DIGITAL TRANSCEIVING SYSTEMS: THE NEXT GENERATION OF AVALANCHE BEACONS

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ABSTRACT: With the application of digital technology to avalanche transceivers in 1998, the snow safety industry has entered a new era. Forces within the growing backcountry recreation market are driving a rapid transition from analog to digital technology. Digital transceiving systems have shown enormous benefits in several key areas of avalanche rescue: search speed, ease of use, ease of learning, deep burials, and—with recent developments—multiple burials. As this technology increases in sophistication, however, so must industry standards. For avalanche transceiver technology to reach its fullest potential, the existing ETS 300 718 guidelines must be modernized to reflect the higher level of precision endemic to digital design. Tighter transmit pulse guidelines will go far to ease the transition into this new digital era.

KEY WORDS: avalanche rescue, snow slides

1. INTRODUCTION

In the 30 years since avalanche transceivers were first introduced to the market, there has never been such a great leap in transceiver technology as took place in 1998. In December of 1997, the Tracker DTS (Digital Transceiving System) was introduced to the North American market. The product was immediately embraced by the recreational public. Response from North American avalanche professionals was also positive, but was tempered with skepticism. In this paper, we will summarize the market forces driving the development of DTS technology, the unique design features of the Tracker DTS, and the key issues surrounding capture-and-display (digital) versus real-time (analog) transceiver design—including a discussion of the fundamental issue behind the analog-versus-digital debate: obsolete standards for transmit pulse rates.

2. MARKET FORCES

The development of digital transceiving systems is being driven by an increasing target market of recreational backcountry users. While, in the past, expert or professional users (avalanche technicians, mountain guides, professional ski patrols, and search and rescue personnel) comprised a large segment of the market, this percentage has decreased dramatically as a proportion of the total market size. Based on market research by Backcountry Access, Inc. (worldwide distributor of the Tracker DTS), the expert/professional segment now comprises five percent or less of the total aggregate transceiver market. The most significant new entrants to the market include mountaineers, backcountry skiers, backcountry snowboarders, and mountain snowmobilers.

Members of these new market segments tend to have very little experience with avalanche transceivers. They are often first-time transceiver purchasers. And once they have made their initial transceiver purchase, they seldom practice using them. For these growing novice market segments, there has been a substantial pent-up demand for an avalanche transceiver that has a short learning curve and is simple to operate.

Existing analog product offerings may not have satisfied this demand. This is evident in a 1997 report by the Swiss Federal Institute of Snow and Avalanche Research and the International Commission for Alpine Rescue, which determined that existing avalanche beacons were too complicated for the majority of users to use effectively (Brugger *et. al.*, 1997). The report concludes that the most effective transceiver design would offer visual distance and directional displays and would be simple to learn how to operate.

As another example, one needs only to

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look at transceiver pricing history. For the first time in years, recreational users are paying full retail prices for this equipment. Until the 1997-98 season, most outdoor retailers in the U.S. were deeply discounting their transceivers as a way to entice customers to use them. This practice was abandoned with the introduction of digital systems. While avalanche professionals were offered discounts, the Tracker sold at the distributor's full suggested retail price wherever it was offered to recreational consumers. In general, analog beacons continued to be offered to recreationalists at a discount.

3. DESIGN OVERVIEW

Existing transceiver design can be categorized by the way the transceiver processes a signal once it is received. Analog systems process the signal in real-time, meaning they receive the electromagnetic pulse of the transmitting beacon and instantaneously translate that pulse into an audible sound (a modulation in volume) to be interpreted by the searcher. In some cases, this audible data is supplemented with visual information, such as a signal strength indicator. Digital systems, on the other hand, typically capture the pulse, transform it to digital signal information, interpret the signal information with a microprocesser, then primarily present that data visually—with supplemental audible data (a modulation in frequency and pitch rather than volume). With the Tracker DTS, this data is displayed 50 milliseconds after the signal is received.

