Lecture 18
Wrapup

CE346 – Microprocessor System Design

Branden Ghena – Fall 2021

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

Northwestern

Administrivia

- This is the last lecture!! 😭
  - No class on Thursday
  - I can schedule meetings with groups if needed

- Project Demos - Next week Tuesday
  - Tuesday 12/7
  - Mudd 3514
  - 2:00-5:00 pm

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

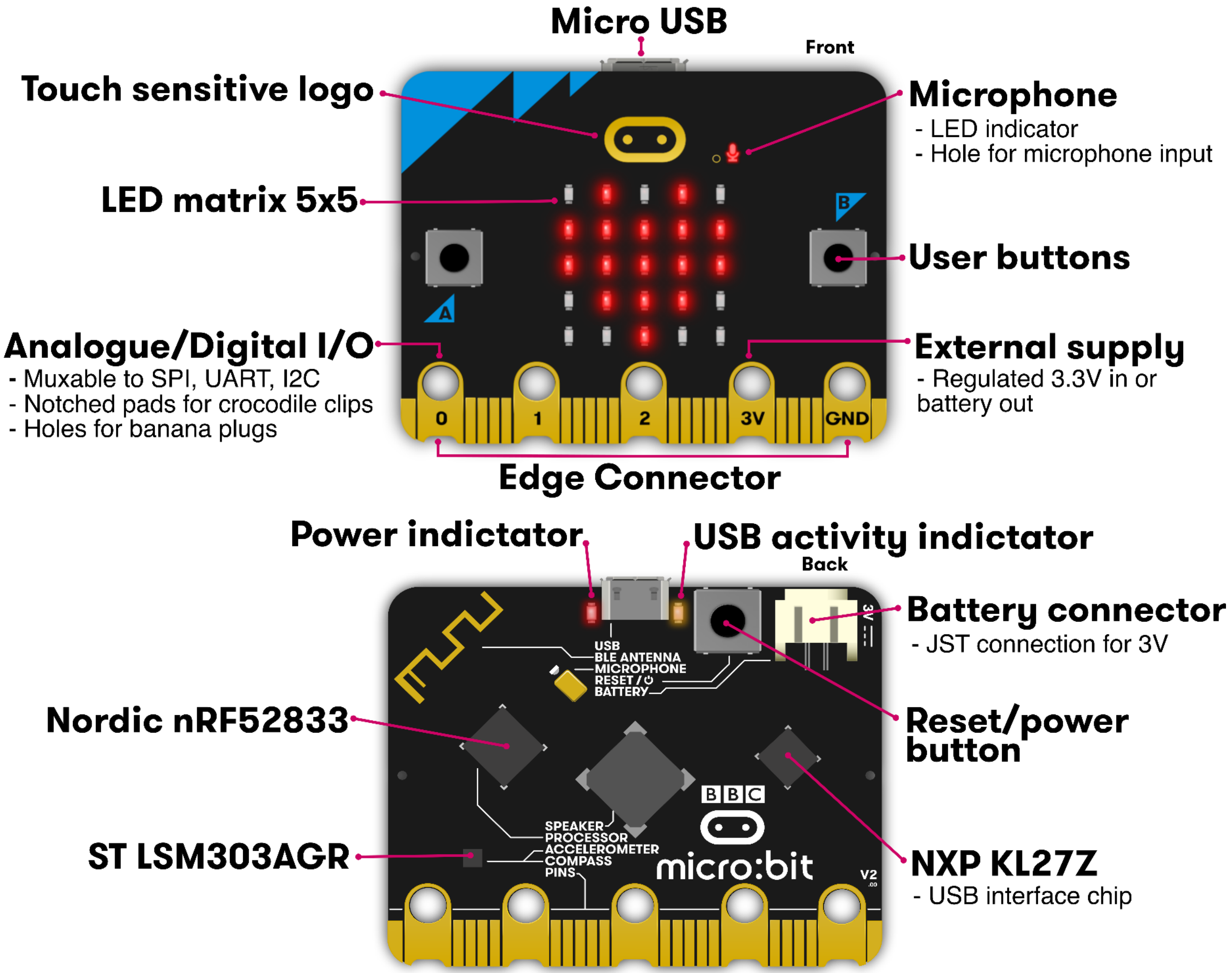
Outline

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

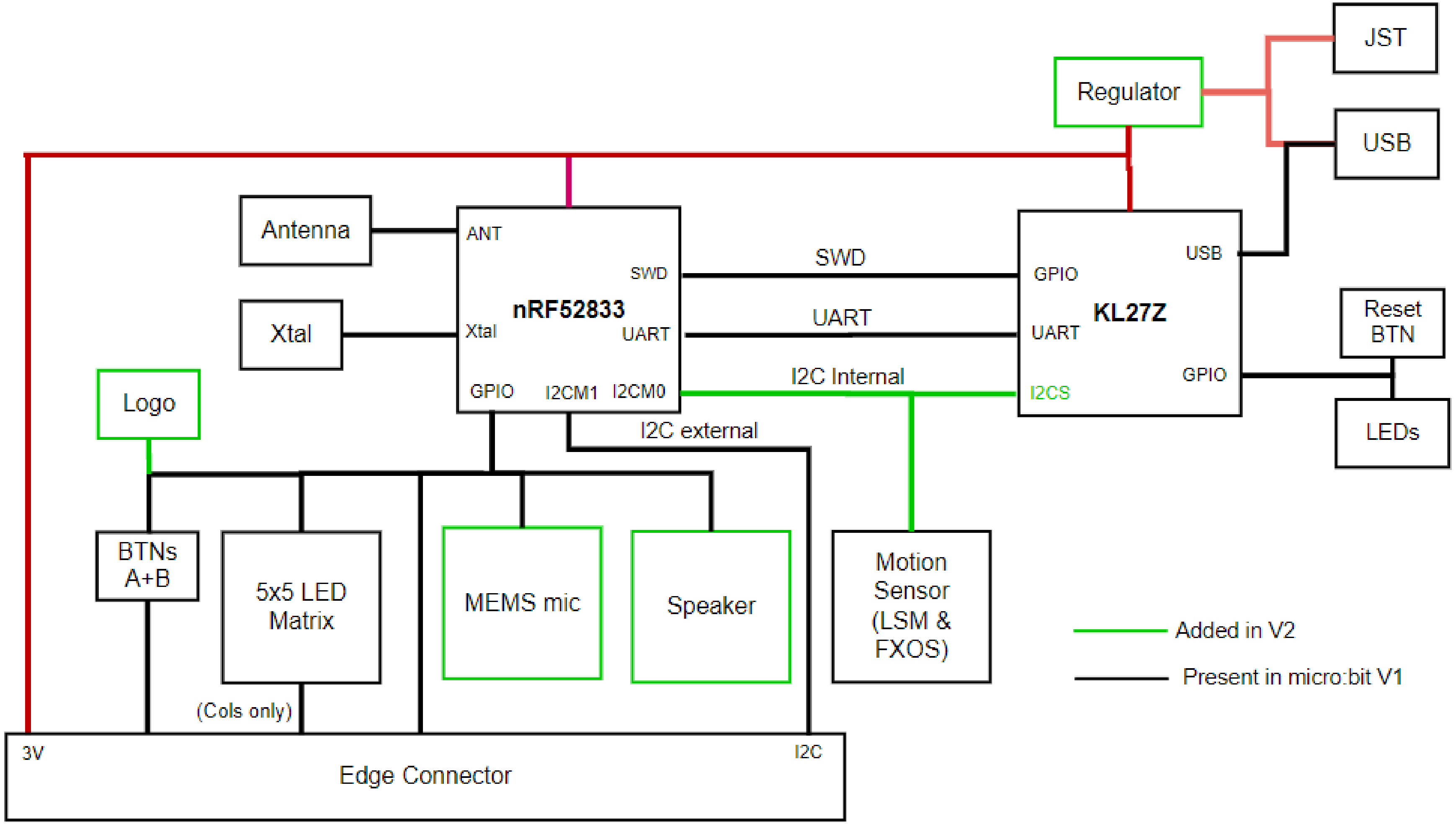
- Sensing Systems Research

Microbit

- Used almost all of this!
- Remaining:
  - Batteries
  - Wireless
  - KL27Z I2C



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

Outline

- **What haven’t we talked about?**
  - Microbit
  - **nRF52833**
    - **Task/Event Chaining with PPI**

- Sensing Systems Research

Software stops when the processor does, but peripherals continue

- Solution to low power: keep the processor off
- Problem: when the processor is off, no code is running

- Solutions
  - Peripherals can wake it up again
    - Can probably go for milliseconds to minutes without any actions
    - Timer interrupt can wake processor to do things
  - Have hardware handle some parts in the background without the processor's involvement
    - DMA
    - PPI

Controlling peripherals while processor sleeps

- DMA (Direct Memory Access)
  - Set up a pointer to memory and a length
  - Peripheral can load/store memory without processor's involvement
  - Usually use completion interrupt to wake processor

- PPI (Programmable Peripheral Interconnect)
  - Any Event can be tied to any Task within the nRF52
  - Allows for complicated actions to be chained together

nRF52 Tasks and Events

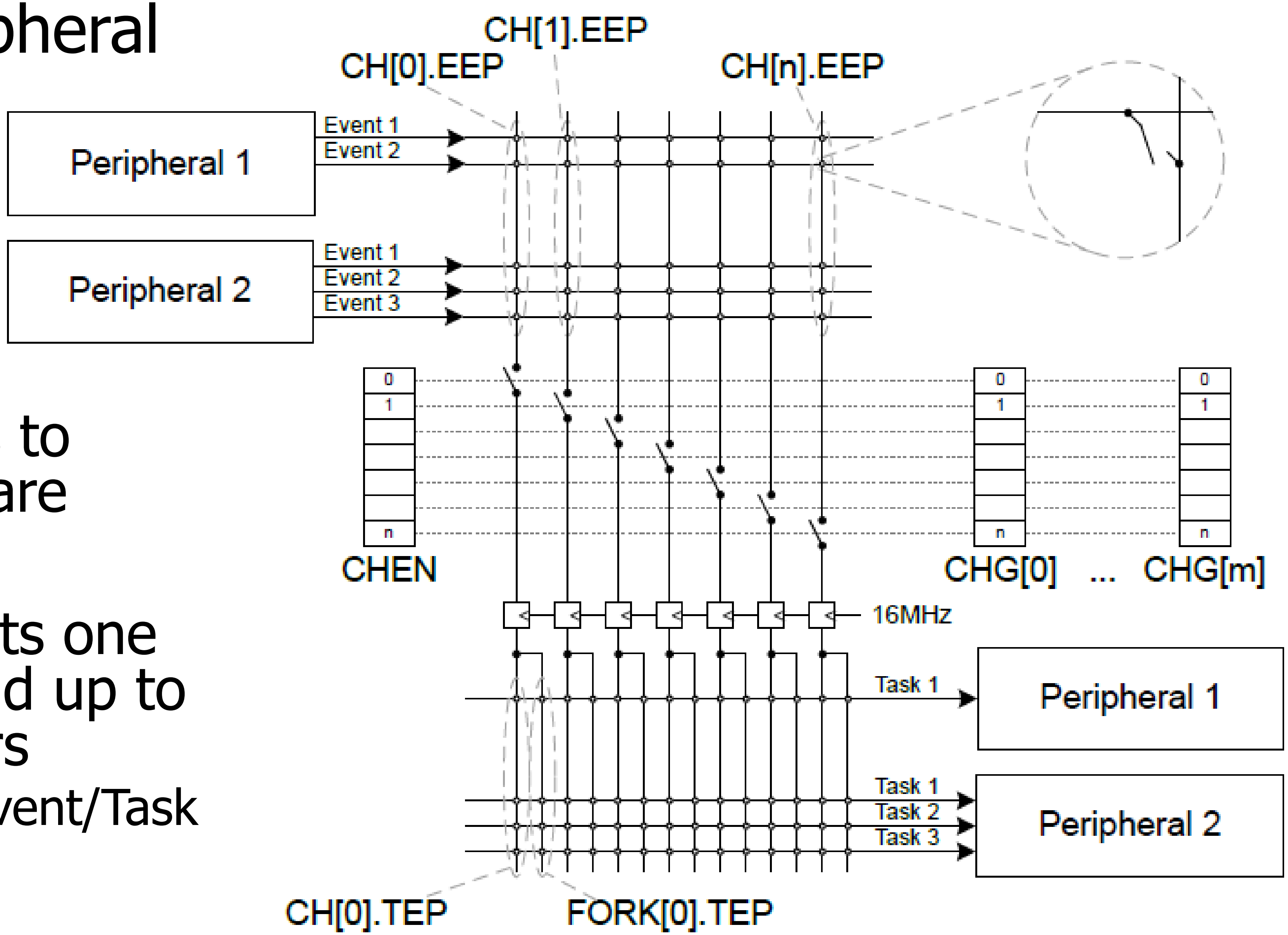
- Tasks are used to perform some operation
  - Often written to by software
- Events change value when some change in status occurs
  - Often used to trigger interrupts
- PPI peripheral can connect any TASK to any EVENT

Example: Timer peripheral

Register	Offset	Description
TASKS_START	0x000	Start Timer
TASKS_STOP	0x004	Stop Timer
TASKS_COUNT	0x008	Increment Timer (Counter mode only)
TASKS_CLEAR	0x00C	Clear time
TASKS_SHUTDOWN	0x010	Shut down timer
TASKS_CAPTURE[0]	0x040	Capture Timer value to CC[0] register
TASKS_CAPTURE[1]	0x044	Capture Timer value to CC[1] register
TASKS_CAPTURE[2]	0x048	Capture Timer value to CC[2] register
TASKS_CAPTURE[3]	0x04C	Capture Timer value to CC[3] register
TASKS_CAPTURE[4]	0x050	Capture Timer value to CC[4] register
TASKS_CAPTURE[5]	0x054	Capture Timer value to CC[5] register
EVENTS_COMPARE[0]	0x140	Compare event on CC[0] match
EVENTS_COMPARE[1]	0x144	Compare event on CC[1] match
EVENTS_COMPARE[2]	0x148	Compare event on CC[2] match
EVENTS_COMPARE[3]	0x14C	Compare event on CC[3] match
EVENTS_COMPARE[4]	0x150	Compare event on CC[4] match
EVENTS_COMPARE[5]	0x154	Compare event on CC[5] match

nRF52 PPI peripheral

- Connects Events to Tasks via hardware
- Each channel gets one Event pointer and up to two Task pointers
  - Must point to Event/Task registers



