Deep Sleep by Design

Building Linux Products that truly Sleep

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Agenda

Module 1: **Physics of Power**
Module 2: **Poor Baseline & Measurement Setup**
Module 3: **Dynamic PM – Throttling** (CPUFreq)
Module 4: **Idle PM – Sleeping** (CPUIdle, Runtime PM, Suspend)
Module 5: **Analysis & Tooling** (powertop, perf, ftrace)
Module 6: **Application & System Design** – “Sleep-First”
Module 7: **Android**

Wrap-up: Checklist & Resources

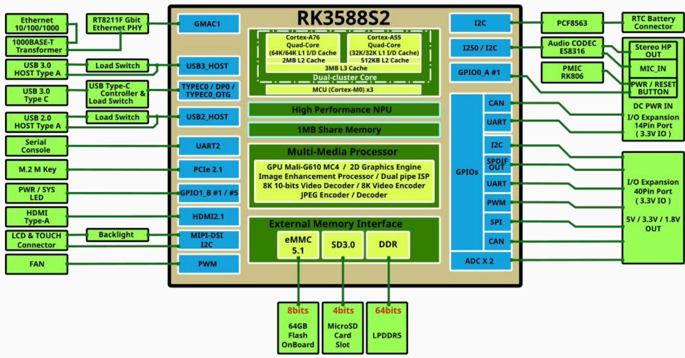
Duration: 3h, no coffee-breaks

Before we start

Goal: move from "my board idles at >1 W" to "measured deep sleep in the few-mW range" with a repeatable method

We'll work with one Arm64 SoC (Odroid M2); the patterns apply to other hardware (Intel, AMD, NXP, TI, Qualcomm, …) even if the exact numbers differ

I assume you are comfortable with shell access, kernel configuration and rebuilding images; we won't cover basic Linux usage



Please interrupt me at any time with questions or real-world problems from your products; the more concrete, the better (this workshop is for you!)

Module 1
The Physics of Power

Why Power Is the Tightest Resource

Power is not just one resource; it's a proxy for three:

- Battery Life: The most obvious device constraint.
- Thermal Budget: Power (W) = Heat. Throttling is the failure of PM.
- System Cost: Smaller batteries, passive cooling, simpler power delivery.

Goal is: not just "race to idle", enter deep sleep and stay there most of the time

Requires a system-wide view: HW + kernel + userspace together

We must combine hardware capabilities with the right software

Core Concept I: Throttling vs Shutdown

Two basic levers: slow down vs turn off

Throttling (Dynamic PM)

- Scale voltage/frequency to match load (DVFS)
- Analogy: dimming a light
- Linux: CPUFreq, DevFreq

Shutdown (Idle PM)

- Gate clocks, power-gate blocks
- Analogy: flipping the light switch
- Linux: CPUIdle, Runtime PM, System Suspend

Key: you cannot throttle to zero – deep sleep needs shutdown

```
osc_24m: osc-24m {
compatible = "fixed-clock";
#clock-cells = <0>;
clock-frequency = <24000000>;
};

ccm: clock-controller@12340000 {
compatible = "acme,mychip-ccm";
reg = <0x12340000 0x1000>;
#clock-cells = <1>;
clocks = <&osc_24m>;
clock-names = "osc_24m";
* 0 = GPU_AHB_ROOT
* 1 = GPU_CORE_ROOT
* 2 = I2C1_BUS_ROOT
* 3 = I2C1_CORE_ROOT
*/
};

pmc: power-controller@12380000 {
compatible = "acme,mychip-pmc";
reg = <0x12380000 0x1000>;
#power-domain-cells = <1>;

pd_gpu: power-domain@0 { reg = <0>; };
pd_periph: power-domain@1 { reg = <1>; };
};

soc: soc@0 {
compatible = "simple-bus";
#address-cells = <1>;
#size-cells = <1>;
ranges = <0x0 0x0 0x40000000>;

gpu: gpu@40000000 {
compatible = "acme,mychip-gpu";
reg = <0x40000000 0x20000>;
interrupts = <0 40 4>;

clocks = <&ccm 0>,   /* GPU_AHB_ROOT  */
<&ccm 1>;   /* GPU_CORE_ROOT */
clock-names = "reg", "core";

power-domains = <&pmc 0>; /* pd_gpu */
status = "disabled";
};

i2c1: i2c@41000000 {
compatible = "acme,mychip-i2c";
reg = <0x41000000 0x1000>;
interrupts = <0 41 4>;

clocks = <&ccm 2>,   /* I2C1_BUS_ROOT  */
<&ccm 3>;   /* I2C1_CORE_ROOT */
clock-names = "bus", "core";

power-domains = <&pmc 1>; /* pd_periph */
status = "disabled";
```

Core Concept II: Clock vs Power Domains

Clock domain (clock gating)

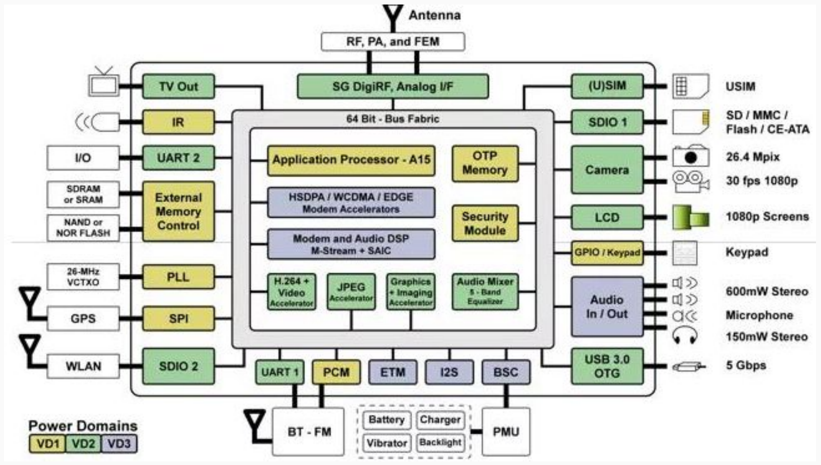
- Stop clock to a block (e.g., UART)
- Very fast to enter/exit
- Still leaks static power

