A COMPREHENSIVE TESTING TOOLKIT FOR AVALANCHE RESCUE TRANSCEIVERS

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ABSTRACT: The goal of the MountainSafety.info Avalanche Rescue Transceiver Testing Toolkit is to provide to anyone with some technical background interested in performing an objective test of one or multiple avalanche rescue transceivers. Independently if you are an institution which needs to make a purchasing decision on a larger number of transceivers, an outdoor magazine which would like to provide to its readers a trustworthy comparative test of the devices currently on the market, or you are simply an interested individual, this toolkit will provide you with a comprehensive collection of tests. The toolkit was designed to reduce the overall testing time by cleverly combining a limited number of individual tests. The governmentally enforced European Standard EN ETS 300718 covers the fundamental safety requirements and ensures compatibility between all devices sold, independently of the brand and model. Certification to EN ETS 300718 includes complex, expensive testing of mechanical, electrical and electromagnetic properties, requiring very specialized, costly equipment and expertise. While EN ETS 300718 covers fundamental safety and compatibility requirements, the Avalanche Rescue Transceiver Testing Toolkit allows to determine what makes the difference between a “device compliant to the bare legal minimum” and an “effective search device with standardized key user interface functionality and design, providing a high level of compatibility to modern search protocols, and additional user safety provided by supplementary functions and criteria”. The toolkit includes a definition of the formal criteria of a clean testing environment followed by individual tests covering: (1) search strip width, (2) limitation of highest distance indication, (3) distance indication scale, (4) deep burials and 3d topography of the debris, (5) marking feature, (6) group check, (7) safety criteria for automatic revert to SEND features, (8) user guidance in specific search phases and (9) standardization of key terminology and symbols.

KEYWORDS: avalanche rescue, transceiver testing, avalanche beacon, search strip width, group check, user interface

1. INTRODUCTION

The European ETSI EN 300 718 (ETSI, 2021) standard for avalanche rescue transceivers regulates fundamental safety and compatibility requirements. These requirements are indispensable, but they leave many criteria undefined which make the difference for a high performance avalanche transceiver with a high level of compliance to modern search and safety protocols. Question faced by a purchasing institution, training organization, technical reviewer, or individual user trying to test a specific transceiver or compare different products require an additional set of quality and performance criterion or testing toolkit.

Concerning real performance of a product in companion or organized rescue, meaningful differences are all within criteria which are well above the minimum requirements imposed by ETSI EN 300 718. This includes : search strip width, the stability and reliability of the first distance and direction indication, guidance and reliability of distance indication in specific areas of the three-dimensional electromagnetic field geometry, marking performance the stability of the content of the list of buried subjects, the reliability and usefulness of a group-check function in detecting faulty products, the safety logic of automatic revert to SEND as well as user interface and terminology coherence with modern search and safety protocols. Earlier work demonstrated based on large field tests that the difference in performance of products on the market is considerable (Schweizer et al., 2012).

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https://doi.org/10.15788/1790098872

A reliable and trustworthy testing protocol requires the test environment, test setup, transmitter signal, device orientation, timings, test duration and number of repetitions as well as pass/fail criteria to be well defined and controlled. The MountainSafety.info Avalanche Rescue Transceiver Testing Toolkit was developed as a systematic, modular protocol which allows to test and compare performance characteristics which are relevant for an effective and reliable search for buried subjects.

2. SCOPE AND DESIGN PRINCIPLES

2.1 *Regulatory relationship*

The toolkit does not replace certification to ETSI EN 300 718. Regulatory conformity assessment requires specialized equipment and expertise for radio-frequency, electrical, electromagnetic and mechanical laboratory testing. The toolkit begins where that baseline ends: it evaluates operational performance and interface behavior that make a difference in search performance and ease of use of devices which fulfill ETSI EN 300 718.

2.2 *Intended users and interpretation*

The protocol is intended for technically interested testers who are willing to strictly adhere to a rigid test protocol. Likely users include public or private organizations making fleet purchases, outdoor publications undertaking comparative reviews, training bodies, and technically experienced individuals.

