Lecture 18
Wrapup

CE346 – Microprocessor System Design

Branden Ghena – Spring 2021

Some slides borrowed from:
Josiah Hester (Northwestern), Prabal Dutta (UC Berkeley)

Administrivia

- This is the last lecture!! 😭
  - No class on Monday

- Friday: Quiz 4

- Next week: Project Demos
  - See signup and details on Campuswire

Today’s Goals

- Discuss remaining parts of the Microbit and nRF52833
  - Realize that we’ve covered almost everything on the system!!

- Explore sensing systems research

Outline

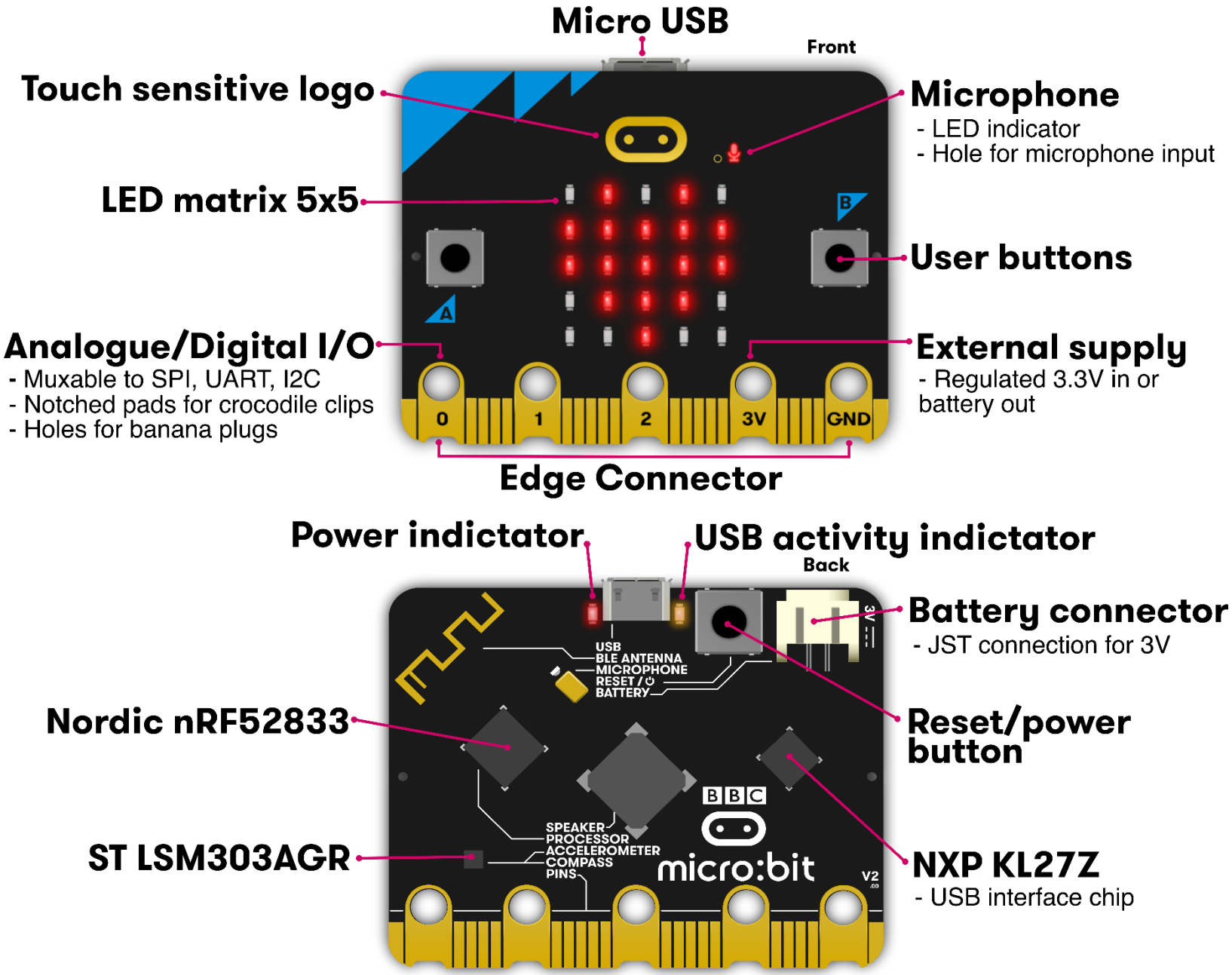
- **What haven’t we talked about?**
  - **Microbit**
  - nRF52833

- Sensing Systems Research

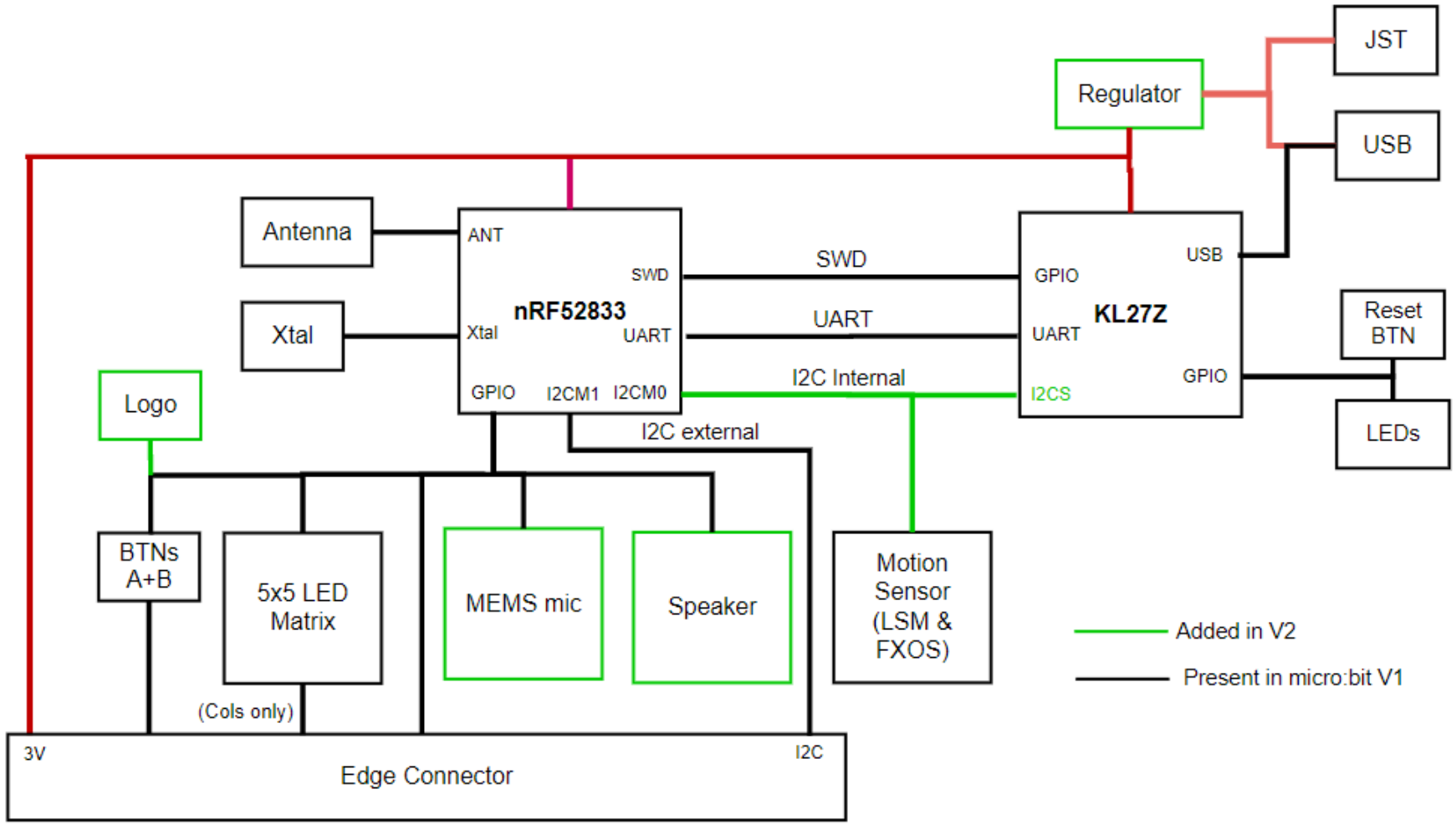
Microbit

- Used almost all of this!

- Remaining:
  - Batteries
  - Wireless
  - KL27Z I2C
  - Touch sensitive pads



Internal Microbit connections



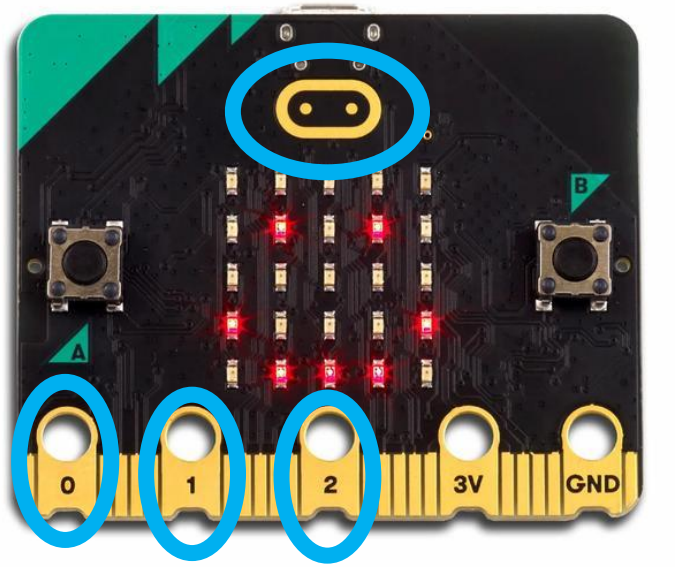
KL27 I2C Interface

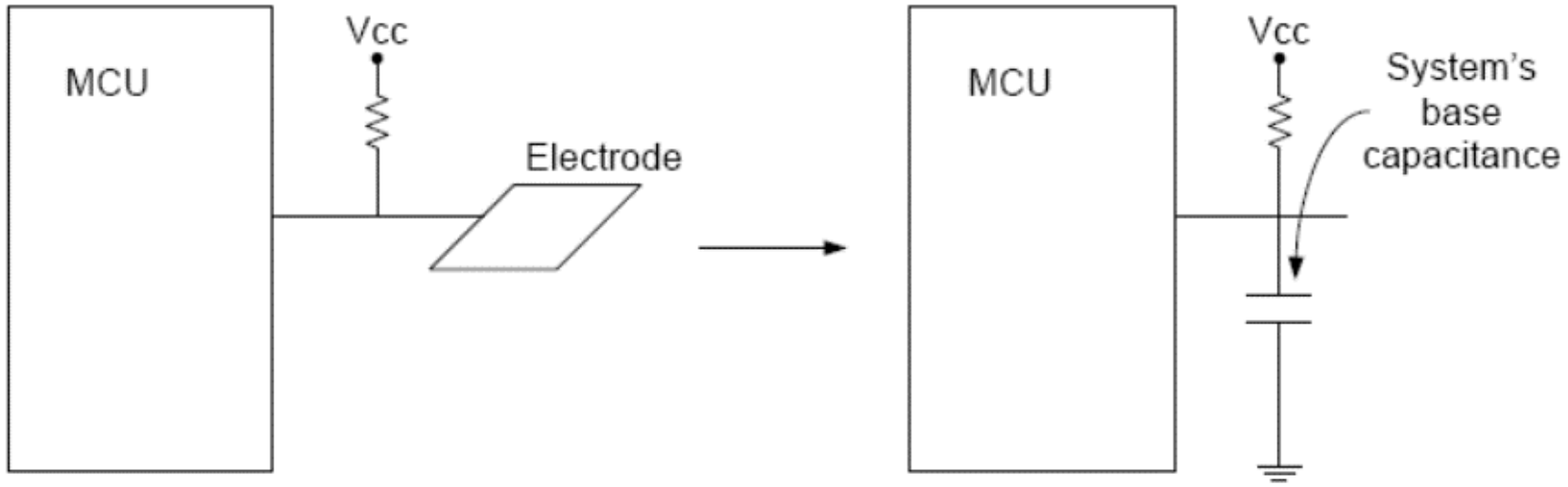
- Device information
  - Version of board and JTAG firmware
  - Power state of board
    - USB, Battery, both
    - Voltage values for battery and VIN
  - USB connection state
  - Disable the power LED!!

- Flash Storage
  - 128 kB of the KL27’s Flash is readable/writable over I2C

Capacitive Touch Sensor

- Pull-up resistors connected to metal pads
  - Also connected to GPIO pin
- Acts as a capacitor connected to ground





Capacitive touch sensing method

1. Drive GPIO pin low
   - Connects the pad to ground

2. Set GPIO pin as input and enable low-to-high interrupt
   - Pad is pulled high. This takes time based on capacitance
   - Use a timer to determine time until interrupt (order ~10 μs)

3. Repeat periodically

Sudden large increase in rise time ⇨ someone is touching!

- Finger acts as a large capacitor

Capacitive touch works on any metal surface

- Idea: Microbit door handle sensor

- Connect a wire and a pull-up resistor to a metal door handle to sense when someone is touching it!
  - Timing will be very different from capacitive pad, but should be repeatable and distinguishable from human touch

Outline

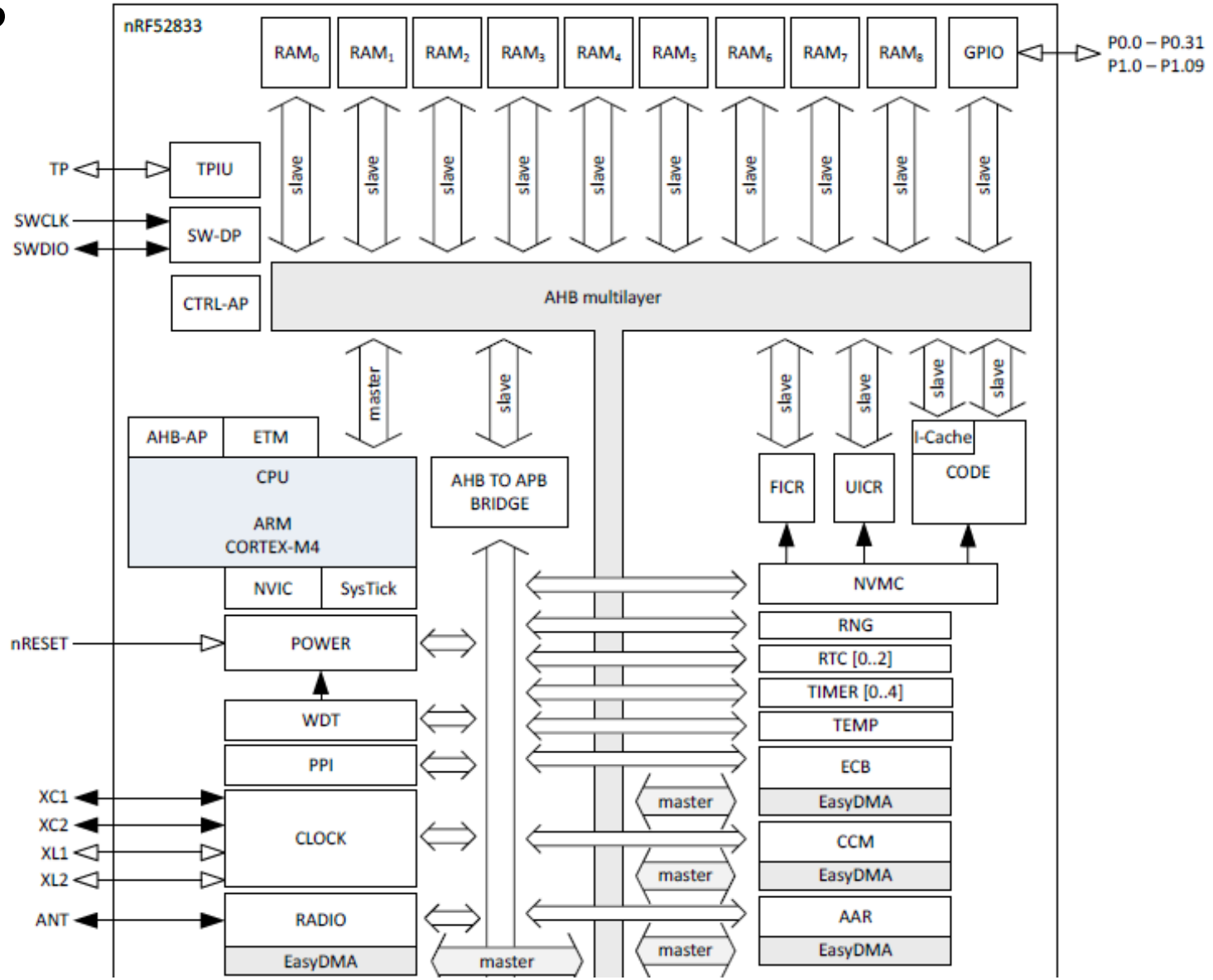
- **What haven’t we talked about?**
  - Microbit
  - **nRF52833**

- Sensing Systems Research

nRF52833 Peripherals

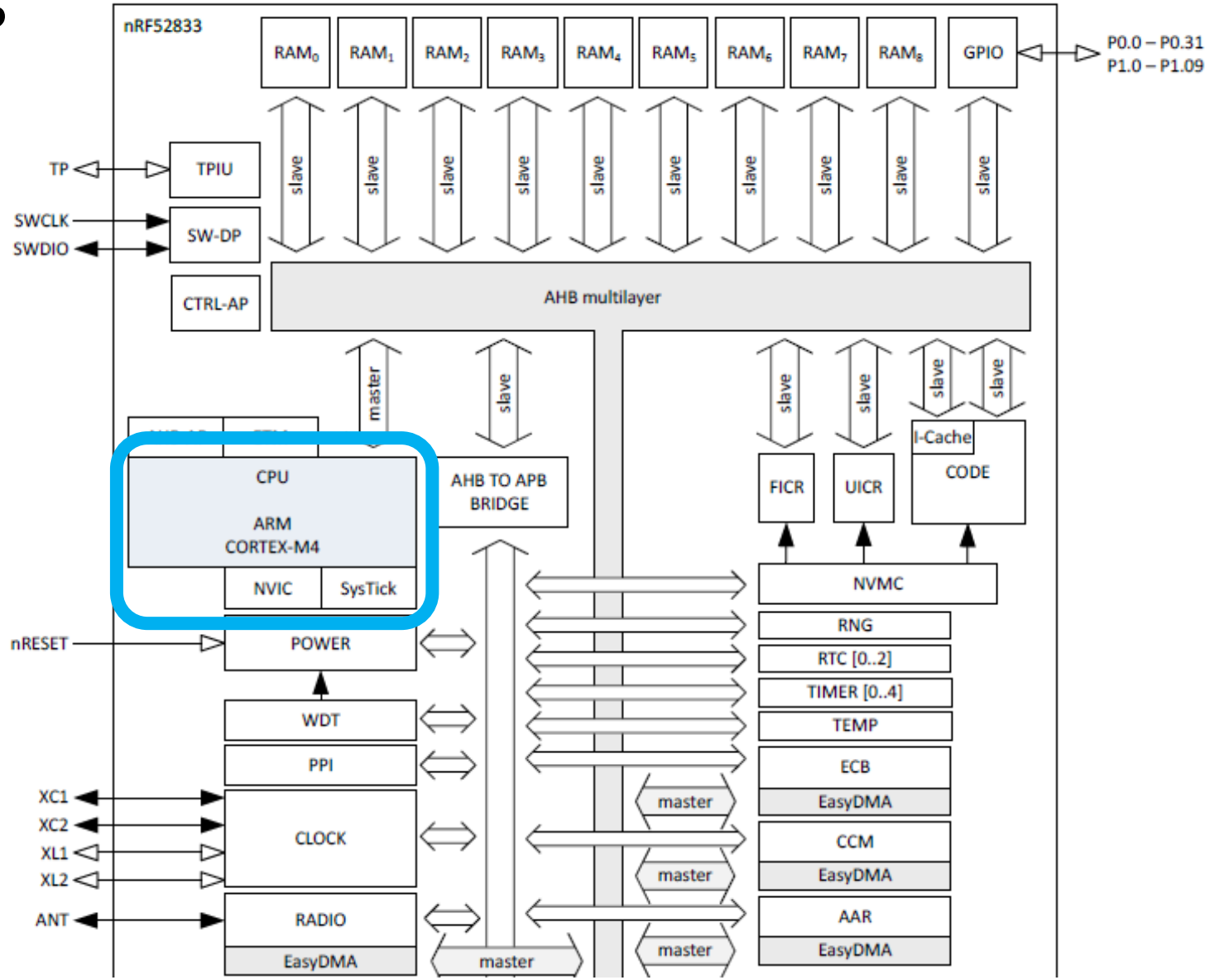
- Tour of the nRF52833 peripherals

- With some details on the ones we haven't talked about
  - Wireless
  - Crypto
  - Audio



