

# Naphome Smart Sleep Device – Phases 0.9, I & II Proposal

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## 1. Overview

**Naphome** is a next-generation smart sleep companion that unites **light, sound, and environmental sensing** to create a restorative bedroom ecosystem. All AI and logic reside in the **cloud**, while an ultra-efficient **ESP32-S3** handles real-time wake-word detection, RGB lighting, audio playback, and sensor telemetry.

The system evolves from **Prototype 0 (Raspberry Pi 5 + WM8960 HAT)** to a **cost-optimized, cloud-connected ESP32-S3 platform** with in-house far-field microphones, stereo sound, and integrated RGB lamp.

### Prototype 0 (P0) – Achievements

**Current Hardware:** Raspberry Pi 5 + WM8960 Audio HAT  
**Status:** Fully functional proof-of-concept with cloud integration

**Implemented Features:** - Voice input/output with WM8960 HAT (mic + speaker)  
- LLM integration (cloud-based conversation processing) - Voice-to-voice capability via ElevenLabs TTS - Addressable LED strip control with dynamic feedback - Temperature & humidity sensor → AWS IoT telemetry - AWS IoT MQTT control (lights, sound, TTS actuation) - IR blaster for AC control (optimal sleep temperature) - Spotifyd integration for music streaming - Access Point mode for device provisioning - User registration flow (first-time setup) - Backend scheduler for routine automation - Python service architecture (auto-start on boot) - OTA-ready architecture

**Transition Goal:** Migrate P0 functionality to ESP32-S3 for cost reduction and mass production.

## 2. System Architecture

Layer	Function
Cloud Layer	Handles speech recognition, LLM processing, TTS (ElevenLabs), user routines, Spotify streaming, and OTA management via AWS IoT Core.
Device MCU (ESP32-S3)	Local wake-word detection, I <sup>2</sup> S audio streaming, RGB lighting control, sensor polling, IR blaster control, and MQTT messaging.
Audio Subsystem	Custom far-field 2–3 mic array → ESP-SR AFE + WakeNet model → TAS5825M DSP amp → stereo ND65 drivers + passive radiators. Premium audio (Nest/Bose class).
Lighting	10–12 × WS2812B addressable RGB LEDs under a frosted diffuser for circadian lighting and visual feedback.
Sensors (7 Total)	SHTC3 (Temp/Humidity), SGP30 or SCD41 (VOC/CO <sub>2</sub> ), VEML7700 (Ambient Light), PIR (Motion), PMS5003 (PM2.5 Air Quality), MEMS Sound Sensor.
Controls	Capacitive touch buttons + rotary encoder (volume knob).
Power	USB-C PD 12 V primary + Li-ion battery backup (2–3 hrs).
Connectivity	Wi-Fi 2.4 GHz, BLE provisioning, secure OTA updates, <b>IR transmitter for IoT control</b> .

## 3. Phase 0.9 – COTS Validation (10–25 Units)

### Purpose

Phase 0.9 bridges the proven Prototype 0 (Raspberry Pi 5) and Phase I (custom

PCB) by validating core functionality using **Commercial Off-The-Shelf (COTS)** ESP32 development boards and Grove sensor modules. This rapid prototype phase allows firmware development, cloud integration testing, and sensor validation without custom PCB investment.

Hardware (All COTS)

- **ESP32-S3 DevKit** (e.g., ESP32-S3-DevKitC-1 or similar) with 8 MB PSRAM
- **Grove Base Shield** or breadboard with Grove connectors
- **Grove Sensors (7 Total):**
  - Grove Temperature & Humidity Sensor (SHTC3 or DHT20)
  - Grove Air Quality Sensor (SGP30 or equivalent)
  - Grove PM2.5 Sensor (PMS5003 compatible)
  - Grove Light Sensor (VEML7700 or TSL2561)
  - Grove PIR Motion Sensor
  - Grove Sound Sensor (MEMS microphone module)
  - Grove CO<sub>2</sub> Sensor (SCD30 or SCD40, optional)
- **Audio:** Generic I<sup>2</sup>S MEMS microphone breakout + MAX98357A I<sup>2</sup>S amp module + small speaker
- **RGB Lighting:** WS2812B LED strip or ring (10–12 LEDs)
- **IR Transmitter:** Grove IR Emitter module or generic IR LED + transistor circuit
- **Power:** USB-C cable (5V) to ESP32 DevKit
- **Controls:** Tactile push buttons or capacitive touch breakout module

