# Jumbo Shoo Project

## LoRa Airtime Calculator - Reference Document

Tool version v2.2 · Sections 1–13 · February 2026

# 1. Project Background - The Jumbo Shoo Sensor Network

Human-elephant conflict (HEC) is one of the most acute conservation and agricultural challenges across sub-Saharan Africa and South Asia. Elephants can destroy an entire season's crop in a single night, with devastating consequences for smallholder farmers. Lethal retaliatory measures, while deeply undesirable, are a frequent response when other deterrents fail.

The Jumbo Shoo project is developing a low-cost, solar-powered seismic detection network that alerts communities before elephants reach field boundaries. The system detects elephant footfall through ground vibration, giving herders enough time to deploy non-lethal deterrents such as acoustic alarms and lights.

## System Architecture

Each deployment consists of three hardware layers:

- Sensor nodes - buried or surface-mounted geophones that convert ground vibration into an electrical signal. The signal is sampled by a microcontroller that applies threshold detection and packages events for transmission.
- Brain module - a Raspberry Pi co-located with a LoRa transceiver (RFM95W). Receives LoRa packets from sensor nodes, processes data, and triggers alerts. One brain can serve multiple sensor nodes.
- LoRa radio link - the wireless communication layer connecting each sensor node to the brain. This is a simple point-to-point (P2P) link, not a LoRaWAN gateway infrastructure.

The LoRa link is the design-constrained element: it must carry detection events with the lowest possible latency while remaining within regulatory duty-cycle limits and the battery budget of a small solar-charged cell. The airtime calculator tool exists to navigate these trade-offs.

## Why Geophones?

A geophone is a passive electromagnetic sensor - a coil suspended inside a permanent magnet. Ground motion causes the coil to move relative to the magnet, generating a voltage proportional to velocity. Geophones require no external power to sense (only to process), are robust against dust and moisture, and produce a clean signal in the 1–100 Hz band where elephant footfall energy is concentrated. For mechanical engineering students: think of it as a voice-coil actuator run in reverse.

> **Engineering connection:** The geophone operates on Faraday's Law ($EMF = -d\Phi/dt$). The detection algorithm is a threshold comparator applied to the envelope of the rectified geophone output - conceptually identical to the peak-detector circuits covered in first-year electronics.

# 2. Why LoRa - Technology Primer

LoRa (Long Range) is a proprietary spread-spectrum modulation technique developed by Semtech. It uses Chirp Spread Spectrum (CSS), where data is encoded as linear frequency sweeps (chirps) across a defined bandwidth. This gives LoRa exceptional noise immunity: it can recover signals 20 dB below the noise floor, enabling multi-kilometer range at milliwatt power levels.

Critically for Jumbo Shoo, LoRa does not require any network infrastructure - two transceivers can communicate directly. There is no SIM card, no cellular subscription, no gateway fee. This makes it appropriate for remote African bush deployments where cellular coverage is absent.

## Technology Comparison

| Technology | Range | Power | Data Rate | Cost | Infrastructure |
|---|---|---|---|---|---|
| **LoRa P2P** | 1–15 km | Very low | 0.3–50 kbps | Low (~$5) | None |
| Cellular (4G) | Everywhere | High | 10–100 Mbps | High + SIM | Tower needed |
| WiFi | <100 m | Medium | 10–600 Mbps | Low | AP needed |
| Zigbee/BLE | <50 m | Very low | 0.25–2 Mbps | Low | Coordinator |

## Key Radio Parameters - What the Tool Configures

LoRa performance is determined by five radio parameters. Every parameter is a trade-off, and the tool makes these trade-offs visible:

| Parameter | Range | Effect on ToA | Effect on Range |
|---|---|---|---|
| **SF (Spreading Factor)** | 6–12 | 2× per SF step | ~5 dB link margin gain per step up |
| **BW (Bandwidth)** | 125/250/500 kHz | ÷2 when BW halved | Lower BW = better sensitivity (–3 dB per halving) |
| **CR (Coding Rate)** | 4/5 to 4/8 | Up to 60% longer | Higher CR = more FEC, better range in interference |
| **TX Power** | 2–20 dBm | None (airtime fixed) | Linear in mW; log in dBm; very range-limited above ~17 dBm |
| **Payload length** | 1–255 bytes | Linear approx. | No direct effect |

**LoRa vs LoRaWAN:** Jumbo Shoo uses LoRa P2P - direct radio-to-radio communication with no network stack. LoRaWAN is a network protocol layer built on top of LoRa that routes packets through gateways to cloud servers. The airtime formula and duty-cycle rules are the same either way, but Jumbo Shoo has no gateway, no server, and no subscription.

# 3. Tool Overview

The Jumbo Shoo LoRa Airtime Calculator is a single-sensor design tool. It computes Time on Air (ToA) from first principles, checks regulatory compliance for EU 868 MHz and US 915 MHz bands, estimates energy per transmission and battery life, and flags configuration errors in real time. It does not perform link budget calculations - that requires antenna gain, path loss, and terrain data beyond the tool's scope.

## Two Versions

| | |
|---|---|
| **Excel workbook (.xlsx)** | Six-tab workbook with formula-driven orange cells, dropdown validation, conditional formatting, and color-coded Section G warnings. Primary tool for design work. Open in Microsoft Excel or LibreOffice Calc. |
| **React web app (.jsx)** | Browser-based interactive version. All dropdowns and toggles update results in real time. Identical formulas to the spreadsheet. Useful for live classroom demonstrations.<br><br>Note: The React app includes a **Configuration Optimizer** feature (Section 8, Demo 7) **not present in the Excel workbook**. The optimizer iterates all SF, BW, CR, TX power, and EU sub-band combinations for a given payload and region, returning the top 5 compliant configurations sorted by re-arm time (EU) or ToA (US), with energy as the tiebreaker. The Excel workbook remains the primary structured reference for formula derivation and manual exploration.<br><br>Available at https://jumboshoo-loracalc.vercel.app/ |
| **Formula equivalence** | Both versions use the same ToA formula, energy formula, and regulatory checks. A value from one will match the other for identical inputs. |
| **Scope** | Single sensor node ↔ brain link. For multi-sensor arrays, see Section 11 - additional considerations apply (CAD backoff, channel staggering, capture effect). |

## Excel Workbook Tab Structure

| Tab | Name | Contents |
|---|---|---|
| 1 | **Calculator** | Main design interface. Seven sections A–G: radio parameters, TX settings, calculated results, energy/battery, EU compliance, re-arm reference, configuration warnings. |
| 2 | **Presets** | Factory default profiles for the four Jumbo Shoo packet types. Edit here to permanently change preset defaults. |
| 3 | **Profiles** | Engineering notes on each packet type, including CAD backoff timing for multi-sensor arrays and channel staggering guidance for EU g3. |
| 4 | **Lookup** | TX power → current map (RFM95W Table 5 data + interpolated values) and EU 868 MHz sub-band duty-cycle reference. Drives Calculator formulas via VLOOKUP. |
| 5 | **References** | Cited sources with annotation: Semtech AN1200.13, ETSI EN 300 220, FCC §15.247, HopeRF RFM95W datasheet, Hoang et al. 2020. |
| 6 | **Info** | Purpose, scope, version history (v2.0 → v2.2), and usage notes. |

# 4. Calculator Tab - Section-by-Section Walkthrough

The Calculator tab is divided into seven lettered sections (A–G). Orange cells are formula-driven by the preset selector (C4) and region selector (F6). Typing directly into an orange cell permanently overwrites its formula for that session - use Ctrl+Z to undo or re-select the preset to attempt recovery.

