Power consumption on MCUs

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WHOAMI

- My name is **Sudeep Mohanty**
- I am working with Espressif Systems since 2021
- I work on Espressif's IoT Development Framework – **ESP-IDF**
  - I am part of the IDF Core Team
  - I work on FreeRTOS and low-power CPU and peripherals

AGENDA

- Why care about power consumption?
- Basic concepts
- Power Modes in ESPs
- Espressif's advanced Low Power offerings

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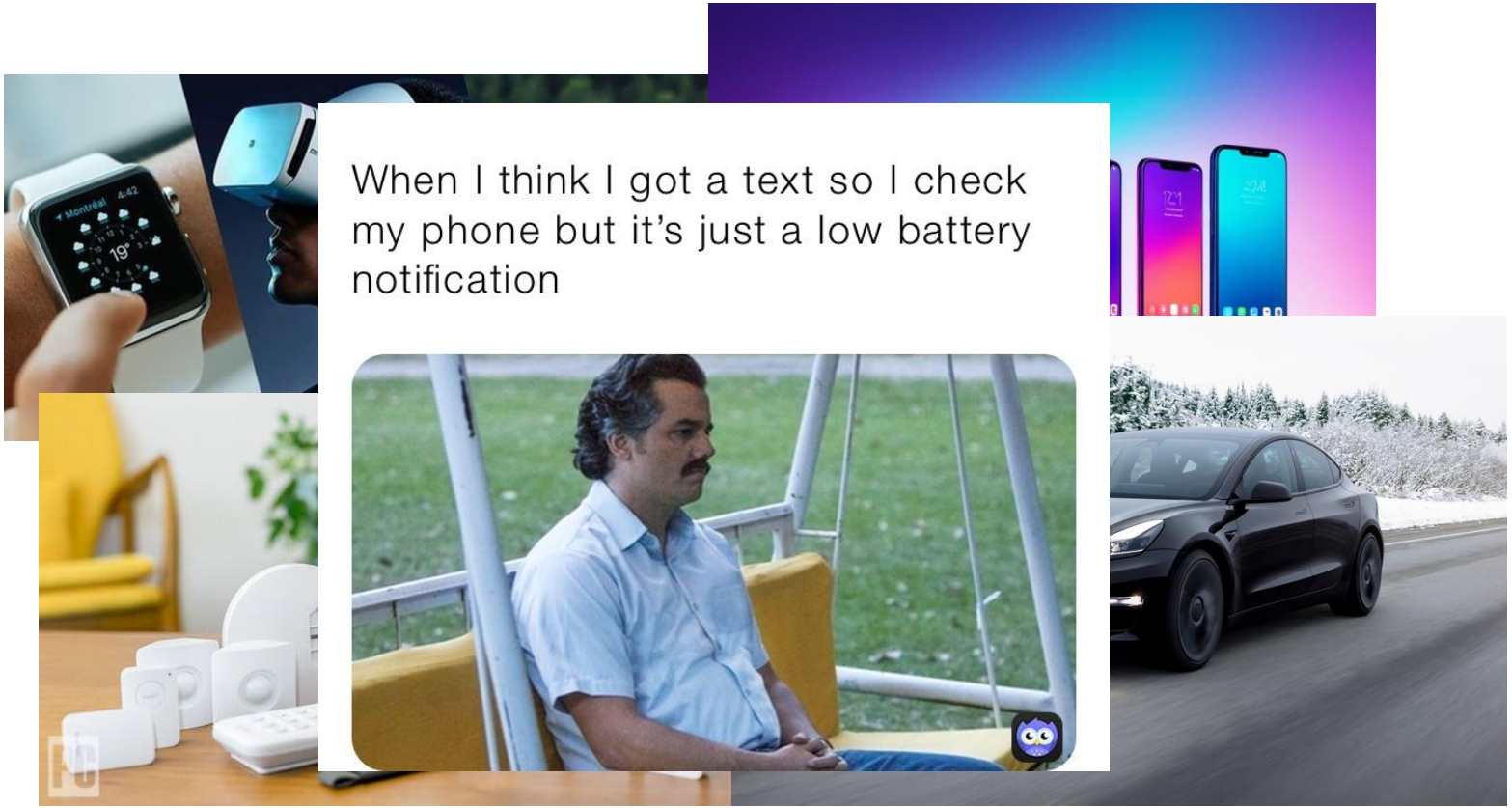

Why care about power consumption?