Firmware Goals

- Port P0 functionality to ESP-IDF + ESP-ADF
- Local wake-word detection (ESP-SR WakeNet)
- MQTT connection to AWS IoT Core
- Sensor telemetry publishing (temperature, humidity, VOC, PM2.5, light, motion, sound)
- RGB LED control via cloud commands
- IR blaster control for AC/TV (test LIRC or ESP32-IR library)
- OTA firmware updates
- Wi-Fi provisioning (Access Point mode)

Validation Objectives

1. Confirm ESP32-S3 can handle simultaneous I<sup>2</sup>S audio, sensor polling, RGB control, and MQTT
2. Test Grove sensor accuracy and I<sup>2</sup>C/UART communication reliability
3. Validate IR transmitter range and command database
4. Measure power consumption and thermal behavior
5. Finalize firmware architecture before custom PCB design
6. Confirm cloud latency and MQTT message throughput

Estimated BOM (Phase 0.9, per unit)

Component	Part Number	Unit Cost
ESP32-S3 DevKit	ESP32-S3-DevKitC-1	\$10.00
Grove Base Shield or connectors	—	\$8.00
Grove Temp/Humidity Sensor	Grove DHT20	\$4.50
Grove Air Quality Sensor	Grove SGP30	\$12.00
Grove PM2.5 Sensor	Grove PMS5003	\$18.00
Grove Light Sensor	Grove VEML7700	\$4.00
Grove PIR Motion Sensor	—	\$5.00
Grove Sound Sensor	—	\$4.50
I <sup>2</sup> S Microphone Breakout	INMP441 or ICS-43434	\$3.00
I <sup>2</sup> S Amplifier Module	MAX98357A	\$4.00
Speaker	Small 4Ω 3W speaker	\$3.00
WS2812B LED Strip	12 LEDs	\$2.50
Grove IR Emitter	IR LED module	\$3.00
USB-C Cable + Power Supply	5V 2A	\$3.00
Breadboard/Jumper Wires	—	\$5.00
<b>Total COTS BOM</b>		<b>≈ \$89.50 / unit</b>

**Timeline:** 2–4 weeks for assembly, firmware porting, and validation testing.

**Outcome:** A fully functional COTS prototype that validates all Phase I features before committing to custom PCB manufacturing.

4. Phase I – Retrofit Pilot (≈ 200 Units)

Purpose

Phase I aims to validate end-to-end cloud interactions, lighting, sensing, and acoustics by retrofitting 200 existing speaker or lamp units with an **ESP32-S3 retrofit module**. **The donor devices already have built-in speakers and RGB lighting**, which will be integrated with the retrofit control module.

Hardware

- ESP32-S3 WROOM (8 MB PSRAM) on custom 2–4 layer PCB.
- 2–3 digital I²S far-field microphones with custom placement and isolation.
- **Utilizes existing RGB lighting and speakers from donor device** (speaker/lamp units with built-in audio and lighting).
- **7 Sensors:** SHTC3 (Temp/Humidity), SGP30 (VOC/eCO<sub>2</sub>), VEML7700 (Light), PIR (Motion), PMS5003 (PM2.5), MEMS Sound Sensor (no display).
- Capacitive touch buttons + rotary encoder (volume control).
- **IR LED transmitter** for IoT device control (AC, TV, etc.).
- Battery backup: 18650 Li-ion cell (2–3 hrs runtime).
- Powered by USB-C PD (12 V primary).

Firmware

- Built on **ESP-IDF + ESP-ADF + ESP-SR**.
- Local wake-word recognition, cloud-based speech streaming.
- MQTT for routines, telemetry, and RGB control.
- OTA update pipeline with dual partitioning.
- Access Point Wi-Fi setup and persistent credentials.

