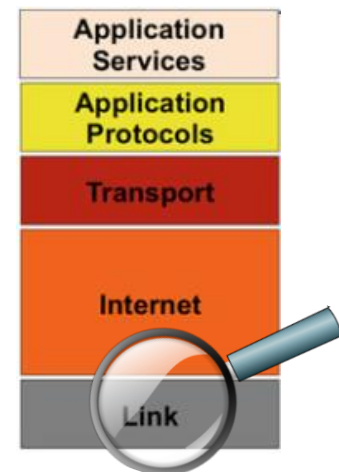


Ch. 11 - IoT Link Layer

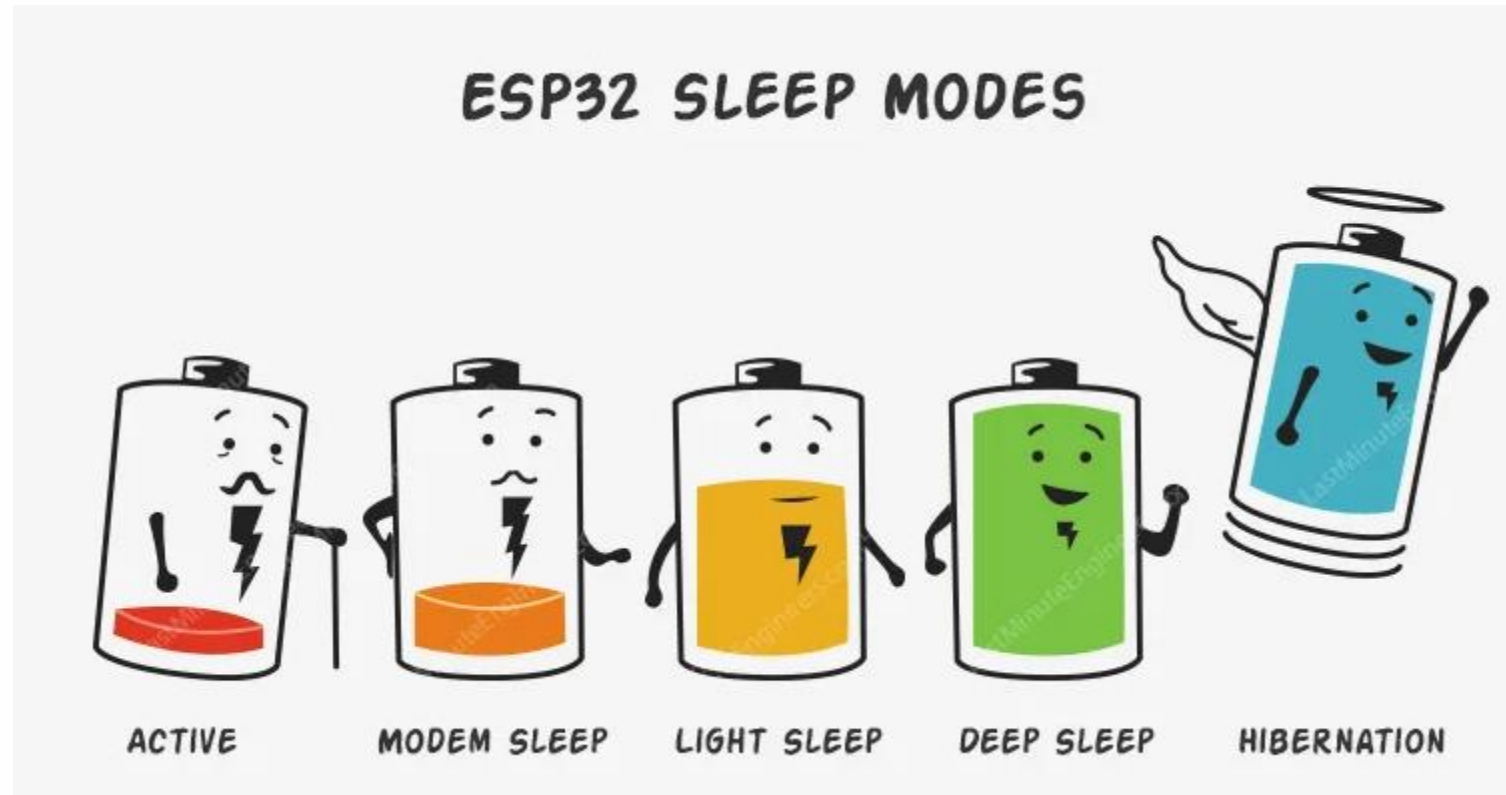
Class Exercise Solutions

COMPSCI 147

Internet-of-Things; Software and Systems



Insight into ESP32 Power consumption



ESP32 in active mode



Active Mode



Active:

- WiFi
- Bluetooth
- Radio
- ESP32 Core
- ULP Coprocessor
- Peripherals
- RTC

Inactive:

Power Consumption:

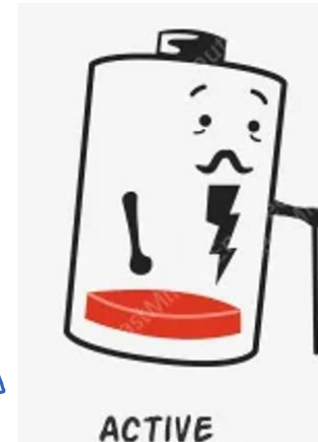
160~260mA

Mode	Power Consumption
Wi-Fi Tx packet 13dBm~21dBm	160~260mA
Wi-Fi/BT Tx packet 0dBm	120mA