Power domain (power gating)

- Remove supply from a block (e.g., GPU, CPU core)
- Near-zero leakage, but slower, state lost

Modern SoCs: many independent clock & power domains

PM is about using these domains aggressively without breaking UX/requirements



Core Concept III: State Retention & Wake Sources

State retention problem

- Power-gated domains lose registers, caches, context

Retention solutions

- Retention flip-flops, retention SRAM, “retention modes”
- Trade-off: less power savings vs faster, easier resume

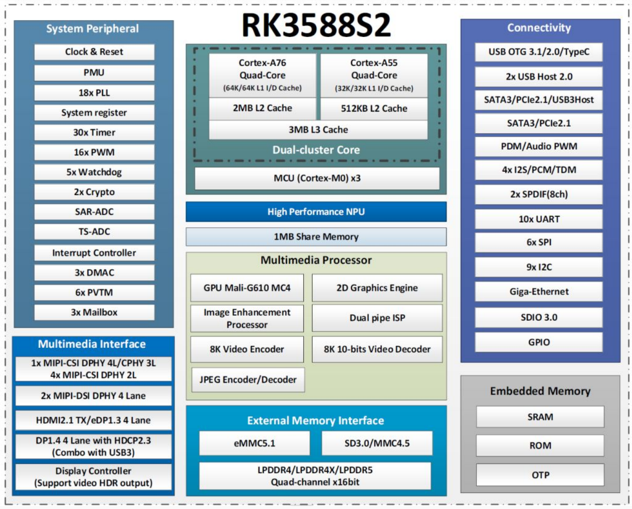
Deeper sleep (e.g. Suspend-to-RAM / S3)

- Only DRAM retained in self-refresh

Wake sources

- Typical: GPIO button, RTC alarm, Ethernet WoL, USB, modem
- Must explicitly enable only the wake sources you really want

Platform Divergence: ACPI vs Device Tree



Kernel frameworks are generic

Platform describes actual capabilities

x86 / Intel Atom

- ACPI firmware advertises C-states, P-states, S-states
- Drivers: intel_idle, intel_pstate, acpi-cpufreq

ARM / ODROID-M2 (RK3588S2)

- Uses Device Tree + PSCI for idle/suspend
- idle-states and power-domains defined in DTS
- Drivers: cpuidle-psci / cpuidle-dt, cpufreq-dt, genpd

Takeaway: same kernel concepts, different description layers

Module 2
The “Poor Baseline” & Measurement Setup

Case Study Hardware: ODROID-M2 & Intel Atom

ARM board: ODROID-M2 (RK3588S2)

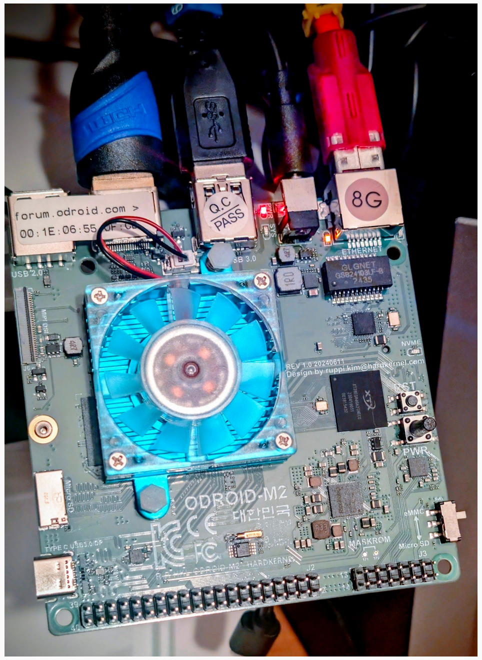
- 4× Cortex-A76 + 4× Cortex-A55, big.LITTLE
- DT-based clocks, power-domains, idle-states

x86 board: Intel Atom (E3900-class)

- ACPI-based C/P/S-states
- intel_idle and intel_pstate on modern kernels

We'll compare patterns on both, not chase board quirks

Focus: methodology, not exact numbers



Info:
This workshop skip the important topic of energy aware scheduling (EAS)

Hardware is Destiny I: The SoC

Software configures, Hardware executes. Your minimum power consumption is set by your hardware choices.

Key SoC features for low power:

- Granular, independent power domains
- Fine-grained clock gating
- An optimized PMIC (Power Management IC) designed for the SoC

Look for SoCs designed for low-power modes

Critical: Does the SoC have mainline Linux support?