Basic concepts

Basic concepts – What is power?

$$P = V \times I$$

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$$P = V \times I$$

- P is the power in watts (W)
- V is the voltage in volts (V)
- I is the current in amperes (A)

Basic concepts – What is power?

- Most devices measure power in terms of “**current consumption**”.

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- Most devices measure power in terms of “**current consumption**”.
- Microcontroller manufacturers publish this data in their data sheets.

Basic concepts – What is power?

5.6 Current Consumption Characteristics

5.6.1 Current Consumption in Active Mode

The current consumption measurements are taken with a 3.3 V supply at 25 °C ambient temperature.

TX current consumption is rated at a 100% duty cycle.

RX current consumption is rated when the peripherals are disabled and the CPU idle.

Table 5-7. Current Consumption for Wi-Fi (2.4 GHz) in Active Mode

Work Mode	RF Condition	Description	Peak (mA)
Active (RF working)	TX	802.11b, 1 Mbps, DSSS @ 21.0 dBm	354
		802.11g, 54 Mbps, OFDM @ 19.5 dBm	300
		802.11n, HT20, MCS7 @ 18.5 dBm	280
		802.11n, HT40, MCS7 @ 18.0 dBm	268
		802.11ax, MCS9, @ 16.5 dBm	252

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Basic concepts – What is power?

Table 22. Typical and maximum current consumption in Sleep mode

Symbol	Parameter	Conditions	f_{HCLK}	Typ	Max(1)		Unit
				T_A = 25 °C	T_A = 85 °C	T_A = 105 °C	
I_{DD}	Supply current in Sleep mode	External clock(2), all peripherals enabled(3)	120 MHz	38	51	61	mA
			90 MHz	30	43	53	
			60 MHz	20	33	43	
			30 MHz	11	25	35	
			25 MHz	8	21	31	
			16 MHz	6	19	29	
			8 MHz	3.6	17.0	27.0	
			4 MHz	2.4	15.4	25.3	
			2 MHz	1.9	14.9	24.7	
		External clock(2), all peripherals disabled	120 MHz	8	21	31	
			90 MHz	7	20	30	
			60 MHz	5	18	28	
			30 MHz	3.5	16.0	26.0	
			25 MHz	2.5	16.0	25.0	
			16 MHz	2.1	15.1	25.0	
			8 MHz	1.7	15.0	25.0	
			4 MHz	1.5	14.6	24.6	
			2 MHz	1.4	14.2	24.3	

1. Guaranteed by characterization results, tested in production at V_{DD} max and f_{HCLK} max with peripherals enabled.
2. External clock is 4 MHz and PLL is on when $f_{HCLK} > 25$ MHz.
3. Add an additional power consumption of 1.6 mA per ADC for the analog part. In applications, this consumption occurs only while the ADC is on (ADON bit is set in the ADC_CR2 register).

Basic concepts – How to measure?

- How do you measure the current consumption?

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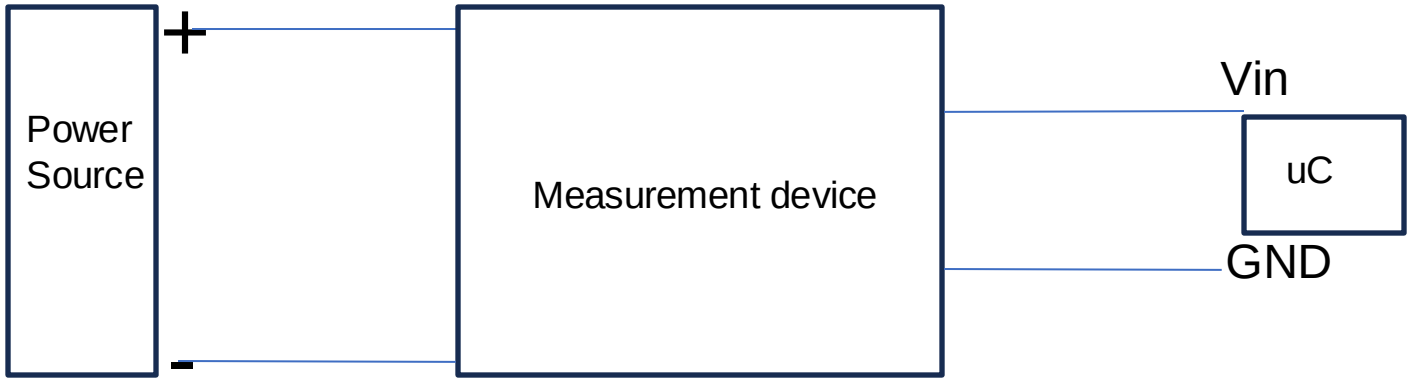