Wi-Fi/BT Rx and listening	80~90mA

Q: How long will battery last in active mode?

- Assume you have :
 - a Li-ion battery with capacity: 1300 mAh
 - ESP32 in active mode consumes 250 mA.

$$\text{Battery life (h)} = \frac{\text{Capacity}}{\text{Current}} = \frac{1300 \text{ mAh}}{250 \text{ mA}} = 5.2 \text{ h.}$$

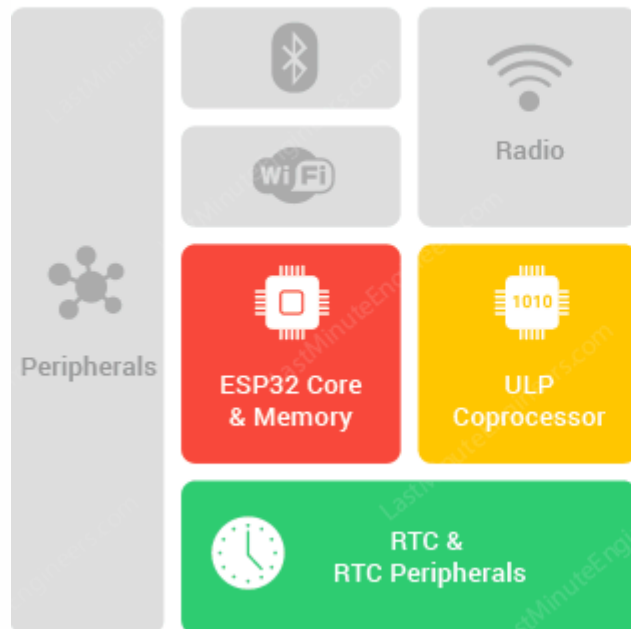


How much is the battery capacity on iPhone 14 ?

ESP32 in modem-sleep mode



Modem Sleep



Active:

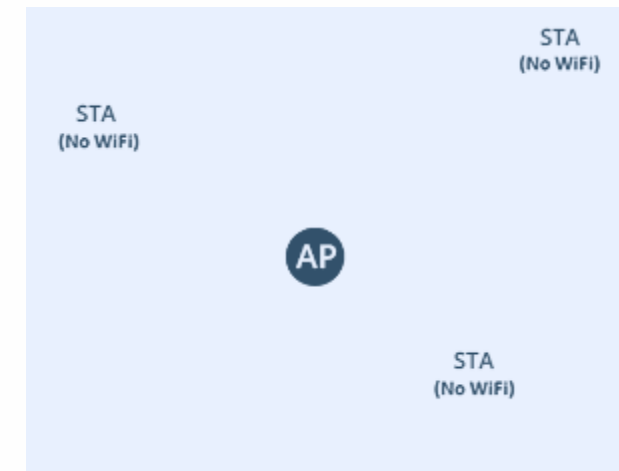
- ESP32 Core
- ULP Coprocessor
- RTC

Inactive:

- WiFi
- Bluetooth
- Radio
- Peripherals

Power Consumption:

3~20mA



Q: How long will battery last in modem-sleep mode?

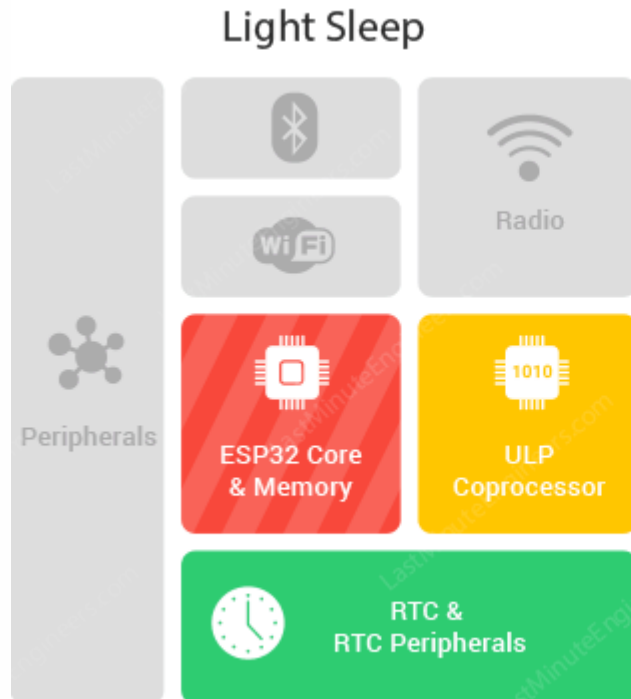
- Assume you have :
 - a Li-ion battery with capacity: 1300 mAh
 - ESP32 in active mode consumes 250 mA
 - ESP32 in modem-sleep mode consumes 10 mA
 - Assume the following cycle:
950ms modem-sleep, 50ms active -> repeat

$$\text{Average current (mA)} = 0.95 \times 10 + 0.05 \times 250 = 22 \text{ mA}$$

$$\text{Battery life (h)} = \frac{1300 \text{ mAh}}{22 \text{ mA}} = 59.09 \text{ h}$$



ESP32 in light-sleep mode



Active:

- ULP Coprocessor
- RTC

Inactive:

- WiFi
- Bluetooth
- Radio
- Peripherals

Paused:

- ESP32 Core

Power Consumption:

0.8mA

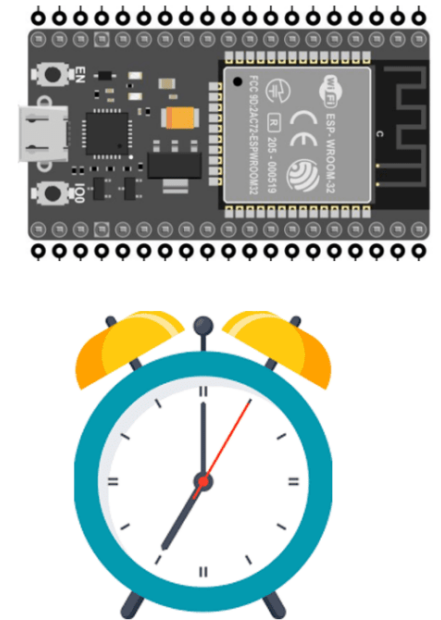
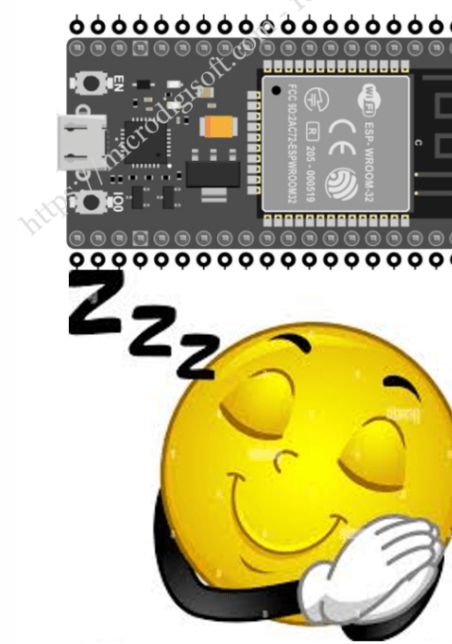
What is Clock Gating?