Hardware is Destiny II: Peripherals & Drivers

A single "bad" peripheral can veto sleep for the entire system

All peripherals (Ethernet, WiFi, sensors) must correctly implement:

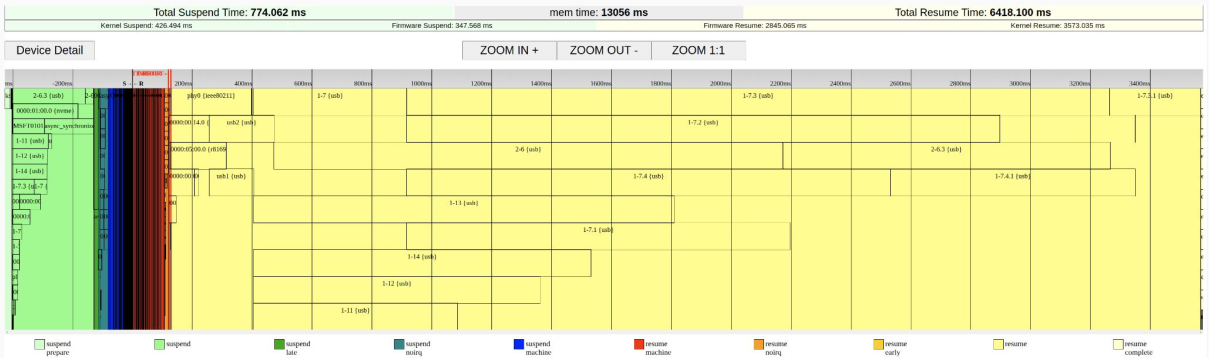
- Runtime PM (autosuspend) for idle savings
- System Suspend hooks for deep sleep.

Common Problem: USB

- Many USB devices (or even host controllers) have poor autosuspend support in hardware or drivers

Choose components with known, high-quality mainline drivers that fully support PM - verify things on reference systems

sleepgraph.py:



Lab 1: The Deliberately Bad Baseline

Kernel config:

- CONFIG_PM = n (PM core frameworks off)
- CONFIG_HZ = 1000 (1000 timer ticks per second)

Userspace:

- CPUFreq governor (if present) = performance
- Stock distro, no tuning, all services on

Lab steps:

- Boot, login over serial / UART
- Let system “idle” at shell prompt
- Measure total board power – this is our baseline

Battery Simulator - Ch1

12:24:47

State of Charge: 68.0%

Status: Discharging

Capacity: 2.107 Ah

Open Circuit Voltage (Voc): 4.068 0 V

Terminal Voltage (Vt): 4.067 79 V

Internal Resistance (ESR): 0.062 Ω

Current: 0.184 76 A

Model: /int/battery/default/LiIon.csv

Battery Capacity: 3.100 Ah

Current Limit: 1.000 00 A

Set SoC

Measurement I:
Shunt Resistor “Ground Truth”

Software estimates (e.g., powertop) are guidance, not truth

Hardware measurement:

- Insert precise shunt (e.g. 100 mΩ) in main supply path
- Measure voltage drop across shunt with DMM/ADC
- Per rail shunt - for maximum observability

Use Ohm’s law:

- I = V / R, P = V_supply * I

Use Kelvin (4-wire) connection for accuracy

Low-side shunt (between load and GND) is usually simpler

Measurement II:
GPIO Toggle for Resume Latency

Kernel timestamps are unreliable across suspend/resume

Use GPIO + scope/LA for real latency:

- Select free GPIO pinned out on header
- In IRQ / wake handler: set GPIO high ASAP
- In late resume / userspace ready: set GPIO low

Measure pulse width on scope ⇒ end-to-end resume time

Repeat for:

- s2idle vs suspend-to-RAM
- Different wake sources (GPIO vs RTC vs network)

Lab 1 Result: The Bad Idle

Example (numbers will differ on your boards):

- ODROID-M2 idle: ~1.25 W

Why so bad?

- PM frameworks disabled (CONFIG_PM=n)
- CPU stuck in C0, often at max frequency
- All peripherals powered, clocks running
- Timer tick at 1000 Hz keeps waking CPU

This is our reference to compare all later improvements

Module 3
Dynamic PM: Throttling (CPUFreq)

Dynamic PM: DVFS via CPUFreq

First optimistic idea: reduce power while active

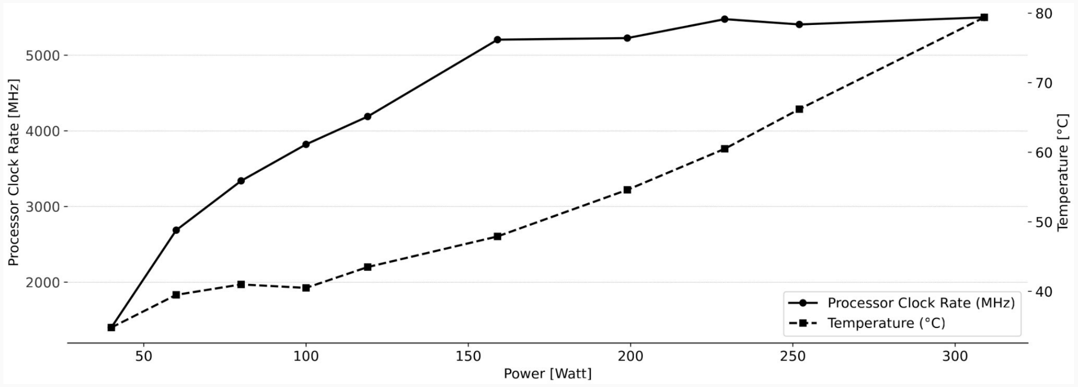
DVFS = Dynamic Voltage & Frequency Scaling

Linux CPUFreq subsystem:

- Core: policy + sysfs (/sys/devices/system/cpu/.../cpufreq/)
- Driver: platform-specific, talks to PLL / regulators
- Governor: policy algorithm choosing frequency

