FOR EVALUATION DOC TORUS-SN-DS-001 REV 2026-07 PacketFive

TORUS FACILITY SENSING • GROUND SENSOR NODE

TORUS-SN

Multi-modal wireless facility security sensor node with seismic • acoustic • LoRa 433 MHz • GNSS

PRELIMINARY

TORUS-SN-DS-001

1 Description

TORUS-SN is a battery-operated, multi-modal wireless facility security sensor node for AI/HPC data center perimeters and data hall approaches. It detects ground vibration through an external 4.5 Hz geophone, captures stereo audio through a MEMS microphone pair, and reports events to a TORUS-MEG gateway over 433 MHz LoRa (EU ISM). A Semtech LR1110 additionally provides multi-constellation GNSS scanning and passive Wi-Fi-AP scanning for low-power geolocation.

A hardware wake-on-seismic path (a comparator on the analog front-end output) wakes the system from deep sleep without CPU involvement. Each sensing subsystem is gated by its own load switch. The node runs single-cell Li-ion operation with onboard USB-C charging.

- **ESP32-S3-WROOM-1** host MCU with dual-core Xtensa LX7, Wi-Fi 2.4 GHz, BLE 5, vector extensions for on-device ML
- **LR1110** transceiver with LoRa sub-GHz, GNSS (GPS/BeiDou) scan, passive Wi-Fi scan; 32 MHz TCXO reference
- **Seismic channel**: OPA2134 AFE, MCP4017 (100 kΩ, I2C) digital gain, LM393 wake comparator
- **Acoustic channel**: 2× INMP441 24-bit I2S MEMS microphones (stereo)
- **DS3231SN RTC**: ±2 ppm TCXO, CR1220 backup, 32 kHz output to LR1110
- **Power**: TP4056 1 A Li-ion charger (USB-C), AMS1117-3.3 LDO, 3× TPS22918 load switches, VBAT ADC monitor
- **80 × 55 mm**, 4-layer, 4× M2.5 mounting holes

