# Power management

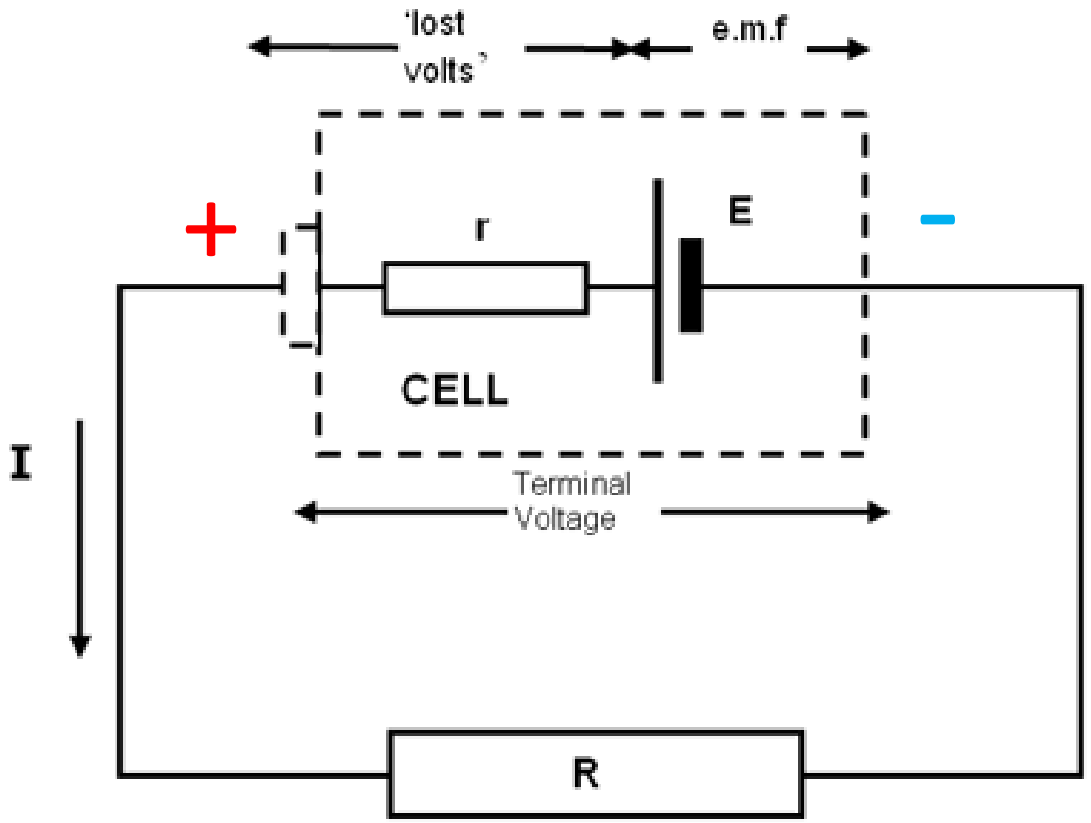
# Agenda

- Power supply
- Batteries
- ESP32 sleep modes

# Power supply

# Power supply

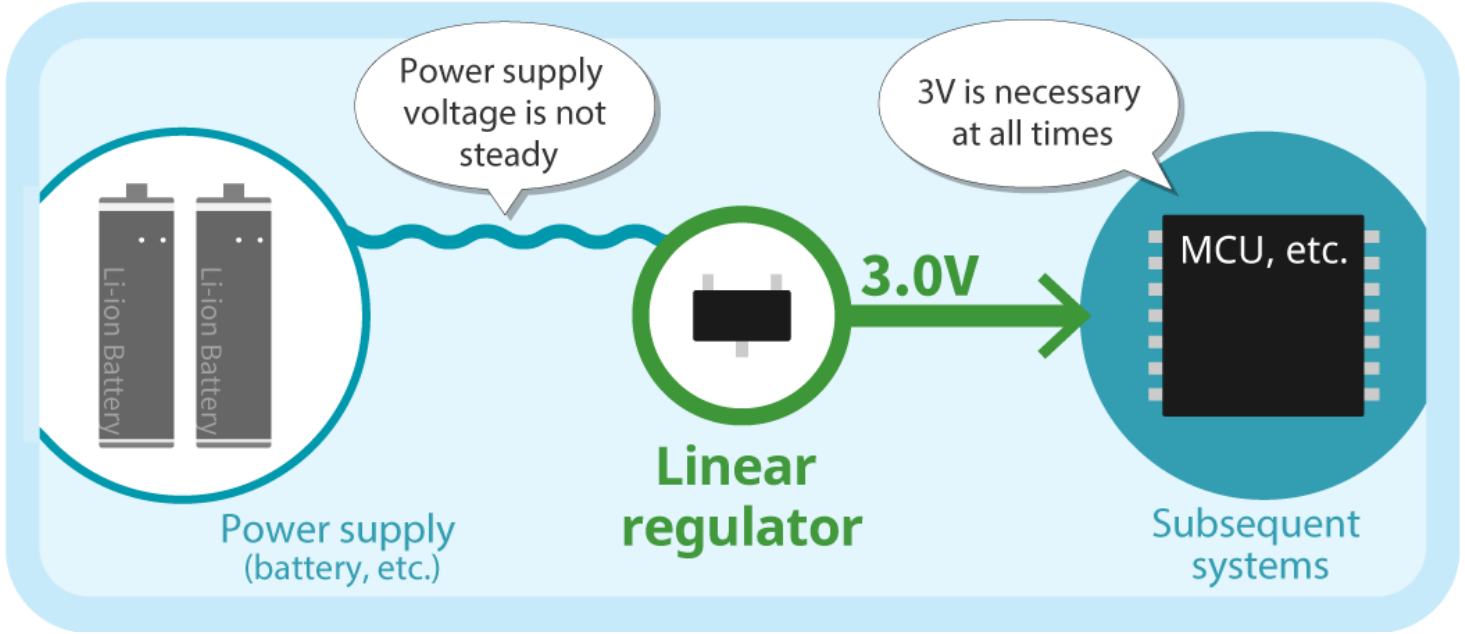
- Sources
  - Grid, Battery, Solar
  - Generator, Peltier, RF harvesting
- Main characteristics
  - Rated voltage and current
  - Polarity
- Undesired effects
  - Noise / Fluctuations
  - Internal resistance




https://www.pathwayz.org/Tree/Plain/INTERNAL+RESISTANCE

# LDO: Low dropout (aka linear) regulator

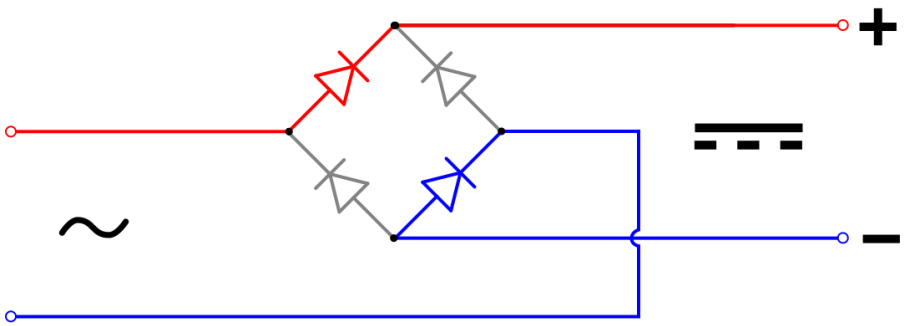
- Stabilize **small** voltage fluctuations
- Low power (power the MCU, sensors …)
- Low noise, but low efficiency (voltage drop = power loss)