Good for reducing active power

Spoiler: doesn't fix idle power



AMD Ryzen 9950X

CPUFreq Governors in Practice

performance

- Always max freq, our baseline

powersave

- Always min freq, hurts latency/UI

ondemand / conservative

- Legacy, reactive to CPU load, “bouncy”

schedutil (default on modern ARM64)

- Integrated with CFS scheduler
- Uses scheduler load tracking for DVFS

For most arm64 systems: use schedutil unless you have a reason not to

Intel Platform: intel_pstate vs acpi-cpufreq

Note: modern x86-64 based systems use "HWP" based approaches (hw controlled, not kernel)

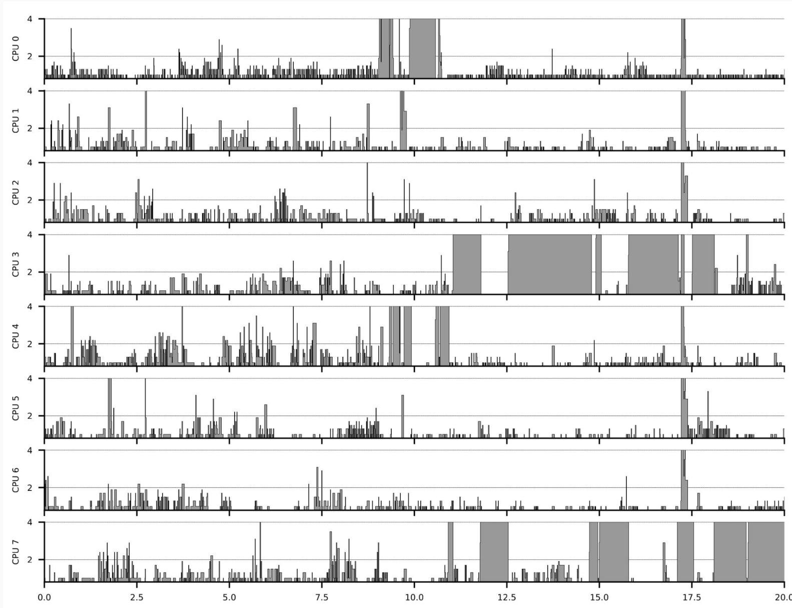
acpi-cpufreq

- Trusts ACPI _PSS tables from firmware
- Exposes standard governors (ondemand, schedutil, ...)

intel_pstate (default on modern Intel/Atom)

- Driver and governor combined
- Uses hardware/firmware feedback to choose P-states
- Exposes "performance" and "powersave" policies
- Usually better than acpi-cpufreq

Override: intel_pstate=disable on kernel cmdline if you must



ARM Platform: cpufreq-dt and OPP Tables

Generic DT-based CPUFreq driver: cpufreq-dt

Uses Operating Performance Points (OPP):

- Frequency / voltage pairs
- Defined via operating-points-v2 in DT

Example (generic Cortex-A53 SoC, not M2-specific):

- 1.5 GHz @ 1.10 V
- 1.2 GHz @ 1.05 V
- 667 MHz @ 0.94 V, etc.

If the OPP table is wrong, your DVFS is wrong

For RK3588S2, vendor trees usually provide OPPs – check them

DevFreq: DVFS Beyond the CPU

CPU is not the only power hog

DevFreq: generic DVFS for devices (GPU, DDR, ISP...)

Same pattern as CPUFreq:
- Core + driver + governor

Governors: ondemand, performance, powersave, passive

Check /sys/class/devfreq/ for available devices

Under load, DevFreq can matter as much as CPUFreq

Lab 2: Enabling CPUFreq

Kernel config (simplified):

- CONFIG_PM = y
- CONFIG_CPU_FREQ = y
- CONFIG_CPU_FREQ_GOV_SCHEDUTIL = y

Steps:

- Load governor: modprobe cpufreq_schedutil if modular
- echo schedutil > .../cpufreq/scaling_governor
- Watch scaling_cur_freq under load

Measurement:

- Repeat idle power measurement
- Result: idle stays basically the same

Lesson: DVFS helps under load, not when “idle”

Module 4
Idle PM: Sleeping

Idle PM: What We Actually Need

To cut idle power, we must turn things off

Three separate frameworks:

- CPUIdle – idle states for CPUs
- Runtime PM – idle states for individual devices
- System Suspend – whole-system low-power states

Mixing them up is the #1 design error

We'll walk each in turn, then combine them

Framework 1: CPUIdle Basics

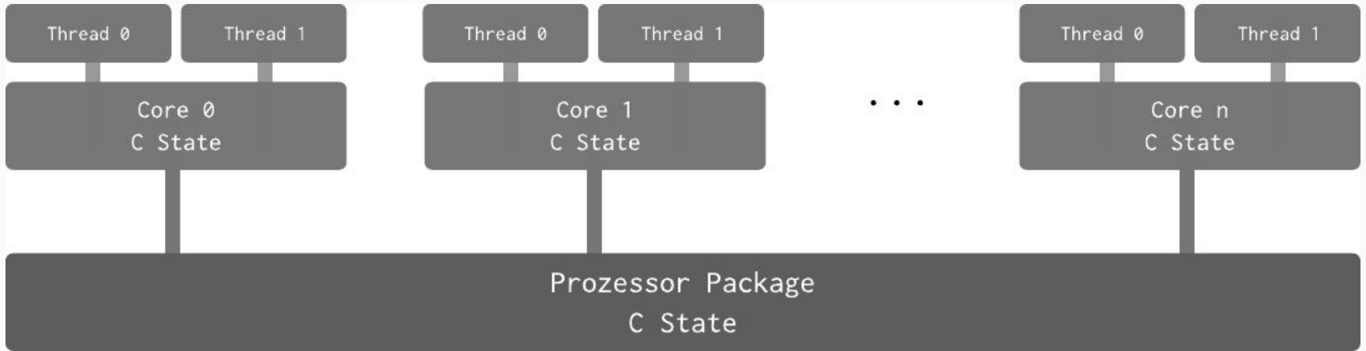
Trigger: CPU has no runnable tasks (idle loop)

