Passive Rescue Radio System (PRRS)

Technical Specification — Version 2.0

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Abstract

The Passive Rescue Radio System (PRRS) is a zero-battery wristband device enabling disaster victims to signal their location and confirm survival to rescue forces through Morse code, 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 button connects or disconnects a zero-bias Schottky diode, producing a detectable ON/OFF pattern at twice the illumination frequency. No power is consumed at any stage of this process.

Version 2.0 corrects three issues identified in the initial concept: (1) the acoustic voice modulation path is removed in favour of Morse-only operation, reducing the required receiver bandwidth from 3,400 Hz to 10 Hz and yielding +25 dB processing gain; (2) the illumination frequency is migrated from 1.575 GHz (GPS L1 — protected band) to 433 MHz ISM, eliminating interference with rescue team navigation and improving soil penetration by approximately 6 dB; (3) the spiral antenna array is redesigned in Van Atta retroreflector configuration, providing +6 dB passive gain through geometry alone. Combined, these changes yield a +27 dB improvement in system link margin with no additional active components.

The critical differentiator from prior systems (e.g., Recco harmonic reflectors) is intentional signaling: a victim who is conscious and wearing PRRS can transmit Morse code, confirming survival, communicating identity, and enabling triage prioritisation. A passive reflector alone cannot provide this information.

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 identity.

PRRS occupies a position between these categories. It is passive in the sense that the wristband requires no battery and no active electronics. It is active in the sense that the victim exercises intentional control over the return signal through a mechanical button. This combination — passive power architecture, active signaling — is the core innovation.

1.1 Comparison with Recco

The Recco system (Recco AB, Sweden, commercial since 1995) employs harmonic backscatter at 917 MHz / 1834 MHz, integrated into ski garments and helmets. It is the closest prior art to PRRS. The physical operating principle is identical: a diode generates a 2nd harmonic reflection when illuminated by an external RF source.

The operational difference is fundamental. Recco produces a continuous, unmodulated reflection. A Recco detector finds a reflector — which may be worn by a living victim, a deceased victim, or may have been separated from the victim entirely. The system cannot distinguish between these cases.

PRRS with Morse keying produces a modulated signal that can only result from deliberate human action at the moment of transmission. A detected Morse pattern confirms: (a) the victim is alive, (b) the victim is conscious, (c) the victim is at that location at that time. In a mass-casualty scenario, this distinction directly determines rescue prioritisation and resource allocation.

Capability	**Recco**	**PRRS v2.0**
Detects presence	Yes	Yes
Confirms survival	No	Yes
Confirms consciousness	No	Yes
Transmits victim identity	No	Yes (Morse ID)
Enables triage priority	No	Yes
Requires battery	No	No
Requires infrastructure	No	No
Proprietary / licensed	Yes	No — open source
Unit cost	~$2–5	< $2 target

1.2 Design Constraints

PRRS is designed under three non-negotiable constraints. First, zero battery: the wristband may not contain any electrochemical energy source, ensuring indefinite shelf life and eliminating chemical leakage risk in flooded environments. Second, zero active electronics: no transistors, integrated circuits, or powered components of any kind. All signal processing occurs at the rescue end. Third, sub-$2 unit cost: the device must be manufacturable at scale by any facility with access to flexible hybrid electronics (FHE) equipment.

2 Operating Principle

The rescue asset — a UAV, helicopter, or ground vehicle — 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, 2f). The victim controls this return signal by pressing the SOS button, which mechanically disconnects the diode from the antenna circuit, extinguishing the 2f reflection. Releasing the button reconnects the diode, restoring the 2f signal. The resulting ON/OFF pattern constitutes Morse code, decoded by a narrow-band receiver at the rescue end.

2.1 Signal Chain

Parameter	Expression	v2.0 value
Received power at wristband	P_rx = P_tx + G_tx + G_rx + FSPL - a*R	>= -18 dBm
FSPL	20*log(lam / 4*pi*R)	lam = 0.69 m @ 433 MHz
Soil attenuation	a * R [dB]	a = 0-15 dB/m
2f harmonic output	P_2f = P_rx + L_conv	−18 + (−22) = −40 dBm
Scanner noise floor	N = kTB, B = 10 Hz	−164 dBm
Scanner sensitivity	P_min = N + NF + SNR_req	−144 dBm
Processing gain (Morse)	PG = 10*log(BW_voice / BW_morse)	+25 dB vs voice
System bottleneck	R_sys = min(R_fwd, R_ret)	R_fwd always limits

2.2 Why the Forward Link is Always the Bottleneck

Once the Schottky diode is activated at its threshold power (−18 dBm), the 866 MHz 2f harmonic signal departs the wristband at −40 dBm. The scanner receiver sensitivity is −144 dBm, providing 104 dB of return link margin. In all scenarios studied, the return signal reaches the scanner at ranges 3–50× beyond the forward activation range. All optimisation effort should therefore focus on the forward link: maximising the power delivered to the diode per watt of transmitter output.