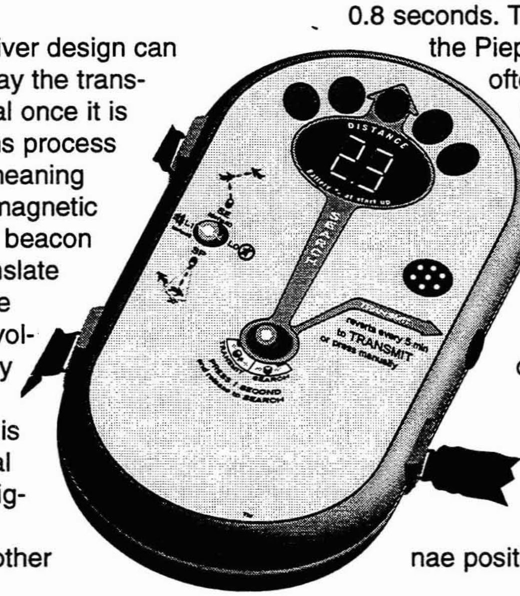

Figure 1. Tracker DTS avalanche transceiver

Digital, or capture/display, transceiving systems include the Tracker DTS and the ARVA 9000. Analog, or real-time, systems include all existing Ortovox, Pieps, Barryvox, and SOS models. The main difference between the two existing capture/display systems is that the Tracker DTS has a three-dimensional antenna system and it displays data digitally throughout its entire receive range. The ARVA 9000 has a single antenna and a digital display range of up to ten meters. Outside that range, visual distance information is not displayed.

3.1 TRACKER DTS DESIGN FEATURES

The Tracker DTS was designed by John Hereford, president and founder of Rescue Technology, L.L.C. of Boulder, Colorado. Following are its key design features.

3.1.1 Transmitter

The Tracker DTS transmits with one antenna only, at the 457 kHz frequency. This antenna is oriented 45 degrees to the long axis of the transceiver case. The transmit pulse repetition rate or "period" is 0.8 seconds, meaning it transmits a continuous series of 457 kHz waves every 0.8 seconds. This is 0.1 second more often than the Pieps Optifinder, 0.2 seconds more often than the Barryvox VS 2000, and 0.5 seconds faster than the Ortovox F1 and SOS F1-ND. This rate is 0.3 seconds slower than the Skadi transceiver, which, in its time, was popular for that reason: a fast "rep" rate provides information to the rescuer more often, creating slightly shorter secondary search times.

3.1.2 Three-Dimensional Antenna

The Tracker DTS has two antennae positioned at right angles to one another within its housing. A "virtual" third antenna is derived from information generated by the first and second antennae. These antennae provide three-dimensional vector analysis, which is controlled by a Microchip PIC microprocessor, also mounted within the housing. This three-dimensional system is unique to the Tracker DTS and is responsible for its precise directionality and its ability to isolate electromagnetic flux lines.

3.1.3 LED Distance/Directional User Interface

The face of the Tracker DTS (Figure 1) provides LED (light emitting diode) readouts to the searcher. These include an arc of five directional LEDs and a numeric distance display. When the center light is flashing, it means the Tracker is aligned with a flux line from the transmitter. When the lights to the left or right of center are flashing, the searcher must rotate the unit in that direction to reacquire the flux line. This ability to break the signal down into fine directional "windows" is made possible by the three-dimensional signal processing system.

The numeric distance display, calibrated in meters, indicates the approximate distance to the transmitter along the flux line engaged in the center search light. This distance reading can be affected by the battery strength of the transmitter and the orientation of the transmitter's antenna. The precision of this display increases with decreasing distance to the transmitter.

3.1.4 Signal-to-Noise Filtration

The PIC microprocessor within the Tracker DTS also contains code which isolates true 457 kHz transmitter pulses from electromagnetic background noise. This microprocessor continuously performs a dynamic measurement of ambient electromagnetic noise along with statistical calculations and other algorithms to determine what is a valid signal. Only the data from signals defined as valid are displayed.