Example PPI use case

- Automatic high-speed ADC sampling

- Software configures and sleeps
  - ADC (buffer and enable)
  - Timer (prescaler, compare value, short from compare to clear, and start)

- PPI: When Timer fires (EVENTS_COMPARE[0]),
  - Sample ADC (TASKS_SAMPLE)

- PPI: When ADC buffer full (EVENTS_END),
  - Stop Timer (TASKS_STOP)
  - Fork: wake processor (via software interrupt from EGU)

Outline

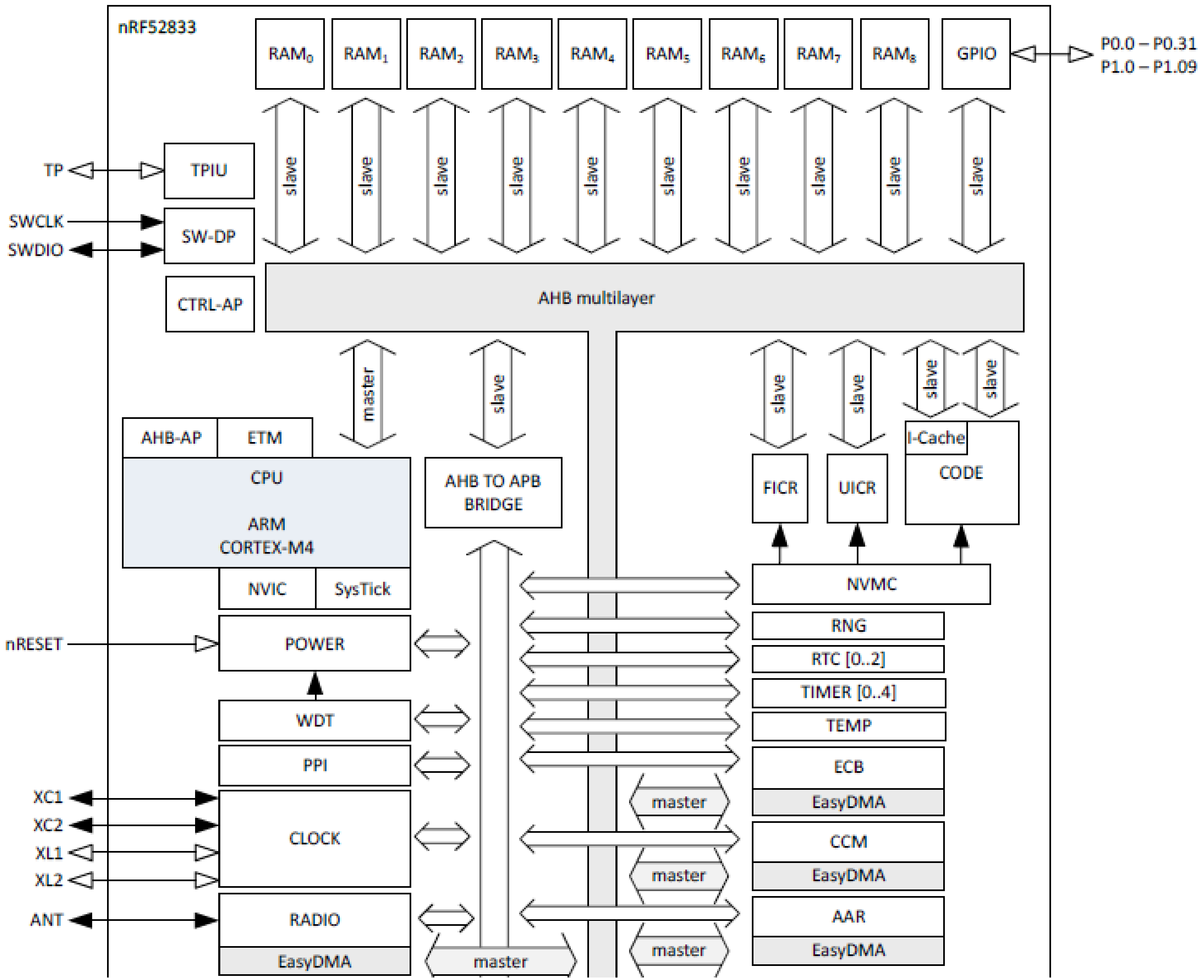
- **What haven't we talked about?**
  - Microbit
  - **nRF52833**
    - **Peripheral overview**