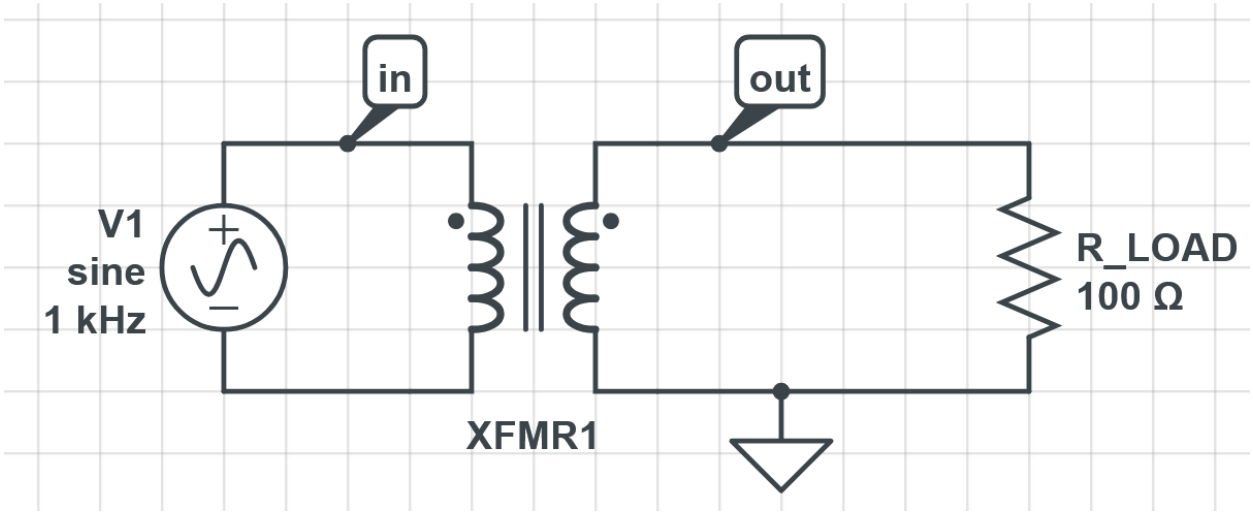



https://www.ablic.com/en/semicon/products/power-management-ic/voltage-regulator-ldo/intro/

# Transformers

- Purpose: step up/down the voltage
- Type: AC (sine) vs Switched
- Rectifiers (Gretz bridge)

