SIGNAL STRENGTH VERSUS SIGNAL TIMING:
Achieving reliability in multiple burial searches

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Introduction

In the past decade, great advancements have been made in the field of avalanche transceiver rescue, most notably the worldwide acceptance of digital technology. Since 1997, average rescue times have decreased dramatically,[1] increasing the odds of survival for avalanche victims. But as avalanche beacon technology becomes increasingly sophisticated, it can become less compatible with the existing mass of beacons already in use. This is particularly the case with new digital transceivers that use signal timing analysis to “mark” victims in complex multiple burials. While this system works well under ideal conditions, it can be surprisingly unreliable when searching for certain types of transmitters, especially as the number of victims increases.

Using a combination of computer modeling and field trials, we determine that “signal overlap” is a major concern when using “marking” functions to search for as few as two beacons at a time. The problem is deeply compounded as the number of signals increases. For this reason, “marking” functions cannot replace existing methods for isolating multiple burials. “Marking” should only be used if the searcher has already mastered reliable backup techniques such as the Three Circle and Micro Search Strip methods that use signal strength instead of signal timing to isolate multiple burials.

This paper should be considered in the context of modern avalanche statistics. Recent reports show that complex “special case” multiple burials requiring special techniques (or technology) are extremely rare.[2] The issues addressed in this paper apply only to the limited number of professionals who are qualified to use such techniques and technologies in the field. Recreationists should be taught to master basic single search techniques, efficient shoveling, and how to organize a rescue before learning specialized techniques and technologies for complex multiple burials.

Definitions

To study the issue of signal overlap, it is first important to define several concepts inherent to transceivers, which are shown in Figure 1.

Signal amplitude: The strength of a signal, measured in volts. In oscilloscope images, this is the height of the signal above ground (or zero amplitude value).

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[1] B. Edgerly and D. Atkins, *Strategic Shoveling: The Next Frontier in Companion Rescue*, ISSW Proceedings, 2006; http://www.backcountryaccess.com/documents/EdgerlyAtkinsISSW06.pdf, p.1.
[2] B. Edgerly and J. Mullen, *Revisiting Multiple Burial Statistics: U.S. Avalanche Incidents 1995-2007*, The Avalanche Review: Vol. 26, No. 1, p. 13.

Pulse width: The "on-time" of the transmit pulse, measured in seconds or milliseconds (1/1000th of a second).

Pulse period: The overall time period between the leading edge of one pulse in a beacon's "pulse train" and the leading edge of the next pulse, also measured in seconds or milliseconds. The pulse period includes both the "on-time" (or pulse width) of a transmit signal, plus the "off-time" between that pulse and the following pulse.

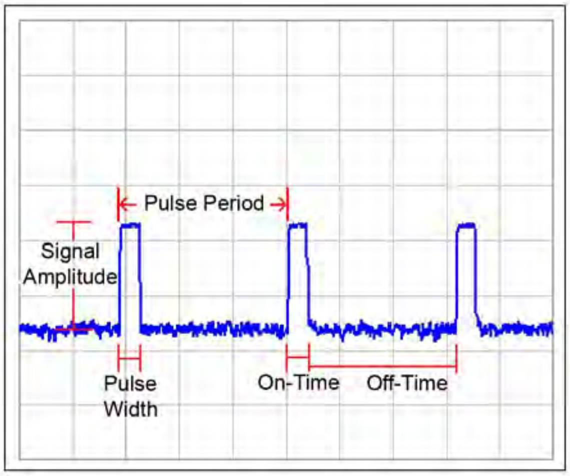

Figure 1. This transmit signal has a relatively narrow pulse width, or "on-time" relative to the overall pulse period. High amplitude makes it easy to distinguish from background noise and other transmitters.

Pulse rate standard: The European standard for avalanche beacons, EN 300-718, requires that all avalanche transceivers have a pulse period from 0.7 to 1.3 seconds (700 to 1,300 milliseconds). The pulse width is allowed to be from .07 to 0.9 seconds (70 to 900 milliseconds).

