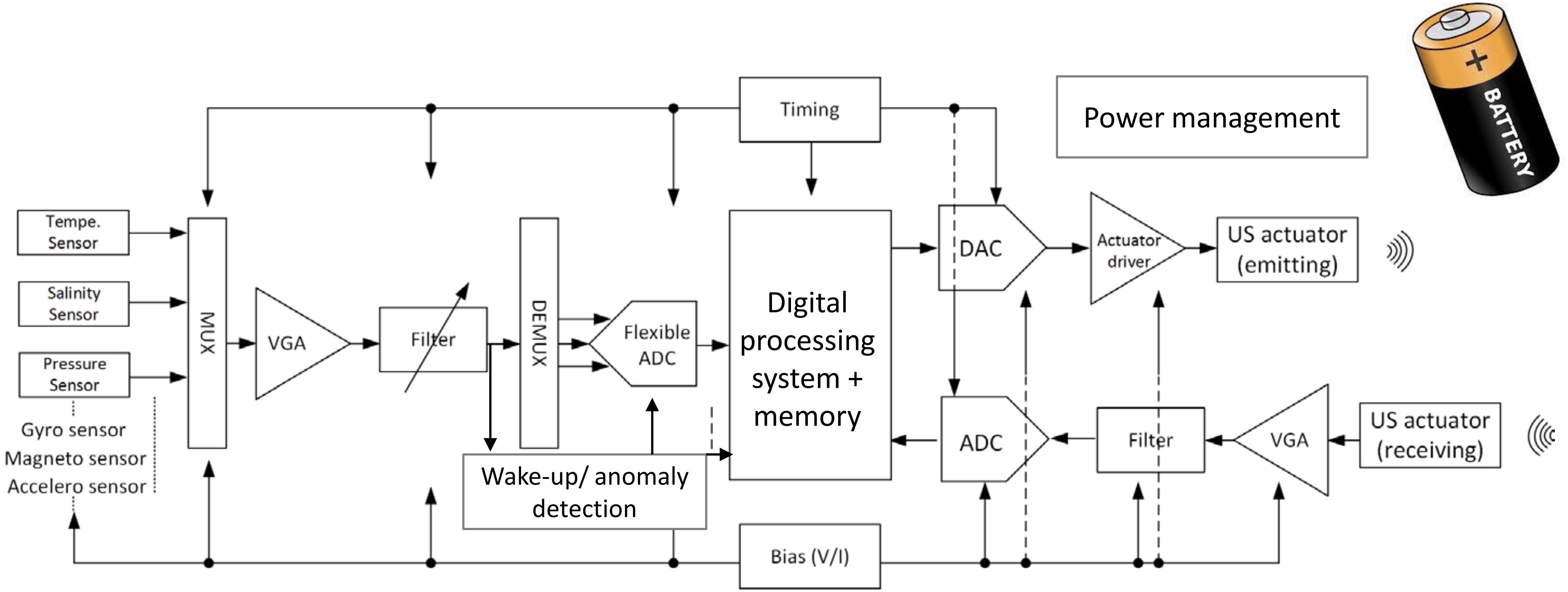
- Phoenix node will consist of
  - Sensors and timers
  - Sensor interface with wake-up detectors
  - Digital processing system with memory
  - US (maybe RF) actuator and receiver

More detail on each block later



Phoenix energy source

- Phoenix node is powered by a battery
  - 2cm^3 battery in INCAS3 mote in project phase1
  - 4mm^3 (?) battery in mm-size node later on