2.3 *Protocol construction*

Development focused on four principles: outcome relevance, reproducibility, efficiency, and architectural neutrality. Fixed geometries and timing windows make outcomes auditable. Related observations are combined where possible, and explicit exceptions are limited to cases with a technical rationale, such as raw analog search modes. The draft procedures were discussed with experienced transceiver development engineers from multiple manufacturers; the final responsibility for the protocol and the thresholds remains with the author.

3. TEST ENVIRONMENT

3.1 *Why a clean outdoor field is required*

Reliable, reproducible testing requires an outdoor site that fulfills the following criteria:

The test site must be at least 500 m away from high-voltage power lines >50 kV and at least 300 m from high-voltage power lines lines ≤50 kV; more than 200 m from other electrical or communication lines; more than 500 m from radio or telecommunication base stations and repeaters; more than 200 m from high-voltage electric-fence wire; more than 150 m from metal cables, pipelines, guardrails, or similar installations; and more than 50 m from communication devices or other electronics. A simple stopwatch may be used only after confirming that it does not add noise or pulsed interference. Conditions associated with strong thermal uplift and atmospheric electrostatic loading are avoided.

An analog transceiver with a coaxial maximum range at least equal to that of the unit under test is kept at maximum sensitivity as an interference monitor. If interference is evident, the affected trial is invalidated and repeated; it is not counted as a fail result on the test procedure. This distinction prevents an uncontrolled site artifact from being converted into a negative product result.

3.2 *Reference equipment and geometry*

Reference transmitters should operate at 457 kHz +/- 10 Hz with a field strength of 2.1 mA/m at 1 m, a period of 1000 ms +/- 10%, and a pulse length of 100 ms +/- 10%. Alkaline batteries are used and the indicated charge is at least 85%. Period and pulse length are verified with suitable equipment or a validated diagnostic function. The transmitting antenna axis and the tested receiver's forward-reference direction are identified before testing. Unless otherwise stated, transmitter and receiver are held 1 m above ground on non-metallic supports; a low-friction, non-metallic receiver platform can improve positional control. Firmware version, battery state, specimen identifier, weather, and site observations are recorded.

4. TEST MODULES

4.1 Search strip width

The first module determines a realistic maximum range under repeatable field conditions and converts it to a search strip width. The transmitter and receiver are placed in coaxial coupling with the receiver antennas in the horizontal plane. Receiver position A is aligned with the transmitter (0 degrees); positions B and C rotate the receiver -45 degrees and +45 degrees. An initial distance is derived from the manufacturer's stated search strip width divided by 1.2 for a non-digital receiver, 1.3 for a digital receiver with one receiving antenna, or 1.4 for a digital receiver with two or more receiving antennas, with a further 10% distance allowance. At position A, after 30 s of stabilization, at least 80% of reference-transmitter pulses must be recognized during 60 s. Distance-indication stability is then observed in ten consecutive one-minute windows.

The mean displayed value and a rounded +/-10% band are calculated. Within a maximum of 10 min, a six-minute interval must contain five compliant minutes with no more than one intervening minute outside the band. At positions B and C, a usable directional indication must occur within 60 s and lie within +/-30 degrees, accounting for the angular sectors represented by discrete arrows. If a criterion is not met, the receiver is moved closer and the relevant step is repeated.

Five specimens are used to include unit-to-unit and stray-field variation. The mean of the paired oblique range determinations is the realistic maximum range. Search strip width is calculated as realistic maximum range multiplied by 1.2 +/- 0.1, 1.3 +/- 0.1, or 1.4 +/- 0.1 for the three receiver architectures above, with a minimum acceptance value of 40 m. These architecture-dependent factors reflect prior survival-optimized modeling rather than a single universal range penalty (Genswein et al., 2009).