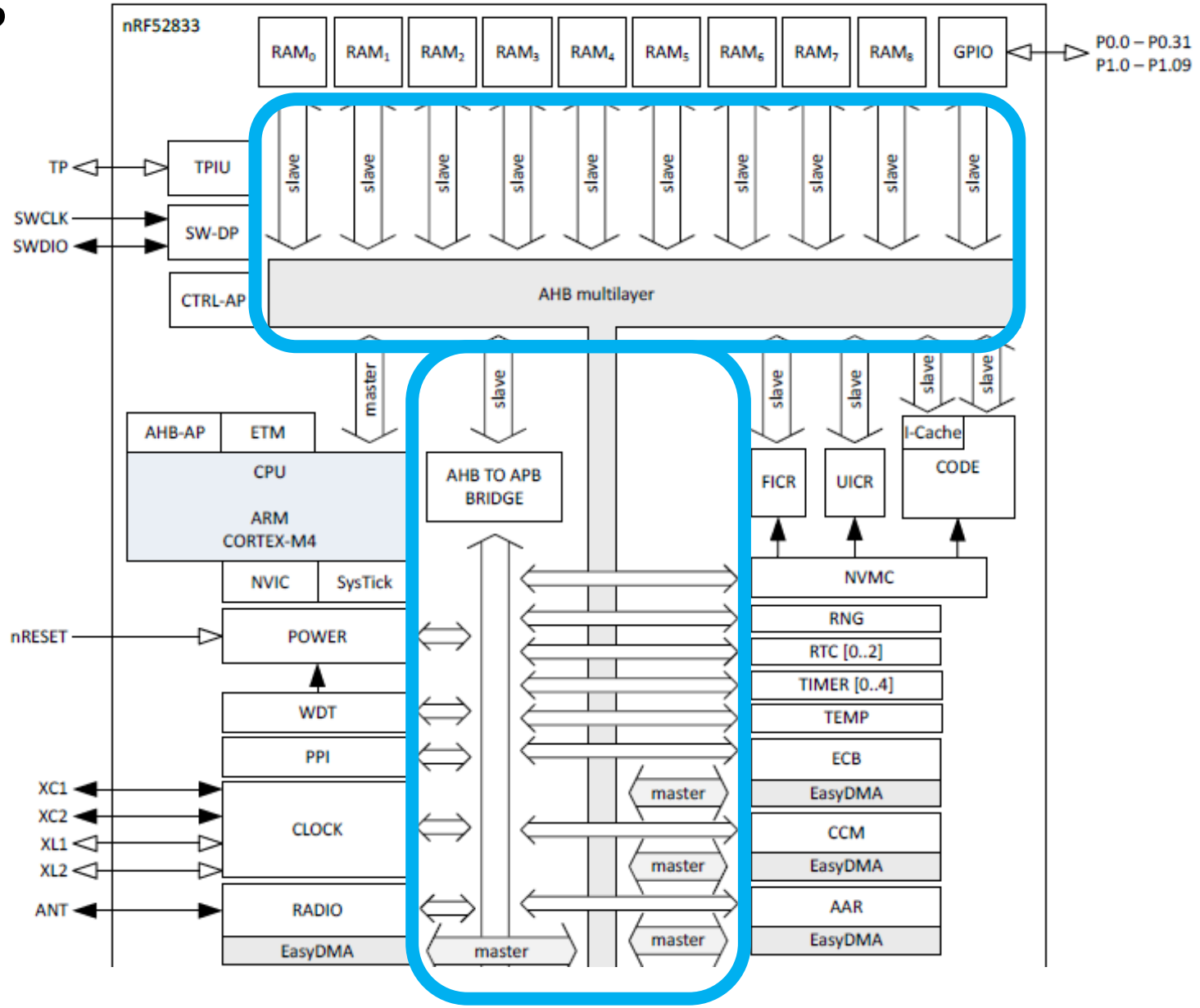
nRF52833 Peripherals

- Cortex-M4F processor
- 32-bit ARM core
- Floating point
- Includes Interrupt control and SysTick (an extra timer)