CPUIdle components:

- Core: generic cpuidle framework
- Driver: platform-specific C-states entry/exit
- Governor: chooses which C-state to use

“Opportunistic sleep”:

- Sleep whenever the CPU is idle
- Wake on any interrupt or timer



CPUIdle Deep Dive: C-States & menu Governor

ACPI naming: C0, C1…Cn

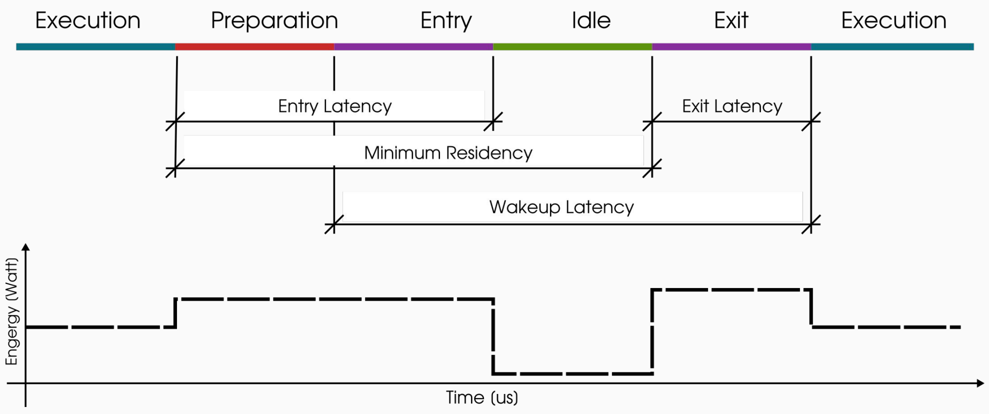
- C0: running
- C1: simple halt/wfi, fast, modest savings
- Deeper C-states: clock gating, power gating, big savings, high latency

Each state has:

- Entry/exit latency
- Target residency (time to break even)

menu governor:

- Predicts next wakeup (timers, I/O, scheduler)
- Selects deepest state that fits within latency + PM QoS limits



Intel: intel_idle Driver

intel_idle bypasses ACPI _CST and uses Intel tables

Enters C-states via MWAIT with hints

Exposes C-states under:

- /sys/devices/system/cpu/cpu0/cpuidle/state*/

Debug:

- state*/name (C1, C3, C6, ...)
- state*/time (total residency)

Tune C-state usage with BIOS/firmware and PM QoS

C State Transition Tracking

Individual C State transitions can be tracked with Perf

```
$ perf record -a -e power:cpu_idle -- sleep 60
$ perf script --gen-script python
$ vim perf-script.py
$ perf script -s ./perf-script.py
    2 36002.863851506 state=4294967295, cpu_id=2
   18 36002.863873513 state=4, cpu_id=18
    2 36002.864113542 state=4, cpu_id=2
   18 36002.864140040 state=4294967295, cpu_id=18
    2 36002.864272308 state=4294967295, cpu_id=2
   16 36002.864349085 state=4294967295, cpu_id=16
   18 36002.864381491 state=4, cpu_id=18
    0 36002.864396402 state=4294967295, cpu_id=0
   12 36002.864403081 state=4294967295, cpu_id=12
    0 36002.864415912 state=4, cpu_id=0
   12 36002.864447521 state=4, cpu_id=12
    2 36002.864472649 state=4, cpu_id=2
   16 36002.864490568 state=4, cpu_id=16
```

ARM: DT idle-states + PSCI

Many ARM64 platforms use PSCI for CPU idle/suspend

DT idle-states node describes:

- entry-method = "psci"
- min-residency-us
- entry-latency-us, exit-latency-us

Driver: cpuidle-psci / cpuidle-dt

As on x86, deep states use power gating + longer latency

Bad DT = bad idle behaviour, no matter what the kernel wants

The Tick Problem: Why CPUIdle Isn’t Enough

CONFIG_HZ = periodic scheduler tick (100–1000 Hz)

Each tick is an interrupt that wakes the CPU

Even if idle, CPU keeps popping back to C0 to do nothing

Result: cannot stay in deep C-states long enough

The periodic tick is often the single worst enemy of low idle power

Tickless Idle (CONFIG_NO_HZ_IDLE)

Enable tickless idle: CONFIG_NO_HZ_IDLE = y

Behaviour:

- When CPU goes idle, kernel stops periodic tick
- Looks ahead to next real timer event
- Programs a one-shot timer for that time
- Lets CPUIdle pick a deep state for the whole interval

Allows multi-second deep C-state residency

Absolutely mandatory for good opportunistic sleep

Beware: majority of these tips guide to a power optimized system - not max-throughput/realtime optimized system

Framework 2: System Suspend

System-wide low-power state (S-states / suspend)

Entry path:

- Userspace initiates (e.g., echo mem > /sys/power/state)
- Freeze userspace tasks
- Suspend devices (top-down prepare, bottom-up suspend)
- Enter platform suspend state (s2idle, S3, etc.)