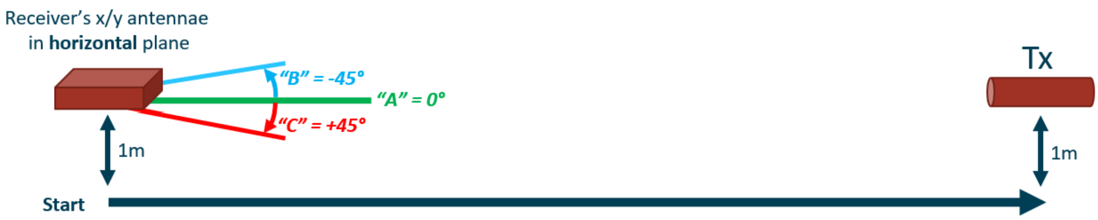

Figure 1: Search-strip-width geometry. Position A aligns the receiver with the transmitter; positions B and C rotate the receiver -45 degrees and +45 degrees. Both devices are held 1 m above ground on non-metallic supports.

4.2 Highest distance indication

Very weak signals beyond a receiver's useful range can generate brief, premature distance or direction indications. If these are presented as established search information, they may divert the rescuer or create false confidence. This module begins at realistic maximum range plus 50% and uses ten trials. In phase 1 the receiver remains stationary for 60 s; every displayed or updated distance/direction indication is counted, and timing pauses while an indication remains visible. In phase 2 the tester approaches at 1 m/s. A transition interval from realistic maximum range plus 8 m to plus 5 m is marked on the ground. Across ten trials, no more than five premature indications are permitted in phase 1 and no more than five in phase 2 after deducting up to three indications occurring inside the transition phase. Any false positive must disappear within 3.9 s. The rule applies to normal user-facing digital search modes. Analog and equivalently raw specialist modes are exempt because their purpose is to expose minimally processed signal information.

4.3 Distance indication scale

Displayed distance should be conservative enough to support speed control and fine-search decisions. Two ranges are tested. From 75% of realistic maximum range down to 10 m, the start is rounded down to the next 5 m step and observations are made at every 5 m. From 9 m to 0 m, observations are made at every 1 m while a 1 m vertical separation remains. Each position is observed for 60 s. The displayed value must be equal to or greater than physical distance, with no more than three lower indications during each 60 s window. The upper range begins below the most variable acquisition region so that the criterion evaluates the useful search scale rather than marginal detection.

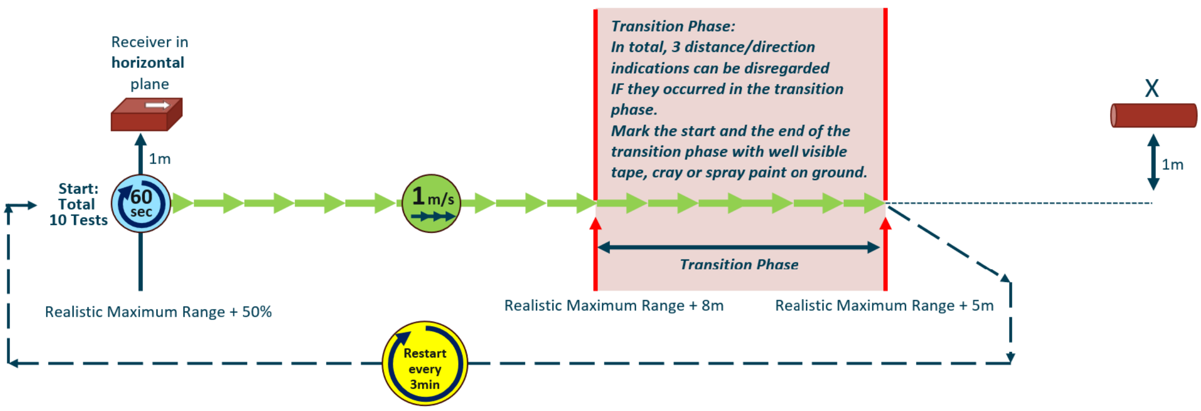

Figure 2: Geometry and timing phases for testing limitation of the highest distance indication. Ten trials start at realistic maximum range plus 50%; the receiver approaches at 1 m/s, with a separately marked transition phase.