Pilot Goals

1. Validate far-field mic performance in real bedrooms.
2. Measure latency for cloud-based voice interaction.
3. Evaluate RGB diffusion and ambient brightness.
4. Gather sensor and thermal behavior data.
5. Finalize firmware and network stack for mass production.

Detailed BOM (Phase I – Retrofit Pilot, 200 units)

Electronics & MCU

Component	Part Number	Qty	Unit Cost	Total
ESP32-S3 WROOM-1 (8MB PSRAM)	ESP32-S3-WROOM-1-N8R8	1	\$3.80	\$3.80
USB-C PD Controller	AP33772	1	\$0.85	\$0.85
12V to 5V Buck Converter	TPS54331	1	\$0.62	\$0.62
5V to 3.3V LDO Regulator	AMS1117-3.3	1	\$0.18	\$0.18
USB-C Connector	GCT USB4105-GF-A	1	\$0.45	\$0.45
Power Protection & Caps	Mixed	—	\$1.20	\$1.20
Subtotal: MCU & Power				\$7.10

Audio Subsystem

Component	Part Number	Qty	Unit Cost	Total
Digital I²S MEMS Mic	ICS-43434 or SPH0645LM4H	3	\$1.80	\$5.40
I²S Audio Codec/DAC	ES8388 or PCM5102A	1	\$2.30	\$2.30
Audio Interface Circuitry	Connectors to donor speakers	—	\$1.50	\$1.50
Subtotal: Audio (mics only, uses donor speakers)				\$9.20

Sensors (7 Total)

Component	Part Number	Qty	Unit Cost	Total
Temp/Humidity Sensor	SHTC3 (I²C)	1	\$1.20	\$1.20
Air Quality Sensor (VOC/eCO <sub>2</sub> )	SGP30 (I²C)	1	\$4.50	\$4.50
PM2.5 Air Quality Sensor	PMS5003 (UART)	1	\$9.50	\$9.50
Ambient Light Sensor	VEML7700 (I²C)	1	\$0.85	\$0.85
PIR Motion Sensor	HC-SR501 or EKMC1601111	1	\$1.25	\$1.25
MEMS Sound Level Sensor	INMP441 or similar	1	\$1.80	\$1.80
Sensor PCB Breakouts	Custom	6	\$0.40	\$2.40
<b>Subtotal: Sensors</b>				<b>\$21.50</b>

**IR Transmitter & Controls**

Component	Part Number	Qty	Unit Cost	Total
IR LED Transmitter	940nm IR LED + transistor	1	\$0.50	\$0.50
Capacitive Touch Buttons	TTP223 or similar	3	\$0.30	\$0.90
Rotary Encoder	EC11 or similar	1	\$0.80	\$0.80
Control Interface PCB	Custom 2-layer	1	\$1.20	\$1.20
<b>Subtotal: IR &amp; Controls</b>				<b>\$3.40</b>

**Note:** RGB lighting uses donor device’s existing LEDs with control interface from retrofit module.

**PCB & Assembly**

Item	Details	Qty	Unit Cost	Total
Main Control PCB	4-layer, FR4, 100×80mm	1	\$3.20	\$3.20
PCB Assembly (SMT)	Stencil + pick-and-place + reflow	1	\$4.50	\$4.50
Testing & Programming	Flash firmware + functional test	1	\$2.00	\$2.00
Connectors & Wiring	JST, headers, wires	—	\$1.80	\$1.80
<b>Subtotal: PCB &amp; Assembly</b>				<b>\$11.50</b>

**Housing & Mechanical (Retrofit)**

Component	Details	Qty	Unit Cost	Total
Donor Speaker/Lamp Unit	Refurbished or surplus units	1	\$28.00	\$28.00
Custom Mounting Bracket	3D-printed or CNC	1	\$3.50	\$3.50
Acoustic Foam/Damping	Isolate mics and speakers	—	\$2.20	\$2.20
Fasteners & Adhesives	Screws, tape, glue	—	\$1.30	\$1.30
<b>Subtotal: Housing &amp; Mechanical</b>				<b>\$35.00</b>