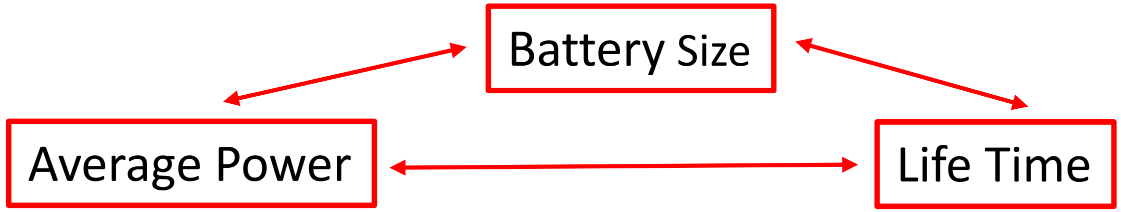


It’s all about energy…

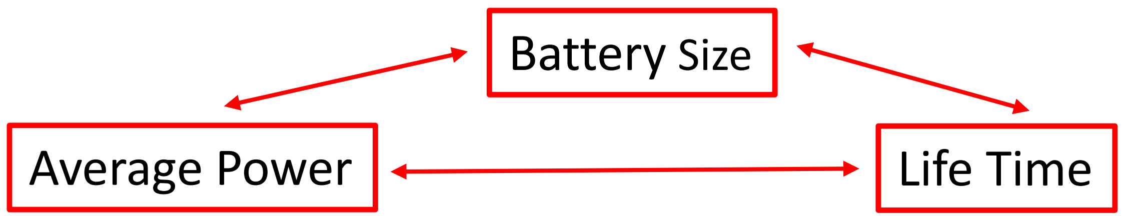
- Battery is a can full of energy
- Energy consumed by each “operation“, being
  - Taking sensor measurement, or actuating US or RF actuator
  - Processing sensor data with digital operations
  - Storing or retrieving data
- Constant energy consumed by “always on” circuits
  - Leaking digital gates and memory
  - Running timer
  - US receiver always in “listening mode”?

Note: Power consumption = average energy consumed per 1 second

Energy is expressed in Joules, power in Watts (=Joules/sec)