3.1.5 Signal Strength Filtration

In 1998-99 models, the Tracker DTS microprocessor is also programmed to isolate transmit pulses by their relative signal strength. This is performed by detecting the pulse digitally, then setting a hysteresis to which the pulse must conform to be considered valid.

4. KEY ISSUES

Digital transceiving systems are proving to yield major benefits in several key areas of avalanche rescue: search speed, ease of learning, ease of use, deep burials, and multiple burials. While digital systems have their limitations in the area of receive range, there is no technical evidence that this adversely affects search times. With respect to multiple burials, some digital systems have had their limitations. However, software improvements to the Tracker DTS implemented in the autumn of 1998 now appear to have met and exceeded that challenge.

In this section, we will analyze these key issues and how they relate to the differences between capture/display (digital) and real-time (analog) systems. We will limit our discussion of digital systems to the Tracker DTS; production models of the ARVA 9000 were not available in North America during the 1997-98 testing season.

4.1 Search Speed

Secondary search speed appears to have reaped the greatest benefit from the development of digital transceiving systems. Tests in April, 1998 by Nic Seaton of the B.C. Ministry of Transportation and Highways showed that the Tracker DTS produced shorter search times for experienced beacon users under all single-burial scenarios (Seaton, 1998):

Transceivers Tested	**Average Time (30m)**	**Average Time (60m)**
Tracker searching Pieps	.40	1.23
Tracker searching Tracker	.47	1.00
Tracker searching Ortovox	1.06	1.15
Ortovox searching Tracker	1.08	1.27
Pieps searching Tracker	1.11	1.42

Testing by Backcountry Access and the Colorado Avalanche Information Center have yielded similar results. Seaton's data on multiple burials is discussed in section 4.5, below.

The Seaton testing program was performed by professionals who had extensive experience with analog beacons. While novices were not used in these tests, informal testing by Backcountry Access has shown the benefits to be significantly greater among inexperienced recreational users. While such users can often take up to 15 minutes to carry out their first search with an analog transceiver, they average 3 to 4 minutes with a Tracker DTS. These results are similar to those obtained in informal testing on students by course instructors at the Colorado Avalanche Information Center. Tests on novices at Mike Wiegele Helicopter Skiing also yielded similar results, as stated in Seaton's report:

> Tests conducted on inexperienced clientele at Mike Wiegele Helicopter Skiing have shown that when using the Tracker for these basic search techniques, times were decreased dramatically in comparison to the time taken when searching with analog transceivers. Guides conducting these tests felt they could simply tell their clients to "keep the light in the center and go until the distance numbers can go no lower."

4.2 Ease of Use/Ease of Learning

The substantial improvement in search times among novice users of the Tracker DTS are most likely attributed to the intuitive nature of its user interface. The system's precise directionality eliminates gridding from the typical search pattern. Instead, users follow the flux (or induction) line method all the way through the pinpoint phase of the search (Figure 2). Due to the high resolution of its three-dimensional design, very little distance is required for the searcher to realize that he or she is off course. If the searcher deviates from the intended flux line, an LED to the left or right of the center LED indicates which way to turn to reacquire that flux line. Likewise, if the searcher is travelling away from the transmitter, the distance indicator immediately increases, meaning the searcher must turn around and travel in the opposite direction.

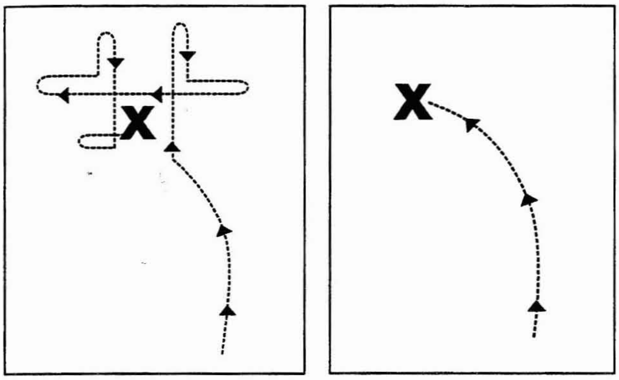

Figure 2. Three-dimensional vector analysis eliminates gridding from the analog search path (left), enabling the searcher to follow the flux line through the pinpoint phase (right).