## Section A - LoRa Radio Parameters (inputs)

| Cell | Parameter | Options | Notes |
|---|---|---|---|
| **C4** | Active Preset | Dropdown | Loads all orange cells. Sensor Heartbeat / Status Report / Detection Event / Alive Ping / Custom. |
| **C6** | SF | 6, 7, 8, 9, 10, 11, 12 | Spreading Factor. Each step doubles ToA. SF6 requires implicit header - see W8. |
| **C7** | BW (kHz) | 125 / 250 / 500 | Bandwidth. Halving BW doubles ToA but improves sensitivity by ~3 dB. |
| **C8** | CR | 5 / 6 / 7 / 8 | Coding rate denominator (4/5 to 4/8). Higher = more error correction, more overhead. |
| **C9** | Preamble symbols | Integer ≥ 8 | LoRaWAN minimum is 8. Section G W7 flags values below 8. |
| **C10** | Payload (bytes) | 1–255 | Packet payload excluding LoRa overhead. See Section 5 for Jumbo Shoo packet sizes. |
| **C11** | CRC | 0 = off / 1 = on | Cyclic Redundancy Check. Leave on (1) unless explicitly testing without. |
| **C12** | Explicit Header | 0 = off / 1 = on | Must be 0 (off) when SF=6. Formula forces implicit header at SF6 regardless. |
| **C13** | LDRO Required? | Auto-calculated | 1 if Tsym > 16 ms. At SF12/BW125, Tsym = 32.768 ms → LDRO auto-on. |
| **C14** | LDRO Manual | 0 / 1 | Allow manual LDRO override when not auto required. Rarely needed. |
| **C15** | LDRO Effective | Auto-calculated | =IF(C13=1,1,C14). This is the value used in the ToA formula denominator. |

## Section B - Transmission Settings (inputs)

| Cell | Parameter | Options | Notes |
|---|---|---|---|
| **F6** | Region | 1 = EU / 2 = US | Switches compliance engine between EU duty cycle (Section E) and US dwell time check. |
| **F7** | EU Sub-band | g / g1 / g2 / g3 | EU only. Determines duty cycle limit and valid BW range. See Section 7 for full sub-band table. |
| **C16** | TX Power (dBm) | 2/5/8/11/14/17/20 | Orange - driven by preset and region. EU max is 14 dBm; US allows up to 20 dBm. |
| **C17** | Voltage (V) | Typically, 3.7 | Used for energy and battery life calculations. 3.7 V = nominal LiPo. |
| **C19** | TX Interval (min) | Any positive number | Used for duty-cycle % calculation and battery life estimate. |
| **C20** | Battery (mAh) | Any positive number | TX-only battery life estimate only. Does not include MCU, sensors, or standby current. |

## Section C - Calculated Results (outputs)

| Cell | Output | Description |
|---|---|---|
| **E21** | **Symbol Duration (Tsym)** | Time per chirp symbol in ms. Tsym = 2^SF / BW. Doubles with each SF increment. Determines LDRO. |
| **E22** | **Payload Symbols** | Number of symbols in the payload portion. See Section 6 for the full formula. |
| **E23** | **Preamble Duration** | Tsym × (preamble + 4.25) ms. |
| **E24** | **Time on Air (ToA)** | Total airtime in ms. The primary design output. Used by all compliance and energy calculations. |
| **E25** | **Nominal Bit Rate** | Informational. SF × BW / 2^SF bps - useful for comparing configurations. |

## Sections D, E, F, G - Energy, Compliance, Re-arm, Warnings

Section D (Energy per TX): Uses TX current from the Lookup tab (VLOOKUP on C16) multiplied by voltage and ToA to give energy in mJ and charge in µAh per transmission. Battery life is a TX-only estimate - divide remaining capacity by daily charge draw.

Section E (Regulatory Compliance): EU region shows duty cycle consumed per transmission and per hour at the configured TX interval, compared against the sub-band limit. US region shows a dwell time check - ToA must not exceed 400 ms per FCC §15.247.

Section F (Re-arm Reference): Minimum time between transmissions to satisfy duty cycle. Computed as ToA ÷ duty-cycle fraction. For EU g3 (10%): re-arm = ToA × 10. This determines how quickly a sensor can legally transmit a second detection event.

Section G (Configuration Warnings): Eight live-updating indicators. Green ✓ = clear. Amber ⚠ = caution. Red ✗ = violation.

| W# | Warning | Level | Condition |
|---|---|---|---|
| **W1** | **BW500 + EU g3** | ✗ Violation | BW 500 kHz selected with EU sub-band g3. g3 is only 250 kHz wide - BW500 cannot physically fit. |
| **W2** | **BW250 + EU g3** | ⚠ Caution | BW 250 kHz on g3 is marginal - leaves no guard band. BW125 strongly preferred. |
| **W3** | **TX Power > 14 dBm (EU)** | ✗ Violation | EU EIRP limit is 25 mW (+14 dBm) on sub-bands g, g1, g3. |
| **W4** | **TX Power = 20 dBm** | ⚠ Caution | RFM95W hardware duty-cycle limited to 1% max at +20 dBm (Table 33, DC_20dBm). Continuous operation rated to +17 dBm. |
| **W5** | **US Dwell Time** | ✗ Violation | ToA exceeds 400 ms FCC §15.247 dwell limit (US region only). |
| **W6** | **EU g2 sub-band** | ⚠ Caution | g2 duty cycle is 0.1% - 10× more restrictive than g/g1. Avoid for regular sensor TX. |
| **W7** | **Preamble < 8 symbols** | ⚠ Caution | LoRaWAN specifies 8 as minimum. Below 8 risks sync failure, especially at range. |
| **W8** | **SF6 + Explicit Header** | ✗ Violation | SF6 requires implicit header mode on SX1276/RFM95W. Set Explicit Header to 0 (off). |

# 5. The Four Sensor Profiles

Jumbo Shoo defines four packet types, each with a fixed payload size and a corresponding preset in the calculator. Understanding their sizes and trade-offs is essential for choosing the right SF for each use case. These packet types are still being designed; therefore, the payload sizes and metadata are estimates are subject to change.

## Packet Type Summary

| Packet Type | Payload | Type ID | SF Default | Primary Content | Interval |
|---|---|---|---|---|---|
| **Sensor Heartbeat** | 12 B | 0x01 | SF12 | Node alive · battery voltage · temperature | 60 min |
| **Status Report** | 24 B | 0x02 | SF12 | RPi diagnostics · sensor health · GPS timestamp | On demand |
| **Detection Event** | 8 B | 0x03 | SF12 | Node ID · timestamp · confidence score | On trigger |
| **Alive Ping** | 6 B | 0x04 | SF12 | Minimal keepalive - no health metrics | 15 min |

## Detection Event - The Critical Path

The Detection Event is the packet that matters most for system performance. It must be transmitted as quickly as possible after a seismic threshold crossing so that the alert system can respond before elephants arrive at field boundaries. Every millisecond of ToA is a millisecond of latency and a millisecond of radio channel occupancy.