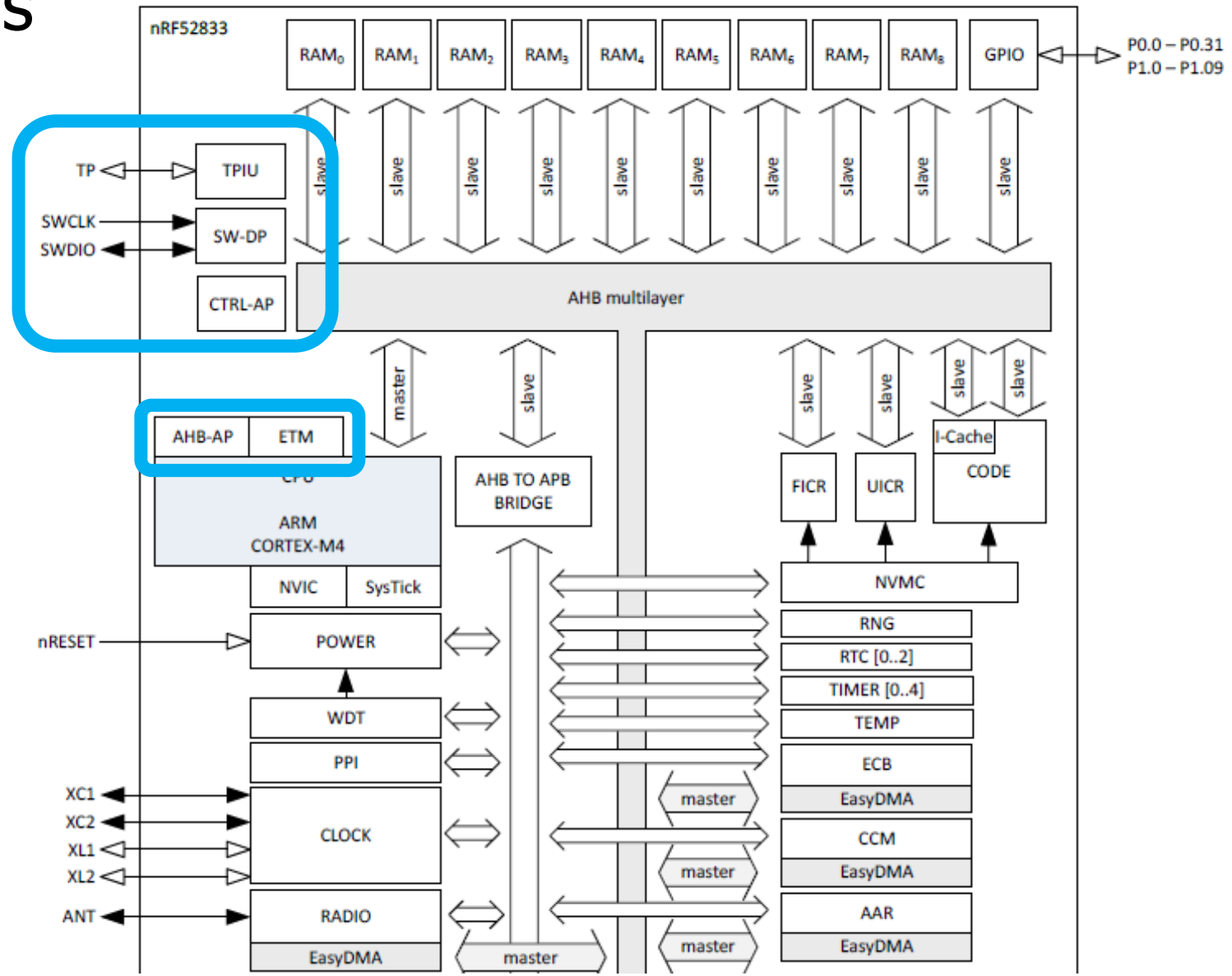
nRF52833 Peripherals

- Memory buses



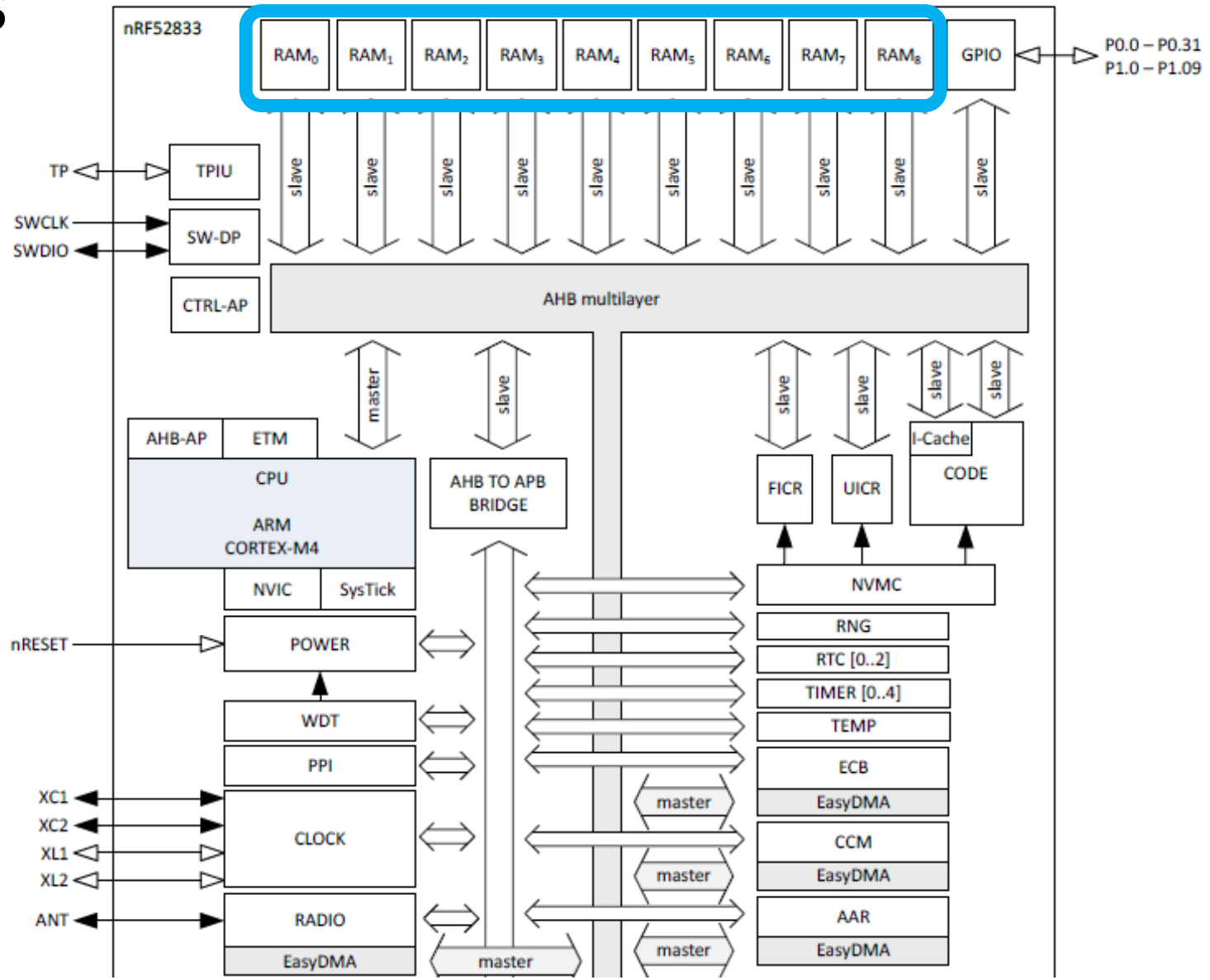
nRF52833 Peripherals

- JTAG and Debugging
- Allows code updates
- Allows GDB to step through code



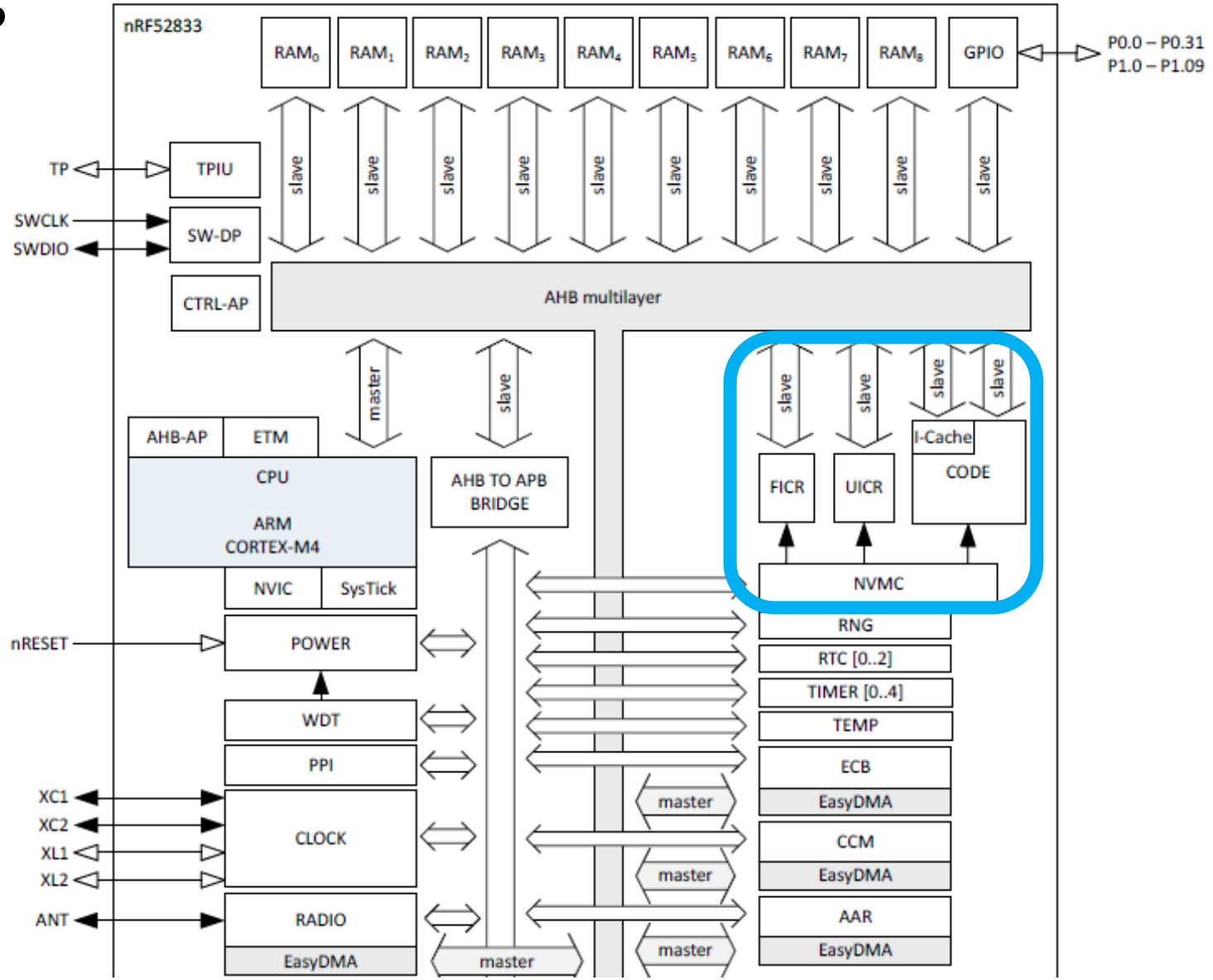
nRF52833 Peripherals

- Volatile memory
- SRAM, 128 kB



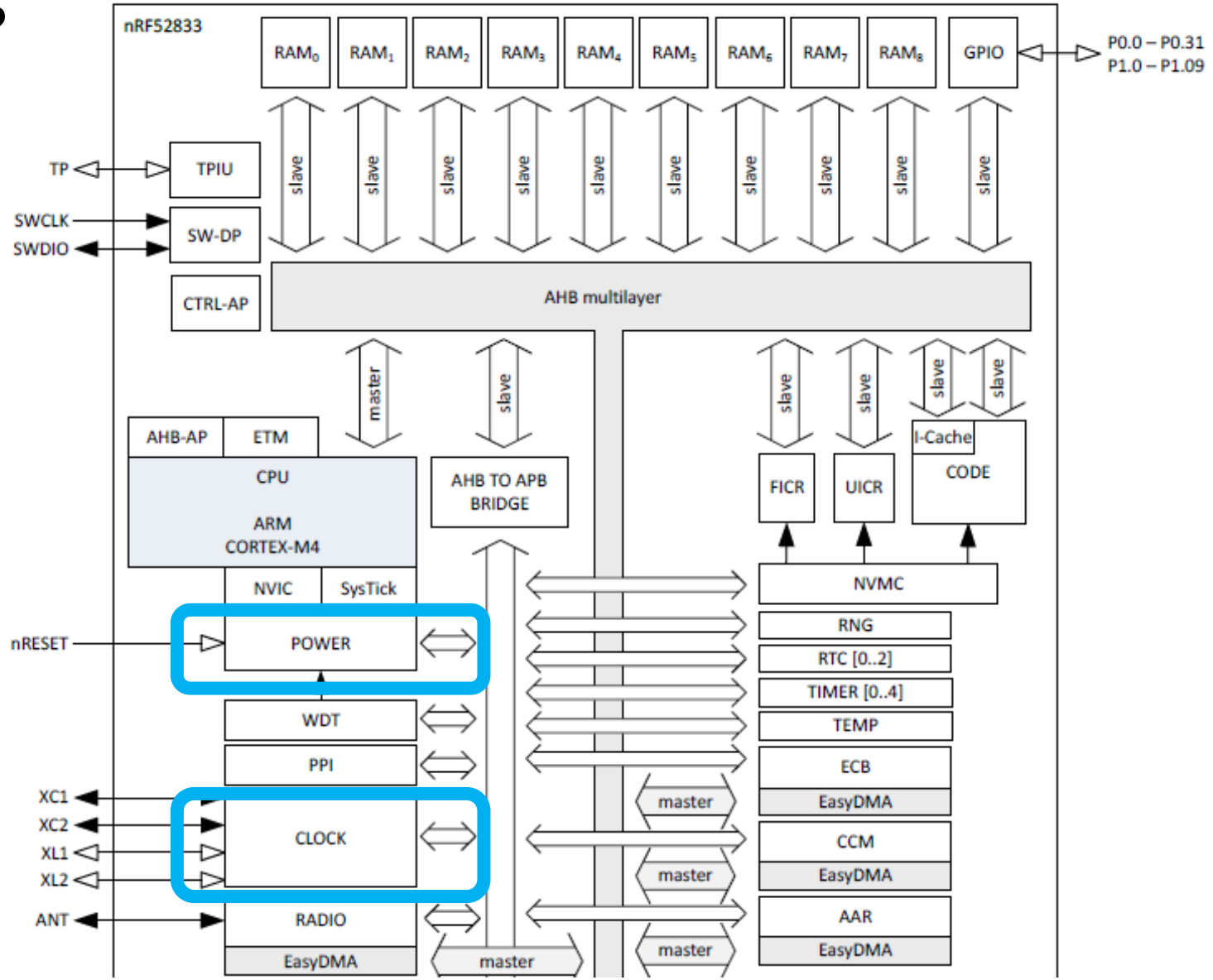
nRF52833 Peripherals

- Nonvolatile memory
- Flash, 512 kB
- Non-Volatile Memory Controller



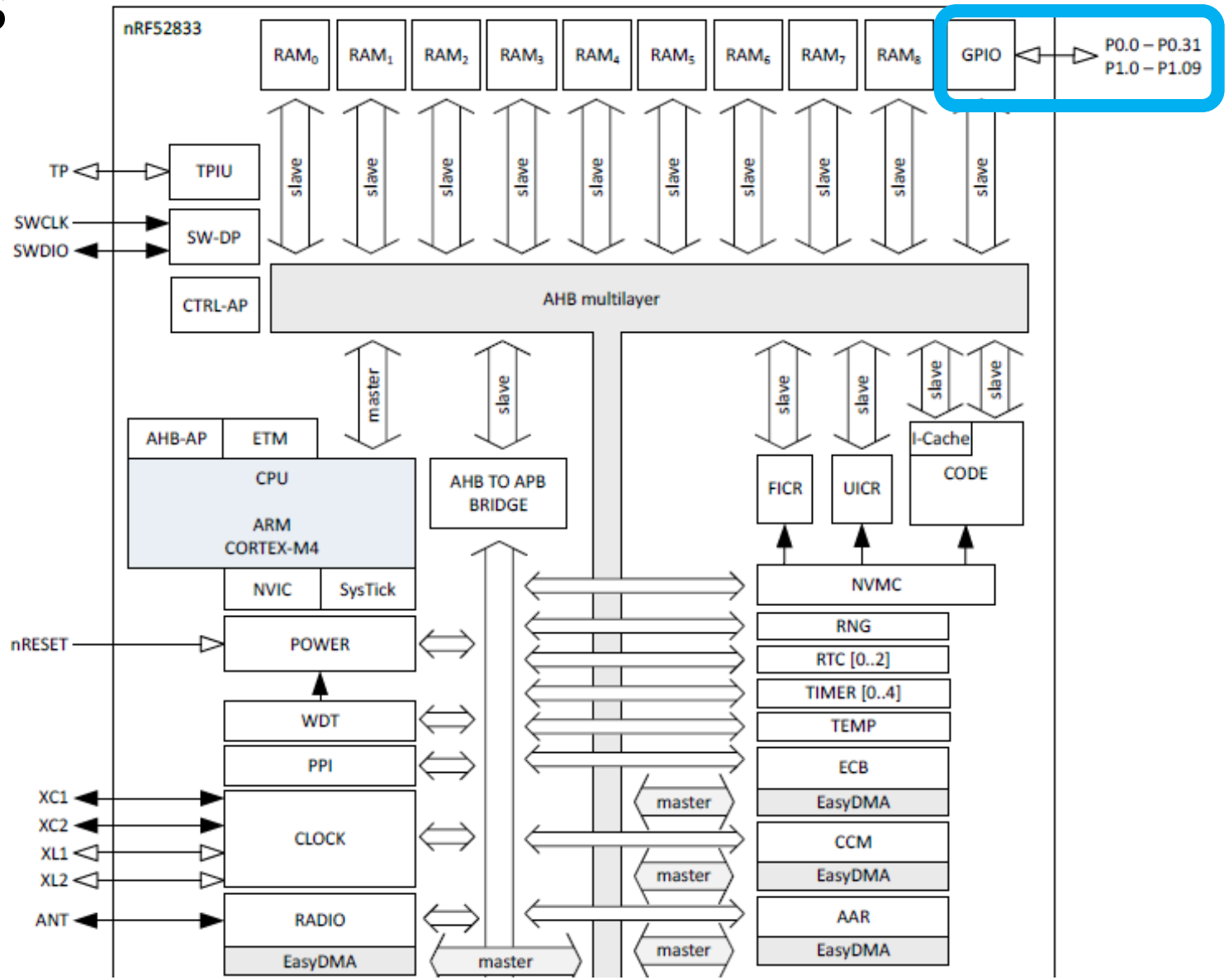
nRF52833 Peripherals

- Power and Clock management



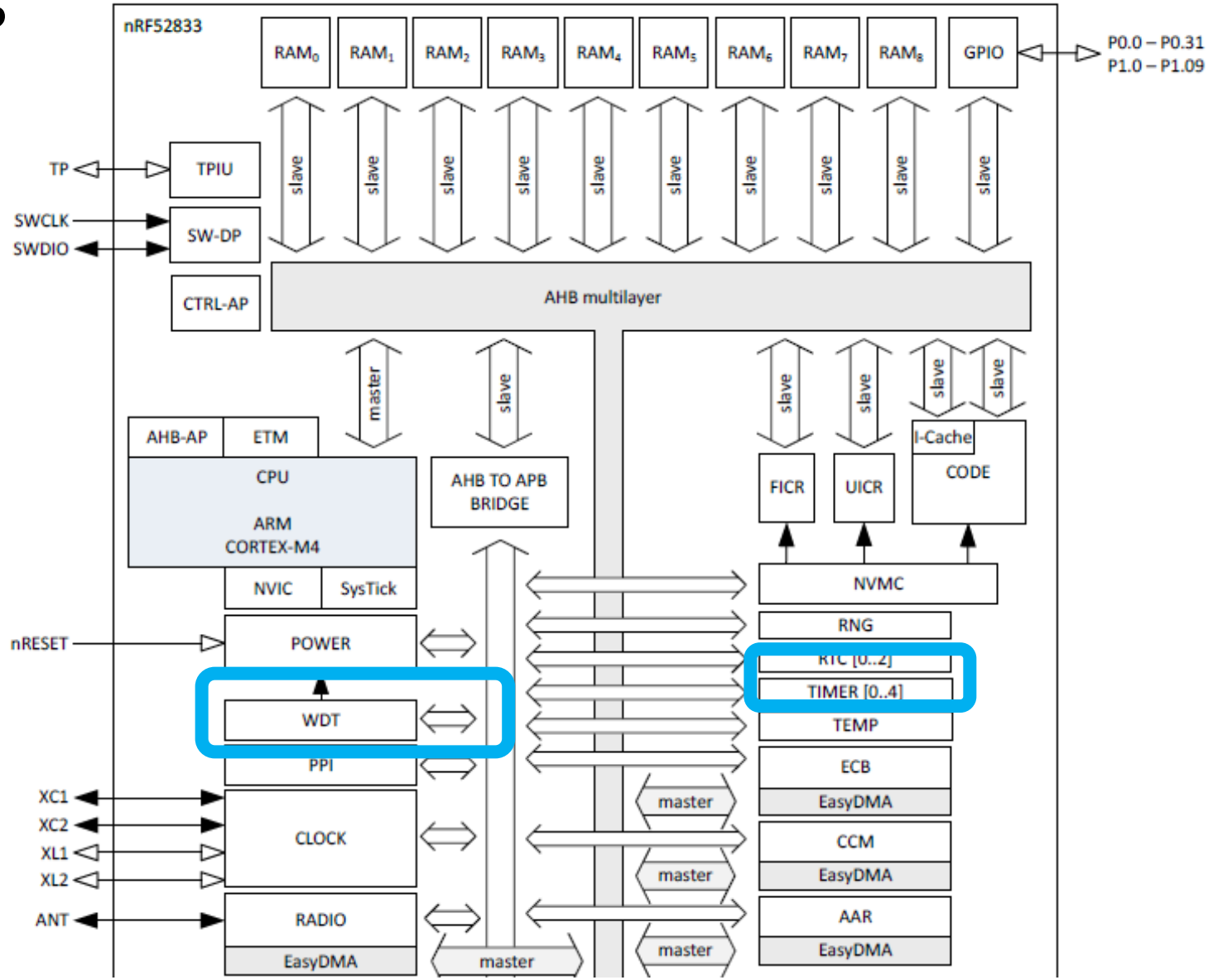
nRF52833 Peripherals

- GPIO pins



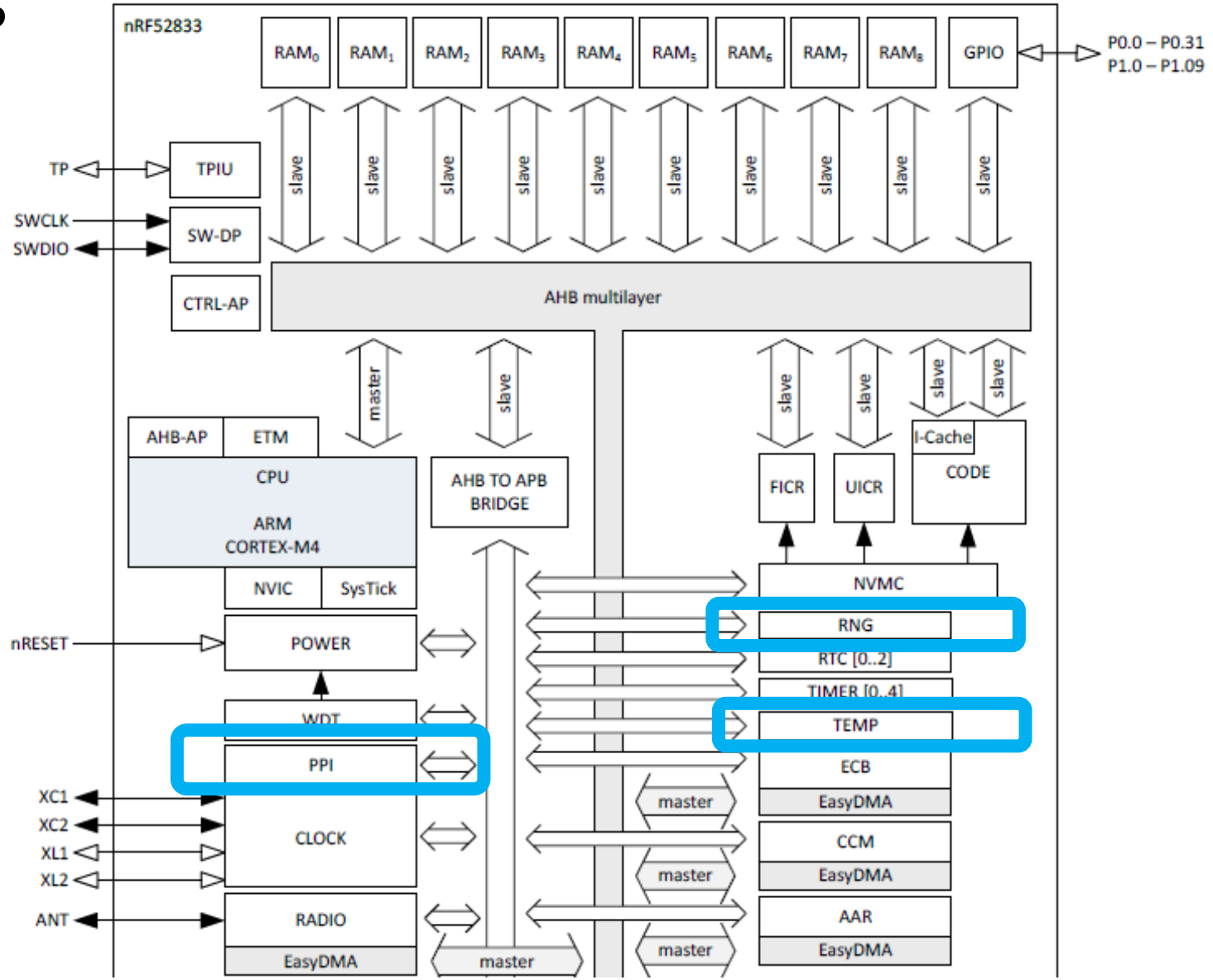
nRF52833 Peripherals

- Various timers
- Watchdog Timer
- Real-Time Counter
- Timer peripheral



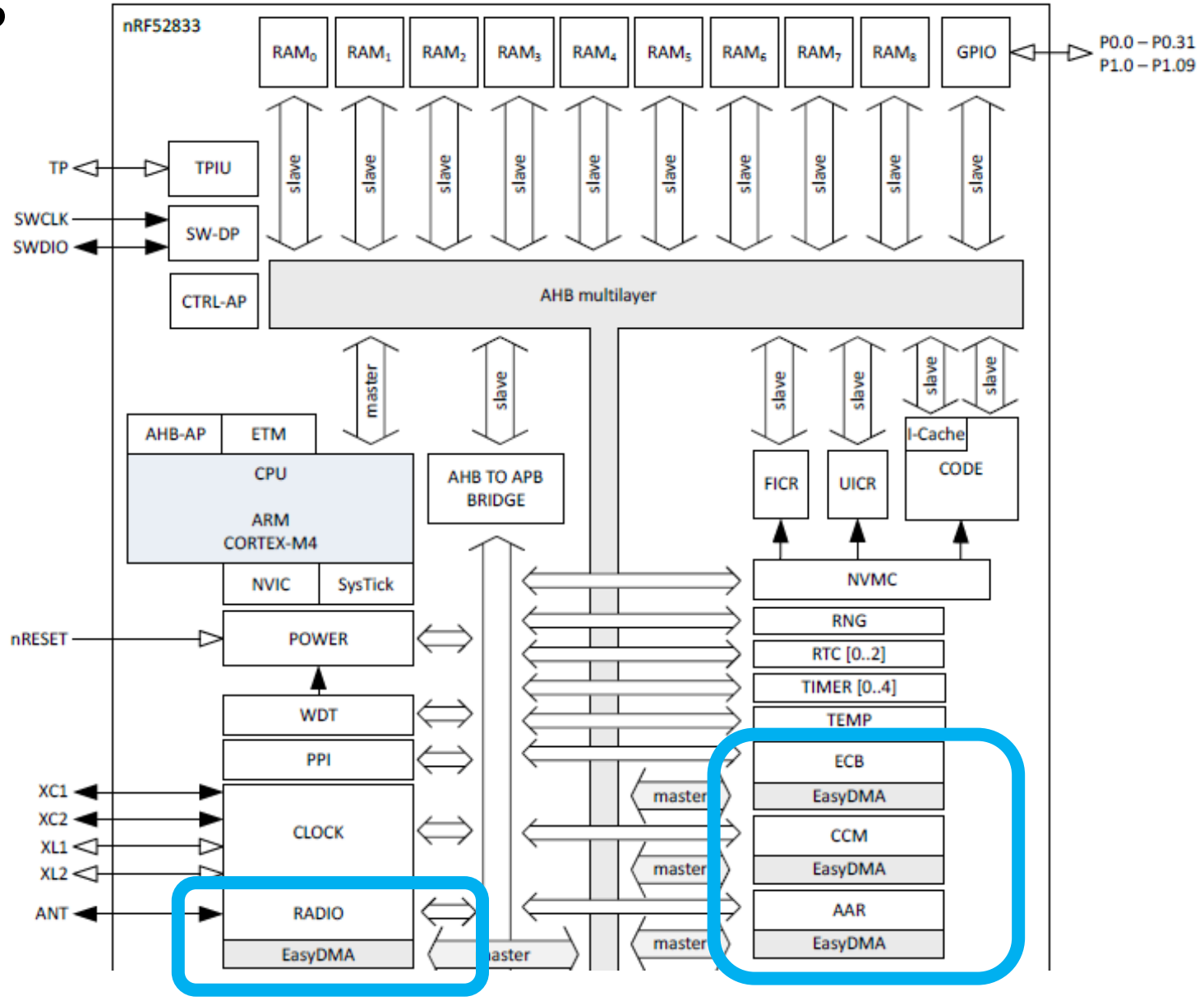
nRF52833 Peripherals

- Programmable Peripheral Interconnect
- Random Number Generator
- Temperature sensor



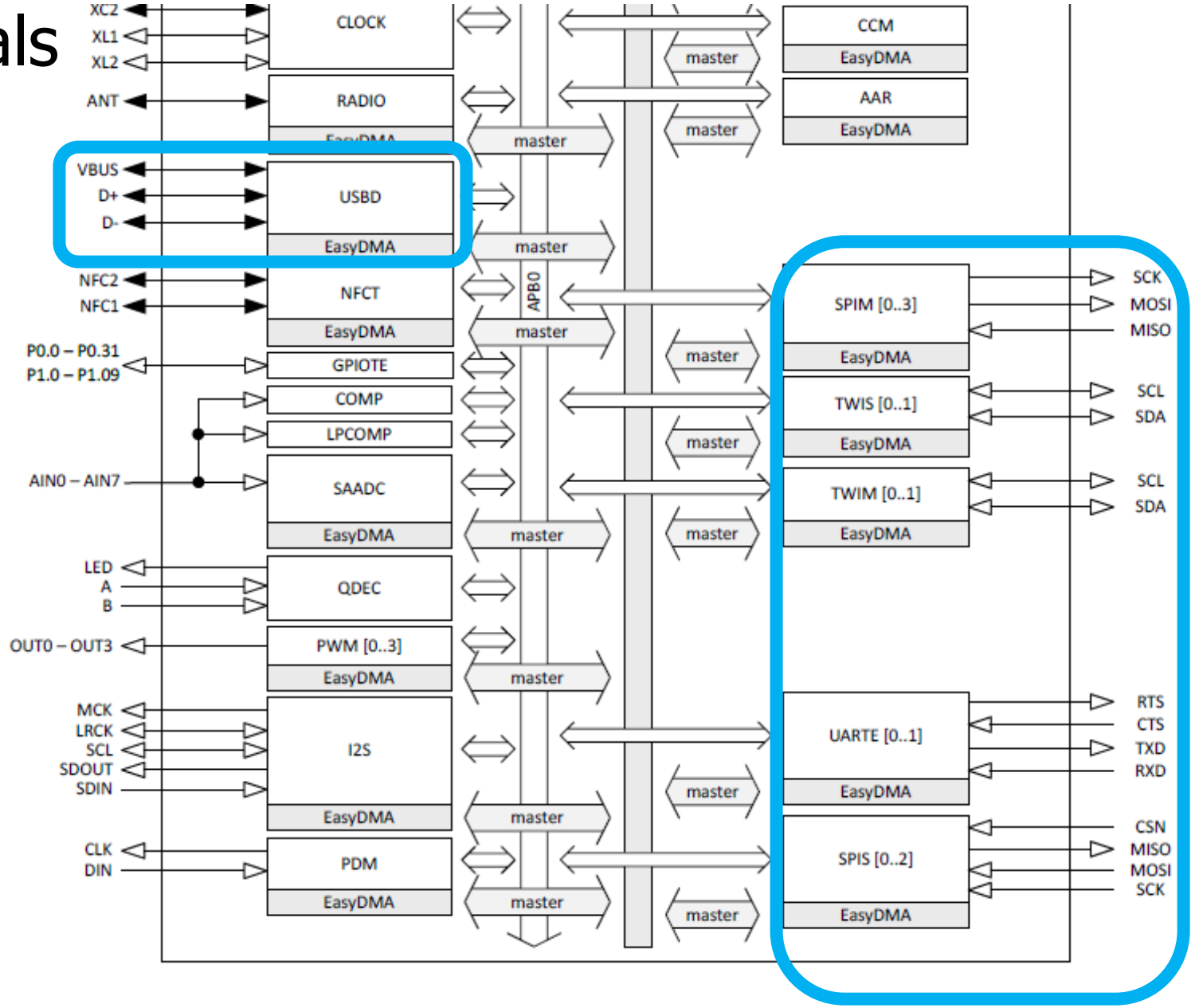
nRF52833 Peripherals

- Wireless radio
  - Bluetooth Low Energy
  - 802.15.4 (Zigbee or Thread)
- Cryptography
  - ECB (AES mode)
  - CCM (AES mode)
  - AAR (Accelerated Address Resolver)
    - For BLE random addresses



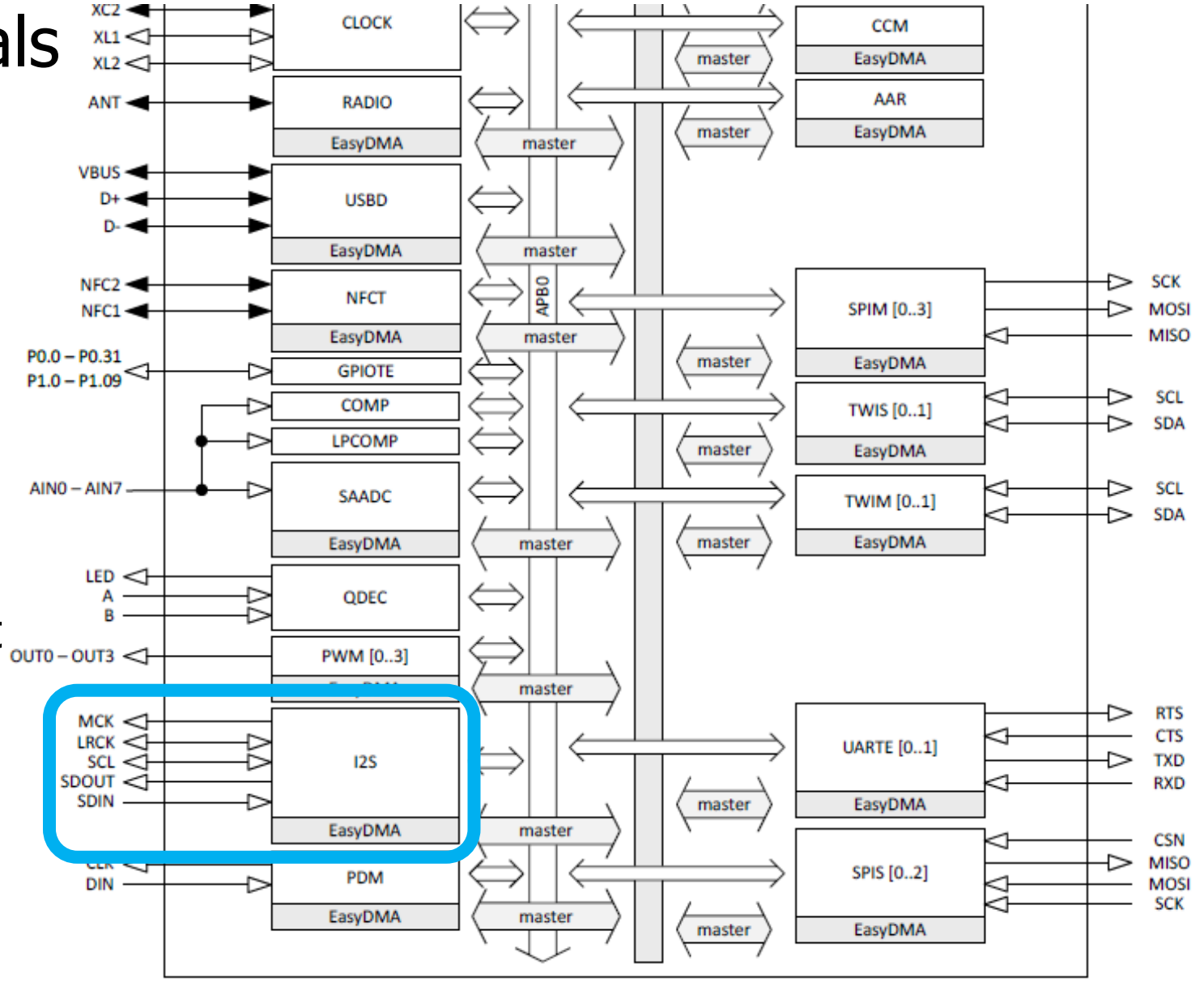
nRF52833 Peripherals

- Wired communication protocols
- USB Device
- SPI
  - Controller/Peripheral
- TWI (I2C)
  - Controller/Peripheral
- UART