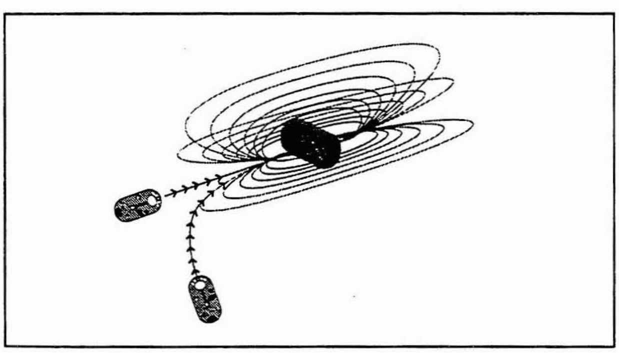

Figure 3. The orientation of the transmitter's antenna will affect the shape of the search path and the distance displayed. Note: the transmitting antenna of the Tracker DTS is oriented at 45 degrees to its long axis, as shown.

In most cases, the Tracker DTS will not lead the searcher to the buried transmitter in a linear path. This is dependent upon the orientation of the transmitter—and the long axis of its flux pattern—when the signal is first acquired (Figure 3). If the transmitter antenna is parallel or perpendicular to the receiver, the search path will follow an arc to the victim. If the transmitter antenna is oriented vertically or in line with the receiver, the searcher will follow a straighter search path. The relative curve of the search path, however, does not appear to have a significant impact on novice search times. The sensation of being "steered" to the transmitter without gridding or losing the flux line appears to be significantly more intuitive to novices than performing grid searches or hybrid flux line/grid searches with analog beacons.

4.3 Receive Range

The receive range of digital transceiving systems is shorter than that of analog beacons. The receive range of the 1998-99 Tracker DTS is 25 to 50 meters (measured in a straight line), depending on transmitter orientation, brand, and battery strength—and the level of ambient electromagnetic background noise. This is for several reasons. First, at 457 kHz, there is a substantial amount of background environmental noise. Relative to the human ear, electronic technology is limited in its ability to distinguish between signals and noise. (Conversely, the human ear is equally limited in its ability to distinguish modulations in volume). In a noisy (urban) electromagnetic environment, the dynamic signal-to-noise ratio determined by the Tracker's microprocessor decreases, lowering the range at which it will display valid signal data. Second, an antenna designed to be portable is less than 0.1 percent efficient when receiving a signal at 457 kHz, which has a wavelength of 650 meters. While this antenna limitation is systemic to all avalanche transceivers, it especially compounds the signal-to-noise issues in digital detection.

This signal-to-noise tradeoff is further compounded by the fact that the international standards on transmit pulse rates are very wide. The current standards mandated by the ETS 300 718 guidelines require a pulse repetition rate or "period" of 0.9 seconds plus or minus 0.4 seconds (Figure 4). This period includes the on time plus the off time of the pulse transmission. The transmission on-time, also called the "pulse width," must be a minimum of 70 milliseconds. The off-time must be a minimum of 200 milliseconds. Consequently, the on-time of currently existing

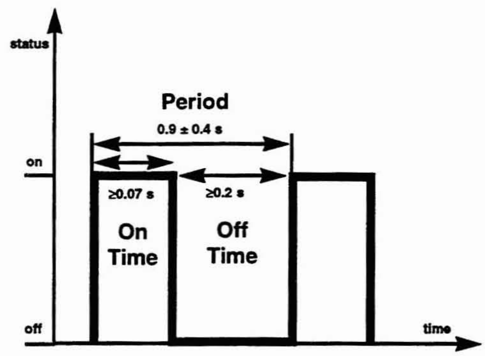

Figure 4. The ETS 300 718 standards on pulse periods and pulse widths are shown above. For an illustration of how widely these standards can vary, see Figure 5, below.