The table below shows ToA and g3 re-arm time for the 8-byte Detection Event across all spreading factors, at BW125/CR4:6/preamble 8. SF6 uses implicit header (H=1) as required by the SX1276 hardware. Production recommendation is SF7.

| SF | Tsym (ms) | ToA (ms) | g3 Re-arm (s) | Energy @14 dBm | Header | Notes |
|---|---|---|---|---|---|---|
| 6 | 0.512 | 19.6 | 0.196 | 2.2 mJ | Implicit | 2× faster than SF7. Requires H=0, sync word 0x65, ~5 dB less margin. Testing only. |
| **7** | 1.024 | **39.2** | 0.392 | 4.5 mJ | Explicit | ✓ Recommended production SF. Best balance of speed and link margin. |
| 8 | 2.048 | 78.3 | 0.783 | 9.0 mJ | Explicit | 2× slower than SF7. |
| 9 | 4.096 | 132.1 | 1.321 | 15.2 mJ | Explicit | Use if SF7 link fails at deployment range. |
| 10 | 8.192 | 264.2 | 2.642 | 30.3 mJ | Explicit | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | 16.384 | 528.4 | 5.284 | 60.6 mJ | Explicit | LDRO auto-on (Tsym > 16 ms). |
| 12 | 32.768 | 1056.8 | 10.57 | 121.2 mJ | Explicit | Default preset value. LDRO on. 27× slower than SF7. |

**Production recommendation:** SF7 / BW125 / CR4:6 / 8 bytes / EU g3 / 14 dBm. ToA = 39.2 ms, g3 re-arm = 392 ms, energy = 4.5 mJ per event. SF6 (ToA 19.6 ms) is available in the tool but should only be used if field testing confirms the link margin penalty is acceptable at the deployment geometry.

# 6. The Airtime Formula - Derivation and Worked Example

Time on Air (ToA) is the sum of preamble duration and payload duration. Both are multiples of the symbol period (Tsym). The formula is from Semtech Application Note AN1200.13 (LoRa Modem Designer's Guide).

## Symbol Duration

```
Tsym = 2^SF / BW       (result in ms when BW is in kHz)
```

At SF12 / BW125 kHz: Tsym = 4096 / 125,000 = 32.768 ms. At SF7 / BW125: Tsym = 128 / 125,000 = 1.024 ms. Every SF increment doubles Tsym and therefore doubles total ToA.

Low Data Rate Optimization (LDRO) is automatically enabled when Tsym > 16 ms. It adjusts the symbol encoding to improve tolerance of frequency drift. In the formula, LDRO changes the denominator of the payload symbol count calculation. The tool computes LDRO automatically in C13.

## Preamble Duration

```
T_preamble = (preamble_symbols + 4.25) × Tsym
```

The 4.25 is a fixed overhead for the sync word and start-of-frame delimiter, always present regardless of the preamble setting.

## Payload Symbol Count

```
N_sym = 8 + max( ceil( (8·PL − 4·SF + 28 + 16·CRC − 20·H) / (4·(SF − 2·DE)) ) ×
(CR+4),  0)
```

Where: PL = payload bytes · SF = spreading factor · CRC = 1 if CRC enabled, 0 if not · H = 1 if implicit header (no header), 0 if explicit header · DE = 1 if LDRO active, 0 if not · CR = coding rate index (1 for 4/5 through 4 for 4/8).

SF6 note: The SX1276 does not support explicit header mode at SF6. When SF=6, H is forced to 1 (implicit header) in both the Excel formula and the React calculation, regardless of the explicit header setting. This reduces overhead but requires the payload length to be known by the receiver in advance.

## Worked Example - Detection Event, SF12 vs SF7

Packet: 8-byte payload · BW125 kHz · CR4:6 (CR=2) · preamble 8 · CRC on · explicit header (SF7) / implicit forced at SF12 not applicable here - both SF7 and SF12 use explicit header for 8B.

| Step | SF 12 | SF 7 |
|---|---|---|
| **Tsym** | 2^12 / 125,000 = 32.768 ms | 2^7 / 125,000 = 1.024 ms |
| **LDRO (DE)** | Tsym 32.768 > 16 ms → DE = 1 | Tsym 1.024 < 16 ms → DE = 0 |
| **Numerator** | 8×8 − 4×12 + 28 + 16×1 − 20×0 = 60 | 8×8 − 4×7 + 28 + 16×1 − 20×0 = 80 |
| **Denominator** | 4×(12 − 2×1) = 40 | 4×(7 − 2×0) = 28 |

| | | |
|---|---|---|
| **Payload symbols** | 8 + ceil(60/40)×(2+4) = 8+2×6 = 20 | 8 + ceil(80/28)×(2+4) = 8+3×6 = 26 |
| **T_preamble** | (8+4.25)×32.768 = 401.4 ms | (8+4.25)×1.024 = 12.5 ms |
| **T_payload** | 20 × 32.768 = 655.4 ms | 26 × 1.024 = 26.6 ms |
| **ToA** | 401.4 + 655.4 = 1,056.8 ms | 12.5 + 26.6 = 39.2 ms |
| **g3 Re-arm (÷ 10%)** | 1,056.8 / 0.10 / 1000 = 10.57 s | 39.2 / 0.10 / 1000 = 0.392 s |
| **Energy @14 dBm/3.7V** | (31/1000)×3.7×(1.0568)×1000 = 121.2 mJ | (31/1000)×3.7×(0.0392)×1000 = 4.5 mJ |

**SF7 is 27× faster than SF12** for an 8-byte packet on BW125/CR4:6. The g3 re-arm time drops from 10.57 seconds to 0.39 seconds - meaning the sensor can legally transmit 27× more detection events per hour. Energy per event drops from 121.2 mJ to 4.5 mJ - a 27× reduction. Both benefits arise from the same cause: 27× less airtime.

# 7. EU 868 MHz Sub-Band Reference

ETSI EN 300 220 divides the 863–870 MHz EU ISM band into sub-bands with individual duty-cycle limits. The calculator supports all four sub-bands. The choice of sub-band is the single biggest variable in EU compliance - g3 allows 10× more transmissions than g/g1.

| Band | Frequencies | Duty Cycle | Max BW | Re-arm @ SF7/8B ToA=39.2ms | Recommendation |
|---|---|---|---|---|---|
| g | 868.0–868.6 MHz | 1% | 500 kHz | 39.2 / 0.01 / 1000 = 3.92 s | General use |
| g1 | 863.0–868.0 MHz | 1% | 500 kHz | 39.2 / 0.01 / 1000 = 3.92 s | Lower EU band |
| g2 | 868.7–869.2 MHz | 0.1% | 500 kHz | 39.2 / 0.001 / 1000 = 39.2 s | ⚠ Avoid - very restricted |
| **g3** | 869.4–869.65 MHz | **10%** | 125 kHz | 39.2 / 0.10 / 1000 = 0.392 s | ✓ Best for events |

**g3 bandwidth constraint:** Sub-band g3 is only 250 kHz wide (869.4–869.65 MHz). BW500 is physically impossible - the signal would extend beyond the sub-band. BW250 is marginal with no guard band. Only BW125 is appropriate on g3. Section G Warning W1 flags BW500 + g3 as a hard violation; W2 flags BW250 + g3 as a caution.