- Clock gating is a technique for reducing the dynamic power consumption.
- It disables portions of the circuitry by powering off clock pulses, so that the flip-flops in them do not have to switch states.
- As switching states consumes power, when not being switched, the power consumption goes to zero.

ESP32 in light-sleep mode: how to enter

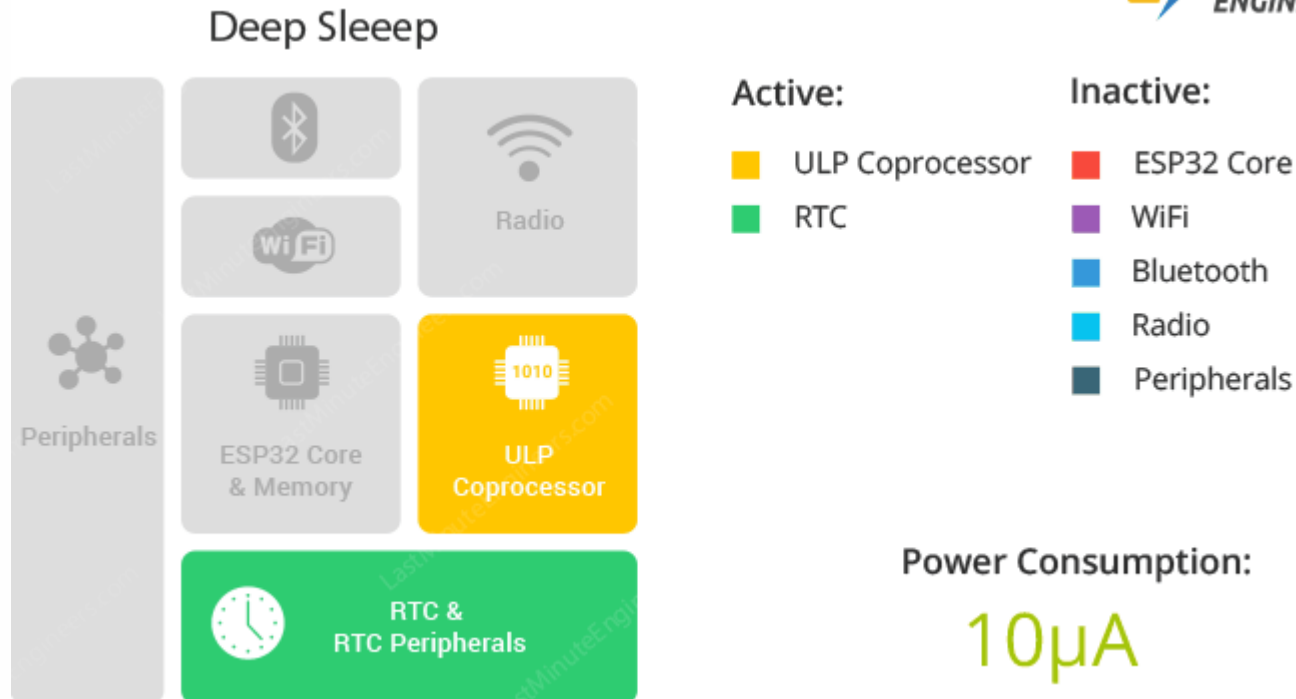
1. Configure wake-up sources:
 1. Timer
 2. Touch pad
 3. External wakeup(ext0 & ext1)

