Spring 2022

ECE 568: Embedded Systems

Lecture #4: Review of MCU hardware

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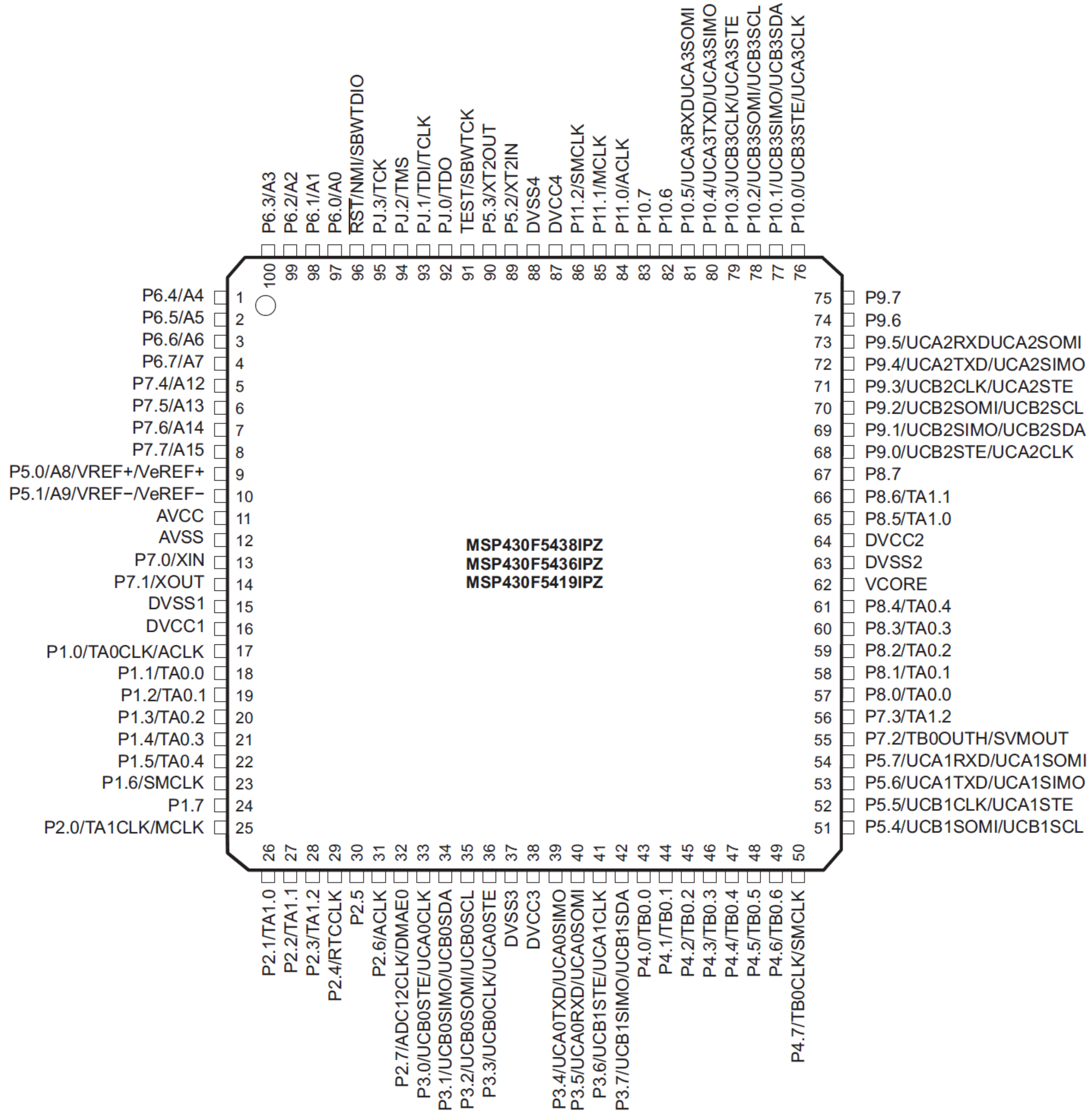