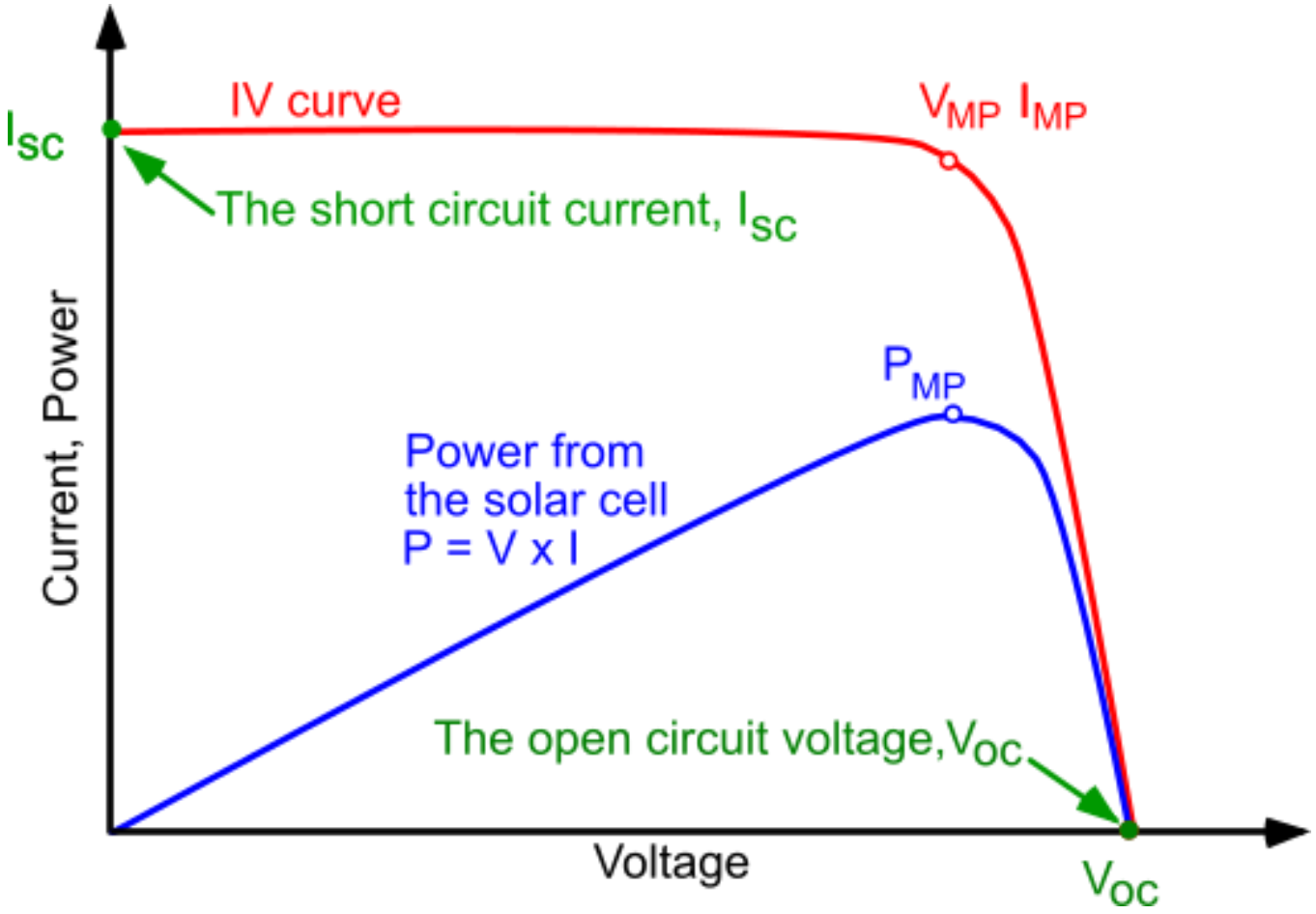



https://www.ablic.com/en/semicon/products/power-management-ic/voltage-regulator-ldo/intro/
https://en.wikipedia.org/wiki/Diode_bridge

# Solar (PV) panels

- Open circuit voltage (Voc)
- I/V curve (at given irradiance)
- Maximum Power Point
- Heat management
- Inverters