2 Block diagram

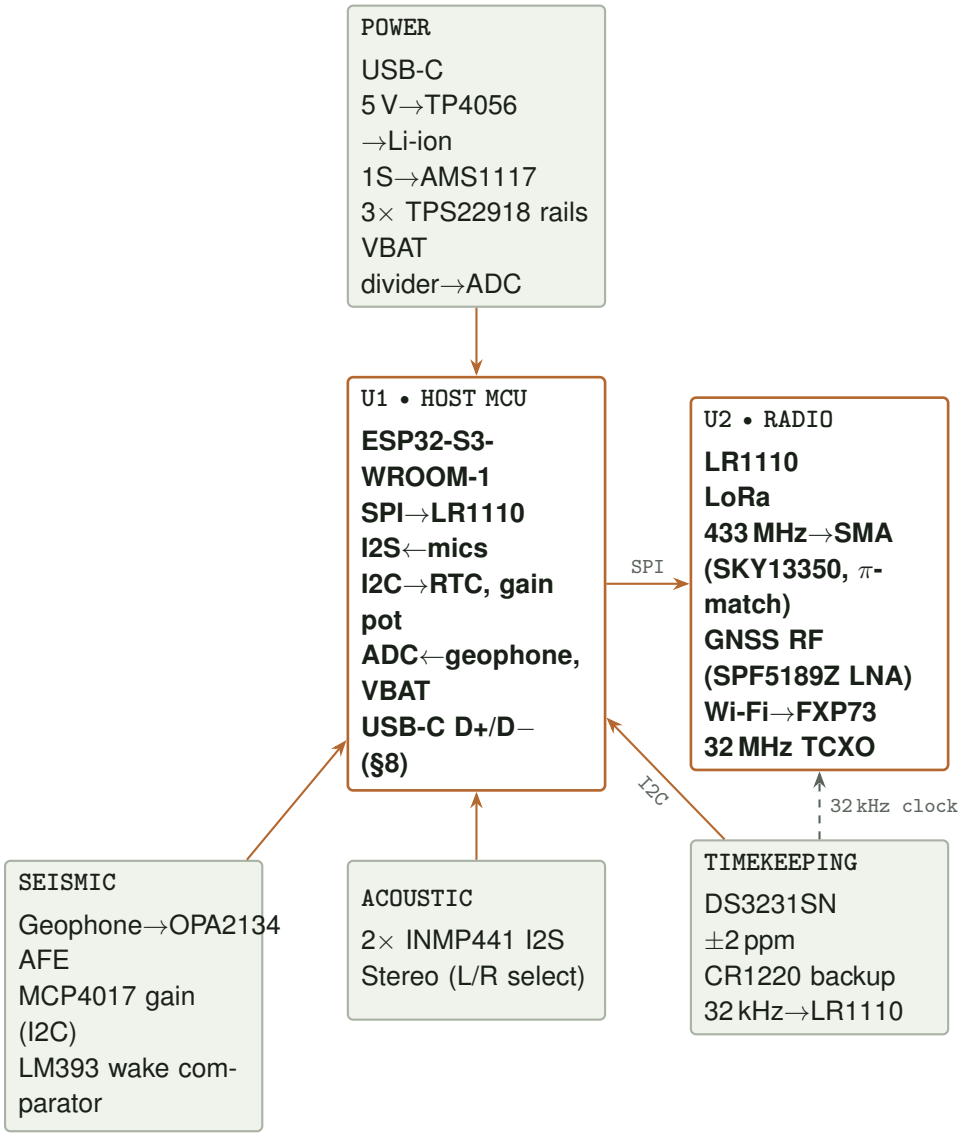

Figure 1: TORUS-SN subsystem block diagram.

3 System summary

Subsystem	Ref	Device	Detail
Host MCU	U1	ESP32-S3-WROOM-1	Dual-core Xtensa LX7, Wi-Fi 2.4 GHz + BLE 5; module substituted for spec'd ESP32-S3-MINI-1 (see §8)
LoRa / GNSS / Wi-Fi-scan	U2	Semtech LR1110 (QFN32)	LoRa 433 MHz uplink, GNSS + Wi-Fi-AP scan geolocation; 32 MHz TCXO (X1) mandatory for GNSS

Subsystem	Ref	Device	Detail
Seismic AFE	U3, U4	OPA2134 + MCP4017-104	Low-noise dual op-amp; 100 kΩ 7-bit I2C digital potentiometer for gain
Wake comparator	U11	LM393	Hardware wake-on-seismic against a set threshold
Microphones	MK1, MK2	2× InvenSense INMP441	24-bit I2S MEMS, omnidirectional, wired as stereo pair
RTC	U5	DS3231SN	±2 ppm TCXO RTC, I2C; CR1220 backup (BT1); 32 kHz out feeds LR1110
Battery charger	U7	TP4056	Single-cell Li-ion, charge current set to 1 A (R17 = 1.2 kΩ); CHRG/STDBY LEDs
Regulator	U6	AMS1117-3.3	3.3 V LDO, 1 A max
Load switches	U8-U10	3× TPS22918	Independent gating of seismic, acoustic, and LR1110 rails
RF front end	SW1, SW2, U_LNA	2× SKY13350 + SPF5189Z	TX/RX switching for the 433 MHz path; LNA on the GNSS path

4 Connectors and indicators

Ref	Type	Function
J1	USB-C receptacle	5 V charge input; USB data to MCU (see §8 note on GPIO mapping)
J2	SMA edge-mount	433 MHz LoRa antenna
J3	JST-PH 2-pin	Single-cell Li-ion battery
J4	Phoenix 3.5 mm terminal, 3-pos	External geophone (R.T. Clark 4.5 Hz 375 Ω vertical, or equivalent)
J5	Tag-Connect TC2030 (DNP)	JTAG / programming
ANT1	FXP73 chip antenna land	Wi-Fi-scan RF (LR1110 HF path)
BT1	CR1220 holder	RTC backup cell
D1 / D2	LED red / green	Charge status (TP4056 CHRG / STDBY)

5 Electrical characteristics

Parameter	Min	Typ	Max	Unit	Notes
Battery input (VBAT)	3.0	3.7	4.2	V	1S Li-ion, J3
USB input (VBUS)	n/a	5.0	n/a	V	J1
Main rail (VCC_3V3)	n/a	3.3	n/a	V	AMS1117, 1 A max
Charge current	n/a	1.0	n/a	A	TP4056, R17 = 1.2 kΩ
Deep-sleep current		TBD		μA	Pending board bring-up; see §8 note 7
Active TX current		TBD		mA	Pending characterization

Values on unbuilt hardware are design values, not measurements. This document describes a pre-production design that has not yet been fabricated.