Signal strength analysis

Traditionally, signals in multiple burials have been isolated using the process of signal strength analysis, either manually (when using analog beacons) or automatically (using most digital beacons). When performed manually, the searcher uses his or her sensitivity control to identify the closest transmitter, then locates that signal using a bracketing or induction line search technique. With most digital beacons, this is performed without the use of a sensitivity control: the microprocessor analyzes the relative amplitude of each signal and leads the searcher to the strongest signal first by only displaying the distance and direction of that signal. This is shown in Figure 2. Some transceivers can also isolate signals by identifying them based on nuances in their transmit frequency.

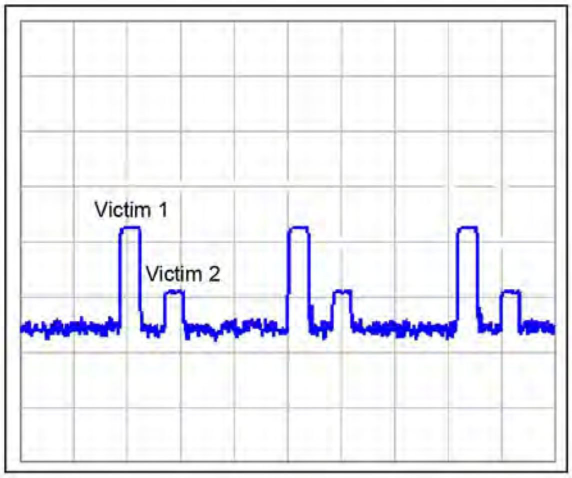

Figure 2. Signal strength analysis enables a transceiver to lead the rescuer to the strongest signal first. One signal will always have higher amplitude than another if the rescuer is moving.

Once this signal is pinpointed, the subsequent victims are located in one of several ways:

• The first victim is excavated and their transceiver is turned off. This turns the scenario into a series of single beacon searches.

• If the first victim's transceiver can't be turned off, or there is adequate manpower to start excavating the first victim and begin searching for the next victim, then a systematic search can be performed using a variety of methods:

• Return to the last point at which several signals were detected, and begin searching there for the next signal,

• Return to the point at which the primary search was abandoned, and begin searching there for the next signal,

• Or if the searcher suspects a close-proximity multiple burial–in which the victims are less than 20 meters apart–then they can perform a specialized technique such as the Three Circle Method, Micro Search Strip Method, Special Mode, or other "special case" technique. These techniques all involve strategically moving away from the pinpointed signal until the next signal is strong enough to be re-captured and pinpointed.

Signal timing analysis

In recent years, signal timing analysis has been used to supplement or replace signal strength analysis as a method for isolating signals in multiple burials. This technique cannot be performed manually, using an analog beacon; it is only possible using certain digital beacons. In this case, the microprocessor analyses a series of transmit pulses and establishes patterns that enable it to identify each transceiver by the timing of their pulse period (the time measured between the leading edge of one pulse and the leading edge of the next pulse). Other systems also attempt to identify each beacon based on the small differences between the various transmitter frequencies.

For best results, the timing analysis integrates many pulses, not just one. The longer this sample is taken, the more accurate the timing analysis will be. However, this requires more processing power and can create “delayed display,” or slow response to changes in distance and direction–even if searching for only one victim.

The benefit of signal timing analysis is that once a transmitter is clearly identified by its pulse rate, it can be “marked,” or cancelled after it is found. Then the searcher can move on to the next signal without performing the Three Circle Method, Micro Search Strip Method or Special Mode. While this sounds quite simple and can work well under ideal conditions, it breaks down when the victims’ transmit pulses happen to be on at the same time. This is commonly referred to as “signal overlap.”

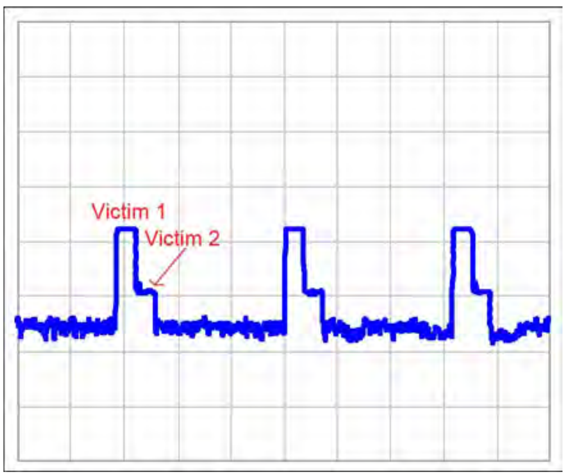

Figure 3. In this example, two signals with narrow pulse widths overlap. In the beacon’s display, an icon will often disappear or a “stop” message will be shown. “Marking” now will eliminate both signals because they are no longer seen as separate victims.