2.3 Morse Processing Gain

Voice modulation requires a receiver bandwidth of approximately 3,400 Hz. Morse code at 5 WPM (the standard SOS rate) requires only 10 Hz. The processing gain from this bandwidth reduction is 10*log(3400/10) = +25 dB, equivalent to increasing the transmitter power by a factor of 340. At 1 WPM — achievable by a conscious but weakened victim holding the button for longer intervals — the bandwidth falls to 2 Hz and the gain reaches +32 dB. This is the reason voice modulation was removed from v2.0: the simplification is also a substantial performance improvement.

3 Wristband Specification

3.1 Component Changes v1.0 → v2.0

Component	v1.0	v2.0	Effect
Frequency	1.575 GHz (GPS L1)	433 MHz (ISM)	+6 dB soil penetration; GPS conflict resolved
Antenna config.	Spiral slot, random orient.	Van Atta array (8-el.)	+6 dBi retroreflective gain
Antenna gain	2 dBi	5 dBi	+3 dB
Matching network	Unspecified	Passive LC, 433/866 MHz	+8 dB harmonic conversion
Diode conv. loss	−30 dB	−22 dB	+8 dB
Acoustic module	PVDF film (voice)	Removed	+25 dB processing gain
SOS button	Mechanical switch	Mechanical switch	No change
Substrate	Polyimide 1.5 mm	Polyimide 1.5 mm	No change
Waterproof rating	IP68+	IP68+	No change
Battery	None	None	No change
Unit cost target	< $2.00	< $2.00	No change

3.2 Van Atta Retroreflector Array

A conventional antenna array scatters backscattered energy in all directions, most of which does not return to the receiver. 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. The result is automatic retroreflection toward the source, regardless of the array orientation. No switching, amplification, or power is 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.

3.3 Passive LC Matching Network

The Schottky diode harmonic conversion efficiency depends critically on impedance matching at both the fundamental frequency (433 MHz) and the 2nd harmonic (866 MHz). The v1.0 specification did not address this. A passive LC network — two inductors and two capacitors in a standard dual-band ladder topology — achieves simultaneous matching at both frequencies without any active components or power consumption. The improvement from −30 dB to −22 dB conversion loss is equivalent to increasing the transmitter power by a factor of 6.3.

3.4 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
Schottky diode	Zero-bias, HSMS-2850 or equivalent	$0.12
Matching network (LC)	Passive, SMD, 433/866 MHz dual-band	$0.06
SOS button	Conductive silicone, mechanical	$0.15

Silicone overmold	IP68+, shock-resistant enclosure	$0.45
TPU wrist strap	Adjustable, food-grade	$0.35
FHE assembly	Roll-to-roll, automated	$0.30
Total		< $1.91

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 UAV-mounted illuminator. The forward link calculation uses the diode activation threshold of −18 dBm (v2.0). The return link calculation uses the scanner sensitivity of −144 dBm at 10 Hz bandwidth.

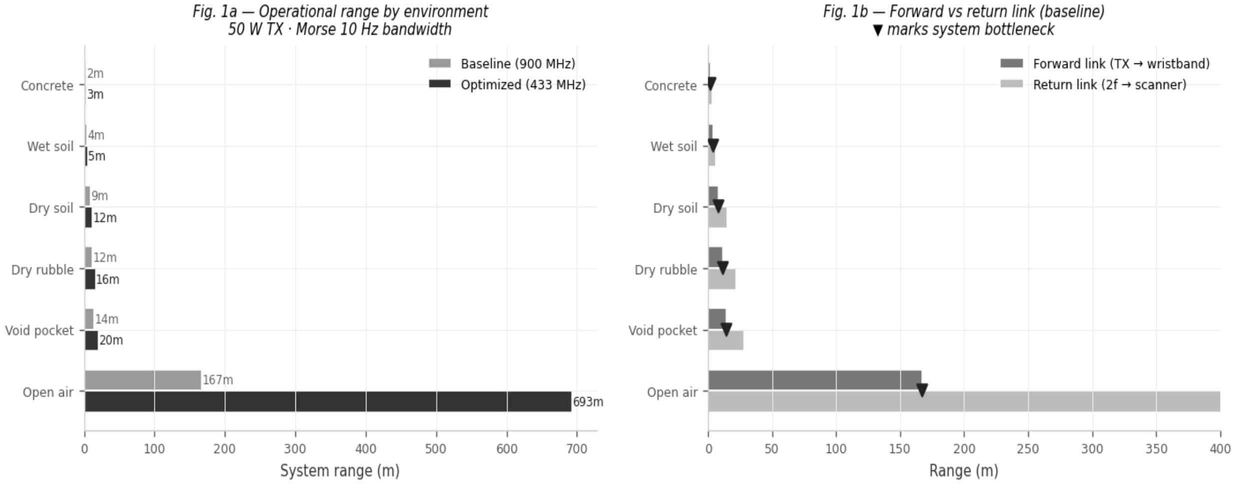

Fig. 1 — (a) Operational range by environment, baseline vs optimised configuration. (b) Forward vs return link ranges for the baseline configuration; triangles mark the system-limiting link in each scenario.