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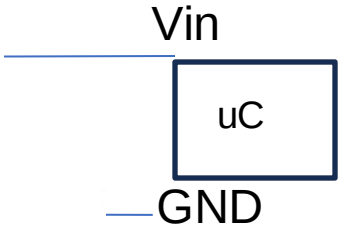


Basic concepts – How to conserve power?

- How do you “reduce” power consumption?

Basic concepts – How to conserve power?

- How do you “reduce” power consumption?
- Decrease voltage

Basic concepts – How to conserve power?

- How do you “reduce” power consumption?

- Decrease voltage
- Power down

Basic concepts – How to conserve power?

- How do you “reduce” power consumption?

- Decrease voltage
- Power down
- Clock-gating

Power Modes in MCUs

- Supported SPI protocols: SPI, Dual SPI, Quad SPI, QPI interfaces that allow connection to flash and other SPI devices off the chip's package
- Flash controller with cache is supported
- Flash in-Circuit Programming (ICP) is supported

Advanced Peripheral Interfaces

- 30 GPIOs (QFN40), or 22 GPIOs (QFN32)
  - 5 strapping GPIOs
  - 6 GPIOs needed for in-package flash
- Analog interfaces:
  - 12-bit SAR ADC, up to 7 channels
  - Temperature sensor
- Digital interfaces:
  - Two UARTs
  - Low-power (LP) UART
  - Two SPI ports for communication with flash
  - General purpose SPI port
  - I2C
  - Low-power (LP) I2C
  - I2S
  - Pulse count controller
  - USB Serial/JTAG controller
  - Two TWAI® controllers, compatible with ISO 11898-1 (CAN Specification 2.0)
  - SDIO 2.0 slave controller
  - LED PWM controller, up to 6 channels
  - Motor Control PWM (MCPWM)
  - Remote control peripheral (TX/RX)
  - Parallel IO interface (PARLIO)
  - 52-bit system timer
  - Two 54-bit general-purpose timers
  - Three digital watchdog timers
  - Analog watchdog timer

Power Management

- Fine-resolution power control through a selection of clock frequency, duty cycle, Wi-Fi operating modes, and individual power control of internal components
- Four power modes designed for typical scenarios: Active, Modem-sleep, Light-sleep, Deep-sleep
- Power consumption in Deep-sleep mode is 7 μA
- Low-power (LP) memory remains powered on in Deep-sleep mode

Security

- Secure boot - permission control on accessing internal and external memory
- Flash encryption - memory encryption and decryption
- 4096-bit OTP, up to 1792 bits for users
- Trusted execution environment (TEE) controller and access permission management (APM)
- Cryptographic hardware acceleration:
  - AES-128/256 (FIPS PUB 197)
  - ECC
  - HMAC
  - RSA
  - SHA (FIPS PUB 180-4)
  - Digital signature

life.augmented

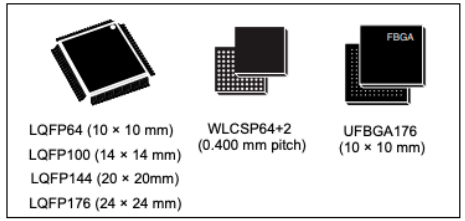
STM32F205xx
STM32F207xx

Arm®-based 32-bit MCU, 150 DMIPs, up to 1 MB Flash/128+4KB RAM, USB OTG HS/FS, Ethernet, 17 TIMs, 3 ADCs, 15 comm. interfaces and camera