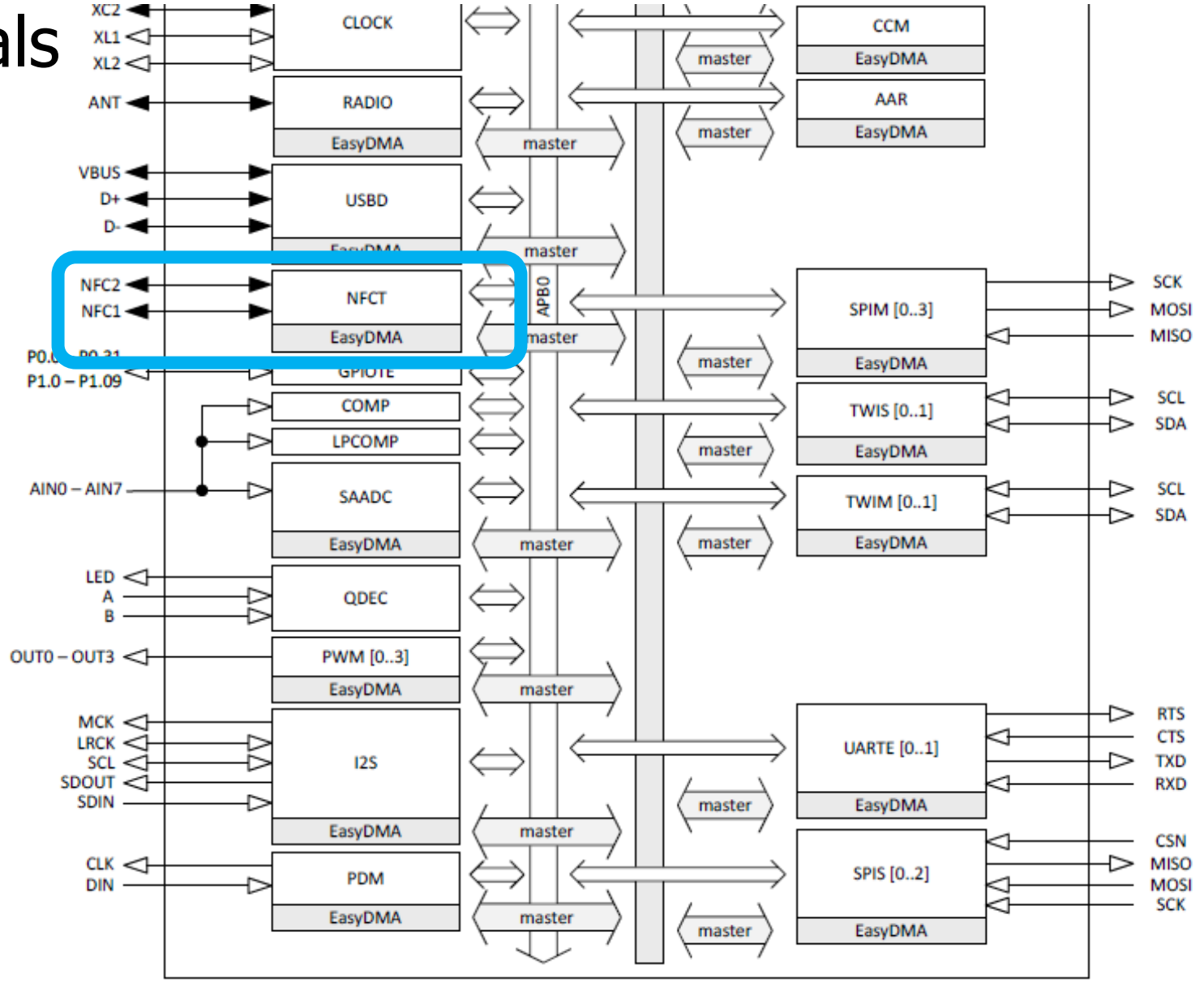
nRF52833 Peripherals

- Inter-IC Sound (I2S)
  - Wired communication bus explicitly for audio data
  - Unrelated to I2C
- Like a synchronous UART
  - Clock, data in, data out
- Additional signals
  - MCK – synchronization
  - LRCK – left/right channel select



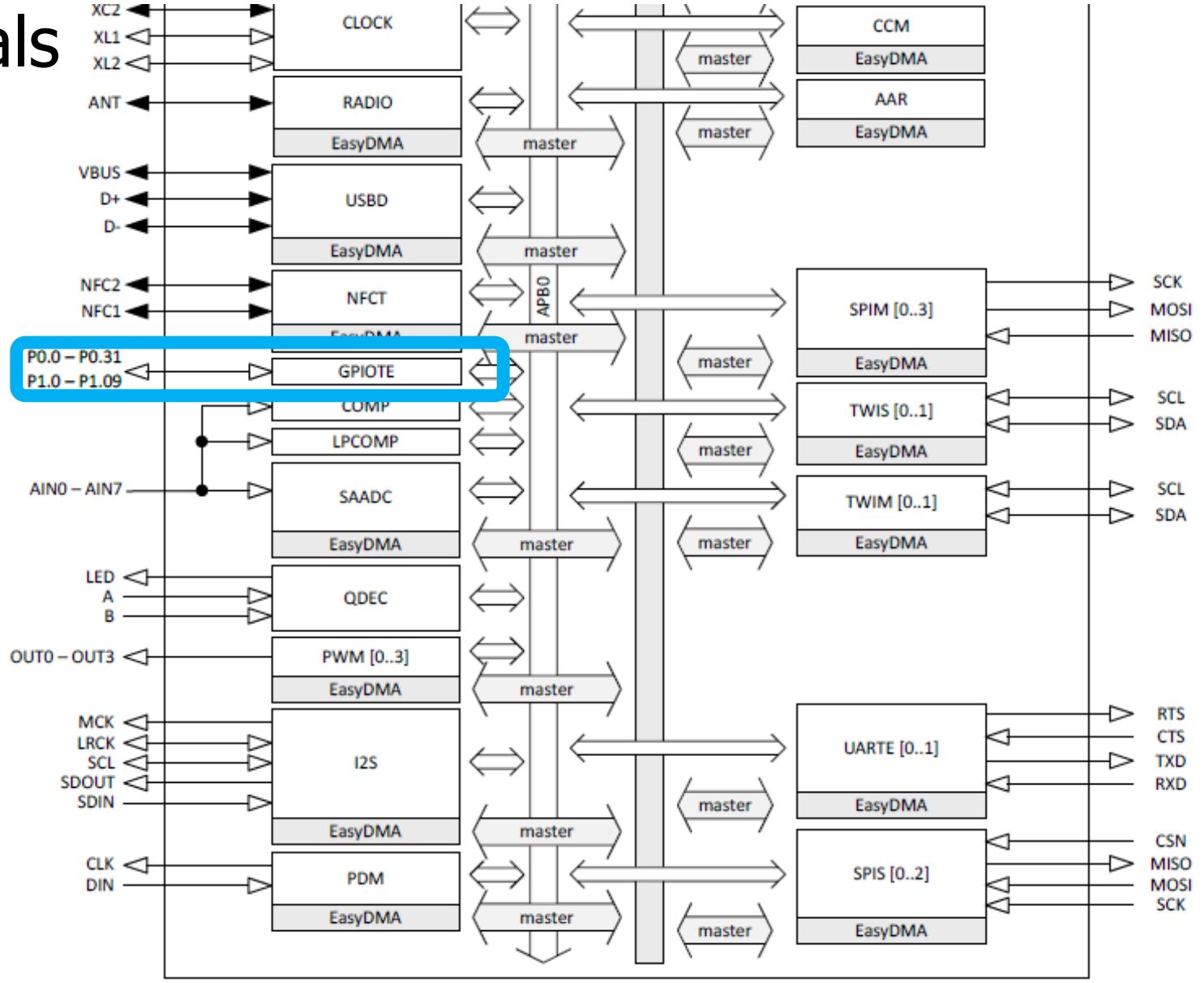
nRF52833 Peripherals

- NFC
  - Near-Field Communication
- Close-range wireless communication protocol
- “Tap-to-pay” systems



nRF52833 Peripherals

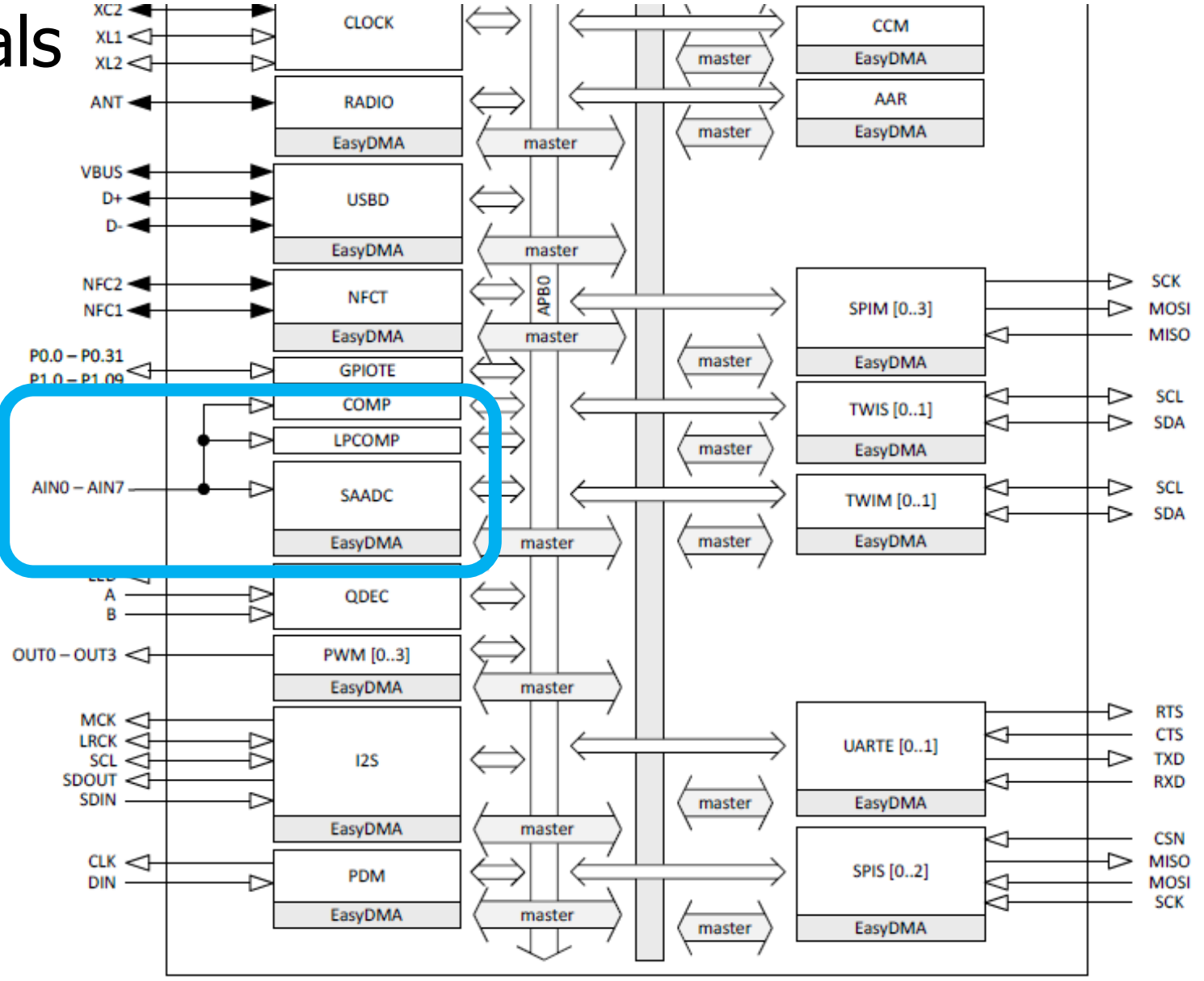
- GPIOTE
  - GPIO interrupts



nRF52833 Peripherals

- Analog inputs

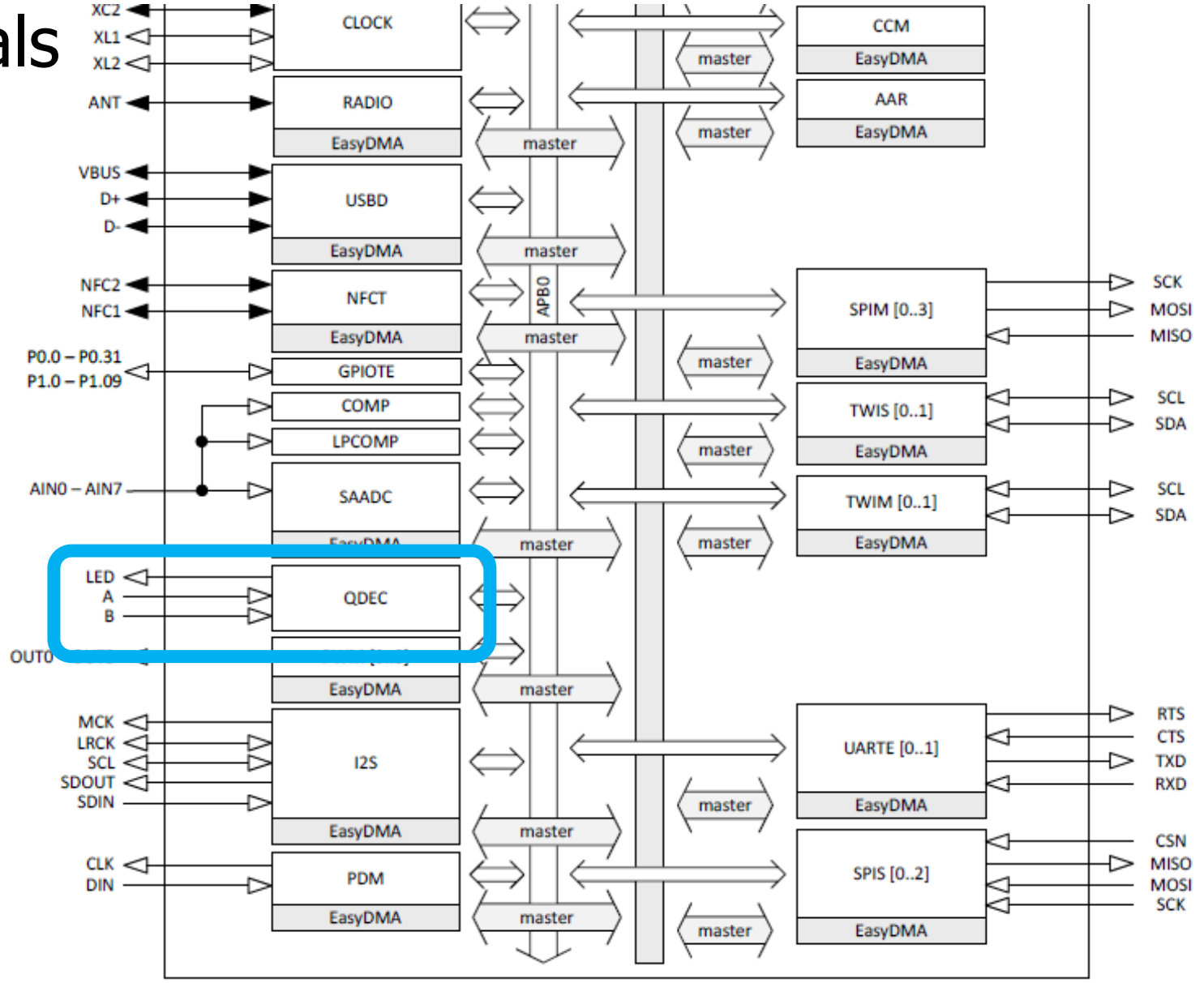
- Comparator
- Low-Power Comparator
- Successive Approximation Analog-to-Digital Converter



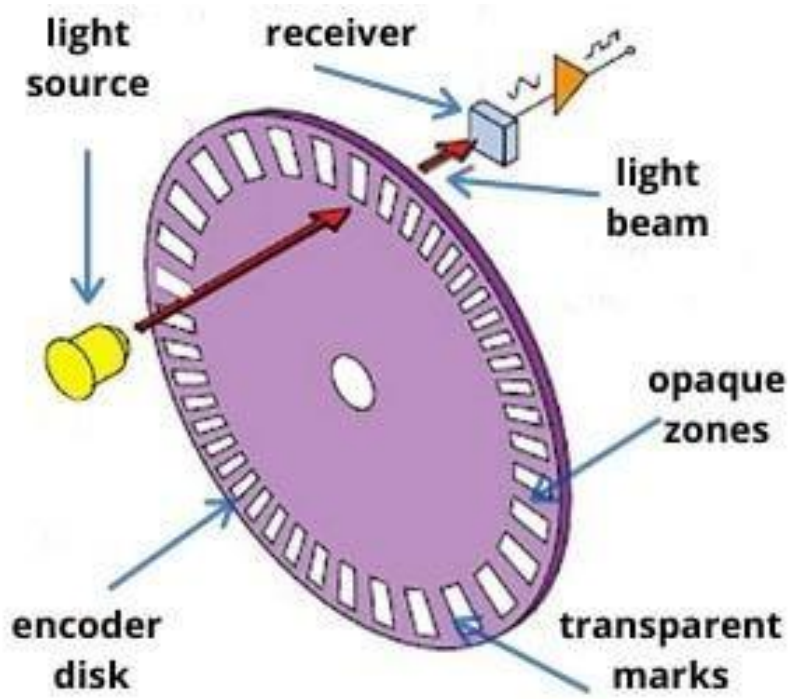
nRF52833 Peripherals

- Quadrature Decoder peripheral

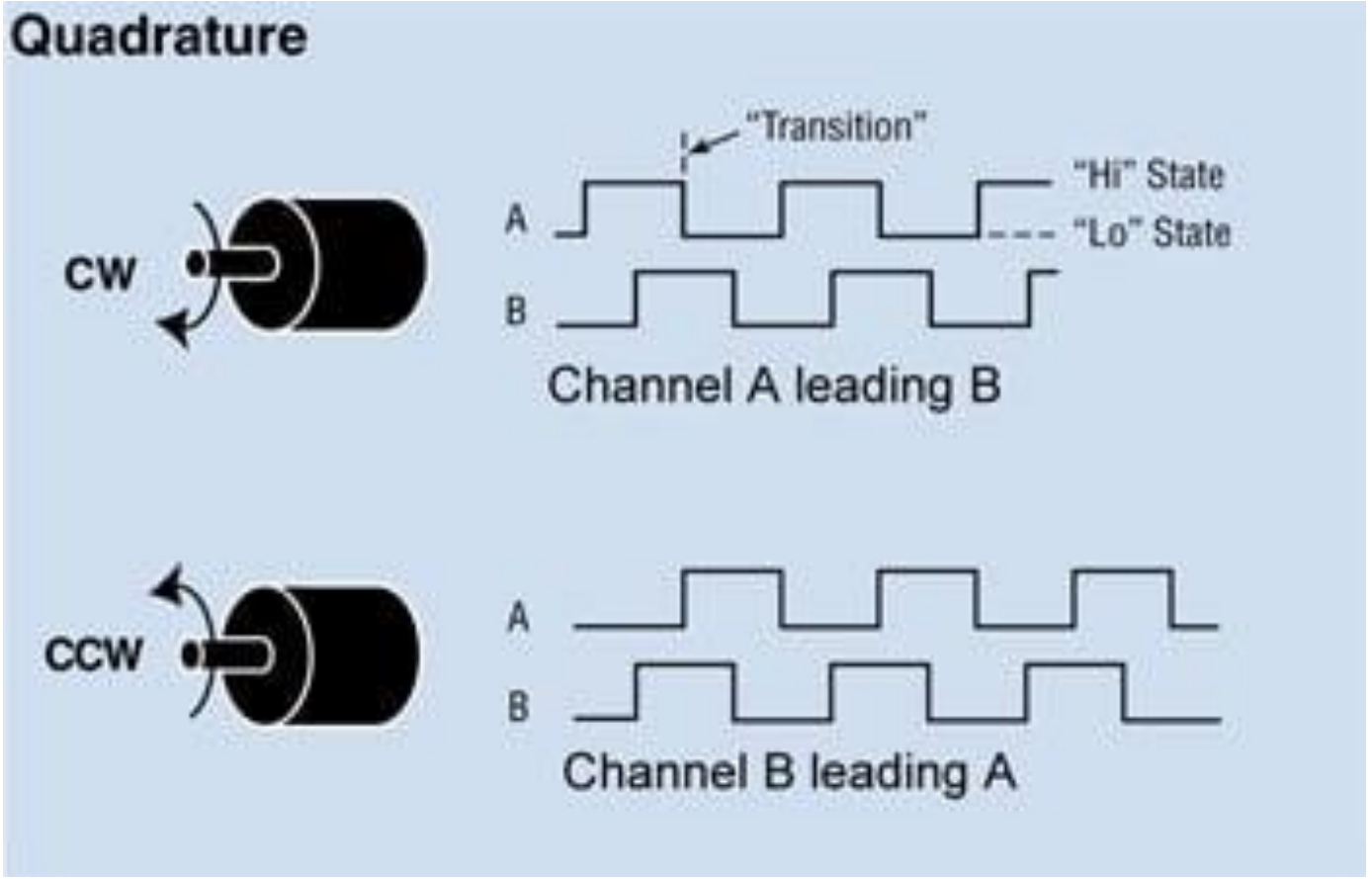
- Detects rotation speeds and direction
  - Usually for motors