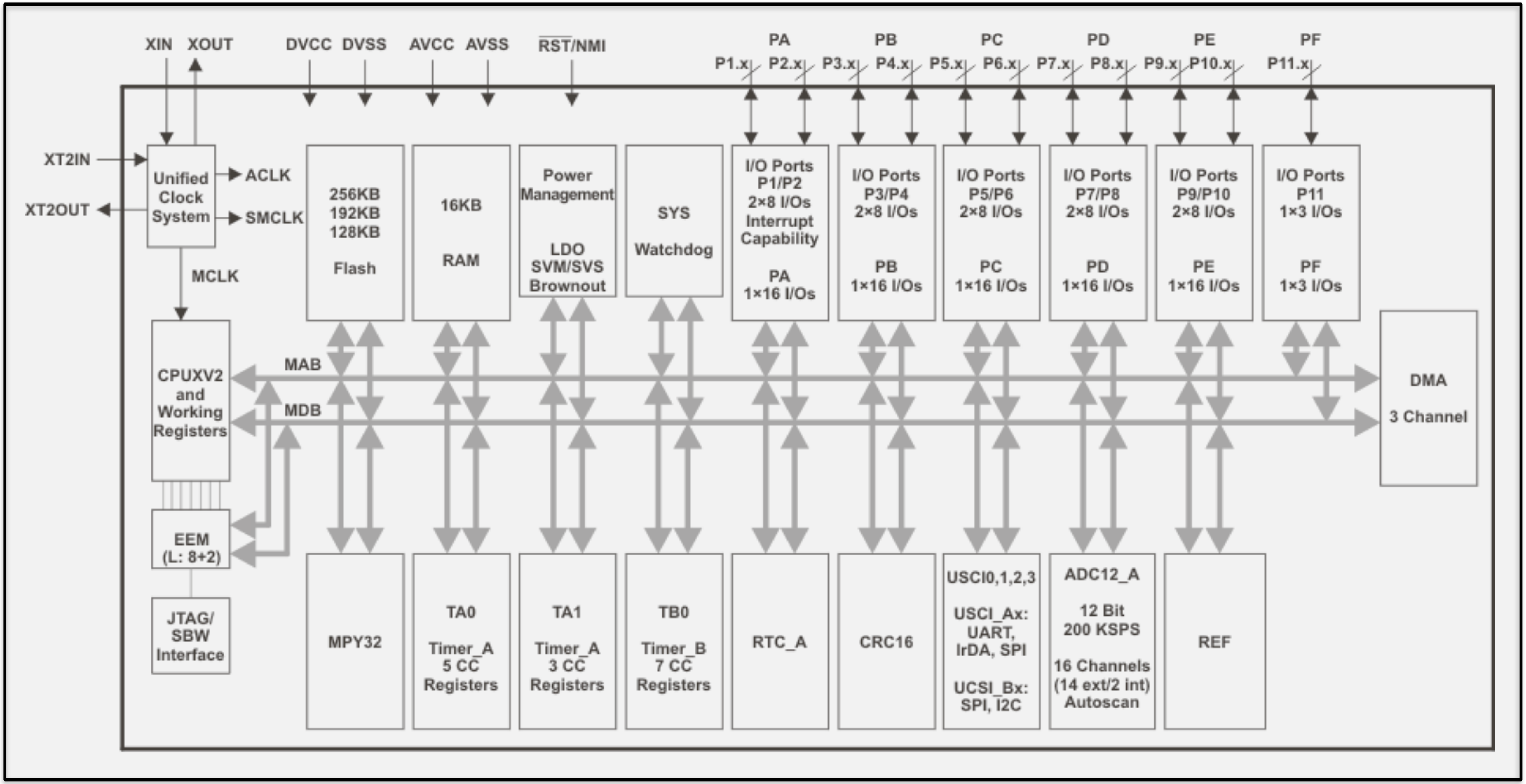
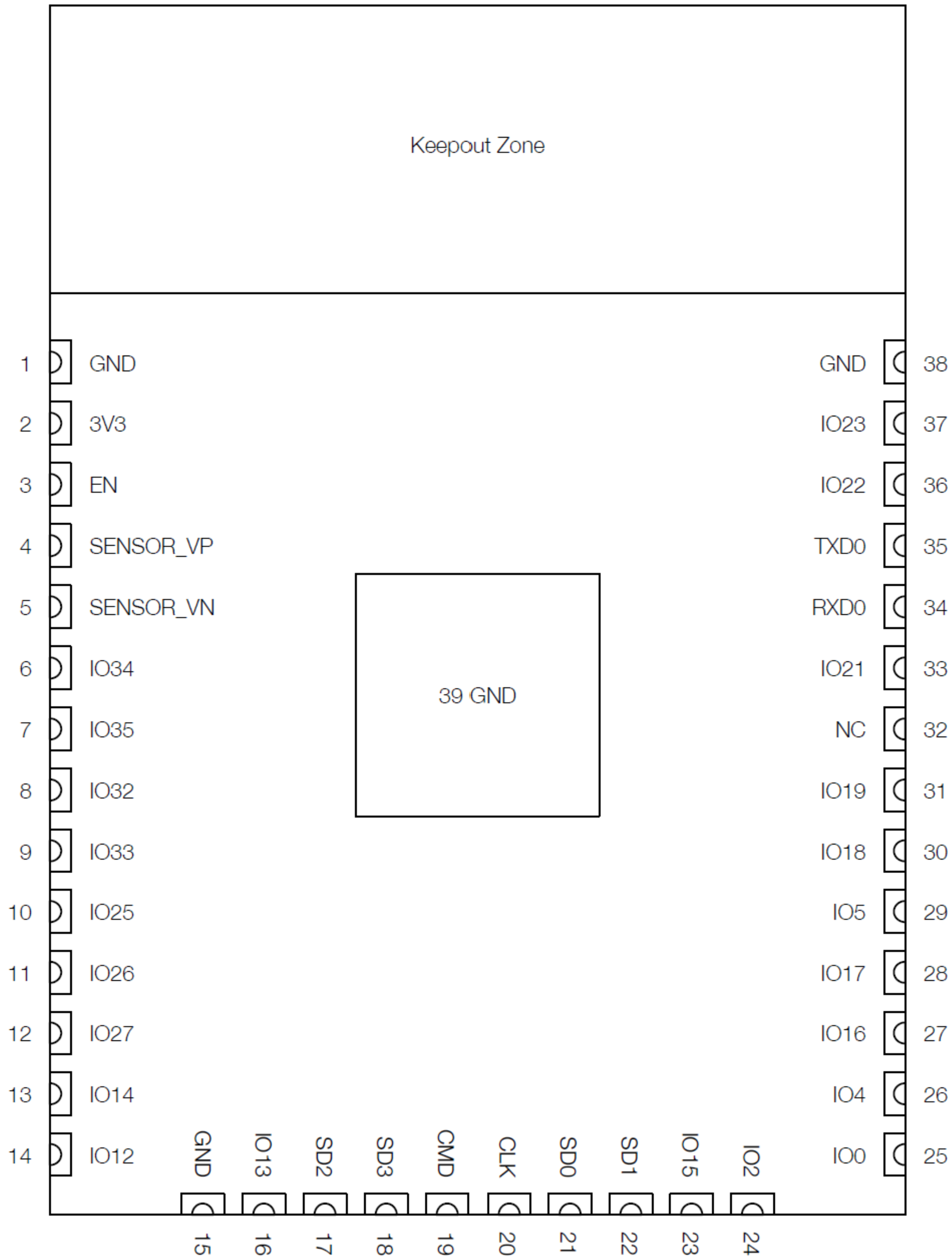
Typical MCU: Pin-Out View