4.4 <u>Deep-burial and 3-D geometry</u>

A surface search over uneven debris or a deep burial introduces substantial vertical components into the field-line geometry. The protocol reproduces an equivalent geometry without placing the transmitter at an impractically high or low absolute elevation. The transmitter is offset vertically by 3 m and the receiver is held in the vertical plane. Starting at 10 m on the ground tape, distance readings are recorded every 0.5 m. The indication must decrease at each step. One isolated increase is allowed only if a point 0.2 m closer or 0.2 m farther produces a value below that of the preceding 0.5 m step. The complete sequence is repeated with the transmitter's X, Y, and Z antennas in the defined orientations.

4.5 <u>Marking feature</u>

The marking module uses three transmitters without auxiliary data frequencies. Two are 8 m from the start and 3 m apart; a third is 18 m away. Their periods differ by at least 100 ms and pulse lengths are 100 ms +/- 10%. Within the first 40 s the receiver must recognize two buried subjects. After walking begins at about 0.5 m/s, the first target must be reached and marked within 15 s. Within 3 s after marking, the displayed distance to the second target must be 2.5-4.5 m; that target must then be marked within 10 s. The third transmitter must be recognized within 90 s of the initial start. In a subsequent 180 s observation at the defined position, the receiver must display 8.0 - 15 m for at least 160 s. The sequence tests acquisition, marking, signal suppression, and stable recovery of the remaining signal rather than the mark command in isolation.

4.6 <u>Group check</u>

A group-check function should support a rapid proximity check without silently becoming an unrestricted search mode. In setup A, the tester approaches a reference transmitter; at a displayed or physical distance of 0.5 m or less, the device must warn that a quantitative check is no longer valid. In setup B, two transmitters 3 m apart are viewed from the midpoint at 1.5 m; during 60 s the group-check mode must neither identify a transmitter nor report multiple transmitters. In setup C, two transmitters 2 m apart are viewed from the midpoint at 1 m after a rapid approach from 3 m. A visual multiple-transmitter indication plus an acoustic or voice alarm must occur within 2.6 s; in ten repetitions, one result up to 3.9 s is allowed.

An additional test uses a 456880 Hz transmitter at 2.1 mA/m with full alkaline batteries. The receiver must not give a positive group-check confirmation and must present an out-of-standard warning, even if detection range is reduced. Group check must not be activatable after the device has already entered SEARCH or SEND, and it must include automatic return to SEND to protect against a user leaving the device in check mode.

4.7 Automatic revert to SEND

Automatic revert features should respond to incapacitation without switching during purposeful searching. Test A therefore has the user walk at about 0.5 m/s for 6 min along a 50 m tape with turns of approximately 2 m radius. The receiver must neither warn of nor execute an automatic reversion. Devices offering standby-, backup-, or rescue-SEND functions are tested again in their carrying system. In test B the user lies supine on a hard floor with the receiver on the abdominal area of greatest respiratory movement. After normal breathing allows the pre-alarm to begin at the manual's stated time, deliberately deep and agitated breathing must not cancel the ongoing reversion. The shortest selectable delay is at least 4 min, and the final switch to SEND is preceded by a loud, distinctive alarm.

4.8 Guidance and terminology

The interface test begins at realistic maximum range plus 50% and advances toward a transmitter at about 1 m/s. In signal search, the device must not emit a sound implying that a signal is present. On entering coarse search, and throughout subsequent phases, sound or voice guidance must confirm signal acquisition. A necessary reduction in search speed must be communicated no later than displayed distance 9.9, unless a device directly measures speed and warns only when movement is excessive. Fine search must be made distinct no later than displayed distance 2.0 by a clear change in visual, acoustic, or voice guidance; a field-line direction display must be removed or replaced by a different fine-search symbol or cross.