- Sensing Systems Research

nRF52833 Peripherals

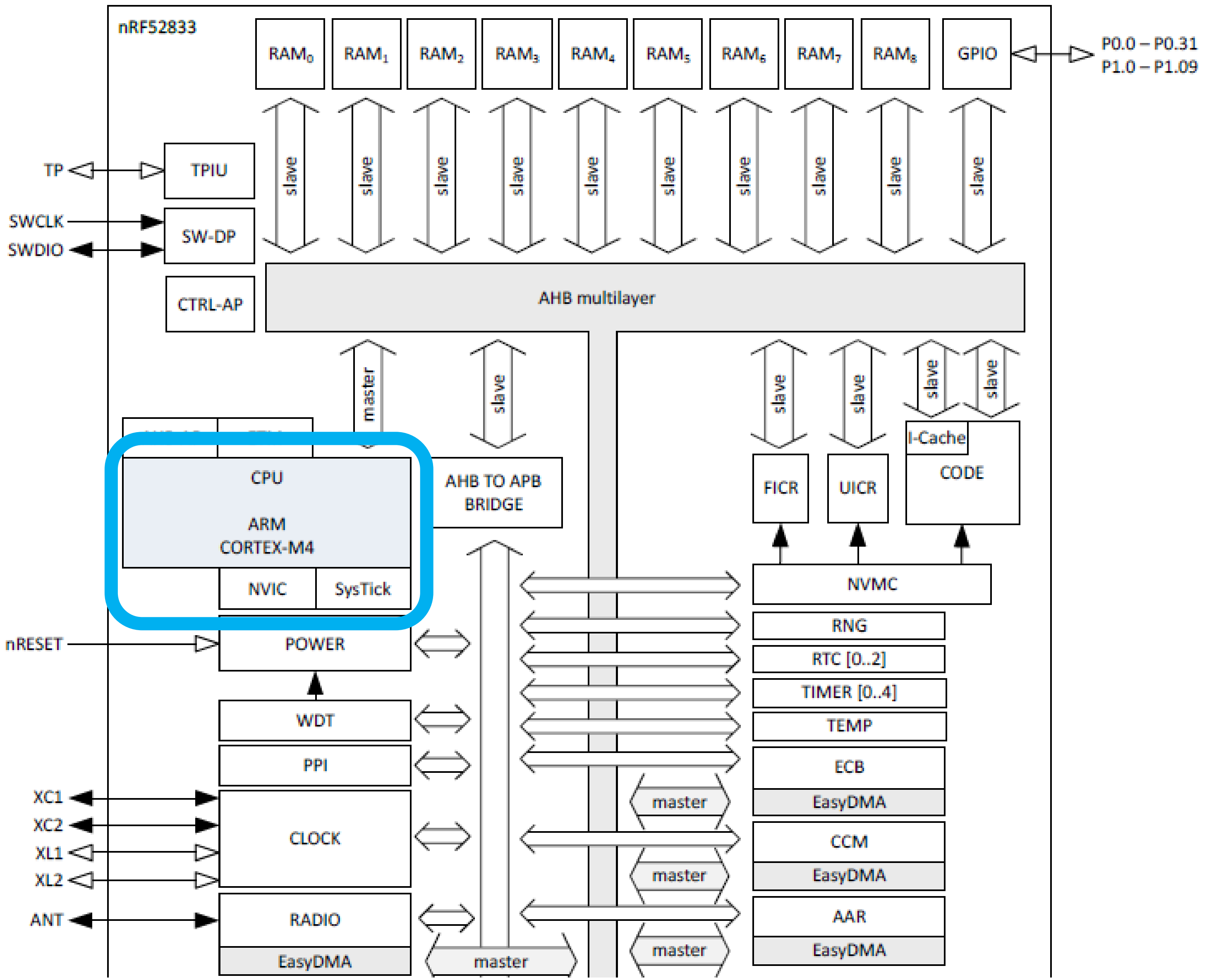
- Tour of the nRF52833 peripherals

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



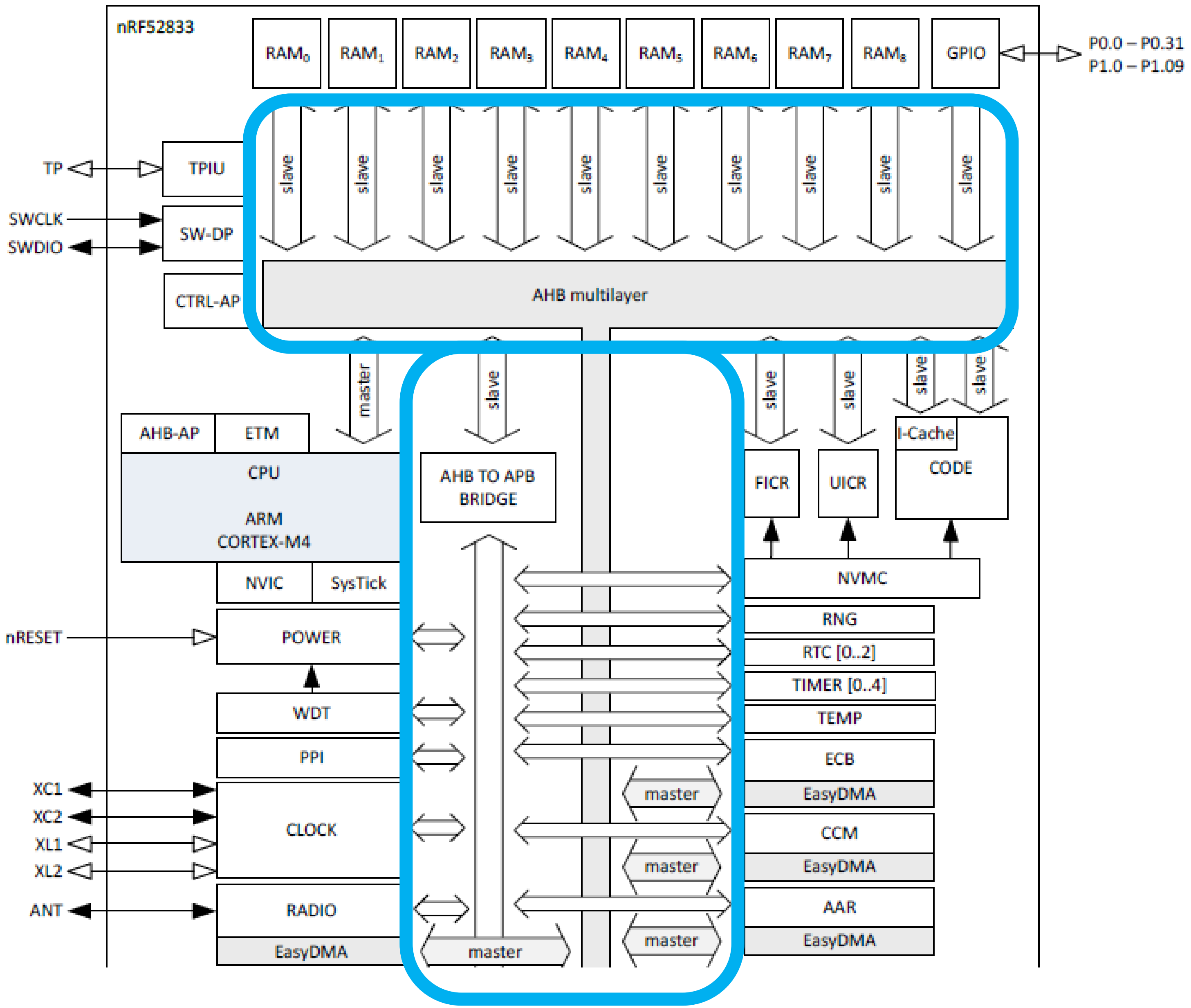
nRF52833 Peripherals

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



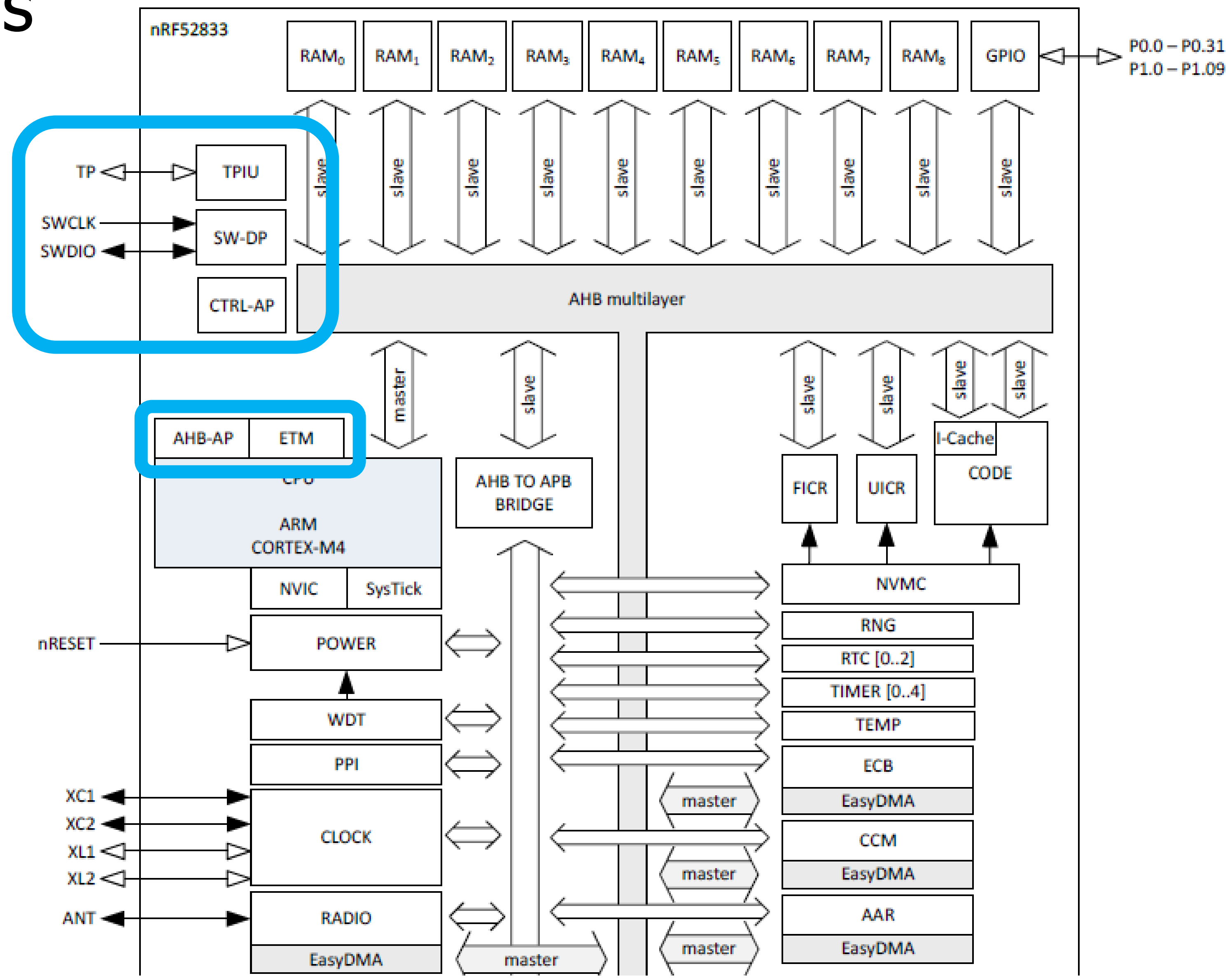
nRF52833 Peripherals

- Memory buses



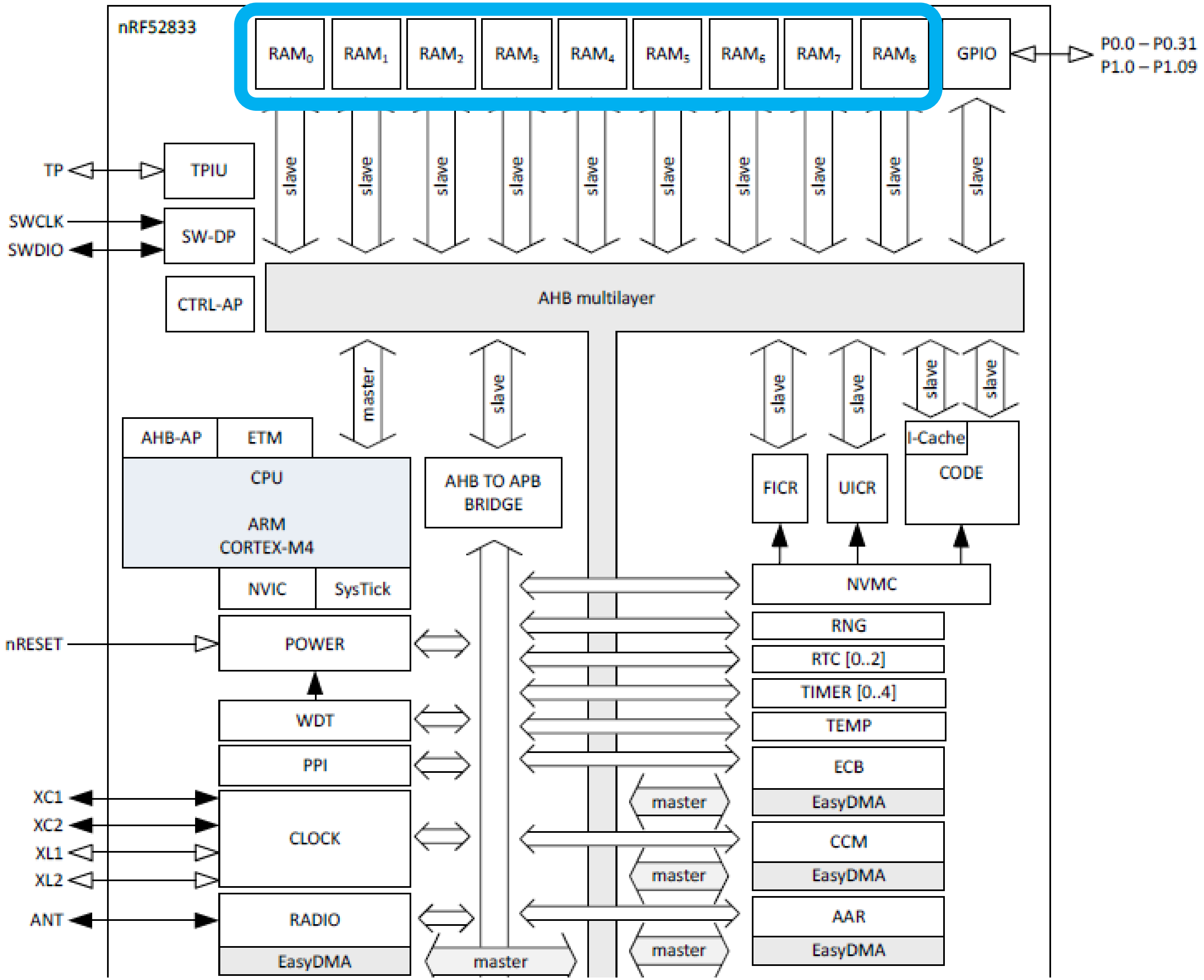
nRF52833 Peripherals

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



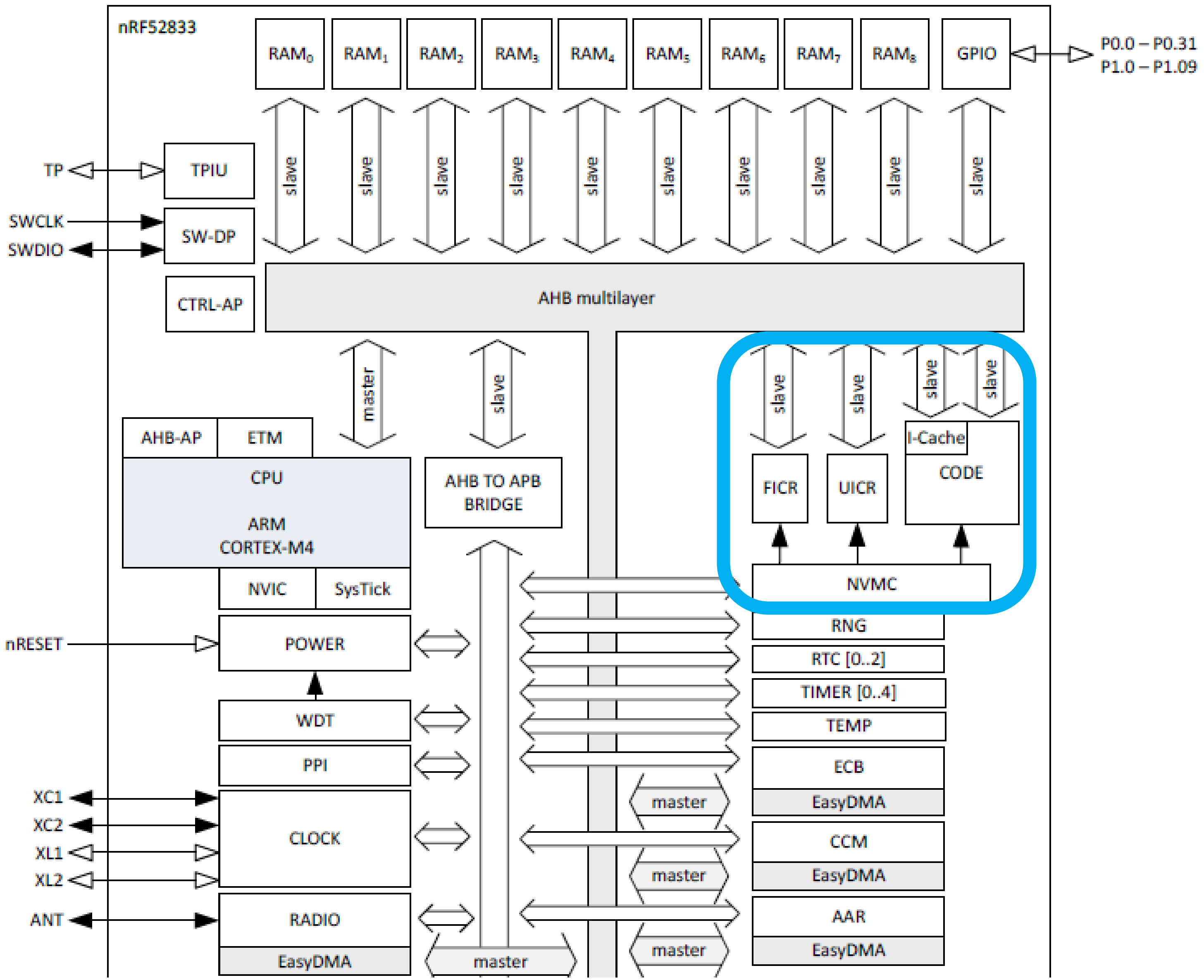
nRF52833 Peripherals

- Volatile memory
- SRAM, 128 kB



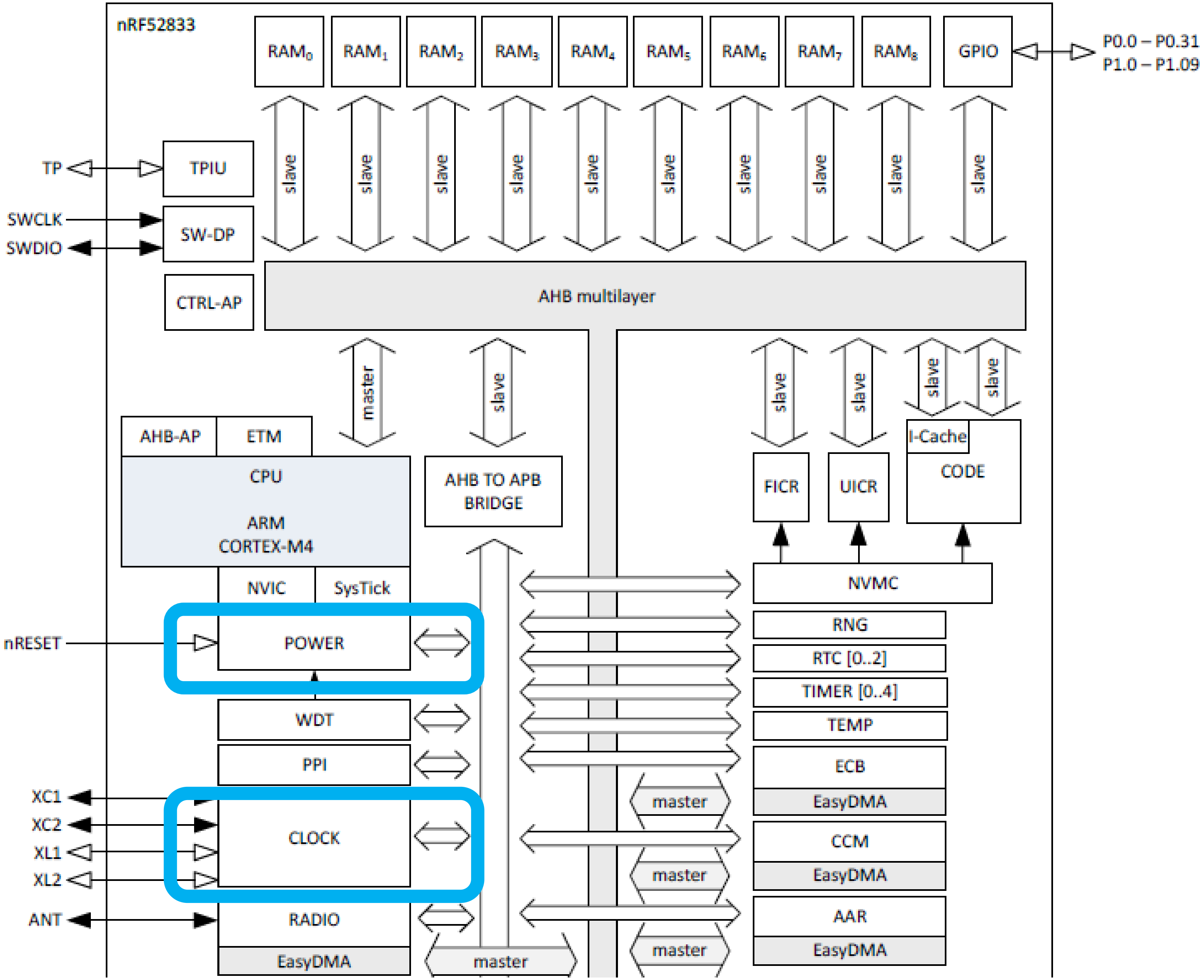
