Passive Rescue Radio System (PRRS)

Technical Specification — Version 3.0

Authors. Nguyen · Z-Lab
Version. 3.0 — revised from v2.0 (10 March 2026)
Date. 30 August 2026
Status. R&D; Framework · Field Calibration and Breadboard Validation Pending

Contact. Z-Lab Internal

Abstract

The Passive Rescue Radio System (PRRS) is a zero-battery wristband device enabling disaster victims to signal active engagement and approximate survival status to rescue forces through a fixed-frequency keyed backscatter pattern, without any active electronics or power source. The device operates by modulating the 2nd harmonic backscatter of an externally-sourced RF carrier wave. A mechanical rate-limiting mechanism (Sec. 3.5) converts an arbitrary press pattern — a single hold, repeated mashing, or activation by mouth/teeth when hands are unavailable — into a signal keyed at a fixed, design-determined rate, independent of how the victim presses. No power is consumed at any stage of this process.

Version 3.0 supersedes v2.0 in three respects. First, the free-form Morse-code signaling model (including the unsubstantiated "Morse ID" identity-encoding concept) is removed in favour of a fixed-frequency keyed signal, since a distressed or panicking victim cannot reliably produce timed Morse patterns, and no realistic identity-card mechanism was ever specified. Second, several quantities previously presented as validated design values — the diode activation threshold, the return-link range figures, and the 433 MHz environmental noise environment — are explicitly relabelled as theoretical estimates pending empirical and field validation, per the correction record in Sec. 0. Third, a new mechanical activation subsystem (Sec. 3.5) and a field calibration protocol (Sec. 5.3) are introduced to address real-world activation conditions (panic, injury, fatigue, submersion) and site-specific RF clutter, respectively.

The differentiator from prior harmonic-reflector systems (e.g., Recco) remains intentional signaling: a victim who is conscious and able to activate PRRS — by hand or by mouth — produces a periodic keyed pattern distinguishable from static or randomly-varying backscatter. Critically, the system is designed to degrade gracefully: an unresponsive victim, or a wristband pinned under debris, still produces a continuous baseline reflection equivalent to a passive reflector such as Recco — the victim is not rendered undetectable by an inability to activate the keying mechanism.

0 · Revision Record — v2.0 → v3.0

This section is included for transparency. Several elements of v2.0 have been removed, corrected, or explicitly relabelled as unverified. Nothing below should be assumed to still apply unless restated in the sections that follow.

- **Removed — "Morse ID" / victim identity encoding.** This capability, referenced in the v2.0 abstract and comparison table, had no defined implementation and no realistic path to one (a victim under acute stress cannot reliably transmit an arbitrary identity code by hand). It has been removed from every section, including the Recco comparison table.
- **Removed — free-form Morse code as the primary signaling model.** Replaced with a fixed-frequency keyed signal produced by a mechanical rate-limiting mechanism (Sec. 3.5), which does not depend on the victim's ability to produce a specific timed pattern under panic, injury, or fatigue.
- **Reclassified — diode activation threshold (–18 dBm).** Previously presented as a hard cutoff. Now described as a detection threshold at an assumed target SNR, approximating a continuous conversion-efficiency curve. Marked as theoretical, pending empirical characterization of the specific diode lot used (Sec. 2.4).
- **Reclassified — return-link range (up to 9,365 m, open air).** Retained for its mathematical role in showing the return link is not the system bottleneck, but explicitly flagged as having no standalone operational meaning, since it exceeds the forward-link-limited range in every scenario (Sec. 4.1).
- **Added — mechanical rate-limiting activation mechanism (Sec. 3.5).** A symmetric dashpot-based cam mechanism that converts arbitrary manual or oral (mouth/teeth) activation into a fixed-period keyed pattern. This is a concept-level design, not yet breadboard-validated.
- **Added — graceful degradation to Recco-equivalent baseline.** Stated explicitly as an intended design property, not an incidental side effect: when the keying mechanism is not activated (unconscious victim, pinned limb, incidental static loading), the diode remains in its default reflective state and the wristband continues to function as a passive harmonic reflector, equivalent to Recco.
- **Added — antenna wet-detuning mitigation.** A hydrophobic silicone coating is specified for the antenna surface (Sec. 3.3, 3.4) to reduce dielectric detuning from surface water contact. Full-immersion performance remains unverified.
- **Added — Field Calibration Protocol (Sec. 5.3).** Z-Lab does not possess site-specific RF clutter or structural-vibration data for any given disaster environment. This section defines a methodology for implementing NGOs and government R&D units to collect that data locally and calibrate the keying frequency and detection SNR threshold accordingly, rather than presenting a single global constant as though it were universally valid.
- **Corrected — regulatory framing.** The v2.0 claim that 433 MHz "requires no individual license in most jurisdictions" is inaccurate at the 50 W transmit power specified in this document (see Sec. 6.2). Reframed as operation under declared-disaster emergency spectrum exemption, with compliance responsibility resting with the deploying agency.
- **Corrected — Table 5.2 arithmetic error.** The 2 WPM row previously listed a range multiplier of ×281, inconsistent with the stated formula and out of sequence with adjacent rows. Corrected to ×28, consistent with multiplier = 10^(gain_dB / 20).
- **Removed — Appendix A "Latency operator (Z-Loop formalism)".** This equation was carried over from an unrelated framework (Nguyen, *Z-Loop Laws*, Z-Lab, 2026 — a long-horizon causality framework for complex systems, unrelated to RF engineering) and had no function within the PRRS link budget. It has been removed; a citation is provided in the References section instead.
- **Added — drone sweep parameters and tethered-vs-free-flight operational split (Sec. 4.3, 6.1).** Free-flying drones are specified for wide-area post-event sweep (Tier 1–2); tethered or stationary ground-fed units are specified for sustained pinpoint monitoring at a suspected location (Tier 3), where continuous power and stable data links matter more than coverage speed.