2. `esp_light_sleep_start()`



https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api-reference/system/sleep_modes.html

ESP32 in deep-sleep mode



In deep sleep mode,

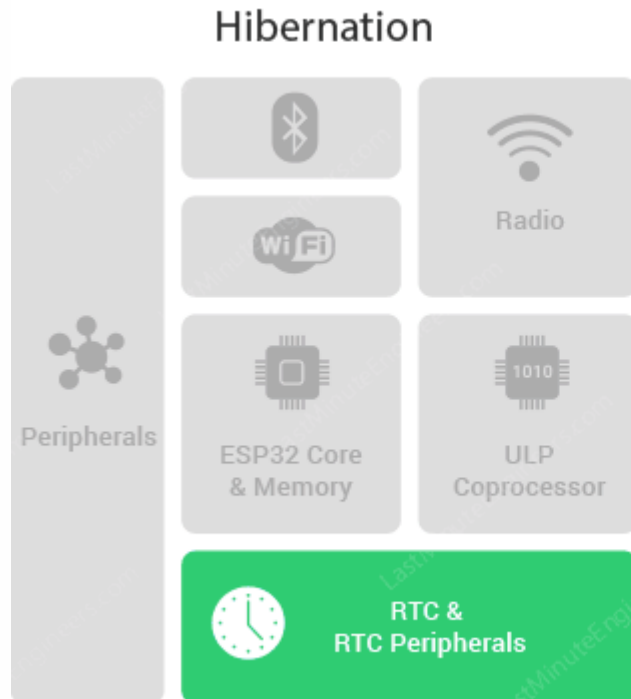
- CPU,
- most of the RAM and
- all the digital peripherals are powered off.

The only parts of the chip that remains powered on are:

- RTC controller,
- RTC peripherals (including ULP co-processor), and
- RTC memories.

```
RTC_DATA_ATTR int bootCount = 0;
```

ESP32 in hibernation mode



Active:

■ RTC

Inactive:

■ ESP32 Core
■ ULP Coprocessor
■ WiFi
■ Bluetooth
■ Radio
■ Peripherals

Power Consumption:

2.5 μ A

ESP32 chip disables internal 8MHz oscillator and ULP-coprocessor as well.

The RTC recovery memory is also powered down, meaning there's no way we can preserve any data during hibernation mode.

Q: How long will battery last in hibernation mode?