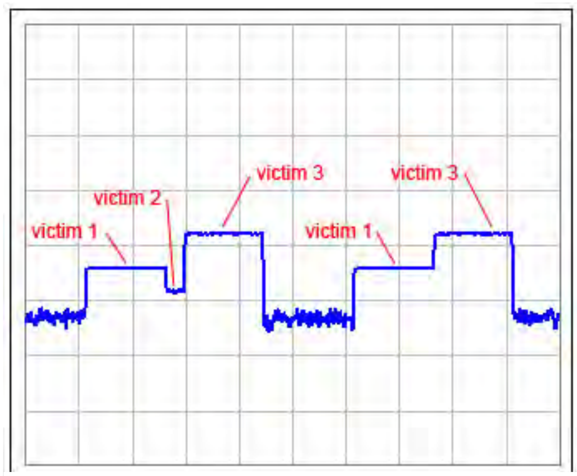

Figure 4. In this scenario, three Ortovox F1 pulses overlap. The F1’s wide pulse width means the overlaps occur more often and last longer. In the second group of pulses, the signal from victim 2 has been completely concealed.

When pulses are overlapped, any number of complications may arise, including the loss of one or more signals, as shown in Figures 3 and 4. If the signals are overlapped while the searcher is “marking,” then both signals will be cancelled. Once the signals no longer overlap, then signals that were originally masked are often shown again on the beacon display. These issues can make a multiple-beacon search unreliable and more complicated than a traditional search using signal strength analysis. The problem can be mitigated, but not eliminated, through analysis of the pulse frequency.

Signal overlap: scope of the problem

How likely is the phenomenon of signal overlap? In the field it can be very unpredictable. It is only a matter of chance (or bad luck) that the searcher will attempt to “mark” a victim when their signal is overlapping with another. In some scenarios it is quite rare and in others it can consistently scuttle a search. This is because the probability of signal overlap varies widely, depending on the configuration and number of transmitters.

To determine the scope of the problem, we developed both a computer simulation program and a mathematical model to predict the overlap characteristics for various combinations of transmitters. Using measured beacon properties (pulse period and pulse width) for a wide selection of beacons, the computer program accurately simulates the simultaneous operation of two to six beacons. Since the overlap characteristics change with time–and may be dependent on when the units are turned on–it is necessary to consider on the order of 1000^N signal pulses when a group of N beacons is analyzed. The computer simulation steps through all of these pulses, keeping track of the durations of both overlapped and clear signal segments.

The mathematical model is the end product of a theoretical analysis that requires the evaluation of a few simple equations instead of the direct counting of a large number of pulses. The mathematical model is much more efficient for large number of beacons and the theory behind it provides insight into the factors that contribute to lengthy overlaps. The mathematical model was verified against the direct computer simulation, which was in turn validated against direct measurements of actual beacons monitored on an oscilloscope.

Results: mixed brands

In the first set of trials, overlap statistics were compiled for the 24 assorted beacons discussed by Eck et al.[3] We considered all possible groupings of 2, 3, and 4 beacons and recorded the duration of all overlapped and clear pulse segments for each. Figure 5 shows a histogram of the overlapped and clear signal durations for all possible combinations of 3 beacons. The histogram shows the probability (vertical axis) of encountering a specified overlap or clear duration (horizontal axis). The probability of overlap is depicted in red and the probability of clear pulses is shown in green. Most of the data is clustered near the center, which indicates a preference for frequent overlapped or clear pulse trains lasting only a few seconds. At reduced probability, there are also a non-negligible number of cases where much longer overlaps are observed.

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[3] M. Eck, R. Sackl, M. Schober, E. Oeljeklaus, and M. Schreilechner, *Investigation of the Interaction Between Different Avalanche Transceivers in Multiple Burials;* www.pieps.com.

Of particular note is the overlap duration of 120 seconds, which shows up as a spike at the right end of the figure. This data point is actually a compilation of all overlaps lasting 120 seconds or more, as plotting all of these data at their actual overlap durations leads to an ineffective figure with a very much elongated horizontal scale. These very long overlaps occur for cases where the transmitters have nearly the same pulse period. These very long overlaps are a real concern for timing-based signal isolation strategies since it is possible to obtain misleading or null indications on the receiver display during this time.