1 · Introduction

Existing disaster rescue technologies rely on two broad categories of victim detection: active devices (mobile phones, PLBs, GPS beacons) that require battery power and infrastructure, and passive reflectors (Recco tags, retroreflective markers) that require no power but can only indicate presence, not survival or engagement. PRRS occupies a position between these categories: no battery, no active electronics, but the victim can exercise intentional control over the return signal through a mechanical mechanism.

1.1 · Comparison with Recco

The Recco system (Recco AB, Sweden, commercial since 1995) employs harmonic backscatter at 917 MHz / 1834 MHz. The physical operating principle — a diode generating a 2nd harmonic reflection under RF illumination — is identical to PRRS. The operational difference is that Recco produces a continuous, unmodulated reflection with no way to distinguish a living, conscious victim from a deceased one or a separated tag. PRRS adds a fixed-frequency keyed pattern, producible only by deliberate or reflexive human action, which indicates active engagement at the time of detection — while degrading gracefully to Recco-equivalent behaviour when that action is not present.

Capability	Recco	PRRS v3.0
Detects presence	Yes	Yes
Indicates active engagement (keyed signal present)	No	Yes
Degrades gracefully to presence-only detection	N/A (baseline)	Yes (by design)
Requires battery	No	No
Requires infrastructure	No	No
Proprietary / licensed	Yes	No — open source
Unit cost	Commercial retail product; unit cost not independently verified by Z-Lab	< $2 target (unverified supply chain, Sec. 3.4)

"Confirms survival / consciousness" and "transmits victim identity" rows present in v2.0 have been removed. A keyed signal indicates that the activation mechanism was engaged at some point within the detection window — it is corroborating evidence of engagement, not a certified medical or identity claim.

1.2 · Design Constraints

PRRS is designed under three non-negotiable constraints. **Zero battery:** the wristband may not contain any electrochemical energy source, ensuring indefinite shelf life and eliminating chemical leakage risk in flooded environments. **Zero active electronics:** no transistors, integrated circuits, or powered components of any kind — all signal processing occurs at the rescue end. **Sub-$2 unit cost:** the device must be manufacturable at scale by any facility with access to flexible hybrid electronics (FHE) equipment. A fourth, non-negotiable operational constraint is added in this revision: **no activation-dependence for baseline detectability** — failure or inability to operate the keying mechanism must never prevent the underlying harmonic reflection from functioning.

2 · Operating Principle

The rescue asset transmits a continuous carrier wave at 433 MHz toward the search area. When this wave reaches the wristband at sufficient power density, the zero-bias Schottky diode enters its nonlinear operating region and generates a return signal at 866 MHz (the 2nd harmonic). In its default state, the diode remains connected to the antenna circuit and this 2f reflection is continuous — functionally identical to a Recco-type reflector. When the victim engages the mechanical rate-limiting mechanism described in Sec. 3.5, the diode is periodically disconnected and reconnected at a fixed rate, producing a keyed ON/OFF pattern independent of how the victim operates the mechanism.