Quadrature Encoding

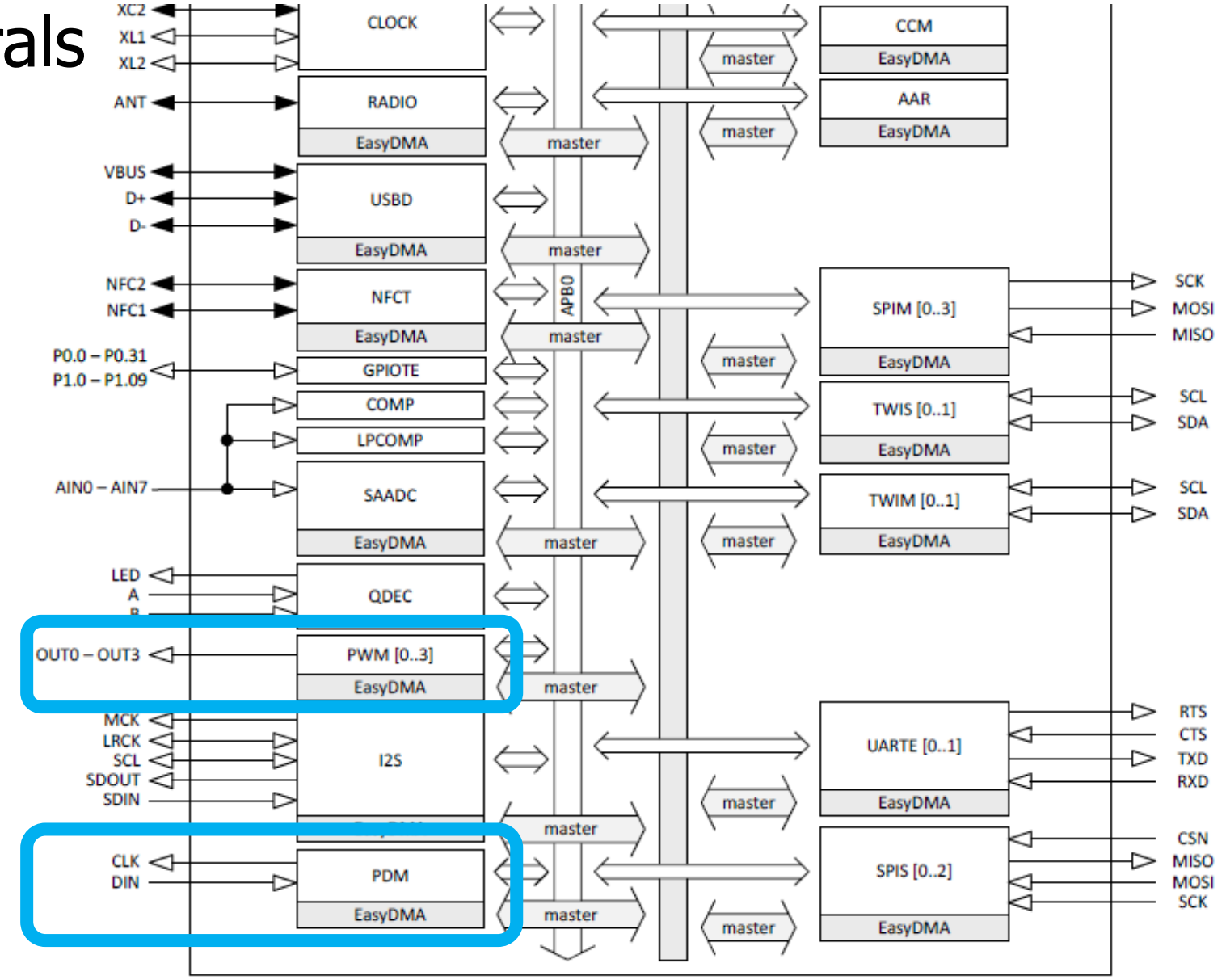


Optical encoder working principle



nRF52833 Peripherals

- Pulse Width Modulation
- Pulse Density Modulation
  - Similar idea to PWM
  - Input-only peripheral
  - Targets microphones



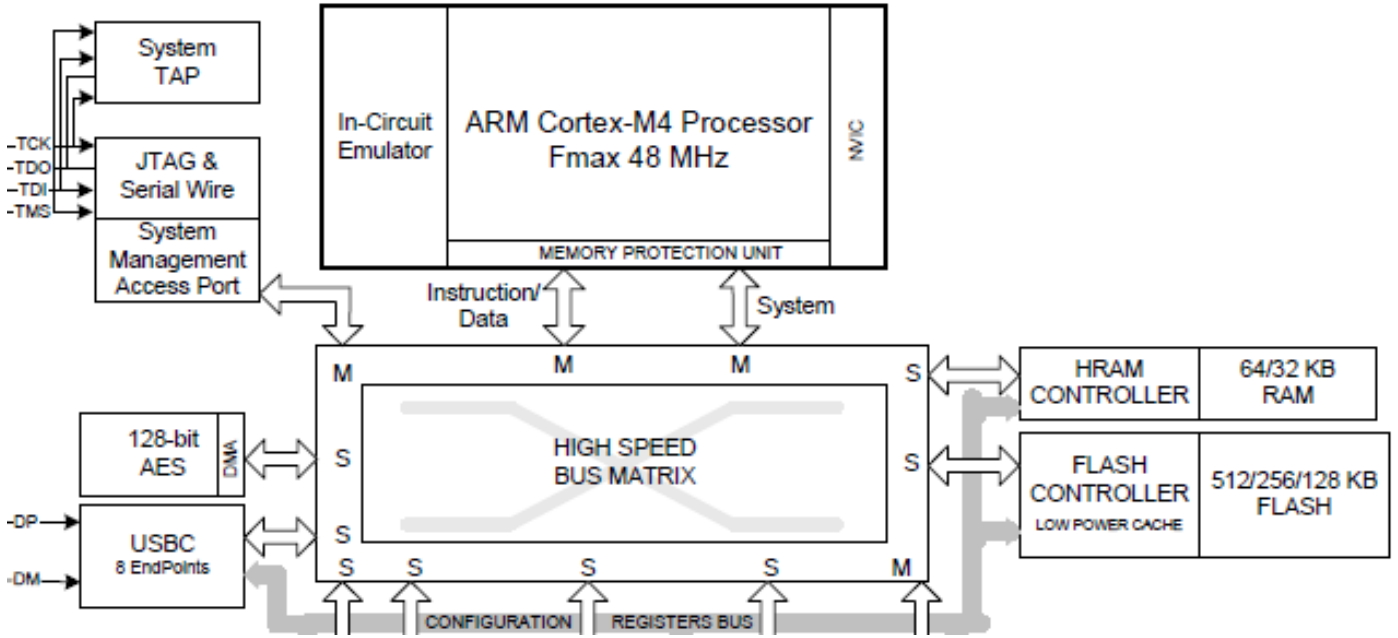
nRF52833 is complete

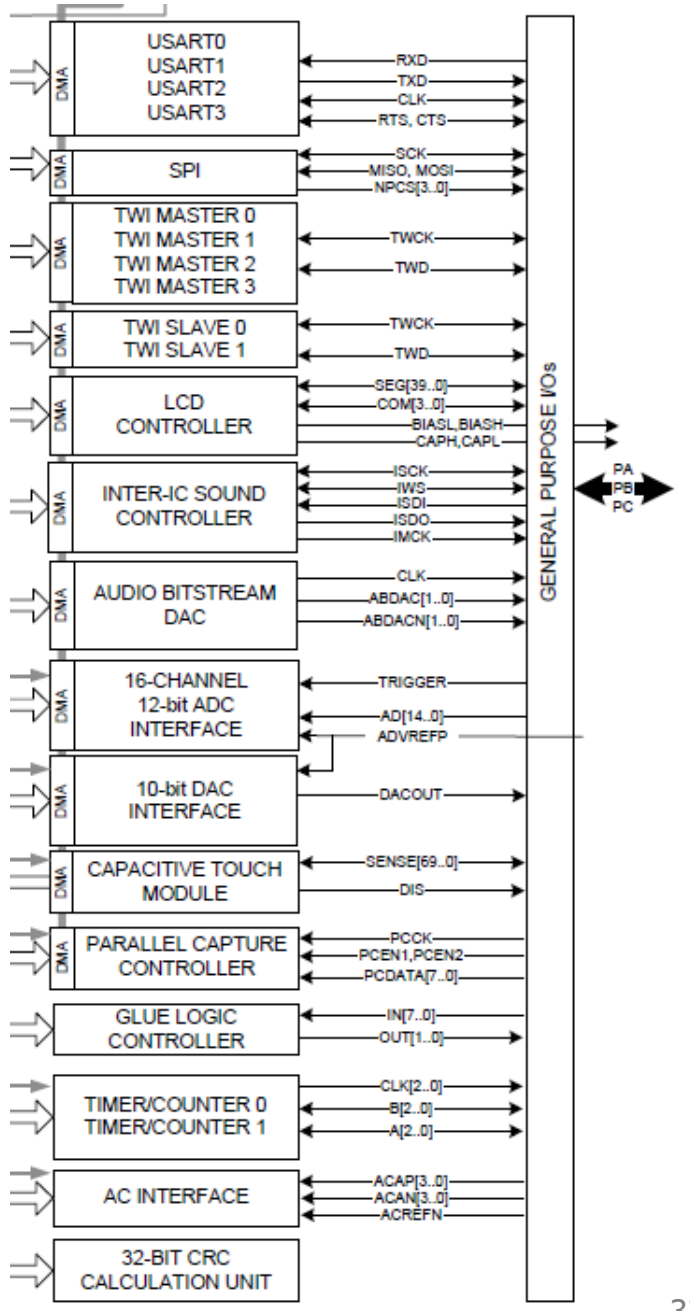
- That’s just about everything!

- First 550 out of 600 pages of nRF52833 datasheet
  - Remaining 50 are hardware details
    - Pinout for different packages
    - Recommended circuit layout
    - Soldering details

This knowledge is transferrable!

- Example: SAM4L datasheet
  - Atmel Cortex M4F
  - Various peripherals
    - USART, SPI, TWI, I2S, DAC, ADC, Timer, …





Outline

- What haven’t we talked about?
  - Microbit
  - nRF52833

- **Sensing Systems Research**

Conferences for sensing systems research

- SenSys
  - Conference on Embedded Networked Sensor Systems
- IPSN
  - Conference on Information Processing in Sensor Networks
- MobiCom
  - Conference on Mobile Computing and Networking
- UbiComp
  - Conference on Pervasive and Ubiquitous Computing

- Various other systems or HCI venues
  - Occasionally Electrical or Civil Engineering venues too

Sensing systems research

- Combination of engineering and exploration
- Generally divides into two different focuses
  - Often projects will mix some of each domain
- Platforms
  - How to improve the capabilities of sensing systems
  - Examples: lower power, better wireless, new sensors
- Applications
  - How to use sensing systems to meet some desired goal
  - Examples: track human interactions, measure household energy use

Sensing systems research

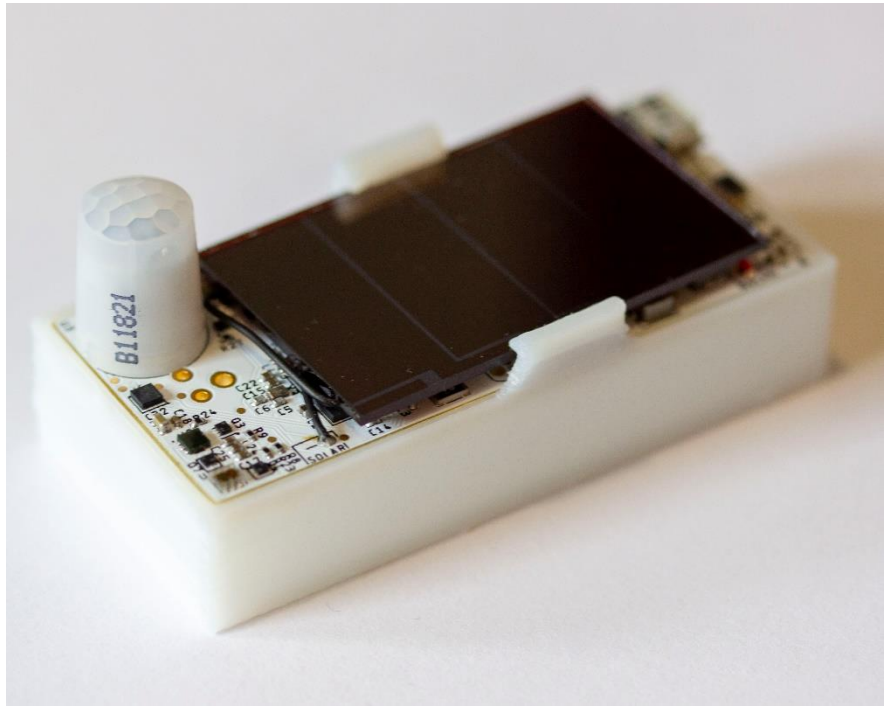
- **Platforms**
  - How to improve the capabilities of sensing systems
  - Examples: lower power, better wireless, new sensors

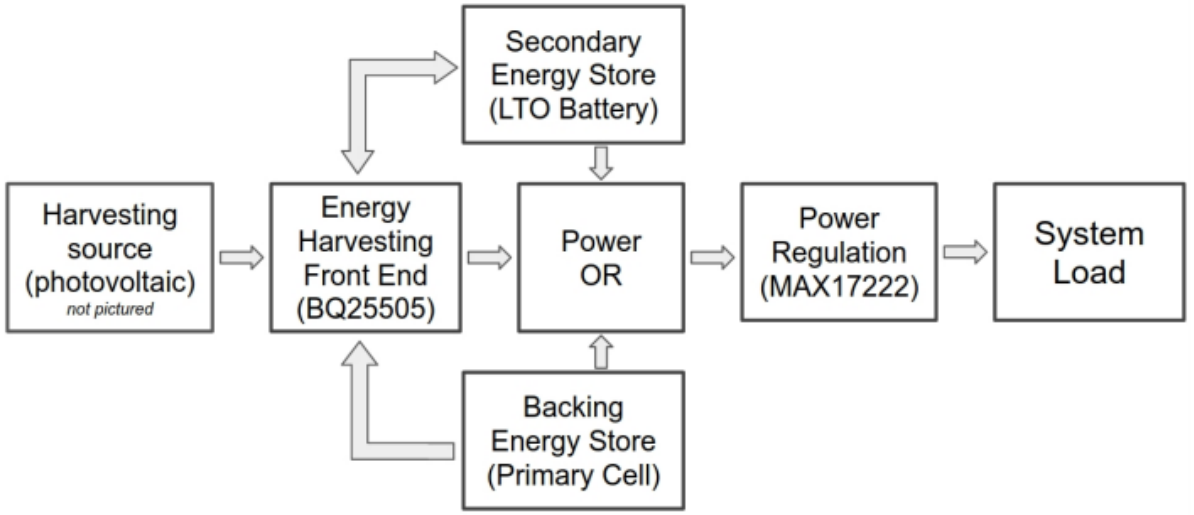
- Applications
  - How to use sensing systems to meet some desired goal
  - Examples: track human interactions, measure household energy use

Permamote (Jackson, Adkins, Dutta)

- Goal: create a 10-year wireless sensor

- Solutions
  - Modern sensors and microcontroller
  - Energy harvesting combined with rechargeable battery
  - Non-rechargeable battery as backup power



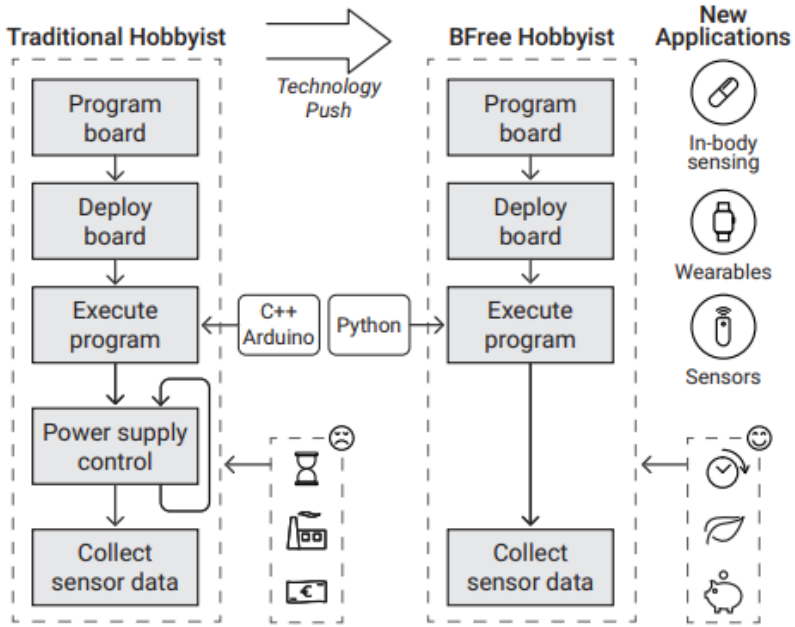


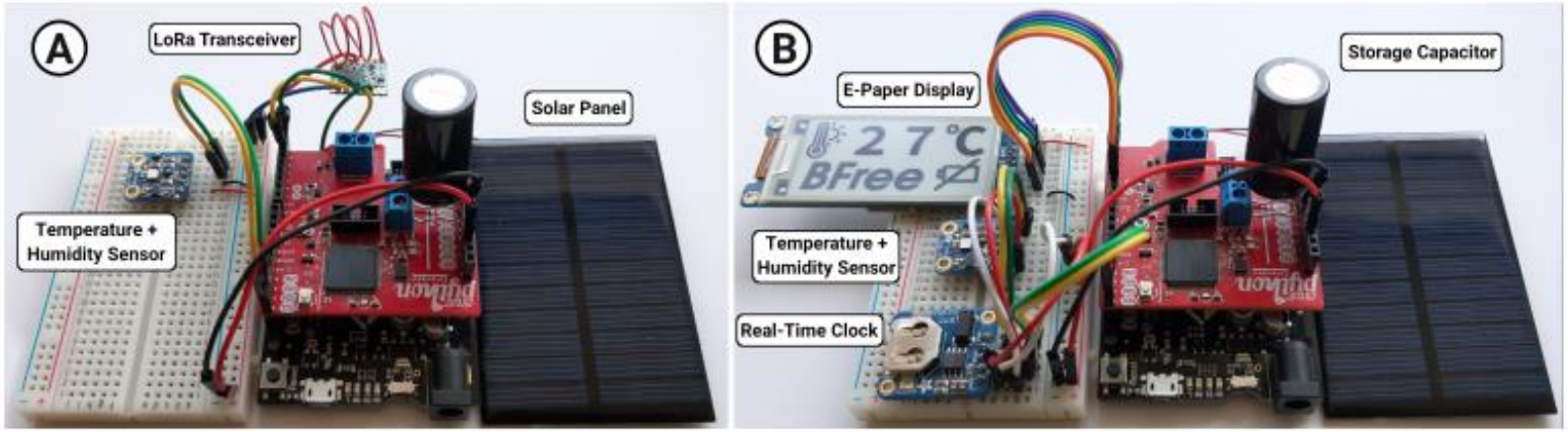
https://lab11.eecs.berkeley.edu/content/pubs/jackson19capacity.pdf

Bfree (Kortbeek, Bakar, Cruz, Yildririm, Pawelczak, Hester)

- Goal: hobbyist intermittent systems

- Solutions
  - Automatic checkpointing in python runtime
  - Hardware module for easy prototyping
  - User studies to demonstrate improvements





https://dl.acm.org/doi/abs/10.1145/3432191

Tock (Levy, Campbell, Ghena, Giffin, Pannuto, Dutta, Levis)

- Goal: safe and reliable embedded OS
  - Demonstrate this is possible on small embedded platforms