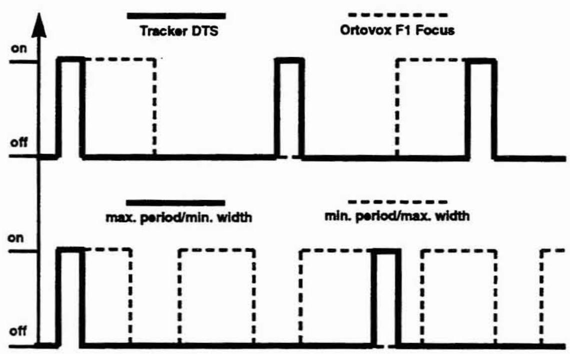

Figure 5. The upper diagram compares the pulse rates of the Tracker DTS and Ortovox F1 Focus. The lower diagram illustrates the widest possible differentiation in pulse rates that could occur under the existing ETS 300 718 guidelines.

avalanche transceiver models now varies from 70 to 400 milliseconds. Under the existing standards, even wider pulse rate differences than this are possible (Figure 5).

When a signal is this poorly defined, it becomes difficult for a computer algorithm to recognize patterns in transmit pulses. The receive range of digital transceiving systems could be significantly increased if their algorithms could be designed around a precisely standardized pulse period, pulse width, and minimum receive range requirement.

However, while receive range is often perceived as an important product benefit, it may have more marketing value than technical significance. Currently, there is no standard for minimum receive range. There is also no technical evidence that the receive range of an avalanche beacon has a significant effect on the speed of a search or the probability of a live recovery.

In a study currently under way by statistician Dale Atkins of the Colorado Avalanche Information Center, provisional data indicates that in small-party avalanche rescues in North America from 1974 through February 1998, 49 percent of buried avalanche victims survived when a shorter-range unit (2275 Hz) was used and 33 percent survived when a longer-range unit (457 kHz) was used. (It should be noted that the sample size for longer range units is limited, due to the relatively recent North American adoption of the 457 kHz standard).

In a 1988 report for the International Snow Science Workshop, Dozier *et. al.* found "no statistical difference between total search times for a 73m unit (Barryvox) and a 29m unit (Skadi)." (Dozier *et. al.*, 1988):

	Primary search		**Secondary search**		**Total search**	
	Mean	Std.	Mean	Std.	Mean	Std.
Skadi	0.47	0.38	2.64	1.44	3.11	1.64
Barryvox	0.15	0.18	2.74	1.47	2.90	1.57

(minutes)

In his 1998 study (see section 4.1, above), Nic Seaton makes a similar determination:

> If you compare the search times of the 30m range to the 60m range it does not appear that the Tracker's shorter range hinders the search times.

While Dozier and Seaton both hypothesize that a shorter receive range might affect (increase) total search times in large slides of 90 meters or greater, this hypothesis has never been tested. However, there is reason to believe just the opposite: that longer-range, lower-resolution transceivers create longer total search times—especially when the information provided in the extended range of the secondary search lacks genuine utility. On the periphery of an analog beacon's receive range, the searcher must cover a relatively large distance before making a determination on signal strength and direction. For novices, this can be extremely time consuming, resulting in unnecessary backtracking and signal interpretation. For such novices, it might very well be less time consuming to continue with the primary search until the signal data can be presented with enough resolution to make quick decisions. This is where the signal-to-noise filtration in digital systems can be seen as a major benefit: it eliminates the "gray area" which can frustrate novice analog beacon users at longer range.

Receive range could very well be an anachronistic product attribute with the changing demographics of the modern transceiver marketplace. The demand for increased receive range was originally stimulated by Swiss search and rescue teams. For this application, in which there is usually no "last seen point," longer range is valuable in identifying or ruling out terrain features to be searched. These operations are almost exclusively body searches: nearly 100 percent of avalanche survivors are rescued by members of their own party (Brugger *et. al.,* 1997). In this case, search speed is not of great importance, except perhaps to minimize the exposure of the rescuing party. But in today's market, comprised primarily of recreationalists, searchers are more likely to be members of the victim's own group seeking to make a live recovery. In this case, search speed and ease of use in a panic situation are of ultimate importance—not range.