2.1 · Signal Chain

Parameter	Expression	v3.0 value
Received power at wristband	P_rx = P_tx + G_tx + G_rx + FSPL – a·R	≥ –18 dBm (detection threshold, see 2.4)
FSPL	20·log10(λ / 4πR)	λ = 0.69 m @ 433 MHz
Soil attenuation	a·R [dB]	a = 0–15 dB/m (site-dependent, see 5.3)
2f harmonic output	P_2f = P_rx + L_conv	–18 + (–22) = –40 dBm (theoretical)
Scanner noise floor	N = kTB, B = matched to keying rate	site- and design-dependent
Scanner sensitivity	P_min = N + NF + SNR_req	–144 dBm (nominal, 10 Hz reference)
Processing gain (narrowband keying)	PG = 10·log10(BW_ref / BW_key)	up to +25–32 dB depending on keying rate
System bottleneck	R_sys = min(R_fwd, R_ret)	R_fwd always limits (Sec. 2.2)

2.2 · Why the Forward Link Is Always the Bottleneck

Once the Schottky diode is activated near its detection threshold, the 866 MHz harmonic departs the wristband at roughly –40 dBm, against a scanner sensitivity of –144 dBm — over 100 dB of theoretical return-link margin. In every scenario studied, the mathematics places the return signal's theoretical range far beyond the forward-link-limited activation range. All optimisation effort should therefore focus on the forward link. **The large return-link range figures that follow from this margin (Sec. 4.1) are a mathematical device to establish this point — they carry no standalone operational meaning** and should not be read as the system's real detection range.

2.3 · Fixed-Frequency Keying and Processing Gain

Voice modulation requires a receiver bandwidth of approximately 3,400 Hz. A signal keyed at a fixed, narrow rate requires only a few Hz of bandwidth, and the processing gain from this bandwidth reduction follows PG = 10·log10(BW_voice / BW_key). At a nominal keying bandwidth of 10 Hz this is +25 dB; at slower keying rates the gain increases further. This is why v2.0 already moved away from voice modulation, and why v3.0 goes further by removing dependence on the victim producing any specific timed pattern at all — the rate is now set by the mechanical mechanism (Sec. 3.5), not by the victim's manual dexterity or state of consciousness.

2.4 · Diode Threshold — Detection Threshold, Not a Hard Cutoff

The Schottky diode's I-V response is exponential, so 2nd-harmonic conversion efficiency degrades continuously as input power falls — there is no physical power level at which the diode abruptly "switches off". The –18 dBm figure used throughout this document is a **detection threshold**: the input power at which the resulting harmonic is expected to clear the scanner's noise floor at an assumed target SNR, not a property of the diode itself. Near this threshold, detection probability falls off gradually rather than dropping from 100% to 0% at a sharp boundary, and the curve itself is expected to vary with diode lot and ambient temperature (Schottky characteristics drift with temperature). **This value is theoretical and has not been empirically**

characterized against the specific diode part (HSMS-2850 or equivalent) and production lot used in a given deployment. Implementers should treat range figures derived from it as approximate and validate with bench measurements before relying on them operationally.

3 · Wristband Specification

3.1 · Component Summary (v2.0 → v3.0)

Component	v2.0	v3.0	Effect / status
Frequency	433 MHz (ISM)	433 MHz (ISM)	Unchanged; regulatory framing corrected (Sec. 6.2)
Antenna config.	Van Atta array (8-el.)	Van Atta array (8-el.) + hydrophobic coating	+6 dBi retroreflective gain; wet-detuning mitigation added
Antenna gain	5 dBi	5 dBi (dry); degraded when wet, unquantified	See Sec. 3.3
Matching network	Passive LC, 433/866 MHz	Passive LC, 433/866 MHz	No change
Diode conv. loss	–22 dB	–22 dB (theoretical, pending empirical curve)	See Sec. 2.4
Signaling model	Free-form Morse code + "Morse ID"	Fixed-frequency keyed signal via mechanical rate limiter	Removes dependence on victim timing accuracy; removes unsubstantiated ID concept
Activation input	Mechanical switch (finger only, implied)	Mechanical switch / rate limiter, hand or mouth/teeth	See Sec. 3.5
Default (unactivated) state	Undefined in v2.0	Continuous reflection — Recco-equivalent baseline	Explicit graceful-degradation design goal
Substrate	Polyimide 1.5 mm	Polyimide 1.5 mm	No change
Waterproof rating	IP68+	IP68+ (surface); full immersion antenna performance unverified	See Sec. 3.3
Battery	None	None	No change
Unit cost target	< $2.00	< $2.00 (unverified supply chain estimate)	See Sec. 3.4