Modes:

- S1: freeze / s2idle: CPUs use CPUIdle, rest mostly stan
- S2: mem: Suspend-to-RAM / S3, CPU off, DRAM in self-refresh
- S4: disk: Hibernate

For deep sleep, we care about mem

Framework 3: Runtime PM (RPM)

Runtime PM for individual devices

Transparent to userspace

Based on a usage counter per device:

- pm_runtime_get*() – increment, resume device
- pm_runtime_put*() – decrement, maybe idle/suspend device

Autosuspend:

- Delay before suspend to avoid bouncing the power state

Goal: if device is not used, it should sleep, even if CPU runs

Generic Power Domains (genpd)

Some devices share a power controller (shared rail)

GenPD models power domains in kernel:

- Devices attach to domains via DT power-domains
- Domain only powered off when all member devices can sleep

Links Runtime PM with real power rails

Without GenPD, Runtime PM can’t actually gate leakage-heavy blocks

Lab 3: Turning on Idle PM

Kernel config (simplified):

- CONFIG_PM = y
- CONFIG_PM_SLEEP = y
- CONFIG_CPU_IDLE = y
- CONFIG_NO_HZ_IDLE = y
- CONFIG_PM_RUNTIME = y
- Platform drivers: CONFIG_INTEL_IDLE or CONFIG_CPUFREQ_DT, PSCI, GenPD

Checks:

- cat cpu0/cpuidle/state*/name (C-states visible?)
- For a device: .../power/control = auto
- .../power/runtime_status → suspended

Measurement:

- Idle power should drop significantly vs Lab 1

Module 5
Analysis & Tooling

What’s Still Keeping Us Awake?

System can sleep, but maybe it does not

Two main reasons:

- Vetoes – explicit “do not sleep” constraints
  - PM QoS latency limits
  - Wakelocks / wakeup sources

- Wakeups – noisy activity resetting idle timer
  - Chatty apps, kernel threads
  - Interrupt storms, periodic timers

Our job: find the veto or wakeup, then remove or tame it

Veto 1: PM QoS

PM QoS = Power Management Quality of Service

Allows code to say:

- "I need wakeup within N μs"

Interface (userspace): /dev/cpu_dma_latency

- Open → register a request
- Write s32 latency (μs) → update request
- Close → remove request

Effect: CPUIdle will avoid deep C-states with higher latency

Debug:

- Check existing constraints with pm_qos debugfs / docs

Veto 2: Wakelocks / Wakeup Sources

Wakeup source framework (Android “wakelocks” concept)

If a wakeup source is active, system suspend is blocked

Two types conceptually:

- Kernel wakelocks (held in drivers / subsystems)
- Userspace wakelocks via /sys/power/wake_lock (if enabled)

A single stray wakelock often explains “suspend never works”

Wakelocks from Userspace

Userspace interface (when USER_WAKELOCK enabled):

Acquire lock:

```
        echo "my_app_lock" > /sys/power/wake_lock
```

Release lock:

```
        echo "my_app_lock" > /sys/power/wake_unlock
```

Inspect active locks:

```
        cat /sys/power/wake_lock
        cat /sys/kernel/debug/wakeup_sources
```

Never leave a lock held longer than necessary

Tooling I: powertop Overview

First responder for power debugging

Run calibration once on battery:

- powertop --calibrate

Key tabs:

- Overview – estimated power, main hogs
- Idle stats – C-state residency per CPU
- Frequency stats – P-state residency
- Device stats – per-device estimates
- Tunables – easy toggles for common settings
- WakeUp – per-process and IRQ wakeups

powertop Tunables & WakeUp

Tunables tab:

- “Good” vs “Bad” settings
- Typical fixes:
  - USB autosuspend to “Good”
  - Disable NMI watchdog
- powertop --auto-tune to flip everything to “Good”

WakeUp tab:

- Sort by wakeups/sec
- Identify top offenders: processes, timers, interrupts
- These are your prime suspects

Tooling II: perf for Profiling

powertop says who, perf tells you why

perf top

- Live view of hottest functions
- Use to spot misbehaving code under idle load

perf record + perf report

- Record CPU cycles, tracepoints, callgraphs
- Offline analysis of problematic intervals

We'll use perf with PM tracepoints to see wake paths

Using perf to Trace Wakeups

Goal: catch full stack that wakes the CPU from idle

Useful tracepoints:

- power:cpu_idle, power:cpu_frequency

Example:

```
perf record -a -e power:cpu_idle --sleep 10
perf script
```

Output: processes + kernel stack causing wakeups

Great for hunting “mystery” wakeups

Tooling III: ftrace as a Scalpel

ftrace = built-in kernel tracer via tracefs (back in the days: debugfs)

Mount tracefs:

```
mount -t tracefs none /sys/kernel/tracing
```

- Interface: /sys/kernel/tracing

Modes:

- function, function_graph – heavy, but detailed
- events – trace specific subsystems (e.g., power/*)

trace-cmd / kernelshark make life easier

- raw fs is fine/great for embedded

ftrace Example: PM Events

Simple PM tracing setup:

```
cd /sys/kernel/debug/tracing
echo 1 > events/power/enable
cat trace_pipe
```

You see live events:

- cpu_idle_enter / cpu_idle_exit
- pm_runtime_suspend / pm_runtime_resume
- suspend_resume phases

Combine with rtcwake tests to understand full PM behaviour

Info: using tracefs is the prefereed interface for embeded systems, compared to perf ftrace interfaces