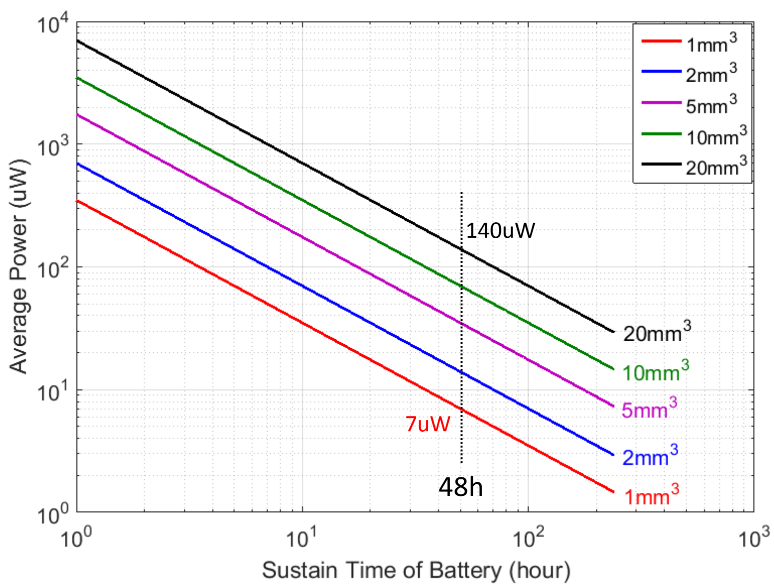


Battery Trade-offs

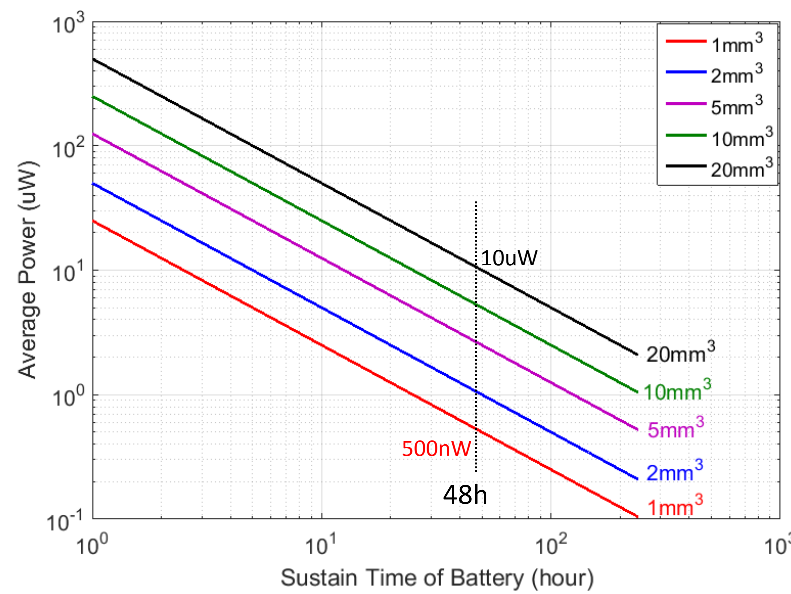


~14 times smaller

State-of-the-art battery research [4]



Commercial battery datasheet [5]

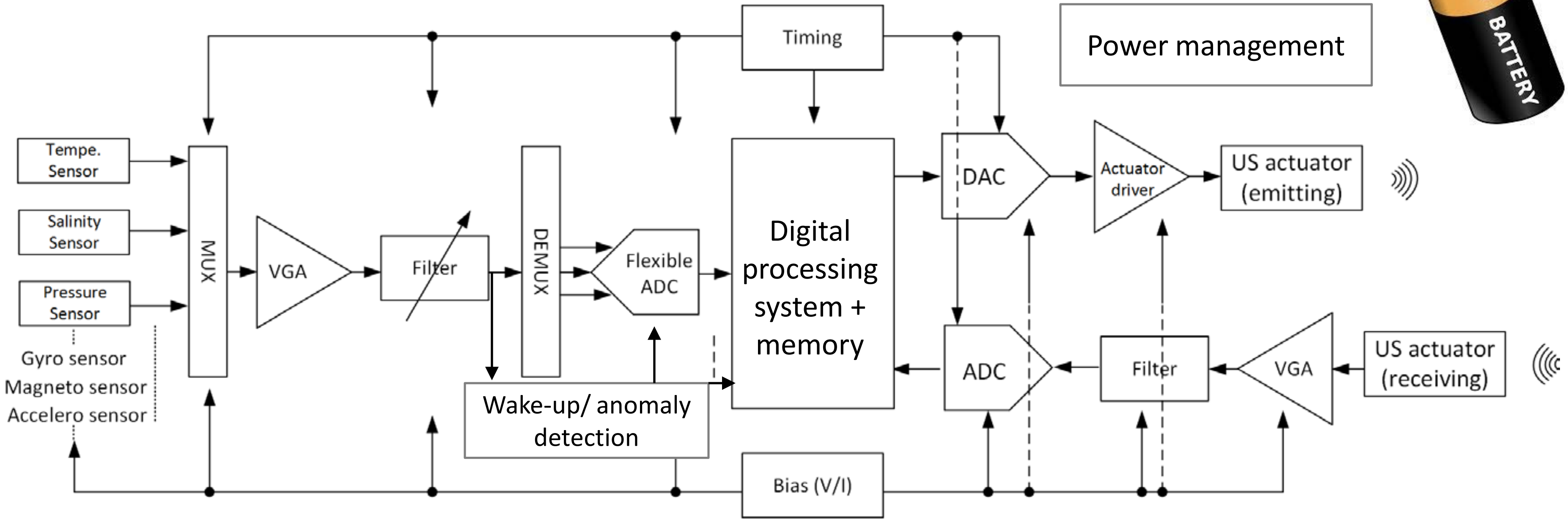


[4] H. Nakazawa, et al., "Charge–Discharge Characteristics of All-Solid-State Thin-Filmed Lithium-Ion Batteries Using Amorphous Nb2O5 Negative Electrodes," Journal of Power Sources 174, pp. 838-842, July 2007.