nRF52833 Peripherals

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



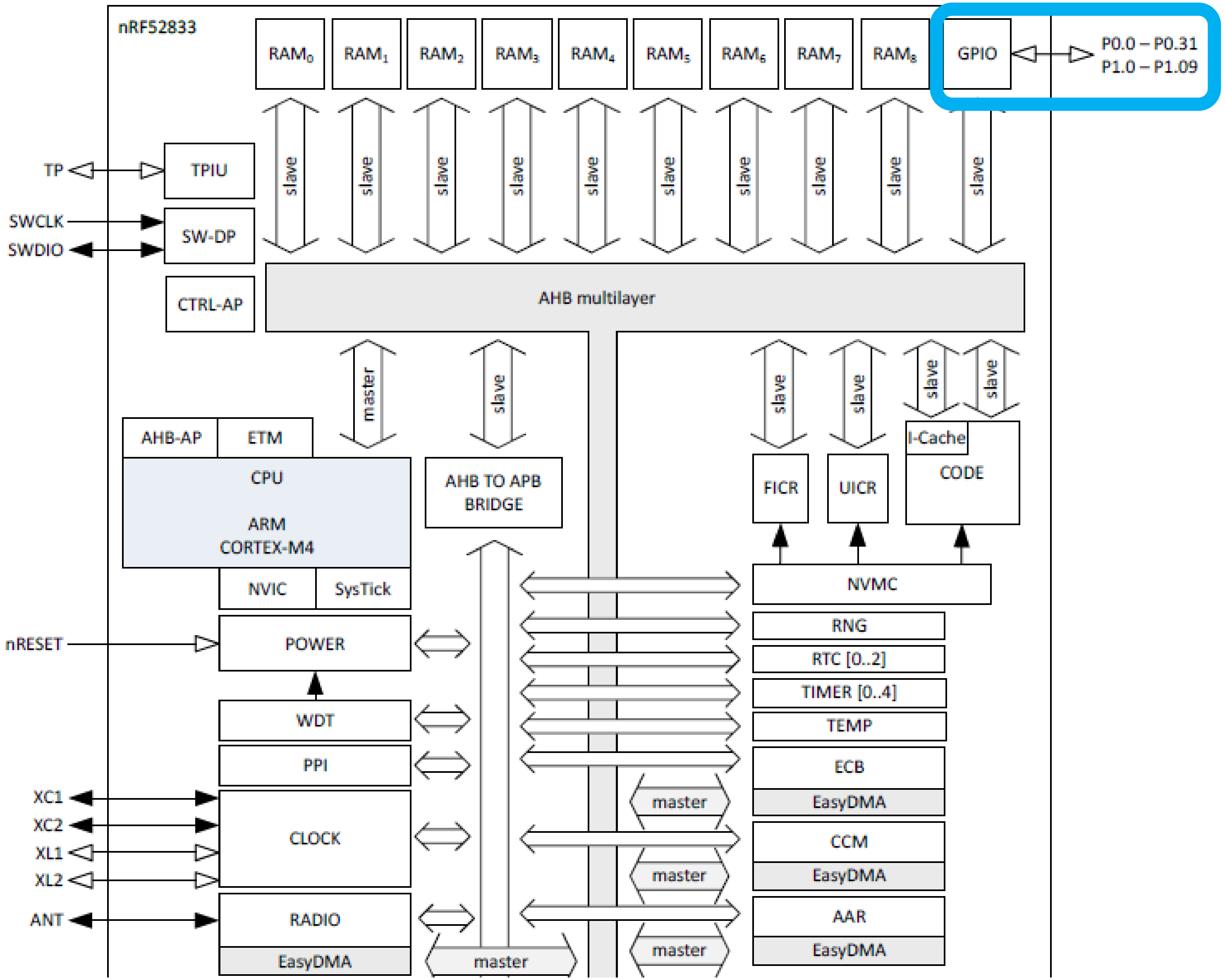
nRF52833 Peripherals

- Power and Clock management



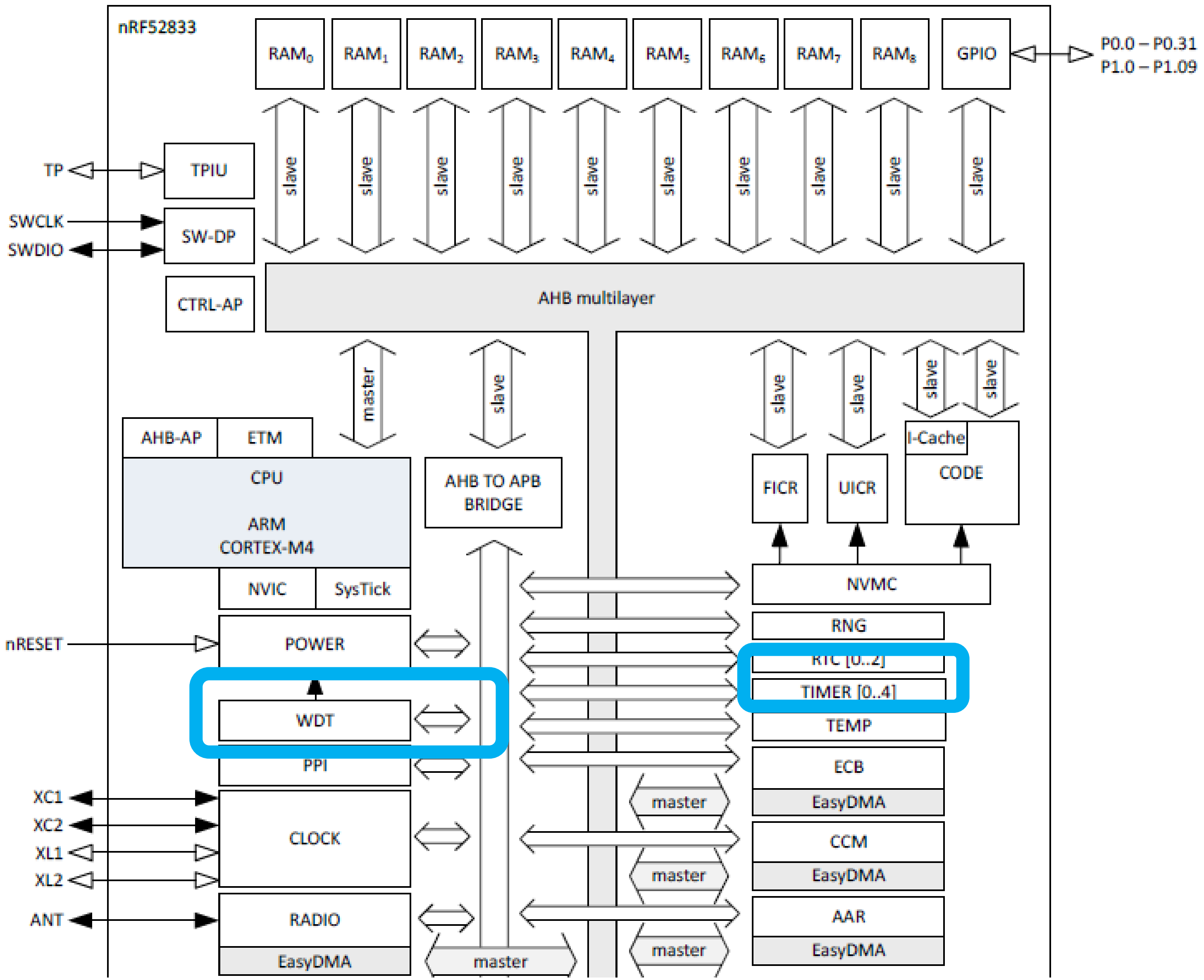
nRF52833 Peripherals

- GPIO pins



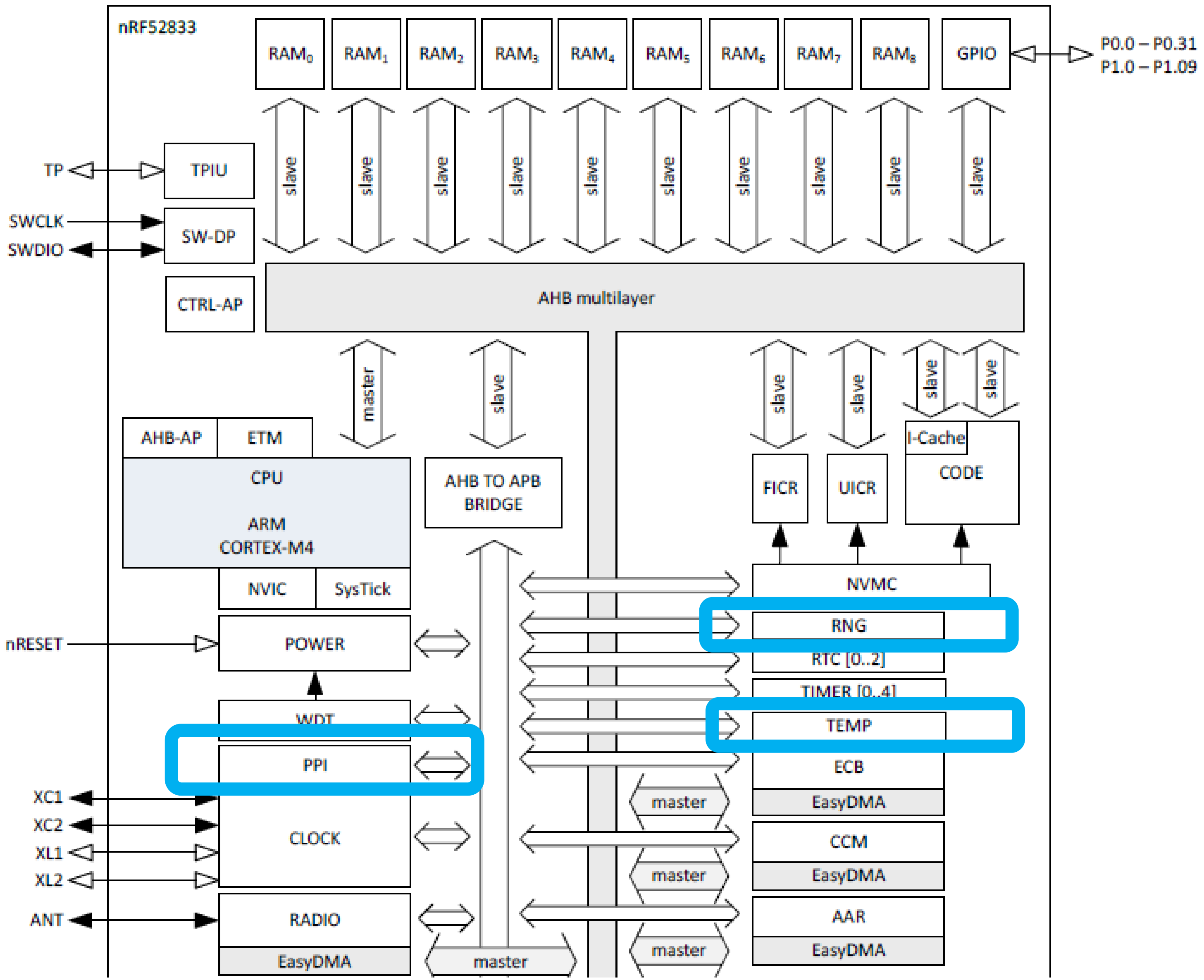
nRF52833 Peripherals

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



nRF52833 Peripherals

- Programmable Peripheral Interconnect
- Random Number Generator
- Temperature sensor

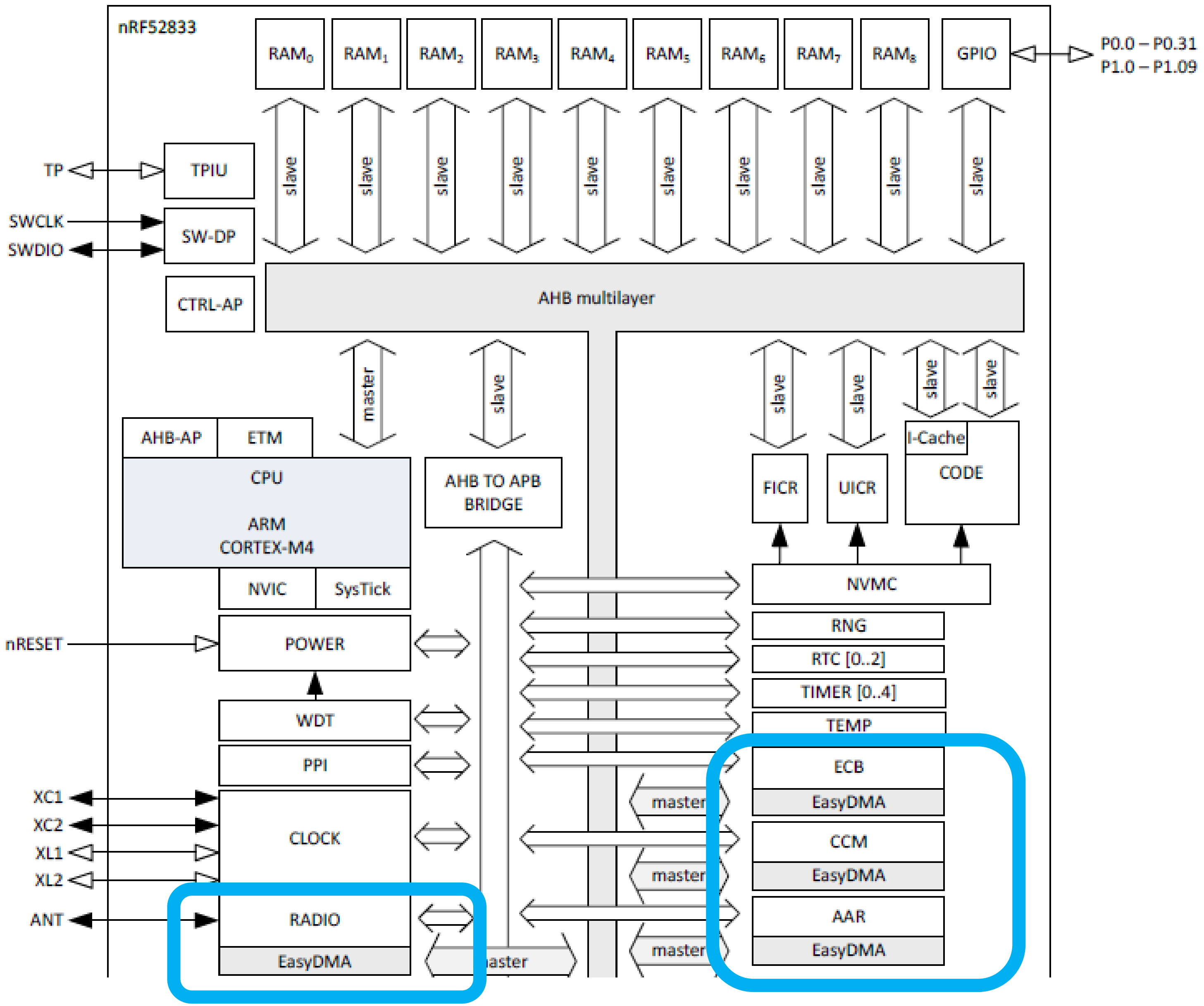


nRF52833 Peripherals

- Wireless radio
  - Bluetooth Low Energy
  - 802.15.4
    (Zigbee or Thread)