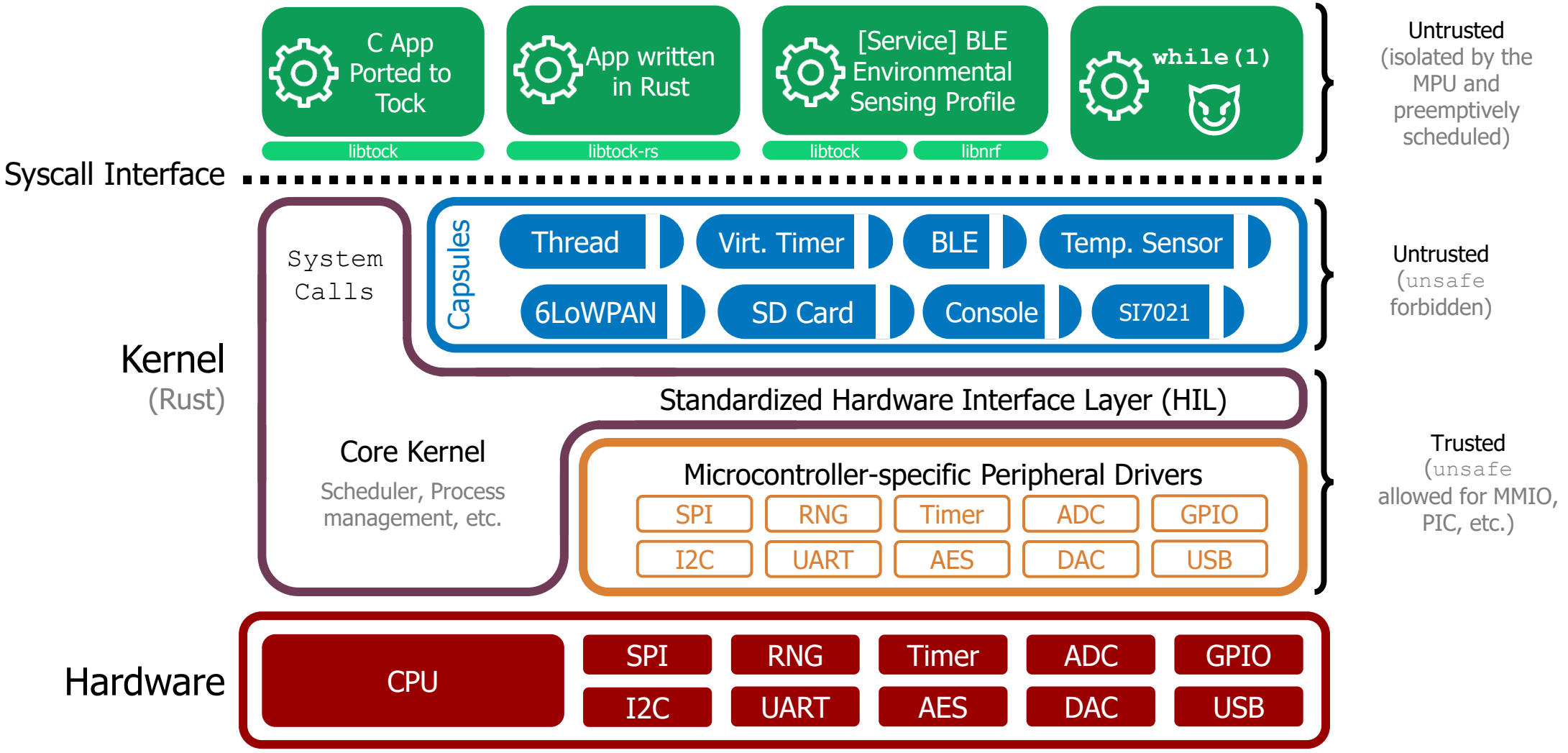
- Solutions
  - Dedicated OS kernel with separate applications

  - Protect applications with hardware features
    - Memory Protection Unit

  - Protect kernel with language features
    - Rust programming language

https://lab11.eecs.berkeley.edu/content/pubs/levy17multiprogramming.pdf

Tock software organization



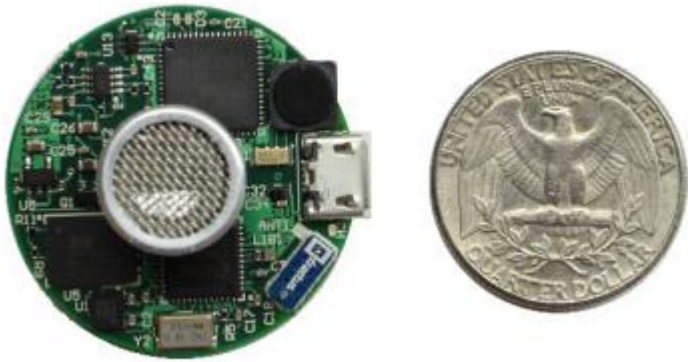
Sensing systems research

- Platforms
  - How to improve the capabilities of sensing systems
  - Examples: lower power, better wireless, new sensors

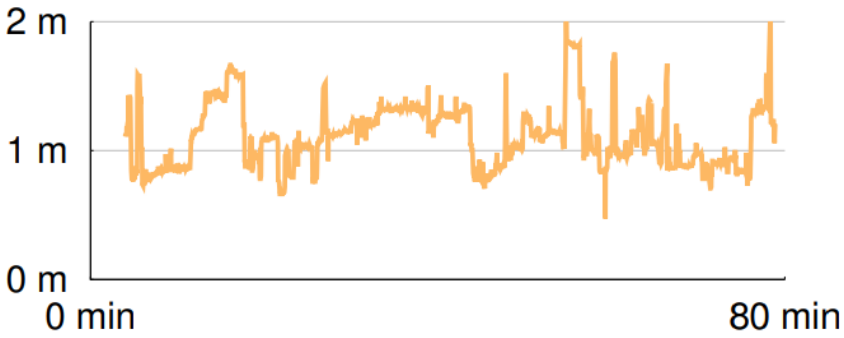
- **Applications**
  - How to use sensing systems to meet some desired goal
  - Examples: track human interactions, measure household energy use

Opo (Huang, Kuo, Pannuto, Dutta)

- Goal: sense distance of human interactions
  - Real-time, high accuracy, deployable



- Solutions
  - Ultrasonic allows for low-power detection of nearby devices
  - Also provides directionality
  - Measure difference in arrival time of RF and Ultrasonic to determine distance

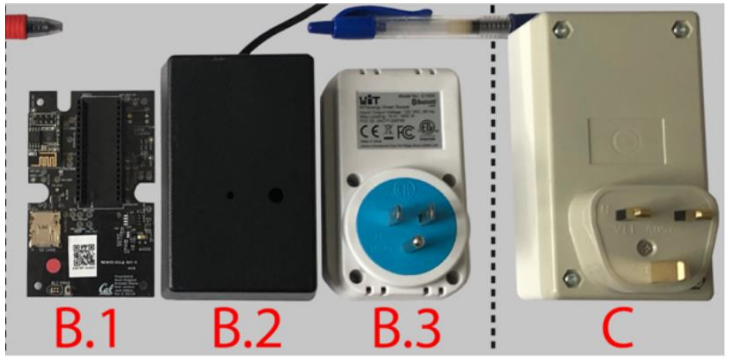


https://lab11.eecs.berkeley.edu/content/pubs/huang14opo.pdf

Powerwatch (Klugman, Adkins, et al.)

- Goal: measure electric grid reliability in developing regions
- "Access alone is insufficient. Reliability matters too."

- Solutions:
  - Wall-powered sensor with battery-backup to detect outages and report over cellular
  - Infrastructure to collect measurements and cross-correlate
  - Create a team to manage the deployment



https://lab11.eecs.berkeley.edu/content/pubs/klugman19scale.pdf

Outline

- What haven’t we talked about?
  - Microbit
  - nRF52833
- Sensing Systems Research

- Bonus: Signpost
  (Adkins, Ghena, Jackson, Pannuto, Rohrer, Campbell, Dutta)

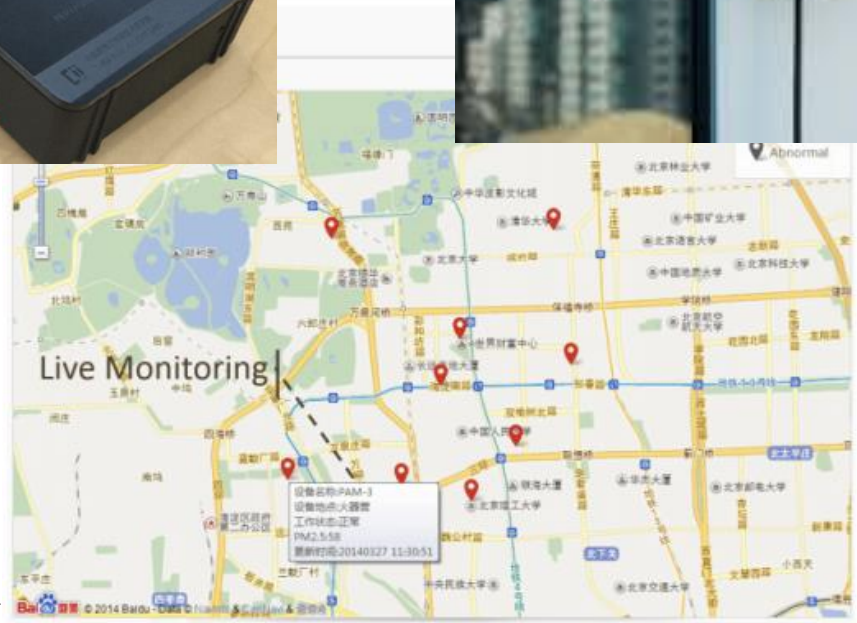
https://lab11.eecs.berkeley.edu/content/pubs/adkins18signpost.pdf

What things might we want to sense at the scale of a city?

Air quality monitoring

[1]

[2]



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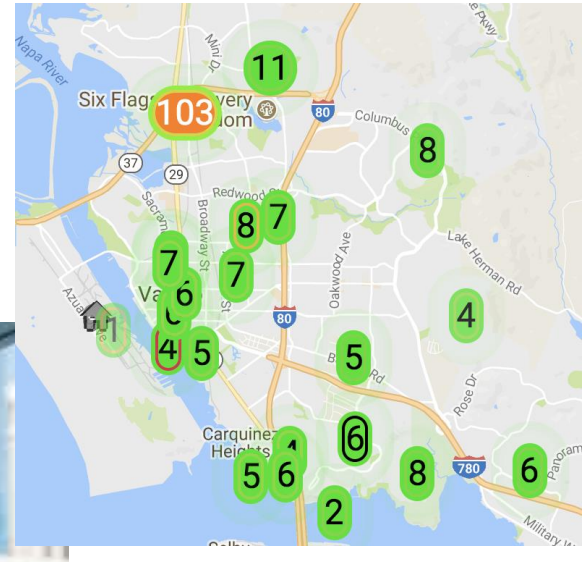

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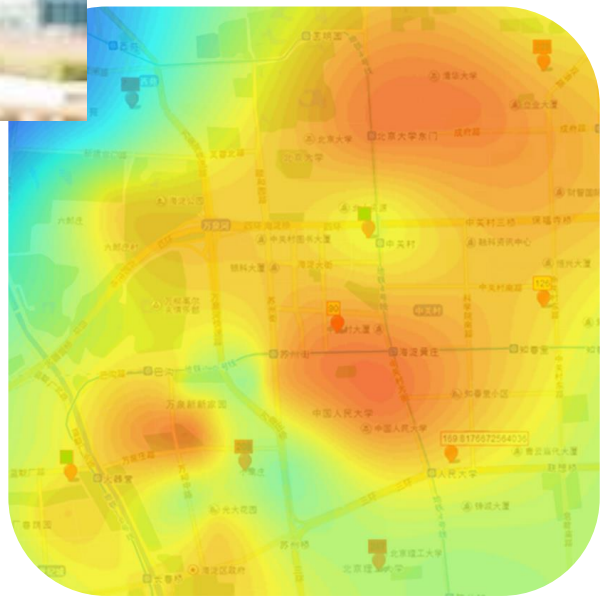
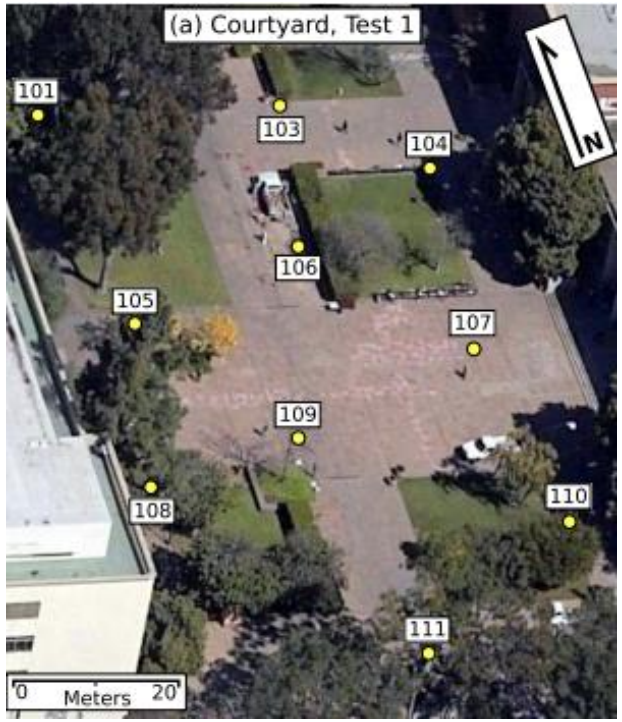


[1] Cheng et al. AirCloud: a cloud-based air-quality monitoring system for everyone. 2014.

[2] Purple Air. 2018.

Audio detection, classification, and localization



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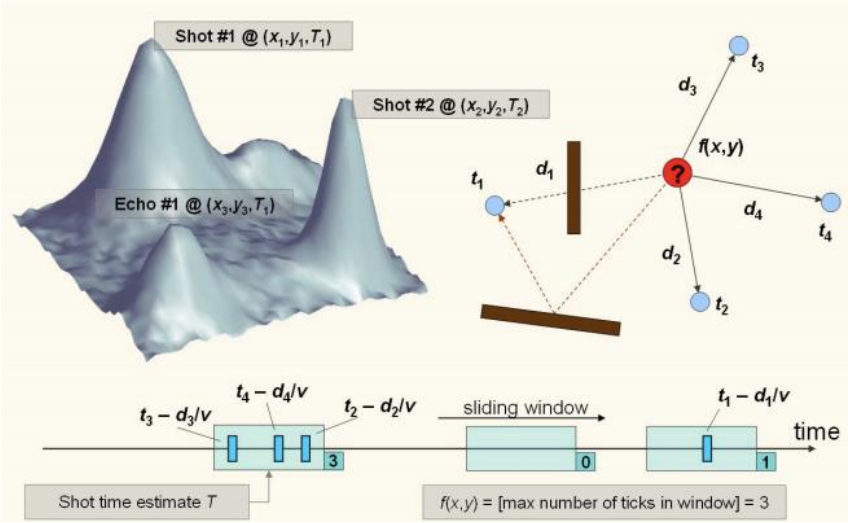

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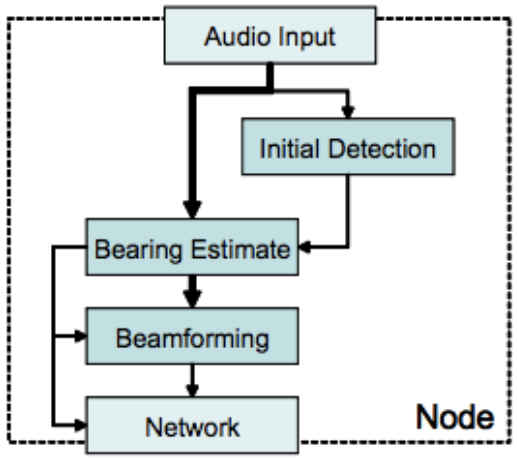

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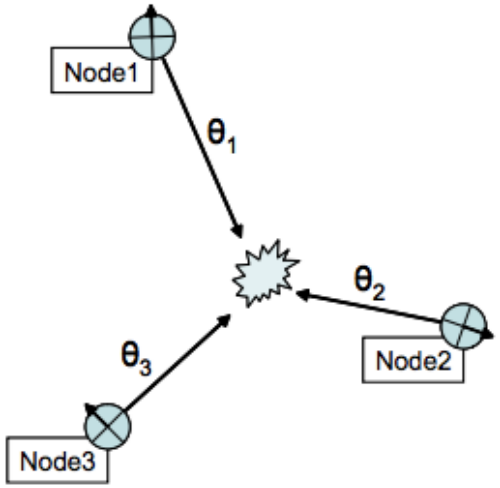
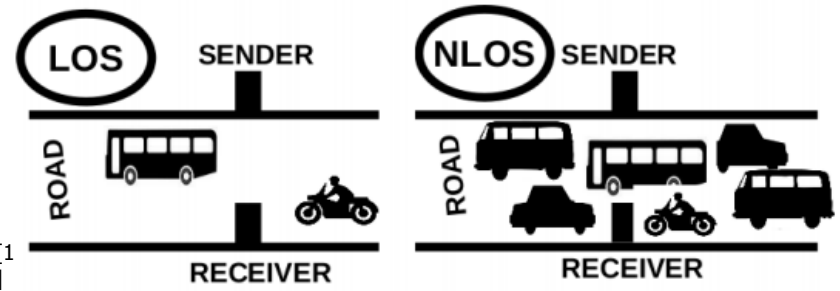


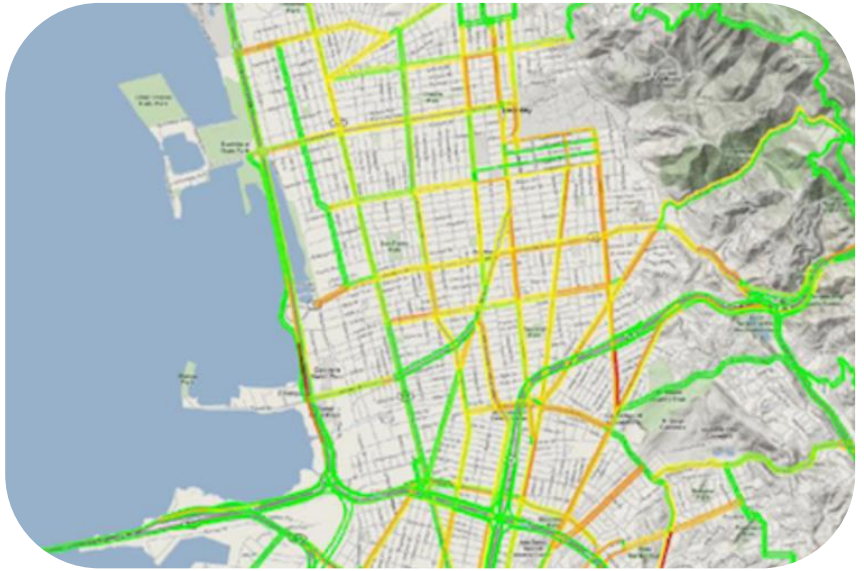
[1] Girod et al. The Design and Implementation of a Self-Calibrating Distributed Acoustic Sensing Platform. 2006.
[2] Lédeczi et al. Multiple Simultaneous Acoustic Source Localization in Urban Terrain. 2005.
[3] Sounds of New York City. 2016.

Traffic queue sensing and congestion control

[1]



[1]



[1]

[1] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

NIST

THE CITY OF COLUMBUS

Enjoy Jakarta

amsmartterdam city

HUAWEI

SMART DUBLIN

NSF

European Commission

Smart Nation SINGAPORE

Many Smart Ideas • One Smart Nation

The City of SAN DIEGO

SMART CITY CHALLENGE

U.S. Department of Transportation

1. City-Scale Sensing Introduction
2. **Signpost**
   - **Motivation**
   - Shared Resources
   - Deployability
   - Implementation
   - Evaluation

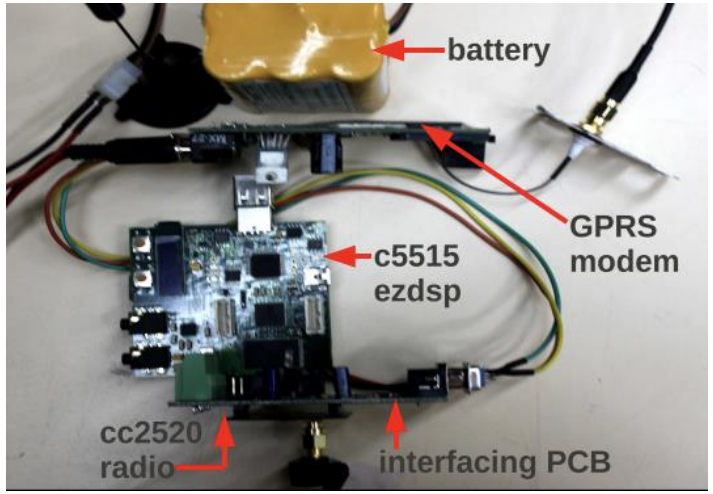
Air Quality Monitoring

[1]

Urban Noise Classification

[2]

Traffic Queue Sensing

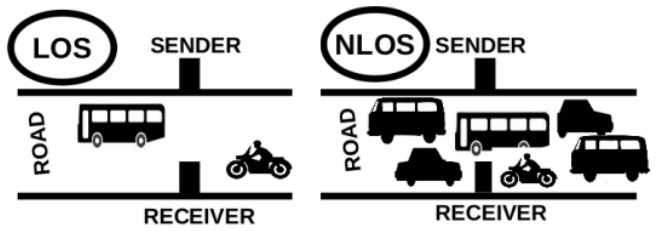


[3]

Lots of interesting applications and interested parties.
But let's look at the process of actually creating and deploying an application.