3.2 · Van Atta Retroreflector Array

A Van Atta array connects antenna element pairs with equal-length transmission lines such that the phase received at each element is retransmitted with conjugate phase at its paired element, producing automatic retroreflection toward the source regardless of array orientation — no switching, amplification, or power required. For a wrist-worn device that may be at any angle relative to the illuminating source, this provides a consistent +6 dBi gain over a randomly-oriented array, under dry conditions (see 3.3 for wet-condition caveats).

3.3 · Antenna Performance in Wet Conditions

Water has a high dielectric constant ($\varepsilon_r \approx 80$ vs. ≈1 for air), so a surface water layer directly against the copper trace detunes the antenna's resonant frequency away from 433/866 MHz, can break the Van Atta phase-matching condition ($l_i = l_{N+1-i}$) if coverage is uneven across element pairs, and adds dielectric absorption loss at the antenna surface distinct from the medium-attenuation figures already listed in Sec. 4.1. This is a materially important effect given the target use case (flood, storm surge). **Mitigation specified for v3.0:** a hydrophobic silicone coating over the antenna trace, using the same overmold process already in the BOM (Sec. 3.4) at negligible added cost. This reduces surface water adhesion for the commonly-encountered case of splashing, rain, and brief contact. **It has not been validated under sustained full immersion**, and the range figures in Sec. 4.1 assume a dry or coated-dry antenna surface; implementers deploying into standing floodwater should treat those figures as optimistic.

3.4 · Passive LC Matching Network

Harmonic conversion efficiency depends on impedance matching at both the fundamental (433 MHz) and 2nd harmonic (866 MHz). A passive LC network — two inductors and two capacitors in a dual-band ladder topology — achieves simultaneous matching at both frequencies without any active components or power draw. The theoretical improvement from –30 dB to –22 dB conversion loss is equivalent to increasing transmitter power by a factor of 6.3; as with the diode threshold (Sec. 2.4), this figure is a design target pending bench confirmation.

3.5 · Mechanical Rate-Limiting Activation Mechanism (Concept — Unverified)

Status: concept-level design, not yet breadboard-validated. This subsystem carries the highest technical risk in the current specification and should be prioritized for prototyping.

The design problem: a distressed victim cannot be relied upon to press a button at any specific rate. Observed real-world behaviour under acute stress ranges from rapid, irregular mashing to a single sustained hold, and the activating body part may not be a finger — hands can be trapped, injured, or occupied, and a victim may resort to mouth or teeth. Any design that depends on the victim producing a specific timed pattern (as free-form Morse does) is expected to fail under these conditions.

Proposed mechanism. Rather than the diode being switched directly by the button contact, the button drives a small mechanical piston through a viscous dashpot (a silicone-gel or air-damped channel, similar in principle to a soft-close hinge). Regardless of how hard, how fast, or how erratically the piston is driven, its travel speed through the damping channel is governed by fluid flow through a fixed restriction, not by the applied force. A contact tab reaches the diode circuit only once the piston completes its travel — nominally after a fixed interval on the order of 3–5 seconds. **The dashpot is specified as symmetric** (damped on both the forward and return stroke), so that continuous mashing, a single sustained hold, or intermittent contact all converge on approximately the same fixed-period ON/OFF cycle for as long as some activating force continues to be applied — this is what allows the keying rate at the scanner to be treated as a known, narrow-bandwidth signal (Sec. 2.3) without needing to model or classify the victim's press pattern.

Distinguishing intentional activation from incidental loading. A static load — debris resting on the wristband, or the wristband caught against a fixed object in moving water — applies continuous, non-alternating force. Because the dashpot requires an alternating push/release motion to produce a repeating cycle, a static load is expected to produce at most a single state transition and then hold, rather than a periodic keyed pattern. Only a repeated biological action — finger press, mash, or bite-and-release with the teeth — is expected to sustain the alternating motion needed for a periodic signal. This gives the system a physical (not software or classification-based) way of separating incidental mechanical loading from active engagement, consistent with the graceful-degradation goal in Sec. 3.6.