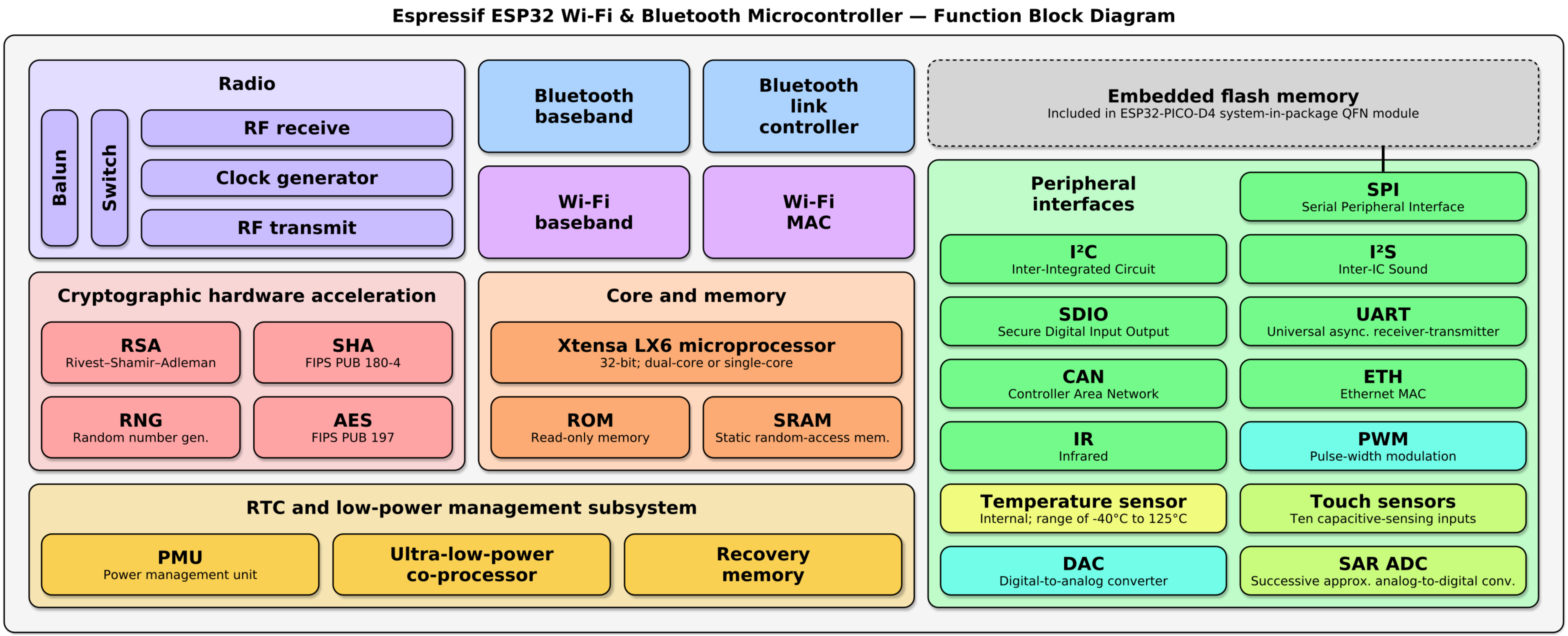
Typical MCU: Inside View



ESP32-WROOM-32D: Pin-Out View



ESP32 Functional Blocks



[https://en.wikipedia.org/wiki/ESP32#/media/File:Espressif_ESP32_Chip_Function_Block_Diagram.svg]

Key Components of MCU

- Core, registers, MULT and CRC modules, memory map
- GPIO
- Clock sub-system
- Timers, Watchdog, RTC
- Serial Communications (UART, SPI)
- Analog to Digital Converter (ADC)
- Direct Memory Access (DMA)
- Power Management Module
- Debug and Emulation Support