[1] Cheng et al. AirCloud: a cloud-based air-quality monitoring system for everyone. 2014. [2] Sounds of New Your City. 2016. [3] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

Many steps to building traffic queue sensing



Sensing Hypothesis/Hardware

[1] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

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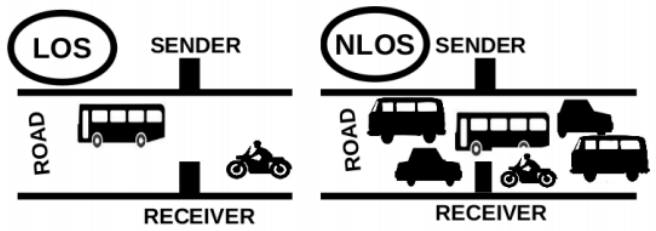

Sensing
Hypothesis/Hardware

Networking

Networking
Driver

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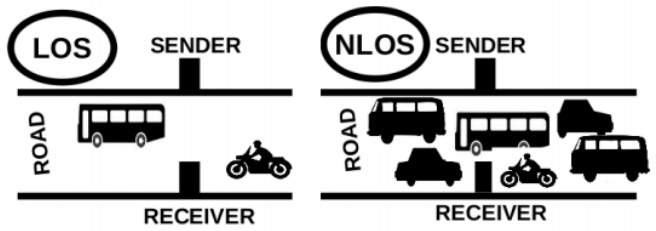
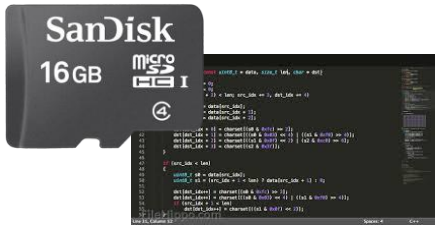


Sensing
Hypothesis/Hardware

Networking

Networking
Driver

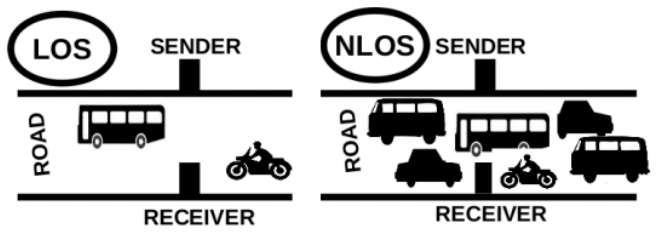


Storage

Storage
Driver

[1] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

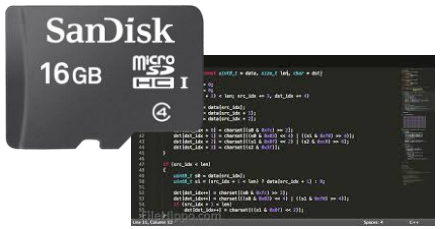
Many steps to building traffic queue sensing



Sensing Hypothesis/Hardware

Networking

Networking Driver



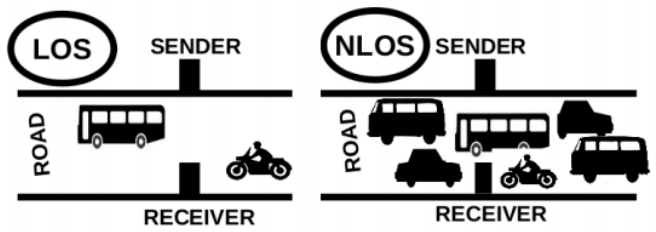
Storage

Storage Driver

Sustainable Power

[1] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

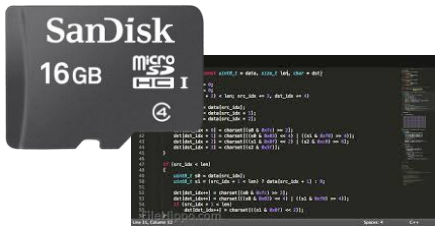
Many steps to building traffic queue sensing



Sensing Hypothesis/Hardware

Networking

Networking Driver



Storage

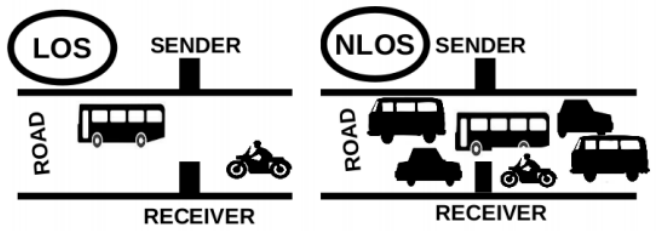
Storage Driver

Sustainable Power

Weatherproof Casing

[1] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

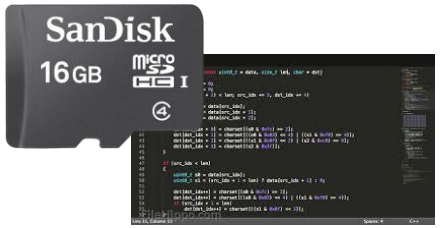
Many steps to building traffic queue sensing



Sensing
Hypothesis/Hardware

Networking

Networking
Driver



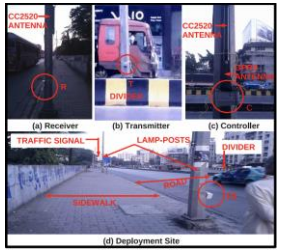
Storage

Storage
Driver

Sustainable
Power

Weatherproof
Casing

[1]



Deploy

[1] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

Key functions are repeated

[1]

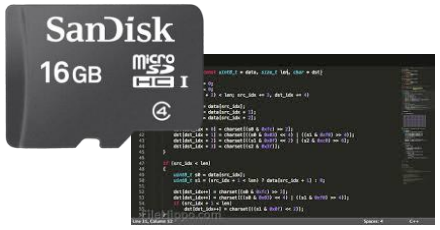
Sensing

Hypothesis/Hardware

Networking

Networking

Driver



Storage

Storage

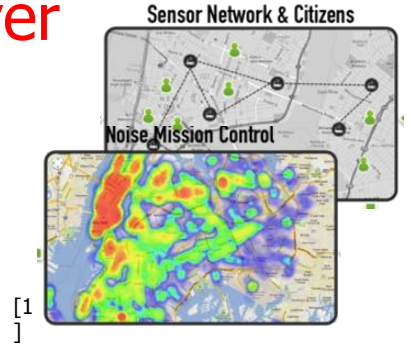
Driver

Sustainable

Power

Weatherproof

Casing



[1]

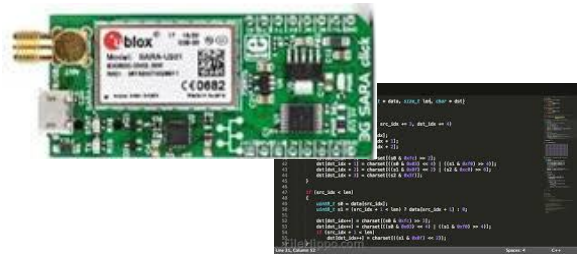
Deploy

[1] Sounds of New York City. 2016

Key functions are repeated

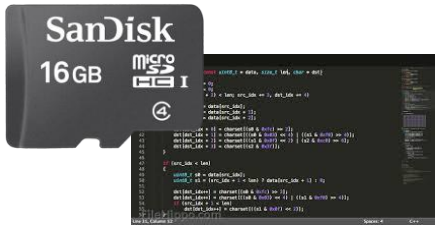
[1]

Sensing
Hypothesis/Hardware



Networking

Networking
Driver

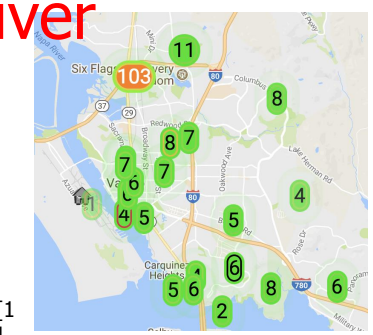


Storage

Storage
Driver

Sustainable
Power

Weatherproof
Casing



[1]

Deploy

[1] Purple Air. 2018

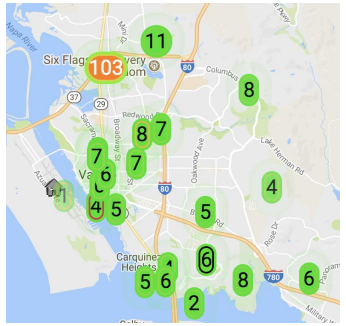
Signpost Enables City-Scale Sensing

[1]

Sensing Hypothesis/Hardware

Integrate with Signpost

[1]



Deploy

Joshua Adkins, **Branden Ghena**, Neal Jackson, Pat Pannuto, Samuel Rohrer, Bradford Campbell, and Prabal Dutta "The Signpost Platform for City-Scale Sensing." *IPSN'18*

[1] Purple Air. 2018.

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2. **Signpost**
   - Motivation
   - **Shared Resources**
   - Deployability
   - Implementation
   - Evaluation

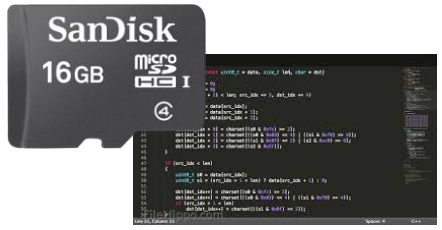
Key functions are repeated

[1]

Sensing
Hypothesis/Hardware

Networking

Networking
Driver

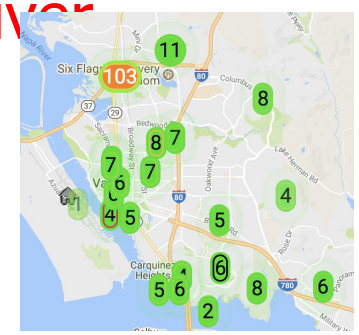


Storage

Storage
Driver

Sustainable
Power

Weatherproof
Casing



[1]

Deploy

[1] Purple Air. 2018

Higher power/linux class processing

Can be provided with a GPS

Deployment	Services Needed						
	Power	Networking	Processing	Storage	Time	Synch	Location
Caraoke [3]							
Bouillet et al. [4]							
Aircloud [5]							
Girod et al. [6]							
Ledeczi et al. [7]							
SenseFlow [8]							
Argos [9]							
SONYC [1]							
Kyun Queue [10]							
Micronet [11]							

Software abstraction through a single interface

Sensor

Platform

Sensing
Hypothesis/Hardware

Platform Interface

- Ubiquitous
- Easy to adapt/implement
- Physically

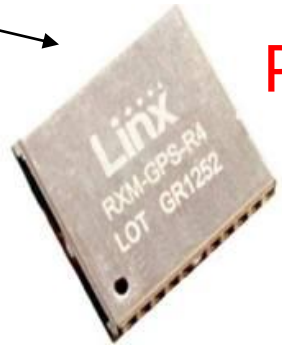
Networking

Storage

Platform Controller

High Performance Processing

Sustainable Power



GPS

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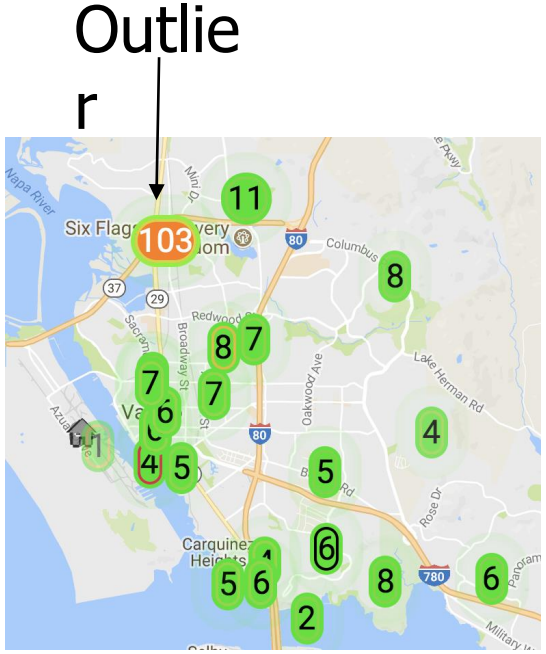
Some applications require granularity

Data can change greatly in low distances



Deployment overhead drives cost

- Expensive to work with the city
- Time consuming
- Not conducive to experimentation!

Do not rely on wired infrastructure

- No wired power
  - Solar provides more power density than batteries
- No wired networking
- Should not modify existing infrastructure

Multi-tenancy is beneficial to testbeds

One deployment can enable many stakeholders simultaneously

- Need to ensure that they do not conflict

Air Quality Monitoring

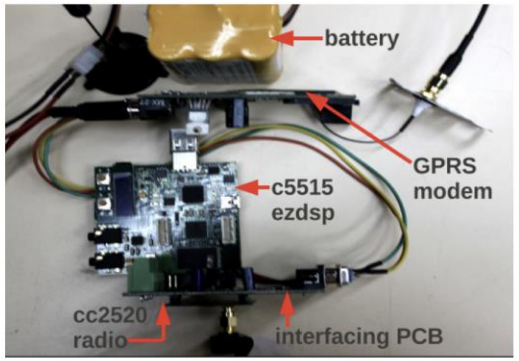
[1]

Urban Noise Classification

[2]

Traffic Queue Sensing

[3]



1. City-Scale Sensing Introduction
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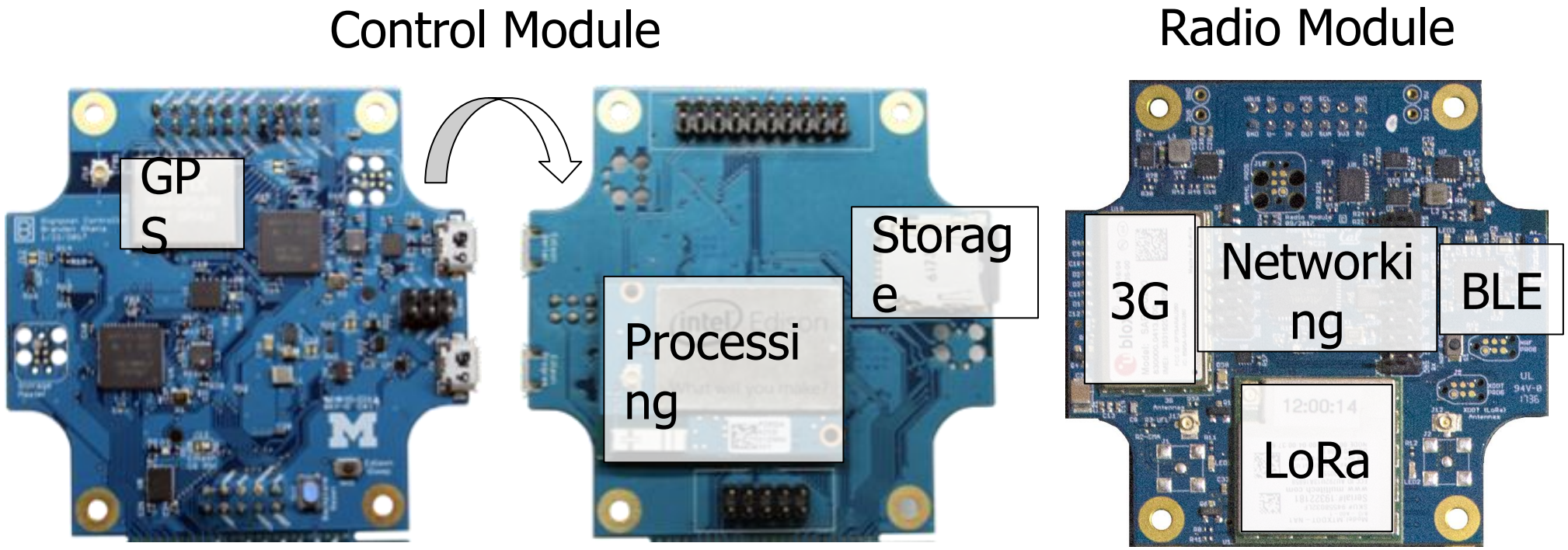
   - **Implementation**
   - Evaluation

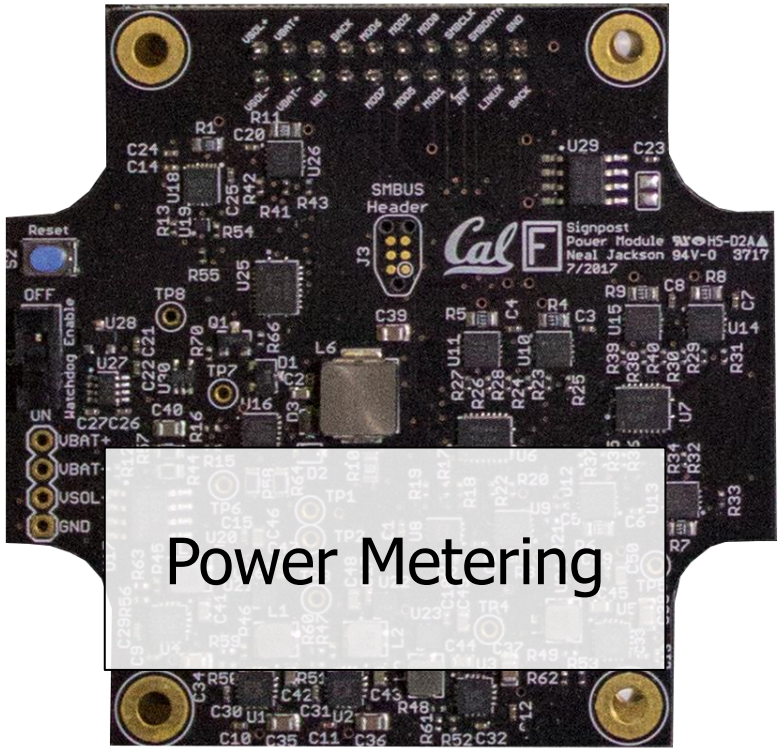
The Signpost Platform

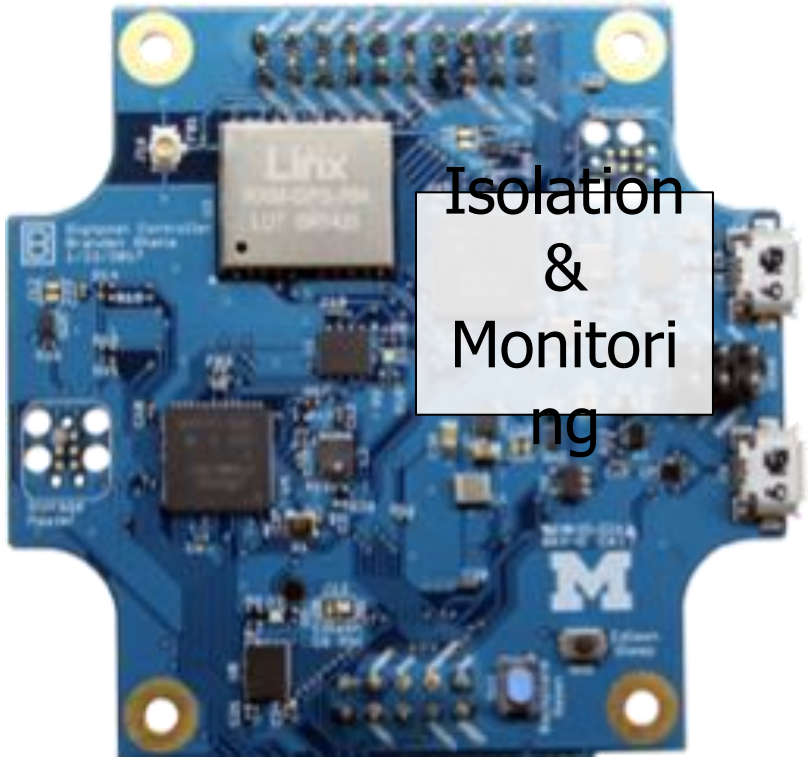
Core modules provide shared resources



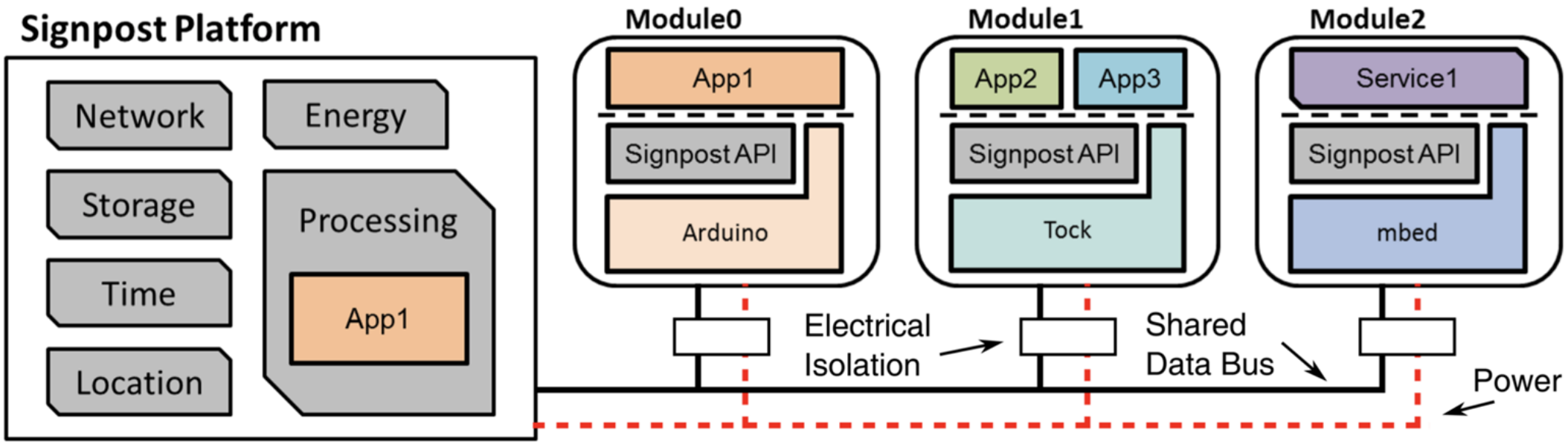
Making the platform modular supports upgradeability