4.4 Deep Burials

Deep burial scenarios also appear to be impacted by the development of three-dimensional DTS technology. In these scenarios, the high resolution of a digital, three-dimensional system can provide a faster, more precise determination of the area to be probed.

In the past, deep burials have presented a challenge to analog beacon searchers using the grid pattern to pinpoint buried transmitters. This is now simplified by the Tracker's ability to follow the flux line method through the pinpoint phase of the search. Using the grid method, the analog beacon user will often encounter a so-called "shadow box" effect, particularly with deep burials. Depending on the orientation of the buried transmitter, up to six "false" maximum readings will be encountered in the region surrounding the transmitter, but not directly over it. This is because flux lines curve abruptly in the vicinity of a transmitting beacon's antenna. As the searcher crosses flux lines using the grid method, he or she will momentarily receive "false" stronger signals where the searcher is temporarily aligned with a curving flux line. This is exacerbated when the burial is deep, as the false maximums are received farther away from the transmitter.

To address this issue, expert users will define a "box" of these false maximum readings, then probe for the victim in the "shadow" within that box. This can be time consuming for experts and frustrating for novices, most of whom are not familiar with this technique.

Tracker DTS users can more precisely define the probe area using either of two techniques: the "tilt" or the "extension" method (Figures 6 and 7). Using the tilt method, the searcher follows the flux line to the snow surface by tilting the Tracker into alignment where it reaches its first minimum reading (for an analog beacon, that would be equivalent to a "false maximum"). Then the searcher follows this "tilt angle" to the snow surface, readjusting if necessary to maintain alignment (minimum distance readings) with the flux line. This point might not be directly over the buried transmitter if it is buried deeply and horizontally (the long axis of the flux lines will be approximately parallel to the snow surface, causing the flux lines to intersect the surface farther away than if the burial were vertical). However, the searcher can establish the probe area by extrapolating the

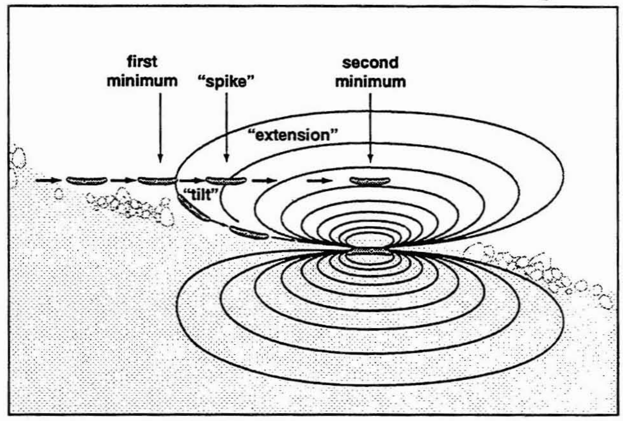

Figure 6. Horizontal Burial. The "tilt" method follows a flux line to the snow surface. The "extension" method pushes past the first minimum in search of a lower, second minimum.

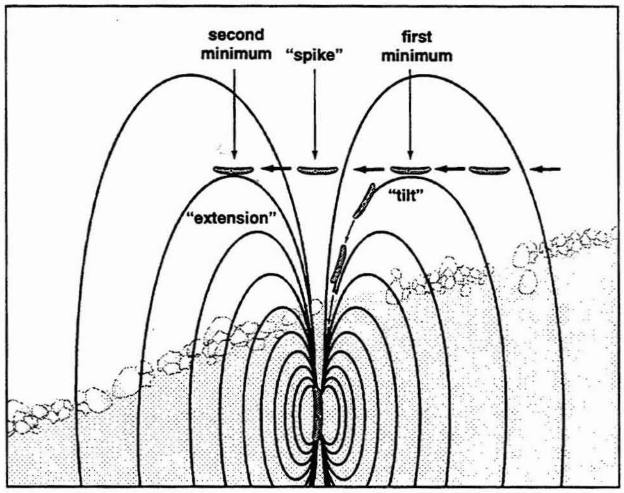

Figure 7. Vertical Burial. The "spike" is directly over the transmitter. Probe here if the second minimum is not significantly lower than the first.

position of the burial using his tilt angle and distance reading.