**Phase I Total BOM**

Category	Cost
MCU & Power	\$7.10
Audio Subsystem (mics only)	\$9.20
Sensors (7 total)	\$21.50
IR Transmitter & Controls	\$3.40
PCB & Assembly	\$11.50
Housing & Mechanical (retrofit)	\$35.00
<b>Grand Total (Phase I)</b>	<b>\$87.70 / unit</b>
<b>Packaging &amp; Shipping</b>	<b>\$8.00</b>
<b>Final Landed Cost</b>	<b>\$95.70 / unit</b>

**Note:** Cost savings from using donor device speakers and RGB lighting (~\$27.50 per unit).

## 5. Phase II – Full Production (10,000 Units)

### Objectives

- Transition to **fully custom housing and board**.
- Integrate **in-house far-field mic array** and RGB light dome.
- Achieve **\$40 BOM (base)**, **\$55 BOM (premium)**.
- Establish scalable manufacturing and QA pipeline.

### Hardware Design

- ESP32-S3 + TAS5825M on single 4-layer PCB.
- Integrated microphone array with acoustic isolation geometry.
- ND65 stereo drivers + passive radiators in dual acoustic chambers.
- 10–12 WS2812B LEDs with internal diffuser and light pipe integration.
- Molded PC/ABS shell with sensor and mic apertures.

### Firmware Enhancements

- Optimized AEC and beamforming (ESP-SR AFE).
- MQTT connection resilience and watchdog.
- Adaptive LED states (sleep, wake, alert).
- Local cache for routines to operate if offline.
- Secure OTA with fail-safe rollback.

### BOM (10k Volume)

Subsystem	Est. Cost (USD)
ESP32-S3 MCU	3.10
TAS5825M Amp	3.30
ND65 Speakers + PRs	15.00
Sensors (SHTC3 + SGP30 + VEML7700 + PIR)	4.00
RGB LED Ring + Diffuser	4.10
Power / USB-C PD	1.50
PCB + Assembly	4.20
Enclosure + Hardware	2.60
Misc / EMI	0.90
<b>Total (Base SKU)</b>	<b>≈ \$40.0</b>
<b>Premium (ND90 + CO<sub>2</sub> sensor)</b>	<b>≈ \$55–58</b>

## 6. Manufacturing Partners

All partners listed below are capable of end-to-end turnkey manufacturing (PCB sourcing → PCBA → speaker/LED assembly → plastic housing → final QA → packaging).

### 1. Zhuhai DB-Way Technology Co., Ltd.

**Capabilities:** Full turnkey manufacturing including PCBA, audio integration, RGB assembly, plastic housing, and end-of-line testing.

**Specialization:** EMS with IoT device experience.

**Relevant Product:** Wake-up Light Alarm Clock with FM Radio Speaker - Bedside lamp with RGB lighting, touch control, USB rechargeable. Demonstrates capability in audio + lighting integration.



DB-Way Wake-up Light Alarm Clock

### 2. Shanghai Kaiji Lighting Technology Co., Ltd.

**Capabilities:** Full turnkey manufacturing with enhanced RGB lighting and diffuser expertise.

**Specialization:** Smart lighting products; in-house optical design and light pipe molding.

**Relevant Product:** Bluetooth Speaker with RGB Dynamic Lighting - Portable bedside table lamp with RGB atmosphere lighting, Bluetooth speaker,

rechargeable. Shows expertise in RGB lighting + audio integration (10k units @ \$8.29).

Kaiji RGB Bluetooth Speaker Lamp

3. Shenzhen Xiteyou Electronic Technology Co., Ltd.

**Capabilities:** Full turnkey manufacturing with strong component sourcing network.  
**Specialization:** Consumer electronics; competitive pricing on sensors, mics, and ICs.  
**Relevant Product:** Smart Sleep Monitor with 32 Soothing Sounds - Rechargeable nightlight with RGB lighting (7 colors), Bluetooth speaker, white noise machine (105×105×150mm, 8-10hr battery, \$19.99 retail). Lead time: 15-35 days for 100-1800 units. Demonstrates strong cost optimization and experience with sleep/audio devices.

Xiteyou Smart Sleep Monitor

4. Dongguan Compro Electronic Technology Co., Ltd.

**Website:** [www.comproelec.com](http://www.comproelec.com)  
**Capabilities:** Full OEM/ODM turnkey manufacturing with certification support.  
**Specialization:** Smart speakers and IoT audio devices; established supply chain for acoustic components.