https://arka360.com/ros/factors-affect-photovoltaic-performance/

# Batteries

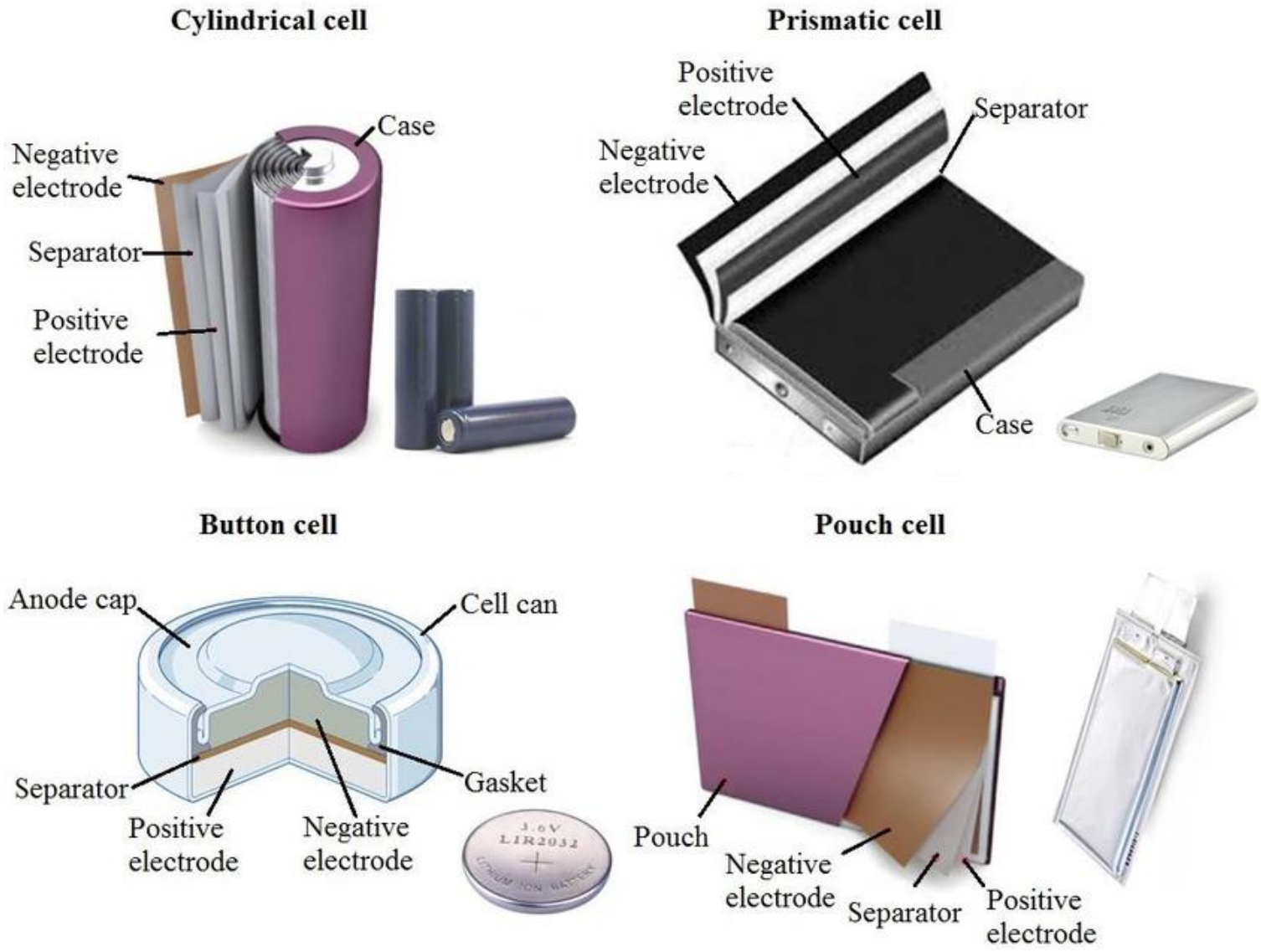
# Common batteries

| Type | Voltage (V) | Capacity (mAh) | Resistance | Self Discharge |
|---|---|---|---|---|
| Coin Cell 2032 | 3.00 | 200 | High | Low |
| AAA/AA/C/D (Alkaline) | 1.2 – 1.5 | 1000/2000/5000/10000 | Medium | Low |
| AAA/AA/C/D (NiMh) | 1.2 – 1.3 | 1000/2000/5000/10000 | Medium | Med/Low |