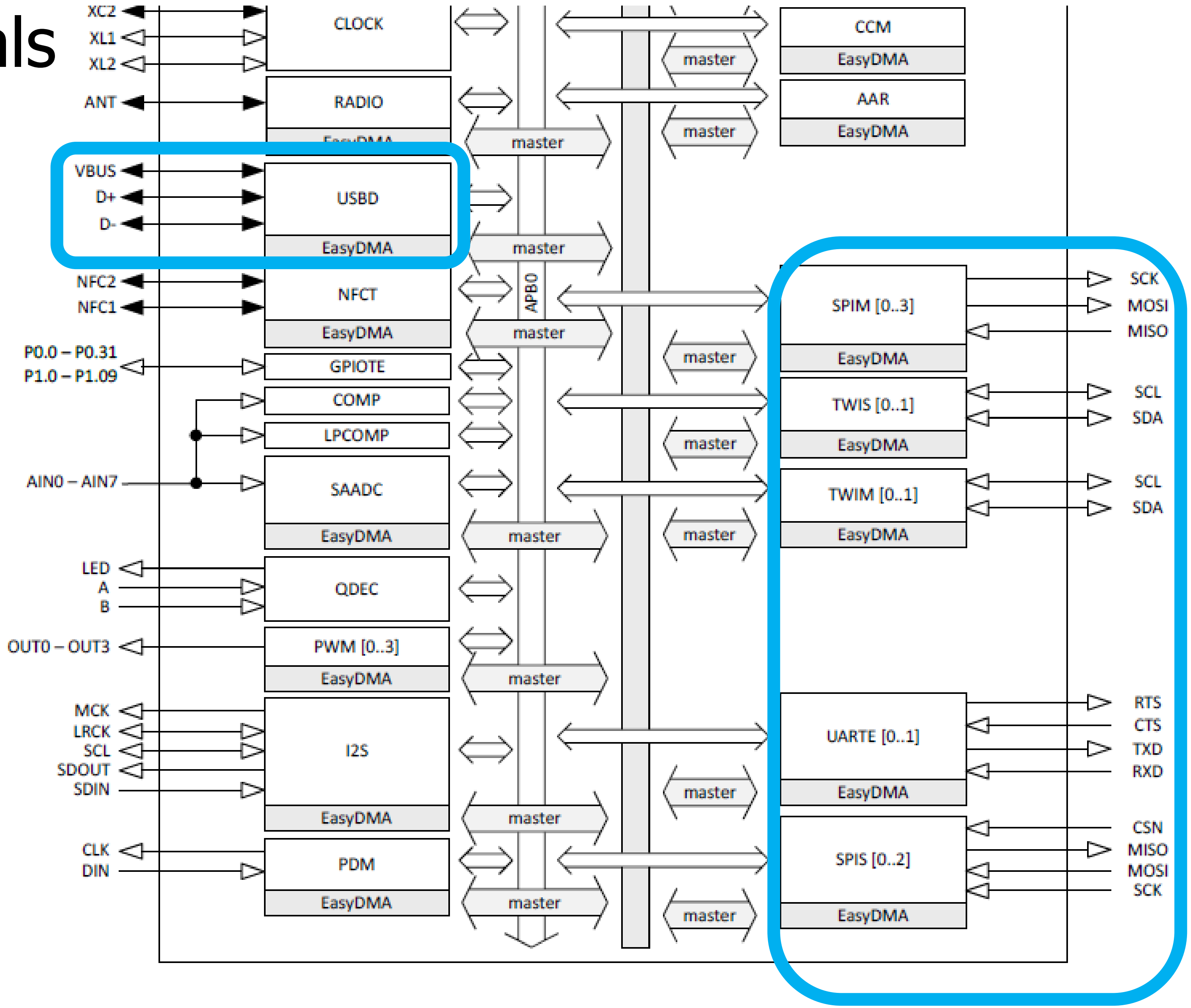
- Cryptography
  - ECB (AES mode)
  - CCM (AES mode)

  - AAR (Accelerated Address Resolver)
    - For BLE random addresses



nRF52833 Peripherals

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

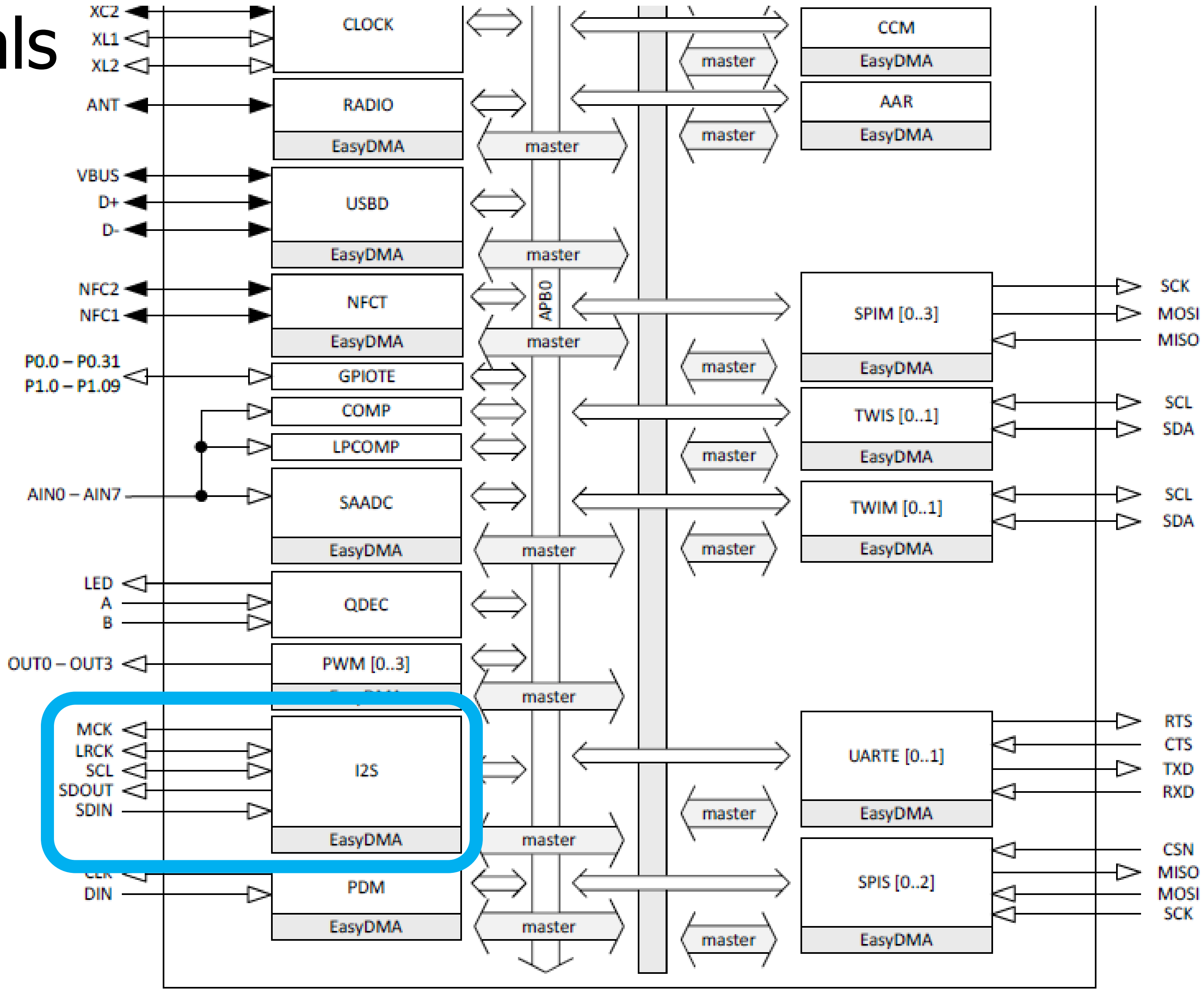


nRF52833 Peripherals

- Inter-IC Sound (I2S)
  - Wired communication bus explicitly for audio data
  - Unrelated to I2C

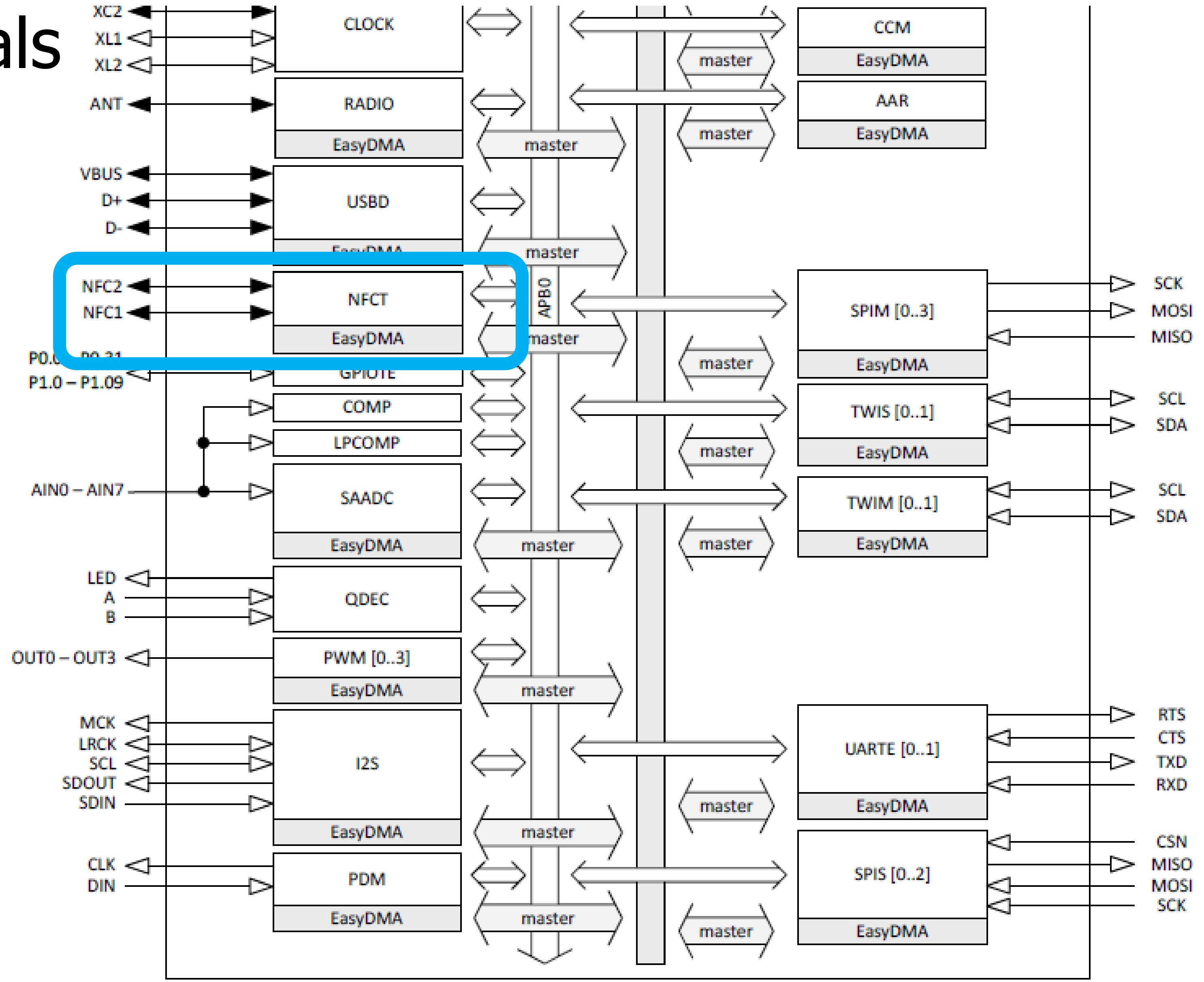
- Like a synchronous UART
  - Clock, data in, data out

- Additional signals
  - MCK – synchronization
  - LRCK – left/right channel select