Our field tests with real beacons confirmed that overlaps lasting at least five minutes are possible with even two beacons and that searches conducted with timing-based isolation features activated during overlap often resulted in the inability to find one or more of the victims. Furthermore, many seconds of signal processing time (during which time the display instructs the searcher to "stand still") are often required as the beacon signals come out of overlap. Our tests also revealed that several additional minutes of time can be lost by a searcher who becomes confused by the misleading information displayed during overlap–and later refuses to follow the correct indications on the display if it would lead him to an area that was apparently void of victims earlier. In certain cases, the combination of these various sources of delay may mean the difference between life and death.

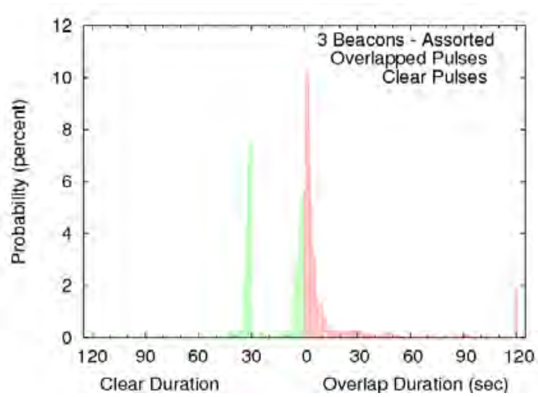

Figure 5. Histogram of overlap and clear durations for all possible combinations of three beacons taken from the study of Eck et al.

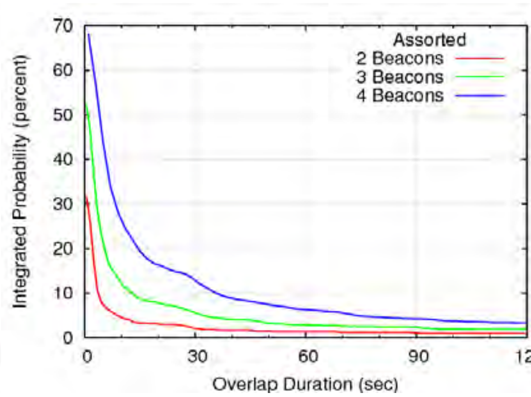

Figure 6. Integrated probability of overlap duration for all possible combinations of two, three, and four beacons taken from study of Eck et al.

Since long overlaps are of primary concern, a histogram like that shown in Figure 5 can be put in a more useful form by summing together all data with an overlap duration greater than or equal to the time in question. This gives the "integrated probability" of encountering an overlap of at least the time shown on the horizontal scale. Such a plot is shown as the green curve in Figure 6, where the data of Figure 5 is replotted. In this case, the data is also included for two- and four-beacon combinations.

This figure shows that, for three beacon combinations, there is a 12 percent chance of encountering an overlap of at least 10 seconds, a 3 percent chance of an overlap greater than one minute, and a 2 percent chance of an overlap of at least 2 minutes. Figure 6 also shows that the likelihood of long overlaps increases with increasing number of transmitters. The probability of encountering a maximum overlap of at least one minute rises from 3 percent for two beacons to 6 percent for four beacons. It is also important to note that there is still a 1 percent chance of overlaps lasting more than two minutes for only two beacons.

Results: identical brands

The data displayed in Figures 5 and 6 is for a collection of assorted beacons that have widely varying pulse periods and pulse widths. It is of interest to investigate the behavior of more homogeneous collections of beacons to see how beacon type affects the maximum overlap duration. To do this we chose fleets of 24 Tracker DTS beacons and 24 Ortovox F1 beacons. These two beacons were chosen since they are the two most common varieties found in the field worldwide. They are also interesting to study since they have rather different characteristics. The Tracker DTS is characterized by a fairly narrow pulse width (W=88-93 ms for the units we tested) and rather precise pulse period (784 +\- 10 ms in our study). The Ortovox F1, on the other hand, is characterized by a very long pulse width (W=334-401 ms for the units we tested), and a wide range in pulse periods (1210 +/- 103 ms in this case).