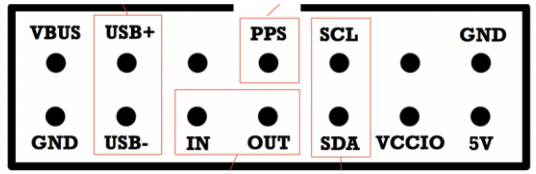
Measurement and isolation support multi-tenancy





Standard interface for accessing shared resources





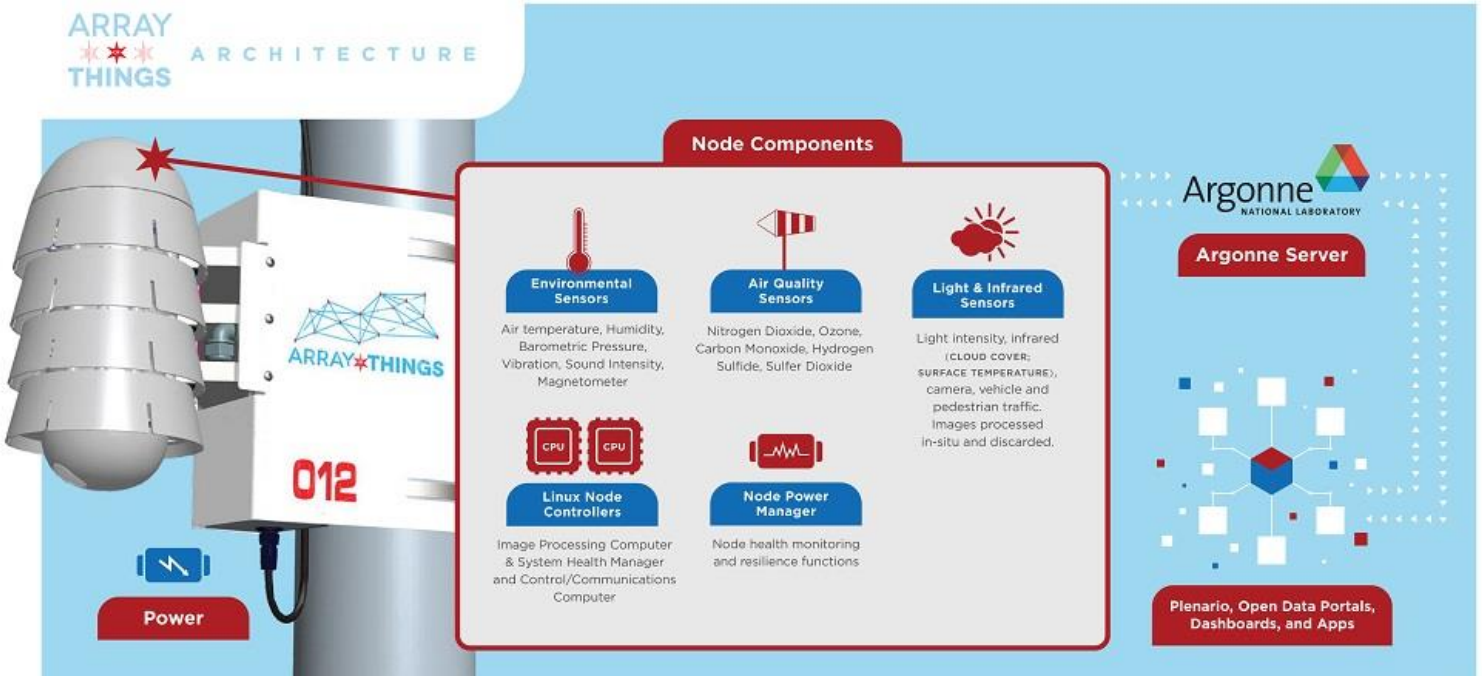
Only I2C and GPIO required

Optional
PPS 100ns global synch
USB

Any software framework can be used for modules

Array of Things is one platform approach

- Include sensors as platform resources
- Applications are software that act on sensor data
- High-power hardware and expensive to deploy



Signpost explores the other end of the spectrum

What can we do with less?

- Low-power, low-capability, extremely deployable
- Limited provided resources, but lots of extensibility

Focus on modularity

- Too difficult to start from scratch for every upgrade/change
  - Components are more expensive
  - Deployments is more difficult
- The platform should be viewed as shared infrastructure!
  - Amortize cost with multiple sensors and applications

1. City-Scale Sensing Introduction
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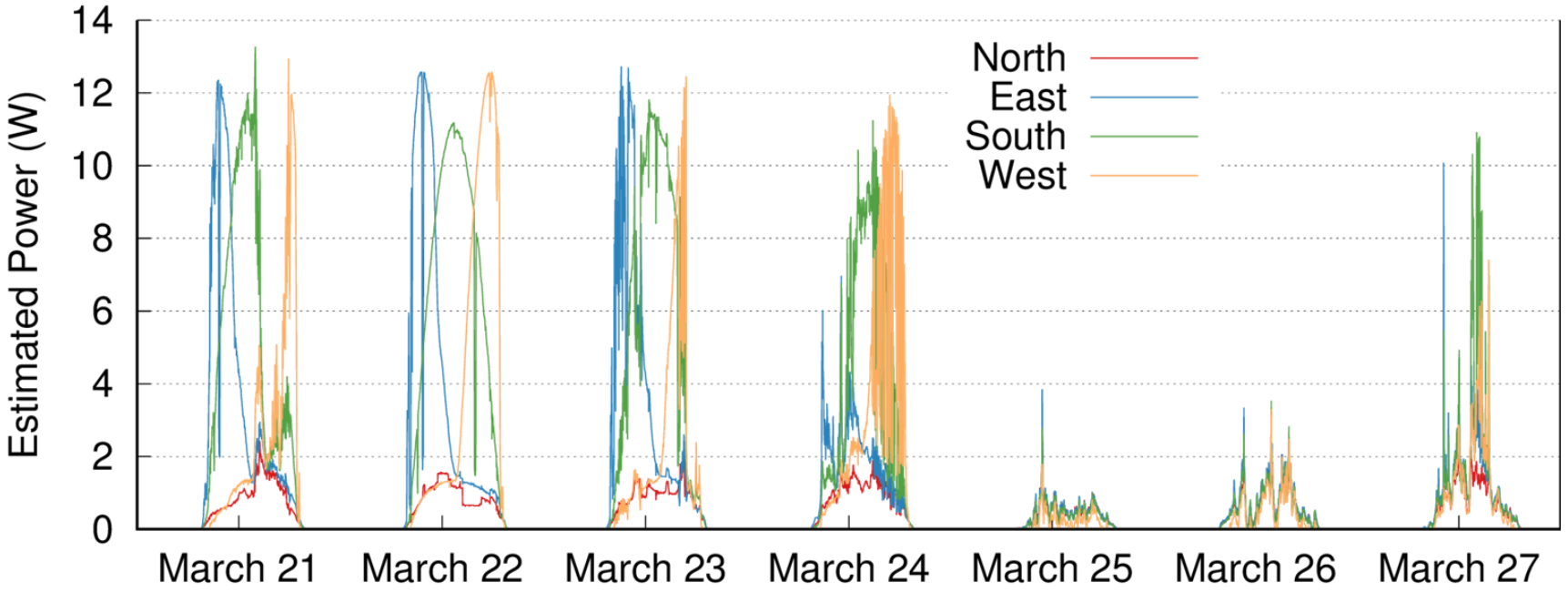
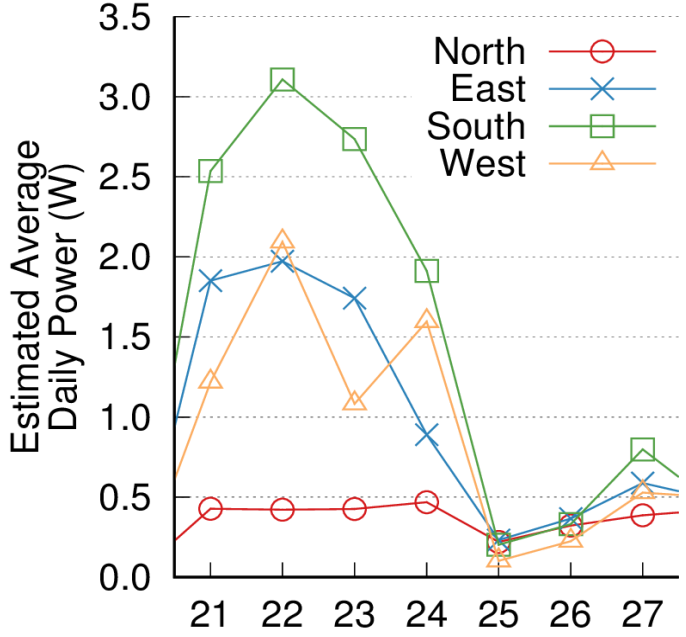
   - Deployability
   - Implementation
   - **Evaluation**

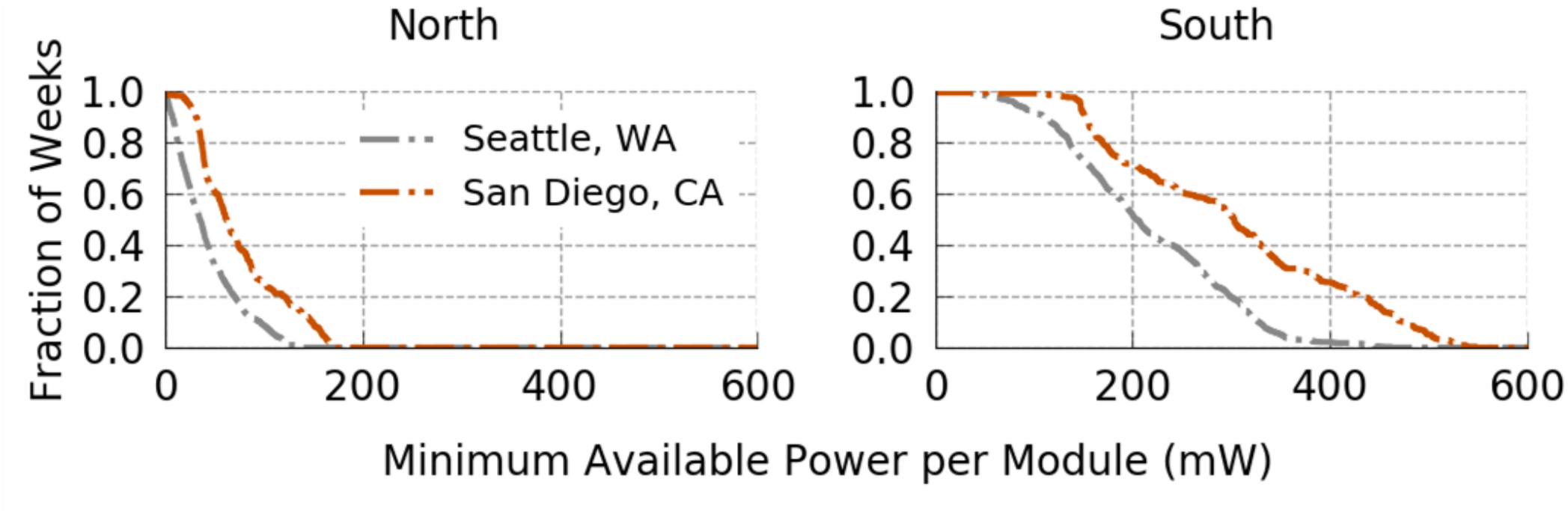
How much power does a Signpost harvest?





Higher daily variations than directional variations

How much power can each module draw?



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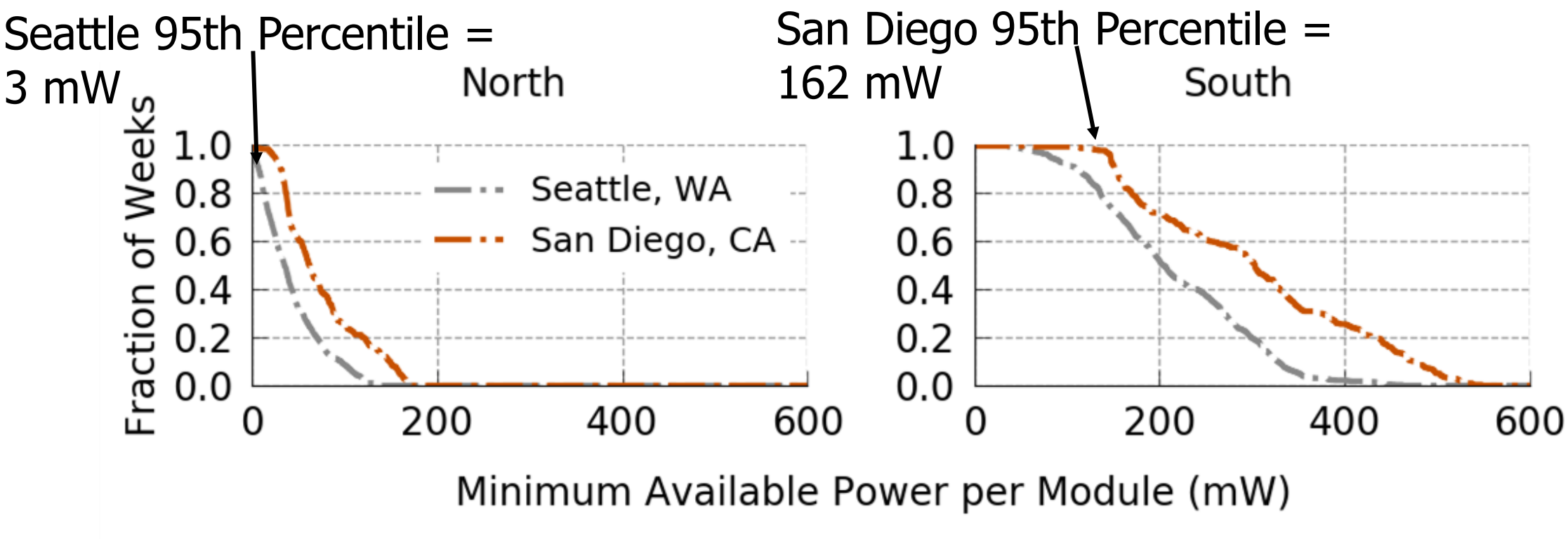

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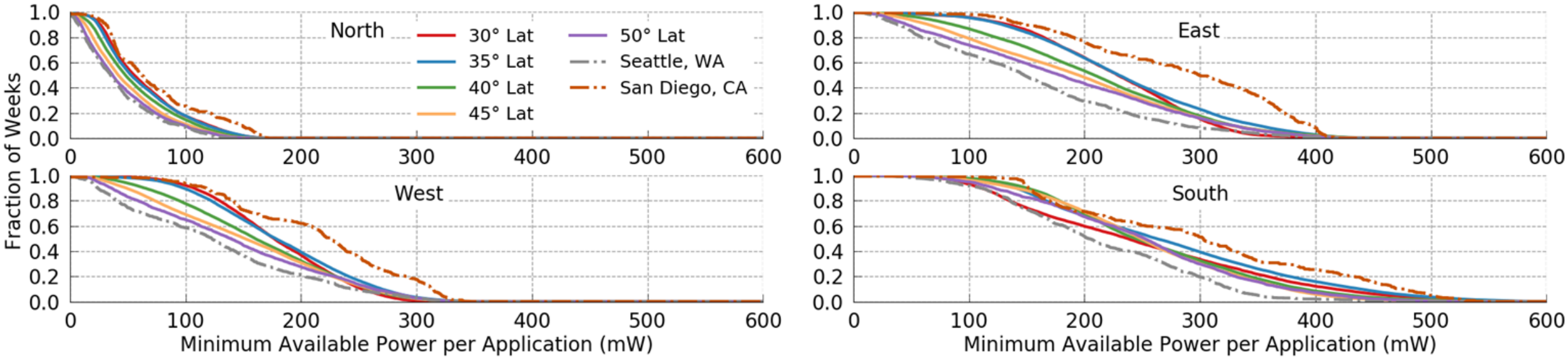
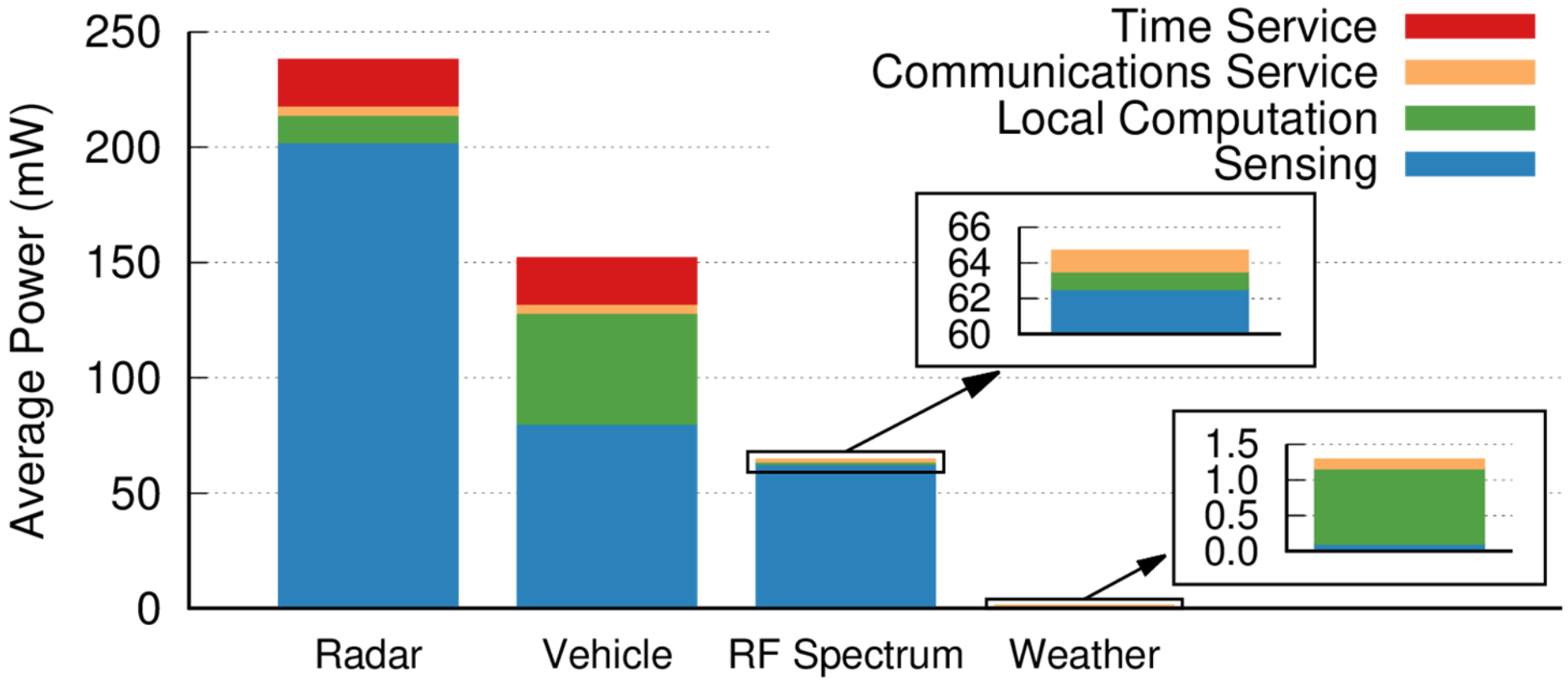


Resources are charged to modules which use them



Applications running on Signpost

- Environmental monitoring (posting to Weather Underground)
- Vehicle counting (and bell tower)
- TV whitespace sensing