ESP32 Components

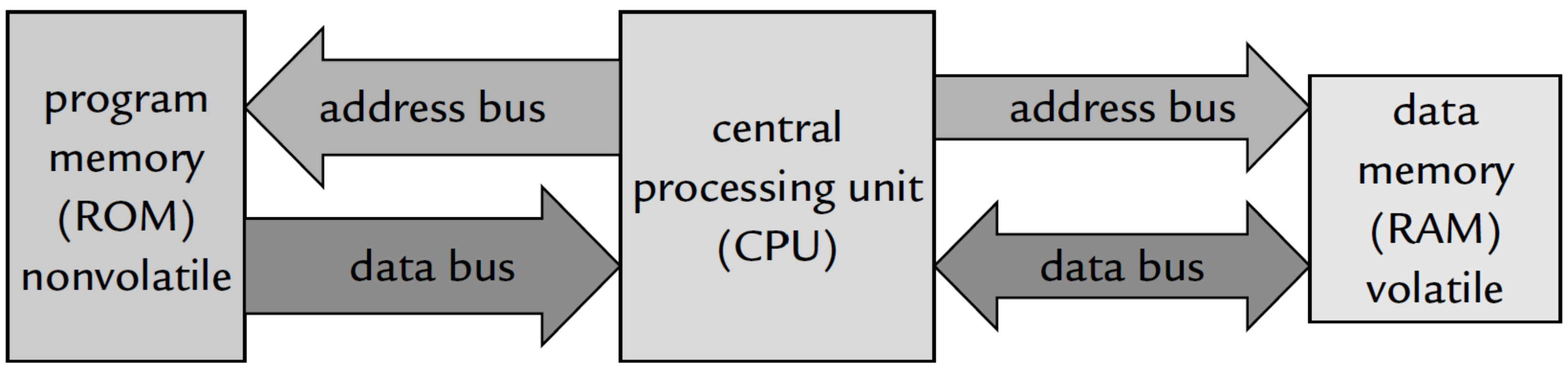
- Core and Memory
  - Single/Dual Core Microprocessor
  - Internal Memory (ROM, SRAM)
- Timer and Watchdog
  - 4 General Purpose timers
  - 3 watchdog timers (to recover from faults)
- RTC (Real-Time Clock)
- Wireless connectivity, 2.4 GHz receiver and transmitter radio
  - Wi-Fi: 802.11 b/g/n
  - Bluetooth: classic and BLE
- RTC (co-processor) and Low-Power management with multiple power modes
- Multiple GPIO pins
- Security
  - IEEE 802.11 standard security features all supported, including WFA, WPA/WPA2 and WAPI
  - Secure boot
  - Flash encryption
  - 1024-bit OTP, up to 768-bit for customers
  - Cryptographic hardware acceleration: AES, SHA-2, RSA, elliptic curve cryptography

ESP32 Components

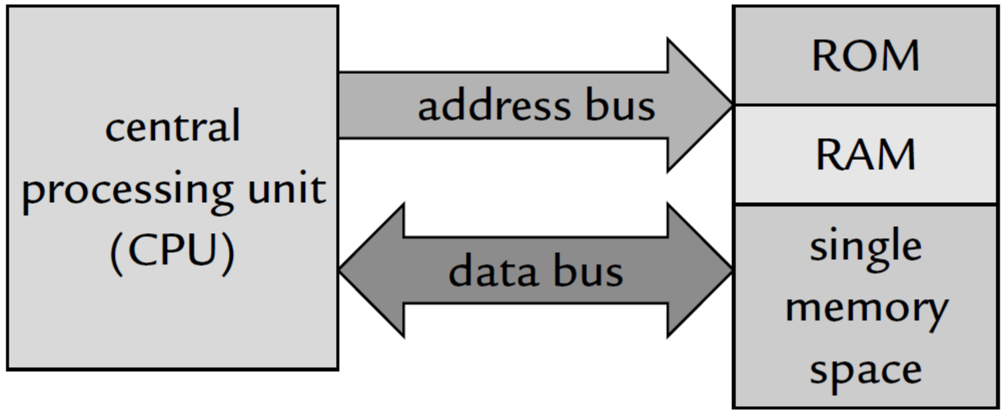
- Peripheral Interfaces
  - 12-bit SAR ADC up to 18 channels
  - 2 × 8-bit DACs
  - 10 × touch sensors (capacitive sensing GPIOs)
  - 4 × SPI
  - 2 × I²S interfaces
  - 2 × I²C interfaces
  - 3 × UART
  - SD/SDIO/CE-ATA/MMC/eMMC host controller
  - SDIO/SPI slave controller
  - Ethernet MAC interface with dedicated DMA and IEEE 1588 Precision Time Protocol support
  - CAN bus 2.0
  - Infrared remote controller (TX/RX, up to 8 channels)
  - Motor PWM
  - LED PWM (up to 16 channels)
  - Hall effect sensor
  - Ultra low power analog pre-amplifier
- Power management
  - Internal low-dropout regulator
  - Individual power domain for RTC
  - 5μA deep sleep current
  - Wake up from GPIO interrupt, timer, ADC measurements, capacitive touch sensor interrupt