Safety-critical terminology is then verified. OFF, SEND, and SEARCH are mandatory in English on the case or switches. Mark may be written as text or represented by a flag, but no other mark symbol is accepted. Group Check or CH is mandatory on the screen of a single-language device and may be translated on a multilingual interface. Stand-by SEND and Rescue SEND are recommended terms for the corresponding functions. Consistency reduces the cognitive cost of moving between models, manuals, training systems, and real rescue operations.

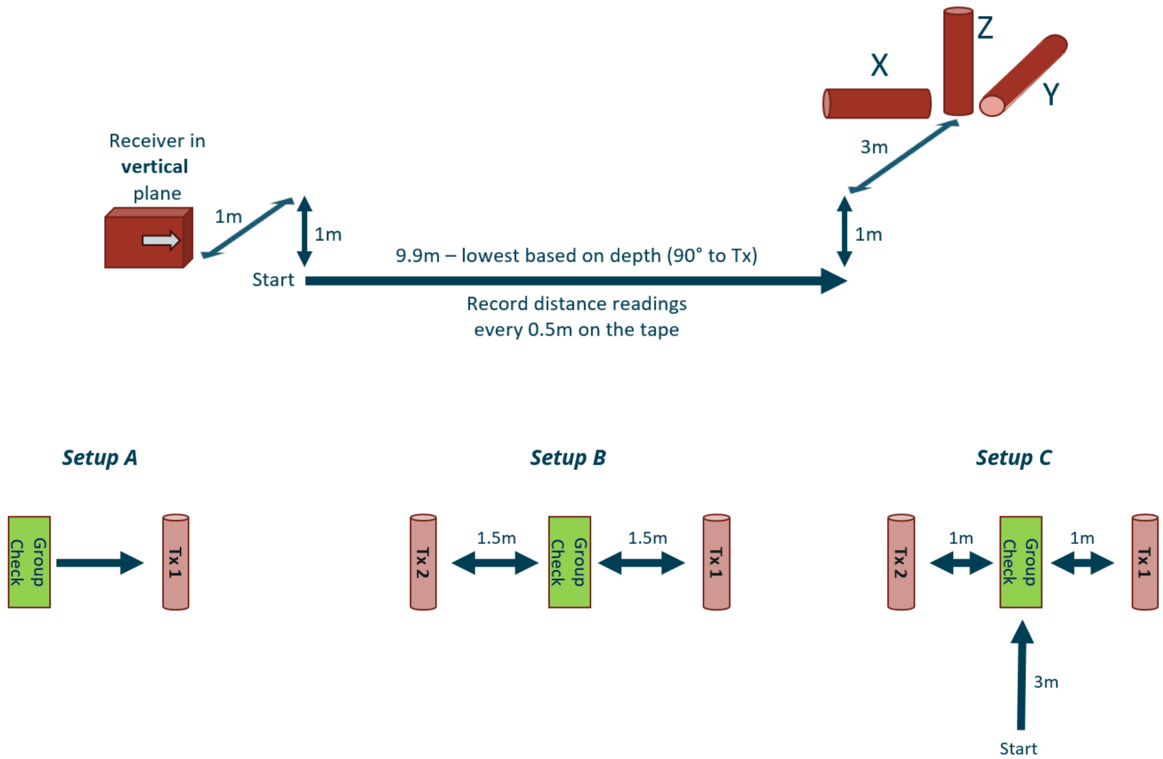

Figure 3: Selected functional test geometries. Upper panel: deep-burial and three-dimensional debris geometry. Lower panel: group-check setups A-C.

5. IMPLEMENTATION AND REPORTING

5.1 *Sequence and division of roles*

The modules are most efficient when executed in sequence. Search-strip-width testing supplies realistic maximum range for subsequent starting positions. Reference-transmitter characterization and site screening are completed once, then rechecked whenever weather, equipment, or nearby activity changes. For long observation windows, three roles reduce error: one tester monitors time and interference, one reads the display aloud without interpreting it, and one records values in a prepared sheet. Roles may be combined only when the measurement can still be observed and documented without missed pulses or timing bias.