Integrated probability distributions for collections of two, three, and four Tracker DTS beacons and similar combinations of Ortovox F1 beacons are shown in Figures 7 and 8 respectively. These distributions are of particular interest since they both show a significantly greater likelihood of long overlaps. The probability of encountering an overlap lasting one minute or more is 16% in the case of four Tracker beacons and 60% in the case of four Ortovox F1's! Both beacon types are predicted to have a measurable probability of overlaps lasting at least five minutes with only two beacons. This probability rises to more than 10% in the case of four F1 beacons.

One might think that the Tracker DTS beacons should have limited maximum overlap durations since they have rather short pulse widths. The key element, however, is that they also have limited differences in pulse periods among various units. This feature results in small differences in the relative timing of pulses sent by different units from cycle to cycle and thus requires many pulses to move the signals out of overlap.

The results for the Tracker DTS beacons illustrates why it is useful to spread the pulse periods over significantly more than 10 milliseconds. A few manufacturers are now randomizing the pulse period in such a way that it is unlikely to obtain two or more units with very similar pulse periods.

The mechanism for long overlaps in the case of the Ortovox F1 beacons is similar to that in the case of the Tracker, with the added complication that these beacons have very long pulse widths. When three beacons with similar pulse periods are grouped together maximum overlap durations exceeding one hour are predicted! Our laboratory tests with real beacons showed that, while drift in the pulse period would often shorten the maximum overlap duration, it was still possible for three F1 beacons to remain overlapped for 10-15 minutes. Since these long overlaps are predicted to occur for more than 10 percent of the time in a four-victim burial, one would want to exercise extreme caution when using timing analysis features to search for multiple victims wearing beacons with wide pulse widths.

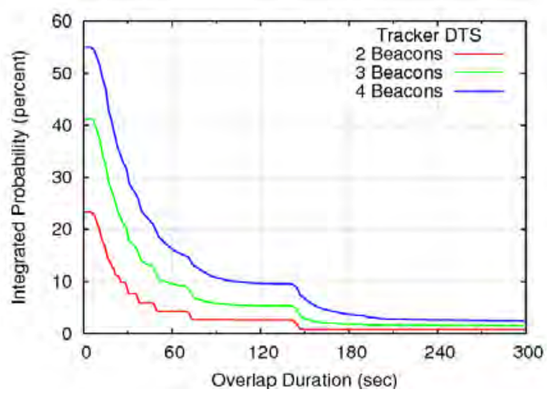

Figure 7. Integrated probability of overlap duration for combinations of two, three, and four tracker DTS beacons.

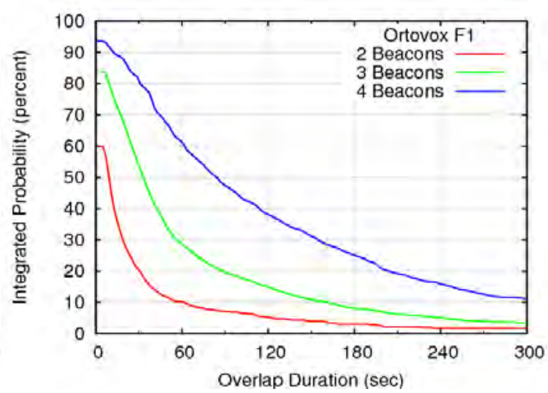

Figure 8. Integrated probability of overlap duration for combinations of two, three, and four Ortovox F1 beacons.

Reliable search techniques

Due to the unreliability of signal timing analysis, “marking” functions should only be used as a technique to possibly enhance a multiple burial search under ideal conditions. This is mainly limited to cases in which the transmitters are known to have pulse rates with a low probability of signal overlap—specifically transceiver fleets of mixed brands or of the same brands in which the pulse rates have been intentionally “randomized” to minimize overlap.

“Smart transmitter” technology is intended to help mitigate the signal overlap problem. However, this technology only eliminates signal overlap with two transmitters located within a radius of approximately five meters; it does not eliminate overlap with more than two transmitters or if the transmitters are further than five meters apart. Additionally, it can create other complications when searching with other “marking” beacons: the shifting pulse rate among “smart transmitters” can throw off the timing analysis of the searching beacon and often count the changed pulse rate as an additional victim.