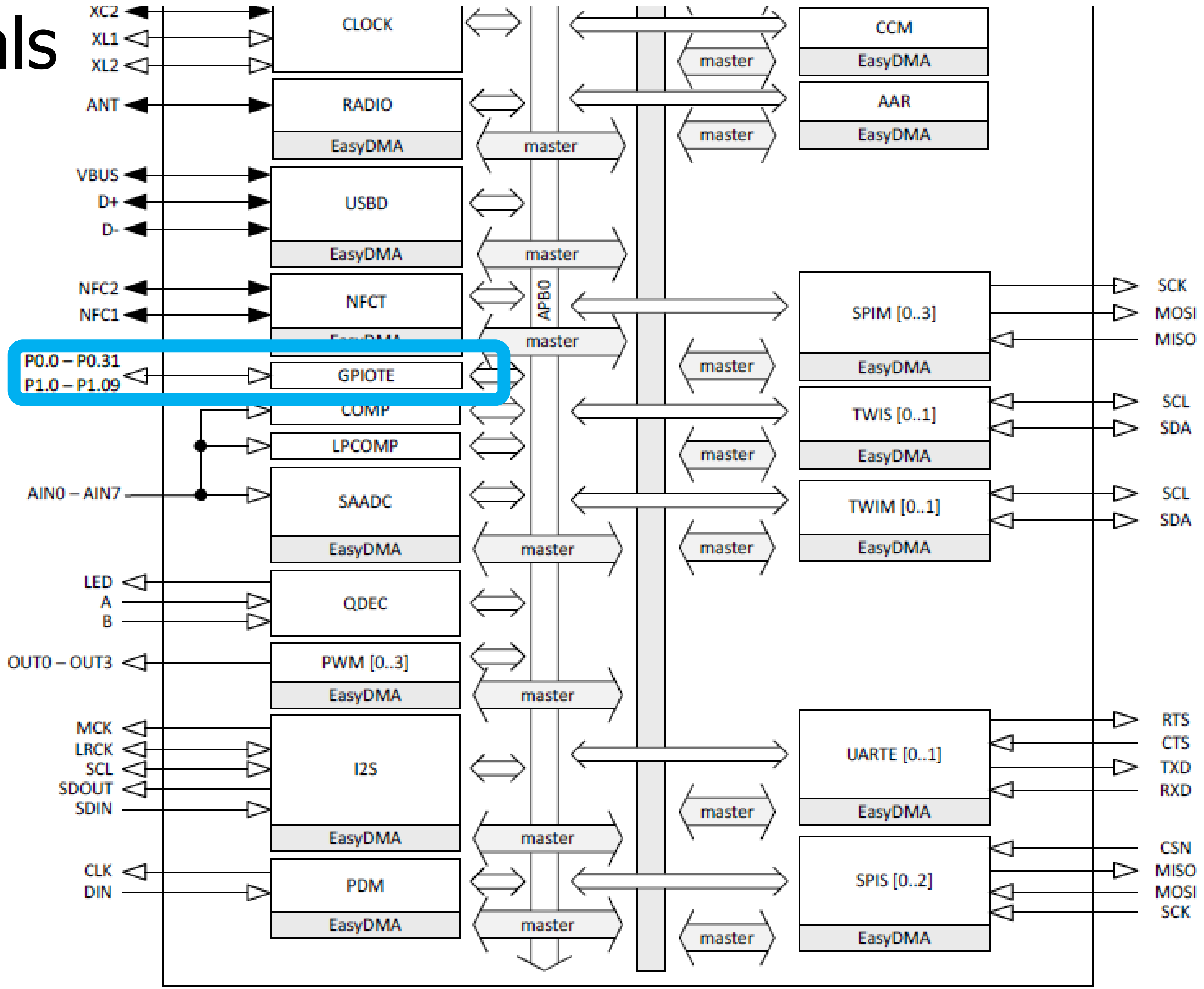
nRF52833 Peripherals

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



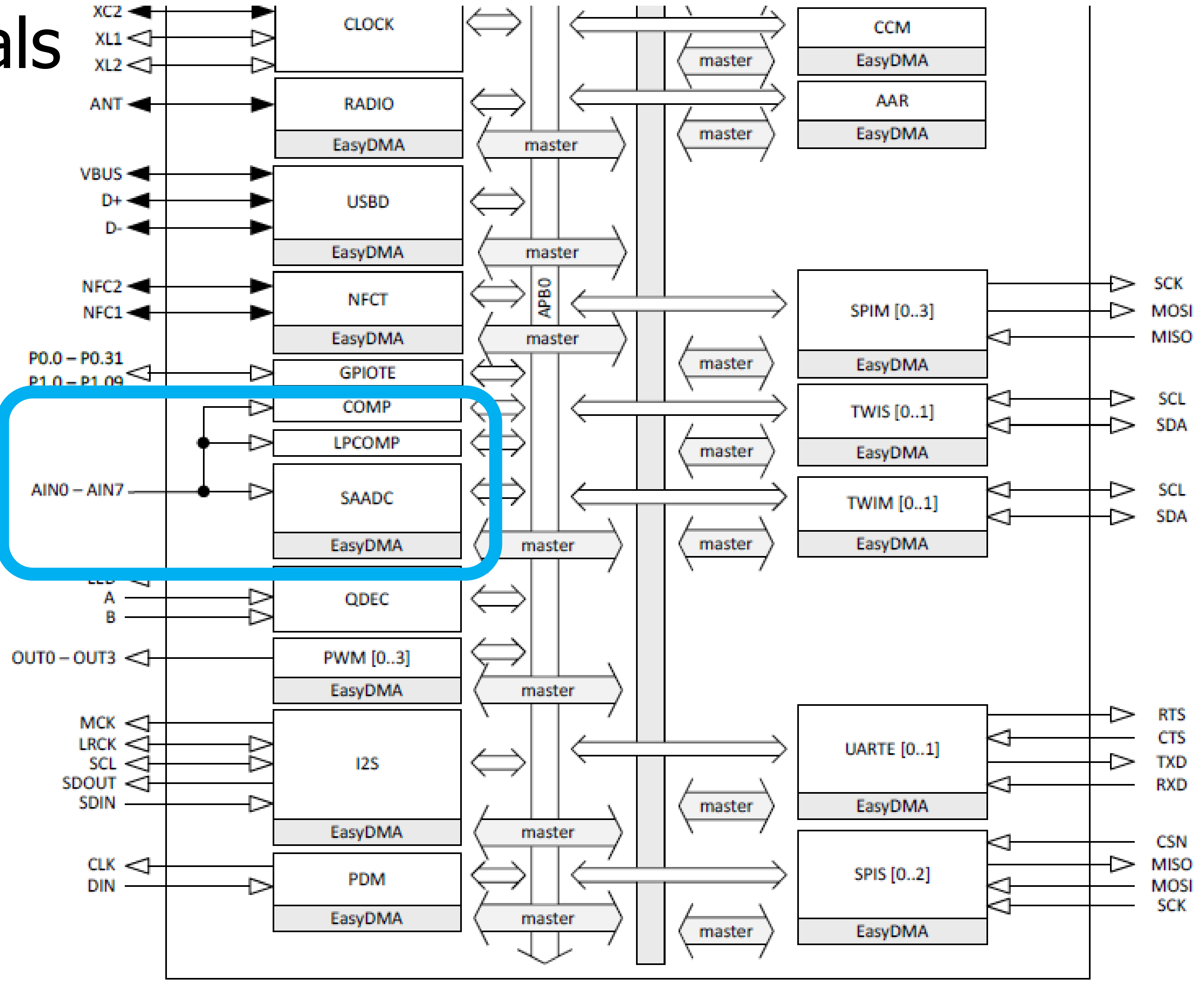
nRF52833 Peripherals

- GPIOTE
  - GPIO interrupts



nRF52833 Peripherals

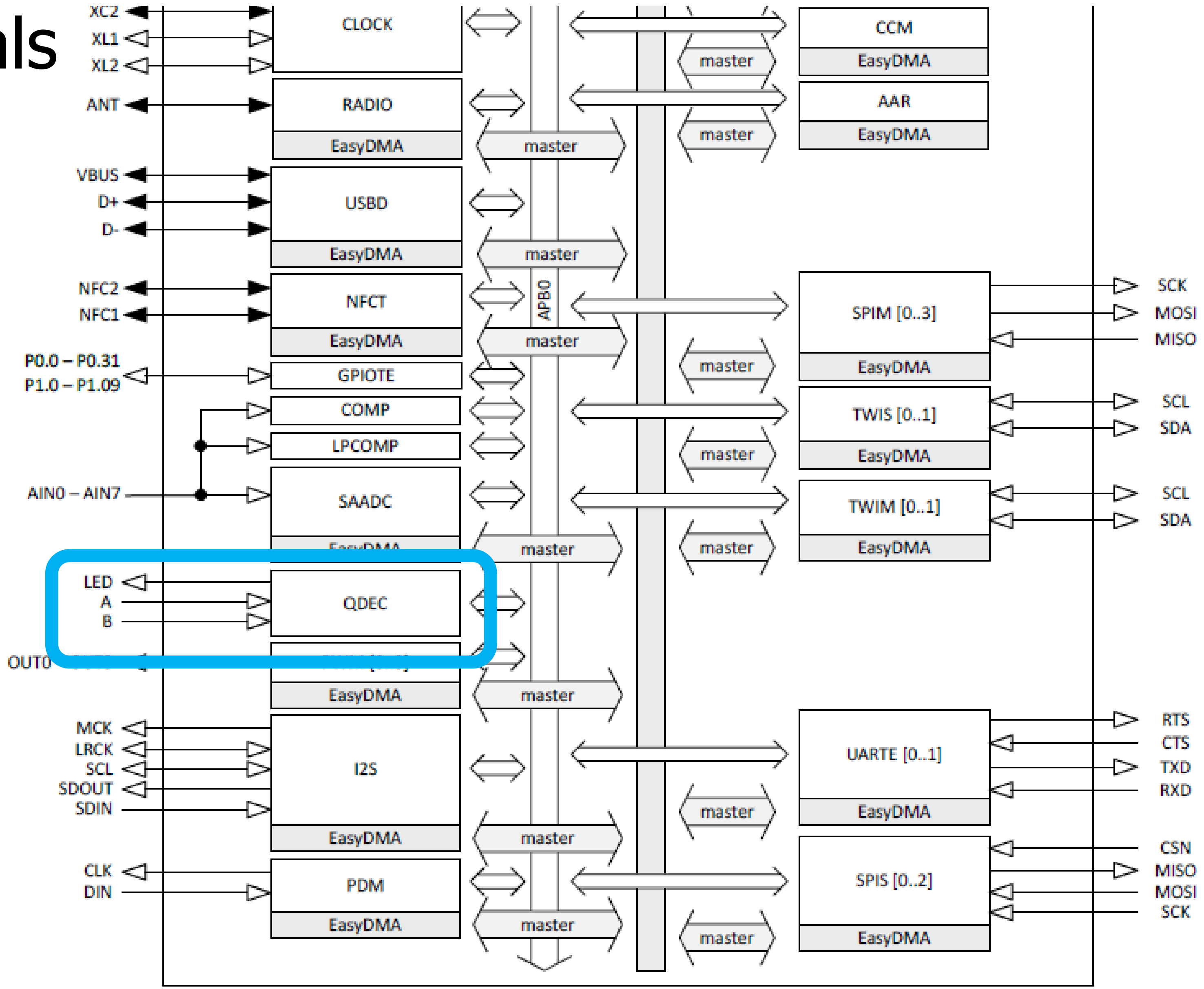
- Analog inputs
- Comparator
- Low-Power Comparator
- Successive Approximation Analog-to-Digital Converter