7. NRE and Certification

Item	Cost (USD)
Enclosure Tooling (2-cavity mold + diffuser dome)	18,000
Test Fixtures / QA Jigs	6,000
Compliance Testing & DoC (using pre-certified ESP32 module)	2,500
Engineering Samples & Validation	4,000
Total NRE	≈ \$30,500 (≈ \$3.05/unit @ 10k)

**Note:** Using pre-certified ESP32-S3-WROOM-1 module eliminates the need for full FCC/CE certification. Only Declaration of Conformity (DoC) and basic compliance testing required.

8. Timeline

Phase	Duration	Key Deliverables
Phase 0.9 (COTS Validation)	2–4 weeks	ESP32-S3 DevKit + Grove sensors, firmware porting (ESP-IDF + ESP-IDF), MQTT + AWS IoT integration, sensor validation
Phase I (Retrofit Pilot)	12–16 weeks	Custom PCB design, 200 retrofit units, far-field mic array, sensor integration, IR blaster validation
EVT (Engineering Validation)	8 weeks	PCB Rev A + mic validation + RGB firmware demo
DVT (Design Validation)	6 weeks	Mold T0 samples + acoustic tuning + sensor calibration
PVT (Production Validation)	4 weeks	300–500 unit pilot run + certification testing
MP (Mass Production)	3–4 months	10k units + QA inspection

9. SKU Summary

SKU	Audio	Sensors	Lighting	BOM	MSRP
<b>Base</b>	ND65 + PR	SHTC3 + SGP30 + PIR + VEML7700	10 × WS2812B	\$40	\$129
<b>Premium</b>	ND90 + PR	SHTC3 + SGP30 + SCD41 + PIR + VEML7700	16 × WS2812B + enhanced diffuser	\$55–58	\$199

## 10. Advantages

- **ESP32-S3 Efficiency:** Simultaneous I<sup>2</sup>S, Wi-Fi, LED, and sensor processing.
- **Cloud Architecture:** Offloads heavy LLM/TTS for low-cost hardware.
- **Custom Mic Array:** In-house beamforming and AEC tuning for wake accuracy.
- **Dynamic RGB Lighting:** Circadian lighting and responsive visual feedback.
- **Flexible Vendor Network:** Five capable partners for risk-mitigated scaling.

## 11. Consulting & Development Services

### Technical Leadership Retainer

**Daniel McShane** – Hardware/Firmware Development Lead

**Scope of Services:** - Phase 0.9 COTS prototype development and firmware porting (ESP-IDF + ESP-ADF) - Phase I custom PCB design, schematic review, and component selection - ESP32-S3 firmware architecture (wake-word detection, MQTT, OTA, sensor integration) - Cloud integration and AWS IoT Core configuration - Manufacturer liaison and technical specifications documentation - Acoustic design consultation and microphone array optimization - IR transmitter implementation and device control database - Quality assurance planning and test fixture specifications

**Rate:** \$1,000 per week retainer

**Estimated Duration:**

- Phase 0.9: 4–6 weeks
- Phase I: 12–16 weeks
- Phase II: Ongoing support (as needed)

**Total Estimated Consulting (Phase 0.9 + Phase I):** \$16,000 – \$22,000

## 12. Next Steps

1. **Phase 0.9:** Procure COTS ESP32-S3 DevKit and Grove sensors, begin firmware porting (2–4 weeks).
2. Finalize Phase I PCB design (ESP32-S3 + mic array + sensor integration).
3. Send RFQs and NDAs to DB-Way, Kaiji, Xiteyou, Yingke, and Compro.
4. Build 25–50 COTS validation units for firmware and cloud integration testing.
5. Transition to custom PCB pilot (200 units) for acoustic and thermal validation.
6. Lock enclosure design and begin tooling for Phase II mass production.
7. Conduct PVT (500 units) and transition to 10k MP.

### Result:

A scalable, cloud-connected smart sleep device with a **\$40 BOM**, full RGB lighting, custom audio design, and multi-partner manufacturing capability — ready for global deployment.