Harvard vs. von Neumann

- Harvard architecture has separate instruction and data buses
  - More efficient (can read both memories in parallel)
  - Can optimize bus-width for the two memories independently
  - Many microcontrollers use this; e.g., Microchip PIC, Intel 8051, Atmel AVR, ESP32



- von Neumann architecture has a single instruction and data bus
  - Can only fetch either instruction or data on any given clock cycle
  - Microcontrollers that use this include TI MSP430, Freescale HCS

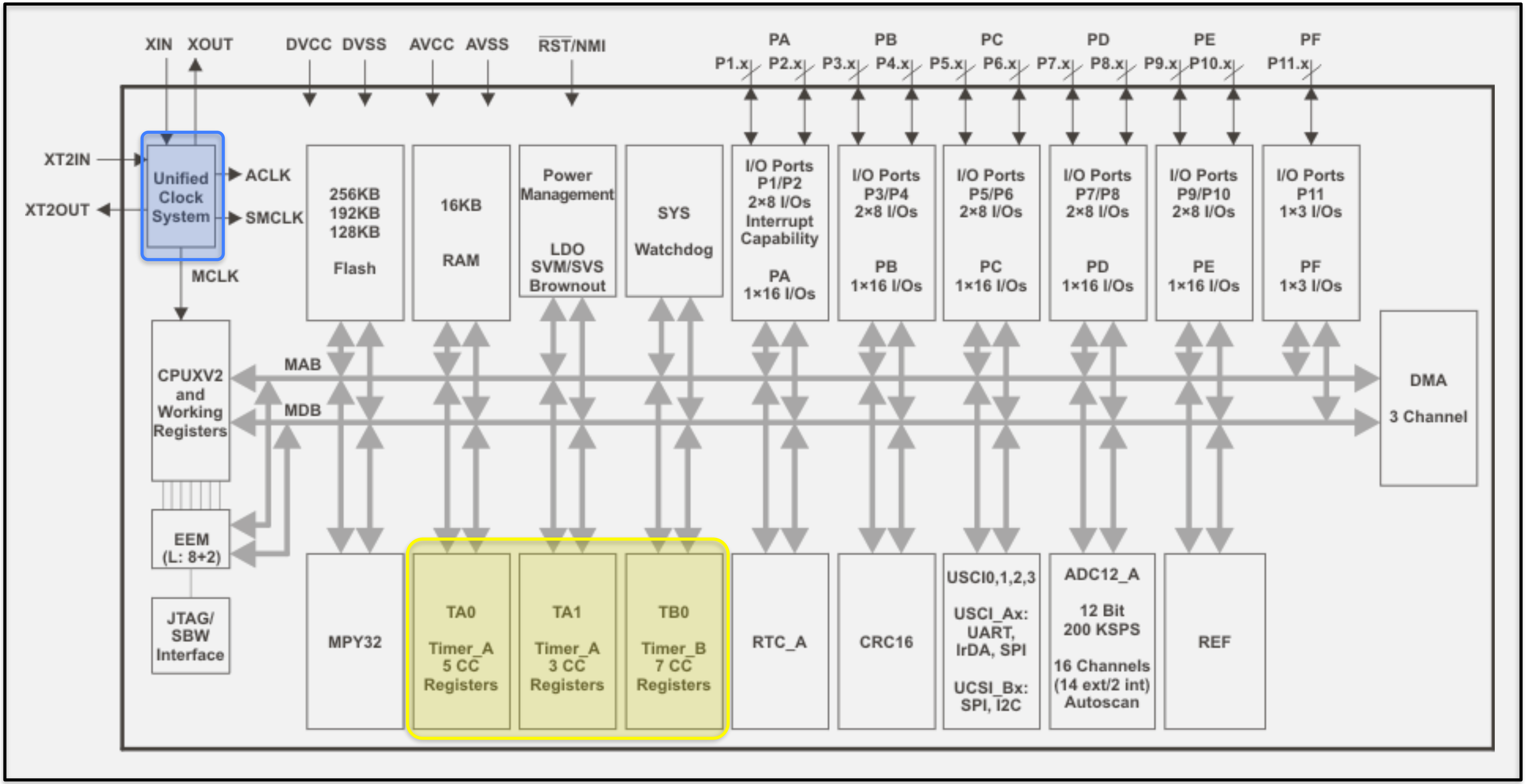


Memory Mapped I/O

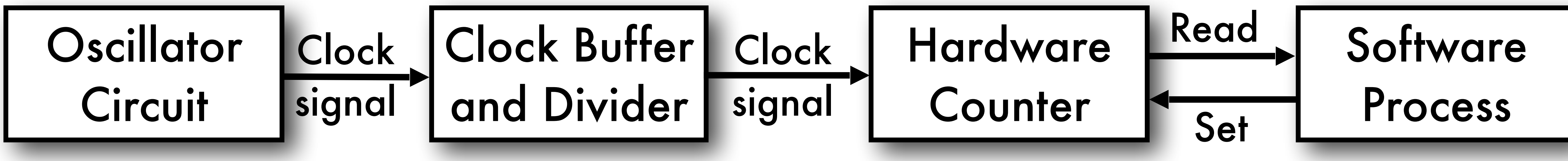
- Instead of having special instructions for accessing peripheral device registers, just read/write to them as if they were memory
- Part of address space reserved for peripherals
- Device registers directly mapped to these main memory locations
- Advantage: Makes programming much simpler
  - No special instructions to access I/O devices
  - Simply used LOAD and STORE
- Disadvantage: Occupies part of memory space
  - Usually very little compared to the size of main memory
- ESP32 Address Space
  - 4 GB (32-bit) address space for both data bus and instruction bus
  - 512 KB peripheral address space

Program	45BFF	10000
Interrupt Vectors	0FFFF	0FF80
Program	0FF7F	05C00
RAM 16 KB	05BFF	01C00
Factory data (4 x 128B)	01BFF	01A00
User Info Segment A (128 B)	019FF	01980
User Info Segment B (128 B)	0197F	01900
User Info Segment C (128 B)	018FF	01880
User Info Segment D (128 B)	0187F	01800
BSL Segment 3 (512 B)	017FF	01600
BSL Segment 2 (512 B)	015FF	01400
BSL Segment 1 (512 B)	013FF	01200
BSL Segment 0 (512 B)	011FF	01000
Peripherals 4 KB	00FFF	00000