Datasheet - production data

Features

- Core: Arm® 32-bit Cortex®-M3 CPU (120 MHz max) with Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait state execution performance from Flash memory, MPU, 150 DMIPS/1.25 DMIPS/MHz (Dhrystone 2.1)
- Memories
  - Up to 1 Mbyte of Flash memory
  - 512 bytes of OTP memory
  - Up to 128 + 4 Kbytes of SRAM
  - Flexible static memory controller that supports Compact Flash, SRAM, PSRAM, NOR and NAND memories
  - LCD parallel interface, 8080/6800 modes
- Clock, reset and supply management
  - From 1.8 to 3.6 V application supply + I/Os
  - POR, PDR, PVD and BOR
  - 4 to 26 MHz crystal oscillator
  - Internal 16 MHz factory-trimmed RC
  - 32 kHz oscillator for RTC with calibration
  - Internal 32 kHz RC with calibration
- Low-power modes
  - Sleep, Stop and Standby modes
  - V_{BAT} supply for RTC, 20 × 32 bit backup registers, and optional 4 Kbytes backup SRAM
- 3 × 12-bit, 0.5 µs ADCs with up to 24 channels and up to 6 MSPS in triple interleaved mode
- 2 × 12-bit D/A converters



- Up to 140 I/O ports with interrupt capability:
  - Up to 136 fast I/Os up to 60 MHz
  - Up to 138 5 V-tolerant I/Os
- Up to 15 communication interfaces
  - Up to three I^2C interfaces (SMBus/PMBus)
  - Up to four USARTs and two UARTs (7.5 Mbit/s, ISO 7816 interface, LIN, IrDA, modem control)
  - Up to three SPIs (30 Mbit/s), two with muxed I^2S to achieve audio class accuracy via audio PLL or external PLL
  - 2 × CAN interfaces (2.0B Active)
  - SDIO interface
- Advanced connectivity
  - USB 2.0 full-speed device/host/OTG controller with on-chip PHY
  - USB 2.0 high-speed/full-speed device/host/OTG controller with dedicated DMA, on-chip full-speed PHY and ULPI
  - 10/100 Ethernet MAC with dedicated DMA: supports IEEE 1588v2 hardware, MII/RMII

Power Modes in ESPs

ACTIVE MODE

- All power domains on
- All peripherals on
- All functionality enabled
- Maximum power consumption

On:

- HP CPU & Memory
- RF
- Digital Peripherals
- LP CPU
- RTC & PMU
- RTC Peripherals

Off:

Power Consumption:

Up to 350 mA*

* Based on current consumption numbers from ESP32-C6 datasheet

Power Modes in ESPs

MODEM SLEEP

- RF analog circuitry powered down

On:

- HP CPU & Memory
- Digital Peripherals
- LP CPU
- RTC & PMU
- RTC Peripherals

Off:

- RF

Power Consumption:

14 ~ 38 mA*

* Based on current consumption numbers from ESP32-C6 datasheet

Power Modes in ESPs

LIGHT SLEEP

- CPU paused
- Internal memory retained
- Digital peripherals optional
- Continue where you left off

On:
- LP CPU
- RTC & PMU
- RTC Peripherals

Partially off:
- HP CPU & Memory
- Digital Peripherals

Off:
- RF

Power Consumption:
35 ~ 180 uA*

* Based on current consumption numbers from ESP32-C6 datasheet

Power Modes in ESPs

DEEP SLEEP

- CPU and internal memory off
- Digital peripherals off
- LP CPU and RTC peripherals can run
- Restart app

On:
- RTC & PMU

Optional:
- LP CPU
- RTC Peripherals

Off:
- HP CPU & Memory
- RF
- Digital Peripherals

Power Consumption:
from 7 uA*

* Based on current consumption numbers from ESP32-C6 datasheet

Power Modes in ESPs

WAKE UP

- Configured before sleeping
- Can have multiple sources
- Not all sources can work from deep sleep
- See TRM for chip specific info

Wakeup Source	Light-sleep	Deep-sleep
EXT0	Y	Y
EXT1	Y	Y
GPIO	Y	Y
RTC timer	Y	Y
Wi-Fi	Y	-
UART0	Y	-
UART1	Y	-
TOUCH Active	Y	-
ULP-FSM	Y	Y
BT	Y	-
ULP-RISC-V	Y	Y
XTAL_32K	Y	Y
ULP-RISC-V Trap	Y	Y
TOUCH Timeout	Y	Y
BROWNOUT	Y	Y