While the tilt method is faster in most cases, the extension method is more precise for deeper burials. Using this technique, the searcher extends past the first minimum reading in the horizontal plane. Immediately after this first minimum distance reading, he will encounter a false maximum reading or "spike" (the low-volume "shadow" for analog beacons) where the Tracker's antennae are momentarily perpendicular to a flux line. If the distance reading on the other side of this spike is lower than the first minimum, then this is the probe point (the transmitter is buried approximately horizontally). If the distance is not significantly lower, then the probe point is at the spike (the transmitter is buried approximately vertically).

Either method can be significantly more precise—and often faster— than the analog "shadow box" technique. That is because by using the flux line method during the pinpoint phase, the long axis of the antenna has been established. The rescuer is now pinpointing on a line, not on a plane. This reduces the potential number of false minimums (maximums) from six to one.

4.5 Multiple Burials

With the introduction of digital transceiving systems in 1998, some avalanche technicians raised the issue of technological "compatibility" in multiple burial scenarios. Seaton's report suggested that new digital systems might not be fully compatible with analog beacons in multiple burials in which both analog and digital beacons were buried. These concerns should be qualified: First, no data was collected on whether these issues made it any more difficult for novices to use digital systems than analog systems in multiple burials. Second, these issues are more related to pulse rates than to analog-versus-digital technology. However, since Seaton's report in May, 1998, DTS technology has evolved so rapidly that these issues have been substantially mitigated.

In his report, Seaton stated that the Tracker DTS was extremely fast in searching for multiple digital beacons. It was slightly less proficient when searching for multiple analog beacons. When the two were mixed, he reported, search times became inconsistent. Differences in pulse rates between brands sometimes made it difficult for the searcher to break away from a faster transmitter to locate a slower one. Sometimes it was possible for a searcher to "jump" flux lines where they intersected, causing the searcher to return to the beacon already found. While this problem can also occur when using the flux line method with an analog beacon, it is more common, he said, with the Tracker DTS. This is due to its ability to follow flux lines so precisely. (The technique for overcoming the "jumped flux line" at intersections is to recognize patterns in the signals displayed, maintaining the flux curve of your intended search).

While Seaton classifies beacons by analog vs. digital technology, it would be more appropriate to address them by their transmit pulse rates. In Search mode, the 1997-1998 Tracker DTS displayed distance and direction data for all buried transmitters within its range. Just as analog beacons, it would provide this data more often per unit time for a faster transmitter than for a slower transmitter—only, with its high resolution, the differences were much more apparent. A more precise international standard on pulse rates would go far to alleviate such differences.

Also, in 1997-98, the Tracker DTS microprocessor could not receive or process one signal while it was displaying another. This meant that slower pulses were even less likely to been "seen" as often through faster pulses.

In addition to the pulse rate issues in Search mode, Seaton also had concerns about the Tracker's Special mode. This mode is used during multiple burials to isolate transmitter signals so the

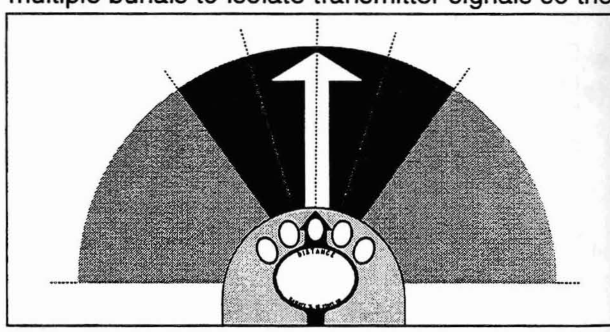

Figure 8. Three-dimensional processing gives the Tracker its precise directionality and its ability to isolate signals. In Special mode, the Tracker's "search window" is reduced to the center three LEDs. Special mode is now used to "unlock" from the closest signal, which now can be isolated in Search mode.