Clocks in MCU

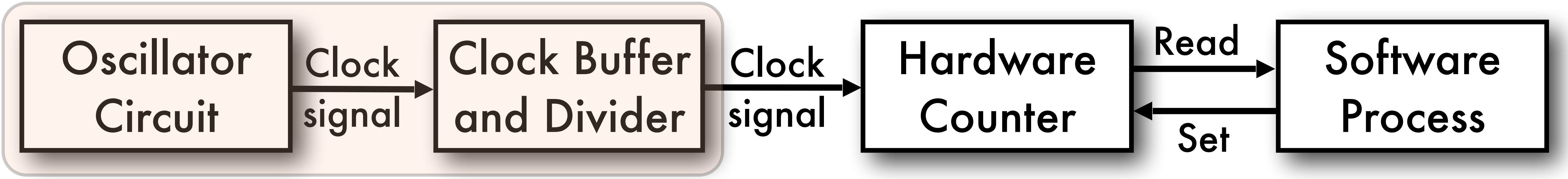


Time in Embedded Systems



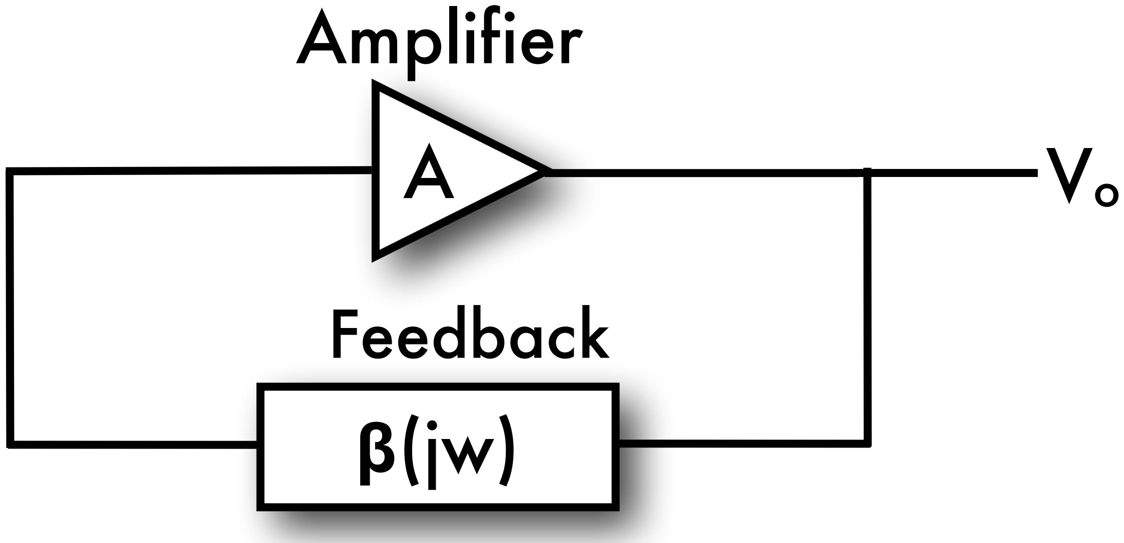
- Time is kept by a hardware counter that is fed by a clock signal
  - The hardware counter is n bits wide; counts from 0 to $(2^n - 1)$ and rolls over
  - The clock signal has a frequency f_{CLK}
- The clock signal increments the counter every 1/f seconds (resolution)
  - At time t, the counter reads $c(t) = \lfloor f_{CLK} \times t \rfloor \bmod 2^n$
- Software can read the counter or set it to a particular value
  - Smallest increment at which software can read the counter (precision)
- How close is timer to UTC? (accuracy)

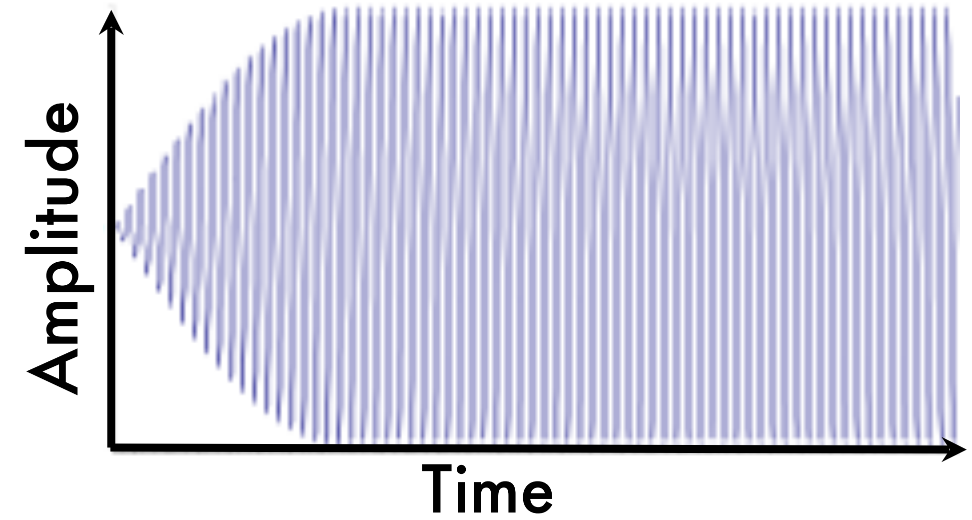
Clock Generation



- An electronic oscillator is a circuit that produces a periodic electronic signal, often a sine wave or a square wave
- Most oscillators operate using the notion of positive feedback
- Several varieties exist. Common types in embedded systems include:
  - Ring Oscillators
  - RC Circuit Oscillators
  - Quartz Crystal Oscillators
  - Ceramic Resonator Oscillators

Oscillator Basics





- Barkhausen criterion: A linear circuit with a feedback loop will sustain steady-state oscillations only for frequencies at which the loop gain (product of forward gain and feedback gain) has a magnitude equal to one and a phase shift equal to zero or an integer multiple of 2π
- In effect, feedback network acts as a band-pass filter
  - Initially, only noise present at amplifier input; feedback network only allows the oscillation frequency through, amplitude increases till stable oscillations start