Lab 4: Killing Wakeups

Step 1: powertop --auto-tune

Step 2: In WakeUp tab, identify top noise sources:

- sshd, serial login
- klogd spamming logs
- USB mouse / keyboard polling
- jbd2 / filesystem journal write
- NMI watchdog

Step 3: Fix one by one, re-measure each time

Goal: stable, very low idle in s2idle

Typical: down to tens of milliwatts on ARM boards

Module 6
Application & System Design (“Sleep-First”)

The “Sleep-First” Design Philosophy

After Module 5, s2idle idle is reasonably low

For an IoT-style device, it’s still not enough

Difference:

- s2idle – cores off, but DRAM + many blocks stay powered
- Suspend-to-RAM – only DRAM in self-refresh, rest off

Philosophy:

- System should be in Suspend-to-RAM by default
- Wake only to do useful work
- Immediately go back to deep sleep

Example Use-Case: “TX Data Every 5 Minutes”

Typical battery product pattern:

- Sample sensors
- Bring up radio / Wi-Fi / LTE
- Send small payload
- Go back to deep sleep

Requirements:

- Stable RTC or equivalent wake source
- All drivers & PM paths working in suspend-to-RAM
- Very predictable wake-to-work latency

The Wrong Way: sleep 300

Naive userspace loop:

```
while true; do
        send_data
        sleep 300
done
```

Problems:

- sleep just blocks the process
- System stays in s2idle / idle C-states
- Idle power maybe ~0.05 W, not µW-level
- Battery dies much sooner than necessary

The Right(er) Way: rtcwake

Use hardware RTC alarm + deep suspend

Pattern:

```
while true; do
        send_data
        rtcwake -m mem -s 300
done
```

-m mem → Suspend-to-RAM (ACPI S3 / equivalent)
-s 300 → RTC wakes system after 300 seconds

Between wakeups, board sits in true deep sleep

rtcwake Deep Dive

Syntax: rtcwake [options] -m <mode> {-s <seconds> | -t <time_t>}

Useful modes:

- standby – shallow sleep, fast resume
- mem – Suspend-to-RAM
- disk – hibernate to storage
- off – full poweroff with RTC wake if supported
- no – set alarm only, don’t suspend

You can also program RTC directly via /sys/class/rtc/rtc0/wakealarm

Always test that RTC alarms really wake from your chosen state

Lab 5: Implement Periodic Task Properly

Implement two versions of “send every 5 minutes”:

- Version A: sleep 300 loop
- Version B: rtcwake -m mem -s 300 loop

Measure both with shunt:

- A: idles in s2idle, e.g. ~0.05 W
- B: idles in suspend-to-RAM, e.g. ~0.005 W

Use GPIO toggle to measure wake-to-send latency

Ask: does latency and energy meet your product spec?

Module 7
Use Case: Android

Android-Style Deep Sleep: Big Picture

Android goal: be asleep as much as possible

- Opportunistic suspend: system goes to suspend-to-RAM whenever no WakeLocks are held
- Framework + kernel cooperate: PowerManagerService + suspend blockers in kernel
- Default state for phones: screen off → deep sleep, not just “idle”

Key idea: Deep sleep is the normal state, wake is the exception

Android-Style Deep Sleep: Big Picture

Android goal: be asleep as much as possible

- Opportunistic suspend: system goes to suspend-to-RAM whenever no WakeLocks are held
- Framework + kernel cooperate: PowerManagerService + suspend blockers in kernel
- Default state for phones: screen off → deep sleep, not just “idle”

Key idea: Deep sleep is the normal state, wake is the exception

WakeLocks & Suspend Blockers

WakeLock (framework)

- App / service tells system: “stay awake until I’m done”
- Partial WakeLock: keep CPU running, screen can be off
- Full WakeLock: keep CPU + display on (rarely used)

Suspend blocker / wakeup source (kernel)

- Kernel-side object that vetoes suspend while held
- Drivers hold it while processing critical work, then release immediately

Key idea: Suspend is allowed only when no WakeLock / suspend blocker is active

Orchestrating Suspend Safely

Suspend entry sequence

- Framework asks kernel for current wakeup_count
- Framework arms suspend and writes wakeup_count back
- If count changed in between, kernel rejects suspend (race detected)

During suspend

- Only marked wakeup IRQs stay enabled
- Any wakeup IRQ can abort suspend and bring system back to running

Key idea: No events are lost between “I want to sleep” and “I am sleeping”

Timed Work – AlarmManager, JobScheduler, WorkManager

AlarmManager

- Time-based wakeups (RTC or elapsed realtime)
- “Wakeup” alarms can bring device out of suspend
- Expensive: each alarm = full SoC wake

JobScheduler

- System batches background work from many apps
- Jobs have constraints: charging, unmetered network, idle, etc.
- Scheduler aligns jobs to existing wakeups to avoid extra resumes

WorkManager

- Higher-level API on top (uses JobScheduler / alarms internally)
- Respects system power policy (Doze, App Standby) automatically

Doze & App Standby – System-Level Policy

Doze mode

- Triggers after long screen-off + device still
- Network access, background jobs, normal alarms are deferred
- System opens short “maintenance windows” to flush queued work

App Standby

- Per-app buckets: active, working set, frequent, rare
- Idle apps get stricter limits on jobs, alarms, network

Key idea: Global policy layer that throttles background work even when Apps where missed