| AAA/AA/C/D (Ni-Zn) | 1.3 – 1.6 | 1000/2000/5000/10000 | Medium | Med/Low |
| LiPo - 18650 | 3.3 – 4.2 (3.7) | 2500-3500 | Low | Low |
| LiPo – 21700 | 3.3 – 4.2 (3.7) | 4000 – 5000 | Low | Low |
| LiPo – 14500 | 3.3 – 4.2 (3.7) | 500 – 1000 | Low | Low |




# LiPo form factors

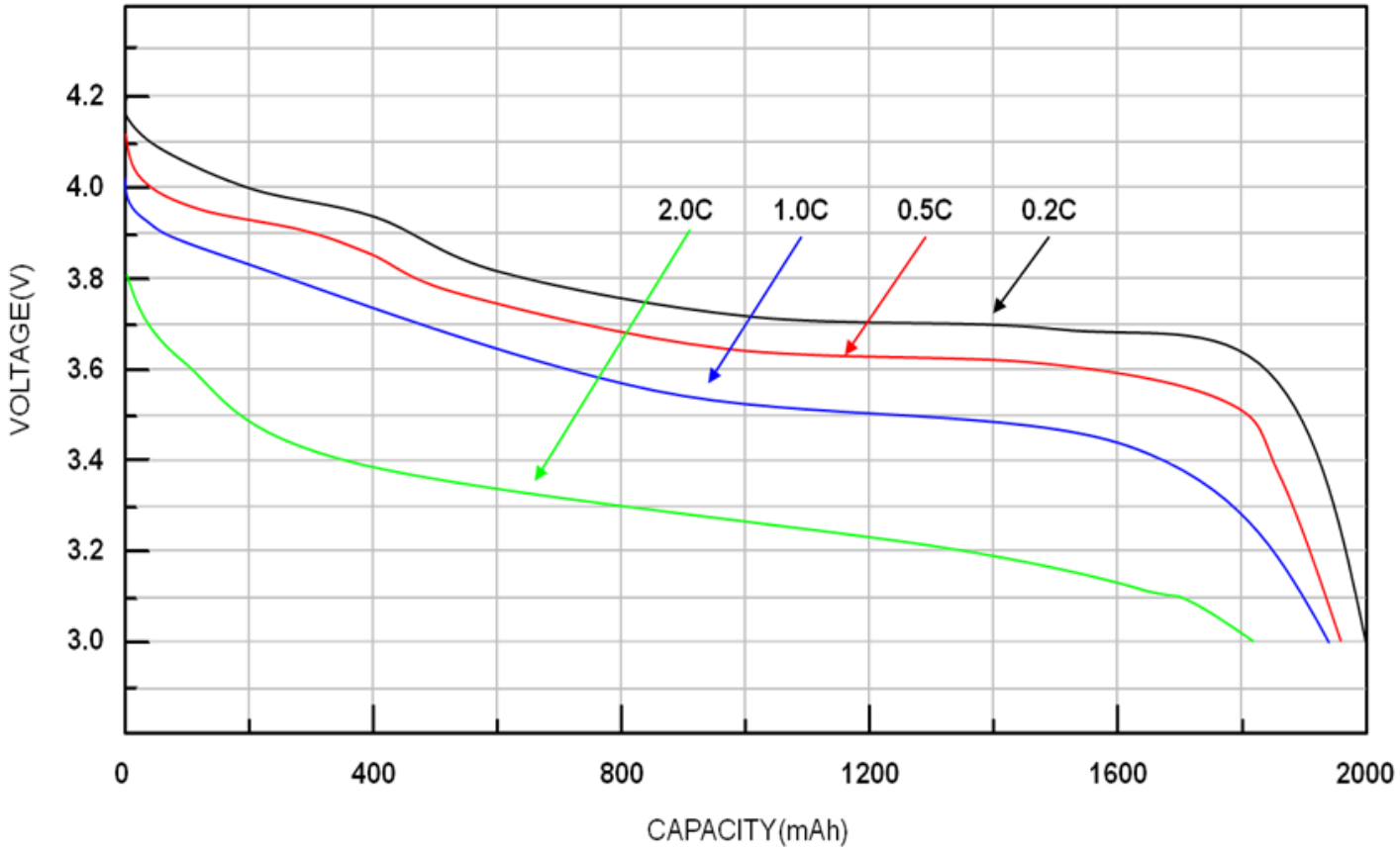
- Cylinder
  - higher density
  - cheaper
  - more robust mechanically
  - safety vent
- Pouch/prism
  - cools better
  - flat devices (phone, laptop)
  - swelling is a problem