Ergonomic and material requirements. Because activation may be by mouth, the contact surface must (a) be locatable by touch/tongue without visual reference, meaning a distinct raised profile rather than a flush button; (b) use food-grade, non-toxic silicone for any surface that may be bitten (the BOM's existing food-grade TPU strap material should be extended to the button overmold, which is not yet specified as food-grade); and (c) be positioned on the wrist where it remains reachable by mouth if the opposite hand is trapped or injured — the inner wrist/mu bàn tay side rather than the outer forearm.

Open technical questions requiring breadboard validation: the exact damping-channel geometry and fluid viscosity needed to hit a 3–5 s nominal period; the degree to which gel/fluid viscosity drifts with temperature (colder floodwater will thicken the damping fluid and lengthen the period; tropical heat will shorten it) — the scanner's matched filter should therefore use a tolerance window (e.g., 2–6 s) rather than a single fixed period; the minimum activation force achievable by an injured or exhausted victim, ideally informed by clinical data on grip force under crush-injury or late-stage exhaustion (a question for medical/field partners, not something Z-Lab can determine from first principles); and long-term reliability of the mechanism after exposure to grit, mud, and saltwater.

3.6 · Graceful Degradation to Baseline Reflection

This is stated as an explicit, deliberate design property of v3.0, not an incidental consequence. In the default (unactivated) state, the diode remains connected and the wristband reflects continuously, exactly as a Recco tag would. This means the ability to operate the activation mechanism is **not a precondition for the victim being detectable** — it is a precondition only for the detection being accompanied by a keyed engagement signal. An unconscious victim, a victim with both hands and mouth incapacitated, or a wristband pinned under debris is still found at the level of a passive reflector; a conscious victim able to engage the mechanism, by any body part capable of applying an alternating force, additionally produces the keyed signal that supports triage prioritisation.

3.7 · Bill of Materials

Item	Specification	Est. cost (USD)
Polyimide substrate	1.5 mm, flexible, –40 to +85°C	$0.30
Copper antenna trace	Van Atta spiral, 8 elements, 433 MHz	$0.18
Hydrophobic coating (antenna)	Applied over trace, surface-water mitigation (Sec. 3.3)	$0.03 (est., unverified)
Schottky diode	Zero-bias, HSMS-2850 or equivalent	$0.12
Matching network (LC)	Passive, SMD, 433/866 MHz dual-band	$0.06
Rate-limiting mechanism	Silicone dashpot + contact tab, food-grade (Sec. 3.5)	$0.20 (est., unbuilt — no vendor quote yet)
Silicone overmold	IP68+, shock-resistant, food-grade where bite-accessible	$0.45
TPU wrist strap	Adjustable, food-grade	$0.35
FHE assembly	Roll-to-roll, automated	$0.30
Total		≈ $1.99 (unverified supply-chain estimate)

All costs are Z-Lab desk estimates, not confirmed vendor quotes. The rate-limiting mechanism line is a rough placeholder pending a real bill of materials once a working prototype exists.

4 · RF Link Budget and Operational Ranges

All range figures are calculated from first principles using the Friis transmission equation with medium-dependent attenuation coefficients. Transmitter power is 50 W throughout, representing a realistic portable ground unit or drone-mounted illuminator. **These figures remain theoretical** — they depend on the diode detection threshold (Sec. 2.4) and dry-antenna assumption (Sec. 3.3), neither of which has been empirically confirmed.

4.1 · Range by Environment

Environment	Fwd. link	Ret. link (theoretical)	System range	Medium notes
Open air / drone	167 m	9,365 m	167 m	a = 0.0 dB/m
Void pocket in debris	14 m	28 m	14 m	a = 1.5 dB/m
Dry rubble / brick	12 m	22 m	12 m	a = 2.0 dB/m
Dry soil / sand	9 m	15 m	9 m	a = 3.0 dB/m
Wet soil / mud	4 m	7 m	4 m	a = 8.0 dB/m
Dense wet concrete	2 m	4 m	2 m	a = 15.0 dB/m

Return-link column is a mathematical upper bound, not an operational range figure (Sec. 2.2). *It is included only to show the forward link is always the binding constraint (System range = Fwd. link in every row). Do not plan search sweeps around the return-link numbers. All figures assume a dry, unobstructed antenna (Sec. 3.3) and the theoretical diode threshold (Sec. 2.4).*