# 8. Step-by-Step Tool Demonstration

Six guided scenarios for live classroom walkthrough. Each demo specifies the complete starting state - set every listed value before executing the numbered steps. All figures have been independently verified against the formula.

**Excel orange cell behavior - read before any demo:** Orange cells contain formulas driven by the C4 preset and F6 region selectors. Typing directly into an orange cell permanently overwrites its formula for the session. Ctrl+Z restores the formula. Re-selecting C4 does NOT restore overwritten formulas in other cells - only the formula in C6 (SF) is restored this way because it is the one that watches C4. The React online tool does not have this limitation.

## Demo 1 - Load a Preset and Read the Results

Objective: show what a preset does and how to read the three main output sections.

| Starting state - set all values before beginning this demo | |
|---|---|
| **Active Preset (C4)** | Sensor Heartbeat |
| **Region (F6)** | EU (= 1) |
| **EU Sub-band (F7)** | g (868.0–868.6 MHz, 1% duty) |
| **TX Interval** | 15 minutes |
| **Battery** | 2,000 mAh |
| **TX Power (C16)** | 14 dBm (set by preset) |
| **SF / BW / CR** | 12 / 125 kHz / 4:6 (set by preset) |
| **Payload** | 12 bytes (set by preset) |
| **Preamble** | 8 symbols (default) |
| **CRC / Explicit Header** | ON / ON (defaults) |
| **Expected ToA** | 1,253 ms |

1. Open the Calculator tab. Use the Active Preset dropdown (C4) to select 'Sensor Heartbeat'.
2. Observe that C6 (SF), C7 (BW), C8 (CR), C10 (payload), and C16 (TX Power) update automatically - these are the orange preset-driven cells.
3. Read Section C - Time on Air (E24). With SF12 / BW125 / CR4:6 / 12 B / preamble 8: ToA = 1,253 ms. Tsym = 32.768 ms, LDRO auto-on (DE=1), 26 payload symbols.
4. Read Section E - at TX interval 15 min on sub-band g (1% duty): duty cycle consumed per hour ≈ 0.14% - well within the 1% limit. Maximum legal transmissions per hour at this ToA on sub-band g: about 28.

## Demo 2 - Feel the Impact of Spreading Factor

Objective: demonstrate that SF is the dominant variable controlling ToA. Everything else stays the same as Demo 1.

| Starting state - set all values before beginning this demo | |
|---|---|
| **Active Preset (C4)** | Sensor Heartbeat (from Demo 1) |

| | |
|---|---|
| **Region (F6)** | EU (= 1) |
| **EU Sub-band (F7)** | g (1% duty) |
| **TX Interval** | 15 minutes |
| **TX Power (C16)** | 14 dBm |
| **BW / CR / Payload** | 125 kHz / 4:6 / 12 bytes (unchanged) |
| **SF - change to** | 7 (manually change C6 dropdown) |
| **Expected ToA** | SF12: 1,253 ms → SF7: 45 ms (~28× reduction) |

5. With Sensor Heartbeat still loaded, use the C6 dropdown to change SF from 12 to 7.
6. Watch Section C: ToA drops from 1,253 ms to ~45 ms - a ~28× reduction. Tsym drops from 32.768 ms to 1.024 ms. LDRO turns off (Tsym now below 16 ms threshold).
7. Section A row 13 (LDRO Required?) changes from 1 to 0. This is an auto-calculated indicator in Section A - there is no LDRO entry in Section G warnings.
8. Read Section F (re-arm reference): g3 re-arm drops from ~12.5 s (SF12) to ~0.45 s (SF7). On sub-band g (1%): re-arm is 125 s vs 4.5 s.
9. Section G: all eight warnings remain green - no violations introduced.

> **Discussion prompt:** If SF7 is 28× faster, why would anyone use SF12? SF12 provides approximately 20 dB more link margin - it can close radio links that SF7 cannot, such as through dense vegetation, across longer distances, or when antenna placement is compromised. The trade-off is always range vs. channel occupancy time and must be validated against a link budget calculation.

## Demo 3 - Trigger a Regulatory Violation

Objective: show that Section G warnings respond live. Reset to a clean state before starting.

| **Starting state - set all values before beginning this demo** | |
|---|---|
| **Active Preset (C4)** | Sensor Heartbeat (re-select to reset) |
| **Region (F6)** | EU (= 1) |
| **EU Sub-band (F7)** | g3 ← change to g3 before starting |
| **SF / BW / CR** | 12 / 125 kHz / 4:6 (from preset) |
| **TX Power (C16)** | 14 dBm (from preset - formula intact) |
| **All others** | Default values |

10. Re-select the Sensor Heartbeat preset in C4 to reset all orange cells. Set region to EU, sub-band to g3.
11. Change C7 (BW) to 500 kHz. Section G W1 immediately shows: ✗ VIOLATION - 'BW500 cannot fit in g3 - sub-band is only 250 kHz wide.' This is a hardware impossibility, not just a regulatory issue.
12. Change BW back to 125 kHz - W1 clears to green.
13. Change C16 (TX Power) to 20 dBm by typing into the cell. Section G shows: ✗ W3 VIOLATION 'EU EIRP limit is 14 dBm' and ⚠ W4 CAUTION '+20 dBm duty-cycle limited to 1% on RFM95W hardware.' Note: typing into C16 overwrites its formula.
14. Change TX Power back to 14 dBm. Both flags clear. ⚠ Press Ctrl+Z twice to undo both TX Power edits and restore C16's formula - verify the formula bar shows '=IFERROR(IF($F$6=1,...)' rather than a bare number. This matters for Demo 5 TX Power auto-update.

## Demo 4 - Design the Optimal Detection Event Configuration

Objective: walk through the engineering case for SF7 on EU g3. Show energy and re-arm improvements.

| Starting state - set all values before beginning this demo | |
|---|---|
| **Active Preset (C4)** | Detection Event |
| **Region (F6)** | EU (= 1) |
| **EU Sub-band (F7)** | g3  (10% duty) ← set manually |
| **TX Interval** | 15 minutes |
| **Battery** | 2,000 mAh |
| **SF (initial)** | 12  (from preset - will be changed in step 3) |
| **BW / CR** | 125 kHz / 4:6  (from preset) |
| **Payload** | 8 bytes  (from preset) |
| **TX Power** | 14 dBm  (EU preset value) |
| **Expected ToA** | SF12: 1,056.8 ms  →  SF7: 39.2 ms after step 3 |

15. Load the Detection Event preset. Set sub-band to g3. Confirm: SF=12, payload=8 B, TX Power=14 dBm.
16. Read ToA = 1,056.8 ms. Section F: g3 re-arm = 10.57 s. Maximum legal detection events on g3 at SF12: about 5 per minute.
17. Change C6 (SF) to 7. ToA drops to 39.2 ms. g3 re-arm drops to 0.392 s (392 ms). Note: C4 still shows 'Detection Event' - Excel does not change the preset label when you manually edit a cell. Only C6's formula is overwritten; all other orange cells remain formula driven.
18. All Section G warnings remain green - no violations introduced.
19. Section D: energy per TX changes from 121.2 mJ (SF12) to 4.5 mJ (SF7) - a 27× energy saving at 14 dBm / 3.7 V. Battery life improves proportionally for the TX-only estimate.