[5] www.cymbet.com/pdfs/**DS-72-41**.pdf

Energy constraints for Phoenix

- Phoenix node is powered by a battery
  - 2cm^3 battery in INCAS3 mote in project phase1
    - ➔ (48h): 170J, or 1mW on average
  - 4mm^3 (?) battery in mm-size node later on
    - ➔ (48h): 0.35J, or 2uW on average

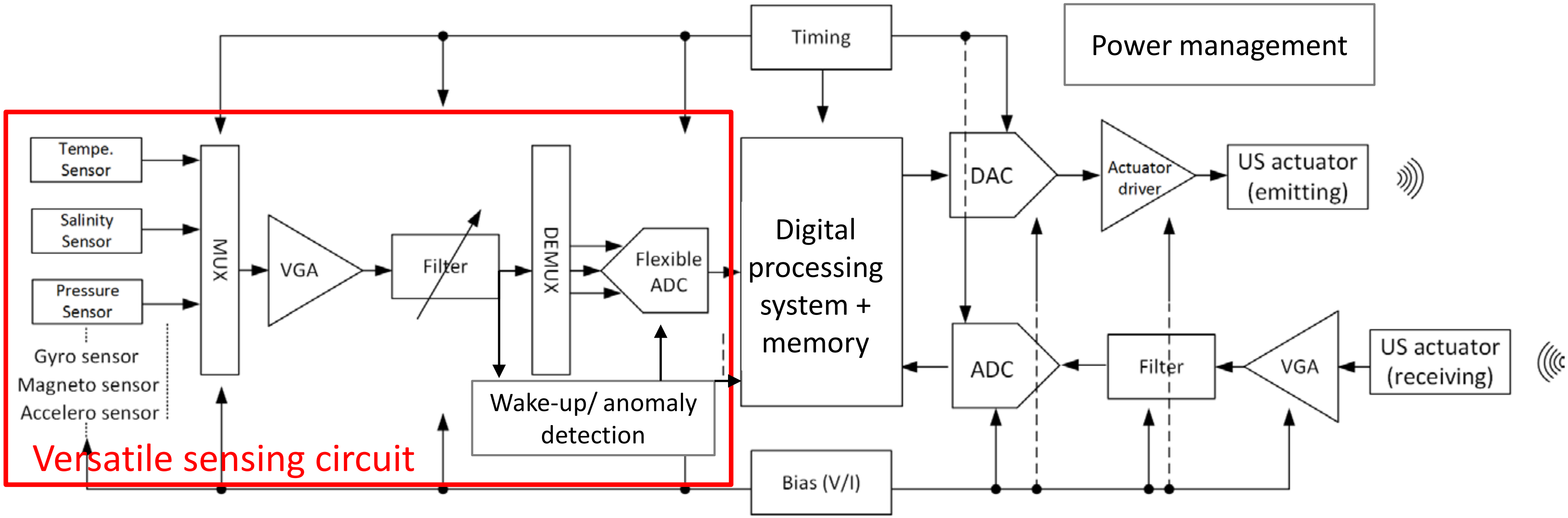


HOW MUCH ENERGY TO EACH FUNCTION?

1. Sensing
2. Actuation
3. Processing
4. Memory
5. Timing
6. Power management

1. Versatile Sensing

- Versatile sensing circuit for multiple sensors
- No need for extremely high precision sensing
- Could be duty-cycled for reducing power
- Needs smart wake-up monitors



* Example; actual topology to be researched

1. Versatile Sensing: energy consumption

- Energy per sensor measurement depends on:
  - Required sensitivity
  - Required sensor resolution (precision)
  - Required sensor biasing (depends on sensor type)
  - ➔ Hence rough to give detailed numbers (needs specs)