6 Physical

Parameter	Value
Board dimensions	80.0 × 55.0 mm, 3.0 mm corner radius
Stack-up	4-layer with signal / GND plane (In1) / 3V3 plane (In2) / signal, GND fill front & back
Mounting	4× M2.5 (2.7 mm holes), 73 × 48 mm pattern
Antenna provisions	SMA (433 MHz), FXP73 land (Wi-Fi scan), GNSS antenna path; pour keepouts under all antennas

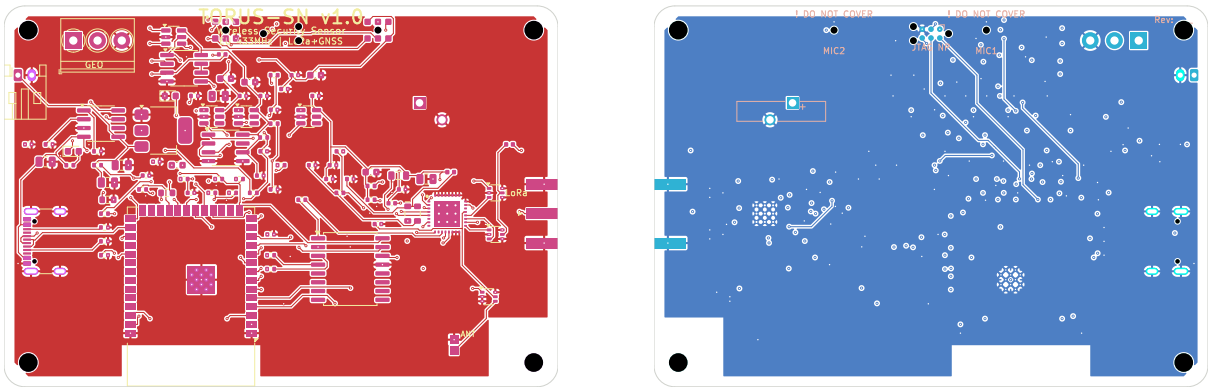

Figure 2: TORUS-SN board render, top and bottom copper (generated from the production gerbers by the `hw/` KiCad 10 pipeline).

7 Firmware and toolchain

The node runs Zephyr RTOS. Hardware design data is fully generated from a single Python source of truth (`torus_design.py`, 91 parts / 68 nets) emits the KiCad 10 schematic and PCB, with autorouting via Freerouting. Schematic ERC is clean, and netlist parity between schematic and layout holds by construction.

8 Design notes and open flags

Engineering flags to verify before fabrication

1. **Module substitution** - spec names ESP32-S3-MINI-1-N8; the larger ESP32-S3-WROOM-1 is fitted (no library footprint existed for the MINI-1).
2. **USB pins** - the design maps USB D−/D+ to GPIO35/36, but the ESP32-S3 native USB PHY is fixed to GPIO19/20. USB programming requires GPIO19/20 or an added USB-UART bridge.
3. **U4 MCP4017** SOT-23-6 pin order is assumed; verify against the datasheet before fab.
4. **SW1/SW2 SKY13350** SC-70-6 pin order; verify before fab.
5. **U_LNA SPF5189Z** SOT-363 pin order; verify before fab.
6. **LR1110 footprint** pad geometry derives from the spec; cross-check the production LR1110 pad map before fab.
7. **Sleep-current budget** - the AMS1117 linear regulator's quiescent current is high relative to μA-class sleep targets; review regulator choice if deep-sleep battery life is critical.