**Recommended production configuration - Detection Event:** SF7 / BW125 / CR4:6 / 8 bytes / EU g3 / 14 dBm. ToA = 39.2 ms · g3 re-arm = 392 ms · Energy = 4.5 mJ per event. Maximum legal events on g3: ~9,180 per hour.

## Demo 5 - Compare EU vs US Compliance

Objective: show how the compliance engine changes between regions and demonstrate the US dwell time constraint on a larger packet. Continues from Demo 4.

| Starting state - set all values before beginning this demo | |
|---|---|
| **Starting state** | Continue directly from Demo 4 end-state |
| **C4 Active Preset** | Detection Event  (C4 label unchanged in Excel) |
| **C6 SF** | 7  (plain value - formula overwritten in Demo 4 step 3) |
| **BW / CR / Payload** | 125 kHz / 4:6 / 8 bytes  (formulas intact) |
| **TX Power (C16)** | 14 dBm  - C16 formula intact (Ctrl+Z done in Demo 3 step 5) |
| **Region** | Switch to US (F6 = 2) in step 21 |

| | |
|---|---|
| **TX Power after region →US** | Auto-updates to 20 dBm if C16 formula is intact. Manual entry required if formula was overwritten. |
| **Expected ToA throughout** | SF7/8B = 39.2 ms \| SR SF12/24B = 1,646.6 ms \| SR SF9/24B = 230.4 ms |

20. With Detection Event at SF7 / 8 B, switch region to US (F6 = 2).
21. Section E changes to FCC dwell time check: ToA 39.2 ms << 400 ms limit - COMPLIANT.
22. TX Power: if C16's formula is intact, it auto-updates to 20 dBm (preset US value). If C16's formula was overwritten and not restored, TX Power stays at 14 dBm - change it manually to 20 dBm.
23. Section G shows ⚠ W4 CAUTION for 20 dBm hardware duty limit - the RFM95W hardware restriction, not a US regulatory limit. No red violations.
24. Load the Status Report preset (24 B payload). Preset resets SF to 12 and TX Power to 20 dBm (US value). ToA = 1,646.6 ms. Dwell check shows ✗ BREACH - exceeds the 400 ms limit.
25. Change SF to 10. ToA = 264.2 ms - still BREACH? No: SF10/24B ToA = 411.6 ms - still BREACH. Try SF9. ToA drops to 230.4 ms - COMPLIANT. SF9 is the highest spreading factor that fits a 24-byte Status Report within the US dwell limit.

## Demo 6 - Battery Life Sensitivity

Objective: show how TX interval and TX power drive battery life estimates and highlight that the tool is a TX-only floor.

| Starting state - set all values before beginning this demo | |
|---|---|
| **Active Preset (C4)** | Alive Ping (6 B, SF12) |
| **Region (F6)** | EU (= 1) - reset from Demo 5 |
| **EU Sub-band (F7)** | g |
| **SF / BW / CR** | 12 / 125 kHz / 4:6 (from preset) |
| **Payload** | 6 bytes (from preset) |
| **TX Power (C16)** | 14 dBm (EU preset) |
| **TX Interval** | 5 minutes ← change manually after loading preset |
| **Battery** | 2,000 mAh |
| **Voltage** | 3.7 V |
| **Expected ToA** | 1,056.8 ms - same as Detection Event SF12/8B (see step 3) |

26. Load Alive Ping preset (6 B, SF12). Switch region back to EU. Set TX interval to 5 minutes. Battery = 2,000 mAh, Voltage = 3.7 V.
27. Read Section D: ToA = 1,056.8 ms, energy per TX ≈ 121.2 mJ, TX-only battery life ≈ 2.1 years at 5-minute intervals and 14 dBm.
28. Discussion point: Alive Ping is 6 bytes, Detection Event is 8 bytes - both at SF12 - yet both show ToA = 1,056.8 ms. Both map to 20 payload symbols after the ceiling calculation rounds up. Below a certain payload threshold, making the packet smaller does not reduce airtime.
29. Change TX interval to 15 minutes. Battery life triples to ≈ 6.3 years - the relationship is linear with interval.
30. Change TX Power from 14 dBm to 17 dBm. TX current jumps from 31 mA to 87 mA (PA_BOOST path). At 5-minute intervals, battery life drops to ≈ 0.7 years - a 3× reduction from a 3-step power increase. The relationship is non-linear in dBm but linear in current.

**Talking point:** The TX-only estimate is always the optimistic floor. A real deployment system energy budget must also add: MCU active current (~5–30 mA when processing), RFM95W standby current (1.6 mA between transmissions), geophone monitoring circuit (continuous), and any LEDs or peripherals. The tool gives the radio contribution only - use it as the starting point, not the final answer.

## Demo 7 - Configuration Optimizer (React app only)

**Objective:** Use the built-in optimizer to find the lowest-energy compliant configuration for a given payload and region, then apply it directly to the calculator.

Note: The Configuration Optimizer is a feature of the React web app (.jsx) only. It is not present in the Excel workbook. The Excel workbook remains the primary classroom reference tool for manual exploration; the optimizer provides a rapid automated search for deployment planning.

> **Starting State**
>
> Region: EU 868 MHz
>
> Payload: 8 bytes (set manually or load Detection Event preset)
>
> TX Interval: 15 minutes
>
> All other settings: any - the optimizer ignores them

Step by step:

- Scroll to the Configuration Optimizer card at the bottom of the app.
- Confirm the description line shows '8-byte payload' and 'EU 868 MHz' - these are the only inputs used.
- Click '⚡ Find Optimal Configuration'. The button shows 'Optimizing…' briefly, then a results table appears.
- Read the results table. For EU the primary sort is re-arm time (shortest = best). For US it would be ToA vs the 400 ms dwell limit. TX power and energy are the tiebreaker - among ties on re-arm, the lowest-energy option wins.
- Verify the top result shows SF7 / 125 kHz / g3 / re-arm ≈ 0.392 s. This confirms g3 dominates because its 10% duty allowance produces shorter re-arm than g/g1 at 1% even though g/g1 allows shorter raw ToA.
- Click the top row. The app immediately updates SF, BW, CR, sub-band, and TX power to match - preset label changes to 'Custom'.
- Switch to US region. The optimizer clears (results are region-specific). Click optimize again - now sorts by ToA vs 400 ms FCC dwell limit.