Sensor type	Energy per sensor measurement
Temperature	1-10nJ
Pressure	1-10μJ
Gyroscope	75μJ
Magnetometer	7.5μJ
Accelerometer	100nJ

1. Versatile Sensing: energy scenario

- Scenario: Take ***only*** accelero-measurements

→Phoenix mm3 size nodes allow 20 measurements per second (on all axis together)

→Phoenix cm3 size nodes allow 10ksamples per second, or 200kHz sampling for 2.5 hours

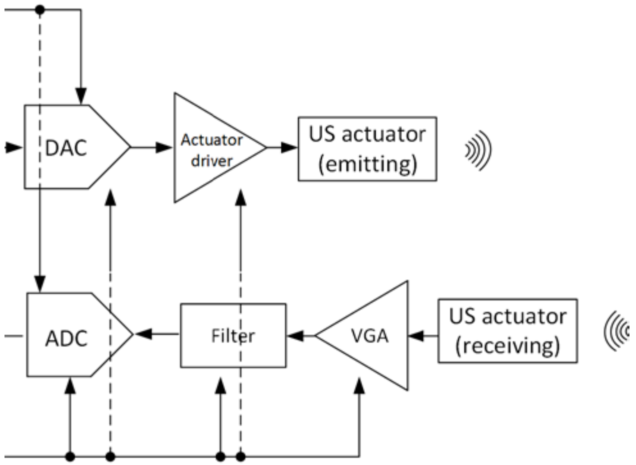
NEED for

- Duty cycling
- Smart wake-up circuits (across multi-sensors)

2. Actuation

- US and RF measurement also need actuation. This is typically more energy consuming
- Too many uncertainties to quantify now. But for now:
  - US or RF receive: 0.1nJ/bit
  - US or RF transmit: 10-100nJ/bit