4.2 · Optimised Configuration (v1.0 → v2.0 Baseline Carried Forward)

Environment	Baseline (v1.0, 900 MHz)	Optimised (433 MHz)	Improvement
Open air / drone	167 m	693 m	×4.1
Void pocket in debris	14 m	20 m	×1.4
Dry rubble / brick	12 m	16 m	×1.4
Dry soil / sand	9 m	12 m	×1.4
Wet soil / mud	4 m	5 m	×1.3
Dense wet concrete	2 m	3 m	×1.3

The 20 m figure is valid only for the void-pocket scenario — an air gap around the body, the realistic condition for a conscious victim in collapsed structural debris. In continuous wet soil, the realistic range is 4–12 m depending on soil conductivity.

4.3 · Drone Sweep Parameters (New)

Two distinct drone operating modes are specified for different phases of a search, reflecting different constraints:

Free-flying drones — wide-area sweep (Tier 1–2). Altitude is bounded above by the forward-link range in Sec. 4.1 (bay cao h■n ph■m vi kích ho■t thì không còn ■■ công su■t t■i wristband); there is no RF-safety reason to fly higher, since 50 W at 433 MHz poses no exposure risk at any altitude relevant here — the altitude ceiling is purely a link-budget constraint, not a safety one. Sweep speed is bounded by **dwell time**: the matched filter needs to observe several full periods of the keyed signal (Sec. 3.5) while the wristband remains within the illumination footprint, i.e. max sweep speed ≈ footprint diameter / (N × nominal keying period), where N ≈ 5–10 cycles is recommended for reliable detection. This calculation is not yet parametrized with a specific drone platform, altitude, or antenna beamwidth — it is a formula for implementers to apply with their own equipment, not a fixed number.

Tethered / ground-fed drones — pinpoint monitoring (Tier 3). Once a suspected location has been identified by other means (Tier 1–2 sweep, canine, acoustic, or satellite cueing), a tethered drone or fixed mast provides continuous 50 W transmission without battery-life limits, a stable high-bandwidth low-latency data link to a ground processing station, and a near-stationary position that removes the dwell-time constraint entirely, at the cost of a limited coverage radius (typically the tether length, ~50–150 m) and the need to physically relocate the ground station to cover a wider search area. This mode is intended for sustained, high-confidence monitoring of one location, not initial area search.

5 · Sensitivity Analysis and Passive Optimisations

5.1 · Passive Optimisation Summary

Optimisation	Mechanism	Gain	Added cost
Diode impedance matching	Passive LC, dual-band 433/866 MHz	+8 dB (theoretical)	< $0.06
433 MHz vs 900/1575 MHz	Lower frequency, better soil penetration	+6 dB	$0
Van Atta array geometry	Retroreflective conjugate pairs	+6 dB (dry)	$0
Narrowband fixed-rate keying	BW reduction via fixed keying period vs. voice reference	+7 to +25 dB (rate-dependent)	$0
Total (nominal)		+27 dB (theoretical, pending validation)	< $0.06

5.2 · Keying Rate and Processing Gain

Processing gain scales with the narrowness of the receiver bandwidth relative to a 3,400 Hz voice-reference bandwidth: PG = 10·log10(3400 / BW_key). Range multiplier is derived from gain in dB as 10^(PG_dB / 20), consistent with an amplitude (voltage) ratio interpretation. The table below corrects an arithmetic error present in the v2.0 document, where the 2 Hz row listed a multiplier of ×281 — inconsistent with the formula and out of sequence with the adjacent rows. The corrected value is ×28.

Reference rate	Bandwidth	Gain vs. voice	Range multiplier
Voice (reference)	3400 Hz	0 dB	×1
Fast keying	20 Hz	+22 dB	×13
Nominal keying (design target)	10 Hz	+25 dB	×18
Slow keying	4 Hz	+29 dB	×28 (corrected from ×281 in v2.0)
Slowest observed keying (deep burial, fatigued activation)	2 Hz	+32 dB	×40

These rows describe a range of possible keying bandwidths depending on mechanism tuning (Sec. 3.5) and are no longer tied to a victim's manual WPM, since the fixed-rate mechanism — not the victim — now determines the keying period.