**What the optimizer iterates:**

| Parameter | Optimizer behavior |
|---|---|
| SF | Iterates SF7–SF12 (SF6 excluded - not recommended for production) |
| BW | Iterates 125 / 250 / 500 kHz, with sub-band physical constraints applied |
| CR | Iterates 4:6 / 4:7 / 4:8 / 4:9 |
| EU sub-band | Iterates g/g1, g2, g3 - each with its own duty cycle and BW limits |
| TX power | Iterates all legal options; lowest energy wins ties on primary metric |
| LDRO | Auto-set based on Tsym > 16 ms - not iterated |
| Preamble | Fixed at 8 (protocol minimum) - not iterated |
| CRC | Fixed ON - protocol constant, not iterated |
| Explicit header | Fixed ON for SF7–SF12 - protocol constant, not iterated |

> **Important: optimizer result is a starting point**
>
> TX power recommendation assumes a perfect link with zero margin pressure.
>
> In real deployments, lower TX power = less link margin = risk of packet loss in dense vegetation or at range.
>
> Always validate the optimizer's TX power recommendation against a link budget calculation before deployment.
>
> See Section 10 (Link Budget and TX Power) for practical guidance.

# 9. The Hardware - RFM95W Transceiver

The Jumbo Shoo sensor node uses the HopeRF RFM95W module, which is built around the Semtech SX1276 LoRa transceiver IC. All specifications in the calculator are sourced from the RFM95W datasheet v2.0.

## Key Specifications (HopeRF RFM95W, Table 5 - §2.4.5 test conditions)

| | |
|---|---|
| **Frequency range** | 862–1020 MHz (HF band - uses PA_HF / RFO_HF output path) |
| **Maximum TX power** | +20 dBm (PA_BOOST path, duty-cycle limited to 1% per Table 33) |
| **Continuous TX rating** | +17 dBm (PA_BOOST, Table 5 direct measurement) |
| **PA_HF (RFO) maximum** | +14 dBm recommended (§5.4.2); +15 dBm register ceiling (Table 31) |
| **TX current @+20 dBm** | 120 mA (Table 5, direct measurement) |
| **TX current @+17 dBm** | 87 mA (Table 5, direct measurement) |
| **TX current @+14 dBm** | 31 mA (RFO_HF path, linear extrapolation from 7/20 mA and 13/29 mA anchors) |
| **TX current @+13 dBm** | 29 mA (Table 5, direct measurement - RFO_HF anchor) |
| **TX current @+7 dBm** | 20 mA (Table 5, direct measurement - RFO_HF anchor) |
| **Sleep current** | 0.2 μA |
| **Standby current** | 1.6 mA |
| **Default test conditions** | SF12, CR 4/6, BW 125 kHz, preamble 8, CRC on (§2.4.5) |

## PA Regime Architecture

The SX1276 has two physically separate power amplifier paths for the HF band. Understanding which path is active at a given TX power is essential for reading the current table correctly.

| | |
|---|---|
| **RFO_HF (PA_HF) - 2 to 14 dBm** | Standard output path. Two Table 5 direct measurements: 7 dBm/20 mA and 13 dBm/29 mA. All intermediate values in the Lookup tab are linearly interpolated at slope 1.5 mA/dBm, labelled [est.] in dropdowns. Maximum is 14 dBm (§5.4.2) or 15 dBm (Table 31 register limit). |
| **PA_BOOST - 17 to 20 dBm** | High-power path, selected explicitly by firmware. Two Table 5 direct measurements: 17 dBm/87 mA and 20 dBm/120 mA. 20 dBm requires duty-cycle limiting to 1% per Table 33 (DC_20dBm). |
| **Transition zone - 15 to 16 dBm** | PA path switch zone. Current draw is indeterminate - either path may be selected by firmware. These levels are intentionally omitted from the calculator dropdown. Do not interpolate across this boundary. |
| **SF6 sync word** | SF6 uses sync word 0x65 rather than the standard 0x12 used for SF7–12. An SF6 transmitter will not be decoded by an SF7–12 receiver, even on the same frequency. Both ends must be configured for SF6 simultaneously. |

# 10. Link Budget Context - What the Tool Does Not Calculate

The airtime calculator computes time, energy, and regulatory compliance for a given radio configuration. It does not verify whether the signal will reach the receiver. That requires a link budget - a separate calculation.

## What a Link Budget Requires

- TX power (dBm) - set in the calculator
- TX antenna gain (dBi) - depends on antenna type and placement
- Free-space path loss: $FSPL = 20\cdot\log_{10}(d) + 20\cdot\log_{10}(f) + 20\cdot\log_{10}(4\pi/c)$
- Vegetation / ground clutter margin - typically 10–20 dB for bush terrain
- RX sensitivity - SF7/BW125: ≈ −123 dBm; SF12/BW125: ≈ −137 dBm; SF6/BW125: ≈ −118 dBm
- RX antenna gain
- Required link margin - minimum 10 dB recommended for reliable outdoor links

The 5 dB sensitivity penalty of SF6 compared to SF7 is directly relevant to the SF6 deployment decision. Before selecting SF6 in production, a link budget must confirm that 5 dB of margin can be sacrificed given the expected deployment geometry, antenna placement, and vegetation density.

## Practical Deployment Checklist

31. Calculate free-space path loss for the maximum expected sensor-to-brain separation.
32. Add a vegetation margin of 10–20 dB for bush terrain.
33. Confirm link margin ≥ 10 dB with the proposed SF/BW configuration.
34. Open the calculator and verify ToA, duty cycle, and re-arm time for the chosen SF.
35. Check Section G - all warnings green before deployment.
36. Use the Detection Event preset at SF7 as the baseline. Step up to SF8 or SF9 only if the link margin calculation requires it.
37. If SF6 is under consideration: re-run link budget with −5 dB sensitivity margin and confirm. Test in the field before committing to SF6 in firmware.

## TX Power Selection and Link Margin

The optimizer recommends minimum TX power because lower power directly reduces energy and never affects ToA or regulatory compliance. In practice, **TX power must be high enough to close the radio link** with adequate margin under worse-case field conditions.

## Link Budget Fundamentals

Received signal power at the brain module antenna is:

Received Power (dBm) = TX Power + TX Antenna Gain − Path Loss + RX Antenna Gain

The link works only if received power exceeds the receiver sensitivity threshold with margin to spare:

Link Margin (dB) = Received Power − Sensitivity Threshold

RFM95W sensitivity at key spreading factors (BW125, CR4:6):

| SF | Sensitivity (approx.) | vs SF7 |
|---|---|---|
| SF7 | −123 dBm | baseline |
| SF8 | −126 dBm | +3 dB |
| SF9 | −129 dBm | +6 dB |

| | | |
|---|---|---|
| SF10 | −132 dBm | +9 dB |
| SF11 | −134.5 dBm | +11.5 dB |
| SF12 | −137 dBm | +14 dB |

## Free-Space Path Loss at 868 MHz

FSPL (dB) = $20 \cdot \log_{10}(d) + 20 \cdot \log_{10}(868 \times 10^6) + 20 \cdot \log_{10}(4\pi/c) \approx 20 \cdot \log_{10}(d) + 91.7$

| Distance | FSPL (868 MHz) |
|---|---|
| 100 m | ~72 dB |
| 300 m | ~82 dB |
| 500 m | ~86 dB |
| 1,000 m | ~92 dB |
| 2,000 m | ~98 dB |

Free space is the baseline only. In a bush deployment, add:

38. Vegetation loss - 10–30 dB depending on density. African acacia or thorn scrub at the high end.
39. Ground reflection and multipath - adds 0–10 dB variability.
40. Fresnel zone intrusion - at 868 MHz over 500 m, the first Fresnel zone radius at midpoint is approximately 10 m. Vegetation or terrain intruding into that zone adds 6+ dB of loss.
41. Antenna placement - a sensor node flush with the ground vs. mounted 1 m high can differ by 10+ dB.