searcher can seek out the flux line of one transmitter at a time (or each rescuer can be assigned to search on each isolated flux line). In Special mode, the Tracker's "search window" is reduced from 360 degrees to 20 degrees, in both directions (Figure 8). This represents the center three LEDs. Distance and directional information is only displayed if the Tracker is pointed within plus or minus ten degrees of a transmitter's flux line. To mask out a signal and isolate another, the searcher rotates the beacon until one signal is outside the 20-degree Special mode search window and the other is inside that window. While Special mode was extremely effective when searching for fast transmitters, Seaton concluded, it was more difficult to use when searching for slower ones. This is because it is possible to pass through the reduced Special mode search window between the pulses of slow transmitters, creating "dead" spots where no data is displayed. In Special mode, the operator must rotate the Tracker slowly to prevent "skipping" past slow transmit pulses.

Recent refinements to the Tracker DTS, however, appear to have substantially mitigated these concerns. The unit's microprocessor can now "multi-task," or receive one signal while it is displaying another. This makes slower pulses more likely to be seen between faster pulses, reducing the incidence of dead spots.

In addition, the Tracker DTS now automatically isolates signals in Search mode by their relative strength. Within 15 meters, it will only display the distance and directional information for the strongest signal. This has two major benefits: First, differing pulse rates no longer compete with each other in Search mode during the critical latter stages of the secondary search. Second, it minimizes the time spent following flux lines in Special mode—which is now only used to "break away" from the closest transmitter once it has been found (assuming it can't be turned off immediately). The searcher now enters Special mode only to isolate the next signal—by position rather than strength—and to get an approximate distance and direction. He or she then breaks away in that general direction for approximately 3/4 of the distance displayed. This positions the searcher close enough to the next beacon so that he or she can then switch back to Search mode to lock in that signal.

Field testing of these improvements during the spring and summer of 1998 showed them to drastically improve the Tracker's performance in multiple burials in which both fast and slow transmitters were buried. However, more precise international standards on pulse periods and pulse widths would permit even greater leaps in performance. With a clearly defined pulse, each transmitter could be assigned an identification number, then be isolated by transmitter ID rather than by signal strength or position. The location of these transmitters could then potentially be displayed to the searcher on a liquid crystal (LCD) display, similar to those found on modern GPS systems.

5. CONCLUSION

Research and development of digital avalanche beacons is in a stage of infancy, but there is no question it is here to stay. Undoubtedly there are still some technological challenges ahead. But with support from the professional snow safety community—and with a new set of international standards—this technology could make huge advances over the next several years that could save scores of lives.

The backcountry recreation market has waited a long time for a transceiver that is easier to learn and easier to use than a conventional analog beacon. Until recently, the only variable keeping digital technology from emerging sooner in this field has been the market's limited size.

With the steady growth of backcountry recreationalism, that time has come. But with the evolution of these markets and the evolution of these technologies, there also must be an accompanying evolution in design standards. Currently in North America, the only existing design standard is the 457 kHz frequency. In Europe, the ETS 300 718 is imprecise. By better standardizing such specifications as pulse periods, pulse widths, and minimum receive range, the designers of the future will be able to harness this emerging technology to its fullest potential—which at this time appears unlimited.

All one has to do is look at the product development that has taken place since May, 1998, when Nic Seaton delivered his report to the Canadian Avalanche Association. The improvements that have been made to the Tracker DTS over those five months are as substantial as any improvements that have been made to analog beacons since they were first introduced in 1968. At this rate, imagine what digital avalanche transceivers would be capable of doing in another five years.

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