https://www.researchgate.net/figure/The-most-common-lithium-ion-cell-types_fig2_304023316

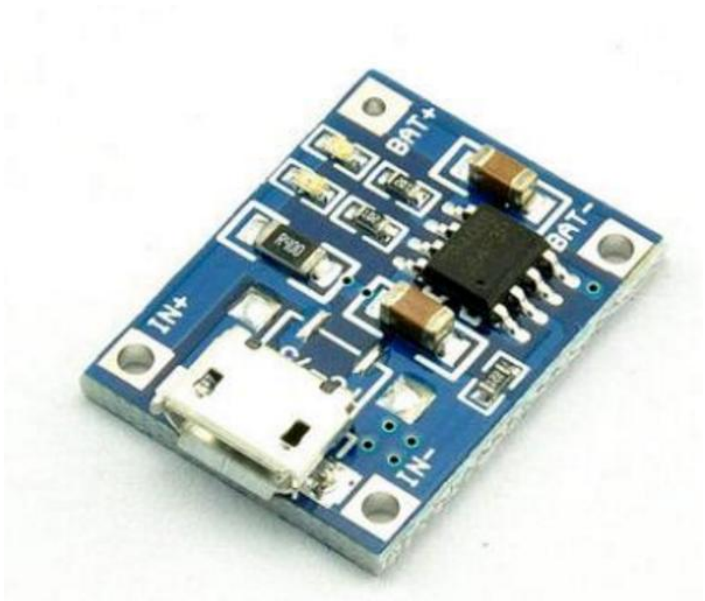
# LiPo Discharge Curve

- Internal Resistance increases with decreased capacity
- 1 om @ 300 ma = 0.3v voltage Drop
- Discharge below 3V may damage the cell