4.1 Range by Environment

Environment	Fwd. link	Ret. link	System range	Medium notes
Open air / UAV	167 m	9365 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

The 20 m figure cited in the v1.0 specification is valid only for the void pocket scenario — a victim with an air gap around the body, which is the realistic condition for a conscious, breathing victim in collapsed structure debris. In continuously wet soil, the realistic range is 4–12 m depending on soil conductivity.

4.2 Optimised Configuration

Environment	Baseline	Optimised	Improvement
Open air / UAV	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

5 Sensitivity Analysis and Passive Optimisations

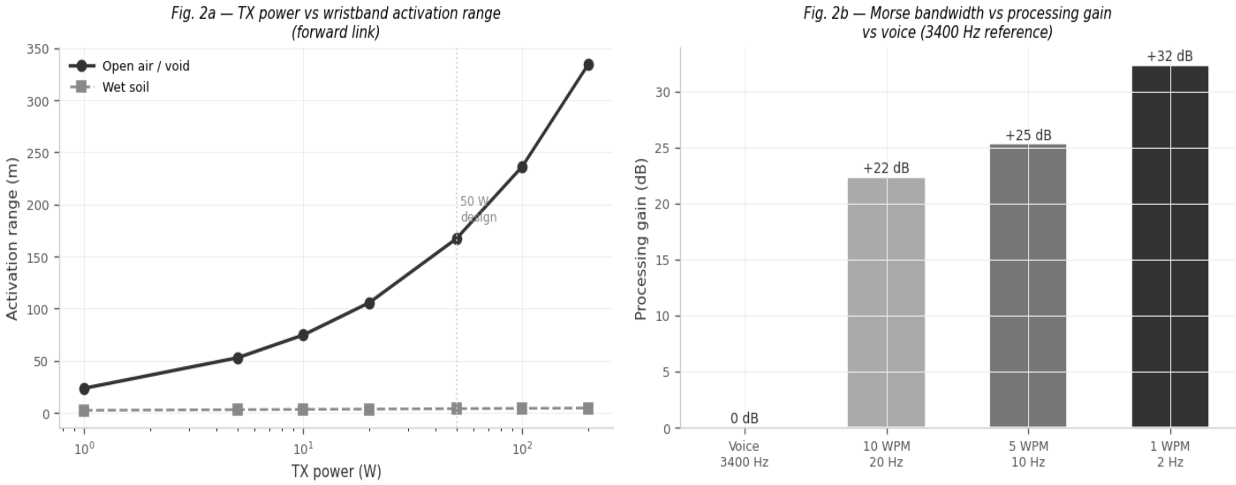

Fig. 2 — (a) TX power vs wristband activation range for void and wet soil scenarios. (b) Processing gain as a function of Morse speed, relative to a voice-bandwidth receiver.

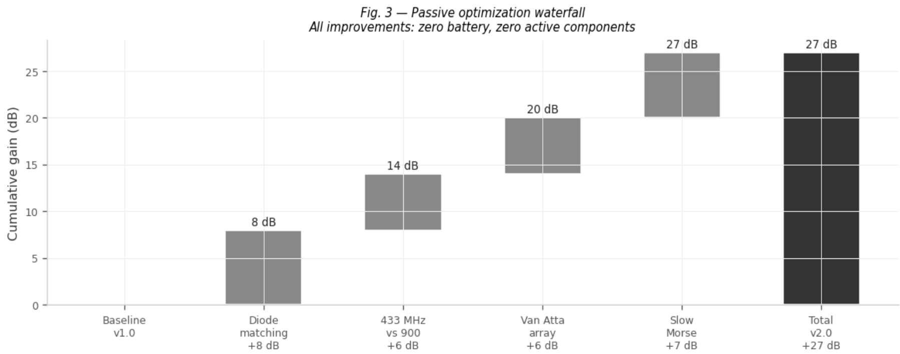

Fig. 3 — Cumulative passive optimisation waterfall. All four improvements require no active components and no battery.

