
ICM (Interface Control Module) — Design Brief (Updated)

0) Role & Placement

- **Role**: The ICM is the head-end brain for provisioning, configuration UI (AP→STA), node pairing/mapping, event logging, sequence policy, and diagnostics. It now also manages **local user feedback (buzzer)** and **environmental sensing (temperature sensor)**.
- **Placement**: Indoors at the home side. Interfaces to the 48 V trunk only indirectly (via the head-end PSM). All field modules are wireless along the driveway.

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1) High-level Block Diagram (text)

- 5 V IN (from PSM-HE) → Input filtering & protection → Primary 3.3 V buck → Clean 3.3 V LDO rail for MCU/RF/logic
- ESP32-S3 (with u.FL external antenna)
- USB-C (CDC) for service logs & firmware loading (factory)
- User I/O: Reset/Factory button; BIT (green) & FAULT (red) LEDs
- **Buzzer for audible feedback** (short beep = action confirm; long beep = error)
- **Temperature sensor** input (OneWire DS18B20 type, with pull-up) for monitoring enclosure ambient/thermal safety
- Optional inputs: Day/Night digital input; dry-contact header (future)
- Secure storage: Internal flash (NVS) + secure boot & flash encryption
- Debug access: UART/JTAG (factory only; locked in field)

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2) Core Electronics

2.1 MCU/RF

- SoC: ESP32-S3-WROOM/N8R2
- Clocking: 40 MHz crystal; optional 32.768 kHz footprint for deep sleep
- Antenna: u.FL to 2.4 GHz external whip, with RF keep-out

2.2 Power Path

- 5 V input (4.75–5.5 V, ≥1 A) with fuse, TVS, reverse protection, and Pi-filter
- Primary 3.3 V buck → Secondary low-noise LDO for RF section
- Brown-out detection + optional 5 V ADC telemetry

2.3 User & Service Interfaces

- USB-C with ESD protection
- Buttons/LEDs: RESET/FACTORY, BIT LED (green), FAULT LED (red)
- **Buzzer (GPIO-controlled, active-high)** for audible UI feedback and alerts
- **Temperature sensor (OneWire DS18B20, GPIO with pull-up)** for monitoring ambient or board temperature
- Optional day/night input (RC + Schmitt + TVS)

2.4 Storage & Identification

- Flash partitioned: bootloader, ota_0, ota_1, nvs (encrypted), keys, coredump
- Device IDs/QR label with Serial, MAC, HW rev, FW rev, Key slot

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3) Cybersecurity & Tamper Hardening

- Secure Boot V2, Flash Encryption, JTAG disabled post-provisioning
- NVS secrets encrypted, factory reset wipes config/keys
- OTA A/B update with rollback, golden image fallback
- Access creds persisted securely in NVS

4) Reliability & Robustness

- All semiconductors derated ≤70% of max stress
- TVS + polyfuse at input; watchdogs always enabled
- Thermal headroom maintained; coredump + safe boot recovery
- ESD/EFT immunity sized for IEC 61000-4-2/-4/-5

5) EMC/Safety Targets

- IEC/EN 62368-1 (safety, SELV)
- CISPR/EN 55032 Class B emissions
- EN 55035 immunity (ESD/EFT/surge)
- IEC 60068-2 environment (–15 °C…+55 °C indoor, humid garage)

6) Firmware Architecture

- FreeRTOS tasks:
  - HTTP/UI + captive portal provisioning
  - ESP-NOW key mgmt + peer registry
  - Sequencer policy & schedule hooks
  - Heartbeat (BIT LED), watchdog kicker
  - Logger (ring buffer to UI/USB)
  - **BuzzerManager** task for audible feedback control
  - **TempSensor task** polling DS18B20 and reporting into monitoring API
- NVS schema versioned and checksummed
- Crash safety: coredump + boot loop detector

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7) Detailed Interface & Pin Budgeting

- Power: 5 V IN terminal → 3.3 V
- USB-C: D+/D-, CC1/CC2, shield to chassis via RC
- LEDs: BIT, FAULT (pins in Config.h)
- Buttons: RESET/FACTORY (pins in Config.h)
- Day/Night IN (GPIO, optional)
- **Buzzer: Pin + polarity stored in Config.h (BUZZER_PIN_KEY, BUZZER_ACTIVE_HIGH_KEY)**
- **Temperature sensor: Pin + pull-up stored in Config.h (TEMP_SENSOR_PIN_KEY, TEMP_SENSOR_PULLUP_KEY)**
- Factory pads: UART/JTAG pads, not populated
- RF: u.FL → SMA whip

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8) Manufacturing Test Plan

- ICT & power rails test
- Bootloader signature check
- USB CDC enumeration
- RF beacon + ESP-NOW self-test
- NVS read/write/erase test (encrypted)
- LED, button, **buzzer tone test**, **temperature sensor readback**
- Secure boot eFuses burned + QR print

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9) Field Diagnostics

- LEDs: BIT blink healthy, FAULT solid error
- **Buzzer patterns**: short beep = success, long beep = failure, repeating = alarm
- USB console: status/log export
- Recovery: Long press factory reset wipes NVS + returns to AP

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10) Pin & Config Management

All pin assignments (LEDs, buttons, buzzer, temperature sensor, UART, SD, etc.) are **centrally defined in Config.h** under hardware mapping keys. This allows field hardware revisions or board spins to re-map I/O via config updates without altering core firmware.

TL;DR

The ICM is still the same secure, long-life, hard-to-kill indoor controller — now enhanced with **audible feedback via a buzzer** and **thermal monitoring via a temperature sensor**, both with their pins configurable in software through