Is probably rather optimistic…

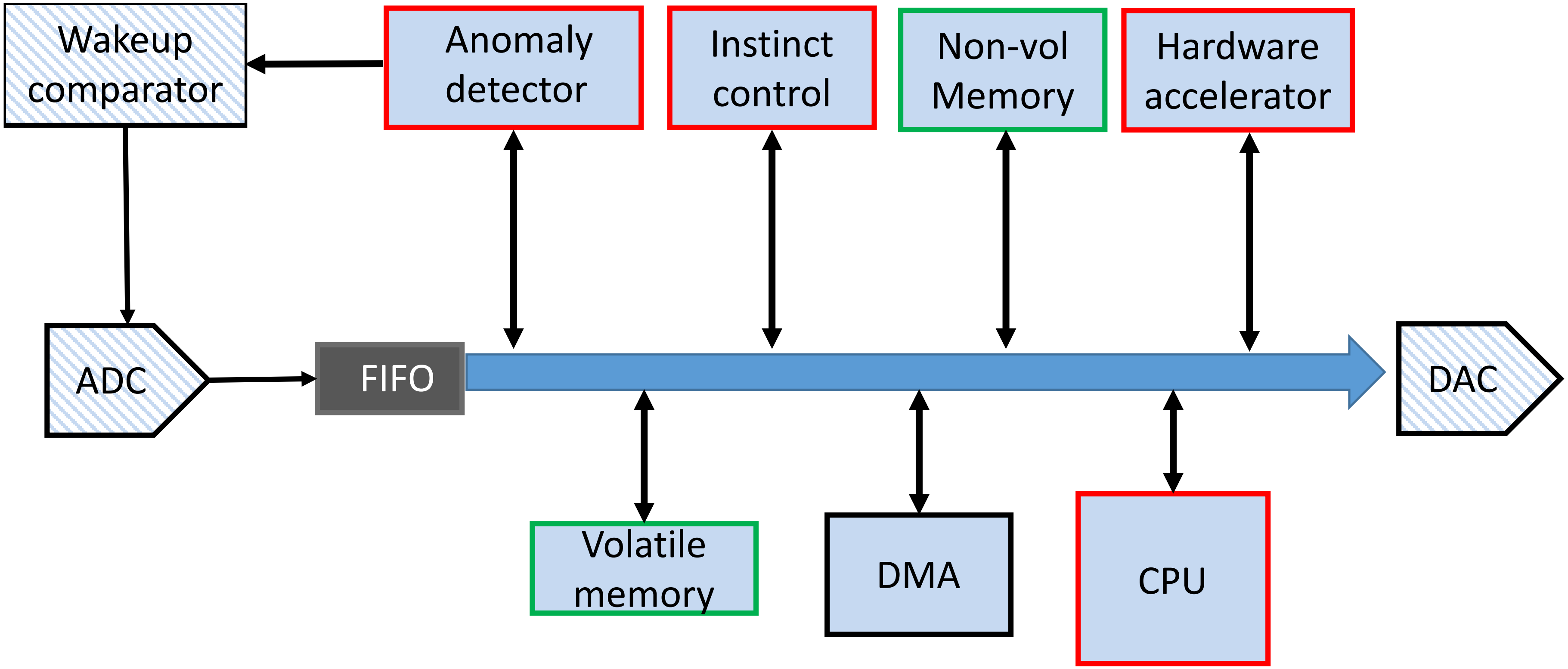


- If we want the US and RF receivers to always "hear" other motes, they have to be constantly monitoring

➔ Will consume constant power (e.g. 10μW)

See separate tutorial on US sensing/processing!

3. Processing



3. Processing energy

- Computations can be done
  A. On processor or on dedicated HW accelerator
  B. In processor in fixed, or floating point

  Rough energy numbers:

Processing type	Energy per (multiply) operation
Floating point	100pJ/operation
Fixed point (16bit)	10pJ/operation
HW accelerator	1pJ/operation

Note: Circuits that are on, leak energy. More so in advanced CMOS.

As our system will process SLOW, latest silicon technology not desirable. ➔ e.g. go for 90nmCMOS

4. Memory

- Memory spend energy in three ways:
  1. Every time you write into it
  2. Every time you read from it
  3. Constant to retain data (storage)
- Best to have volatile memory for intermediate data (buffer), and store long term things to non-volatile.

Memory type	Write energy (per bit)	Read energy (per bit)	Storage energy (per bit)
Volatile (flipflop)	?	?	?
Volatile (SRAM)	40pJ	40pJ	0.3pW
Non-volatile (on-chip)	5uJ	40pJ	~0
Non-volatile (Flash)	5uJ	5uJ	0

(On-chip memory limited to few (10's of)kB)

5. Timing

- To remember: when events occur and to time localization measurements, we need a time reference (watch) → 'always on', so power has to be low
- A frequency reference might also be needed for US/RF communication → much higher frequency, but can be duty-cycled
- Finally, a clock is probably needed for the DSP and mixed-signal blocks.

- Multiple frequencies can be derived from each other or use separate reference
- Power of the timer depends on: frequency, phase noise, variation over voltage and temperature (ppm), type of oscillator

Oscillator type	Example performance from literature
Crystal	50ppm, 2nW, 32kHz, 1.5mm^3
MEMS	10ppm, 1μW, 32kHz, 1.2mm^3
Ring	~2000ppm, 190nW, 32kHz, <<0.1mm^3
FBAR/SAW/BAW	>>100MHz, >>μW
LC	TBD

See separate tutorial on timing!

6. Power management

- All power for these circuits has to be derived from a common battery voltage
- This is typically done with voltage conversion and regulation blocks
- Their efficiency (output power/input power) is typically <100%, and is much lower for small current values.

Conclusions

- Every "action" in our system costs energy
- By characterizing these energy cost, the system can be optimized toward information maximization under the limited energy budget.
- Need to determine which sensors and processing is necessary
- Need to define their specification to improve energy estimates
- Duty cycling and instinct-based smart wake-up will be crucial!