## Practical Worked Example

Sensor 300 m from brain through moderate African bush:

42. FSPL: ~82 dB
43. Vegetation margin estimate: 15 dB (moderate) - could be 25 dB in dense cover
44. Total estimated path loss: ~97 dB
45. SF7 / BW125 sensitivity: −123 dBm
46. At +2 dBm TX: received = 2 − 97 = −95 dBm → link margin = 28 dB. Appears fine.
47. But if vegetation is 25 dB, not 15 dB: received = −105 dBm → link margin = 18 dB. Getting thin.
48. At 600 m through denser bush (path loss ~110 dB): +2 dBm gives −108 dBm received → 15 dB margin. Any underestimate of vegetation kills the link.
49. At +14 dBm TX: received at 600 m = 14 − 110 = −96 dBm → 27 dB margin - robust.

The 12 dB difference between +2 dBm and +14 dBm is the difference between marginal and robust links in challenging terrain.

## Recommended Link Margin Thresholds

| Scenario | Recommended minimum margin | Notes |
|---|---|---|
| Open ground, short range (<200 m) | 10 dB | Good conditions, clear line of sight |
| Moderate bush, medium range | 15 dB | Standard Jumbo Shoo deployment |
| Dense vegetation or long range | 20 dB | Conservative - recommended default |

## Field Validation Procedure

The optimizer gives a theoretical minimum. Field validation establishes the practical minimum:

- Deploy with TX power at +14 dBm for all initial testing - safe, legal, no cautions.

- Enable RSSI and SNR logging in the brain module firmware for every received packet.
- Run a 24-hour test period with sensors at all planned deployment positions, including worst-case (most distant, most vegetated) locations.
- Find your worst-case link: lowest RSSI reading across all sensor positions.
- Calculate actual margin: margin = measured RSSI − sensitivity floor (−123 dBm for SF7).
- Step TX power down in the calculator (2, 5, 8, 11, 14 dBm options). Each step saves energy. Stop when margin drops below your threshold.
- Use that field-validated TX power as the production setting - set it in both the calculator and firmware.

### RSSI and SNR Interpretation

The SX1276 reports both metrics per received packet:

50. RSSI - raw signal strength in dBm. Should be comfortably above the sensitivity floor. Every 6 dB improvement is equivalent to halving the distance or one step down in TX power.
51. SNR - signal-to-noise ratio. LoRa can decode down to −20 dB SNR at SF12 - this is why it operates below the noise floor. Positive SNR = signal above noise (strong link). Negative SNR = signal below noise (LoRa's normal operating regime at range).

Healthy link indicators: RSSI above −110 dBm at SF7, SNR above −10 dB. Marginal: RSSI between −110 and −120 dBm, SNR between −10 and −18 dB. At or near the noise floor: step up SF or increase TX power.

> **Summary: optimizer vs. field deployment**
>
> Optimizer output: theoretical minimum energy, assuming perfect link closure.
>
> Field recommendation: start at +14 dBm, log RSSI/SNR, step down to field-validated minimum.
>
> The optimizer is most impactful for SF and BW selection (27× energy difference between SF7 and SF12) rather than TX power (modest gains, real link margin risk).
>
> Never sacrifice link margin for energy savings on the detection event path - a missed elephant incursion defeats the system purpose.

## 11. Multi-Sensor Arrays - Beyond the Single-Sensor Model

The calculator models a single sensor node. Real Jumbo Shoo deployments use arrays of multiple geophones around a field perimeter. When an elephant approaches, seismic waves propagate through the ground at 100–500 m/s and trigger multiple sensors within milliseconds of each other.

### The Concurrent Transmission Problem

If two sensor nodes transmit on the same frequency at the same time, the LoRa receiver applies the capture effect: it locks onto the stronger signal and discards the weaker one. This creates a systematic bias - nodes physically closer to the brain are preferentially received, which corrupts the relative arrival-time data needed for elephant localization.

For alert-only applications (where knowing that an event occurred matters more than knowing which sensors triggered) this bias is acceptable. For localization applications, it must be managed.

### Channel Access and CAD Backoff

The Semtech SX1276 includes a Channel Activity Detection (CAD) mode that listens for LoRa preamble symbols before transmitting. A randomized CAD backoff algorithm (documented in Hoang et al., Procedia Computer Science 177, 2020) can reduce simultaneous transmission probability.

CAD backoff timing at SF7 / BW125:

| Parameter | Value at SF7/BW125 |
|---|---|
| **Symbol duration (Tsym)** | 1.024 ms |

| | |
|---|---|
| **CAD duration (2 symbols)** | 2 × 1.024 = 2.048 ms ≈ 2.0 ms |
| **Delay slot (= CAD duration)** | 2.0 ms |
| **Preamble detection window** | 12.288 ms (12 symbols × 1.024 ms) |
| **MaxDelayCnt** | 6 (maximum random slots before transmitting) |
| **Maximum random delay** | 6 × 2.0 = 12.0 ms (< 12.288 ms preamble window ✓) |
| **Algorithm constraint** | Max delay must be < preamble duration - satisfied at SF7 |

## Channel Frequency Staggering - EU g3

Sub-band g3 spans 869.4–869.65 MHz (250 kHz wide). Two non-overlapping BW125 channels can be placed within this range: one centered at 869.4 MHz and one at 869.525 MHz. Assigning adjacent sensor nodes to different channels halves collision probability for arrays of two or more sensors.

For larger arrays, channels from g or g1 can be added, but the duty-cycle budget drops from 10% to 1% on those sub-bands, so re-arm times increase proportionally.

> **Scope note:** The calculator models a single sensor → brain link. Multi-sensor coordination, CAD backoff scheduling, and channel staggering are firmware concerns that cannot be captured in a single-channel airtime tool. The Profiles tab contains engineering notes on these topics for reference.