5.3 · Field Calibration Protocol (New)

Z-Lab has no access to site-specific structural-vibration or RF-clutter data for any given disaster environment, and does not attempt to supply a universal constant for either the detection threshold (Sec. 2.4) or the keying frequency. Debris composition, ambient wind conditions, standing water, and nearby generator/pump equipment vary by event and by country, and produce different background vibration spectra that could coincide with a poorly-chosen fixed keying rate. This is deliberately left as a protocol for the deploying NGO or government R&D unit to execute locally, using their own equipment and site access:

1. **Baseline survey.** Before search operations begin (or in a representative unaffected area), sweep the target frequency band with the scanner and record the ambient vibration/clutter spectrum from debris, wind-loaded structures, and any nearby machinery.

2. **Frequency selection.** Choose a keying rate/tolerance window (Sec. 3.5) that avoids the strongest peaks in the measured baseline spectrum, rather than assuming the nominal 2–10 Hz range used as a design default in this document is clutter-free at every site.

3. **Waveform discrimination.** Where the scanner supports it, match on keyed waveform shape (duty cycle, edge steepness) in addition to frequency — natural debris vibration is expected to produce damped or asymmetric waveforms rather than a clean fixed-duty-cycle square pattern, which improves discrimination beyond frequency matching alone.

4. **Repeat-scan confirmation.** Treat a single detection as provisional. A tentative detection should be re-observed at the same coordinates after an interval; wind-driven debris noise is expected to vary between scans, while a genuine activated mechanism should reproduce a consistent pattern.

5. **Local documentation.** Record the site-specific parameters chosen (frequency, tolerance window, SNR threshold used) so they can be reviewed and reused for subsequent operations in similar terrain, and so that any false-positive/false-negative outcomes can be fed back into future calibration.

6 · Operational Escalation Matrix

PRRS operates across three tiers of increasing search depth. Each tier uses the same wristband; only the rescue-side equipment and platform change.

Tier	Scenario	Mechanism	Platform	Range
1	Open flood / surface isolation	Fixed-frequency keyed 2f backscatter, direct detection	Free-flying drone, ground unit, or vehicle-mounted illuminator	167 m (theoretical) activation; several km line-of-sight scanner range
2	Mudslide / light debris void	Fixed-frequency keyed 2f backscatter, area scan pattern	Free-flying drone, wide sweep	14–45 m
3	Deep burial / collapsed structure — pinpoint	Sustained 2f keyed monitoring at a suspected location	Tethered / ground-fed drone or fixed mast (Sec. 4.3)	3–20 m subsurface

6.1 · Frequency Plan

Link	v2.0	v3.0	Notes
Primary illuminate	433 MHz (ISM)	433 MHz (ISM)	No change
Deep search	900 MHz	900 MHz	No change — adequate soil penetration
Primary return	866 MHz (2f)	866 MHz (2f)	Follows 433 MHz fundamental
Deep return	1.8 GHz (2f)	1.8 GHz (2f)	Follows 900 MHz fundamental
Receiver / keying bandwidth	10 Hz (fixed Morse rate assumption)	Site-calibrated (Sec. 5.3), nominal 2–10 Hz	Now tunable per deployment, not a global constant

6.2 · Regulatory and Power Framing (Corrected)

v2.0 stated that 433 MHz "requires no individual license in most jurisdictions." This is misleading at the 50 W transmit power specified in this document: most national ISM allocations at 433 MHz permit unlicensed operation only at power levels several orders of magnitude below 50 W (commonly tens to hundreds of milliwatts ERP). **This document does not claim 50 W operation at 433 MHz is unlicensed spectrum use under normal peacetime regulation.** The intended operating basis is a declared-disaster emergency spectrum exemption or coordination with the relevant national telecommunications/emergency-management authority at the time of deployment, consistent with practice seen in recent large-scale disaster responses. Responsibility for confirming the applicable legal basis in a given country and event rests with the deploying agency, not with this specification.

Human RF exposure limits for bystanders and rescue personnel operating equipment at close range over extended, repeated shifts are a separate, purely practical consideration (distinct from victim exposure, where the priority is unambiguous) — deploying agencies should maintain a reasonable operator standoff distance from the transmit antenna where practical, particularly for personnel running multiple shifts across a multi-day operation.

7 · Limitations

The following limitations are stated explicitly and are not subject to optimisation within the current design constraints. Several replace or extend the v2.0 limitations list in light of the corrections in Sec. 0.