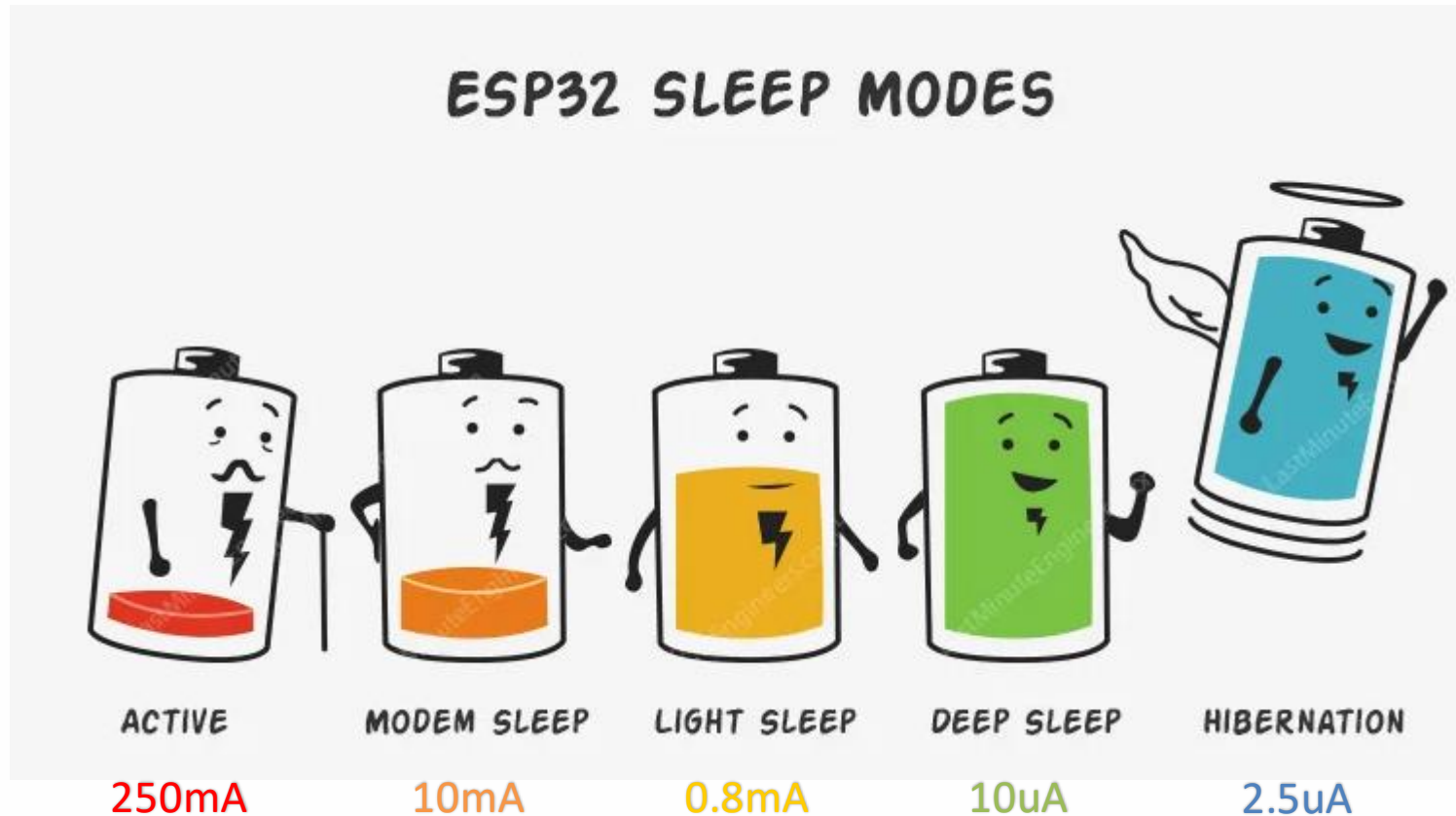
- Assume you have :
 - a Li-ion battery with capacity: 1300 mAh
 - ESP32 in active mode consumes 250 mA
 - ESP32 in hibernation mode consumes 2.5 μ A
- Assume the following cycle:
996ms hibernation, 4ms active -> repeat

$$\text{Average current (mA)} = 0.004 \times 250 + 0.996 \times 2.5 \times 10^{-6} \approx 1 \text{ mA}$$

$$\text{Battery life (h)} = \frac{1300 \text{ mAh}}{1 \text{ mA}} = 1300 \text{ h} !$$



Power mode Summary



- **Active mode:** The chip radio is powered on. The chip can receive, transmit, or listen.
- **Modem-sleep mode:** The CPU is operational and the clock is configurable. The Wi-Fi/Bluetooth baseband and radio are disabled.
- **Light-sleep mode:** The CPU is paused. The RTC memory and RTC peripherals, as well as the ULP coprocessor are running. Any wake-up events (MAC, host, RTC timer, or external interrupts) will wake up the chip.
- **Deep-sleep mode:** Only the RTC memory and RTC peripherals are powered on. Wi-Fi and Bluetooth connection data are stored in the RTC memory. The ULP coprocessor is functional.
- **Hibernation mode:** The internal 8 MHz oscillator and ULP coprocessor are disabled. The RTC recovery memory is powered down. Only one RTC timer on the slow clock and certain RTC GPIOs are active. The RTC timer or the RTC GPIOs can wake up the chip from the Hibernation mode.

Expect quiz questions!