5.1 Passive Optimisation Summary

Optimisation	Mechanism	Gain	Added cost
Diode impedance matching	Passive LC, dual-band 433/866 MHz	+8 dB	< $0.06
433 MHz vs 900/1575 MHz	Lower frequency, better soil pen.	+6 dB	$0
Van Atta array geometry	Retroreflective conjugate pairs	+6 dB	$0
Slow Morse (1 WPM)	BW: 10→2 Hz, integration window	+7 dB	$0
Total		+27 dB	< $0.06

5.2 Morse Speed and Processing Gain

Speed	Dot duration	Bandwidth	Gain vs voice	Range multiplier
Voice (reference)	—	3400 Hz	0 dB	×1
10 WPM	120 ms	20 Hz	+22 dB	×13
5 WPM (SOS)	240 ms	10 Hz	+25 dB	×18
2 WPM	600 ms	4 Hz	+29 dB	×28

1 WPM (deep burial)	1200 ms	2 Hz	+32 dB	×40

The range multiplier applies to the return link only. The forward link (wristband activation) is independent of Morse speed and depends solely on TX power and medium.

6 Operational Escalation Matrix

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

Tier	Scenario	Mechanism	Frequency	Range
1	Open flood / surface isolation	RF backscatter Morse direct	433 MHz illuminate 866 MHz return	167 m activate 2–5 km LoS
2	Mudslide / light debris void	2f Morse backscatter NLJD pattern scan	433 MHz primary	14–45 m
3	Deep burial collapsed structure	2nd harmonic NLJD pinpoint location	433 or 900 MHz (deep penetration)	3–20 m subsurface

6.1 Frequency Plan — v1.0 vs v2.0

Link	v1.0	v2.0	Reason
Primary illuminate	1.575 GHz (GPS L1)	433 MHz (ISM)	GPS L1 is protected — causes rescue GPS interference
Deep search	900 MHz	900 MHz	No change — adequate soil penetration
Primary return	3.15 GHz (2f)	866 MHz (2f)	Follows 433 MHz fundamental
Deep return	1.8 GHz (2f)	1.8 GHz (2f)	Follows 900 MHz — no change
Receiver BW	3400 Hz (voice)	10 Hz (Morse)	+25 dB processing gain

Note on GPS L1 conflict. The 1.575 GHz band is allocated to GPS L1 and is actively used by rescue helicopters, ground vehicles, and coordination units during SAR operations. Transmitting 50 W at this frequency in a disaster zone risks degrading or disabling GPS navigation for the rescue team itself. The migration to 433 MHz ISM eliminates this conflict entirely. 433 MHz requires no individual license in most jurisdictions and is widely available in low-cost RF hardware.

7 Limitations

The following limitations are stated explicitly and are not subject to optimisation within the current design constraints.

Limitation	Detail
20 m claim is conditional	Valid only for void pocket scenario. Continuous wet soil: 4–12 m.
TX power governs range	Range scales as √P_tx. 50 W is the practical portable limit.
Consciousness required for Morse	Unconscious victims produce only a continuous 2f reflection — location only, no Morse.
No two-way communication	Wristband cannot receive. No acknowledgment signal reaches the victim.
Metal clutter produces false 2f	Urban rubble contains natural nonlinear junctions. Scanner operator must discriminate.
Victim ID not yet specified	Pre-coded Morse ID pattern requires a manufacturing convention not defined in this document.
Scanner hardware not specified	Rescue scanner is a separate deliverable. Interoperability protocol is not yet defined.

8 Conclusion

PRRS v2.0 presents a passive, zero-battery wristband device that enables conscious disaster victims to transmit Morse code to rescue forces using only the mechanical energy of a button press. The operating principle — Schottky diode harmonic backscatter modulated by mechanical switching — is physically proven and requires no novel components. The three corrections applied in v2.0 (frequency, antenna geometry, matching network) collectively improve the link margin by 27 dB through purely passive means.

The system's primary differentiator from existing harmonic reflector technology (Recco and derivatives) is intentional signaling. A detected Morse transmission constitutes confirmation of life at a specific location at a specific time. This information cannot be obtained from a passive reflector alone and has direct consequence for rescue prioritisation in mass-casualty events.

The next milestone is prototype fabrication and empirical validation of the forward link range figures across representative debris media. Clutter rejection methodology for the rescue scanner constitutes the primary open technical problem.

A Appendix — Mathematical Notation

Forward link power at wristband:

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P_rx = P_tx [dBm] + G_tx [dBi] + G_rx [dBi] + 20*log10(lam/4*pi*R) - a*R [dB]
```

Latency operator (Z-Loop formalism, for reference):

```
L(I_t) = min{ k | dS_{t+k}/dI_t != 0 }
```

Harmonic output:

```
P_2f = P_rx + L_conv, L_conv = -22 dB (v2.0)
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Processing gain:

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PG = 10*log10(BW_voice / BW_morse) = 10*log10(3400/10) = +25.3 dB
```

Van Atta condition:

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