# 12. Quick Reference Tables

## Preset Defaults

| Profile | SF | BW | CR | Payload | TX EU | TX US | Type ID |
|---|---|---|---|---|---|---|---|
| **Sensor Heartbeat** | 12 | 125 | 4:6 | 12 B | 14 dBm | 20 dBm | 0x01 |
| **Status Report** | 12 | 125 | 4:6 | 24 B | 14 dBm | 20 dBm | 0x02 |
| **Detection Event** | 12 | 125 | 4:6 | 8 B | 14 dBm | 20 dBm | 0x03 |
| **Alive Ping** | 12 | 125 | 4:6 | 6 B | 14 dBm | 20 dBm | 0x04 |

## TX Power / Current Reference (RFM95W, v2.1 corrected values)

| TX Power | Current (mA) | PA Path | Source / Notes |
|---|---|---|---|
| 2 dBm | 13 mA | RFO_HF | Linear interpolation - slope 1.5 mA/dBm from Table 5 anchors [est.] |
| 5 dBm | 17 mA | RFO_HF | Linear interpolation [est.] |
| **7 dBm** | **20 mA** | RFO_HF | Table 5 direct measurement (§2.4.5) - anchor point |
| 8 dBm | 22 mA | RFO_HF | Linear interpolation [est.] |
| 11 dBm | 26 mA | RFO_HF | Linear interpolation [est.] |
| **13 dBm** | **29 mA** | RFO_HF | Table 5 direct measurement - anchor point |
| 14 dBm | 31 mA | RFO_HF | Linear extrapolation - PA_HF max (§5.4.2 / Table 31) [est.] EU default |
| - | - | - gap - | 15–16 dBm: PA path transition zone - current indeterminate, omitted from dropdown |
| **17 dBm** | **87 mA** | PA_BOOST | Table 5 direct measurement - continuous rated maximum |
| **20 dBm** | **120 mA** | PA_BOOST | Table 5 direct measurement - duty-cycle limited to 1% (Table 33) |

## Glossary

| Term | Definition |
|---|---|
| **AP** | Access Point - device that creates a local WiFi network, requiring mains power and wired infrastructure. Unavailable in remote bush deployments. |
| **BW** | Bandwidth - the frequency range swept per chirp. Wider BW = faster but less sensitive. Must not exceed sub-band width. |
| **CAD** | Channel Activity Detection - SX1276 mode that listens for a LoRa preamble before transmitting, enabling polite channel access. |
| **Capture Effect** | LoRa receiver property: when two signals arrive simultaneously, the stronger one is decoded and the weaker discarded. |
| **CR** | Coding Rate - fraction of bits used for error correction (4/5 to 4/8). Higher CR = more robust, more overhead. |
| **CSS** | Chirp Spread Spectrum - LoRa's modulation technique where data is encoded as linear frequency sweeps. Allows signal recovery 20 dB below the noise floor. |

| | |
|---|---|
| **Duty Cycle** | Fraction of time a transmitter may occupy a channel. EU g3: 10%, EU g/g1: 1%, EU g2: 0.1%. |
| **Dwell Time** | US FCC §15.247 equivalent of duty cycle - maximum single transmission duration of 400 ms. |
| **EIRP** | Effective Isotropic Radiated Power - total power in the direction of maximum antenna gain. EU limit on g3: 14 dBm EIRP. |
| **EMF** | Electromotive Force - voltage generated by changing magnetic flux (Faraday's Law: EMF = $-d\Phi/dt$). The physical basis of geophone sensing. |
| **FEC** | Forward Error Correction - redundant bits added so the receiver can reconstruct errors without retransmission. LoRa's Coding Rate controls FEC overhead. |
| **FSPL** | Free-Space Path Loss - signal attenuation through open air. At 868 MHz, every doubling of distance adds ~6 dB. |
| **Geophone** | Passive electromagnetic velocity sensor. Converts ground motion into voltage via Faraday induction. No power required to sense. |
| **HEC** | Human-Elephant Conflict - crop raiding and property damage where farming communities border elephant habitat. The core problem Jumbo Shoo addresses. |
| **IC** | Integrated Circuit - a complete electronic circuit on a single silicon chip. The RFM95W module is built around the Semtech SX1276 LoRa IC. |
| **Implicit Header** | LoRa packet mode where payload length, CR, and CRC presence are absent from the packet - receiver must know them in advance. Required at SF6. |
| **ISM Band** | Industrial, Scientific and Medical Band - license-free radio bands. LoRa uses 863–870 MHz in the EU and 902–928 MHz in the US. |
| **LDRO** | Low Data Rate Optimization - automatic SX1276 modem mode that activates when Tsym > 16 ms to handle frequency drift. |
| **LiPo** | Lithium Polymer - rechargeable battery with nominal cell voltage 3.7 V, the default in the calculator's energy calculations. |
| **MCU** | Microcontroller Unit - single chip containing processor, memory, and I/O peripherals. Runs the geophone detection algorithm and packages events into LoRa packets. |
| **P2P** | Point-to-Point - direct radio link between two devices with no infrastructure. Jumbo Shoo uses LoRa P2P - sensor to brain directly, no gateway or cloud. |
| **PA_BOOST** | High-power amplifier path on SX1276/RFM95W, selected by firmware for 17–20 dBm. Separate from the standard RFO_HF path. |
| **Re-arm Time** | Minimum interval between transmissions to comply with duty cycle. Re-arm = ToA ÷ duty-cycle fraction. |
| **SF** | Spreading Factor (6–12). Controls the number of chips per symbol. Each SF increment doubles ToA and adds ~5 dB link margin. |
| **ToA** | Time on Air - total duration in milliseconds for the radio to transmit one complete packet, including preamble and payload. |

# 13. References

| | |
|---|---|
| **Semtech AN1200.13** | LoRa Modem Designer's Guide. Primary source for the ToA formula, payload symbol calculation, preamble timing, and all LDRO/DE derivations. All formula terms in Section 6 trace directly to this document. |
| **ETSI EN 300 220-2** | Short Range Devices - EU 868 MHz sub-band definitions, duty-cycle limits, and frequency allocation. Source for the g, g1, g2, g3 table in Section 7 and the compliance engine in Section E of the calculator. |
| **FCC §15.247** | US frequency hopping and dwell time requirements. Source for the 400 ms dwell time limit checked in Section E (US mode) and Section G Warning W5. |
| **HopeRF RFM95W datasheet v2.0** | Actual transceiver module in Jumbo Shoo sensor nodes. Source for: Table 5 TX current measurements (7/13/17/20 dBm anchor points); Table 31 PA_HF register ceiling (15 dBm); §5.4.2 recommended PA_HF maximum (14 dBm); §2.4.5 default test conditions; Table 33 DC_20dBm duty-cycle restriction; maximum TX power (+20 dBm, PA_BOOST). Interpolated current values derived from Table 5 anchors at slope 1.5 mA/dBm. |
| **Hoang et al. 2020** | 'Multi-Sensor Collision Avoidance in LoRa Networks', Procedia Computer Science 177, pp. 130–137. Source for the CAD backoff algorithm parameters and timing constants used in Section 11 and the Profiles tab. |

HopeRF RFM95W Note: The Jumbo Shoo project uses the Adafruit RFM95W LoRa packet radio breakout, which repackages the HopeRF module with regulator, level-shifting, and antenna options, but the actual transceiver silicon, RF specs, and register map are the same. The HopeRF module uses a Semtech-compatible LoRa transceiver (SX127x-class) covering 868/915 MHz.