Limitation	Detail
Diode threshold is theoretical	The –18 dBm detection threshold (Sec. 2.4) approximates a continuous conversion-efficiency curve and has not been empirically validated against a specific diode lot or temperature range.
Return-link range has no operational meaning	The theoretical return-link figures in Sec. 4.1 exceed the forward-link range in every scenario and should not be used to plan scanner positioning or search sweeps.
Antenna performance under full immersion is unverified	The hydrophobic coating (Sec. 3.3) mitigates surface water contact but has not been validated for sustained submersion; range figures assume a dry or briefly-wet antenna.
Rate-limiting mechanism is unbuilt	The dashpot-based activation mechanism (Sec. 3.5) is a concept-level design pending breadboard validation; nominal 3–5 s period and temperature drift behaviour are unconfirmed.
Minimum activation force is undetermined	No data yet exists on the minimum force an injured, exhausted, or crush-syndrome victim can reliably apply; this is a clinical/field question outside Z-Lab's scope, flagged for partner input.
No RF clutter baseline exists	Z-Lab has not collected, and does not claim to possess, site-specific structural-vibration or RF-noise data for any disaster environment; Sec. 5.3 defines a protocol for deploying agencies to collect this locally.
TX power governs range	Range scales with the square root of transmit power in the link budget model; 50 W is treated as the practical portable/tethered limit for this design.
No two-way communication	The wristband cannot receive. No acknowledgment signal reaches the victim.
Metal clutter and natural nonlinear junctions produce false 2f returns	Urban rubble contains natural nonlinear junctions (rusted joints, loose rebar contact) that can generate harmonic reflections; waveform discrimination and repeat-scan confirmation (Sec. 5.3) are the primary mitigations, not classification software.
Scanner hardware not specified	The rescue scanner, including its matched-filter implementation and field calibration UI, is a separate deliverable not defined in this document.
Cost figures are desk estimates	The BOM (Sec. 3.7) has not been confirmed against real vendor quotes, particularly for the newly-added rate-limiting mechanism.

8 · Conclusion

PRRS v3.0 presents a passive, zero-battery wristband device that enables disaster victims to signal active engagement to rescue forces using only mechanical energy, without depending on the victim's ability to produce a specific timed pattern. The operating principle — Schottky diode harmonic backscatter, keyed by a mechanical rate-limiting mechanism — is physically plausible and requires no novel active components, but several of its key parameters (diode threshold, wet antenna behaviour, and the rate-limiting mechanism itself) remain theoretical or unbuilt and are flagged accordingly throughout this document rather than presented as validated.

The system's differentiator from existing harmonic-reflector technology (Recco and derivatives) is a keyed signal indicating active engagement, combined with an explicit graceful-degradation design goal: the inability to activate the mechanism never removes the underlying passive detectability. The next milestones are, in order of priority: (1) breadboard validation of the rate-limiting mechanism (Sec. 3.5), (2) empirical characterization of the diode conversion curve (Sec. 2.4), and (3) field-representative wet-antenna and RF-clutter measurements to replace the theoretical placeholders used in Sec. 4 and Sec. 5.3 with validated data.

Appendix A — Mathematical Notation

Forward link power at wristband:

$P_{rx} = P_{tx}$ [dBm] + G_{tx} [dBi] + G_{rx} [dBi] + $20\cdot\log_{10}(\lambda / 4\pi R) - a\cdot R$ [dB]

Harmonic output:

$P_{2f} = P_{rx} + L_{conv}$, $L_{conv} = -22$ dB (theoretical, Sec. 2.4)

Processing gain:

$PG = 10\cdot\log_{10}(BW_{ref} / BW_{key})$

Van Atta condition:

$l_i = l_{N+1-i}$ for all $i = 1...N/2$ (equal transmission line lengths)

Note (v3.0): *the v2.0 appendix included a "Latency operator (Z-Loop formalism)" equation, $L(I_t) = \min\{k \mid \partial S_{t+k}/\partial I_t \neq 0\}$. That equation belongs to an unrelated framework (see References) and played no role in the RF link budget above. It has been removed from this appendix; the underlying work is cited below for attribution instead.*

References

1. Recco AB. Harmonic radar avalanche rescue system. Commercial product documentation, Sweden.

2. Nguyen. *Z-Loop Laws.* Z-Lab, 31 January 2026. Licensed CC BY 4.0. (Unrelated long-horizon causality framework; cited for attribution only — not used in this document's link budget or technical claims.)