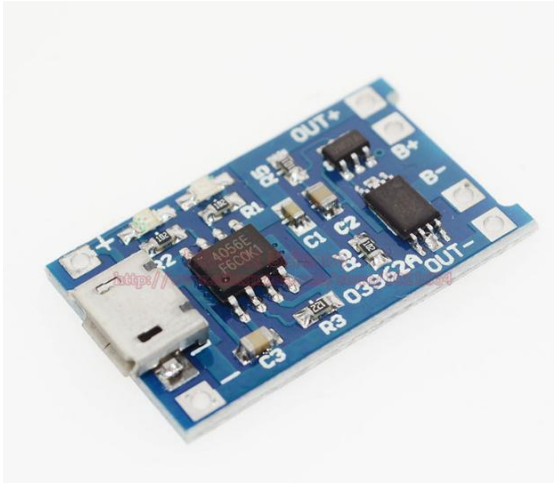


# LiPo chargers

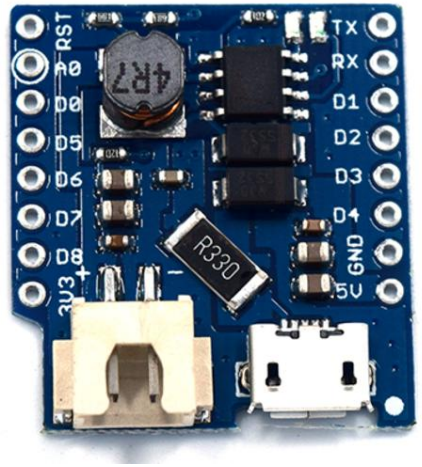
- Only Charge




- + battery protection




- Wemos Battery Shield
  - + battery protection
  - + 5v Boost



# ESP32 sleep modes

# ESP32 sleep modes (datasheet)

| Power mode | Description | | | Power Consumption |
|---|---|---|---|---|
| Active (RF working) | Wi-Fi Tx packet | | | ~100–240 mA but bursts to 790 mA |
| | Wi-Fi/BT Tx packet | | | |
| | Wi-Fi/BT Rx and listening | | | |
| Modem-sleep | The CPU is powered up. | 240 MHz * | Dual-core chip(s) | 30 mA ~ 68 mA |
| | | | Single-core chip(s) | N/A |
| | | 160 MHz * | Dual-core chip(s) | 27 mA ~ 44 mA |
| | | | Single-core chip(s) | 27 mA ~ 34 mA |
| | | Normal speed: 80 MHz | Dual-core chip(s) | 20 mA ~ 31 mA |
| | | | Single-core chip(s) | 20 mA ~ 25 mA |
| Light-sleep | - | | | 0.8 mA |
| Deep-sleep | The ULP coprocessor is powered up. | | | 150 $\mu$A |
| | ULP sensor-monitored pattern | | | 100 $\mu$A @1% duty |
| | RTC timer + RTC memory | | | 10 $\mu$A |
| Hibernation | RTC timer only | | | 5 $\mu$A |
| Power off | CHIP_PU is set to low level, the chip is powered down. | | | 1 $\mu$A |

# Modem sleep mode (automatic)

- Router (AP) broadcasts DTIM beacon regularly (100-1000 ms)
- ESP32 (STA) tunes to the beacon timing and wakes up Radio on time
- Power consumption: ~20mA (modem sleep) to ~240mA (active)
- CPU clock is adjusted automatically

# Light sleep mode

- CPU, RAM and peripherals are **clock-gated** (paused), voltage reduced
- RTC and ULP remain active
- Power consumption: **~1mA**
- No data loss, program resumes upon wake up

# Deep sleep mode

- CPU, RAM and peripherals are **powered down** (data lost)
- RTC and ULP remain active (RTC RAM preserved)
  - Example: `RTC_DATA_ATTR int myVar = 0;`
- Power consumption: **~10-150uA**
- Wake up resets the CPU
  - “deep sleep wake stub” callback can alter the boot process

# Hibernation mode

- CPU, RAM and peripherals are powered down (data lost)
- ULP and 8MHz Oscilator (clock) powered down
- Only RTC timer and RTC GPIOs remain active (**RTC RAM lost**)
- Power consumption: **~2.5uA**
- Wake up resets the CPU

# Wake up sources

- Timer: `esp_sleep_enable_timer_wakeup (microseconds);`
- Touch (interrupt): `esp_sleep_enable_touchpad_wakeup();`
- External wake up (interrupt)
  - ext0:  a single, preconfigured GPIO pin interrupt
  - ext1: any RTC pin, pull up/down not available, RTC memory not required

```
esp_sleep_enable_ext0_wakeup(GPIO_PIN, LOGIC_LEVEL)
esp_sleep_enable_ext1_wakeup(BUTTON_PIN_MASK, LOGIC_LEVEL)
```

# ULP coprocessor

- Uses (SLOW) RTC memory
  - A big enough chunk must be reserved for ULP code and data
  - Program(s) embedded into main program as a blob
  - And loaded to RTC memory with : `ulp_riscv_load_binary / ulp_riscv_run`
- Code is triggered periodically by a timer (136KHz RTC_SLOW_CLK)
- Can share variables with the main program
  - Synchronization: `ulp_riscv_lock_acquire/release`
- Can wake up main CPU
- Can read sensors (I2C, bit banging) / GPIOs / ADC
- Programmed in C or assembly (RISCV)