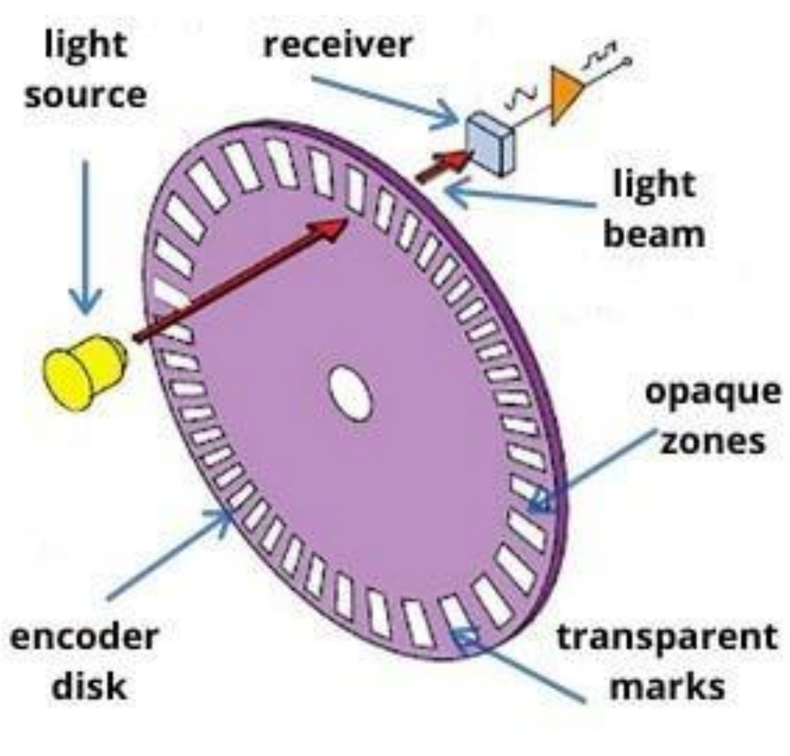
nRF52833 Peripherals

- Quadrature Decoder peripheral

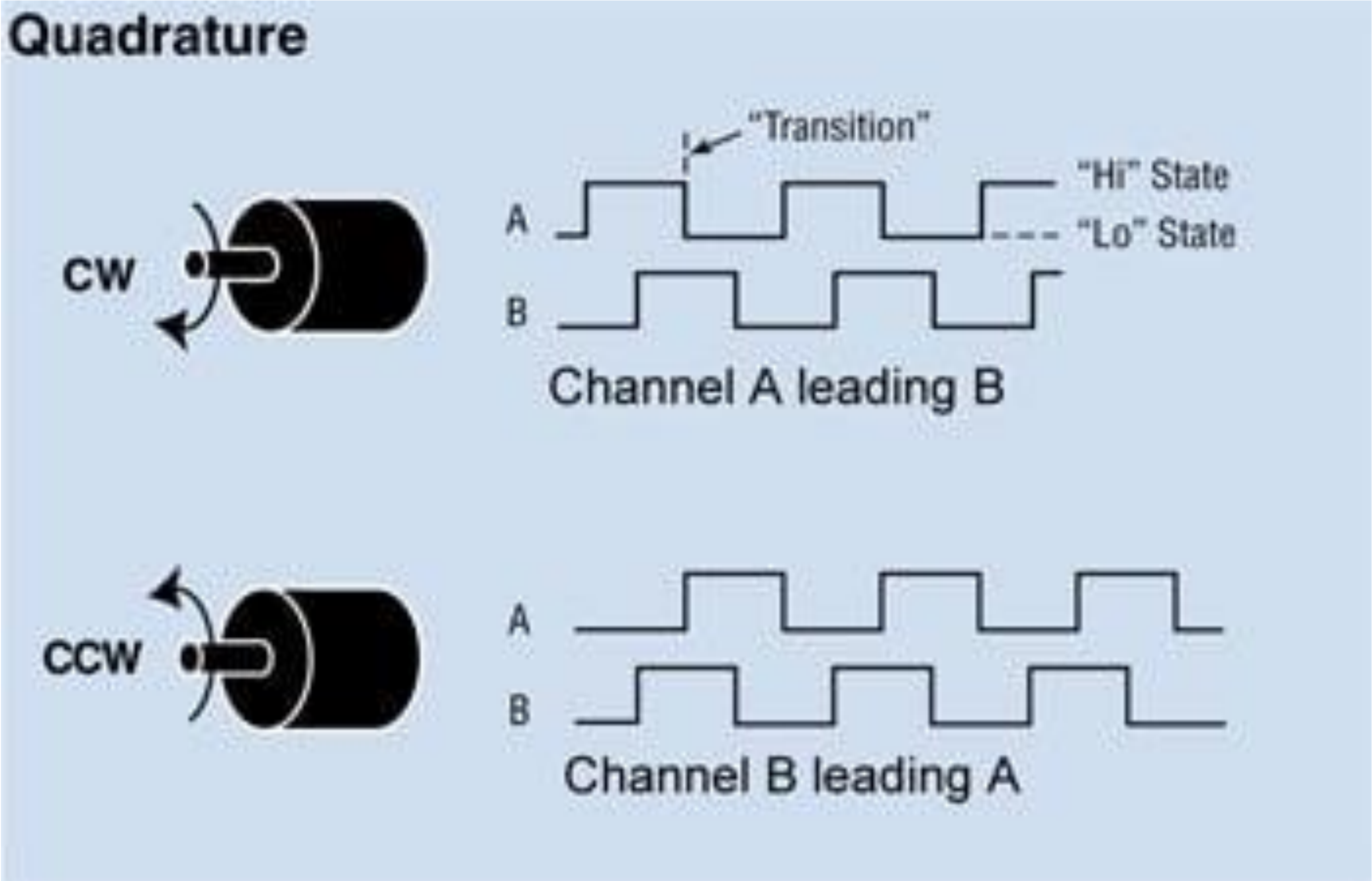
- Detects rotation speeds and direction
  - Usually for motors



Quadrature Encoding

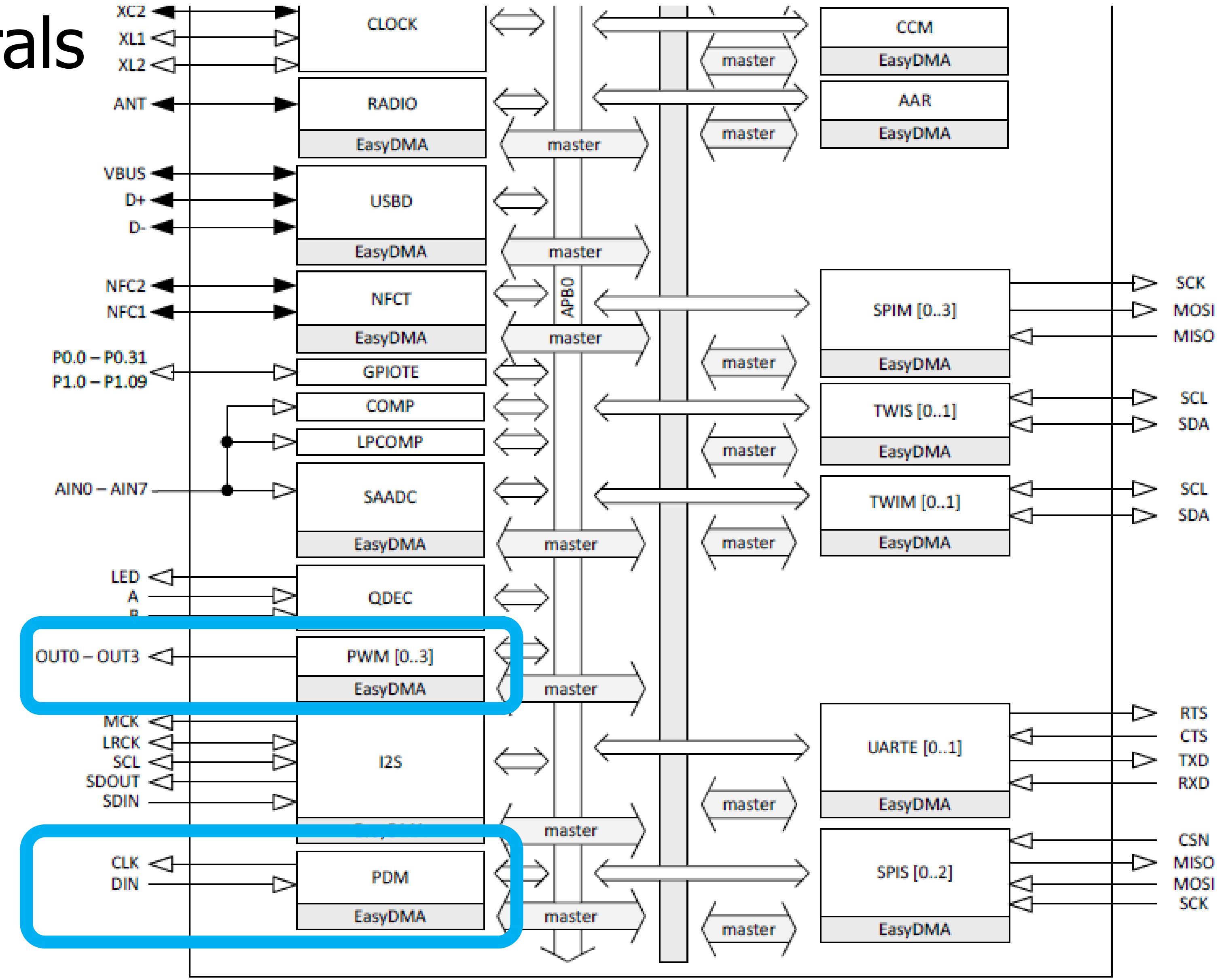


Optical encoder working principle



nRF52833 Peripherals

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



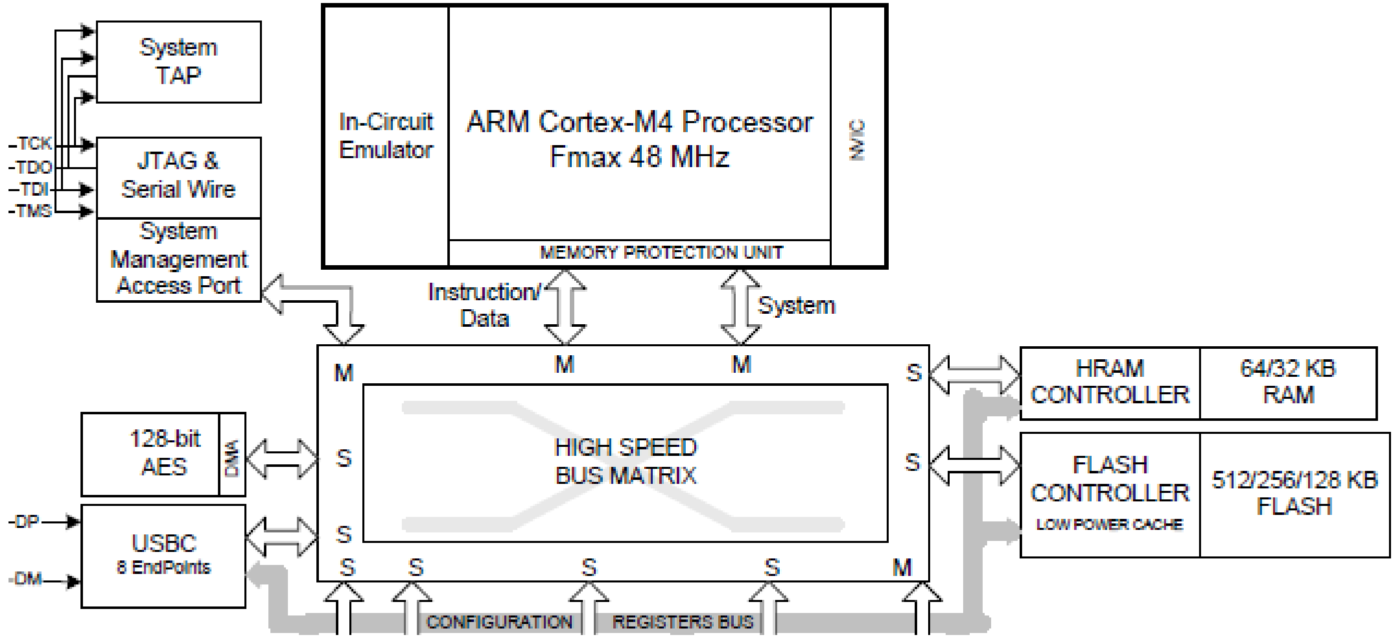
nRF52833 is complete

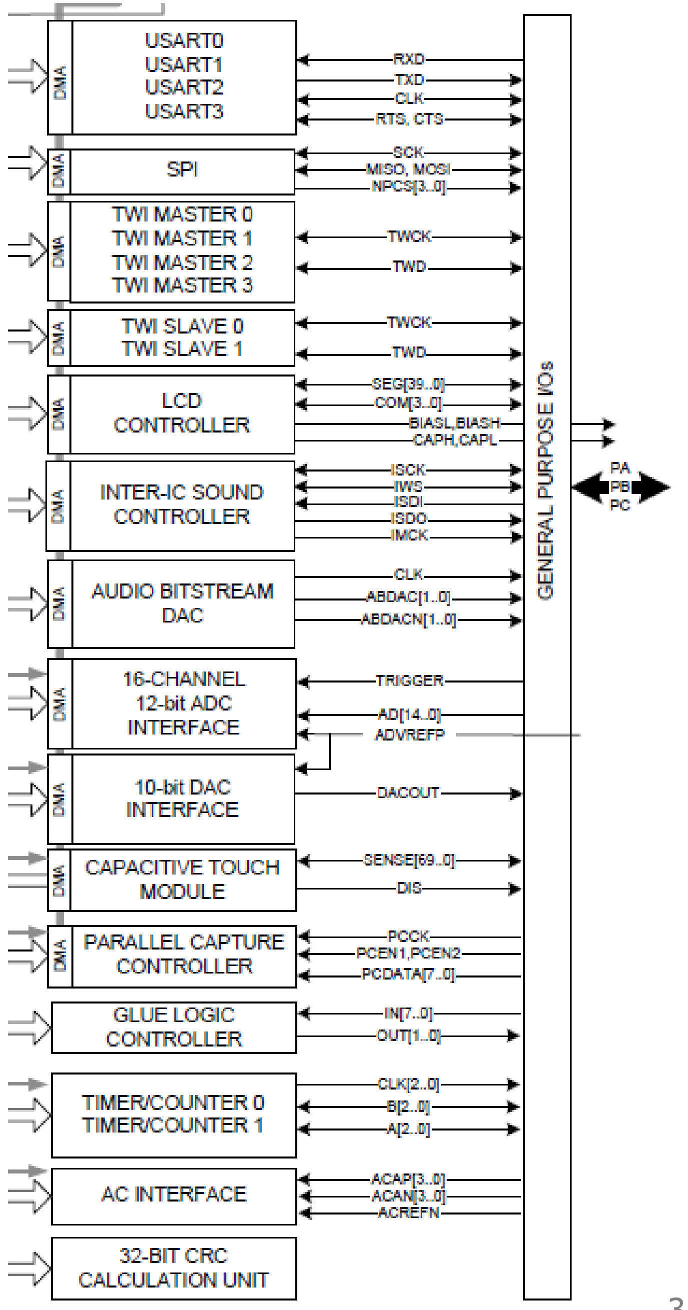
- That’s just about everything!