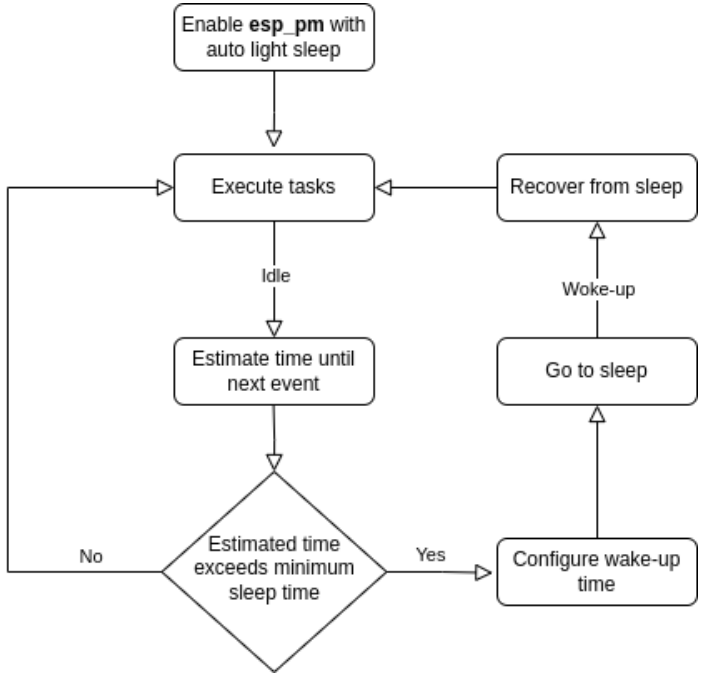
Deep Sleep Demo

Advanced low power options

Advanced low power options

AUTO LIGHT SLEEP

- Based on “FreeRTOS Tickless Idle” feature.
- Automatically puts the chip into light sleep.



Advanced low power options

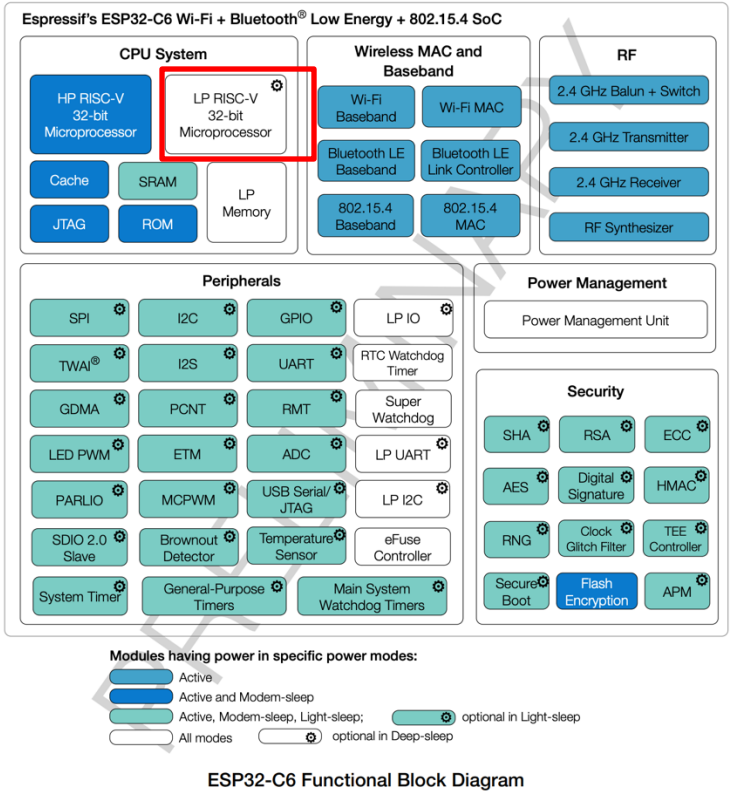
Dynamic Frequency Scaling (DFS)

- ESP will scale the operating frequency opportunistically.
- Frequency can range 80 MHz and 240 MHz
- Frequency scaling depends on “PM locks”

Advanced low power options

Low Power CPU

- A separate 32-bit RISC-V coprocessor
- Can run independently when the main CPU is in Active mode, Light Sleep or Deep Sleep
- Can control peripherals like GPIOs, UART, I2C, SPI
- 20 MHz CPU
- 8 ~ 16 KB RAM



ESP32-C6 Functional Block Diagram

ESPRESSIF

Thank you !