5.2 *Repeatability and uncertainty*

Repetition is built into the tests that are most susceptible to signal variability: five receiver specimens for realistic maximum range, ten trials for premature indications, timed windows for display stability, repeated group-check approaches, and all three transmitter axes for the deep-burial geometry. These rules reduce the influence of an specific favorable or unfavorable conditions, such as the timing of the measurement relative to the timing of the transmit signals or specific points in the 3-dimentional electromagnetic field.

6. DISCUSSION

The toolkit's principal contribution is a coherent bridge between regulatory compliance and end-user performance. It covers the search chain from signal acquisition through coarse and fine search, multiple-signal management, pre-tour checking, and safety reversion. The criteria are operational: they specify a geometry, a time window, and an observable output. This makes a result easier to reproduce and challenge than an expert impression such as 'good range' or 'intuitive marking.' It also discourages a comparison in which different products are tested in different orientations, at different sites, or with non-equivalent transmitters.

The search-strip-width module illustrates the benefit of linking tests. A single field sequence establishes pulse recognition, distance stability, directional usefulness, realistic maximum range, and the input needed for the search-strip calculation. The architecture-specific multipliers are consistent with simulation results showing that digital processing and the number of receiving antennas change the relationship between realistic maximum range and survival-optimized search strip width (Genswein et al., 2009). Similarly, the marking test does not stop after a mark icon appears; it continues until the receiver has recovered and stably presents the remaining distant signal, which is the function required by the rescuer.

Several limitations should guide interpretation. First, the outdoor isolation distances make site selection demanding, and a site that is clean on one day may be disturbed by weather on another. Second, human movement and observation remain part of some modules. Defined speeds, prepared records, role separation, and repetition mitigate but do not remove operator effects. Third, firmware can alter interface timing without changing hardware; the tested firmware is therefore part of the result. Fourth, the thresholds are engineering acceptance criteria. Except where supported by earlier survival-optimization work, they should not be interpreted as direct clinical survival cut points.

The protocol is also intentionally narrower than a certification standard. It does not repeat mechanical shock, temperature, battery endurance, spurious-emission, or every other conformity test. It assumes that the device has valid regulatory certification and adds comparative information. Conversely, passing a supplementary user-function test cannot compensate for a regulatory non-conformity.

7. CONCLUSIONS

ETSI EN 300 718 represents the essential common, legally enforced foundation for interoperable avalanche rescue transceivers, but compliant devices can still differ in operational search performance, interface behavior, and supplementary safety functions. The MountainSafety.info Avalanche Rescue Transceiver Testing Toolkit defines a practical, repeatable field method for examining those differences. Its nine modules share controlled reference signals, geometries, timed observations, repetitions, and explicit acceptance rules, while closely related measurements are combined to limit total test time.

The toolkit is best used as a complete, versioned protocol and reported transparently with raw observations, device firmware, site conditions, and any invalidated trials. It is supplementary to, not a replacement for, regulatory conformity assessment. Used within those limits, it provides institutions, technical reviewers, and individuals with a consistent basis for distinguishing minimum legal compliance from effective support for modern avalanche rescue practice.

A detailed step-by-step testing protocol for each module, including options concerning the use of regular transceivers as test transmitters, as well video tutorials on how to perform the tests practically are provided at www.MoutainSafety.info

ACKNOWLEDGEMENTS

The author thanks the avalanche transceiver development engineers Christian Le Goff, Tobias Schädel, Toni Leskela, Wolfgang Platzer, Giang Tran and Daniel Forrer for their technical considerations; the representatives Patrick Giraudon, Hugo Stalder and Patrick Wesch for their application specific and strategic considerations; and Marc Beverly for moderating discussions and providing some organizational support for this workgroup who did not receive any institutional support.

CONFLICT OF INTEREST STATEMENT

No equipment sponsored by manufacturers was used as part of the research project. No financial support or other resources were provided by other organizations.

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