Wakeup Sources & Hardware Policy

Wakeup-capable devices

- Only selected IRQs allowed to wake the SoC: power button, RTC, modem, selected sensors
- Drivers mark wakeup IRQs explicitly (e.g., enable_irq_wake)

Handling wakeups

- Non-wakeup IRQs fully disabled in suspend
- First wakeup IRQ aborts suspend; handler runs after resume

Design rule

- Minimize number of wakeup sources
- Prefer co-processors / sensor hubs that pre-filter events and wake SoC only on “real” activity

Applying This to Embedded Linux

From sleep 300 to Android-style design

- Use hardware wake sources (RTC, GPIO, modem), not busy userspace loops
- Model long-running work as short wake cycles + quick return to mem
- Batch periodic tasks: one wakeup → do all pending sensor reads, logging, uploads

Borrow from Android

- Introduce a simple WakeLock-like API for your daemons (userspace or kernel)
- Add a central "power manager" process that decides when suspend is allowed
- Use rtcwake -m mem … (or direct /sys/power/state) only when no internal locks are held
-

Key idea: Recreate the pattern: central power arbiter + wakeup-count + minimal wake sources → maximal deep-sleep time

Module 8
Conclusion & Checklist

Summary: Baseline vs Optimized

Stepwise improvement path (example numbers):

- Lab 1 – Bad baseline: ~1.25 W
- Lab 2 – +CPUFreq: ~1.25 W (no idle gain)
- Lab 3 – +CPUIdle + tickless: ~0.35 W
- Lab 3 – +Runtime PM & GenPD: ~0.10 W
- Lab 4 – +Wakeup fixes: ~0.05 W (good s2idle)
- Lab 5 – rtcwake -m mem: ~0.005 W (deep sleep)

Net improvement: >99% reduction in idle power

Same boards, just smarter use of kernel PM features

Programming Language Selection

Tier 1	**C / C++ / Rust / Zig**
Tier 2	**Go / Swift / Kotlin / Java / C#**
Tier 3	**Python / JS / Ruby / Perl / Lua**

The Sleep-First Checklist

Hardware

- Peripherals with proper Runtime PM support?
- Clean wake sources (RTC, GPIO, maybe WoL)?

ARM DT / Intel ACPI

- DT: clocks, power-domains, idle-states correctly described?
- ACPI: usable _CST, _PSS, _S3 in firmware?

Kernel config

- CONFIG_NO_HZ_IDLE, CONFIG_CPU_IDLE, CONFIG_PM_RUNTIME, CONFIG_PM_SLEEP enabled?

Drivers

- All custom drivers implement dev_pm_ops (runtime + system)?

Userspace

- Periodic work uses rtcwake, not sleep
- No stray PM QoS constraints or wakelocks

Validation

- Power: shunt resistor + logging
- Latency: GPIO + scope or logic analyzer

Resources & Further Reading

Linux kernel docs (current tree):

- Documentation/admin-guide/pm/* (cpuidle, cpufreq, suspend, QoS, runtime PM)

Devicetree bindings:

- idle-states, power-domain bindings, OPP / operating-points-v2

Good slide decks / talks:

- “Linux Kernel Power Management: An Overview” (Linaro)
- Recent PM talks from Bootlin, Linaro, ELCE/EOSS

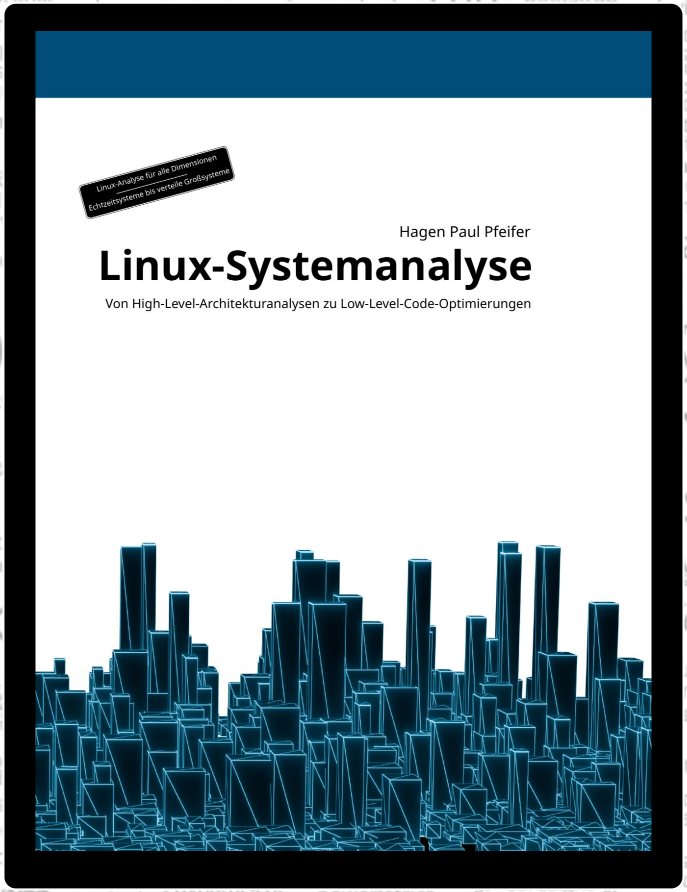
Tools:

- powertop, perf, trace-cmd / kernelshark docs

For later: bring your own board and repeat this exact pipeline

Linux Systemanalyse

Short commercial break:
If you like this workshop, you might like the book.



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Thank you very much!

Let’s Tackle Your Questions!

Got more questions? Feel free to catch me at the event or email me!
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