Before using any “mark” function, all beacon users must be fully proficient in the use of signal strength to isolate signals. If this is not taught, then relying on “marking” functions alone could decrease the probability for live recovery. This is why, in their manuals, the manufacturers all suggest using a “backup” technique if more than three victims are buried. Ideally, however, the most reliable technique should be the primary technique, not the secondary, “backup” technique. Without knowing the reliable “backup” technique, users are taking risks by relying only on “marking.”

The most widely accepted technique for multiple burial searching; using signal strength—other than simply turning off the found transmitters—is the Three Circle Method.[4,5] This method has been widely accepted by manufacturers and user groups worldwide, including the German Alpine Club (DAV), the world’s largest mountaineering organization. In a suspected close-proximity burial, after pinpointing the first signal, the rescuer searches in expanding concentric circles around the first victim in search of other signals nearby.

Multiple burials: separating myth and reality

While signal overlap is a significant issue, how common are complex “special case” multiple burials in the first place? Recent research shows that it is extremely uncommon: that less than one percent of avalanche incidents in North America and Austria involve situations where a special technique or technology might apply.[6,7] The same studies also documented that the most demanding and time-consuming aspect of most avalanche rescues is the excavation phase, not the beacon search. The conclusion is that it is much more important for educators to stress single burials and efficient shoveling than it is to focus on specialized multiple burial techniques.

The bigger issue is “downward compatibility.” With hundreds of thousands of avalanche beacons already in use in the field worldwide, it is imperative that manufacturers design transceivers that are compatible with the existing installed base of products—including those with wide pulse widths and non-randomized pulse periods. In the absence of such downward compatibility, then a new standard should be implemented that better defines pulse rates so the newer generation of transceivers can be more reliable. This would mean, however, that transceivers not meeting this new standard should be declared obsolete and be retired from use.

Conclusion

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[4] D. Stopper and C. Semmel, *Beacon Searches with the Three-Circle Method: A baseline method for beacon searches with multiple burials.* DAV Panorama; www.alpenverein.de/panorama.html, 2004.

[5] S. Christie, *Multiple Beacon Searching for the Masses: A Standardized Approach For Avalanche Educators,* ISSW Proceedings 2006; http://www.backcountryaccess.com/documents/ISSW06SteveChristie.pdf, 2006.

[6] Edgerly and Mullen, p. 13.

[7] D. Stopper and J. Mullen, *How common are multiple burial situations? Avalanche incidents in Tyrol, Austria, 1997-2003*, ICAR 2007; *http://www.backcountryaccess.com/documents/MultBurialsinTyrol.pdf, 2007.*

While “marking” and signal timing analysis are exciting new technologies, they are not downwardly compatible with the existing base of avalanche transceivers—especially transceivers with similar pulse periods and wide pulse widths. We have found that signals from even two beacons can remain overlapped for more than five minutes. For three beacons this time easily increases to 5-10 minutes. When four or more victims are buried, it is possible for the beacon signals to remain overlapped indefinitely. We also found the information displayed on the searcher’s receiver was often inaccurate and confusing when the signals overlap and timing analysis features are engaged. The number of perceived victims would often change during the course of the search, sometimes showing more than the actual number. “Marking” a particular beacon once located would sometimes take a second beacon out of the search, making it impossible to find! Other times a “marked” beacon would reappear later as a target. In all cases, switching the unit to a basic signal strength mode and employing the Three Circle or Micro Search Strip method would locate all of the beacons.

Professionals using specialized techniques for “special case” multiple burials should rely on existing techniques, such as the Three Circle and Micro Search Strip methods, that use signal strength to isolate signals rather than signal timing.

“Special case” multiple burials are extremely rare and most multiple burials can be solved as a series of single burials. Professionals teaching recreational avalanche courses should emphasize owning beacons, mastering single searches, organizing a rescue, and efficient shoveling technique. “Marking” should be taught only after these fundamentals are mastered, as well as existing, reliable multiple-burial technique.

In the future, to better optimize “marking” technology, a new pulse rate standard may need to be adopted. Transceivers not conforming to this new standard should be retired.

Appendix : Theoretical Analysis

The theoretical analysis shows that the maximum number of consecutive overlaps for two beacons is

$$Nc = \frac{W_2 + W_1}{|P_2 - P_1|}$$

where P_1 and P_2 are the two pulse periods and W_1 and W_2 are the two pulse widths. This equation shows that the longest overlaps can be expected for two beacons with long pulse widths and similar pulse periods.

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