- 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

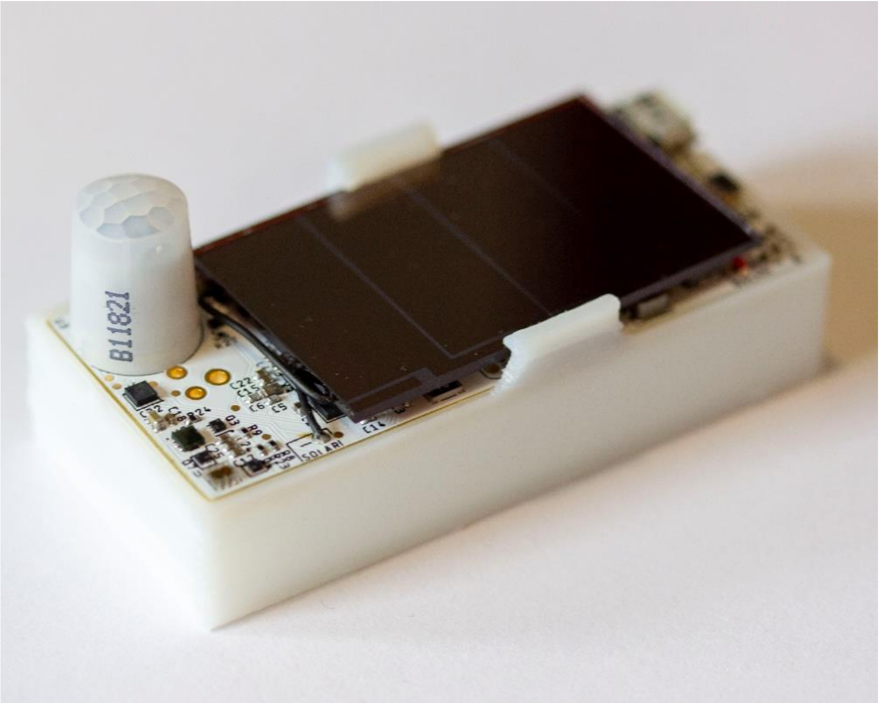
- **Platforms**
  - How to improve the capabilities of sensing systems
  - Examples: lower power, better wireless, new sensors

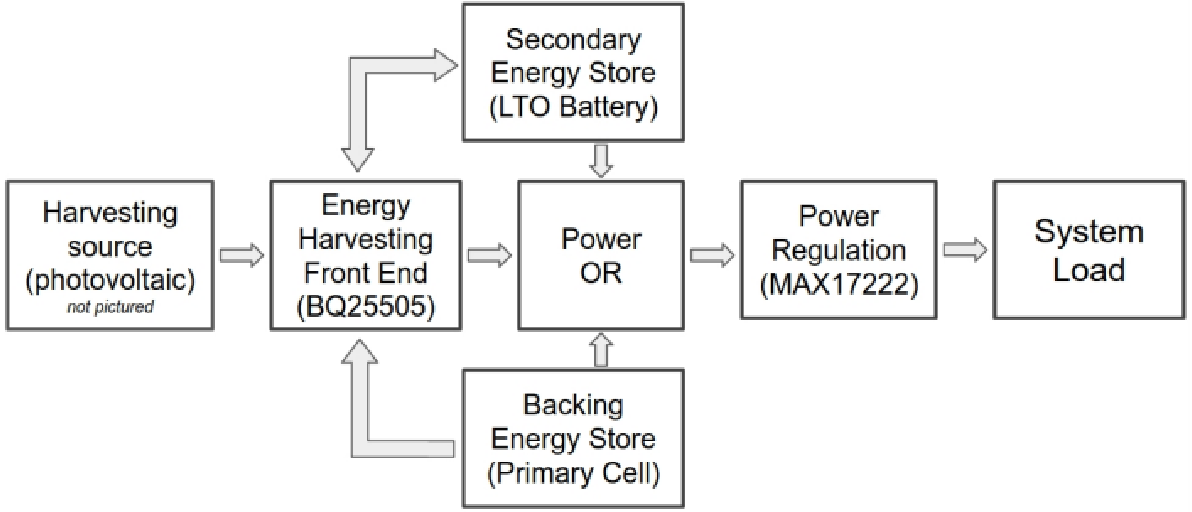
- Applications
  - How to use sensing systems to meet some desired goal
  - Examples: track human interactions, measure household energy use

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



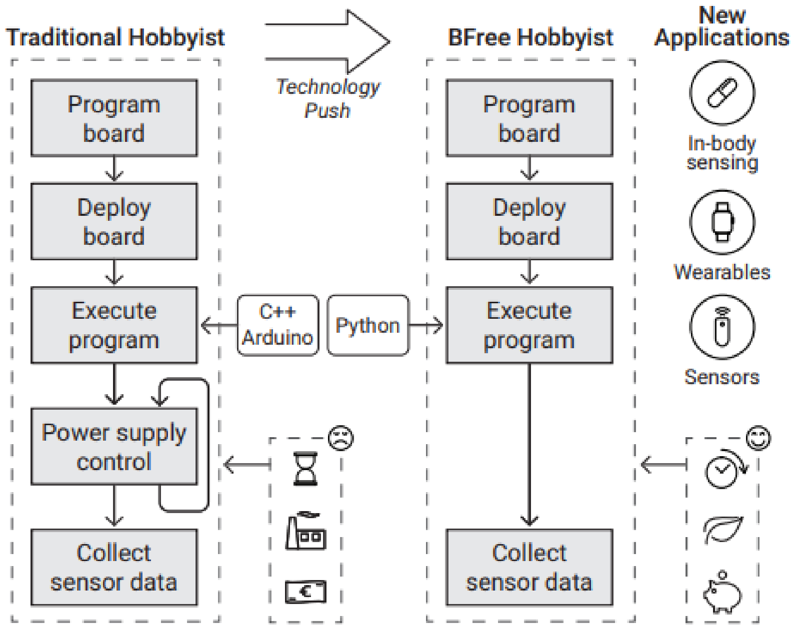


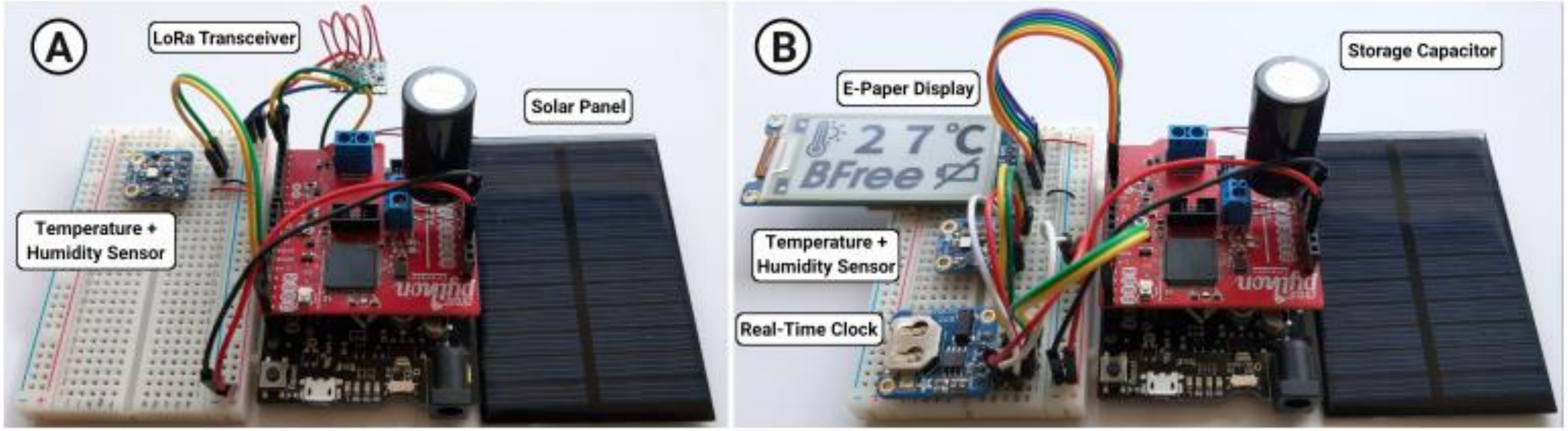
https://lab11.eecs.berkeley.edu/content/pubs/jackson19capacity.pdf

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

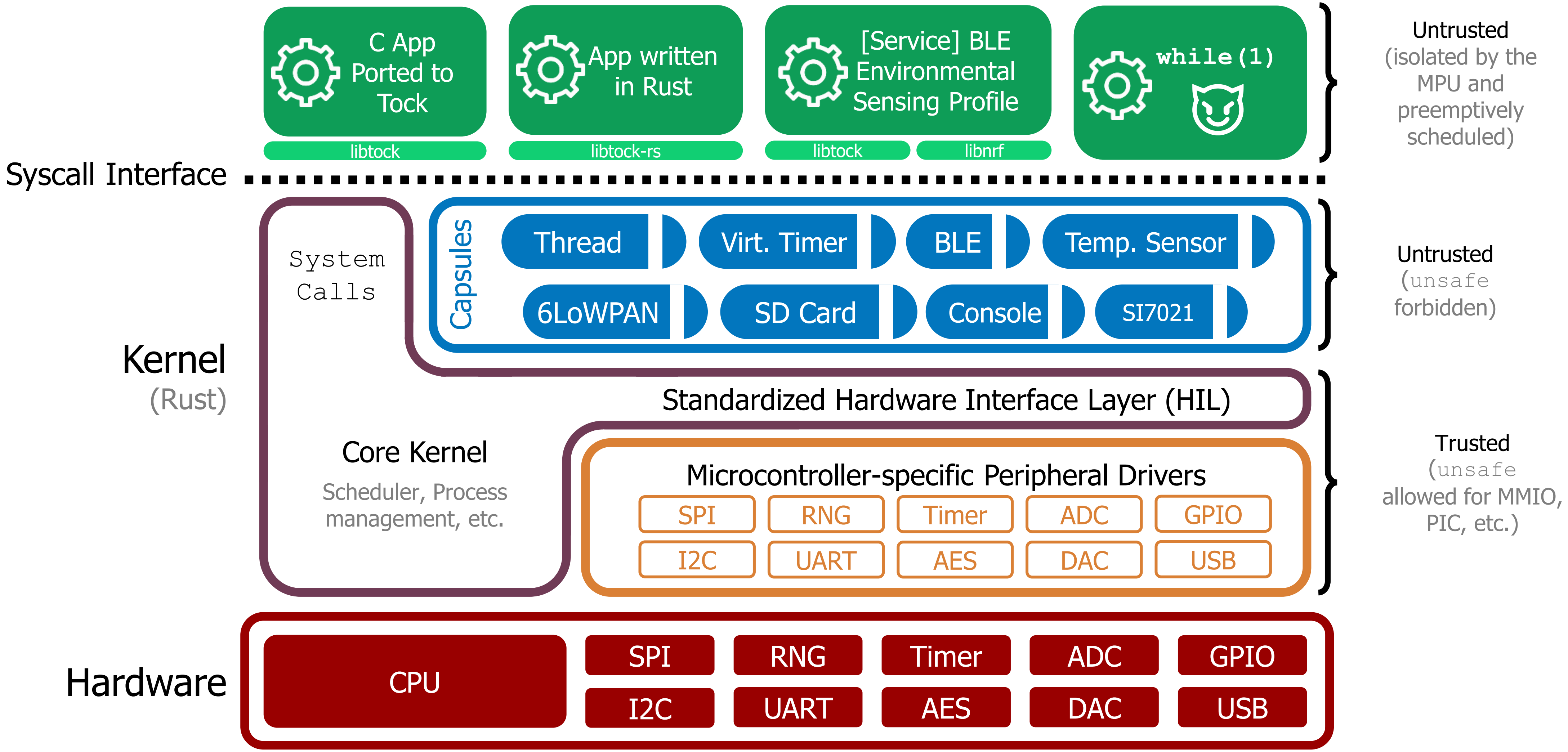
Tock (Levy, Campbell, Ghena, Giffin, Pannuto, Dutta, Levis)

- 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



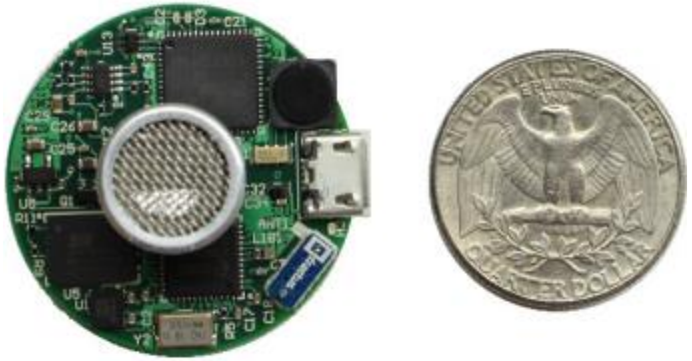
Sensing systems research

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

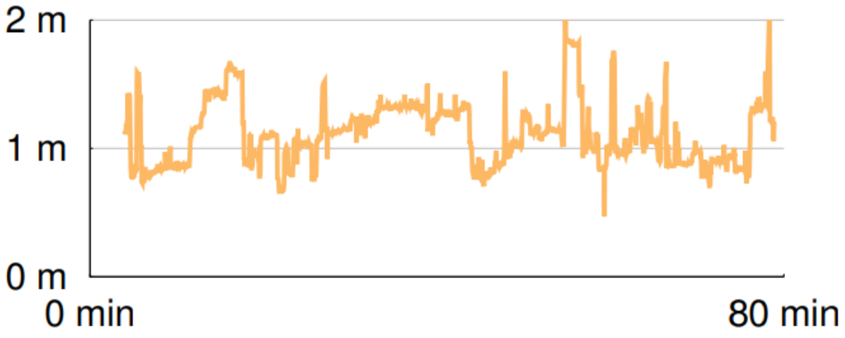
- **Applications**
  - How to use sensing systems to meet some desired goal
  - Examples: track human interactions, measure household energy use

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

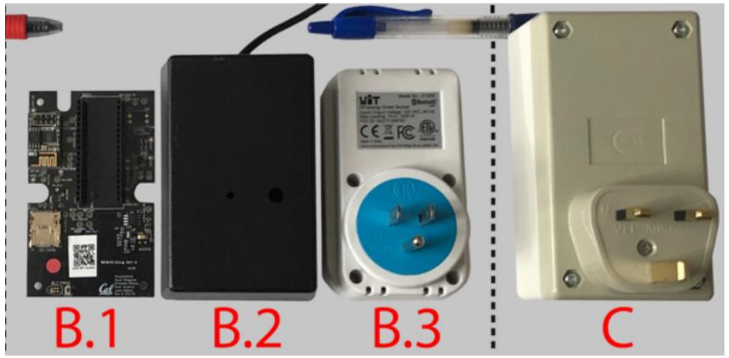


https://lab11.eecs.berkeley.edu/content/pubs/huang14opo.pdf

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

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- Sensing Systems Research